

**DEVELOPING COMMUNITY-INFORMED TECHNOLOGY FOR HARVESTING RAINWATER
FOR DOMESTIC USE IN A SEMI-ARID AREA OF SOUTH AFRICA**

By

Pertina Nyamukondiwa

(Student Number: 11576183)

**A thesis submitted to the Institute for Rural Development (IRD), School of Agriculture in
fulfilment of the requirements for the Doctor of Philosophy in Rural Development Degree**



University of Venda
Creating Future Leaders

South Africa

Promoter: Prof. J. Francis

Co-Promoter(s): Dr. M. Manjoro

Dr. P.F. Kapila

March 2019

DECLARATION

I, Pertina Nyamukondiwa, hereby declare that this thesis for PhD in Rural Development (PHDRDV) submitted to the Institute for Rural Development in the School of Agriculture at the University of Venda has not been submitted previously for any degree at this or another university. It is original in design and in execution, and all reference material contained therein has been duly acknowledged.

Signature _____

Date _____

Ms. P. Nyamukondiwa

ABSTRACT

Approximately, 780 million of people in the world lack access to safe water for domestic use. Out of these, 37 % are found in sub-Saharan Africa. Because of the negative impact of climate variability and change, scarcity of water is likely to continue worsening. Although semi-arid areas experience water shortages, they receive limited amounts of rainfall. Rainwater might help alleviate temporal water shortages. However, rainwater is rarely harvested for use when most needed. The PhD in Rural Development thesis research was carried out in Mabayeni village, which falls under Ward 35 of Collins Chabane Local Municipality in Limpopo Province of South Africa. It was designed to develop a grassroots community-informed prototype for a technology that could be used to harvest rainwater for domestic use. A series of interrelated studies with the following specific objectives underpinned the research: (1) To determine the extent of water scarcity; (2) To identify strategies households used to cope with inadequate availability of water for domestic use; (3) To document the rainwater harvesting techniques rural households used; (4) To compare the features of rainwater harvesting technology that people of different age groups preferred; (5) To develop community-preferred prototypes of rainwater harvesting technology with the best potential to increase access to water for domestic use; and (6) To evaluate the community-preferred prototypes of rainwater harvesting technology.

Partly, the study was conducted as a follow-up to a Master's research study on climate change carried out in 2014 in Mabayeni village. In the 2014 study, it was revealed that water scarcity was a major result of climate change in the area. In addition, Mabayeni was perceived as the driest compared to other villages in the ward. The Cresswell (2013) explanatory sequential mixed method design guided the study. Multi-stage sampling was followed to select respondents. This entailed categorizing respondents first dividing them by age and gender. Respondents were placed in the following clusters: children (boys and girls), youth (male and female), adult (men and women), and the elderly. This was done in order to ensure that there was triangulation of data sources. Various participatory research techniques were used to collect qualitative data for the same reason. For objective 1, data collection techniques such as photo voice, key informant interviews, focus group discussions, participatory mapping, transect walks, storytelling and seasonal diagramming were used. Data were analysed through card sorting, Atlas.ti version 7.5.7-mediated thematic content analysis, map ranking, matrix scoring and conversation analysis. Data collection techniques employed for objective 2 were similar to those used in objective 1 with the exception of participatory mapping. Thematic content analysis in Atlas.ti, map ranking and matrix ranking were used to analyse data for this objective.

Only focus group discussions, key informant interviews and transect walks were used to collect data for objective 3. Data analysis techniques used were similar to those used in the previous objective with the exception of map ranking. For objective 4, data were collected through focus group discussions and analysed using matrix ranking and Atlas.ti-aided thematic content analysis. In objective 5, development of artefacts was guided by prototyping and sketch modelling techniques. Techniques such as verbal protocol analysis, mathematical calculations and presentation and analysis were used to analyse data. A questionnaire with open and closed ended questions was also used to collect data for the last objective. Open-ended questions were analysed using thematic content analysis. In addition, the Kruskal Wallis test in SPSS version 25 determined first, the two prototypes (one for zinc and another for thatch roof) that were regarded as the best; and second, if prototype component ratings significantly differed ($p < 0.05$) across prototypes. As a post hoc test, the Dunn's test in R Statistical Software version 3.3.0 was used for pairwise comparisons. Data saturation determined the sample size. A total of 17 community engagement sessions were held to collect, analyse and validate findings with the grassroots community members in Mabayeni village.

Water scarcity in Mabayeni village was reconfirmed to be seasonal. The dry season in each year was five months long. During this time, residents adopted random, risky and unhygienic coping strategies. Although rainwater was collected from rooftops, there was no formal technology used to gather and store large quantities for later use. This was attributed to lack of resources and knowledge on how to develop such technologies. The most commonly preferred features of rainwater harvesting technology across interest groups related to water quality, construction materials and security. All interest groups preferred a technology that harvested clean/potable water. Moreover, the elderly wanted a technology that would help them access the stored water easily.

In total, 14 prototypes were developed. When all the interest groups evaluated the prototypes, the ones that boys and men developed were selected as the best for zinc and thatched roof-based technologies, respectively. Selection of a prototype that children produced as the best underlined that children were an important resource that communities should never marginalise. Nor should their ability to contribute useful ideas be underestimated when seeking solutions to local challenges. Active involvement of grassroots community members in the entire design process helped tailor specifications of the technology to user needs, thereby highlighting the importance of inclusive decision making in development practice. This was also important because it created ownership and increased chances of adopting the technology. Lastly, the

current study reaffirmed the view that postgraduate degree research can be harnessed to coproduce solutions to community-identified challenges.

Key words: Collins Chabane Local Municipality; community-informed; domestic use; rainwater harvesting; rural communities; technology; water scarcity

To my mom and dad

ACKNOWLEDGEMENTS

I would like to thank God, The Almighty who protected, guided and comforted me throughout the PhD journey. I would not have successfully finished this work without Him.

I am grateful to my team of promoters, namely Professor J. Francis, Dr M. Manjoro and Dr P.F. Kapila for their immense contribution to the thesis. Their dedication in providing mentorship and guidance throughout the doctoral studies is greatly appreciated. The Institute for Rural Development family deserves special appreciation for its extensive academic support during my time as a PhD candidate. Special thanks to Ms. Mphaphathe for her unwavering support.

The National Research Foundation was the major source of funding for the study (UID 102532) under the Masters and PhD Innovation and Scarce Skills Scholarship. In addition, the University of Venda Research and Publications Committee provided funding for the project (SARDF/16/IRD/07). Moreover, the UNIVEN Research Ethics Committee sanctioned the operationalization of the project (SARDF/16/IRD/07/2904).

I am indebted to Mabayeni community members for welcoming me and participating in my study. I am particularly thankful to the headman, the late Mr. Macevele TP and village representatives such as Mrs. Baloyi F, Ms. Mangani N, Mr. Baloyi KG and Ms. Baloyi T for providing advice and support throughout the data collection phase of the study. I am thankful to my team of research assistants, viz. Ngonyama T, Hlaiseka A, Maluleke S, Hlongwane TG, Masingi A and Mhlanga J for their hard work and dedication during and after data collection. Special thanks go to Dr. Bere A and Mr. Dondofema F for sharing their expertise in statistics and geographical information systems, respectively.

I express gratitude to my Institute for Rural Development colleagues: Kavhai S, Shoko D, Ndlovu W, Mudimeli R, Munsaka C, Dlamini DD, Matiku S, Chidembo R, Iwara IO and others for providing critical insights into my PhD work. I appreciate the emotional support and valuable insights I received from my friends; Takayindisa FM, Nyete L, Murimwa C, Nyasha T, Muganda JM, Chaka R, Motadi RS, Matshavha L and Dr. Samanyanga E.

Special thanks to my parents Mr. A and Mrs. W Nyamukondiwa, as well as my siblings Praise, Ashley, Rodney and Natley for believing in me and encouraging me to remain strong despite the challenges I faced.

TABLE OF CONTENTS

DECLARATION	ii
ABSTRACT	iii
ACKNOWLEDGEMENTS	vii
LIST OF TABLES	xiv
LIST OF FIGURES	xvii
LIST OF APPENDICES	xx
CHAPTER 1 INTRODUCTION	1
1.1 Background	1
1.2 Statement of the Research Problem	3
1.3 Research Objectives	5
1.4 Research Assumptions	5
1.5 Operational Definitions of Key Terms and Concepts	5
1.6 Organisation of the Thesis	7
1.7 References	8
CHAPTER 2 LITERATURE REVIEW	12
2.1 Introduction	12
2.2 Understanding Water Scarcity	13
2.3 The Extent of Water Scarcity in the World	14
2.4 Coping Strategies for Water Scarcity	20
2.5 Origins of Rainwater Harvesting	22
2.6 Examples of Traditional Rainwater Harvesting Techniques	23
2.7 Existing Rainwater Harvesting Techniques	25
2.8 Major Features of Rainwater Harvesting System	27
2.9 Community Preferences of Rainwater Harvesting System Features	28
2.9.1 Affordability	28
2.9.2 Physical compatibility	29
2.9.3 Ease of construction and maintenance	29
2.9.4 Image and relative advantage	30
2.9.5 Availability of resources	31
2.10 Success Stories on Rainwater Harvesting in Africa	32

2.11 Rainwater Harvesting in South Africa	35
2.12 Theoretical Framework of the Study.....	38
2.12.1 Sustainable community development	38
2.12.2 Asset-based community development.....	39
2.12.3 Co-designing	40
2.13 Rainwater Harvesting Technology and the Science-Policy Interface	43
2.14 Summary of Literature Review	44
2.15 References	47
CHAPTER 3: EXTENT OF SCARCITY OF WATER FOR DOMESTIC USE IN RURAL HOUSEHOLDS OF SOUTH AFRICA: A CASE STUDY OF MABAYENI VILLAGE IN LIMPOPO PROVINCE	58
3.1 Abstract	58
3.2 Introduction.....	59
3.3 Methodology.....	60
3.3.1 Description of the study area	60
3.3.2 Formalization of the research project.....	61
3.3.3 Social preparation for data collection.....	61
3.3.4 Adoption of data collection tools	64
3.3.5 Research philosophy and design.....	64
3.3.6 Population and sampling procedures	65
3.3.7 Data collection	66
3.3.8 Data analysis	71
3.3.9 Ethical considerations	74
3.4. Results	75
3.4.1 Photo voice with key informant interviews.....	75
3.4.2 Structured focus group discussions and matrix ranking.....	76
3.4.3 Participatory mapping and transect walks	76
3.4.4 Storytelling and observation guide.....	82
3.4.5 Seasonal diagramming and matrix scoring.....	90
3.4.6 Non-participant observation	99

3.5 Discussion	103
3.6 Conclusion.....	108
3.7 References	109
CHAPTER 4 RURAL HOUSEHOLD COPING STRATEGIES FOR INADEQUATE DOMESTIC WATER	114
4.1 Abstract	114
4.2 Introduction.....	115
4.3 Methodology.....	116
4.3.1 Research design	116
4.3.2 Population and sampling procedures	116
4.3.3 Data collection	117
4.3.4 Data analysis	120
4.3.5 Ethical considerations	120
4.4 Results.....	120
4.4.1 Preferred coping strategies for water scarcity	124
4.4.2 Effective strategies for coping with water scarcity	132
4.5. Discussion	134
4.6. Conclusion.....	138
4.7 References	140
CHAPTER 5 CURRENT RAINWATER HARVESTING PRACTICES USED IN RURAL COMMUNITIES OF LIMPOPO PROVINCE: A CASE STUDY OF MABAYENI VILLAGE	144
5.1 Abstract	144
5.2 Introduction.....	145
5.3 Methodology.....	146
5.3.1 Research design and sampling procedures	146
5.3.2 Data collection	147
5.3.3 Data analysis	147
5.4. Results	147
5.4.1 Rainwater harvesting practices used in Mabayeni village.....	147
5.4.2 Most Preferred Rainwater Harvesting Practices.....	148
5.4.3 Most Effective Rainwater Harvesting Practices	151

5.5. Discussion	154
5.6 Conclusion.....	157
5.7 References	158
CHAPTER 6 FEATURES OF ROOFTOP RAINWATER HARVESTING TECHNOLOGY AS PERCEIVED BY RESIDENTS OF MABAYENI VILLAGE	161
6.1 Abstract	161
6.2 Introduction.....	162
6.3 Methodology.....	164
6.3.1 Research design	164
6.3.2 Population and sampling procedures	164
6.3.3 Data collection	164
6.3.4 Data analysis	166
6.3.5 Ethical clearance	166
6.4 Results.....	166
6.5 Discussion	174
6.6 Conclusion.....	180
6.7 References	181
CHAPTER 7 DEVELOPING COMMUNITY-INFORMED PROTOTYPES OF ROOFTOP RAINWATER HARVESTING TECHNOLOGY WITH BEST POTENTIAL TO REDUCE WATER SCARCITY	185
7.1 Abstract	185
7.2 Introduction.....	186
7.3 Methodology.....	188
7.3.1 Research design	188
7.3.2 Sampling procedures	188
7.3.3 Data Collection Process	189
7.3.4 Data Analysis.....	190
7.4 Results.....	191
7.4.1 Description of the Selected Rainwater Harvesting Technology Option	191
7.4.2 Sizing of Storage Tank.....	197
7.4.3 Runoff coefficient and catchment area	199

7.4.4	Rainfall characteristics and harvesting potential	199
7.5	Discussion	201
7.6	Conclusion.....	204
7.7	References	206
CHAPTER 8 SELECTING THE MOST PREFERRED PROTOTYPES OF THE RAINWATER HARVESTING TECHNOLOGY WITH BEST POTENTIAL TO IMPROVE ACCESS TO WATER IN MABAYENI VILLAGE.....		210
8.1	Abstract	210
8.2	Introduction.....	211
8.3	Methodology.....	212
8.3.1	Research design	212
8.3.2	Population and sampling procedures	213
8.3.3	Data collection.....	213
8.3.4	Data analysis	214
8.3.5	Ethical considerations	216
8.4	Results.....	216
8.5	Discussion	228
8.6	Conclusion.....	230
8.7	References	232
CHAPTER 9 SYNTHESIS OF THE STUDY ON COMMUNITY-INFORMED RAINWATER HARVESTING TECHNOLOGY IN RURAL AREAS		235
9.1	Introduction.....	235
9.2	Methodological aspects	235
9.3	Enablers and challenges faced during the study	240
9.3	Major Findings.....	246
9.4	Characteristics of a PhD	246
9.4.1	Originality and contribution to knowledge	248
9.4.2	Substantial coherence and student autonomy	250
9.4.3	Training and apprenticeship.....	251
9.4.4	Innovation and applicability	253
9.4.5	Engagement	255

9.6 Conclusions.....	259
9.7 Recommendations	259
9.7.1 Research	259
9.7.2 Policy	260
9.7.3 Practice.....	261
9.8 Dissemination plan.....	261
9.8 References	263
APPENDICES	266

LIST OF TABLES

Table 2.1 The nature of water scarcity in different regions of the world	15
Table 3.1 ATLAS.ti summary results of data gathered through different techniques.....	77
Table 3.2 Rank totals for water sources and preferred uses across interest groups.....	78
Table 3.3 Ranks showing the most preferred sources of water for drinking as perceived by different interest groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	79
Table 3.4 Preferences for water sources for washing dishes as perceived by different interest groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	80
Table 3.5 Water sources that were found in Mabayeni village through transect walks	84
Table 3.6 Observations recorded during storytelling in a study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	87
Table 3.7 Major themes, selected subthemes and verbatim quotations from ATLAS.ti	88
Table 3.8 Actual water sources for drinking in Mabayeni village as perceived by representatives of interest groups	93
Table 3.9 Actual water sources for bathing in Mabayeni village as perceived by representatives of interest groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	94
Table 3.10 Actual water sources for washing dishes in Mabayeni village as perceived by representatives of interest groups	96
Table 3.11 Actual water sources for washing clothes in Mabayeni village as perceived by representatives of interest groups	97
Table 3.12 Actual water sources for sanitation purposes in Mabayeni village as perceived by representatives of interest groups	100
Table 3.13 Non-participant observation results of a study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality.....	101
Table 4.1 Number of quotations for each data collection technique used in investigating rural household coping strategies for inadequate domestic water in Mabayeni Village of Collins Chabane Local Municipality.....	121

Table 4.2 Consolidated results for codes and quotations generated for each data collection technique used in investigating rural household coping strategies for inadequate domestic water in Mabayeni village of Collins Chabane Local Municipality	123
Table 4.3 The most preferred coping strategies for water scarcity as perceived by residents of Mabayeni Village of Collins Chabane Local Municipality in Limpopo Province	125
Table 4.4 The most effective coping strategies to water scarcity as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	133
Table 5.1 The most preferred rainwater harvesting practices as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	149
Table 5.2 The most effective rainwater harvesting practices as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	153
Table 6.1 The most important features of rainwater harvesting technology as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	168
Table 6.2 The different rooftop rainwater harvesting technology options emerging in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	170
Table 6.3 The most preferred rooftop rainwater harvesting technology option in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	172
Table 7.1 The Description of a Rooftop Rainwater Harvesting Technology Developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	192
Table 7.2 Experiences of community members on prototyping exercises for developing a technology for harvesting rainwater in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	196
Table 7.3 Averages of estimated water demand per day in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	198
Table 7.4 Rainwater harvesting potential for different roof sizes in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	200
Table 8.1 The Distribution of Scores According to Prototypes across Groups in Mabayeni Village of Collins Chabane Local Municipality in Limpopo Province	217
Table 8.2 The distribution of scores according to prototype component across groups in Mabayeni village of Collins Chabane Local Municipality of Limpopo Province	219
Table 8.3 The distribution of scores according to prototype across groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	221
Table 8.4 The distribution of scores according to prototype across groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	223

Table 8.5 Design feedback for zinc prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	224
Table 8.6 Design feedback for thatch prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	225
Table 9. 1 Data collection techniques used in developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo province.....	238
Table 9. 2 Data analysis techniques used in developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo province.....	239
Table 9. 3 Summary of major findings on developing a technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	247
Table 9. 4 Criteria for assessing doctoral work	249

LIST OF FIGURES

Figure 2. 1 Conceptual framework for developing a rainwater harvesting system	42
Figure 3.1 Map of Mabayeni village in Collins Chabane Local Municipality as the study area (GIS Department, University of Veda).....	62
Figure 3.2 Diagrammatic presentation of stages of community entry and data collection in the study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	63
Figure 3.3 Summary of data collection methods, techniques and tools used to determine the extent of water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	67
Figure 3.4 Sequence of data collection and number of participants engaged per data collection technique.....	68
Figure 3.5 Data analysis methods, techniques and tools used in determining the extent of water scarcity in mabayeni village of Collins Chabane Local Municipality in Limpopo Provinc.....	73
Figure 3.6 The map of Mabayeni village showing water features that were selected to guide transect walks in Mabayeni village of Collins Chabane local municipality in Limpopo Province	81
Figure 3.7 Water sources found in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	83
Figure 3. 8 An illustration of the major themes, sub-themes and relationships between themes produced in ATLAS.ti.....	85
Figure 3.9 Availability of water for drinking in Mabayeni village throughout the year as perceived by all interest groups in a year.....	92
Figure 3.10 Availability of water for sanitation uses in Mabayeni village throughout the year as perceived by different interest groups	98
Figure 3.11a: Woman collecting her water from a donkey-drawn cart (hired transport).....	102
Figure 3.11b: Woman going to fetch water with multiple containers	102
Figure 3.11c: A truck filled with empty containers going to fetch water in a neighbouring village	102
Figure 3.11d: Women fetching water with multiple containers	102
Figure 4.5.1 Using donkey-drawn carts to fetch water from municipal taps as a coping strategy to water scarcity in Mabayeni village.....	129
Figure 4.5.2 Harvesting rainwater from rooftops as a coping strategy to water scarcity in Mabayeni village throughout the year as perceived by interest groups	129

Figure 4.5.3 Buying Jojo tanks as a coping strategy to water scarcity in Mabayeni village.....	129
Figure 4.5.4 Using water from small dams for different household uses as a coping strategy to water scarcity in Mabayeni village.....	129
Figure 4.5.5 Boiling river water as a coping strategy to water scarcity in Mabayeni village throughout the year as perceived by interest groups.....	131
Figure 5.1 Photographs of common rainwater harvesting practices in Mabayeni village of Collins Chabane in Limpopo Province	150
Figure 5.2 Rainwater harvesting practices in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province.....	152
Figure 6.1 Embedded research design used in the study	165
Figure 6.2 Features of rainwater harvesting technology as perceived by residents of Mabayeni village of Collins Chabane Municipality in Limpopo Province.....	169
Figure 6.3 Preferred features of rainwater harvesting technology and their explanations as perceived by residents of Mabayeni village of Collins Chabane Municipality in Limpopo Province	173
Figure 7.1 An illustration of the participatory design process followed in developing the prototypes of a rooftop rainwater harvesting technology in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	193
Figure 7.2 An illustration of the engineering design process used as reference in the development of prototypes of rooftop rainwater harvesting technology in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	193
Figure 7.3 Prototypes of Rainwater Harvesting Developed by Residents of Mabayeni village of Collins Chabane Municipality in Limpopo Province	195
Figure 8.1 An illustration of the Box and Whisker Plot.....	215
Figure 8.2 Box and whisker plot showing the distribution of scores for zinc prototypes developed in Mabayeni village of Collins Chabane Municipality in Limpopo Province.....	218
Figure 8.3 The box and whisker plot showing the distribution of scores for thatch prototype developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province ...	222
Figure 8.4 An improved pictorial view of the rooftop rainwater harvesting technology for zinc roof developed in Mabayeni village of Collins Chabane Municipality in Limpopo Province.....	226
Figure 8.5 An improved pictorial view of the rooftop rainwater harvesting technology for thatch roof developed in Mabayeni village of Collins Chabane Municipality in Limpopo Province.....	227

Figure 9. 1 The hybrid research design used in the study on developing community-informed technologies for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	236
Figure 9. 2 Teaching and learning process throughout the PhD training	252
Figure 9. 3 An illustration of the full design process for developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	257

LIST OF APPENDICES

Appendix 3.1 Ethical Clearance Certificate	266
Appendix 3.2 Data collection and ethical clearance tools.....	267
Appendix 3.3 Preferences for water sources and use as perceived by boy children in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	268
Appendix 3.4 Preferences for water sources and use as perceived by girl children in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	269
Appendix 3.5 Preferences for water sources and uses as perceived by youth male in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	270
Appendix 3.6 Preferences for water sources and use as perceived by youth female in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	271
Appendix 3.7 Preferences for water sources and uses as perceived by adult women in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	272
Appendix 3.8 Preferences for water sources and uses as perceived by adult male in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	273
Appendix 3.9 Preferences for water sources and use as perceived by the elderly in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	274
Appendix 4.1 Fetching water from the river as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	275
Appendix 4.2 Digging wells in the river as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	276
Appendix 4.3 Fetching water from neighbouring villages as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	277
Appendix 4.4 Hiring cars to fetch water from Malamulele town as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province.....	278
Appendix 4.5 Buying from those with boreholes as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	279
Appendix 4.6 Creating water holding structures (<i>Xikerepe</i>) for livestock drinking as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	280
Appendix 4.7 Using wheelbarrows to fetch water from municipal taps as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	281

Appendix 4.8 Sterilizing water with Sodium Hypochlorite (Jik) as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	282
Appendix 7.1 Small Zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	283
Appendix 7.2 Small thatch-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	284
Appendix 7.3 Medium zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	285
Appendix 7.4 Large zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	288
Appendix 8.1 Questionnaire or assessment sheet used to evaluate the prototype for harvesting rainwater in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	291
Appendix 8.2 The distribution of scores for prototype components for zinc prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province	293
Appendix 8.3 The distribution of scores for prototype components for thatch prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province ...	295

ABBREVIATIONS AND ACRONYMS

ABCD	Asset-based Community Development
ACORD	Agency for Cooperation and Research in Development
ATPS	African Technology Policy Studies
CDW	Community Development Workers
DTU	Development Technology Unit
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
FAO	Food and Agriculture Organisation
NGO	Non-Governmental Organisation
NWA	National Water Act
RWH	Rain Water Harvesting
SCD	Sustainable Community Development
SSA	Sub Saharan Africa
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environmental Programme
UNICEF	United Nations Children’s Emergency Fund
WHO	World Health Organisation
WSA	Water Services Act

CHAPTER 1 INTRODUCTION

1.1 Background

The global demand for water has been increasing at a rate of about 1 % per year, and will continue to grow significantly over the next two decades (United Nations World Water Development Report, 2018). Reports from the United Nations Children's Fund (UNICEF) and the World Health Organisation (WHO) also exposed that about 780 million people worldwide lacked access to safe water (UNICEF & WHO, 2012). In sub-Saharan Africa (SSA), about 37 % of the people experience water shortages (Bocanegra-Martinez *et al.*, 2014). In addition, the United Nations (UN, 2014) estimated that approximately 1.8 billion people would be living in regions classified as absolutely water scarce by 2015. At present, an estimated 3.6 billion people live in areas that are potentially water-scarce for at least one month per year. This population is expected to increase to about 4.8-5.7 billion by 2050 (United Nations World Water Development Report, 2018). The statistics above indicate the increasing rate of water scarcity at a more rapid rate than had been projected. Within Africa, a third of the population lacks safe drinking water and on average 25 countries will experience water scarcity by the year 2025 (Mati *et al.*, 2007). The statistics presented above indicate that water is a global, regional and local challenge that must be addressed as a matter of urgency. Both natural and human-made causes are responsible for this shortage. The United Nations Economic Commission for Africa (UNECA, 2011) blames climate change for altering the hydrological cycle, temperature balance and rainfall patterns across the world with effects mostly felt in Africa. Apart from this, the UN (2014) reveals that unplanned management of resources, insufficient planning and lack of political will contribute to the shortages of water.

In rural communities and urban centres throughout SSA, hundreds of millions of people suffer from lack of access to clean water (Amin *et al.*, 2013). Although all community groups irrespective of gender and age have been found to take part in collecting water (Asueline *et al.*, 2014), it has been widely established that the burden of fetching water fall disproportionately on women and girls. (Dugbazah, 2012; Amin *et al.*, 2013; Graham *et al.*, 2016; Geere *et al.*, 2017). Women and girls fetch water from sources such as rivers, streams and ponds. These water sources are the major sources of water-borne diseases for humans. Illness resulting from drinking dirty water and the time lost fetching it rob entire communities of other possible economic opportunities (UNICEF, 2010; Caruso, 2016). The situation is dire in South Africa where Naidu-Hoffmeester (2014) describe the fresh water status as under immense pressure. It is estimated that South Africa will suffer serious water shortages by 2020. The water scarcity and poor rainfall distribution experienced in Cape Town had major implications on climate sensitive sectors such the Water, Agriculture, Biodiversity and also on the economy of the Western Cape.

In 2017, growing uncertainty regarding the amount of water in the Cape Town city's reservoirs triggered panic. The City of Cape Town had to impose severe (level 3) water restrictions to manage the resource until the winter rains (Sorensen, 2017). Water shortages are also a common feature in rural South Africa (Mwenge Kahinda *et al.*, 2007), with residents experiencing the challenge mainly during the dry season. During that time, they often travel several kilometres to fetch water. In light of the water situation presented above, Adler *et al.* (2013) notes that immediate attention should be paid to its supply, in particular in remote rural areas. This observation takes into account the fact that the global target of halving the number of people without access to water and sanitation by 2015 as specified in the Millenium Development Goals was not met.

Harvesting rain water might enhance the provision of water for drinking and other domestic purposes directly to households. Available literature (Ward *et al.*, 2010; Fisher-Jeffes *et al.*, 2017) suggests that rain water harvesting (RWH) can be a sustainable solution that augments the current shortages provided proper design and water quality issues are addressed. Rainwater harvesting can also promote small-scale home-based productive activities such as vegetable gardening. This can positively contribute to food security for individuals from low income groups (Mwenge Kahinda *et al.*, 2010; Rezaei *et al.*, 2017). Based on the preceding realities, there is need to carry out studies that might enhance RWH in rural areas. Thus, the aim of the current study was to develop a technology for harvesting rainwater for multiple domestic uses. Mabayeni village located in the Collins Chabane Municipality of Vhembe District in South Africa was the study area. The fact that rural communities are often poorly resourced (Sullivan *et al.*, 2003) dictated the choice of the study area. In addition, rural communities considerably rely on water for agricultural production (Rezaei *et al.*, 2017).

Groups of children, youth, adults and the elderly are viewed as integral components of rural communities (Francis *et al.*, 2010). This argument is strengthened by the fact that all interest groups were involved in fetching water thus, justifying their participation in this study. In addition, the disparities in water collection responsibilities due to gender explained above also warranted further separation of participants based on gender. It was assumed that groups of participants were likely to have different perspectives given that they were affected by inadequate availability of water in different ways. In the same vein, the different interest groups might have had different views on the suitable type of RWH technology. Moreover, separating groups of participants using age and gender was done to eliminate power and other cultural boundaries that are usually evident in collective decision making experiences (Francis & Kabit, 2017). Thus, participants were engaged in these groups in order to get group perspectives related to water scarcity and the RWH technology.

1.2 Statement of the Research Problem

In semi-arid areas of South Africa, households are experiencing a worsening shortage of water for drinking and other domestic uses (Baiyegunhi, 2015). Various studies (Mwenge-Kahinda *et al.*, 2010; Amin *et al.*, 2013; Bocanegra-Martinez *et al.*, 2014) reveal that persistent droughts as a result of climate change, poor planning, and ageing infrastructure has caused this state of affairs. Although South Africa has made some progress in addressing climate change through different departments such as Agriculture Forestry and Fisheries, Water and Sanitation, Agricultural Research Council, Water Research Commission among others, response on the implementation of climate change strategies has been slow. This has prompted scholars such as Mwenge-Kahinda *et al.* (2010), Amin *et al.* (2013) and Bocanegra-Martinez *et al.* (2014) to conclude that there has been lack of political will to effectively deal with water scarcity in the country. According to Mwenge-Kahinda *et al.* (2010), the official database of the Department of Water Affairs (DWA, 2007) indicates that more than 70 % of the population has piped water supply. However, this does not guarantee reliable supply because in some areas, water can be unavailable for periods ranging from days to weeks. Nyamukondiwa (2014) studied the effects of climate change on local populations in the then Ward 40 of Thulamela Municipality (now Ward 35 of Collins Chabane Municipality) and observed that municipal water was only available to rural households once or twice in a week. When the water was available, residents endured considerable time in long queues waiting for their turn to fetch it. There were times when girls, women and the elderly in particular had to be in the queues at night, which exposed them to possible rape, murder and other crimes. Some community members resorted to buying water. This grave situation points towards the need for finding sustainable solutions to water scarcity.

Although the semi-arid areas experience water shortages, they receive some rainfall during the rainy season. Rarely is the water harvested for later use. Quite often, it is received during short seasons in intense bursts, resulting in surface runoff and uncontrolled gully erosion. Considerable amounts of the rainfall returns to the atmosphere through evaporation. This means that there are limited benefits to the water-starved communities. If this rainwater could be harvested properly, it might alleviate the temporal water supply challenges and supplement conventional supply systems during dry seasons (Mwenge Kahinda *et al.*, 2005; Fisher-Jeffes *et al.*, 2017). Although promising as an alternative source of water, scholars such as Bulcock & Schulze (2011) and Peters (2016) maintain that the potential of RWH has not yet been fully exploited in South Africa. Domenech *et al.* (2012) report that planners frequently disregard RWH for domestic consumption and use because little is known about its benefits. Furthermore, the same authors note that governments are probably reluctant to promote RWH due to the uncertainties relating to the capacity of users to manage the system appropriately and mitigate associated risks. This might

be because traditionally, the RWH systems were products of 'experts' developing them for the people without beneficiaries' active participation. According to Kamrani & Masr (2010), conventional technology development is predominantly top-down and driven by scientists or engineers. Strategies are often solution-focused. Coughlan *et al.*, (2007) argue that engineers design solutions first, then consult with end users to check the extent to which the solution responds to the problem. Carulli *et al.*, (2013) expound that this results in marginalization of the end-user which compromises acceptance, ownership and adoptability of technologies. There is therefore, need for adopting emancipatory or user-focused approaches in technology development which allows for active involvement of target beneficiaries/community in order to satisfy user needs, goals and desires (Isa, 2014).

In literature, success stories of rainwater harvesting in countries such as Tanzania (National Peace Corps Association, 2016), Ethiopia and Uganda, (Eggens, & Patrick, 2015), Ghana (Gould & Nissen-Petersen, 2006) and South Africa (WRC Technical Brief, 2008) have been associated with active involvement of community members. However, there is a dearth of information on the processes that were followed in the design and installation of RWH systems. In addition, the level of involvement of communities has not been clarified. Moreover, the assumption that all groups regardless of age and gender experience life in a uniform way is a fallacy. Though staying in the same geographical area, community members experience life challenges differently based on their gender and age group since their realities are different. This definition or disaggregation of community has also been lacking in rainwater harvesting studies.

In order to develop appropriate RWH technology, there was need to unravel community preferences on it. The information would then be used to develop prototypes and ultimately, the technology. The Van Vuuren (2013) observation that little information is available on how local communities feel about using harvested water should be taken into account when developing the technology. This entails involving end users in all RWH processes in order to understand their perspectives. By so doing, community members would develop a sense of ownership of the technology-making process and products. Community participation has been emphasized as key in understanding communities' social needs, designing more locally-appropriate services and beneficial in policy making (Nimegeer & Farmer, 2016; Roosli *et al.*, 2018). However, some community groups such as children and youth have been excluded from community conversations. The reason being that these groups have not been recognized as citizens with the ability to make decisions (Lekies, 2007; Perri, 2007). The current study attempted to address this gap through involving all community groups in Mabayeni village regardless of age and gender.

1.3 Research Objectives

The main objective of the study was to develop a community-informed technology with the best potential to harvest rainwater for domestic use. In order to achieve this, the following specific objectives were adopted in the study carried out in Mabayeni village of Limpopo Province:

1. To determine the extent of scarcity of water for domestic use;
2. To identify strategies households used to cope with inadequate availability of water for domestic use;
3. To document the rainwater harvesting techniques that rural communities used;
4. To compare the features of rainwater harvesting technology that people of different age groups preferred;
5. To develop community-preferred prototypes of rainwater harvesting technology with the best potential to increase access to water for domestic uses; and
6. To evaluate the prototypes of rainwater harvesting technology using community feedback.

1.4 Research Assumptions

1. The extent of water scarcity in Mabayeni village is not known.
2. The strategies that households are currently using to cope with inadequate availability of water for domestic use are not known.
3. Water harvesting techniques that households use do not meet domestic needs.
4. The community-preferred prototypes of rainwater harvesting technology can increase access to water for multiple domestic uses;

Hypotheses

- a) H_0 : There are no differences in preferred prototypes of rainwater harvesting technology among interest groups in Mabayeni village
- b) H_0 : There are no differences in preferred features of rainwater harvesting technology among different age groups.

1.5 Operational Definitions of Key Terms and Concepts

Rainwater harvesting refers to a process of collecting and concentrating precipitation from various forms of runoff for various beneficial uses (Oweis & Hachum, 2009). Silva *et al.* (2015) further unpacks this to include collection, storage, treatment and use of the rainwater harvested water either as a principal or supplementary source.

In the current study, the Oxford English Dictionary's definition of *Coping*, which is the action or process of overcoming a problem or difficulty or managing or enduring a stressful situation or condition, was adopted. In the context of this study, the difficulty or stress refers to water scarcity.

Sketch modelling refers to a simple, physical representation of ideas made of soft, low cost, easy-to-work materials. Sketching enables one (or groups) to brainstorm, explore multiple ideas, define flows, communicate with team members in a quick and cheap way (Lothrop, 2012).

A *prototype* is a rough approximation of what a finished product might look like. It helps gather thoughts, compare options, and generate healthy debate about a product being considered. Validation or rejection of product hypotheses with users is made possible without having to invest in the cost of building a finished product (Moggridge, 2007).

Community is defined as a group of people (see below) residing in a particular area and affected by same water challenge. In this study, *community* refers to children (boys and girls), youth (male and women), adults (men and women) and the elderly people.

Bush (1981) defines *technology* as a form of human cultural activity that applies the principles of science and mechanics to the solution of problem. In the context of this study, *community-informed technology* is defined as an activity involving the different interest groups from the same geographical area, which applies the principles of science and mechanics to provide an intervention for inadequate availability of water.

Water scarcity means imbalances between water availability and demand, the degradation of groundwater and surface water quality (FAO, 2015). This can be categorised into economic and physical water scarcity. *Economic water scarcity* results from lack of investment in water or insufficient human capacity to satisfy demand. Lastly, *physical water scarcity* is a situation whereby there is lack of access to safe water (Biswas & Mandal, 2014).

The South African Department of Water Affairs and Forestry (DWAF, 1996) characterises *domestic use* of water as that allocated for drinking, food and beverage preparation, hot water systems, bathing and personal hygiene, washing dishes, laundry, and gardening (which may include water for fish ponds). In the current study, *domestic use* refers to water for drinking, cooking, bathing, washing dishes and clothes, and sanitation.

Sanitation is a broad concept that refers to a number of uses including collection, removal or disposal of human waste. However, for purposes of the current study, it refers to water used for washing hands after use of ablution facilities.

Semi-arid areas is a concept used to describe areas that receive low average rainfall (300 to 600 mm per annum), often associated with high temperatures, which impose fundamental limits on animal and plant populations, and on human activities such as agriculture (Ribot *et al.*, 2005)

1.6 Organisation of the Thesis

The thesis comprises nine chapters. Chapter 1 is a brief introduction that addresses the motives underpinning the research, study objectives and the statement of the problem. Key terms and concepts are also explained. In Chapter 2, literature on the different forms and types of water scarcity, the state of water scarcity in the world and the strategies that have been used to cope with water scarcity around the world are reviewed. In addition, literature on the origins of RWH, the coping strategies to water scarcity, various RWH techniques and major features of RWH are reviewed. The preferences of community members with respect to features of RWH system, success stories of RWH, its benefits, and associated techniques are also reviewed. The theoretical framework underpinning this research is also presented in this chapter.

Chapters 3-8 are all products of empirical research, each one of them anchored on a specific objective of the study. Each chapter is packaged in the form of a standard empirical research paper, using the following outline: abstract, introduction, methodology, results, discussion, conclusions and references. The ninth chapter is a synthesis of the entire study. In the latter chapter, key elements of the background, underlying research problem and objectives are articulated briefly. Thereafter, methodological issues and major results are discussed before conclusions and recommendations are drawn. Some appendices are included in the thesis to help clarify some issues in the text. Individual chapters are presented with their lists of references in order to tell a complete story in one place without having to cross-reference excessively.

1.7 References

- Adler, I., Hudson-Edwards K. A. & Campos L. C. 2013. Evaluation of a silver-ion based purification system for rainwater harvesting at a small-scale community level, *Journal of Water Supply: Research and Technology—AQUA* **62(8)**:545-550
- Amin, M.T., Alazba, A.A. & ElNesr, M.N. 2013. Adaptation of climate variability/extreme in arid environment of the Arabian Peninsula by rainwater harvesting and management, *International Journal of Science and Technology* **10**: 27-36
- Asuelime, L., Yaro, J. & Francis, S (Eds). 2014. Selected themes in African Development Studies: Economic growth, governance and the environment. Springer International Publishing, Switzerland.
- Baiyegunhi, L.J.S. 2015. Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. *Water South Africa*, **41(1)**: 33-40.
- Biswas, B.K. & Mandal, B.H. 2014. Construction and evaluation of rainwater harvesting system for domestic use in a remote and rural area of Khulna, Bangladesh, *International Scholarly Research Notices* 2014: 1-6.
- Bocanegra-Martínez, A., Ponce-Ortega, J. M., Nápoles-Rivera, F., Serna-González, M., Castro-Montoya, A. J., & El-Halwagi, M. M. 2014. Optimal design of rainwater collecting systems for domestic use into a residential development. *Resources, Conservation and Recycling*, **84**: 44-56
- Bulcock, L.M., & Schulze, R. E. 2011. Climate change and a case study in rainwater harvesting: A 2011 perspective. *A 2011 perspective on climate change and the South African water sector. WRC Report, 2* (11)
- Bush, C.L. 1981. Taking hold of technology: Topic guide for 1981-1983. Washington, DC: American Association of University Women
- Careso, B. 2016. Women still carry most of the world's water. Available at <http://theconversation.com/women-still-carry-most-of-the-worlds-water-81054> retrieved on 18 July 2018
- Carulli, M., Bordegoni, M., & Cugini, U. 2013. An approach for capturing the voice of the customer based on virtual prototyping. *Journal of Intelligent Manufacturing*, **24(5)**: 887-903.
- Coughlan, P., Suri, J. F., & Canales, K. 2007. Prototypes as (design) tools for behavioral and organizational change: A design-based approach to help organizations change work behaviors. *The journal of applied behavioral science*, **43(1)**: 122-134.
- DWAF, (Department of Water Affairs and Forestry of the Republic of South Africa). 1994. *Water Supply and Sanitation Policy White Paper. Water – An Indivisible National Asset*. Department of Water Affairs and Forestry, Pretoria.

- DWAF, (Department of Water Affairs and Forestry of the Republic of South Africa). 1996. South African Water Quality Guidelines Volume 1: Domestic use, Second Edition. Available at http://www.dwa.gov.za/iwqs/wq_guide/Pol_saWQguideFRESH_vol1_Domesticuse.PDF, Retrieved on 6 August 2017
- Domènech, L., Heijnen, H. & Saurí, D. 2012. Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: benefits and risks. *Water and Environment Journal*, **26(4)**: 465-472.
- Dugbazah, J. 2012. Gender, livelihoods and Migration in Africa. Xlibris, United Kingdom
- Fisher-Jeffes, L. N., Armitage, N. P., & Carden, K. 2017. The viability of domestic rainwater harvesting in the residential areas of the Liesbeek River Catchment, Cape Town. *Water South Africa*, **43(1)**: 81-90.
- Food and Agricultural Organisation (FAO). 2015. FAOSTAT—FAO Database for Food and Agriculture (Rome: Food and agriculture Organisation of United Nations Available at (<http://faostat3.fao.org/home/E>) Retrieved 23 February 2017
- Francis, J., Dube, B., Mokganyetji, T. & Chitapa, T. 2010. University-rural community partnership for people-centred development: Experiences from Makhado Municipality, Limpopo Province. *South African Journal of Higher Education*, **24(3)**: 345-373
- Francis, J. & Kabiti, H.M. 2017. Amplifying community voices in South Africa: Nurturing transformative leaders through dialogic action. In Hoyt, L., 2017. *Regional Perspectives on Learning by Doing: Stories from Engaged Universities around the World*. MSU Press.
- Geere, J.A. & Cortobius, M. 2017. Who carries the weight of water? Fetching water in rural and urban areas and the implications of water security. *Water Alternatives*, **10(2)**: 513-540
- Graham, J.P., Mitsuaki, H. & Kim, S.S. 2016. An analysis of water collection labor among women and children in 24 Sub-Saharan African countries. *PLoS ONE*, **11(6)** doi <https://doi.org/10.1371/journal.pone.0155981>
- Isa, S. S., & Liem, A. 2014. Classifying Physical Models and Prototypes in the Design Process: A study on the Economical and Usability Impact of Adopting Models and Prototypes in the Design Process. In *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference*.
- Kamrani, A. K., & Nasr, E. A. 2010. Engineering design and rapid prototyping. Springer Science & Business Media.
- Lekies, K.S., Eames-Sheavly, M., MacDonald, L. & Wong, K.J. 2007. Greener voices: Strategies to increase the participation of children and youth in gardening activities. *Children Youth and Environments*, **17(2)**: 517-526.
- Lothrop, T., 2012. Design Drawing-An Integrated Visualization System. Doctoral dissertation,

presented in partial fulfillment of the requirements for the Master of Fine Arts Degree in the Graduate School of The Ohio State University, United States of America.

Mati. B., De Bock. T., Malesu. M., Khaka, E., Oduor, A., Nyabenge, M. & Oduor, V. 2007.

Mapping the potential of rainwater harvesting technologies in Africa: a GIS overview on development domains for the continent and ten selected countries. Technical manual No. 6 Technical Report (Kenya: World Agroforestry Centre (ICRAF)), Netherlands Ministry of Foreign 10 Affairs, Nairobi)

Moggridge, B. 2007. *Designing Interactions*. The MIT Press, USA.

Mwenge Kahinda, J.M, Taigbenu, A. E., & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.

Mwenge-Kahinda, J.M., Taigbenu, A.E. & Boroto, J.R., 2007. Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, **32(15-18)**: 1050-1057.

Mwenga Kahinda, J., Boroto, R.J., & Taigbenu, A.E., 2005. Developing an integrated water resources management and rainwater harvesting system in South Africa. 12th SANCIAHS Symposium, Midrand, 5-7 September.

Naidu-Hoffmeester, R. 2014. South Africa's water resources under immense pressure, available at <http://www.unisa.ac.za/news/index.php/2014/04/south-africas-water-resources-under-immense-pressure>. Retrieved on 15 April 2015

Nimegeer, A. & Farmer, J. 2016. Prioritising rural authenticity: community members' use of discourse in rural healthcare participation and why it matters. *Journal of rural studies*, **43**: 94-103.

Nyamukondiwa, P. 2014. Resilience of rural communities of Ward 40 of Thulamela Municipality to effects of climate change. Thesis submitted for the fulfilment of a Masters degree in Rural Development, University of Venda, South Africa.

Oweis, T. & Hachum, A., 2009. *Water harvesting for improved rain fed agriculture in the dry environments - Rain fed agriculture: Unlocking the potential*, CAB International. London, UK

Peters, E. J. 2016. Success and Success Factors of Domestic Rainwater Harvesting Projects in the Caribbean. *Journal of Sustainable Development*, **9(5)**: 55-69

Perri, M. 2007. Vaughan youth cabinet: Youth participation in community planning and design. *Children Youth and Environments*, **17(2)**: 581-593.

Rezaei, A., Salmani, M., Razaghi, F. & Keshavarz, M. 2017. An empirical analysis of effective factors on farmers' adaptation behavior in water scarcity conditions in rural communities. *International Soil and Water Conservation Research*, **5(4)**: 265-272.

Ribot, J.C., Magalhaes, A.R. & Panagides, S. 2005. *Climate variability, climate change and social*

- vulnerability in the Semi-arid tropics*, Cambridge University Press. UK
- Roosli, R., Nordin, J. & O'Brien, G. 2018. The Evaluation of Community Participation in Post-Disaster Housing Reconstruction Projects in Malaysia. *Procedia engineering*, **212**: 667-674.
- Silva, C.M., Sousa, V. & Carvalho, N.V. 2015. Evaluation of rainwater harvesting in Portugal: Application to single-family residences, *Resources, Conservation and Cycling* **94**:21-34
- Sorensen, P. 2017. The chronic water shortage in Cape Town and survival strategies. *International Journal of Environmental Studies*, **74(4)**: 515-527.
- Sullivan, C. A., Meigh, J. R., & Giacomello, A. M. 2003. The water poverty index: Development and application at the community scale. *Natural Resources Forum* **27(3)**:189-199.
- United Nations Economic Commission for Africa (UNECA) Climate Change and Water Resources of Africa: Challenges, Opportunities and Impacts, African Climate Policy Centre Working Paper 5, November. 2011.
- United Nations Children's Fund. 2010. Gender and water, sanitation and hygiene (WASH). Available at https://www.unicef.org/esaro/7310_Gender_and_WASH.html Retrieved on 18 July 2018
- United Nations World Water Development Report, 2018. Nature-based solutions for water, United Nations Educational Scientific and Cultural Organisation, Paris, France.
- Van Vuuren, L. 2013. Rainwater harvesting from tanks-Useful yes, but can you drink it? The Water Wheel. Available at <http://www.thewaterwheel.com> Retrieved on 12 May 2015.
- Ward, S., Memon, F. A. & Butler, D. 2010. Harvested rainwater quality: The importance of appropriate design, *Water Science and Technology* **61(7)**:1707–1714.
- Water Research Commission Technical Brief. 2008. Rainwater harvesting: In-field rainwater harvesting adoption on small farm plots, April 2008.
- World Health Organization. 2012. Progress on Drinking-Water and Sanitation–2012 update WHO/UNICEF Joint Monitoring Programme for Water supply and Sanitation, launched on 6 March 2012.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Water harvesting can be described as all activities relating to collecting available water resources, temporarily storing any excess for use when required, especially in periods of drought or when no perennial resources are available (The Netherlands Water Partnership, NWP, 2007). This entails collection of rainfall, fog, runoff, ground and waste water, all of which would otherwise have escaped. According to Urama & Ozor (2010), RWH has been practiced for more than 4 000 years. In most developing countries, it is becoming essential owing to the temporal and spatial variability of rainfall. Rainwater harvesting is necessary because it brings water closer to the houses compared to what a stream could do. It is also important in areas having enough rainfall but lacking any kind of conventional, centralized government supply system, and also in areas where good quality fresh surface water or ground water is lacking.

Rainwater harvesting is one possible appropriate technological option to improve water supply (Heyworth *et al.*, 2006; Pathak & Heijnen, 2006). Communities have for years supplemented and substituted household water supply. They have used rainwater to reduce problems such as water salinity, reducing time and energy taken off to fetch water, and replace unsafe sources such as wells, ponds and rivers (Mwenge Kahinda *et al.*, 2007). Most rural households' income however is low and installation of rain water harvesting is unaffordable (Thomas & Martison, 2007). Nevertheless, in countless communities, water scarcity causes great hardships to families particularly to women and children who must spend many hours each day collecting water from distant sources. In some instances, it is common for the poor to experience longer queuing times where few water sources are found, given that the richer or the more influential people get priority (Sullivan *et al.*, 2003). It is, therefore, clear that water shortage is a serious challenge affecting mainly the poor.

Usually, rain comes in intense bursts resulting in uncontrolled rill or gully erosion (Oweis & Hachum, 2009). According to the NWP Report (2007), in typical dry land without adequate vegetation cover and degraded forest and grassland, 90 % of precipitation will run off or evaporate, and only 10 % will be retained. Therefore, there is need for more efficient capture and use of the scarce water resources in arid and semi-arid areas. The RWH mechanism using different techniques covers a whole range of methods of collecting and concentrating various forms of runoff (Shah *et al.*, 2014). Some of these methods are suitable for exploitation by rural communities living in semi-arid regions where water is a limited resource.

2.2 Understanding Water Scarcity

Literature has revealed different types, forms and causes of water scarcity. Water scarcity can be physical or economic. Physical water scarcity occurs when there is not enough water to meet all demands (including the environment) (Vanham *et al.*, 2018). According to Kummu *et al.* (2016), physical water scarcity can be fundamentally divided into two aspects, that is, water shortage (population-driven water scarcity) and water stress (demand-driven water scarcity). Demand-driven water scarcity is defined as the ratio of water-use to availability (Kummu *et al.* 2016). According to Brown and Matlock (2011), physical water scarcity occurs in a country when more than 75 % of river flows in a country are withdrawn for domestic, industrial and agricultural purposes, making the country unable to meet future demands after accounting for its adaptive capacity.

Economic water scarcity on the other hand, occurs when there is not enough water for agricultural activities. The water availability referred to in economic scarcity is also called “green water” that is water held in unsaturated zone of the soil and available for plants (Vanham *et al.*, 2018). According to Rijsberman (2006), economic water scarcity is considered to occur in countries where renewable water resources are adequate (that is, water withdrawals are less than 25 % of river flows) but where there is a lack of significant investments in water infrastructure in order to make these resources available. Water scarcity can also be defined using the different forms of water availability. “Green water” has already been explained. “Blue water refers to liquid water in rivers, lakes, wetlands and aquifers (Rockstrom *et al.*, 2009). Water can also be regarded as “grey water” which refers to the volume of freshwater needed to dilute pollutants to meet the applicable water quality standards (Hoekstra & Mekonnen, 2011).

Another dimension of water is added by Serrano *et al.* (2016) who argues that other approaches to water ignore international trade of products with substantial amounts of embodied water which can have an impact on domestic water resources. This is called virtual water. It is this argument that challenged the idea of absolute water scarcity. The author explains that in a context of growing global interdependence on water resources, the water footprint should focus on both direct and indirect water use. The water footprint of a nation or region is the total amount of freshwater that is used to produce the goods and services consumed by its inhabitants. In other words, it is the sum of domestic water use and net virtual water import (Hoekstra & Mekonnen, 2011). This makes virtual water a broader concept encompassing blue, green and grey water.

Water scarcity may also be temporal or spatial. Temporal water scarcity is related to time, that is, variability in water resources in an area in a given period for instance, seasonal variations in water

availability (Udimal *et al.*, 2017). On the other hand, spatial water scarcity is related to space and deals with variability in water sources in a given area, for example, unequal distribution of water resources in an area (Rijsberman, 2006). Water scarcity and water stress though sometimes confused and used interchangeably are quantitatively different concepts. Although both deal with deficit of water, water stress is defined as a situation whereby available water is less than 1700m³ per capita per year whereas with water scarcity the cut-off point is just 1000m³ per capita per year (Taffere *et al.*, 2016). Moreover, Rijsberman (2006) emphasize the need to recognise water quality aspects especially access to safe water when discussing indicators of water scarcity. Walter *et al.* (2011) adds that water scarcity not only originates from quantitative or qualitative scarcity, but also from inefficient use and poor management.

Water scarcity can be a result of a variety of causes which can either be man-made or natural. At the same time, climate change is believed to have significantly caused water scarcity (Distefano & Kelly, 2017; Udimal *et al.*, 2017) yet it is both a natural and man-made phenomenon. Man-made causes of water scarcity include pollution (Udimal *et al.*, 2017), mismanagement of water resources (Lippman, 2014) and poor water infrastructure management (Chitonge, 2014), among others. Natural causes of water scarcity include reduced rainfall, high evaporation rates which have been exacerbated by climate change (Pachauri & Meyer, 2014; Alminana *et al.*, 2017) and population growth (Costa *et al.*, 2016). Therefore, different parts of the world experience diverse types of water scarcity impacting a variety of sections of their societies. In the following section, water scarcity issues in different parts of the world are discussed.

2.3 The Extent of Water Scarcity in the World

Water scarcity is affecting regions of the world in different ways. Table 2.1 provides a summary of the types of water scarcity, causes, as well as affected areas in each region. Some counties in Europe are beginning to feel the effects of water scarcity. Florke *et al.* (2013) has it that the withdrawal of water for the production of electricity continues to assume an upward trend in this continent. In 2010, it was estimated that 627 km³ of water per year is used in fossil fuels, biomass and nuclear for cooling of thermoelectric. In addition, water consumption for cooling systems takes approximately 43 % of the total surface withdrawal (Florke *et al.*, 2013). According to Alminana *et al.* (2017) the Mediterranean area is becoming drier and therefore more vulnerable to wildfires and drought. There is a high probability that the Mediterranean river basins will suffer an important decline in water resources availability attributable to climate change (Vorgas-Amelin & Pindando, 2014). It is expected that the increasing water demand, in combination with water scarcity due to climate change will intensify current stress in the near future.

Table 2.1 The Nature of Water Scarcity in Different Regions of the World

Region	Authors	Type of water scarcity	Major causes	Mainly affected sector
Europe	Florke <i>et al.</i> (2013) Vorgas-Amelin & Pindando (2014) Alminana <i>et al.</i> (2017)	Physical water scarcity (demand-driven)	Climate change (increased droughts)	Agricultural production
Asia	Gleick (2009) Manju & Sagar (2017) Bandyopadhyay (2017)	Economic water scarcity	Pollution of water sources and climate change	Agricultural production and economic expansion (businesses)
North America	Howitt <i>et al.</i> (2015) Hansen (2017)	Physical water scarcity (demand-driven)	Climate change (increased rate of prolonged droughts)	Human and ecosystems
Australasia	Qureshi <i>et al.</i> (2013) Sahin <i>et al.</i> (2018)	Physical water scarcity (demand-driven)	Climate change (increased rate of prolonged droughts)	Agricultural production and environment
South America	Giupponi & Paz (2015) Hurlbert & Mussetta (2016)	Economic scarcity	Poor management of water resources, pollution of water sources and population growth	Agriculture, domestic use and health (sanitation)
Middle East	Sowers (2011) Al-Suhaimy (2013) Lippman (2014)	Economic scarcity and physical water scarcity (demand-driven)	Poor management of water resources, climate change	Businesses (Economic expansion)
Africa	Mati (2007) Chitonge (2014)	Economic scarcity and Physical scarcity (population-driven water scarcity)	Poor management of water resources urbanisation, population growth and climate change	Agricultural production, domestic use and health (sanitation)

Within Europe, Spain is one of the most exposed countries to climate change-induced water scarcity caused by its socio-economic and geographical features. Agriculture in Southern Spain especially rice farming is by far the largest water consuming sector (De Jalon *et al.*, 2014). Rice farming in the Guadalquivir basin suffers the most adverse effects from water scarcity. Evidence of this can be seen in the period between 1983 and 2013 when the average cultivated area of Donana rice fields as a percentage of the total decreased by more than 20 % due to droughts (De Jalon *et al.*, 2014). In addition, viticulture will be affected by lower temperatures, higher air and soil temperatures, more frequent and longer extreme climate events (for example, heat waves and extreme droughts) (IPCC, 2013) that are predicted in Spain and other countries in Europe (Lionello *et al.*, 2014). Thus water shortages in Spain are mainly affecting the agricultural sector. Portugal is relatively well endowed in terms of water resources. However, these resources are unevenly distributed with marked difference between the rainy and cooler North and Central Atlantic regions of the country, and the dry and warmer south regions such as Alentejo (Lionello *et al.*, 2014). The same occurs with Spain which presents large differences in terms of water reserves and precipitation between the Atlantic and Northern Regions and the Southern Mediterranean regions. It is thus clear that countries in Europe are also beginning to feel water stress which will affect the agricultural sector especially viticulture and rice farming.

In South America, water resources are said to be abundant as the region is estimated to have about 35 % of the world's fresh water (Hurlbert & Mussetta, 2016). However, only 20 % of the population has access to adequate safe water and sanitation (Hurlbert & Mussetta, 2016). This situation is attributed to poor management of water resources, physical access, affordability and pollution. In Latin America, there is a large water pricing inequality which favours the rich. To make matters worse, the quality of water is much worse for the poor exposing them to water-borne diseases (Giupponi & Paz 2015). Water scarcity in this region also affect agricultural production especially viticulture, horticulture and fruit production (Hurlbert & Mussetta, 2016). For example, wine production in Argentina is one of the main sources of economic income and the main consumer of water (Castex *et al.*, 2015).

The Asian continent is no exception to water scarcity challenges. Hosting about 20 % of the world's total population, China's water bodies is only about 7 % of the world's total fresh water bodies (Shao *et al.*, 2006). About a third of lakes and rivers in China are polluted beyond possible human consumption. The growth in China's population, and an improved economic fortune has brought great pressure on the country's resources including its environment of which water is not an exception (Gleick, 2009).

Water bodies in China are polluted to the extent that vast stretches of water bodies are drying up and aquatic lives are getting extinct (Turner, 2006). China is regarded as one of the most polluted countries in the world. According to Turner (2006), out of the 20 most polluted cities in the world, 16 are found in China.

The problem of water pollution in China has become a threat to economic expansion of the country. It is reported that some counties have been cancelling future expansion plans and others closing their businesses in the country because of water issues in the country (Turner, 2006). In addition, local farmers in some regions have reportedly sold their grains which were produced using polluted water and later bought from regions where water is safer (Bandyopadhyay, 2017). Even water managers in China are said to be having challenges in handling the water situation as groundwater is overexploited. In India, the exponential increase in population has led to stress in water resources in the country. Rapid population growth, climate change, overexploitation of water resources and increased pollution has led to scarcity of fresh water resources across the country (Manju & Sagar, 2017). It is forecasted that India will rank 40th in the world by 2040 in terms of water scarcity (Luo *et al.*, 2015). However, the presence of a coastline in India gives an added advantage to use the desalination technique to overcome projected scarcity (Manju & Sagar, 2017). It can therefore be deduced that water scarcity in Asia especially in China is a result of pollution and has mainly affected business expansion in the region.

In Western United States, recent and ongoing droughts have already challenged existing water infrastructure and management institutions. California was said to be in its 4th year of severe drought (Hansen, 2017) which had profound impacts on humans and ecosystem in the state (Howitt *et al.*, 2015). The Colorado River Basin was also in the midst of a multi-year drought which had prevailed for 16 years, prompting significant regional discussion on how to adapt to a drier future (Hansen, 2017). Urban water utilities in Australia are also said to be struggling to meet the increasing demand for water as they are confronted by a number of challenges including severe droughts, increasing population, highly variable rainfall and ageing infrastructure (Qureshi *et al.*, 2015). Supply augmentation and demand management are two main strategies used by water utilities to address water scarcity (Sahin *et al.*, 2018). As a major food exporting country, Australia contributes to food security in its neighbouring countries (Qureshi *et al.*, 2015). However, due to the changing climate and resulting water shortages, the country's agricultural production has been threatened with potentially serious economic and environmental consequences. This shows that even in developed countries, increased droughts as a result of climate change have led to water scarcity in both rural and urban areas.

The Middle East is also now in a water crisis with Saudi Arabia and other countries of the Gulf Cooperation Council already classified by the UN as water scarce nations. According to Sowers *et al.* (2011), because water resources are already so scarce, the Middle Eastern countries will be particularly vulnerable to the effects of climate change. Saudi Arabia constitutes the majority of the Arabian Peninsula and is one of the largest arid countries without permanent rivers or lakes. The country is located in the tropical and subtropical desert region of the Middle East between the Persian Gulf and the Red Sea and temperatures can reach more than 50°C in some areas producing overwhelmingly dry and hot conditions. Average rainfall in the country is as low as 114 mm per year.

Despite being one of the wealthiest nations globally due to swift economic growth and prosperity from oil (Ng *et al.*, 2011), Saudi Arabia is one of the poorest nations in terms of natural renewable resources (Al-Suhaimy, 2013). According to Lippman (2014), mismanagement of water use in the agricultural sector, and increasingly westernized and consumerism-based shift in lifestyle are mostly to blame for the country's water-starved status. The author adds that precious groundwater sources have been injudiciously used over many years to the point of depletion. Furthermore, the combination of a more than average annual population growth rate of 25 % coupled with an 8.8 % annual increase in the demand for water and the changes brought about by climate change (Al-Suhaimy, 2013) will have significant effects on the future of both the availability and quality of water resources in Saudi Arabia (Sowers *et al.*, 2011). Fortunately, Saudi Arabia is a wealthy country and has the ability to address growing water demand. The same cannot be said for poorer countries in the same region such as Yemen and Syria. These countries do not have the means to finance, operate and maintain water infrastructure such as expensive desalination plants although their need for water resources are most urgent (De Nicola, 2015). The situation in this region reveals that although water scarcity affects both rich and poor nations, rich countries are able to cope better. This is due to the fact that rich developed countries have the means to finance a variety of water management schemes.

Within Africa, about a third of the population lacks safe drinking water and it is estimated that 25 countries will be experiencing water scarcity by 2025 (Mati, 2007). Africa has about 3991km³ of renewable freshwater resources per year, yet the continent continues to suffer from water scarcity. This situation is caused by poor temporal and spatial distribution rather than absolute lack of water (Mati, 2007). Chitonge (2014) argues that in Africa and other low income regions, people in rural areas are often attracted to urban life because the provision of basic services such as piped water, electricity and clean sanitation, among others is better than in rural areas. This has increasingly constrained water services in urban areas. Moreover, water stress is predicted

to affect about 50-250 million Africans by 2020 (Parry *et al.*, 2007). Urbanisation is thus one of the causes of water scarcity in Africa.

There is a rising concern about access to water supply in semi-arid regions of SSA which has the largest share of low water access in the continent (Taffere *et al.*, 2016). According to the author, five of the bottom listed countries in the Joint Marketing Programme report are found in semi-arid region of the African continent, except for Papua New Guinea in Southeast Asia. The increased demand for water is mainly associated with population growth, economic development, while environmental needs, climate change, water pollution and over abstraction of groundwater will worsen (Ngigi, 2009). In this region, demand surpasses available water resources in a number of countries, many of them face either water stress or water scarcity. In Zimbabwe, Zambia, Malawi and South Africa, rainfall has been erratic. These countries have experienced late rainy seasons, large dry spells and fewer rainy days over the last 50 years (Taffere, *et al.*, 2016). The causes of water scarcity in SSA are therefore multiple and affecting countries in ways that are unique.

Schlosser (2014) argues that countries that are already experiencing water stress will be the most impacted in future under the combined effects of socio economic shifts and climate change. South Africa is no exception. The country is ranked as the 30th driest country of the world. Its semi-arid areas receive rainfall varying from less than 100 mm per annum in the west to over 1500 mm per annum in the east. The average rainfall is 450 mm per annum which is well below the world average of 860mm per annum (Nomqophu, 2005). Sixty five percent of the country receives less than the national average rainfall per annum which is regarded as the minimum of dryland farming while 21 % of the country receives less than 200 mm per year. Water scarcity in South Africa places considerable strain on rural communities who directly rely on rainfall to sustain their livelihoods especially poor communities living in low income houses with little access to services and resources (Bulcock & Schulze, 2011). The authors add that irregularities in timing and distribution of rainfall often leave communities without access to water for the most basic daily needs.

Water scarcity has affected the urban areas too. The 2016 drought, which has been recorded as the worst drought in decades left many towns and cities with extremely compromised water supply systems (Fisher-Jeffes *et al.*, 2017). In Cape Town, it has led to shortages of water even just for basic domestic uses. A drop in the amount of water in reservoirs has resulted in the imposition of stringent water restriction measures by the Cape Town Local Municipality as already indicated. Water scarcity has also resulted in limited production across the country putting pressure on the already fragile economy. The Vhembe District Municipality has also been experiencing water scarcity for years now. This has mainly been caused by the changing climate and poor water

infrastructure maintenance. The story is the same for Mabayeni village. Due to water shortages, municipal water is only available on taps for a couple of days per week. This has resulted in shortages of water for basic domestic uses.

It is clear from the discussion above that water scarcity affects both the developed and developing countries. Climate change has greatly contributed to this challenge in almost all regions. The most common contributing causes of water scarcity in developing countries are poor management of water resources and population growth. This shows that although availability of financial resources is critical in developing and maintaining water resources, this needs to be coupled with effective policies and political will or investment in the water sector. These characteristics have been lacking in some developing countries. In the following section, the different coping strategies that have been used to cope with inadequate availability of water are discussed.

2.4 Coping Strategies for Water Scarcity

Literature on communities' coping strategies to water scarcity mainly focuses on pastoralists. According to Pearson *et al.* (2015), the main coping strategies identified by communities were the use of water from the boreholes and wells. Similarly, Adeniji-Oloukoi *et al.* (2013) also noted underground and surface water resource development such as drilling boreholes and wells as one of the coping strategies employed in Nigerian communities. The authors also note that those without access to public water resorted to migration as a primary coping strategy. Adeniji-Oloukoi *et al.*'s (2013) study revealed a high level of water sharing and reciprocity albeit at much lower levels for outside ethnic groups and between wealthy and poor alike. This is evidence of reliance on social capital bridging between the wealthy and poor for coping as wealthy households tended to have larger water resources because of having larger plots of land. In addition, the authors observed the significance of strong social capital within community set-ups although this impacted negatively on outsiders.

Pearson *et al.*'s (2015) findings are echoed in a study done in Nigeria where households were reported to close sources of water to outsiders during times of water scarcity. There was, thus, a reliance on purchasing water for these groups of people (Adeniji-Oloukoi, 2013). Mukuhlani & Nyamupingidza (2013) also recorded some coping strategies to water scarcity from their study in Entumbane, Bulawayo in Zimbabwe. Residents stated that water only came on the taps for two hours at most, which forced them to opt for boreholes in the area. The result has been long queues at the boreholes. These researchers also note that women were forced to wake up as early as three o'clock in the morning to queue at the local boreholes. One can only imagine the security risks involved in these situations. Residents resorted to storing water in containers to ensure that they have enough water for drinking and other domestic purposes.

Mukuhlani & Nyamupingidza (2013) noted walking long distances to fetch water as another coping strategy to water scarcity even in urban areas. In Zimbabwe, residents from urban areas such as Entumbane had to walk approximately two to three kilometres to Mpopoma to fetch water. Mpopoma is in relatively lower ground compared to Entumbane. Here, residents had to forge relations with Mpopoma residents to get water. So residents from Entumbane had to buy water from Mpopoma residents who were selling it for approximately five rands or fifty cents a bucket. Walking long distances has also been recorded by Ishaku *et al.* (2013) in their study in Nigeria. The authors observed that 60 % of their respondents mentioned walking more than two km to fetch water especially during dry seasons as a coping strategy to water shortages. More interesting coping strategies are explained in the Adeniji-Oloukoi *et al.* (2013) work. Rescheduling of water collection times particularly from community wells is one of them. Some households were also reported to adopt alternate bathing days instead of bathing every day. Others minimized the amount of water for bathing, cleaning, washing and controlled children's bathing by disallowing them to bath on their own (Adeniji-Oloukoi *et al.*, 2013).

Ishaku *et al.* (2013) witnessed the importance of water storage facilities on RWH. In fact, it was noted as one of the factors discouraging water harvesting in the communities under study. Results of this study indicated that the majority of people stored water in 100 litre drums, pots, jerry cans and buckets that lasted a few days. Although 85 % of the respondents indicated awareness of RWH, only 2 % confessed to using it due to lack of large water storage facilities. This is a clear testimony that despite the willingness to adopt rooftop RWH technology; communities are discouraged by having to use small containers.

In their study in Nigeria, Ahile *et al.* (2015) also reported rain water harvesting as another strategy employed by some residents to cope with scarcity of water. The authors view rain water harvesting as the most convenient coping strategy. Water is collected from rooftops and stored in containers for use during lean periods. They add that this eliminates financial cost and drudgery of water collection. However, this strategy is limited to the rainy season. Furthermore, minimising the use of water was another way of coping with scarcity. It was observed that the majority of households combine a number of coping strategies, yet the measures have proved inadequate to address their water scarcity problems. Adeniji-Oloukoi *et al.* (2013) also alluded to RWH as another coping strategy to water scarcity in the Oke-Ogun region of Nigeria. Nevertheless, the authors explain that this coping strategy is rather uncommon due to weak awareness and poor capacity for water conservation in the study area.

In South Africa, RWH (both in-field and rooftop) has been used as a coping strategy to water scarcity. In-field RWH practices have been documented by Denison & Wotshela (2005), Botha *et al.* (2012), Botha *et al.* (2014) among others. Practices such as contouring, stone terracing (practiced in KwaZulu-Natal), Gelesha (practiced in central and Eastern Cape), homestead ponds (practiced in Thaba Nchu, Free State and Tyume Valley (Eastern Cape) have been documented by Denison & Wotshela (2005). These indigenous water harvesting and conservation strategies entail minimum tillage of soil, directing and redirecting water to croplands, creating basins in the field or next to plants among others. As much as they are water harvesting techniques, these practices are also soil conservation techniques.

Rooftop RWH has also been used to cope with inadequate availability of water in the Eastern and Western Cape provinces, Free State, Limpopo and KwaZulu-Natal. Rooftop harvested rainwater has been used for home gardening (Thaba Nchu and Amathole Districts in Free State) as well as supplementing other domestic water needs (WRC Technical Report, 2013). In the Western Cape, under the Kleinmond housing project, rainwater harvested from rooftops was used for domestic uses to supplement municipal water. Rainwater was also used for drinking after treatment (Mannel *et al.*, 2014). Rooftop RWH was also carried out at Kharkams High School in the Northern Cape and rainwater was used for drinking, to irrigate the vegetable gardens, and to irrigate the sports grounds. These are only a few examples of in-field and ex-field rainwater harvesting techniques used in South Africa to cope with inadequate availability of water.

From the studies reviewed above, it is apparent that community members are doing what they can to survive under difficult water situations. The extreme experiences warrant urgent intervention strategies. There is a dearth of information on current strategies communities are using to cope with water shortages at household and domestic level. This study therefore sought to fill this gap and provide a range of coping strategies rural communities from arid areas could use to cope with water shortages. Rainwater harvesting has shown potential in alleviating water scarcity in different parts of the world where water scarcity was experienced. This coping strategy is dealt with in detail in the next segment.

2.5 Origins of Rainwater Harvesting

The first water harvesting techniques are believed to have originated from Iraq over 5 000 years ago, in the Fertile Crescent of Mesopotamia, where agriculture originated in 8 000 BC (Agarwal & Narain, 1997). Since then, many civilizations have used such techniques. In some, the development of water harvesting probably formed the very basis for their existence (for instance, the agricultural societies of the Negev desert and the spate irrigation societies of the horn of Africa). In India, water harvesting systems have been practiced for millennia. Archaeological

findings show that rain water collection in stone rubble dams for irrigation purposes was practiced as early as 3 000 BC. As shown by Agarwal & Narain (1997), these old traditional water harvesting systems developed into a multitude of different systems for domestic use and crop production. The authors add that these systems formed an important backbone of the Indian farming systems in the semi-arid savannah environments until the early 20th century.

Therefore, Rockstrom (2002) argues that water harvesting is nothing new, but received little development attention during the decades of modernization of agriculture from the 1940s onwards. The recent realization of the potential of small scale water solutions for improvement of rural livelihood has resulted in renewed interest in water harvesting (Rockstrom, 2002). For a couple of decades, farmers and development agencies in both South Asia and SSA are paying more attention to these technologies and methodologies. This is because of the increasing demand of water due to population growth and climate change, as well as the realisation of the potential of RWH.

In Africa, the importance of rain water harvesting for various agricultural activities received great attention in the 1970s and 1980s (Hatibu & Mahoo, 1999). This was caused by the widespread droughts which led to crop failures, and caused serious threats to human and livestock growth. The main aim was to curb the impact of drought and improving agriculture production and in some cases rehabilitating abandoned and degraded land (Hatibu & Mahoo, 1999). In SSA, *in-situ* water harvesting systems, generally defined as soil and water conservation, is the most dominant indigenous water harvesting practice. Traditionally, the so-called Zai pits; small planting pits for concentration of within-field sheet runoff, originating from Burkina Faso, have been practiced for centuries among small holder farmers in the farmed savannahs (Reij *et al.*, 2013). However, in general terms, water harvesting systems for supplemental irrigation are much less common in SSA as compared, for instance, to South Asia (Uramar & Ozor, 2010). This is likely because of lack of support of RWH projects from governments and other institutions. In order to understand the development of RWH systems, traditional RWH systems are reviewed below.

2.6 Examples of Traditional Rainwater Harvesting Techniques

A study by the ATPS (2013) documented traditional RWH practices. One such practice is hanging pieces of clothes on the roof edge to collect and filter dust and mud particles from water before it is collected in the buckets placed on the ground. Another technique was tapping runoff through digging shallow holes in open spaces surrounding houses. According to the ATPS (2013), this is mostly done in a few areas where soil types have a mixture of clay, sand and loam. Water collected in this way is immediately stored in buckets and allowed to settle before it can be used. These techniques are not wide spread and were invented by a few villagers in their struggle to

tap rain water for their household use. Although water collected in this way is never sufficient, it however supplements household water needs. Improvement of such techniques as well as their cost analysis has revealed their feasibility and reliability.

The application of appropriate RWH technology can make possible the utilization of rain water as a valuable and necessary water source. Mbilinyi *et al.* (2005) narrates that people who rely completely on rain water have over the years developed indigenous techniques to harvest it for agricultural purposes. In Tanzania, experience with RWH has a long history. Individual communities have over the centuries developed traditional water harvesting techniques. These are also regarded as water conservation methods. For instance, excavated banded basins known as “majaluba” are done for rice production in the Lake Zone. In addition, raised broad basins locally known as “vinyungu” in Iringa region and water storage structures locally called “Mashamba ya mbuga” where farmers grow high water demanding crops in the lower parts of a landscape using rainwater from surrounding high grounds have been practiced for a long time in semi-arid areas of Tanzania. In Uganda, RWH is widely practiced in most rural areas (Baguma *et al.*, 2009) and is supported by both government and donors.

These traditional techniques have been sustainable for many years. This is because they are compatible with local lifestyles, local institutional farmers, and local social systems. In order to develop sustainable RWH strategies, it is, therefore, important to capitalize on the available local knowledge (ATPS, 2013). Salas (2007) argues that the use of RWH is not only prevalent in developing countries. To protect the environment, many European countries are using RWH for water supply for non-potable use and irrigation and for ground water seepage. For instance, the United Kingdom reports that the value of RWH industry doubles every year and Germany reports that there are 50 000 RWH professionals supporting the RWH industry. The industry is mainly run to manage rain water and to ensure that it does not contaminate streams and surface water (Salas, 2007). It is therefore clear that although developing and developed countries have been engaging in RWH, the water uses show that developing countries are more desperate for the resource. This is evidenced by the fact that in the developing world harvested rainwater is used for drinking which is not the case for the developed world.

Rainwater harvesting techniques have also been documented by Weiner (2015) as part of high efficiency water management in the past. Making reference to the Bible (II Kings 3:16, 17), the author explains how artificial cisterns were used to store water from the short and erratic rainy season for use in the long dry summer spell in ancient times. According to Weiner (2015), there is also evidence on the existence of water supply systems in the emerging cities dating back to

the second millennium BC. The latter author argues that the water conservation and conveyance works dating back to the eighth-century BC of 520 metres long tunnel bringing water from the Shiloah Spring to Jerusalem, bears witness to an impressive water supply technique.

Other indigenous methods of conserving water were those developed by the Nabatean dwellers of the Negev more than 1 500 years ago (Weiner, 2015). They are said to have developed the most efficient ways over centuries of conserving the desert's scarce water resources. Since rainfall was insufficient for farming, the Nabateans meticulously collected runoff from cultivated slopes and conveyed it to limited areas of cultivation in the valleys. To avoid erosion, the Nabateans constructed extensive diversion and drop structures, guide walls, terraces, and a system of basin irrigation, as well as storage dams and water cisterns. Dry farming in Israel's semi-arid north was equally intensive and put similar emphasis on water conservation. Water conservation was especially successful in the then carefully terraced Judean and Galilean hills (Weiner, 2015). It is interesting to discover that RWH practices and techniques have existed since the beginning of human history. Just like a variety of RWH techniques have been used in the past, a range of RWH techniques are currently being used.

2.7 Existing Rainwater Harvesting Techniques

Current RWH techniques are summarized by Mbilinyi *et al.* (2005). According to the authors, the first category technique is on-farm systems or *in-situ*. This is basically capturing and using rainfall where it falls. It is a water conservation method that minimizes the amount of net run off and ensures that crops use the scarce water resource. This technique includes conventional approaches to soil and water conservation that are designed to enhance infiltration of water into the soil. Examples of *in-situ* RWH techniques include deep tillage, dry seeding, mixed cropping, ridges and borders, terraces and trash lines (Mbilinyi *et al.*, 2005). These are water conservation techniques that are practiced in the field and require limited expertise.

The second category of RWH is a micro-catchment system that involves a distinct division between a run-off generating catchment area and a cultivated basin where run off is concentrated, stored and used by plants. In this case, the catchment area and the cultivated basin are adjacent to each other (Gowing *et al.*, 1999). This system is suitable for growing medium water demanding crops such as sorghum, millet, groundnuts and maize. Techniques of RWH in this system include pitting, strip catchment tillage, contour bunds, semi-circular bunds and charco dams locally known as "lambo" in Kilimanjaro region (Mbilinyi *et al.*, 2005). This type of harvesting rainwater also requires relatively limited expertise although it's labour intensive.

The third category is macro-catchment system RWH. This is characterised by huge catchment areas which are located outside the cropped area where individual farmers have little or no control over them. The systems include intermediate components of collecting, transferring and storing runoff. Gowing *et al.* (1999) argues that such systems are difficult to differentiate from conventional irrigation systems, but they are referred to as RWH as long as the harvested water is available beyond the rainy season. Water storage structures such as “ndiva” in the Kilimanjaro region and “Mashamba ya mbuga” (already explained) are examples of indigenous macro-catchment RWH systems. It is clear that this category of RWH, can be utilized by multiple beneficiaries at the same time.

Domestic RWH which is the focus of the study, is whereby rainwater is collected from rooftops, courtyards and low frequented streets and stored close to these catchment areas (Helmreich *et al.*, 2009). The storage tanks are built either underground or aboveground and storage size depends on requirements. According to Helmreich *et al.* (2009), common tank shapes are cuboid, cylindrical or doubly curved. For storage, smaller storage tanks are made of bricks, stabilized soil, rammed earth, plastic sheets and mortar jars. For larger quantities, rainfall water containers can be made of pottery, ferrocement, or polyethylene. There are precautions however that need to be taken when using tanks for rainwater storage. There is need for provision of an adequate enclosure to minimize contamination of water by human, animal or other environmental contaminants, and a tight cover to prevent algal growth and breeding of mosquitos (Helmreich & Horn, 2009). Therefore, domestic RWH systems can be customised to meet the needs of the user(s).

Amin *et al.* (2013) argue that roof catchment method of RWH has widely been used to provide urban dwellers with potable water supply in many parts of the world. This is proof that stored rainwater can be used for drinking although there would be need for purification. The main advantage of domestic RWH according to Helmreich *et al.*, (2009) is that it provides water right near the household, lowering the long distances walked by communities to water collection points. Rainwater harvesting offers benefits such as promoting self-sufficiency and encourages water and energy conservation (Retamal & Turner, 2010). The stored water using roof top RWH systems can be used for a variety of domestic purposes for instance, washing, bathing, garden watering, toilet flushing or even car washing. In short, RWH systems are profitable for the community and result in permanent decrease in mains water demand (Grandet *et al.*, 2010). Despite the range of RWH techniques available, common features are observed.

2.8 Major Features of Rainwater Harvesting System

Although the sophistication of RWH system components are generally different between developed and developing countries, a typical RWH system in both cases comprises three basic elements. These are; the collection surface, the conveyance system and the storage and distribution systems (Abdulla & Al-Shareef, 2009; Sturm *et al.*, 2009; and Amin & Han, 2011). According to Sturm *et al.* (2009), every RWH system consists of preferably waterproof catchment surfaces for collecting rainwater which are either roof or ground surfaces. The collection surface usually corresponds to roofs and terraces, with the configuration and material of the collection surface affecting the rainwater quality and quantity (Silva *et al.*, 2015). Well-constructed corrugated iron roofs provide ideal catchments for RWH according to Gould & Niessen-Petersen (2003). Thatched roofs cannot be recommended for high quality rainwater collection since they discolour the water and make it less palatable and attractive for human consumption (Sturm *et al.*, 2009).

After collection, rain water goes through the conveyance or delivery system, which normally includes gutters and downpipes. Gutters and downpipes are usually made out of plastic or metal, as these materials are most durable (Development Technology Unit: DTU, 1997). Rainwater then goes through a first flush device and a filtration device. The first flush device diverts the initial precipitation volume that tends to be more contaminated due to washing of the pollutants deposited on the collection surface over the preceding dry weather period. The filtration device provides some degree of treatment to the rainwater, but is limited mostly to the physical characteristics. After filtration, the rainwater is stored in a tank from which it is conveyed to the end-use point by a distribution system (Silva *et al.*, 2015). Distribution systems may be in the form of pipes, channelled pavements, or other materials depending on availability and preference.

A rainwater system may have distinct storage and distribution tanks, or only one tank for both functions. It is also suggested that at least one of the tanks be connected to another water source, usually the public water system, to ensure water supply when rainwater is not sufficient (Silva *et al.*, 2015). An air gap must be guaranteed to prevent contamination of the public water system. Depending on the location of the tanks, elevated or underground and end-use point, a pumping system may be required to provide adequate water pressure at delivery. Optionally, additional treatment stages can be included before the storage tank to ensure rainwater quality, but this is not generally required for non-potable uses. Amin & Han (2011) however maintain that if the system is designed well, it requires little or no electricity, chemicals or maintenance. It is, thus, of paramount importance to take note of all the technicalities involved in designing and construction of RWH technology if harvested water is to be used for drinking. In order for a RWH technology

to be accepted by users, it should meet certain standards depending on a particular community. Examples of common community preferences of RWH system features are explained below.

2.9 Community Preferences of Rainwater Harvesting System Features

Community preferences when designing or constructing a RWH system should be taken into consideration. This is because if there are characteristic features that communities are not comfortable with, it will be difficult for them to look after the technology. For this reason, community members should be in the forefront of the development of the RWH system. Issues to do with affordability, physical compatibility, ease of construction as well as ease of maintenance should be particularly considered. There is little research on community preferences of RWH systems features. Most studies have focused on factors affecting acceptability and adoption of RWH technologies.

2.9.1 Affordability

In a study done by Oweis & Hachum (2006), lack of capital and credit was one of the reasons given by farmers for their negative perception of the RWH technology. Drawing from this finding, once farmers feel that the RWH technology is expensive or demands a lot of capital, they are likely not to accept or adopt it. The authors additionally noted household income as having a statistically significant effect on adoption of RWH. For instance, farmers with higher family incomes are more likely to adopt RWH technology than those with lower incomes. A higher level of household income implies a greater incentive for investment in agricultural technologies and the ability to bear the risk associated with this adoption (Oweis & Hachum, 2006). Therefore, RWH requires some financial investment.

This observation is also true and applicable for RWH technologies for harvesting water for domestic purposes. The more expensive it is; the less people adopt it. As long as communities feel they have to pay too much for a new technology, they simply will not adopt it because it will be an additional stress on their livelihoods. According to the Water Research Committee Technical Brief (2013) few households in Cata, Eastern Cape exploited RWH to help meet water needs due to lack of financial and labour resources to put up harvesting structures. Moore & Benbasat (1991) contend that the cost-benefit of an innovation in general influences its adoption, with lower initial outlay as a barrier to entry and conducive to adoption and on-going financial benefit conducive to continuity. Related to this is the role played by investment costs (Lasage & Verburg, 2015) in relation to the water yield of the structure. If investment costs are too high compared to water yield, very few or no community members will consider the technology. Therefore, a RWH technology should be affordable to rural communities if it is to be accepted and

adopted. Consequently, this should be reflected in the designing of the technology and the materials used should be cheap and locally available.

2.9.2 Physical compatibility

Communities are also likely to prefer and adopt RWH technologies that are compatible with already available infrastructure or building set up. Otnes (1988) in White (2010), and Rogers (2003), argue that innovations that are compatible with the physical constraints (like space) and the values of the household are more likely to be adopted. Basically, it would be easier to fit a few new structures to already existing buildings as this will mean fewer additional costs. According to Lasage & Verburg (2015), water harvesting measures should be technically applicable under the physical circumstances in the field. The authors also emphasize the importance of accounting for the cultural acceptance of the technique and the need for complex governance after implementation of the technology. It was discovered in a global survey on attitudes of communities towards RWH that in some arid areas, RWH was viewed as a pagan practice and therefore unacceptable (Mannel *et al.*, 2014). Lasage & Verburg (2015) also note many examples of failed water harvesting projects due to complexity of governance, or because they were not acceptable to the population as a result of cultural and environmental barriers. Therefore, when designing a RWH technology for communities, it should be taken into cognisance that the easier it can be integrated with existing community structures, the easier it becomes for communities to adopt. This is because they would not have to change a lot in their lives. Communities' cultures should also be considered.

2.9.3 Ease of construction and maintenance

Communities are also likely to prefer a RWH technology that is easy to construct, maintain and use. According to Simonsen & Robertson (2012), a number of RWH projects have failed to combine technical efficiency with low cost and acceptability to local farmers. The authors attributed this to lack of technical know-how regarding the maintenance of the systems and also due to selection of inappropriate approaches with regard to prevailing socio-economic conditions. Again, although results were deduced from information obtained from farmers, this is also applicable to RWH systems for collecting water for household use. Moore & Benbasat, (1991) add that easy understanding, installation, use and maintenance of RWH systems facilitate community adoption. Put simply, any innovation that is easy to construct, maintain and use is likely to be adopted. If local community people are able to use and take care of the technology, there would be no need to hire or wait for qualified technicians and engineers to come and fix in the event of damage or malfunction.

In other words, community members should have the knowledge on how the RWH system is constructed and designed. Oweis & Hachum (2006) add that knowledge plays an important role for people involved in the RWH scheme as they need to fully understand how it operates. One potential negative effect of implementing complex RWH technologies (designed by experts) is that those who are left to use it are unfamiliar with the technology and thus unable to properly maintain it. Therefore, local communities should participate in the process from the designing and construction phases until the end. This would enable them to acquire the necessary knowledge to maintain the RWH technology. It is this element that has been missing in a lot of RWH projects (Simonsen & Robertson, 2012) which has contributed to their failure.

2.9.4 Image and relative advantage

According to Holloway (1977), adoption of a technology is facilitated when improved social status is obtained by the adopter. In this case, this means that if communities see the benefits of harvesting rainwater from their roof tops and storing it for later use, they will adopt the technology. This should also go hand in hand with their priorities. Rainwater harvesting aims to increase the availability of water resources for productive use, and it is, therefore, important that the RWH infrastructure meets the needs of the individuals who are using it (Critchley & Siegert, 1991). Rogers (2003) notes relative advantage as another feature that influences adoption of RWH systems. The advantages perceived to be conferred by adoption of RWH directly facilitate adoption. The author adds that this construct was modified due to the concerns about the advantages of RWH technologies relative to other water supply technologies. Baiyegunhi, (2015) explains the theory of maximizing utility and its relevance in adoption of RWH technologies. According to the theory (Greene, 2003), a farmer will adopt a new technology if the utility obtained from the new technology exceeds that of the former. Therefore, a RWH technology that offers significant advantages compared to other water supply technologies is likely to be preferred and adopted if it improves communities' well-being and social status.

Mankad (2012) notes the importance of understanding psychological influences on community decisions to accept and use decentralised water. Although putting more emphasis on the role of emotions, the author acknowledges researchers like Marks (2004), Nancarrow *et al.* (2008) and Hurlimann & Dolnicar (2010) who have highlighted that community acceptance plays a vital role in the eventual success of alternative water initiatives. Over and above, a RWH system should be chosen and designed for the local circumstances, taking into account the purpose of water harvesting, available funds, technical expertise, and the physical surroundings (Frasier, 1980; Mwenge-Kahinda *et al.*, 2007).

2.9.5 Availability of resources

The resources necessary for construction (physical, labour, knowledge, capital) and their effects on the surrounding environment and hydrologic conditions (quantity and quality) also need to be taken into account when designing a RWH technology (Lasage & Verburg, 2015). Community leaders should determine if the technology will be feasible in their area taking into cognisance resources available. Community members should take ownership of the technology, for instance in the selection of local resourceful people (artisans or craftsmen) who would be leaders in the technology development. This should be done in the early phases of design so that everything is planned out well for implementation. This gives no room for uncertainties that may lead to community members doubting if the technology will work at all. When uncertainty and doubt creep in, the chances of adopting the RWH technology are significantly lowered. Water quality is also important when a structure provides water for domestic use. Water quality is less relevant when water is used only for irrigation. In essence, community members would prefer a technology that they can make using simple local materials. In this case, they would be confident to replicate it in the absence of professional engineers or qualified technicians.

There is also lack of information on community-informed major features as well as preference features regarding the RWH technology. This is because very little or no studies have been done in the past in which consultations were done with communities. Since they are the end-users of RWH technologies, it is only right to afford communities the voice to determine what in their views count as major features in the RWH technology. Community-informed major features of the technology are likely to address their expectations and, therefore, be appropriate for their needs. Often, the designing of technologies is so specialised that it is left for engineers and technicians. Yet rural communities have their own expectations, beliefs and resources to support the technology. This has led to technologies that have not been adopted because of failure to meet communities' minimum expectations.

It is in the light of the above that this study focused not only on making sure that community members were consulted on the main components of the RWH technology, but also on ensuring that they participated from problem formulation, to the actual designing and construction, evaluating their own RWH technology prototypes as well as selecting the best intervention strategy. In actual fact, rural community members who were prospective end-users of the technology were the 'experts' in the designing process since they understood their community better. Therefore, they knew what worked best for them. This process cultivated trust and confidence in the technology. These two elements are essential in developing technologies that are appropriate for the social, economic and physical set up of the community, thus adoptable. A

combination of some of the community-preferred RWH technology features have worked in many communities in Africa. Below are their success stories.

2.10 Success Stories on Rainwater Harvesting in Africa

In one Tanzanian community called Karagwe, RWH became a success after the realisation that plastic tanks were an ineffective way of storing water. This was also coupled by an understanding of the need to use local materials in constructing tanks as the most efficient and logical technique to implement (National Peace Corps Association, 2016). The plan consequently included families in the construction and upkeep process and so kept the community devoted to the water systems as the project focused on community needs. For instance, instead of originally facilitating the construction of several smaller tanks, the community was adamant they needed a tank as large as 300 000 litres. Thus, the project plans changed to fit the community's need. Some of the unexpected aspects of the project included the add-on of the fruit tree farm which helped address water security issues and educational initiatives which provided food and agricultural support to the community. The community also participated in the construction of the water tanks through contributing local materials and also the actual construction. Additionally, maintaining partnerships with other Non-governmental Organisations (NGOs) and the community made the project successful. Although this story does not explicitly explain the process involved in the project and how the Karagwe community interacted with outside organisations, there is evidence of involvement of the community from inception and throughout the construction of the RWH system.

In Ethiopia, two champion groups harvested and stored water in underground tanks. These cisterns were made of cement and were either covered by corrugated iron sheet or cement roof, preventing evaporation and contamination. Rain that fell on roofs or surfaces around the tanks was then directed to the cistern through small ditches. Water passed through a filtering system that removed the silt before entering the cisterns. The tanks were equipped with hand pumps, either on top of the cover or connected to a water point with faucets (Eggens & Patrick, 2015). In a community called Mehoni, the cylindrical cistern measured 20 cubic metres, while in Bule Gufu it held about 60 cubic metres of water serving 113 households for over 3 months. Water was used for domestic use in Bule Gufu and for livestock and small-scale irrigation in Mehoni.

The tank and silt traps needed to be cleaned regularly to ensure that water quality was better than that of ponds or other open surfaces. A distance of at least 20 metres from the village prevented contamination. Additional water treatment at the point of use was necessary to ensure safe drinking water because most of the contamination occurred when water was retrieved. The technology was simple to understand and was maintained by the community. It could also be

constructed by local artisans although cement was not always available or affordable on the local market. The cement structure was durable, though somewhat difficult to expand (Eggens & Patrick, 2015). This is a more detailed example, with clear guidelines of how water harvesting was done in this community. What is also commendable in this story is the fact that it was the community leadership that championed the project and was responsible for the whole RWH process.

In Uganda, the Nyamitooma community also successfully installed RWH tanks with the help of the Agency for Cooperation and Research in Development (ACORD). The agreement was that the community would also contribute but before that, each family had to install basic sanitation facilities like a latrine, bathing shelter, drying rack for utensils, and a kitchen (Eggens & Patrick, 2015). This way, the two main water-related challenges in the area; water and sanitation were addressed. The ACORD prepared the community with training courses about group dynamics, communication, resolving potential disagreements, family planning and proper hygiene. In addition, local masons were trained in tank construction and repair. It was agreed that ACORD and community groups would both finance 23 tanks of 7 000 litres each, enough to provide families with water during two to three months, almost covering a dry season. The community agreed to contribute local materials for instance; stones, poles and water. All Nyamitooma families were required to contribute an equal amount and were allowed to pay in monthly instalments of 30 000 Uganda Shillings (9 Euros). Though this was not easy for community members, they managed to pull through because they really wanted better water supplies. Nyamitooma is now regarded a model village in sanitation and is visited by many from within and outside the district to learn. This was a unique experience because the technology was demand-driven, and also an elaborate group approach to co-financing was taken up by the community.

In Ghana, rooftop RWH has enabled households as well as communities to manage their own supply of drinking water, domestic use, irrigation and other income-generating activities. They have done this through the use of community buildings, schools and clinics. In Namibia, the Curve Waters Project introduced three different options for *ex-situ* RWH in central-northern Namibia. The pilot plants were built in the villages of Epyeshona and Lipopo in the Oshana region and were conceived based on research (Gould & Nissen-Petersen, 2006), a participatory demand-responsive approach with local communities (Deffner & Mazambani, 2010), and consultations with Namibian ministries and the Namibian Desert Research Foundation. During this process, the pilot plants were adjusted to local needs and wishes in terms of size, combinations and materials. The three facilities that were introduced differed in terms of harvesting surface and storage capacity. The first consisted of a corrugated iron roof (100 square metres) and a tank (30 cubic metres) either made of ferrocement, bricks or polyethylene. Such tanks could be used for single

households and public buildings (Waltersdorf *et al.*, 2014). The active participation of communities in this instance, was critical in the success of the RWH facility.

A second pilot facility collected rainwater from a concrete ground catchment (480 square metres) and a greenhouse roof (160 square metres) and stored the water in a covered underground ferrocement tank (120 cubic metres) and a covered and sealed pond (80 cubic metres) (Waltersdorf *et al.*, 2014). The stored water irrigated an outside garden (900 square metres) and a greenhouse (160 square metres) jointly used by six households. A third pilot facility collected rainwater from nearby ephemeral rivers called *Oshanas* at the height of the rainy season and stored the water in a covered ferrocement underground tank and a pond with a combined storage capacity of 400 cubic metres (Waltersdorf *et al.*, 2014). The stored water was sufficient to irrigate a 1 000 square metres of outdoor garden area and a greenhouse of 176 square metres which were jointly managed by ten households.

The *Oshanas* were difficult to use for permanent irrigation owing to high evaporation rates, quick quality degradation and the salinization of water. The possible duration of irrigation of gardens with harvested rainwater depended on the irrigation technique, cropping pattern, garden area and the extent of the rainy season. Considering these factors, the stored water was sufficient for the irrigation of one or two additional annual growth seasons (Waltersdorf *et al.*, 2014). Again, what made this project a success is likely the involvement of the end users of the technology in the whole process although there was contribution of external players that is, the Namibian ministries and the Namibian Desert Research Foundation. The combined efforts of different stakeholders should also not be taken for granted.

Rainwater harvesting has been practiced in different parts of the country especially in KwaZulu Natal, Free State, Eastern Cape and Limpopo on RWH. Examples of communities involved in harvesting rainwater include Kwezana West and Cata in Eastern Cape, (WRC Technical Brief, 2013) Thaba Nchu and Botshabelo in the Free State (WRC Technical Brief, 2008) and Lambani in Limpopo (Badisa, 2011). These communities mainly practiced in-field RWH with the exception of Cata. The Kleinmond Housing Scheme (van Vuuren, 2013) is another example of rooftop RWH initiative in Western Cape. However, challenges with adoption have been faced in some examples given above. In Thabanchu District, the reliance of communities on external support to install RWH infrastructure was reported to create a dependency syndrome among community members (WRC Technical Brief, 2013), while lack of financial and labour resources in some households in Cata (Eastern Cape) hindered adoption of RWH. In the Kleinmond Housing Scheme, the initiative could have been more successful had community members been involved from the beginning of the scheme. Community members have not fully participated in the installation process of RWH

systems. Many indicated that they did not know how to maintain the systems. They had to wait for the Municipality whenever there were malfunctions in the technology. Thus, in order for communities to buy into a RWH technology and for it to be successful, they need to be a part of it, know how to build as well as maintain it. Mannel *et al.* (2014) argue that public participation is fundamental to the sustainability of domestic RWH projects. It is clear that community participation, capacity building and funding are needed to enable communities to adopt RWH technologies.

From the above RWH stories, it is clear that the primary ingredient for success is the inclusion of the intended users in the whole process. Evidence has shown that participation of rural communities not only through giving their ideas, but also their presence and physical contribution in terms of materials needed to build the technology, cultivates a spirit of ownership and responsibility. In simple terms, no one would sabotage a process or a technology they have worked hard for. Mannel *et al.* (2014) emphasizes that public participation is fundamental to the sustainability of domestic RWH projects. The authors add that the success depends on the interest, ownership and active support of the users.

The mentioned examples came from arid and semi-arid areas where rainfall is erratic. The examples show that RWH can really assist communities to deal with water shortages especially for domestic uses. Saving one raindrop at a time has helped some communities to have reliable sources of water close to their homes. For others, rainwater has helped fill the gap that used to exist in the dry season wherein communities would travel very long distances and spend a lot of time fetching water. Harvesting rainwater has meant more productive time and less labour in collecting water. It has also meant extending the growing seasons therefore reaping more. Even if RWH does not result in an absolute solution to water shortages, it surely lessens the burden communities are already bearing, making it a worthy opportunity to take advantage of. South Africa stands to benefit a lot from RWH if resources are channelled into installation and management of the technology. The section below examines the progress that South Africa has made with regards to harvesting rainwater.

2.11 Rainwater Harvesting in South Africa

The efforts of the Department of Water and Sanitation (DWS) to provide all South African citizens with access to basic water and sanitation services by 2014 have been met with challenges. Achieving the provision of potable water to rural communities has been regarded as a priority by the Department. Rainwater harvesting has been earmarked as a short term intervention to provide water, especially to dispersed settlement areas (DWS, 2009). In the 2011/2012 financial year, the DWS installed 8 068 RWH tanks in eight provinces of South Africa (Dobrowsky *et al.*, 2014).

Together with the Water Research Commission, the DWA has initiated discussions on RWH for domestic use in South Africa for purposes of augmenting water supply to all citizens (Dunker & Matsebe, 2013).

Considerable research has also been carried out under the Water Research Commission (WRC) on RWH in South Africa. Botha *et al.* (2005) evaluated the agronomic sustainability of the in-field RWH technology in SA. It was concluded that in-field RWH contributed to higher crop yields than normal conventional tillage. Denison & Wotshela (2009) examined the indigenous water harvesting and conservation techniques and came to the same conclusion. Botha *et al.* (2012) contributed a farmer and extension manual on both in-field and rooftop RWH. Botha *et al.* (2014) also provided guidelines on best management practices for RWH and conservation for cropland and rangeland productivity in communal semi-arid areas of South Africa. Badisa (2011) evaluated the socio-economic factors determining in-field RWH technology adoption for cropland productivity in Lambani village. Casey *et al.* (2016) evaluated the risks associated with the use of rooftop RWH and groundwater for domestic use and livestock watering. These examples serve as evidence of substantial research that has been carried out on RWH in the country.

Mwenge-Kahinda (2010) observes that in spite of the overwhelming potential that domestic RWH offers, less than 1 % of rural households use a RWH tank as their main water source. Baiyegunhi (2015) adds that the full potential of this type of water supply has not been fully exploited in South Africa, especially in the rural areas. About 72 % of South Africa's poor which constitute the majority of the population live in rural areas. These areas are mostly semi-arid to arid, and are marginal for crop production, except for a small portion under irrigation (Baiphethi *et al.*, 2006). Hatibu *et al.* (2006) even see potential of RWH to go as far as providing water for backyard gardens for rural homesteads. Domestic RWH is the least used water source in South Africa. According to the 2006 water services coverage, domestic RWH is the main source of supply for only 0.3 % of the total rural households. Initially, domestic RWH tanks in South Africa were installed by non-governmental organisations. Later on, the government provided a grant for the construction of domestic RWH systems (De Lange, 2006). South Africa has about 34 000 RWH tanks of which over 96 % are located in the rural areas, indicating that domestic RWH remains rural in nature.

Rainwater harvesting has been used in South Africa for a long time now. Hoston & Still (2002) assert that it was used in farms, schools, trading stations and mission hospitals decades before sophisticated water supplies became available. The authors add that commercial farms that rely on water from boreholes, also have evidence of old rainwater tanks, which are at times still used.

Challenges that have been faced in the history of water harvesting in South Africa include the lack of a ceiling on the capital costs of such schemes; the scarcity of RWH design guidelines, as well as insufficient RWH advocacy (Mwenge Kahinda & Taigbenu, 2011). This has resulted in South Africa lagging behind other African countries in the exploitation of this alternative water resource.

In addition, health risks associated with the consumption of harvested rain water is another major obstacle hampering the large-scale implementation of RWH systems. For instance, microbial and chemical contaminants have previously been detected in rainwater tanks (Huston *et al.*, 2012) presenting a challenge to this promising opportunity. This is also reiterated by Efe (2006) arguing that although RWH improves water supply, water-related risks and diseases still occur, and the expected health improvements have not been achieved.

A variety of RWH techniques have been used in South Africa. In rural areas of the Eastern Cape and KwaZulu-Natal, rooftop RWH is a source of drinking water (Mwenge Kahinda *et al.*, 2010). Houston & Still (2001) documented the uses of harvested rainwater in different provinces of South Africa. In Xolo (KwaZulu-Natal), Garies (Northern Cape) and Karkams (Northern Cape), groundwater is too saline so RWH was used for drinking purposes. In Paulshoek (Northern Cape), RWH was used to recharge the aquifer in order to augment borehole water supply. In Lepelfontein (Northern Cape), the raw saline ground water was blended with water harvested on the granite dome rainwater before being treated by reverse osmosis.

The following RWH techniques practiced in South Africa have been documented by Denison & Wotshela (2009). In Gogela (KwaZulu-Natal), stone terracing is used. In this technique, specific portions of land are enclosed by boulders and stones that prevent runoffs from cascading further down the fields. In Thaba Nchu (Free State) and in Tyume valley (Eastern Cape), hand dug ponds (Matambo in Sotho) or Ipitsi in Xhosa are used to store water. In Ploegvore (Northern Cape), planting pits are constructed in a variety of circles and ellipses, for tree crops and closer for field crops. In Stilbaai (Western Cape), natural hardened and impermeable surface is cleaned and compacted in order to harvest rainwater that is channelled to an underground tank. Across South Africa, the trench bed gardening is used. The trench system consists of removing soil from the bed, placing organic material at the bottom of the trench, and replacing the soil forming a terraced bed which effectively holds water (Denison & Wotshela, 2009). These are just a few examples of water harvesting techniques already implemented in South Africa. This is evidence that there is no single formula for harvesting rainwater. Techniques depend on available resources, geographical characteristics of the area, the water demand, and uses of harvested water among others.

The South African water-related legislations do not fully support or give room for RWH to flourish. Mwenge Kahinda & Taigbenu (2011: 971) argue that “South African water-related legislations do not give a clear legal framework for the adoption of RWH, making it illegal by strict application”. The authors cite The National Water Act (NWA) (Act No. 36 of 1998) as the main legal instrument relating to water resources management in South Africa. Its central guiding principles are equity, efficiency, sustainability and representativity. The Water Services Act (WSA) (Act No. 108 of 1997) provides a regulatory framework for the provision of water supply and basic sanitation, and for the manner in which municipalities must fulfil their duty to provide water and sanitation services to their communities. The Interpretation of WSA is subject to the NWA.

Mwenge Kahinda & Taigbenu (2011) assert that although Section 3 of Chapter 1 of the WSA states that rainwater can be harvested to provide water for basic needs, strict interpretation of Section 6 (1) requires users of rooftop RWH systems in urban and peri-urban areas to get the approval of their service provider. Section 4 of Chapter 1 of the NWA recognizes the right to use water for purposes such as reasonable domestic use, domestic gardening, and animal watering. However, it excludes any gardening for commercial purposes (Mwenge-Kahinda & Taigbenu, 2011). It looks like the NWA allows for storage and use of runoff water from a roof but only have reservations on using harvested rain water for commercial purposes. Although this presents difficulties for communities who would like to engage in commercial farming, it makes logical sense to allow all communities to have at least enough water for domestic purposes before they can engage in farming that is dependent on harvested rainwater. In order to understand community dynamics and their effect on development, it is important to view them in the context of theories and approaches to development. The theoretical framework below is presented for this purpose.

2.12 Theoretical Framework of the Study

Three theories or approaches underpin the study. These are Sustainable Community Development (SCD), Asset-Based Community Development (ABCD) as well as the Co-design approaches. These approaches help unpack and clarify the linkages among several aspects that knit community activities which have the potential to uplift rural community people.

2.12.1 Sustainable community development

Proponents of SCD argue that strategies formulated at the national or global scale tend to prevent significant practical work (Yanarella & Levine, 1992a). At such macro-levels, the scale of change required is so great that problems of coordination across political units are bound to be enormous (Bridger & Luloff, 2001). Attempts to achieve sustainability on a grand scale also tend to be crushed in the technocratic language of planning and administration, emphasizing the need for

global planners to work with national and local people in solving existing problems. Yanarella & Levine (1992a) claim that the major problem with such solutions is that relations of domination are left in place. Those with control of resources are left with the responsibility of delivering services. Experience has shown that this top down approach either has too many delays until the services are delivered on the ground, or it never happens at all.

A promising alternative would be focusing on sustainability at the local level. This can be a promising alternative if changes are to be seen and felt more immediately. Bridger & Luloff (2001) observe that discussions of a “sustainable society” or a “sustainable world” are relatively meaningless to most people since they require levels of abstraction not relevant in their daily lives. The community in contrast is more conceptually manageable. It is, therefore, easier and quicker to implement development activities at the very local level where specific problems are experienced. Yanarella & Levine (1992a: 769) conclude that SCD may ultimately be the most effective means of showing the potential for long term improvement on a broader scale because it places the concept of sustainability “in a context within which it can be validated as a process”. Sustainable Community Development therefore offers a plausible alternative intervention strategy that brings positive change to communities promptly. Although this approach seems to have been drawn from politics, it applies to rural development activities. Deductively, this approach rests on the observation and understanding that development strategies are much easier to implement at a local level rather than a broader scope. Therefore, it supports a bottom-up approach which is easier to implement, monitor and improve since the language is simple and is understandable to local people.

2.12.2 Asset-based community development

Based on extensive inquiry into the characteristics of successful community initiatives in the United States of America, John McKnight and Jody Kretzmann at the Institute for Policy Research (IPR) at North Western University presented Asset-Based Community Development (ABCD) as a way of counteracting the predominant needs-based approach to development in the United States’ urban context. In this approach, according to the authors, well-meant efforts of universities, donor agencies, and governments have generated needs surveys, analysed problems, and identified solutions to meet those needs. In the process, however, they have inadvertently presented a one-sided negative view, which has often compromised, rather than contributed to, community capacity building.

Mathie & Cunningham (2003) observe that ABCD has attracted a small but dedicated following, particularly among those who are disenchanted with the needs-based approach to community development. The needs-based approach to community development is so entrenched in

government and non-governmental service delivery. As an alternative approach, the appeal for ABCD lies in its promise that people in communities can organize to drive the development process themselves. They can do this through identifying and mobilizing existing (though often unrecognized) assets, thereby responding to and creating local economic opportunity (Mathie & Cunningham, 2003). In particular, ABCD draws attention to social assets: the particular talents of individuals, as well as the social capital inherent in the relationships that fuel local associations and informal networks. It is this appreciation of the capabilities of the rural communities that forms the backbone of this study.

The authors assert that ABCD has the potential to encourage active citizenship in the sense of promoting citizen-to-citizen ties, while simultaneously strengthening the capacity of people as citizens to claim their rights of access to assets on which they depend for their livelihood (Mathie & Cunningham, 2003). According to the authors, the needs-based approach promotes a situation wherein communities no longer act like citizens. Instead, they begin to act like clients or consumers of services with no incentive to becoming producers.

Kretzman & Mcknight (1993) describe an alternative approach as one that recognizes that it is the capacities of local people and their associations that build powerful communities. The process of recognizing these capacities begins with the construction of a new lens through which communities can begin to assemble their strengths into new combinations, new structures of opportunity, new sources of income and control, and new possibilities for productions. This way, communities would be able to tackle any developmental challenges they would be facing and move forward with their lives. Moore & Punterney (1999) recommend that communities shift from being consumers of services to designers of community programmes, and finally producers of community. In this study, a step is taken further to get communities to be designers of their own technologies that solve their daily challenges.

2.12.3 Co-designing

The principle of co-designing requires that the community participate in all technology design activities if they are to understand and adopt the technology. According to Steyn & Van der Vyver (2013), design has been around since the birth of humanity, with other denominations that evolved through time. The craftsmanship model of production characterizing the beginning times of design required that the end users of products be fully involved in the conception, development, and evaluation of products (Shah *et al.*, 2009). With the Industrial Revolution, mass production emerged, causing a divide between end users and the whole production cycle (Castellacci, 2004). End users or clients became mainly targets of marketing and selling activities.

Design as a plan or scheme devised by a person (or people) for something that is to be implemented (Benhard & Burdek, 2005) became highly specialized and left little space for the involvement of end users in the design process. Of late, higher standards and increasing competition on the quality levels determined an increased attention to the needs and views of the end users within the design process. This ensures better quality and higher relevance of products and services for users' needs (Wheelwright *et al.*, 1992). Thus, involvement of end users is beneficial in making sure that whatever design that is made is appropriate.

The social embeddedness approach emphasizes the importance of local factors in the design and appropriation of innovation. This new understanding of development stresses the importance of design partnerships and participation by the civil society as the best method to achieve actual adoption and appropriation, and hence sustainable development (Sonnenwald, 1997). In this paradigm, user participation in the design process is considered a key factor for designing technology that has relevance and can be used sustainably in a socio-cultural context (Waisboard, 2001). It is clear from this approach that the absence of partnerships between technology designers and local society is an impediment to technology relevance.

In summary, SCD emphasizes the importance of employing a bottom-up approach to development. This results in targeted developmental strategies that are easy to implement, are meaningful to people, and can be achieved within reasonable periods. Asset Based Community Development focuses on community assets that are usually not recognized. If these capitals are organized, communities can become drivers of their own development. The Co-designing principle accentuates the need for end users of products to be fully involved in the conception, development and implementation of technologies. If this is done, the process would produce technologies that are appropriate and, therefore, easily adoptable. These three interrelated approaches form the basis of this study wherein communities are given an opportunity to display their capabilities and become technology designers. This way, they grow into agents of their own development to become not "clients" but active citizens.

Figure 2.1 shows the conceptual framework for developing a RWH system. This framework maps out the different stages (step-by-step) that were involved in the development of the technology and the processes involved. In addition to the theories and approaches to development, the global commitments to development that have been set by nations of the world are another lens that can be used to understand the significance of water in different sectors. The appropriate sustainable goals are presented below.

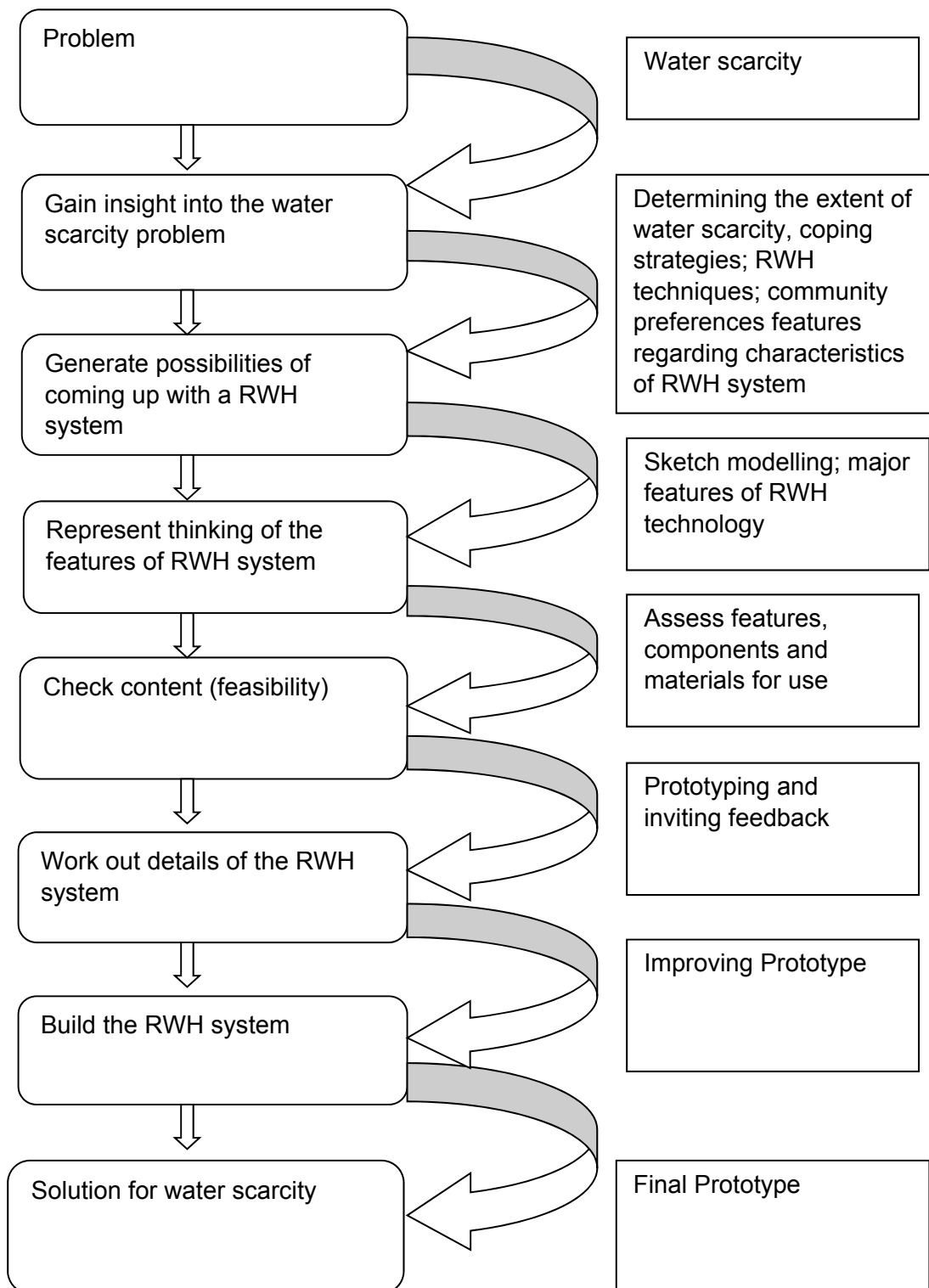


Figure 2. 1 Conceptual framework for developing a rainwater harvesting system

Source: Adapted from (Hubka & Eder, 2012)

2.13 Rainwater Harvesting Technology and the Science-Policy Interface

The scope of this study falls well within the ambit of the United Nations Sustainable Development Goals (UN SDGs) that were put in place in 2015. Goal 6 of the UN SDGs talks about achieving universal access to water and sanitation. According to a joint report by the International Council of Science and the International Social Science Council (Le Blanc, 2015), safe drinking water should be measured both in terms of water quality and safe access to the water supply. This report suggests that Target 6b of this goal could most effectively be handled as part of a larger perspective on the role of community development in planning and managing water resources. Goal 6 of the UN SDGs also expresses the need to expand international cooperation and capacity building support to developing countries in water and sanitation-related activities and programmes including water harvesting, desalination, water efficiency, waste water treatment, recycling and reuse technologies. Provision of support and strengthening of participation of communities in improving water and sanitation management is also highlighted. The study is in line with this goal wherein focus is put on building water infrastructure while at the same time enhancing human and institutional capacity. Goal 13 of the UN SDGs talks about taking urgent action to combat climate change and its impacts.

At a regional level, in the African Union (AU)'s AGENDA 2063, Aspiration 6 talks about "an Africa whose development is people-driven, relying on the potential of the African people, particularly its women and youth and caring for its children" (AGENDA 2063 First Ten-Year Plan: 2014-2023, 2015). Women empowerment, violence and discrimination against women and girls, as well as youth empowerment and children's rights are also emphasised in this aspiration. However, children are only seen as a group that needs care and not equal citizens of the society. In this study, all community groups regardless of gender or age are given an equal opportunity to think, learn and to change their worlds. Moreover, the AU adopted a 10-year Science Technology and Innovation Strategy for Africa (STISA-2024). The strategy is meant to act as a tool that accelerates Africa's transition to an innovation-led knowledge-based economy. One of its pillars (innovation and entrepreneurship) proposes a multidisciplinary and multi-sectoral approach to collaborative open innovation and entrepreneurship as essential to achieving the knowledge economy and sustainable socio-economic development across Africa (AU STISA-2024, 2014). Collaboration between education and research, private and public sector stakeholders are also underscored to help facilitate co-creation, adaptation and commercialisation of research and innovation outputs (AU STISA-2024, 2014).. Contrary to conventional approaches where technology design is done by scientists, this study promotes co-creation with targeted beneficiaries.

The South African White Paper on Science, Technology and innovation (Government Gazette, 2018) also reiterates the importance of participation of civil society through its quadruple helix

approach. It is argued that the inclusion of the fourth helix (that is civil society) is critical as science, technology and innovation (STI) is increasingly evaluated by its social robustness and inclusivity. This highlights the importance of appropriateness of technology which is ensured by involvement of end users – a very crucial element of the current study. The White Paper also explains a South African responsible research and innovation (RRI) approach would rest upon pillars such as engagement of all societal actors throughout the process of framing societal challenges, and developing joint solutions and maintaining a high level of ethics in terms of the relevance and acceptability of STI to society and environmental sustainability.

In her White Paper Summit Speech delivered on the 9th of November 2018, the Minister of Science and Technology, Ms Mmamoloko Kubayi-Ngubane acknowledged the importance of placing science, technology and innovation at the centre of its developmental agenda if South Africa is to achieve the 2030 goals. It was admitted that the Department of Science and Technology cannot promote science on its own thus the importance of collaboration among different stakeholders such as business, labour, academia and government (Kubayi-Ngubane, 2018). She added that society as a whole needs to embrace scientific research as an important element of creating a better world characterised by low unemployment, reduced poverty and inequality. The minister's speech stresses the role of research in improving lives as well as the importance of collaboration among different stakeholders in research activities including civil society. This is also in line with the principles of the 1955 Freedom Charter. "The people shall govern" entail entitlement of all people to take part in the administration or any activities meant to improve their lives. The policy imperatives outlined above highlight science, technology and innovation as important pillars of development. They also illustrate the enabling environment for successful, relevant and adoptable technologies.

Successfully harvesting rainwater for domestic use will help strengthen communities' resilience and adaptive capacity to climate-related hazards and natural disasters (Long, 2015). The study aims to develop water infrastructure with the end users using locally available materials. This would lead to construction of a simple, socially acceptable, affordable and lasting water scarcity intervention that is sustainable. When communities have alternative safe, accessible water sources in their yards, they become more resilient to effects of droughts, safe from waterborne diseases, and will be in a position to adapt easily to other climatic shocks.

2.14 Summary of Literature Review

Climate change (through altering the rainfall patterns, amounts and distribution, and increasing temperatures), poor planning and ageing infrastructure have contributed significantly to current water shortages in South Africa. Water scarcity as a concept can be understood in a variety of

ways, that is, qualitative, quantitative as well as within socioeconomic contexts. A variety of causes have been attributed to scarcity of water in different countries. The most common ones were rising population growth, pollution, climate change, poor management of water resources, among others. It has been revealed that water scarcity has already affected communities mainly in Africa and Asia. Although many countries in continents such as Europe, Australia, and America have not yet experienced severe water scarcity, they will not escape climate-induced water scarcity. Nevertheless, developed countries will be able to adapt successfully to water scarcity since they have the resources to do so. The same cannot be said for a lot of poor countries especially in Africa.

Communities have had no option but to resort to a range of coping strategies, for instance, fetching water from boreholes and wells, migrating to areas with water during dry seasons, buying water as well as storing water in containers. Studies also indicate that rain water harvesting is nothing new. Communities have for centuries adapted to water shortages through harvesting rain water for different household purposes. However, a review of the origins of water harvesting show that the technology emanated as a solution to curbing water shortages for agricultural purposes. Traditional water harvesting techniques have included hanging pieces of clothes on the roof edge to collect water in the buckets placed on the ground. Another technique has been to tap runoff water through digging shallow holes in open spaces surrounding houses. These techniques among others have been developed for centuries to adapt to a changing climate as well as increasing needs.

Current rainwater harvesting techniques have included on-farm systems such as *in-situ* rain water harvesting, micro-catchment, macro-catchment as well as domestic RWH. Studies also show that it is not only in developing countries that RWH is practiced. Developed countries have been doing it too. The difference is only that for developed countries, the main purpose of harvesting water has not been out of desperation. In most cases, water has been harvested to conserve the natural environment and prevent contamination of safe water sources and not necessarily due to shortage of water. In constructing a RWH system, five major features should be taken into account. These are the collection surface, the conveyance system, the first flush device, an infiltration device and the storage tank.

A number of lessons have been learnt from reviewing success water harvesting stories from the continent. In order for community members to accept and adopt a RWH technology, they should understand it, and it should speak to their needs. The importance of their involvement in the process should also not be underestimated. That way, in the current study, a RWH technology that was affordable, easy to construct, easy to maintain and use, was designed. In South Africa,

efforts to provide adequate water to citizens have not always been successful. Given the varied contamination pathways of RWH, there is need for guidelines on suitability of RWH systems per locality or geographical space for instance, at district level. In addition, insufficient RWH advocacy and also some health risks associated with consumption of harvested water have impeded implementation of RWH. Moreover, there has been a lack of community involvement in many RWH projects in South Africa. This led to development of inappropriate technologies which local communities found very complicated to maintain. In this study, local communities formed part of the whole technology formulation process. This presented an opportunity of empowering community members and promote sustainability.

2.15 References

- Abdulla, F.A., & Al-Shareef, A.W. 2009. Roof rainwater harvesting systems for household water supply in Jordan, *Desalinisation* **243**: 195-207
- Adeniji-Oloukoi, G., Bob, U., & Moodley, V. 2013. Household coping strategies to address water shortages related to climate variability in Oke-Ogun, Nigeria. *Environmental Development*, **5**:23-38.
- Agarwal, A. & Narain S 1997 Dying wisdom. Centre for Science and Environment/Thomson Press Ltd, Faridabad
- Ahile, S. I., Udoumoh, E.F. & Adzande, P. 2015. Residents' coping strategies with water scarcity in Makurdi town Nigeria, *Mediterranean Journal of Social Science* **6(4)**: 100-108
- Al-Suhaimy U. Saudi Arabia: the desalination nation. Asharq Al-Awsat. July 2, 2013. Available at: <http://www.aawsat.net/2013/07/article55308131>. Accessed August 17, 2015.
- Amin, M.T. and Han, M.Y., 2009. Roof-harvested rainwater for potable purposes: application of solar collector disinfection (SOCO-DIS). *Water research*, **43(20)**: 5225-5235.
- Amin, M.T., Alazba, A.A. & ElNesr, M.N. 2013. Adaptation of climate variability/extreme in arid environment of the Arabian Peninsula by rainwater harvesting and management, *International Journal of Science and Technology* **10**: 27-36
- Badisa, K.T. 2011. Socioeconomic factors determining in-field rainwater harvesting adoption for cropland productivity in Lambani village: A case study of Thulamela Local Municipality of the Vhembe District in Limpopo Province. Mini-dissertation submitted in partial fulfilment of the requirements of the Degree of Master of science in Agriculture (Agricultural Economics) in the Department of Agricultural Economics and Animal Production at the University of Limpopo.
- Baguma, D., Loiskandl, W. & Jung, H. 2009. Water management, rain water harvesting and Predictive Valuables in Rural Households, *Journal of Water Resource Management*, **24**: 3333- 348.
- Baiphethi, M.N., Viljoen, M.F., Kundhlande, G., Botha, J.J. & van Rensburg L.D. 2006. Quantifying the impact of in-field rainwater harvesting (IRWH) production techniques on household food security for communal farmers in Thaba Nchu, Free State Province. *Agrekon* **45(3)**:279–293.
- Baiyegunhi, L. J. S. 2015. Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. *Water South Africa*, **41(1)**: 33-40.
- Baiyegunhi, L.J.S. 2014. Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa, *Water South Africa* **41(1)**: 33-39
- Bandyopadhyay, J. 2017. Restoration of Ecological Status of Himalayan Rivers in China and

- India: The Case of the Two Mother Rivers - The Yellow and the Ganges. *Environmental Sustainability from the Himalayas to the Oceans*. Springer, Nature Switzerland
- Bernhard, E. 2005. *Theory and Practice of Product Design* Springer, USA
- Botha, J.J., Anderson, J.J., Joseph, L.F., Snetler, R.M., Monde, N., Lategan, F., Nhlabatsi, N.N., Lesoli, M.S. & Dube, S. 2012. Farmer and Extension Manual, WRC Report No. TT542/12
- Botha, J.J., van Rensburg, L.D., Anderson, J., Hensley, M. 2005. Evaluating the agronomic sustainability of the in-field rainwater harvesting technique. OECD workshop on agriculture and water: Sustainability, markets and policies.
- Botha, J.J., van Staden, P.P., Anderson, J.J., van der Westhuizen, H.C., Theron, J.F., Talijsaard, D.J., Venter, I.S. & Koatla T.A.B. 2014. Guidelines on best management practices for rainwater harvesting and conservation for cropland and rangeland productivity in communal semi-arid areas of South Africa. WRC Report No. TT590/14
- Bridger, J. C., & A. E. Luloff, A. E. 1999. Toward an Interactional Approach to Sustainable Community Development, *Journal of Rural Studies* **15(4)**:377-88.
- Bridger, J.C. & Luloff, A.E. 2001. Building the sustainable community: Is social capital the answer?. *Sociological inquiry*, **71(4)**: 458-472.
- Brown, A. and Matlock, M.D., 2011. A review of water scarcity indices and methodologies. *White paper*, 106.
- Bulcock, L. M., & Schulze, R. E. 2011. Climate change and a case study in rainwater harvesting: A 2011 perspective. *A 2011 perspective on climate change and the South African water sector. WRC Report*, 2 (11).
- Casey, N.H., Korsten, L. & Chidamba, L. (Eds) 2016. Evaluation of the risks associated with the use of rooftop rainwater harvesting and groundwater for domestic use and livestock watering. Vol 2; Chemical quality of groundwater for potable use and livestock watering. Report to the WRC and Department of Agriculture Forestry and Fisheries. WRC Report No. 2175/2/16
- Castellacci, F. 2004. How does innovation differ across sectors in Europe? *Oslo, Centre for Technology*.
- Castex, V., Tejada, E.M. & Beniston, M. 2015. Water availability, use and governance in the wine producing region of Mendoza, Argentina. *Environmental Science & Policy*, **48**: 1-8.
- Chitonge, H. 2014. Cities beyond networks: The status of water services for the urban poor in African cities. *African Studies*, **73(1)**: 58-83.
- Costa, J.M., Vaz, M., Escalona, J., Egipto, R., Lopes, C., Medrano, H. & Chaves, M.M. 2016. Modern viticulture in southern Europe: vulnerabilities and strategies for adaptation to water scarcity. *Agricultural Water Management*, **164**: 5-18.
- Critchley, W. & Siegert, K., 1991. *Water Harvesting*. FAO, Rome, Italy.
- Denison, J. & Wotshela, L. 2009. Indigenous water harvesting and conservation practices:

- historical context, cases and implications. Report to the Water Research Commission by Umhlaba Consulting Group (Pty) Ltd. WRC Report No. TT 392/09.
- De Jalón, S.G., Iglesias, A., Cunningham, R. & Díaz, J.I.P. 2014. Building resilience to water scarcity in southern Spain: a case study of rice farming in Doñana protected wetlands. *Regional Environmental Change*, **14**(3): 1229-1242.
- De Lange, Marna. 2006. War on hunger: some impacts of the DWAF Rainwater Harvesting Pilot Programme. Report to the Water Resources Finance and Pricing DWAF directorate. Department of Water Affairs and Forestry, Pretoria, South Africa. Department of Health (DOH), 2003a. Malaria. <<http://www.doh.gov.za/>
- Deffner, J. & Mazambani, C. 2010. Participatory empirical research on water and sanitation demand in Central-Northern Namibia: a method for technology development with a user perspective. CuveWaters Papers, No. 7, Institute for Social-Ecological Research (ISOE), Frankfurt/Main, Germany.
- DeNicola, E., Aburizaiza, O.S., Siddique, A., Khwaja, H. & Carpenter, D.O. 2015. Climate change and water scarcity: the case of Saudi Arabia. *Annals of global health*, **81**(3): 342-353.
- Denison, J., & Wotshela, L. 2009. Indigenous water harvesting and conservation practices: historical context, cases and implications. *Water Research Commission Report No. TT, 392* (09).
- Development Technology Unit, Recommendations for designing Rainwater Harvesting system tanks, Domestic Roofwater Harvesting Research Programme, O-DEV Contract No. ERB IC18 CT98 027, Milestone A6: Report A4, University of Warwick, 2001.
- Distefano, T., & Kelly, S. 2017. Are we in deep water? Water scarcity and its limits to economic growth. *Ecological Economics*, **142**: 130-147.
- Dobrowsky, P.H., De Kwaadsteniet, M., Cloete, T.E. & Khan, W., 2014. Distribution of indigenous bacterial and potential pathogens associated with roof-harvested rainwater. *Applied and environmental microbiology*, pp.AEM-04130.
- Dunker, L & Matsebe, G. 2013. Rainwater harvesting for domestic use: Report on the National Domestic Rainwater Harvesting Workshop, Birchwood Hotel, 21 November 2013
- Efe, S.I. 2006. Quality of rainwater harvesting for rural communities of Delta State, Nigeria. *Environmentalist*, **26**(3): 175-181.
- Eggens, L. & Patrick, S. (Eds), Meerman, R., Boelee, E. and Chavez, T.J. 2015. Rainwater champions: Stories from Ethiopia, Kenya and Uganda, Amsterdam, The Netherlands.
- Everson, C.S. 2014. Guidelines for rainwater harvesting. Chapter 2. In Smith, M.T. & Everson, T.M. (Eds). Improving rural livelihoods through Biogas generation using livestock manure and rainwater harvesting. Volume 2, Guidelines Report. WRC Report N. TT645/15
- Fisher-Jeffes, L. N., Armitage, N. P., & Carden, K. 2017. The viability of domestic rainwater

- harvesting in the residential areas of the Liesbeek River Catchment, Cape Town. *Water South Africa*, **43(1)**: 81-90.
- Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F. & Alcamo, J. 2013. Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. *Global Environmental Change*, **23(1)**: 144-156.
- Flörke, M., Kynast, E., Bärlund, I., Eisner, S., Wimmer, F. & Alcamo, J. 2013. Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. *Global Environmental Change*, **23(1)**: 144-156.
- Giupponi, M.B.O. & Paz, M.C. 2015. The implementation of the human right to water in Argentina and Colombia. *Anuario Mexicano de Derecho Internacional*, **15(1)**: 323-352.
- Gleick, P.H., 2009. China and water. *The world's water 2008–2009: The biennial report on freshwater resources*, 79-100.
- Gould, J., Nissen-Petersen, E., 2003. Rainwater Catchment Systems for Domestic Supply- Design, Construction and Implementation. ITDG Publishing, London.
- Gowing, J.W., Mahoo, H., Mzirai, O.B. & Hatibu, N. 1999. Review of rainwater harvesting techniques and evidence for their use in semi-arid Tanzania. *Tanzania Journal of Agriculture Science* **2 (2)**:171-180.
- Grandet, C., Binning, P.J., Mikkelsen, P.S., Blanchet, F. 2010. Effects of rainwater harvesting on centralized urban water supply systems. *Water Science Technology: Water Supply* **10(4)**:570–576.
- Greene, W.H. 2003. *Econometric Analysis* (5th edn.). Prentice-Hall, Upper Saddle River, NJ
- Hansen, K., 2017. Meeting the Challenge of Water Scarcity in the Western United States. In *Competition for Water Resources: Experiences and Management Approaches in the US and Europe* : 2-18.
- Hatibu, N. & Mahoo, H. 1999. Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzania. Conservation tillage and animal traction. In: Kaumbutho PG, Simalenga, T.E. (eds) A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). ATNESA, Harare, Zimbabwe.
- Hatibu, N., Mutabazi, K., Sekondo, E.M. & Msangi, A.S.K. 2006. Economics of rainwater harvesting for crop enterprises in semiarid areas of East Africa. *Agric. Water Manage.* **80(1-3)** 74–86.
- Heijnen, H. and Pathak, N., 2006. Rainwater harvesting quality, health and hygiene aspects. In *International Workshop on Rainwater Harvesting*, “Making Rain Water Everybody’s Business”, 27-29th September, Kandy, Sri Lanka
- Helmreich, B., & Horn, H. 2009. Opportunities in rainwater harvesting. *Desalination*, **248(1-3)**: 118-124.
- Heyworth, J. S., Glonek, G., Maynard, E. J., Baghurst, P. A. & Finlay- Jones, J. 2006.

- Consumption of untreated tank rainwater and gastroenteritis among young children in South Australia, *International Journal of Epidemiology* **35(4)**:1051–1058.
- Hoekstra, A.Y. & Mekonnen, M., 2011. Global water scarcity: The monthly blue water footprint compared to blue water availability for the world's major river basins. Value of Water Research Report Series Number 53, Twente Water Centre, Enschede, The Netherlands.
- Holloway, R. E. 1977. Perceptions of an innovation: Syracuse University's Project Advance. PhD thesis, in Rogers, E. M. (2003) *Diffusion of Innovations* (5th edition). New York: Free Press.
- Houston, P. and Still, D. 2001. An Overview of Rainwater Harvesting in South Africa. Available at www.pid.co.za/files/Rain%20Water%20Harvesting.pdf Retrieved 20 March 2016
- Howitt, R.E., Medellin-Azuara, J.D., MacEwan, J.R. & Lund, D.A. 2015. Sumner Economic Analysis of the 2015 Drought for California Agriculture. Center for Watershed Sciences University of California, Davis, California. Available at: <http://watershed.ucdavis.edu>
- Hubka, V. & Eder, W.E., 2012. *Design science: introduction to the needs, scope and organization of engineering design knowledge*. Springer Science & Business Media.
- Hurlbert, M. & Mussetta, P. 2016. Creating resilient water governance for irrigated producers in Mendoza, Argentina. *Environmental Science & Policy*, **58**: 83-94.
- Hurlimann, A. & Dolnicar, S., 2010. When public opposition defeats alternative water projects – the case of Toowoomba Australia. *Water Research* **44(1)**: 287-297.
- Huston, R., Chan, Y.C., Chapman, H., Gardner, T. & Shaw, G., 2012. Source apportionment of heavy metals and ionic contaminants in rainwater tanks in a subtropical urban area in Australia. *Water research*, **46(4)**: 1121-1132.
- IPCC Climate Change 2013: The Physical Science Basis. I Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, P.M. Midgley (Eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA
- Ishaku, H.T., Abayomi, A. P., Sahabo, A.A. & Dama, F.M. 2013. Complementing water supply through rainwater harvesting in some selected villages of Sahel savannah ecological zone in Borno state Northe-eastern Bigeria, *Journal of Water Resource and Protection* **5**: 200-207.
- Jiang, Y. 2009. China's water scarcity. *Journal of Environmental Management*, **90(11)**: 3185-3196.
- Juana, J.S., Kahaka, Z. & Okurut, F.N., 2013. Farmers' perceptions and adaptations to climate change in sub-Sahara Africa: A synthesis of empirical studies and implications for public policy in African agriculture. *Journal of Agricultural Science*, **5(4)**: 121-133
- Kummu, M., Ward, P.J., de Moel, H. & Varis, O., 2010. Is physical water scarcity a new

- phenomenon? Global assessment of water shortage over the last two millennia. *Environmental Research Letters*, **5(3)**: 1-10.
- Lasage, R. & Verburg, P.H. 2015. Evaluation of small scale water harvesting technologies for semi-arid environments. *Journal of Arid Environments* **118**: 48-57.
- Le Blanc, D. 2015. Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, **23(3)**: 176-187.
- Lionello, P., Abrantes, F., Gacic, M., Planton, S., Trigo, R. & Ulbrich, U. 2014. The climate of the Mediterranean region: research progress and climate change impacts. *Regional Environmental Change*, **14(5)**: 1679-1684
- Lippman TW. Biggest Mideast crisis: growing water scarcity. Business Mirror. May 24, 2014. Available at: <http://www.ipsnews.net/2014/05/biggest-mideast-crisis-probably-dont-know-enough/>. Accessed September 17, 2017
- Lippman, T.W. Biggest Mideast crisis: growing water scarcity. Business Mirror. May 24, 2014. Available at: <http://www.ipsnews.net/2014/05/biggest-mideast-crisis-probably-dont-know-enough/>. Accessed August 17, 2015.
- Luo, T., Young, R. and Reig, P., 2015. Aqueduct projected water stress country rankings. *Technical Note*.
- Mannel, D., Prozesky, H. & Cloete, T.E. 2014. Domestic rainwater harvesting: A survey of perceptions of users in Kleinmond. WRC Report No. TT 604/14
- Manju, S. & Sagar, N. 2017. Renewable energy integrated desalination: A sustainable solution to overcome future fresh-water scarcity in India. *Renewable and Sustainable Energy Reviews*, **73**: 594-609.
- Mankad, A. 2012. Decentralised water systems: Emotional influences on resource decision making, *Environment International* **44**:128-140.
- Marks, J.S., August 2004. Advancing community acceptance of reclaimed water. *Water*, 46-51.
- Mathie, A., & Cunningham, G. 2003. From clients to citizens: Asset-based community development as a strategy for community-driven development. *Development in Practice*, **13(5)**: 474-486.
- Mati. B., De Bock. T., Malesu. M., Khaka, E., Oduor, A., Nyabenge, M. and Oduor, V. 2007. Mapping the potential of rainwater harvesting technologies in Africa: a GIS overview on development domains for the continent and ten selected countries. Technical manual No. 6 Technical Report (Kenya: World Agroforestry Centre (ICRAF)), Netherlands Ministry of Foreign 10 Affairs, Nairobi)
- Mbilinyi, B.P., Tumbo, S.D., Mahoo, H.F., Senkondo, E.M., & Hatibu, N., 2005. Indigenous knowledge as decision support tool in rainwater harvesting. *Physics and Chemistry of the Earth* **30**:792-798.
- Moore, G. C. & Benbasat, I. 1991. Development of an instrument to measure the perceptions of

- adopting an information technology innovation. *Information Systems Research* **2(3)**: 192–222.
- Moore, G.C. and Benbasat, I., 1991. Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information Systems Research*, **2(3)**: 192-222.
- Moore, H. & Puntenney, D. 1999. *Leading by Stepping Back: A Guide for City Officials on Building Neighborhood Capacity*, Chicago: ACTA Publications.
- Mukuhlani, T. & Nyamupingidza, M. T. 2014. Water scarcity in communities, coping strategies and mitigation measures: The case of Bulawayo. *Journal of Sustainable Development*, **7(1)**:144-154.
- Mwenge Kahinda, J., Taigbenu, A. E. & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.
- Mwenge Kahinda, J., Taigbenu, A. E., & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.
- Mwenge-Kahinda, J.M., Taigbenu, A.E. & Boroto, J.R., 2007. Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth, Parts A/B/C*, **32(15-18)**: 1050-1057.
- Nancarrow, B., Leviston, Z., Po, M., Porter, N. & Tucker, D., 2008. What drives communities' decisions and behaviours in the reuse of wastewater? *Water Science and Technology* **57(4)**: 485-491.
- National Peace Corps Association. 2015. Success stories: Katie Difilippo and water security in rural Karagwe, Tanzania. Available at <http://www.peacecorpsconnect.org/karagwesuccess>, Retrieved on 27 January 2016
- Ng, S.W., Zaghoul, S., Ali, H.I., Harrison, G. & Popkin, B.M. 2011. The prevalence and trends of overweight, obesity and nutrition-related non-communicable diseases in the Arabian Gulf States. *Obesity Reviews*, **12(1)**:1-13.
- Ngigi, S.N. 2009. *Climate change adaptation strategies: water resources management options for smallholder farming systems in sub-Saharan Africa*. New York: The Earth Institute at Columbia University.
- Nomqophu, W. 2005. Overview of the situation and challenges for the water quality monitoring and reporting in South Africa. *Work session on Water Statistics, Vienna 20-22 June 2005*.
- Otnes, P. 1988. *The Sociology of Consumption*. Humanities Press International, Atlantic Highlands.
- Oweis, T. & Hachum, A., 2009. *Water harvesting for improved rain fed agriculture in the dry*

environments - Rain fed agriculture: Unlocking the potential, CAB International. London, UK

- Oweis, T., & Hachum, A. 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management*, **80(1-3)**: 57-73.
- Parry, M., Parry, M.L., Canziani, O., Palutikof, J., Van der Linden, P. & Hanson, C. (eds). 2007. *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC (4)*. Cambridge University Press.
- Pearson, A. L., Mayer, J. D., & Bradley, D. J. 2015. Coping with household water scarcity in the savannah today: implications for health and climate change into the future. *Earth Interactions*, **19(8)**: 1-14.
- Qureshi, M.E., Hanjra, M.A. & Ward, J. 2013. Impact of water scarcity in Australia on global food security in an era of climate change. *Food Policy*, **38**: 136-145.
- Reij, C., Scoones, I., Toulmin, C. (Eds.). 2013. *Sustaining the Soil. Indigenous soil and water conservation in Africa*. Routledge: London
- Retamal, M. & Turner, A. 2010. Unpacking the energy implications of distributed water infrastructure: how are rainwater systems performing? *Water Science Technology: Water Supply* **10(4)**:546–553.
- Rijsberman, F. R. 2006. Water scarcity: fact or fiction? *Agricultural water management*, **80(1-3)**: 5-22.
- Rockström, J. 2002. Potential of rainwater harvesting to reduce pressure on freshwater resources international water conference, Hanoi, Vietnam.
- Rockström, J., Falkenmark, M., Karlberg, L., Hoff, H., Rost, S. & Gerten, D., 2009. Future water availability for global food production: the potential of green water for increasing resilience to global change. *Water resources research*, **45(7)**:1-16
- Rogers, E.M. 2003. *Diffusion of innovations*. (5th edition) New York. Free Press.
- Sahin, O., Bertone, E., Beal, C. & Stewart, R.A. 2018. Evaluating a novel tiered scarcity adjusted water budget and pricing structure using a holistic systems modelling approach. *Journal of environmental management*, **215**: 79-90.
- Salas, J. C. 2007. Rainwater harvesting: A community's technology for coping with climate change. *Rainwater and Urban Design* **18(2)**: 952-968.
- Schlosser, C. 2014. The future of global water stress: An integrated assessment. *Earth's Future* **2(8)**: 341-361.
- Serrano, A., Guan, D., Duarte, R. & Paavola, J. 2016. Virtual water flows in the EU27: A consumption-based approach. *Journal of Industrial Ecology*, **20(3)**: 547-558.
- Shah, H., Akmal, N., Farooq, W., Azeem-Khan, M., and Munir, S. 2014. Shift from site

- development to skill development, *Pakistan Journal of Agriculture Resources*, **27(4)**: 85-98.
- Shah, S., Ghulam, S., Ian, R. & Sarmad A., 2009. Developing medical device technologies from users' perspectives: A theoretical framework for involving users in the development process. *International Journal of Technology Assessment in Health Care* **25(4)**: 514-529.
- Shao, M., Tang, X., Zhang, Y. & Li, W., 2006. City clusters in China: air and surface water pollution. *Frontiers in Ecology and the Environment*, **4(7)**: 353-361.
- Silva, C.M., Sousa, V. & Carvalho, N.V. 2015. Evaluation of rainwater harvesting in Portugal: Application to single-family residences, *Resources, Conservation and Cycling* **94**:21-34
- Simonsen, J. & Robertson, T. (eds). 2012. *Routledge international handbook of participatory design*. Routledge.
- Sonnenwald, D. H. & Liewrouw, L. A. 1997. Collaboration during the design process: A case study of communication, information behavior, London: Taylor Graham, 179-204.
- Sowers, J., Vengosh, A. & Weinthal, E. 2011. Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change*, **104(3-4)**: 599-627.
- Steyn, J. & Van der Vyver, A.G. (eds.). 2013. Public and private access to ICTs in developing regions. Proceedings of the 7th International Development Informatics Association Conference, held in Bangkok, Thailand (152-166).
- Sturm, M., Zimmermann, M., Schütz, K., Urban, W., & Hartung, H. 2009. Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia. *Physics and Chemistry of the Earth, Parts A/B/C*, **34(13-16)**: 776-785.
- Suárez-Almiñana, S., Pedro-Monzonis, M., Paredes-Arquiola, J., Andreu, J. & Solera, A. 2017. Linking Pan-European data to the local scale for decision making for global change and water scarcity within water resources planning and management. *Science of the Total Environment*, **603**: 126-139.
- Sullivan, C. A., Meigh, J. R., & Giacomello, A. M. (2003, August). The water poverty index: Development and application at the community scale. In *Natural Resources Forum* **27(3)**:189-199)
- Taffere, G.R., Beyene, A., Vuai, S.A., Gasana, J. & Seleshi, Y. 2016. Reliability analysis of roof rainwater harvesting systems in a semi-arid region of sub-Saharan Africa: Case study of Mekelle, Ethiopia. *Hydrological Sciences Journal*, **61(6)**: 1135-1140.
- Team, C.W., Pachauri, R.K. and Meyer, L.A., 2014. IPCC, 2014: Climate change 2014: Synthesis report. Contribution of Working Groups I. II and III to the Fifth Assessment Report of the intergovernmental panel on Climate Change. IPCC, Geneva, Switzerland, 151.
- The African Union Commission AGENDA 2063: The Africa We Want. A shared strategic framework for inclusive growth and sustainable development: First Ten-Year Plan: 2014-2023, September 2015. Available at

<http://www.un.org/en/africa/osaa/pdf/au/agenda2063-first10yearimplementation.pdf>,
accessed on 1 March 2019

The African Union Science Technology Innovation Strategy of Africa-2024. June 2014. Available at https://au.int/sites/default/files/newsevents/workingdocuments/33178-wd-stisa-english_-_final.pdf accessed on 4 March 2019

The Department of Science and Technology, Draft White Paper on Science, Technology and Innovation, Government Gazette, 14 September 2018. Available at https://www.gov.za/sites/default/files/gcis_document/201809/41909gon954.pdf, accessed on 1 March 2019

The Freedom Charter, Adopted at the Congress of the People at Kliptown, Johannesburg, on 25 and 26 June 1955

The Netherlands Water Partnership (NWP). 2007. Smart Water Harvesting Solutions: Examples of innovative, low cost techniques for rain, fog, run off water and ground water.

Thomas, T.H. & Martinson, D.B. 2007. Roof rainwater harvesting: a handbook for Practitioners. Technical paper series, number 49, IRC International Water and Sanitation Centre Delft, The Netherlands.

Turner, J.L., 2006. New Ripples and Responses to China's Water Woes. *Woodrow Wilson International Center for Scholars, China Brief*, 6.

Udimal, B.T., Emmanuel, Z.J., Ayamba, E.C., & Owusu, S.M. 2017. China's water situation: The supply of water and the pattern of its usage, *International Journal of Sustainable Built Environment*, **6(2)**: 491-500.

Urama, KC. & Ozor, N. 2010. Impacts of climate change on water resources in Africa: The role of adaptation. African Technology Policy Studies Network, December 2013.

Van Vuuren, L. 2013. Rainwater harvesting from tanks-Useful yes, but can you drink it? The Water Wheel. Available at <http://www.thewaterwheel.com> Retrieved on 12 May 2015.

Vanham, D., Hoekstra, A.Y., Wada, Y., Bouraoui, F., de Roo, A., Mekonnen, M.M., Van De Bund, W.J., Batelaan, O., Pavelic, P., Bastiaanssen, W.G. & Kummu, M., 2018. Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4. 2 "Level of water stress". *Science of the Total Environment*, **613**: 218-232.

Vargas-Amelin, E. & Pindado, P. 2014. The challenge of climate change in Spain: Water resources, agriculture and land. *Journal of Hydrology*, **518**: .243-249.

Waisbord, S. 2001. Family tree of theories, methodologies and strategies in development communication. *Rockefeller Foundation*, 99. Available at http://omec.uab.cat/Documentos/com_desenvolupament/0126.pdf Retrieved on 12 April 2017

Water Research Commission Technical Brief. 2013. Assessing the social and economic acceptability of rainwater harvesting and conservation practices, October 2013.

- Water Research Commission Technical Brief. 2008. Rainwater harvesting: In-field rainwater harvesting adoption on small farm plots, April 2008.
- Walter, T., Kloos, J. & Tsegai, D. 2011. Options for improving water use efficiency under worsening scarcity: Evidence from the Middle Olifants Sub-Basin in South Africa. *Water South Africa*, **37(3)**:358-370
- Wheelwright, S. C., & Clark, K. B.1992. *Revolutionizing product development: quantum leaps in speed, efficiency, and quality*. Simon and Schuster.
- White, I. 2010. Rainwater harvesting: Theorizing and modeling issues that influence household adoption. *Water Source and Technology* **62(2)**:370-377.
- White Paper Summit Speech, Remarks by the Minister of Science and Technology, Ms Mmamoloko Kubayi-Ngubane at the Science, Technology and Innovation White Paper Summit on the 9th of November 2018
- Woltersdorf, L., Jokisch, A. & Kluge T. 2014. Benefits of rainwater harvesting for gardening and implications for future policy in Namibia, *Water Policy*, **16**:124-143.
- World Health Organization. 2012. Progress on Drinking-Water and Sanitation–2012 update WHO/UNICEF Joint Monitoring Programme for Water supply and Sanitation, launched on 6 March 2012.
- Yanarella, E. J., & R. S. Levine. 1992a. Does Sustainable Development Lead to Sustainability? *Futures* (October): **7(5)** 9-74.

CHAPTER 3: EXTENT OF SCARCITY OF WATER FOR DOMESTIC USE IN RURAL HOUSEHOLDS OF SOUTH AFRICA: A CASE STUDY OF MABAYENI VILLAGE IN LIMPOPO PROVINCE

3.1 Abstract

Climate variability and change are making it difficult to realize universal access to water and sanitation as stated in the United Nations Sustainable Development Goal 6. In South Africa's semi-arid areas, water scarcity continues to hamper health and development. Thus, a study was conducted to explore the extent of water scarcity in Mabayeni village of South Africa. A multi-method qualitative approach was used to examine available, actual and preferred water sources and uses. Views on the extent of water scarcity were obtained from groups of children, youth and adults. These groups were further subdivided according to gender. Various participatory rural appraisal techniques such as photo voice, focus group discussions, key informant interviews, storytelling, transect walks, participatory mapping and seasonal calendars were used to collect qualitative data. Matrix scoring and seasonal diagramming, thematic content analysis through applying ATLAS.ti version 7.5.7, and conversation analysis were used to analyse data. Scarcity of water in Mabayeni village was a result of negligence, uneven distribution of water resources as well as poor maintenance of water infrastructure. This led to conflicts, health and safety challenges. Water scarcity was only experienced during the dry season (between May and September). Sources of water included municipal tap water, private and public boreholes, rainwater, Shingwedzi River, and small dams among others. Private boreholes, were rarely relied on because participants paid for the water, while water from public boreholes was regarded as too sour to use. Municipal tap water was most preferred because it was safe for all domestic uses. Although seasonal, rainwater ranked second most important because it was said to be clean, cheap and convenient. The results of the current study highlighted the significance of developing a deeper understanding of specific community contexts before crafting intervention strategies to deal with inadequate availability of water. This is recommended in order to develop intervention strategies that are locally-relevant.

Keywords

Climate change; semi-arid; village; water shortage

3.2 Introduction

Various definitions of water scarcity have been suggested and to date, there is no universally accepted meaning. Rijsberman (2006) explains that for an area to qualify as water scarce, it depends on how people's needs are defined, the fraction of the resource available to meet the needs, and the temporal and spatial scales used in the definition. According to El Kharraz *et al.* (2012), scarcity refers to the extent to which demand exceeds the available resources. Drought or human actions such as population growth, and misuse and inequitable access to water result in scarcity. Jiang (2009) and Damkjaer & Taylor (2017) extend the definition, categorizing it into physical and economic water scarcity. Physical water scarcity is attributed to the shortfall in terms of the amount required to meet needs. In contrast, economic scarcity is related to mismanagement or underutilization of available water sources. Moreover, there is quality-related scarcity, which refers to a situation wherein water is available but is not fit for drinking and other uses. This is the case when there is salt water intrusion. Based on the definitions given above, it can be concluded that water scarcity encompasses the imbalances between water supply and demand caused by natural or man-made factors.

Water scarcity has become one of the most pressing issues in recent times. It will continue to worsen in the coming decades consequently precipitating negative effects on health, environmental sustainability, food security and economic development (Alcamo *et al.*, 2007; Ercin & Hoekstra *et al.*, 2012; Hoekstra, 2014a). Some authors argue that water will be as valuable as oil in the current century (Qadir *et al.*, 2003). The Department of Water Affairs and Forestry (DWAF, 2010) regards water as "liquid gold". Inability to meet the United Nations Millennium Development Goals targets has led to another commitment through the United Nations Sustainable Development Goals. Under this, Goal 6 calls for significant reduction of the number of people suffering from water scarcity by 2030 (Damkjaer & Taylor, 2017). In order for this to happen, there is need for collaboration among sectors, organizations and inter-governmental stakeholders in crafting appropriate strategies that help address the types of water scarcity that currently exist.

For rural communities, the effects of water scarcity will continue to be felt mainly due to the fact that water resources at their disposal have often been neglected (Rijsberman, 2006; Mwenge-Kahinda *et al.*, 2010). In addition, rural communities find it difficult to cope with the effects of water scarcity because they are unable to afford alternative strategies to acquire the resource in the event that communal sources fail. According to United Nations World Water Development Report (2018), an estimated 1.8 billion people use an unimproved source of drinking water with no protection against contamination. Most of these people come from poor rural communities with

an income below the poverty datum line (Mwenge-Kahinda & Taigbenu, 2011). This situation calls for adoption of capacitation strategies that would enable rural communities to access water easily.

In South Africa, water supply is limited, unevenly distributed and climate change has a negative impact on it (Blignaut *et al.*, 2009). The spread of invasive alien plant species worsens the challenge of poor supply of water (Blignaut *et al.*, 2007; Cullis *et al.*, 2007). In 2010, the Department of Water and Sanitation (DWS) rolled a number of interventions designed to support the ever-increasing water demand. Among these were water recycling, controlled or alternative irrigation methods, installation of water efficient fixtures and appliances, and construction of surfaces with permeable materials (storm water control), among others. However, there was a bias towards urban communities. Thus, it is not surprising that the provision of potable water to rural communities is now a top government priority, including in Vhembe District of Limpopo Province.

Rural communities in Vhembe District are currently facing severe water shortages. According to a community survey carried out by Statistics South Africa (2016), only 33 % of households in the district had piped water inside their households. The remainder relied on sources of water supplied by regional or local service many of which were far from their dwellings. Therefore, the aim of the current study was to determine the extent of water scarcity in semi-arid areas of Vhembe District. Mabayeni village, which is located in the area under Chief Madonsi's jurisdiction in Collins Chabane Local Municipality was the study area. The two dimensions that were considered in the characterisation of water scarcity were seasonality and community preference. First, the time during the year when water scarcity was most severe was examined. The second part of the study determined the actual water sources available to the community to meet the demand for different domestic uses. Lastly, the community preferred water sources for selected water uses were identified. It was anticipated that information on seasonality would be useful in implementing season-specific strategies to help rural communities successfully adapt to water scarcity. Community preferences on water sources and uses were considered because they gave an indication of the available sources of water throughout the year, including how this met the quality expectations.

3.3 Methodology

3.3.1 Description of the study area

As already indicated, the study was undertaken in Mabayeni village located in Collins Chabane Local Municipality. This local municipality is classified as Category B and located in the far north of Limpopo Province. The Municipality shares borders with Municipalities such as, Musina in the

north, Thulamela in the west, Louis Trichardt in the south west and Mopani District in the south. It is one of the four Municipalities in the District, making up 20 % of its geographical area. Collins Chabane Local Municipality was established in August 2016 through amalgamating portions of the Thulamela and Makhado Local Municipalities (Limpopo Provincial Gazette, 2017). Mabayeni village is one of the nine villages that make up Ward 35 of the Municipality (Figure 3.1). It is located about 60 km and 20 km to the east of Thohoyandou and Malamulele towns, respectively.

3.3.2 Formalization of the research project

After preparing the Doctor of Philosophy in Rural Development research proposal, it was presented to the Institute for Rural Development in order to source technical inputs for use in improving it. In a follow up seminar, the research proposal was presented in the School of Agriculture Higher Degrees Committee. After that, it was recommended for submission to the University of Venda Higher Degrees Committee (UHDC) for approval. The UHDC approved the proposal for funding and registration with the Research and Publication Committee. Subsequently, ethical clearance was secured from the University Research Ethics Committee, thereby giving the green light for commencement of fieldwork.

3.3.3 Social preparation for data collection

Figure 3.2 illustrates the approach to community entry that was followed in order to prepare for smooth data collection. Several meetings were held with a wide range of key stakeholders. This was done with the aim of creating awareness and securing support for project implementation. The stakeholders involved representatives of the Vhembe District Water Department, Water Users Association and community leaders

In Mabayeni village, meetings were held with community leaders to negotiate entry as well as create awareness on the RWH project. Traditional leaders, Ward Councillors, Ward Committee members, community development workers, the local water committee, South African National Civic Organisation, Home-based carers and those involved in the government's Community Works Programme formed part of the community members. In the course of laying the ground for data collection, the research project implementation team was established. The team comprised the principal researcher and six research assistants, all of whom were students from the University of Venda. Research assistants were pursuing Honours, Masters and PhD studies. Although the Research and Publications Committee of the University of Venda normally recommends recruiting only two research assistants, the nature of the current study necessitated hiring at least six. The reason for this departure from the university norm was that engaging community members in groups divided based on age and gender meant that at least six groups would be formed in each engagement session.

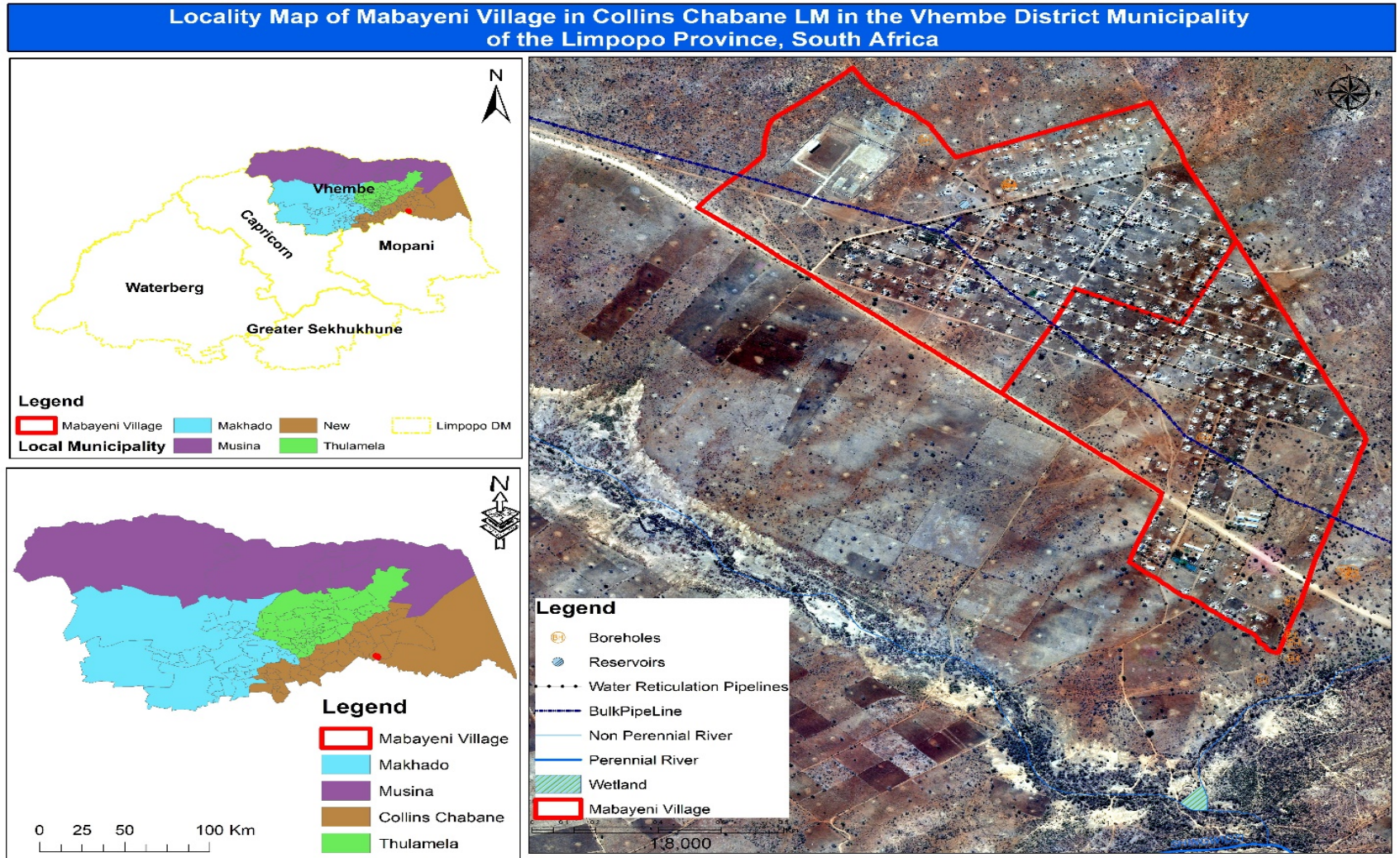


Figure 3.1 Map of Mabayeni village in Collins Chabane Local Municipality as the study area

(Source: Dondofema, 2018)

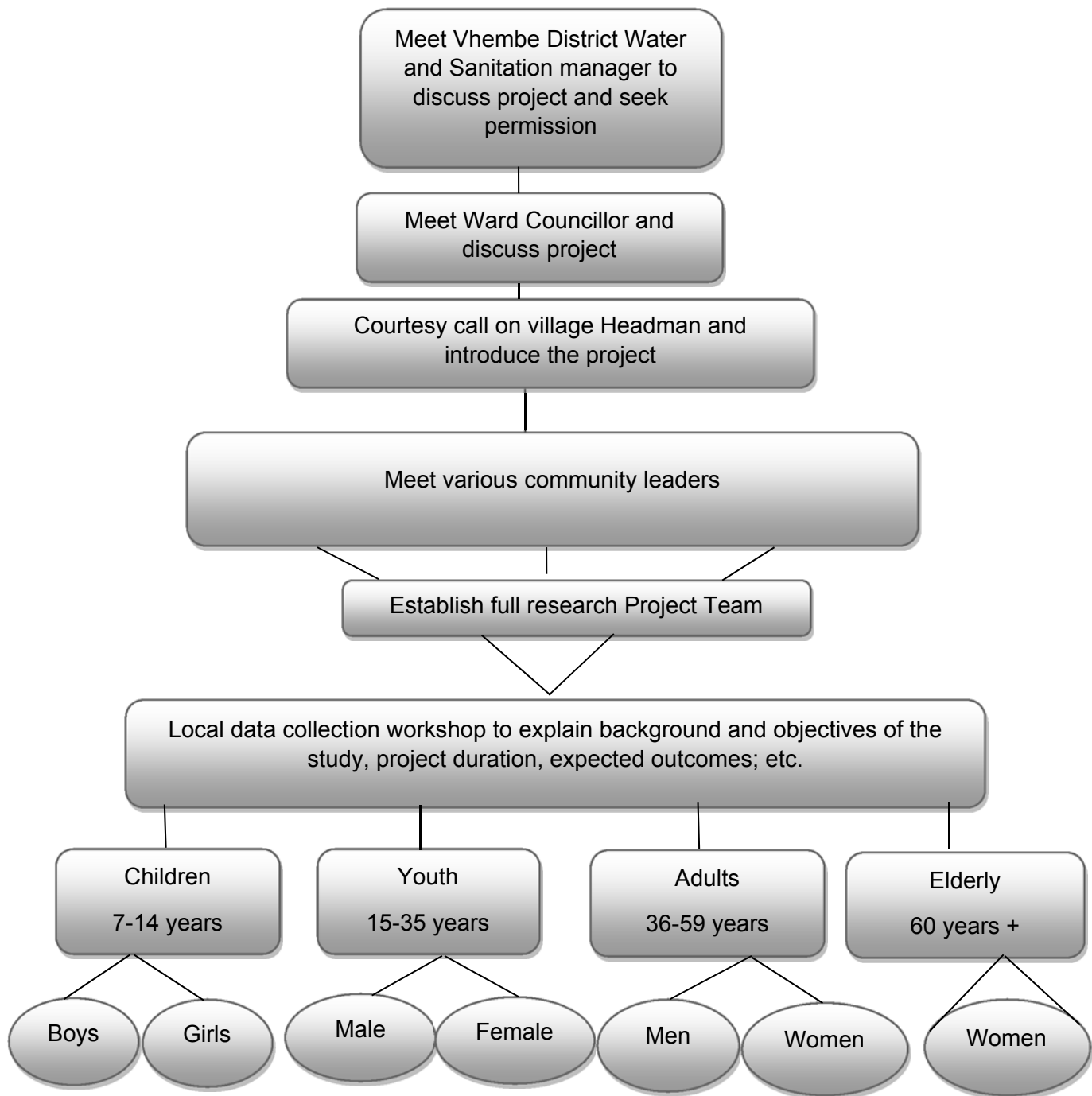


Figure 3.2 Diagrammatic presentation of stages of community entry and data collection in the study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

The six research assistants were thus hired to facilitate one focus group each. Prior to commencement of data collection, an orientation workshop was held. Research assistants and community leaders were oriented on the fundamentals of the RWH project.

3.3.4 Adoption of data collection tools

Before data were collected, relevant tools were developed and pretested in order to check the accuracy and clarity of questions posed. Tools involved semi-structured interview guides for photo voice discussions, and key informant interviews. This was done with two groups of volunteer community members from Mabayeni village. The two groups completed the two sets of questions before they were requested to give comments to the tool itself. Judging from the response time, both tools were found to be too long. Responses were also scrutinized to detect unclear, repeating and overlapping questions. After this exercise, unclear questions were clarified while those that were repeating were removed. Finally, overlapping questions were rephrased.

Pilot testing was also carried out with a group of community leaders. This was done to check the sequence of questions and ascertain the duration of administering specific tools and questions. The pilot testing revealed that the questions underpinning photo voice were too many and thus consumed too much time. As a result, fewer questions were retained and incorporated into the SHOWeD technique (Wallerstein & Bernstein, 1988) to save time. This significantly reduced the amount of time taken to respond from two hours thirty minutes to just under two hours. The SHOWeD technique entailed considering each photograph a code (Sharma, 2006). A set of questions were then used to interrogate each water-related photograph. These were; What can you See?, What is really Happening?, How does the story relate to Our lives?, Why is it happening?, how is it possible to become Empowered?, and What can we Do about it?

3.3.5 Research philosophy and design

The ontological and epistemological positions which underpinned this study were grounded on the belief that no ultimate or absolute reality or knowledge exists (Al-Saadi, 2014). A subjectivist approach to ontology was therefore adopted. According to this approach, reality is subjective. Although external reality exists, it is only known through human mind and socially-constructed meanings. Thus, there is no absolute reality, but rather approximate observations or views of reality. Regarding the nature of knowledge and how it is acquired (epistemology), an interpretivist view was taken. This view emphasizes a close relationship between the researcher and the social world. The two are seen to impact one another making objective, value-free inquiry impossible (Scotland, 2012). Knowledge of the social world is thus produced by exploring and understanding the people's behaviour, perceptions and interpretations of the world rather than just observing and explaining these perceptions and interpretations. Consequently, the researcher understands

the social world using both his/her, as well as the participants' understanding. These philosophical foundations informed the kind of evidence needed to answer research questions, and determined the appropriate research strategies for the study.

An inductive process was deemed most appropriate for the study. This approach emphasizes gaining an understanding of the meanings human beings attach to events, a close understanding of the research context, hence reducing its concern with the need to generalise. In light of this, an exploratory and descriptive study design was adopted. It was planned such that deeper insights on the extent and nature of water scarcity in Mabayeni village were explored. This was done in line with the Maxwell (1996) argument that exploratory studies should be conducted when there are few or no earlier studies to refer to or rely upon to predict an outcome. Apart from this, the study was a case study. Bryman (2012) explains a case study research as an assessment of a single unit in order to establish its key features and draw generalizations. In this case, an in-depth study on water scarcity in Mabayeni village was carried out aiming to develop a prototype for RWH. It should be noted that the above mentioned research philosophies and research design underpinned all the subsequent chapters except for Chapter 8.

3.3.6 Population and sampling procedures

The current study was a follow-up to the research that the principal investigator undertook towards a Masters in Rural Development degree (Nyamukondiwa, 2014). It focused on the resilience of rural communities to effects of climate change in the same village. The scarcity of water experienced in the village and surrounding areas was attributed to climate change. Out of the nine villages constituting the then Ward 40 of Thulamela Local Municipality (now Ward 35 of Collins Chabane Municipality), Mabayeni village was found to be the most affected. Thus, the village was purposively selected for the current study.

An open invitation was extended to all persons at least seven years old who were willing and able to participate in the study. Phone calls were made to the village Headman and the two project team members from the village, as well as through volunteer group representatives whose contacts had been obtained during pre-test and pilot testing. These contact persons were responsible for disseminating the invitation message to others through word of mouth. Phone calls were made at least three days before each engagement. Subsequently, the same people were reminded about the engagement the evening before the visit.

The meetings were held at Mabayeni Old Age Home, a venue that was selected by the community leaders with permission from the Headman. On each day of the engagement, a programme was used to guide the meeting and copies of the attendance register were used to keep a record of

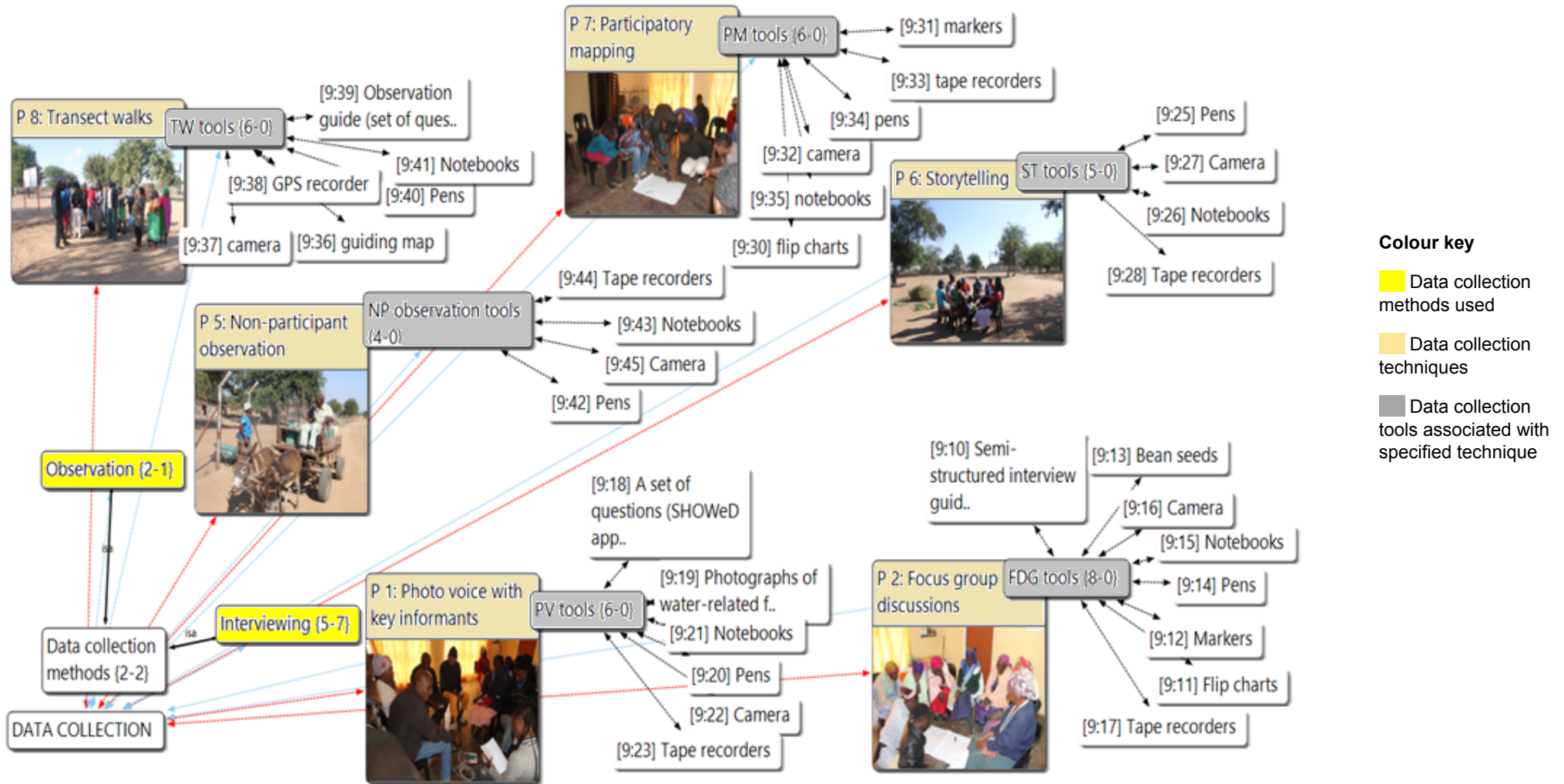
the participants. The background and purpose of the research project, the project outline, expected date of completion, possible benefits of the project to the community were explained. After the main session, participants broke into seven groups according to age (youth, adults and the elderly) and also gender (male and female separately). This was done to explore the various views and levels of imagination among groups as well as detect any emerging age or gender-related dynamics. Dividing respondents by age and gender also ensured that descriptions of extent of water scarcity in the village were exhaustive given that every interest group reflected on its daily activities. This was a form of triangulation called triangulation of data sources which is important for completeness of data.

3.3.7 Data collection

A summary of the data collection methods, techniques and tools used in the study is presented in Figure 3.3. Data were collected using various participatory rural appraisal (PRA) techniques. Various scholars (Webb, 1996; Bryman, 2004; Leech & Onwuegbuzie, 2007) argue that triangulation is crucial in social research because it reduces uncertainty of findings. Yeasmin & Rahman (2012) add that triangulation of techniques is helpful for cross-checking and confirming completeness of results. In this study, triangulation of data collection techniques helped to gain a deeper understanding of the extent of water scarcity in the village. Photo voice with key informants, structured focus group discussions (with key informants and community interest groups), participatory mapping, transect walks, storytelling, seasonal diagramming and non-participant observation were used to collect data. Each one of these techniques is described in more detail below. Figures 3.4 shows the number of participants involved per technique.

Photo voice with key informants

A combination of photo voice and key informant interviews was adopted at the beginning of the study so as to gather as much information as possible to understand the extent of water scarcity. Photographs were valuable as they represented reality with regard to water scarcity in Mabayeni village. According to Schwartz (1989) photographs can be used as data and data generators. When viewed as works of art, photographs are thought to embody the personal concerns of the photographer. When viewed as records, photographs are thought to reproduce the reality which is unmediated and unbiased (Schwartz, 1989). Therefore, photographs were valuable as they presented an opportunity to understand participants' concerns regarding water scarcity using recent and original representations of their reality.



(Photographs P3 and P4 were removed because they were repeated therefore not adding value)

Figure 3.3 Summary of data collection methods, techniques and tools used to determine the extent of water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

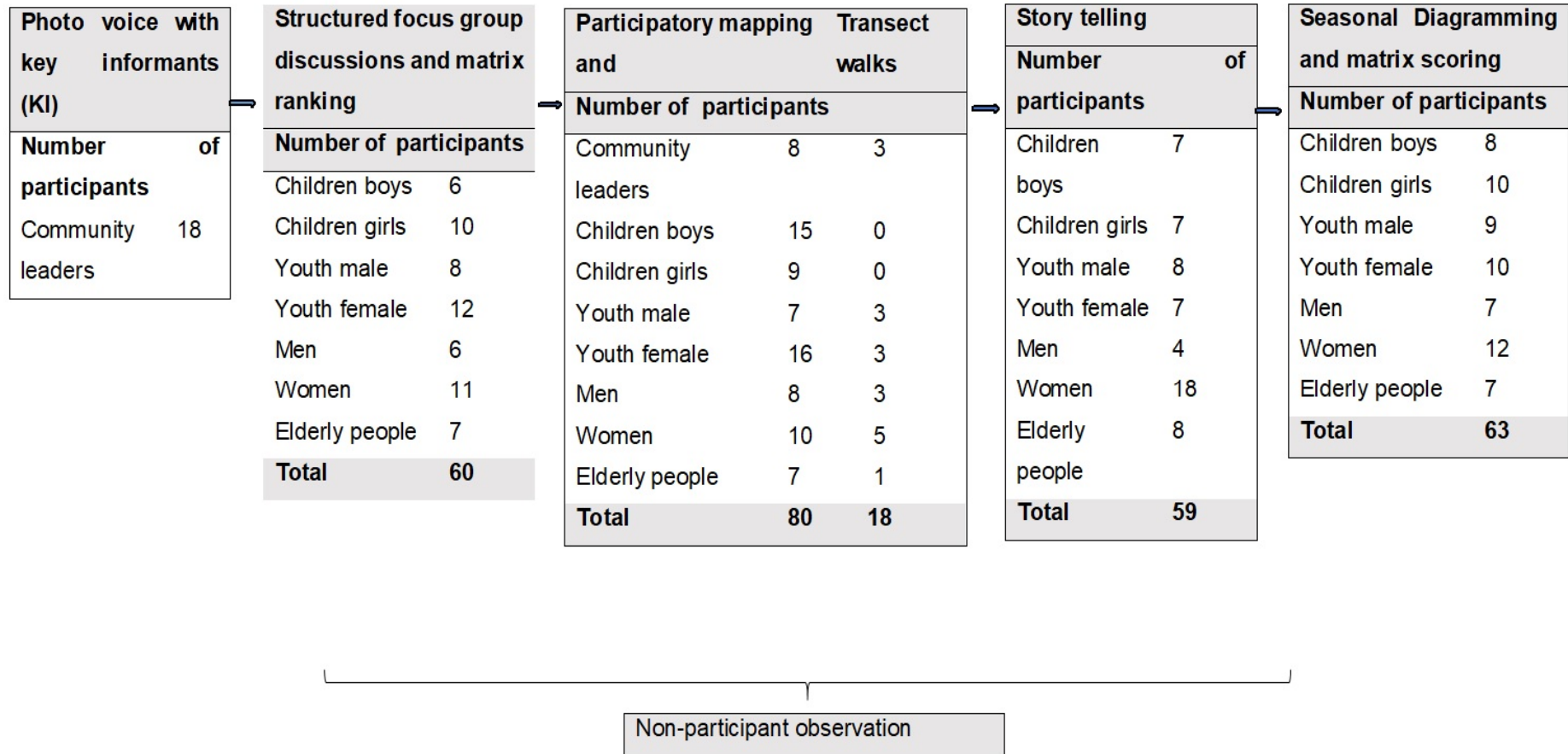


Figure 3.4 Sequence of data collection and number of participants engaged per data collection technique

Key informants were representatives of different community leadership structures such as Ward Committee, Community Development Forum, Water Committee, Mabayeni Cabinet and Mabayeni Society for the Aged, among others. In the introductory meeting, key informants were requested to take photographs that exhibited the water situation in their village. One of the three nominated community representatives volunteered to coordinate the sending of photographs to the principal researcher via social media (WhatsApp) for printing. In total, 15 water-related photographs were received and printed. The photos formed the basis for the photo voice-focus group discussions. In a large group of 18, participants were first requested to organize photographs into categories, then explain why they had sorted them in that manner. Second, participants were randomly divided into two groups to deliberate on the three sets of photographs that they had categorized. Then, for each photograph, the Wallerstein & Bernstein's (1988) SHOWeD technique (already explained) was used to guide the discussions. The two groups exchanged the sets of photographs until all the photographs were discussed by both groups.

Structured focus group discussions

After photo voice discussions with key informants, structured focus group discussions were held with ordinary community members. In their interest groups, participants were requested to indicate water sources in the village and their associated uses. In addition, they were asked to indicate the most preferred sources and give reasons. Moreover, participants specified the availability of these water sources throughout the year. The focus group discussions were meant to get an idea of the sources of water and their uses in Mabayeni village as well as frequency of availability in preparation for seasonal diagramming and preference ranking. These data collection techniques were used at a later stage.

Participatory mapping

Participatory resource mapping was carried out in focus groups made up of community leaders who were key informants (as already indicated) as well as ordinary community members in their interest groups. Each of these groups was requested to draw a map showing the distribution of water features or water sources, across the village. Participatory mapping was done in order to map out the village and understand the water features found in the village. This information was used to prepare for transect walks. Tools such as pencils, flipcharts and markers were used. Out of these maps, the one regarded as the best was used to guide transect walks in the community.

Transect walks

In a previous meeting, volunteer representatives had been requested to register their names and contact details for participation in the transect walks. These were the only people invited for the exercise. Before commencing with transect walks, volunteers were invited to draw the transect route to be followed. The transect walk was done to see, understand and record the water-related features in the village, as well as to determine available resources that would be utilized to enhance coping strategies to water scarcity in the area. Photographs and notes were taken for each water feature or water-related resource that was found.

Story telling

Stories depicting water issues were also collected from different community interest groups. Water scarcity-related stories were gathered from groups of children both boys and girls from ages seven to 14, youth male and female from ages 15 to 35, adult men and women from ages 36 to 64, and the elderly group aged 65 and above. For the elderly group, only one group of women was available. Grouping participants according to age and gender was important for isolating and dealing with biases emanating from gender as well as ensuring completeness of responses. In their different groups, participants were requested to share stories on water scarcity in their village. Trained research assistants were responsible for notetaking, probing, and asking questions for clarity. Tape recorders were also used to record audio conversations and a camera for taking photographs.

Non-participant observation

The behaviour of participants was observed as they worked in their different focus groups. In addition, activities in the community (outside the venue) were also noted. According to Liu & Maitlis (2010), non-participant observation can offer a more "nuanced and dynamic" appreciation of situations that cannot be as easily captured through other methods. Therefore, as they were facilitating focus group discussions, research assistants also paid attention to activities taking place in the community. Using an observation guide, activities that were seen to be relevant to water scarcity were recorded in notebooks as well as through photographs. The guide contained questions describing the water or water scarcity-related phenomenon, the actors involved, and explanations for phenomenon. In some cases, short interviews were held to gather perspectives from community members that were not participating in the study. These spontaneous

observations were made to get a comprehensive understanding of the magnitude of water scarcity in the village.

Seasonal diagramming

This technique was employed to ascertain the part of the year scarcity of water was most experienced. Freudenburger (1999) argues that seasonal calendars are a vital data collection technique for they help deal with seasonality bias. The calendar assisted in understanding the reality changes during seasons as conditions changed in the community. In this case, seasonal diagramming was used to indicate availability of water for a particular use, as well as, water sources that were available for different uses throughout the year. Each interest group was tasked to indicate the extent of relative availability of water per month from each source. Sixty seeds of beans were given to each group. Using the seeds, each group distributed them across January-December. Months that were allocated the least number of seeds were the worst in terms of water scarcity and vice versa. This technique is similar to budgeting in financial management. Separately, participants also indicated the water sources that were available for different uses throughout the year.

3.3.8 Data analysis

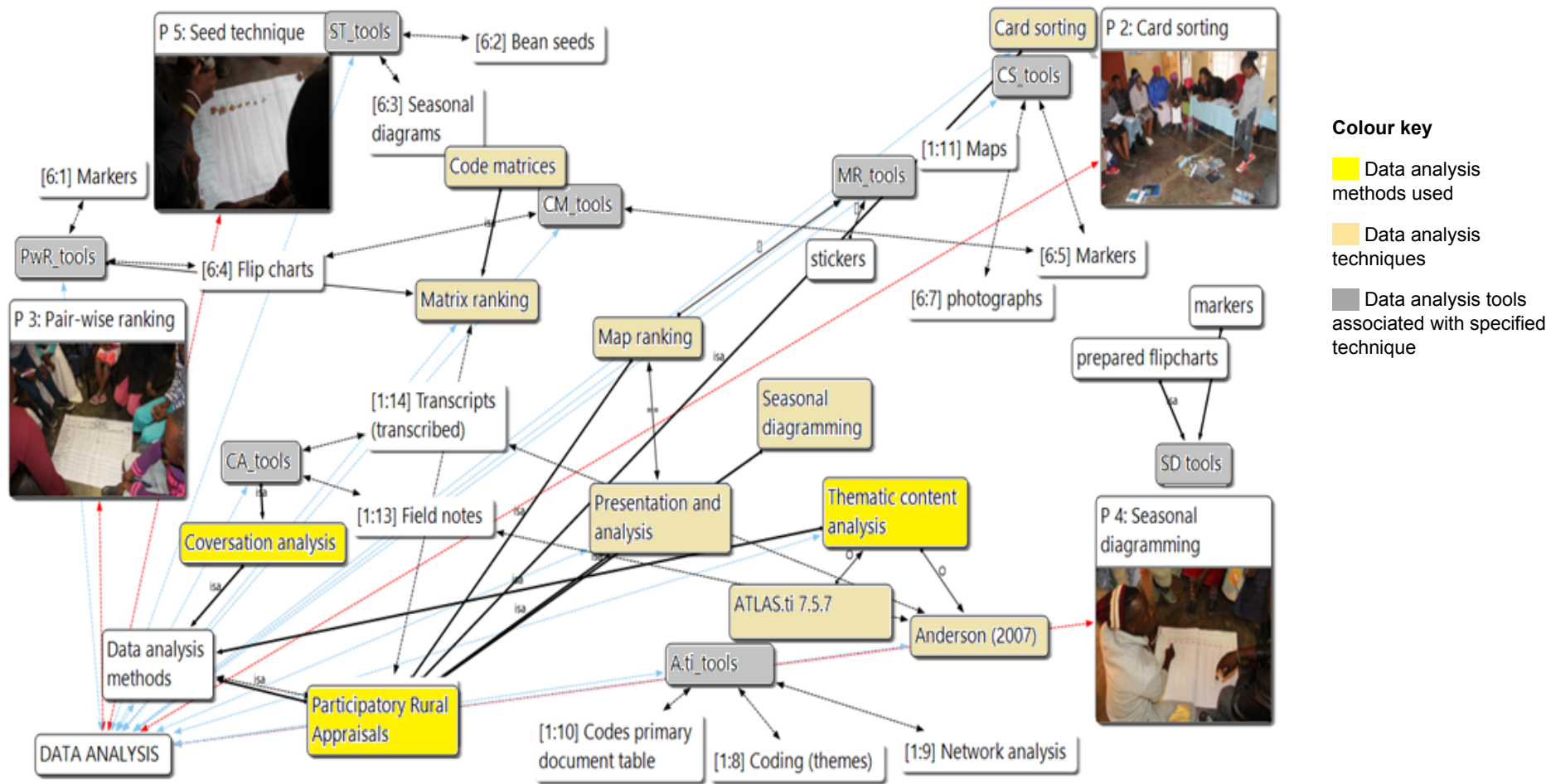
Most of the data were analysed in the community with study respondents through use of PRA techniques, thematic content analysis as well as conversation analysis. Three data analysis methods and eight associated techniques were used (Figure 3.5). Thurmond (2001) terms this data analysis triangulation. In addition, within-method triangulation was also done. This is defined as the use of at least two data analysis procedures from the same design approach (Kimchi *et al.*, 1991). In the current study, PRAs and thematic content analysis had at least two data analysis procedures. Data collected during photo voice discussions were first analysed with participants through card sorting. Data from key informant interviews, storytelling and structured focus group discussions were coded, before being organised into broad themes or categories analysed using thematic content analysis (Anderson, 2007). After that, data from the above sources including photo voice were subjected to further analysis using ATLAS.ti software version 7.5.7. The latter analysis highlighted dominating themes and showed relationships and networks existing among themes and related subthemes. Atlas.ti software automatically assigns a number to each segment highlighted as a quotation. This enables the software to aggregate quotations and codes linked to a particular theme. This software also helps with sorting of results from the coding process using units called density and groundedness. Density shows the number of codes linked to each

other while groundedness reveals the themes with the highest number of quotations. In this study, groundedness was mainly used to determine major themes. However, the software was also used to provide a visual illustration of the data collection and analysis procedures (Figure 3.5). For this section, the software was used not for analysis but for organisation and presentation of data collection and analysis techniques. For the latter, the Atlas.ti-assigned digits shown in the diagrams should be ignored.

Participatory maps that the interest groups developed were primarily used to elaborate water-related features in Mabayeni village, and also to mark a route that would be followed during transect walks. Each interest group presented their maps explaining the features. All the maps were stuck on the wall. Then, using stickers (sticker voting), participants selected the best. The techniques used in this process were a combination of presentation and analysis (Chambers, 1994) and map ranking (Chambers, 1994; Mukherjee, 1995).

Conversation analysis (Leech & Onwuegbuzie, 2007) was also used to analyse field (observation) notes from storytelling. When using conversation analysis, there was special focus on the way the participants spoke, their choice of words, and the meaning borne. Roger & Bull (1989) defined conversation analysis as examining the procedures used in the production of ordinary conversation. According to Markee (2000), the four assumptions underlying conversation analysis are that; conversation has structure; conversation is its own autonomous context, that is, the meaning of a particular utterance is shaped by what immediately precedes and follows it; there is no justification for believing that any detail of conversation, however minute, is disorderly, accidental or irrelevant; and the study of conversation requires naturally occurring data. Although Heritage (2004) outlines six basic elements of this data analysis method, only three elements (turn taking, structural organisation, and lexical choice), were observed during water-scarcity related conversations.

As the discussions unfolded, apart from the use of tape recorders, research assistants recorded the turn-taking process, how participants interacted with the facilitator and each other, and the descriptive terms and gestures that were used. This information was used to supplement data which was analysed using ATLAS.ti. Moreover, data obtained through spontaneous community observation were analysed together with interview and storytelling data since it complemented and confirmed the latter data. Matrix scoring was carried out during analysis of seasonal diagrams of water scarcity. This was done in three ways. First, the seed technique was used to provide a



Colour key

- Data analysis methods used
- Data analysis techniques
- Data analysis tools associated with specified technique

Figure 3.5 Data analysis methods, techniques and tools used in determining the extent of water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

picture of relative availability of water for different uses throughout the year. Line graphs were drawn to show the trends. The second analysis involved the use of codes to illustrate the actual use of water sources across months. Lastly, preferred sources of water and their uses were displayed using preference tables. For each water use, each interest group was requested to indicate the source it preferred most. The results were consolidated and ranks created to determine the water sources that were most preferred for each use. Each interest group assigned a score starting from 1, which meant most preferred to the highest (least preferred) against each water source.

3.3.9 Ethical considerations

Ethical clearance was secured from the University Ethics Committee. Permission to conduct the research was sought from Vhembe District Municipality, the Ward 35 Councillor and Mabayeni village Headman (Figure 3.2). Meetings were held with leaders of various local community-based organisations to orientate them about the project. The purpose of the research was explained. It was highlighted that participation in the research project would be voluntary. Thus, they were free to withdraw at any point if/when they felt uncomfortable to continue participating. Permission to engage children from as young as seven years old was sought from the leaders, as well as, community members. In addition, leaders were encouraged to invite other community members to participate in the study without discrimination.

The residents of Mabayeni village were Tshivenda and Xitsonga-speaking. Extending open invitations was meant to ensure that everyone had the chance to participate in the research. Thus, interviews were conducted with the residents who were willing and available to participate. Before commencement of data collection, the nature, purpose and objectives of the research were explained to all candidate respondents. The need for them to participate voluntarily was emphasized. Respondents were given the chance to ask questions before deciding whether to participate in the study or not. Those who volunteered to participate signed an informed consent form (Appendix 3a). Verbal consent was obtained from those who could not read or write. The signed consent forms were stored separately from all the other research materials. Permission to capture photographs and tape records of the deliberations of the project meeting proceedings and to record conversations during research engagements was sought and granted.

Assurance was given to participants that information collected would be used only for purposes of the study and would most likely be published in various scholarly media. A copy of the PhD thesis would be handed over to the Headmen and serve as a community resource. In addition to this, a series of community feedback workshops were held throughout the study to ensure that community members understand the progress and outcomes of the study. Results of the study

were shared with community members to enable them to verify or revise them. This process enhanced the accuracy of results. Furthermore, recommendations on ways to improve water availability and access were shared with all the water stakeholders in the community, as well as, the water department in Vhembe District Municipality.

During the entire data collection process, deliberate efforts were made to ensure that the respondents were treated with respect and integrity. Partly, this was achieved by requesting them to choose suitable dates and venues for the data collection engagements. Whenever they felt tired or uncomfortable, or had emergencies in the middle of interviews, postponements were made in which they chose dates and venues for further engagements. Adverse weather conditions such as heat, rain or wind also caused postponements of data collection sessions. Data were processed immediately after collection before being stored in Microsoft Excel spreadsheets.

3.4. Results

It was resolved that the community leaders would help identify and recruit locals who would work closely with the research team. Apart from serving as research assistants, the latter were tasked to lead the mobilization of community members to participate in the study. In one of the first community meetings, the local village Headman made a verbal commitment to support the research project.

In his words, he said that

“...all we have to do is support you [the researchers] because the success of this project means our success as a community since water is really a challenge here”.

With respect to transect walks, out of the 23 people who had registered intent, 18 turned up. Out of the seven interest group, two groups (children boys and girls) did not turn up because they were at school. However, the other five groups were well represented. The transect walks took about two and half hours.

3.4.1 Photo voice with key informant interviews

Participants sorted photographs into three categories and labelled them “damaged taps”, “the water struggle” and “empty tanks”. They indicated that several municipal taps in the village were damaged. It was believed that the people responsible for stealing tap heads used them to make jewellery. No one knew the culprits and nothing had been done about the issue. With regard to “the water struggle”, participants explained the difficulties they faced in accessing clean water

including buying, travelling long distances, conflicts that took place at water access points and sometimes using unclean river water. As for “empty tanks”, participants indicated that Mabayeni village only had two community water tanks. These were said to have been non-functional for many years. They added that even if the tanks had water, the water would be insufficient to supply the whole village. Mabayeni residents blamed the Vhembe District Municipality for failing to repair water pipes and service the water tanks. A detailed analysis of data (obtained through photo voice discussions with key informants) using ATLAS.ti version 7.5.7 revealed that results were confirmed by those obtained from other techniques such as focus group discussions with interest groups, storytelling and transect walks as shown in Table 3.1.

3.4.2 Structured focus group discussions and matrix ranking

The different water sources in Mabayeni village were municipal tap water, rainwater, boreholes (private and community-owned) and river water. Interest groups ranked the above water uses according to importance. It was agreed that the most important uses were drinking, cooking, bathing, washing clothes, washing dishes and sanitation. Although other uses such as, car wash, animal watering, irrigation, cow dung plastering, building, cleaning the house, firefighting, and making bricks were identified, they were not considered any further due to the focus of the study being domestic. Interest groups also indicated that municipal tap water and rainwater were the most preferred water sources for all the most important uses (Table 3.2 and 3.3). However, only the female youth and adult women preferred using river water the most for washing clothes (Table 3.4). The results of preference ranking per interest group are presented in Appendices from 3.2-3.8. In addition, municipal tap water was said to be available for two to three days in a week. For Magangeni sub-village people, the pipes were said to be blocked making it impossible for them to access water from taps. Borehole water was said to be available all the time, while the local river (Shingwedzi) was believed to have water from December to April. Rainwater was observed to be available between October and March.

3.4.3 Participatory mapping and transect walks

As indicated above, different interest groups selected the best map out of the eight. The participatory map shown in Figure 3.6 was used to guide transect walks in Mabayeni village because it was regarded as neat, clear, showing all the village streets and a variety of water resources in the village. The water sources that were found in the village are displayed in Table 3.3. These included boreholes, municipal taps, water holding structures (*Swikerepe*), small dams (*Magraveleni*), Shingwedzi River, and water tanks. These results confirmed, as well as supplemented results on water sources provided through other data collection techniques above. It should be noted that water holding structures, small dams and water tanks were not mentioned when other techniques were used.

Table 3.1 ATLAS.ti summary results of data gathered through different techniques

Major themes	Structured key informant interviews	Photo voice with key informants	Focus group discussions with interest groups	Stories with interest groups	Transect walks with volunteer community members	Totals
a) Experiences	6	116	60	133	86	401
b) Water quality issues and health	0	26	39	17	36	118
c) The water struggle	2	17	21	39	22	101
d) Negligence	1	49	0	10	36	96
e) Administration issues	0	41	1	19	18	79
f) Conflict	0	4	3	49	2	58
Totals	9	253	124	267	200	853

Table 3.2 Rank totals for water sources and preferred uses across interest groups

Water use	Rainwater	Borehole	River	Municipal tap water	Small dams (Magraveleni)	Water holding structure (Xikerepe)
a) Drinking	15	25	23	7	35	42
b) Cooking	15	25	23	7	35	42
c) Bathing	15	28	18	9	35	42
d) Washing clothes	14	28	17	11	35	42
e) Washing dishes	13	26	22	9	35	42
f) Sanitation	14	23	25	8	35	42

*A higher rank denotes the least preferred water source

Table 3.3 Ranks showing the most preferred sources of water for drinking as perceived by different interest groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Interest group	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Water holding structures (<i>Xikerepe</i>)
a) Youth male	2	4	3	1	5	6
b) Youth female	3	2	4	1	5	6
c) Adult women	2	3	4	1	5	6
d) Adult men	2	4	3	1	5	6
e) Boy children	2	4	3	1	5	6
f) Girl children	2	4	3	1	5	6
g) The elderly	2	4	3	1	5	6
Total	15	25	23	7	35	42

*A higher rank denotes the least preferred water source

Table 3.4 Preferences for water sources for washing dishes as perceived by different interest groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Interest group	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Water holding structures (<i>Xikerepe</i>)
Youth male	2	3	4	1	5	6
Youth female	1	4	3	2	5	6
Adult women	1	4	3	2	5	6
Adult men	3	4	2	1	5	6
Girl children	2	3	4	1	5	6
Boy children	2	4	3	1	5	6
The elderly	2	4	3	1	5	6
Total	13	26	22	9	35	42

*A higher rank denotes the least preferred water source

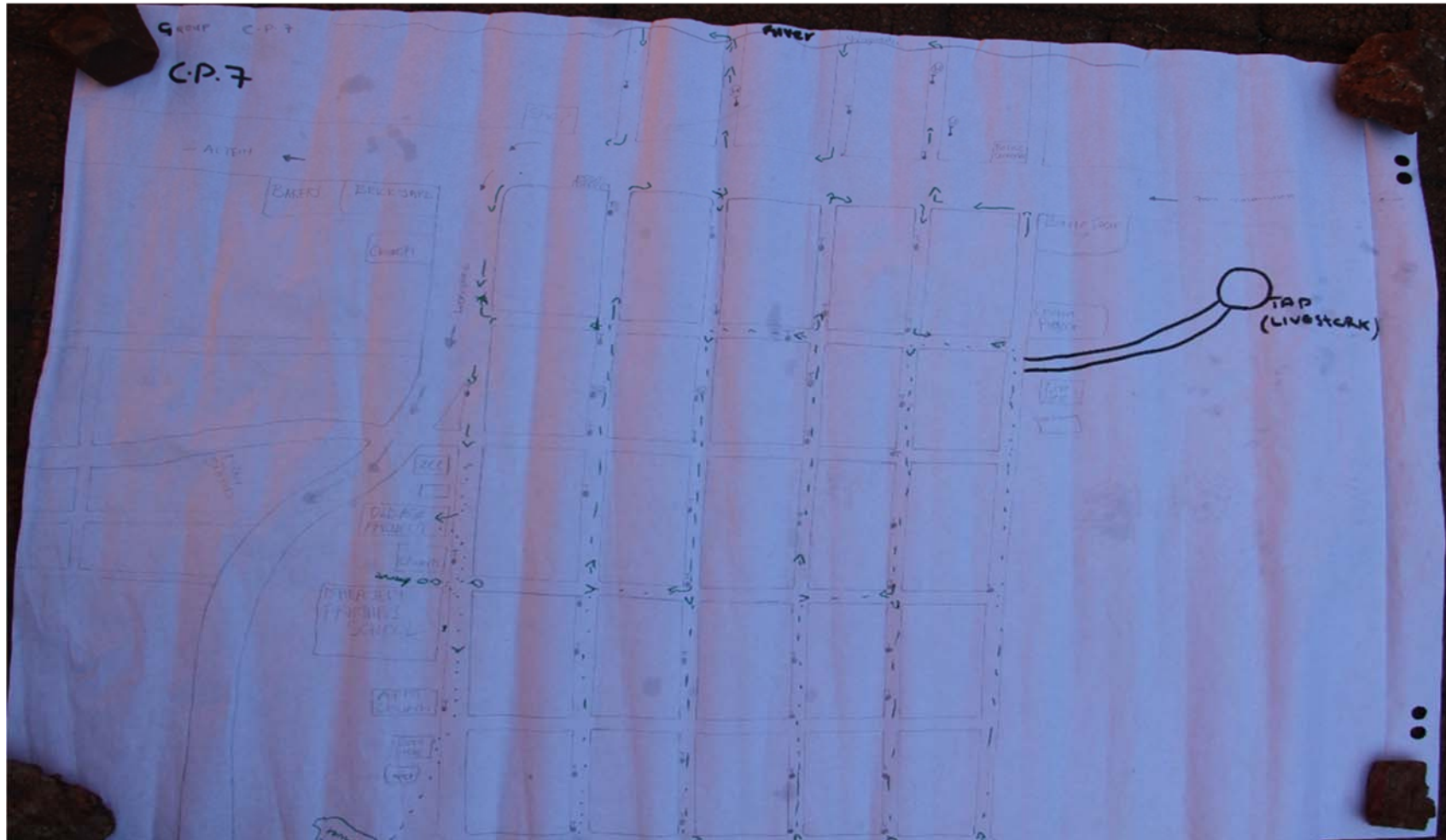


Figure 3.6 The map of Mabayeni village showing water features that were selected to guide transect walks in Mabayeni village of Collins Chabane local municipality in Limpopo Province

The photographs of water sources that were found in Mabayeni village are shown in Figure 3.7. It should be noted that during cleaning, blurry and repeating photographs were removed leaving only the best. The water sources found are displayed in Table 3.5. During transect walks, participants spoke about issues relating to negligence and poor administration of water resources. They spoke about the damage that was being done on water infrastructure such as boreholes, water pipes and taps and not taking action against theft.

“Come and see here, this is the borehole. So it is dead and they have stolen the machine”,
[youth male]

“...you see even the zinc material [that was used to cover the borehole] is rusty and they stole some of these to repair their houses”, [adult man]

“They broke the taps so that they can be able to drain water themselves from a tap.” [adult man]

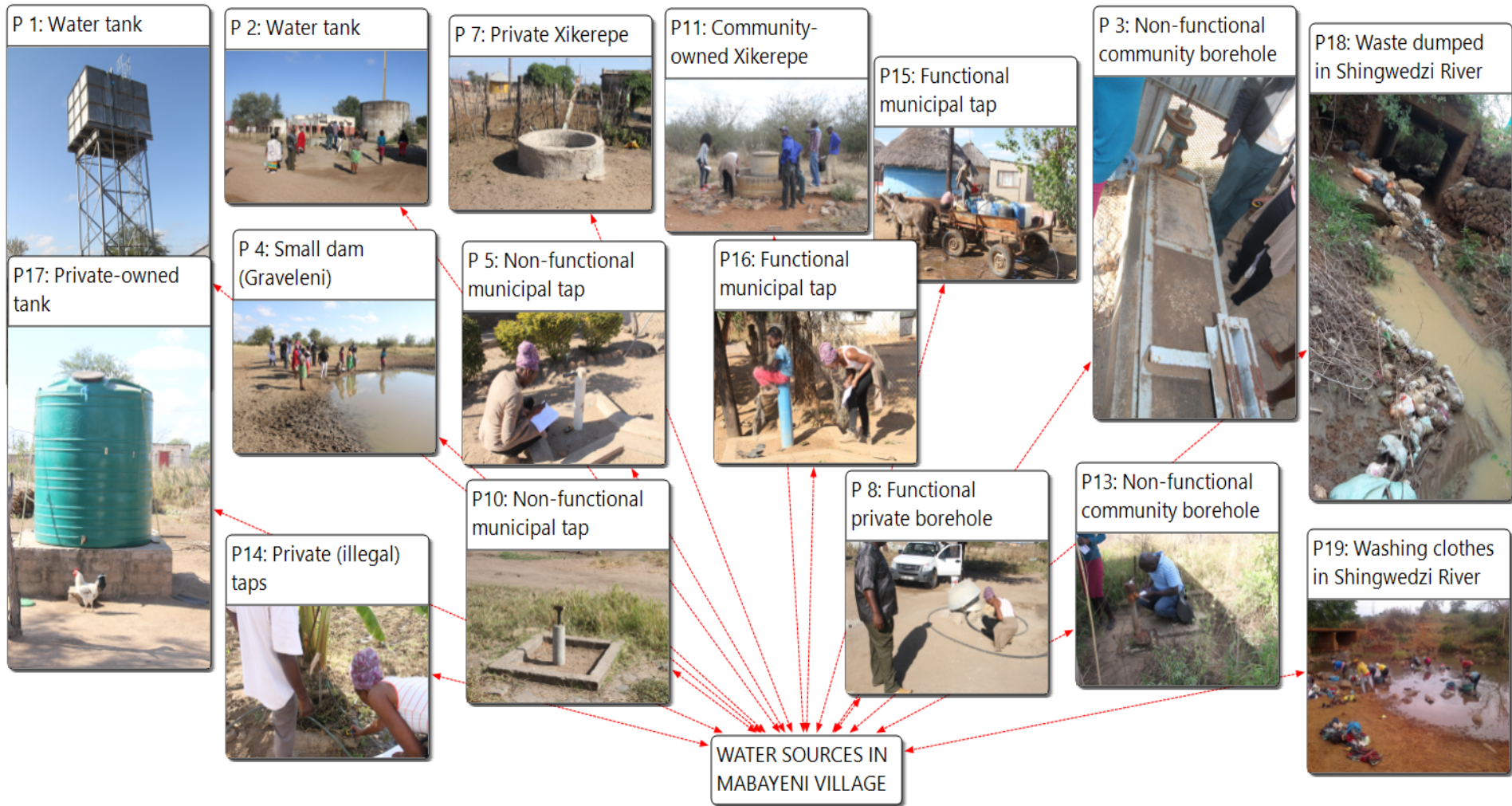
In addition, the two main water tanks in the village were reported to not have worked for more than 20 years. Some respondents expressed their frustration:

“There is no water in the tank. We are not sure why but it used to store water from Rivubye River near Nandoni dam.” [adult man]

“We just see people coming to the big tank and touching things there. They don’t talk to us. It has been too long since these tanks worked. We don’t know what the problem is.”
[adult man]

3.4.4 Storytelling and observation guide

The key themes (code families) that came out from ATLAS.ti analysis were administration issues, conflict, experiences, negligence, the water struggle and water quality issues and health. These are highlighted in Figure 3.8. The key subthemes based on the number of quotations were “poor water quality”, “water access hardships”, “abuse of water infrastructure”, “water infrastructure maintenance” as well as, “fighting and disagreements”. These subthemes summarized the state of water affairs in the village as well as the experiences community members endured, when obtaining water for basic household uses. The relationships between the major themes as well as subthemes are also shown using dotted lines.



(Photographs P6, P9, P12 and P15 were removed from the analysis due to poor quality and also to avoid repetition)

Figure 3.7 Water sources found in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 3.5 Water sources found in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water sources	Ownership	Functional	Non-functional	Total
a) Boreholes	Community-owned	1	4	5
	Private	2	1	3
b) Municipal taps	Public	5	43	48
	Private (illegal)	4	-	4
c) Water holding structures (Swikerepe)	Community-owned	-	1	1
	Private	3	1	4
d) Small dams (Magraveleni)	Community-owned	5	-	5
e) River (Shingwedzi)	Community-owned	Non-perennial		1
f) Water tanks	Community-owned	-	2	2
	Private-owned	6	-	6
Total		26	52	79

In addition, behaviour and conduct that was observed during discussions included repeating expressions, volunteering others, interrupting each other, raising voices, use of language expressions, laughing, use of hand gestures and different facial expressions as displayed in Table 3.5. During conversations, expressions such as “we want water, we have a problem”, “the issue of water is a big challenge”, “we just want water” and “you should help us” were noted. These statements were mostly said in the beginning and at the end of contributions. In addition, some participants volunteered others at different stages of the conversation. As the conversations got heated, some participants interrupted others despite their awareness of acceptable conduct as encouraged by the facilitators. Sometimes participants could not wait for the voice recorder to be brought to them before they spoke, instead they demanded it saying “*Thisa xilo xeiwane*” [bring that thing]. Moreover, repeated use of non-vocal gestures such as face expressions, head nodding, rise-fall of voice pitch were observed.

There were also several moments of laughter as participants shared and listened to stories told by others. Laughter particles or the number of laughter occurrences were also recorded per interest group. In addition, different hand gestures and facial expressions were also used to emphasize some elements of the conversation. As illustrated in Table 3.6, women, female youth and the elderly group expressed themselves more for both verbal and non-verbal expressions compared to groups of children and male youth.

Table 3.7, summarizes the experiences that community members went through when accessing water from different sources. Respondents explained the challenges regarding community borehole water. The quality of water from community boreholes was said to be so poor that it was avoided at all costs. Below are some sentiments echoed by community members regarding the quality of community borehole water:

“Borehole water is sour, you can’t do anything with it”, [elderly people]

“The soap is not effective as there is too much salt in the water,” [girl children and women]

“The water from the hand pumps and the boreholes can be used for washing cars since the water is very salty and nobody can drink the salty water” [women group]

Table 3.6 Observations recorded during storytelling in a study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Observations		Children		Youth		Adults		Elderly people	Total
		Boys	Girls	Male	Female	Men	Women		
Verbal expressions	“we want water, we have a problem”	2	3	5	4	4	6	3	27
	“the issue of water is a big challenge”	1	1	4	5	3	6	4	24
	“we just want water”	0	0	2	3	2	5	1	13
	“you should help us”	0	0	1	0	2	2	1	6
	“ <i>thisa xilo xeiwane</i> ” (bring that thing)	1	0	0	2	1	7	1	12
	“You can go first”	0	0	0	0	1	1	3	5
	“Let him/her talk first”	1	1	0	0	2	4	0	8
Non-verbal expressions	Shared laughter	2	3	2	3	0	8	0	18
	Head nodding	1	1	2	4	3	5	4	20
	Hand gestures	0	1	2	4	2	7	3	19
	Raising voice	0	0	0	1	0	8	0	9
	Facial expressions (frustration)	0	0	2	4	3	6	4	19
Total		8	10	20	30	23	65	24	180

Table 3. 7 Major themes, selected subthemes and verbatim quotations from ATLAS.ti

Theme (family)	Subtheme (code)	Verbatim quotation
a) Water quality and health issues	Poor water quality	“Borehole water is sour, you can’t do anything with it”, “The soap is not effective as there is too much salt in the water”, “In deed water from Magraveleni is smelly because we have to keep it here so that it can be used later on for washing and for cleaning”.
	Water, human safety and security	“When I come back from fetching water late in the evening, it will be dark and there is no electricity”
b) The water struggle	Water access hardships	“Sometimes we go to fetch water in the mid night during winter season and we make fire so that we stay warm”
c) Negligence	Abuse of water infrastructure	“They steal tap caps and make jewellery. They do it at night”
	Not taking action	“We are also suffering as we do not guide our children. We need to improve ourselves going forward” “We must save the small amount of water that we get. For example, we know that on Thursday there is water”
d) Administration issues	Water infrastructure maintenance	“This community tank hasn’t worked for about 20 years. There is no water. We do not know why. It used to store water from Levubu river connected to Nandoni”
	Dependence on government and outsiders	“The government and you guys should think of us especially about the things we are discussing so that it doesn’t end here, if we tackle the matter and do something then it will be good”
e) Conflict	Fighting and disagreements	“I once asked to fetch water in one of the houses around. I had 10 water containers and I was told that she (the owner) would fetch water for me that night but I was supposed to bring R20 the following day. So she had to collect water for me and give me the following morning. Then I went there the following morning with only R10 then I explained to her that that’s all I had but she couldn’t take it. She then went on to open all those water containers with water and emptied them in front of me. I was so disappointed and hurt at the same time. She gave me those empty containers and ordered me to go back with my R10. Imagine I didn’t even have water to drink at the time”
	People with and without taps	“Families who are having taps that people are getting water from also have a problem with people fetching water at 3 in the morning...they will not leave the premises until the water is finished. Families are forced to wake up to open the gate so that people can fetch as they knock until the families open. Sometimes people start fighting and end up breaking windows... others steal fruits.”
f) Uneven distribution of resources	Magangeni	“The worst area is Magangeni where they never had water at all unlike us who are staying on this lower part of the village... at least we do sometimes have water”, “I have never seen a community where others are buying water while others are getting it for free but it only happens here in Mabayeni village”
	New stands	“People from the new stands do not have piped water from the municipality. So they connected pipes illegally”

Although water from private boreholes was said to be of better quality, the water was not for free. The following explanation given by one respondent provides clarification:

“The price of water is R2 per 25 or 30 litre. If you are also hiring transport it will be expensive, up to R3 per container... imagine if you are six in your family, how much money will you need for all household uses?” [Women and female youth groups]

Regarding river water, the source was said to be too far (about five kilometres from the village) and the water contaminated, therefore, only preferred for livestock drinking. Respondents expressed their dissatisfaction towards river water by saying the following:

“Other people are collecting water from the river where many unclean objects are found such as cow dung, diapers and plastics”; [elderly people: women]

“Nowadays, water from Shingwedzi River does not smell good, people do their laundry there, and others dump nappies ...we think it will get to a point where we will all have to drink river water which will cause us sicknesses.” [elderly people: women]

Community members also lamented about difficulties around accessing public municipal tap water. As indicated above, water was said to run on a few municipal taps, for only two to three days in a week. More than three quarters of the municipal taps in the village were said to not have worked for more than five years and all of the three community boreholes had not worked for more than 10 years. This was a result of negligence on the part of community. In addition, water pipes were reported to have been bursting on their own since they were more than 20 years old. Apart from reporting to the water authorities, nothing had been done to fix the tanks or pipes. The municipal water authority was blamed for failing to maintain water infrastructure. Therefore, the few functional taps that remained led to long queues and a myriad of problems for instance, health, safety and security issues, loss of productive time, illegal water connection, and conflict, among others. With regards to conflict, the fighting and disagreements which sometimes turned physical, and the bullying (Table 3.7) which caused hatred among community members dominated the conversations:

“Sometimes people curse each other in the water queue as they fight over who should fetch water first” [boy children group]

It also emerged that some community members extended their yards to take advantage of the municipal taps. This has led to more conflicts between community members with water taps in their yards and those without.

“Families that are having taps in their yards also have issues with people fetching water from three in the morning and not leaving the premises until the water no longer comes out.” [women group]

“Imagine water comes back at two in the morning. So I should wake up and open my gate at two in the morning? It's not fair. But what can I do when they start making noise, I have to wake up and let them fetch” [women group].

3.4.5 Seasonal diagramming and matrix scoring

Results obtained from seasonal diagramming are summarised for each water use. Only water uses regarded as most important were considered.

Water for drinking

A uniform pattern emerged across interest groups regarding availability of water for drinking from January to December (Figure 3.9). All the seven interest groups perceived that availability of water for drinking in Mabayeni village increased in early September, reached a peak between November and February, and decreased in March. The dry season was perceived to be between May and September. Although this was the case, the actual water sources that were available for drinking from May - September were borehole followed by public municipal tap water (Table 3.5). During this period, adult women indicated that they relied entirely on municipal tap water for drinking. With the exception of the boy children group, the rest of the interest groups reported that they relied on a combination of public municipal tap water and borehole water for drinking. From October - March, interest groups revealed that rainwater was the most available water source for drinking. Only the female youth group highlighted rainwater as their only water source for drinking during this period. The rest of the groups reported that they used a combination of borehole, municipal tap water and rainwater.

Water for cooking

Results for perceived availability of water for cooking in Mabayeni village followed the same pattern as that of water for drinking presented in Figure 3.9. There were however, differences across groups with regard to the exact months in which availability of water for cooking increased. While groups such as the male youth, adult women, adult men and the group comprised of the elderly perceived that availability of water for cooking started increasing in October, the remaining groups reported that the increase began in September. All interest groups explained that it was difficult for them to give an accurate estimation of the beginning and end of the rainy season because of the shift of seasons and unpredictable weather caused by climate change.

“Nowadays it’s difficult to say when the rain will come and when it will go, the weather keeps changing...sometimes it comes in September, sometimes in October or even early November. It is difficult to say. We don’t know anymore ...” [women group]

Nevertheless, all the seven groups agreed that availability of water for cooking had diminished in March. The water sources that were said to be available from May - September were borehole and public municipal tap water. In the same period, male youth revealed that they relied entirely on municipal tap water, while adult women presented borehole as their only source of water for cooking. The rest of the interest groups relied on a combination of public municipal and borehole water even though borehole water appeared more dominant. Like in Table 3.8, the available source of water for cooking in the period between October and March, was rainwater. This water source was used in conjunction with public municipal tap water, and to some extent, borehole water. In the same period, only female youth indicated public municipal tap water as their only source of water for cooking.

Water for bathing

Observed results for availability of water for bathing across months were also the same as those of water for drinking and cooking. However, community members reported that the available sources of water for bathing between May and September were public municipal tap water and borehole water (Table 3.9). In the same period, youth male demonstrated that they relied solely on municipal tap water, while female youth and girl children indicated entire dependence on borehole water.

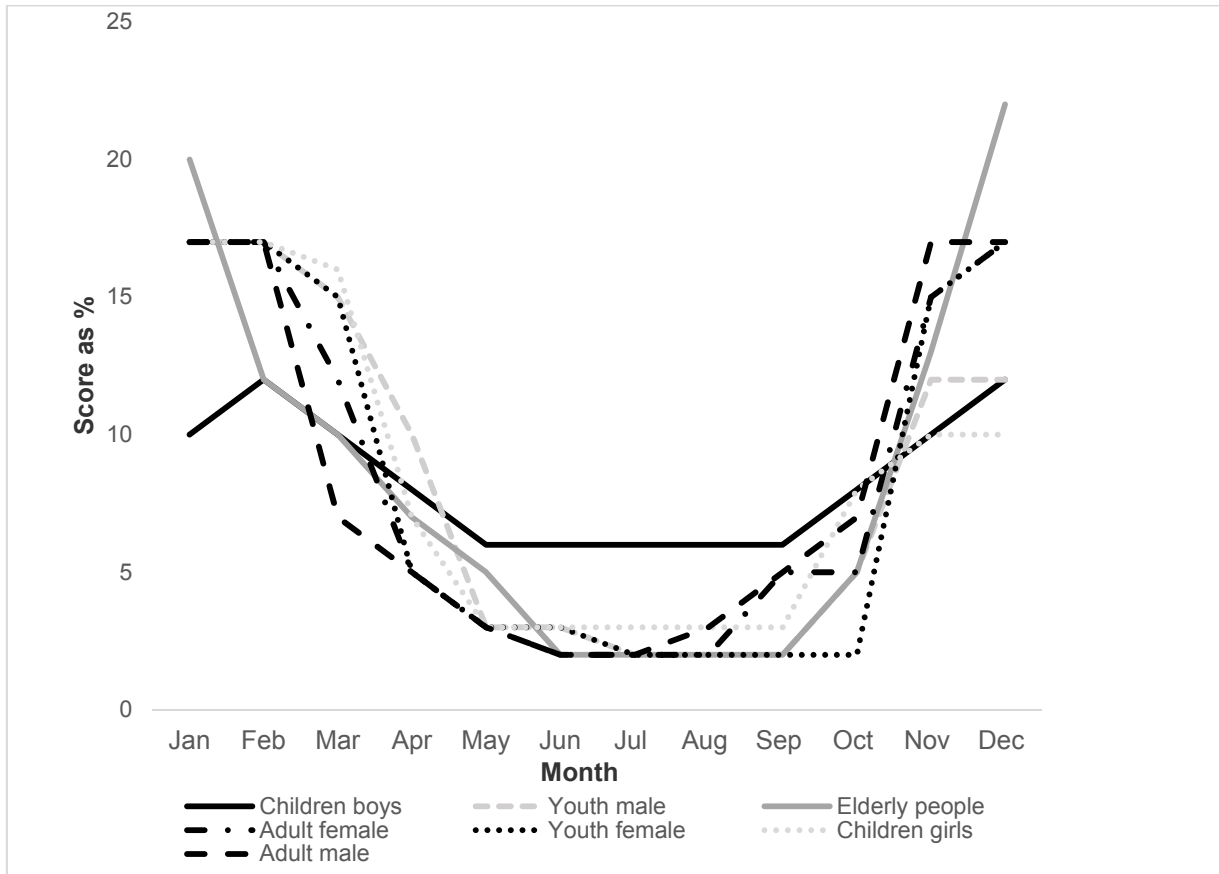


Figure 3.9 Availability of water for drinking in Mabayeni village throughout the year as perceived by all interest groups in a year

Table 3.8 Actual water sources for drinking in Mabayeni Village as perceived by representatives of interest groups

Interest group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a) Youth male	MU	MU	RA	BO	BO	MU	MU	MU	BO	RA	RA	MU
b) Youth female	RA	RA	RA	RA	BO	MU	BO	BO	BO	RA	RA	RA
c) Adult women	RA	RA	RA	MU	MU	MU	MU	MU	MU	RA	RA	RA
d) Adult men	RA	RA	RA	RI	MU	BO	BO	BO	BO	RA	RA	MU
e) Girl children	RA	MU	BO	RI	BO	MU	MU	BO	BO	RA	RA	RA
f) Boy children	MU	MU	BO	BO	BO	BO	BO	BO	RA	RA	RA	RA
g) The elderly	MU	MU	RA	RA	BO	BO	BO	MU	MU	RA	RA	RA

MU represents Municipal water

RA represents Rainwater

BO represents Borehole water

Table 3.9 Actual water sources for bathing as perceived by representatives of interest groups in Mabayeni Village of Collins Chabane Local Municipality in Limpopo Province

Interest group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a) Youth male	RA	RA	MU	MU	MU	MU	BO	BO	MU	RA	RA	MU
b) Youth female	RA	RA	RA	RA	BO	BO	BO	BO	BO	BO	RA	RA
c) Adult women	RA	RA	RA	RA	MU	MU	MU	MU	MU	RI	RI	RI
d) Adult men	RA	RA	RI	RI	MU	RI	RI	RI	MU	RA	RA	RA
e) Girl children	RA	RA	RA	RA	BO	BO	BO	BO	BO	RA	RA	RA
f) Boy children	RI	RI	BO	BO	MU	MU	MU	BO	BO	MU	RA	RA
g) The elderly	RA	RA	RA	BO	BO	BO	MU	MU	MU	RA	RA	RA

MU represents Municipal water; RA represents Rainwater; BO represents Borehole water; and RI represents River water

The rest of the groups relied mostly on a combination of municipal tap water with either borehole water or river water. For the rest of the months, available water sources were believed to be rainwater and river water although rainwater was more dominant. Only adult men disclosed that they relied absolutely on river water for bathing in the period between October and April, while female youth, adult women and girl children indicated total dependence on rainwater.

Water for washing dishes

The pattern of availability of water for washing dishes resembled that of the preceding illustrations. During the perceived dry season, Mabayeni residents relied on a combination of public municipal tap, borehole and river water for washing dishes (Table 3.10). Only the adult women and girl children stated that they washed dishes using public municipal tap water only. Between October and April, the source of water reported to be available for washing dishes was rainwater. During this period, female youth and adult women indicated that they relied exclusively on rainwater for washing dishes.

Water for washing clothes

Data on availability of water throughout the year and preferred sources for washing clothes in Mabayeni village revealed results similar to those of the other uses. Nevertheless, the sources that were available for washing clothes from May - September were municipal tap water, river and borehole water (Table 3.11) with municipal tap water being the dominant water source. Only adult women and girl children demonstrated dependence on municipal tap water for washing clothes. From October - April, participants revealed that rainwater was readily available for washing clothes. Female youth, adult women, girl children and the group comprised of the elderly people indicated that they relied only on rainwater for washing clothes between October and April.

Water for sanitation purposes

In Figure 3.10 interest groups perceived the driest months of the year to be between June and September. Water availability for sanitation uses also followed a trend similar to the rest of the water uses. However, for the elderly and boy children, the peak was reached in January.

Table 3.10 Actual water sources for washing dishes in Mabayeni village as perceived by different interest groups

Interest group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a) Youth male	RA	RA	BO	MU	MU	MU	MU	BO	MU	RA	RA	MU
b) Youth female	RA	RA	RA	RA	BO	BO	MU	BO	RI	BO	RA	RA
c) Adult women	RA	RA	RA	RA	MU	MU	MU	MU	MU	RA	RA	RA
d) Adult men	RA	RA	RA	RI	MU	MU	RI	RI	RA	RA	RA	RA
e) Girl children	RA	RA	RI	RI	MU	MU	MU	MU	MU	RA	RA	RA
f) Boy children	RI	RI	MU	MU	BO	BO	MU	RA	MU	MU	RA	RA
g) The elderly	RA	RA	MU	MU	BO	MU	BO	MU	BO	RA	BO	RA

MU represents Municipal water

RA represents Rainwater

BO represents Borehole water

RI represents River water

Table 3.11 Actual water sources for washing clothes in Mabayeni Village as perceived by different interest groups

Interest group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a) Youth male	RA	RA	BO	MU	MU	MU	MU	BO	MU	RA	RA	MU
b) Youth female	RA	RA	RA	RA	MU	MU	MU	BO	RI	BO	RA	RA
c) Adult women	RA	RA	RA	RA	MU	MU	MU	MU	MU	RA	RA	RA
d) Adult men	RA	RA	RI	RI	MU	RI	RI	RI	RA	MU	RA	RA
e) Girl children	RA	RA	RA	RA	MU	MU	MU	MU	MU	RA	RA	RA
f) Boy children	RI	BO	MU	MU	RA	RI	MU	MU	BO	RA	RA	RA
g) The elderly	RA	RA	RA	RA	RA	RI	RI	RI	BO	BO	RA	RA

MU represents Municipal water

RA represents Rainwater

BO represents Borehole water

RI represents River water

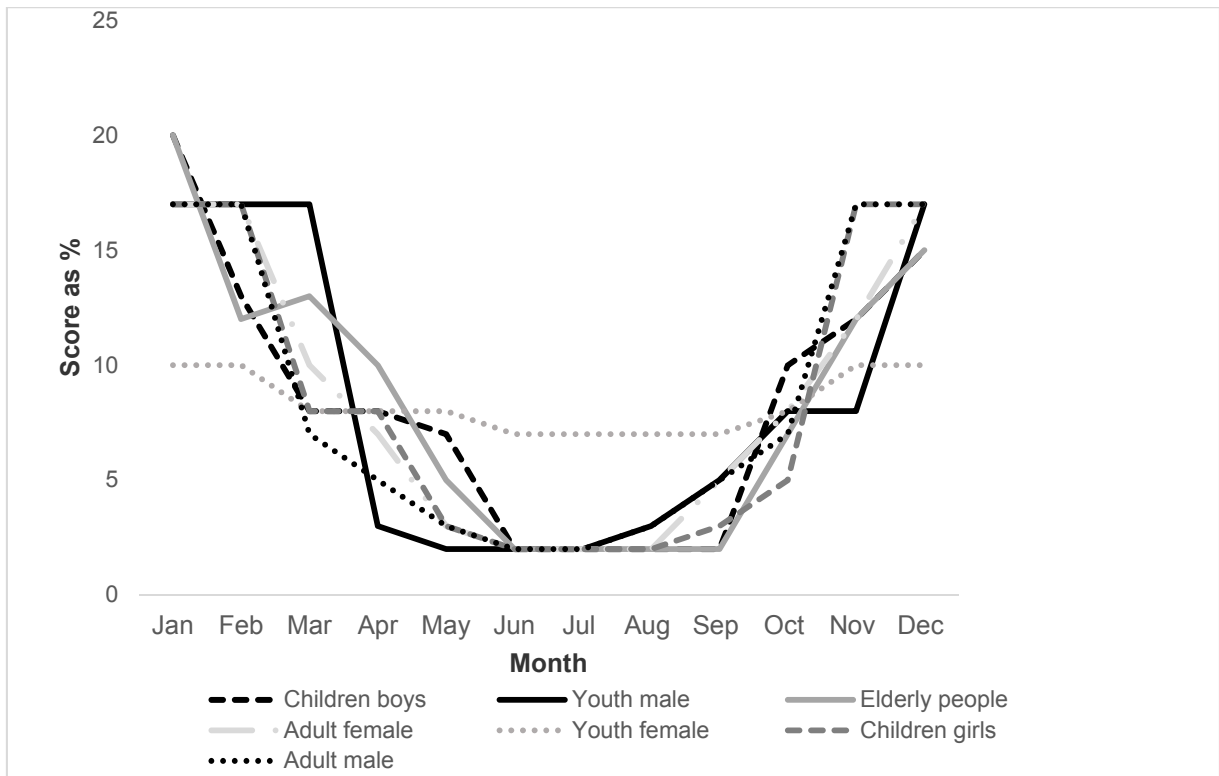


Figure 3. 10 Availability of water for sanitation uses in Mabayeni village throughout the year as perceived by different interest groups

There were also differences among interest groups on the exact months in which availability of water for sanitation started decreasing. While female youth and the elderly people perceived that availability of water for sanitation diminished during early February, the adult men and youth male believed that the decline was in March. Yet, the water source that was readily available during the perceived dry period was borehole although it was supplemented by public municipal tap water (Table 3.12). The group made up of the elderly people was the only one which reported dependence on public municipal tap water for sanitation purposes throughout the year. Female youth, adult women and adult men revealed that they relied on borehole water only. From October - April, rainwater was the readily available source of water, followed by municipal tap water, then borehole water and finally river water. Adult women and girl children relied only on rainwater. The rest of the groups relied on a combination of public municipal tap water, rainwater and borehole water for sanitation uses during this period.

3.4.6 Non-participant observation

The water-related activities that were observed included women fetching water with multiple containers, men on donkey-drawn carts delivering water to different households, long queues at water access points, men drinking traditional beer in the village among others. A list of water scarcity-related observations and their explanations is presented in Table 3.13. These provided a visual confirmation to the results obtained from other data collection techniques mentioned above especially on the water struggle. In addition, the short interviews that were held also confirmed the amount that was charged for transportation of water. Photographs that were taken as part of this technique are exhibited in Figure 3.11a-d.

Table 3.12 Actual water sources for sanitation purposes in Mabayeni village as perceived by different interest groups

Interest group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a) Youth male	MU	MU	MU	MU	BO	BO	MU	MU	BO	RA	RA	RA
b) Youth female	RA	RA	RA	BO	BO	BO	BO	BO	BO	BO	RA	RA
c) Adult women	RA	RA	RA	RA	BO	BO	BO	BO	BO	RA	RA	RA
d) Adult men	RA	RA	BO	BO	BO	BO	BO	BO	BO	BO	BO	BO
e) Girl children	RA	RA	RA	RA	RA	MU	MU	MU	MU	RA	RA	RA
f) Boy children	RI	RA	MU	MU	BO	BO	MU	MU	BO	BO	RA	RA
g) The elderly	MU	MU	MU	MU	MU	MU	MU	MU	MU	MU	MU	MU

MU represents Municipal water

RA represents Rainwater

BO represents Borehole water

Table 3.13 Non-participant observation results of a study on developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality

Observation	Meaning
a) Women and youth female were seen going to fetch water with multiple containers	Water scarcity was a real problem mainly affecting females who are responsible for cooking and other household chores. People spend a lot of time in queues losing productive time
b) One of the volunteers at the old age home brought water from her house to cook for the elderly people	
c) Long queues at a water tap when water had been reopened	
d) A donkey-drawn wagon distributing water to different houses	Community members pay for transport in order to fetch in large quantities
e) Transport costs R1.50 per container to ferry water from municipal taps;	Amount is within the range given in focus group discussions
f) Participation of residents of Magangeni was very low, they only joined for a short while after some convincing then disappeared;	Magangeni area is disproportionately affected by water scarcity, much of their time was spent collecting water
g) Only women were seen fetching water throughout the duration of the study	Confirms arguments from focus group discussions that men do not fetch water. There is a gender dimension to water scarcity
h) Participation of men in the study was low when there was traditional beer	It is important to stay informed about any developments in the community which may hinder research activities. Knowing them beforehand helps to adjust and plan accordingly.
i) Participation in the study was generally low on the days when water was running on municipal taps	



Figure 3.11b: Woman going to fetch water with multiple containers



Figure 3.11 a: Woman collecting her water from a donkey-drawn cart (hired transport)



Figure 3.11c: A truck filled with empty containers going to fetch water in a neighbouring village



Figure 3.11d: Women fetching water with multiple containers

3.5 Discussion

The fact that all the interest groups preferred municipal tap water and rainwater for all the six water uses is clear evidence that Mabayeni residents valued water of good quality above anything else for their domestic uses. It could also be because municipal water was regarded as the most reliable water source as it came out from the taps all year through. This is despite the fact that this water source was only available once or twice a week. Apart from being clean, rainfall could have been chosen because of its convenience. When harvested, rainwater was available in one's household making it an affordable and easily accessible water source. Good quality water is emphasized as a right and a need to sustain a healthy life (Constitution of the Republic of South Africa, 1994; WHO, 2004). In addition, having a convenient water source saves time for more productive activities (Keefer & Bousalis, 2015). It is therefore not surprising that community members preferred the above mentioned water sources. The rest of the water sources presented numerous challenges that made community members' lives difficult.

Although regarded as most preferred, municipal tap water also had its challenges. Municipal taps in Mabayeni village were unevenly distributed. Having functional taps only on the lower part of the village created an additional burden to some community members especially those from Magangeni who had to walk long distances to fetch water. Thus, scholars such as Fenwick (2010) and Udimal *et al.* (2017) advocated for inclusion of temporal and spatial scales in analyses of water resources. In addition, uneven distribution of water sources in an area has been viewed as a common cause of water scarcity in South Africa (Schlosser, 2014) and other parts of the world such as Spain and Portugal (Costa *et al.*, 2016). This reveals that even in an area where water supplies are available, water scarcity can be experienced if water is unevenly distributed.

Conflicts over water in Mabayeni reportedly took place both verbally and physically. Similar results were found in Javed *et al.*'s (2016) study whereby conflicts were reported amongst farmers over water resources. However, conflicts reported in their study were not physical. In Kenya, violence over water resources was observed in 2012 where more than 100 people died in riots involving farmers and cattle herders (Gleick & Heberger, 2014). In 2001, at least 130 people were killed in a string of clashes between the same two communities over access to a river (Almer *et al.*, 2017). This is a clear indication that conflicts over water resources can be expressed verbally or become extremely violent leading to loss of life. Therefore, Almer *et al.* (2017) conclude that competition for access to water is often considered to be an important factor behind social conflict in less advanced communities.

Exposure of female community members to dire situations in search of water showed the extent of their desperation. While walking long distances and fetching water at night put their lives at risk, buying water exhausted their pockets. Those who did not have money to buy water ended up in debts, some of which were never paid resulting in conflicts. Women were exposed to what Keefer & Bousalis (2015) call structural violence. According to the authors, the term describes social arrangements that put people and communities in imminent danger. In addition, women in many developing countries spend hours each day obtaining water when they could be in school or workforce contributing to their family's income and their country's gross domestic product (Pereira *et al.*, 2009; Keefer & Bousalis, 2015;). This was exactly the case with Mabayeni women, youth and girls who spent a lot of their time fetching water for multiple domestic uses such as cooking, drinking, bathing among others.

The above water struggles go against the community's expectation of the government's role, and the government's declaration of water as a constitutional right central to the livelihood of the rural poor (DWAF, 2005). According to the Bill of Rights, everyone has a right to have access to sufficient water. (Bill of Rights, Constitution of the Republic of South Africa, 1994). The South African standards relating to basic level of water is defined as 25 litres per person per day which is a level sufficient for a healthy living (DWAF, 2002). This translates to 6 000 litres of water per household per month. The Strategic Framework for Water Services (2003) stipulates that the minimum flow rate should not be less than 10 litres per minute and the water source should be located within 200 metres of a household. In addition, interruptions of potable water supply should be less than 48 hours at any one time which amounts to a cumulative interruption of 15 days in a year (The Strategic Framework for Water Services, 2003). Although municipal water is regarded as safe for drinking, conditions regarding frequency, flow rate and interruptions have not been met in Mabayeni village. This left community members dissatisfied with the quality of service delivery they had been receiving.

According to DWAF (2004), the perception by community members that water is a free commodity and that access to water is an inalienable right is misleading. The right to water has an extended user responsibility of paying for water beyond the free basic amount, as well as taking care of the water resources. Seemingly, community members in Mabayeni did not understand this extension to their right to water. They vandalized and neglected water infrastructure. Tap heads borehole machines and other infrastructure were reportedly stolen in the village and nothing was done about it. Although the local municipality has been blamed for failing to maintain water

infrastructure, Mabayeni residents did not help the situation. Not taking responsibility, vandalizing and stealing existing infrastructure, although portrayed as a sign of frustration worsened the situation.

An experimental study carried out by Prediger *et al.* (2014) on pastoralists in Namibia provides some insights to this kind of destructive and antisocial activities. The authors argued that scarcity may encourage people to engage in antisocial activities that are detrimental to overall welfare such as theft or conflict. Results of their study revealed that people facing a higher degree of real-life scarcity tend to be more concerned about outcompeting others and less reluctant to engage in spiteful acts. People are driven by the need to sustain their livelihood and are likely to perceive their interaction partner as a competitor against whom they have to prevail (Prediger *et al.*, 2014). This is likely true for Mabayeni community members. Out of the frustration of water scarcity, members began to steal the water infrastructure for their individual benefit which was in turn detrimental to their access to water in the long run.

The district municipality has also been blamed by community members for not doing its job regarding maintenance of water infrastructure. Most of the water infrastructure in the village was said to be too old and had not been serviced since the democratic government was elected in 1994. This is a challenge facing many developing countries. Chitonge (2014) argues that low political priority given to water services, as well as failure to restructure the colonial urban planning and management patterns have contributed to the challenges that many poor rural and urban communities are facing today. The transition from having the financing of basic water infrastructural services as the responsibility of the state, to it being a responsibility of the end users has not been successful. This has led to infrastructure funding gaps due to inadequate user fees to cover operation and maintenance of water infrastructure.

In South Africa, Water Service Authorities experience difficulties in monitoring and metering the use of water over the prescribed free basic water. In many cases, it's impossible to quantify how much water is 'billable' water (DWAF, 2004). This often leads to no billing done at all and the provision of free basic water in reality becoming unlimited free provision of water services to the rural water supply and sanitation schemes under the municipality's jurisdiction. In addition, the costs of installing, operating and maintaining effective metering systems at rural water supply and sanitation schemes are widely regarded by the municipality as prohibitive as the returns from marginal collections of funds at these schemes would not cover the running costs of the systems.

In addition, transport costs for the collection of relatively small amounts of money in dispersed and widely ranging water supply and sanitation schemes are considered to exceed the expected returns (DWAF, 2004). This therefore shows high expectations from rural communities on free water on one hand, and the municipal authorities' frustrations over inability of users to pay for maintenance costs on another. There is therefore need for communication between the water service providers and consumers on the kind of services that municipalities are realistically able to provide, as well as the responsibilities of the water consumers as stipulated in the Bill of Rights.

The seasonality of water scarcity in Mabayeni village strengthens Udimal *et al.*'s (2017) argument to consider temporal water availability when examining water scarcity in an area. This is very common in many localities in Africa and the world. Although community members had access to adequate water during the rainy season, it was the dry period that was difficult for them to go through. In addition, the dry period was believed to have extended from four to about six months, lengthening the suffering time for rural community members. The effects of climate change on the amount and timing of rainfall has extensively been discussed (Mwenge-Kahinda *et al.*, 2010; Baiyegunhi *et al.*, 2015; Sorensen, 2017). Mabayeni village has also not been spared by the effects of climate change.

Jiang (2009) emphasize the need to consider the quality or usability of water when accounting for water availability in an area. This is because sometimes the water sources that are regarded as available are unusable. This was the case in Mabayeni village. Although borehole and municipal water sources were said to be available throughout the year, they had their own challenges. The challenges of municipal tap water has already been discussed. The only community borehole that was functional had saline water (which was regarded as useless) while water from private boreholes was costly. In other words, the available water was not usable therefore not needed. The water quality challenges of these two water sources made it difficult for community members to obtain sufficient water for their everyday basic needs. In addition, another dimension that could be added in determining water footprints for communities is preference. This is because a water source that meets the requirements of the community is likely to be preferred to one which doesn't. By extension, the level of scarcity would therefore be understood from the difference between what is preferred and what is available. In this case, it's the reasons that are provided for such a difference that would be addressed.

Paying attention to verbal and non-verbal expressions during conversations expanded the understanding of the extent of water scarcity in the village through considering the emotions evoked by the subject. This is in line with Lausberg & Sloetjies (2009) who argue that knowledge about gestural behaviour is theoretically relevant for understanding cognitive, emotional and interactive processes. Participants gave each other a chance to speak not out of hesitation or discomfort, but to give the most relevant or knowledgeable people (about a particular subject) the opportunity to speak first. This shows that participants were confident, knowledgeable and willing to participate. Although laughter is regarded as a social activity (Petitjeon & Congemi, 2016) and also used to achieve several social activities (Jefferson, 2010; Cakmak & Dutoit, 2018), shared laughter in this study demonstrated alignment, affiliation or familiarity of a group with the story being told. Berger & Rae (2012) emphasize the importance of analysing connections between separate channels of communication (verbal and non-verbal) in order to check for potential conflict, and identification of deception. In this study, evidence of agreement of participants during conversations through nodding, laughter and other facial expressions confirmed the truthfulness of the stories.

Analysing verbal and non-verbal behaviour helped capture a variety of emotions evoked by water scarcity in Mabayeni village. Wagner *et al.* (2014) expound that accounting for verbal or textual information only does not suffice to provide a full picture of human communication as they lack emotions. When communicating using their full multi-modal expressive potential, speakers can increase communicative efficiency by simultaneously transporting complementary information and foster robustness, by providing redundant information in various modalities (Wagner *et al.*, 2014). The facial expressions displayed, and some verbal statements uttered revealed that water scarcity stories evoked emotions of frustration, sadness, anger and desperation among participants. This brings a psychological dimension to the extent of water scarcity in the village in addition to socio-economic and political issues. Thus, conversation analysis helped in ascertaining the truthfulness of data, revealed emotions associated with water scarcity, confirmed and complemented results obtained from other sources.

The fact that the female groups expressed themselves more than males could have been influenced by the fact that females are more actively involved in collection of water than men. This was confirmed during non-participant observation wherein only youth female and women were seen fetching water. During key informant interviews and photo voice discussions, men confessed that fetching water was a responsibility for women. This echo Pereira *et al.* (2009) and Keefer &

Bousalis' (2015) sentiments that water scarcity is gendered. Its effects are therefore disproportionately felt by the above mentioned groups

3.6 Conclusion

Community members in Mabayeni village provided details of their daily lives that gave a fuller picture of the extent of water scarcity in their village. Three indicators of the extent of water scarcity were used. These were, what was preferred, what was regarded as available, as well as what was actually used. Although a number of sources were regarded as available in the village, they were neither actually used nor preferred. Even those that were preferred such as municipal tap water had a number of challenges. Nonetheless, there is sufficient evidence of desperation in most of the activities that were undertaken in order to obtain water. These involved buying water from private boreholes, using saline water, queuing for long periods and fetching water at night, among others. It was also apparent that water scarcity in the community was seasonal. While adequate water was available during the rainy season, the dry season was a challenge. In addition, community members preferred water sources that were reliable, provided clean water, were affordable, as well as convenient. Having this kind of a situation necessitated an inquiry into the coping strategies that were used in the community. Building on the ABCD approach, this was important in order to understand existing coping strategies so as to build on them. Thus, coping strategies that were used in Mabayeni village are presented in the following chapter.

3.7 References

- Alcamo, J., Flörke, M., & Märker, M. 2007. Future long-term changes in global water resources driven by socio-economic and climatic changes. *Hydrological Sciences Journal*, **52(2)**: 247-275.
- Almer, C., Laurent-Lucchetti, J. & Oechslin, M. 2017. Water scarcity and rioting: Disaggregated evidence from Sub-Saharan Africa. *Journal of Environmental Economics and Management* **86**: 193-209.
- Al-Saadi, H. 2014. Demystifying Ontology and Epistemology in research methods. School of Education, University of Sheffield.
- Baiyegunhi, L. J. S. 2015. Determinants of rainwater harvesting technology (RWHT) adoption for home gardening in Msinga, KwaZulu-Natal, South Africa. *Water South Africa*, **41(1)**: 33-40.
- Berger, I. & Rae, J. 2012. Some uses of gestural responsive actions. *Journal of Pragmatics* **44(13)**:1821-1835
- Blignaut, J. N., Marais, C., & Turpie, J. K. 2007. Determining a charge for the clearing of invasive alien plant species (IAPs) to augment water supply in South Africa. *Water South Africa*, **33(1)**: 27-34.
- Blignaut, J., & Van Heerden, J. 2009. The impact of water scarcity on economic development initiatives. *Water South Africa*, **35(4)**: 415-420.
- Bryman, A., & Becker, S. 2012. Combining quantitative and qualitative research.
- Bryman, A., 2004. Triangulation and measurement. Available at Department of Social Sciences, Loughborough University, Loughborough, Leicestershire: [www. referenceworld.com/sage/socialscience/triangulation. pdf](http://www.referenceworld.com/sage/socialscience/triangulation.pdf). Retrieved on 19 June 2018
- Cakmak, H. & Dutoit, T. 2018. HMM-based generation of laughter facial expression. *Speech Communication* **98**:28-41
- Chitonge, H. 2014. Cities beyond networks: The status of water services for the urban poor in African cities. *African Studies*, **73(1)**: 58-83.
- Constitution, S. A. 1996. Bill of Rights. Available on <http://www.greenvalleykashmir.com/CMS/Files2/Fundamental%20Rights.pdf> Retrieved on 10 November 2017.
- Costa, J. M., Vaz, M., Escalona, J., Egipto, R., Lopes, C., Medrano, H., & Chaves, M. M. 2016. Modern viticulture in southern Europe: vulnerabilities and strategies for adaptation to water scarcity. *Agricultural Water Management*, **164**: 5-18.

- Cullis, J. D. S., Gorgens, A. H. M., & Marais, C. 2007. A strategic study of the impact of invasive alien plants in the high rainfall catchments and riparian zones of South Africa on total surface water yield. *Water South Africa*, **33(1)**: 35-42.
- Damkjaer, S., & Taylor, R. 2017. The measurement of water scarcity: Defining a meaningful indicator. *Ambio*, **46(5)**: 513-531.
- Department of Water Affairs and Forestry. 1998. National Water Act for South Africa. Pretoria: DWAF.
- Department of Water Affairs and Forestry. 2002. National Water Resource Strategy Pretoria: DWAF.
- Dondofema, F. 2018. University of Venda Geographical and Information Systems (April 2018, Source: SG 2012, Projection: WGS84).
- DWAF (Department of Water Affairs and Forestry) .2004. National Water Resource Strategy: First edition, September. Pretoria: DWAF.
- DWAF (Department of Water Affairs and Forestry). 2005. Establishment of a Pricing Strategy for Water Use Charges in Terms of Section 56 (1) of the National Water Act, 1998. Pretoria: DWAF.
- El Kharraz, J., El-Sadek, A., Ghaffour, N., & Mino, E. 2012. Water scarcity and drought in WANA countries. *Procedia Engineering*, **33**: 14-29.
- Ercin, A. E., & Hoekstra, A. Y. 2012. *The United Nations World Water Development Report—N° 4—Carbon and Water Footprints (Concepts, Methodologies and Policy Responses)*. UNESCO. Paris, France
- Fenwick, C. 2010. *Identifying the water poor: An indicator approach to assessing water poverty in rural Mexico* (Doctoral dissertation, UCL (University College London)).
- Freudenberger, K. S. 1999. *Rapid rural appraisal (RRA) and participatory rural appraisal (PRA): a manual for CRS field workers and partners*. Baltimore: Catholic Relief Services.
- Gleick, P. H., & Heberger, M. 2014. Water and conflict: Events, Trends, and Analysis (2011–2012). *Water Brief* **3**: 159-171.
- Heritage, J., 2004. Conversation analysis and institutional talk: Handbook of language and social interaction. Lawrence Erlbaum Associates Inc. USA.
- Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E., & Richter, B. D. 2012. Global monthly water scarcity: blue water footprints versus blue water availability. *PLoS One*, **7 (2)**: e32688.
- Hoekstra, A. Y. 2014. Water scarcity challenges to business. *Nature Climate Change*, **4(5)**: 318.
- Javed, M. A., Muhammad, S., & Akhtar, S. 2016. Causes of disputes among water users and role

- played by Wuas in resolving the disputes: A case study of Sargodha District, Punjab, Pakistan. *Journal of Agricultural Research*, **54(3)**:545-554.
- Jefferson, G., 2010. Sometimes a frog in your throat is just a frog in your throat: Gutturals as (sometimes) laughter-implicative. *Journal of Pragmatics*, **42(6)**: 1476-1484.
- Keefer, N., & Bousalis, R. 2015. How Do You Get Your Water? Structural Violence Pedagogy and Women's Access to Water. *The Social Studies*, **106(6)**: 256-263.
- Kimchi, J., Polivka, B., & Stevenson, J.S. 1991. Triangulation: Operational definitions. *Nursing Research*, **40(6)**: 364-366.
- Lausberg, H. & Sloetjies, H. 2009. Coding gestural behaviour with the NEUROGES-ELAN system. *Behaviour Research Methods* 41 (3): 841-849
- Leech, N. L., & Onwuegbuzie, A. J. 2007. An array of qualitative data analysis tools: A call for data analysis triangulation. *School Psychology Quarterly*, **22(4)**: 557-584.
- Limpopo Provincial Gazette. 2017. General notice number 85 of 2017, issued on 29 June 2017, Available on https://www.greengazette.co.za/notices/local-government-municipal-systems-act-117-2000-notice-is-hereby-given-by-lim345-local-municipality-to-publish-the-proposed-name-for-the-municipality-subsequent-to-the-council_20170629-LIM-02828-00085.pdf Retrieved on 18 June 2018
- Markee, N. 2000. *Conversation analysis*. Mahwah, NJ: Lawrence Erlbaum.
- Maxwell, J. A. (1996). *Qualitative research design: An interactive approach*. Second edition. Available on http://sutlib2.sut.ac.th/sut_contents/H94621.pdf Retrieved from 12 May 2018.
- Mwenge Kahinda, J., Taigbenu, A. E., and Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.
- Kahinda, J.M. & Taigbenu, A.E., 2011. Rainwater harvesting in South Africa: Challenges and opportunities. *Physics and Chemistry of the Earth, Parts A/B/C*, 36(14-15): 968-976.
- Pereira, L. S., Cordery, I., & Iacovides, I. 2009. *Coping with water scarcity: Addressing the challenges*. Springer Science & Business Media.
- Petitjeon, C. & Congemi, F. 2016. Laughter in correction sequences in speech therapy sessions. *Journal of Pragmatics* **99**: 17-38
- Prediger, S., Vollan, B., & Herrmann, B. 2014. Resource scarcity and antisocial behaviour. *Journal of Public Economics*, **119**: 1-9.
- Qadir, M., Boers, T. M., Schubert, S., Ghafoor, A., & Murtaza, G. 2003. Agricultural water

- management in water-starved countries: challenges and opportunities. *Agricultural Water Management*, **62(3)**: 165-185.
- Rijsberman, F. R. 2006. Water scarcity: fact or fiction? *Agricultural Water Management*, **80(1-3)**: 5-22.
- Roger, D., & Bull, P. 1989. Introduction. In D. Roger & P. Bull (Eds.), *Conversation: An interdisciplinary perspective* (pp. 21–47). Clevedon, UK: Multilingual Matters.
- Schlosser, C. 2014. The future of global water stress: An integrated assessment. *Earth's Future* **2(8)**: 341-361.
- Scotland, J. 2012. Exploring the philosophical underpinnings of research: Relating ontology and epistemology to the methodology and methods of the scientific, interpretive, and critical research paradigms. *English Language Teaching*, **5(9)**: 9-16.
- Sorensen, P. 2017. The chronic water shortage in Cape Town and survival strategies. *International Journal of Environmental Studies*, **74(4)**: 515-527.
- Statistics South Africa: South African Community Survey 2016. Indicators derived from the full population Community Survey. Available at <https://wazimap.co.za/profiles/district-DC34-vhembe/> Retrieved on 2 July 2018
- The Constitution of the Republic of South Africa. 1993. **343(15466)**. Creda Press Printer, Pretoria.
- The Local Government Handbook of South Africa. 2017. A guide to local municipalities in South Africa. Available on <https://www.localgovernment.co.za/locals/view/241/Collins-Chabane-Local-Municipality> Retrieved on 24 February 2017.
- The Strategic Framework for Water Services (2003) Water is life, sanitation is dignity. Available at <http://www.dwaf.gov.za/Documents/Policies/Strategic%20Framework%20approved.pdf> Retrieved on 2 July 2018
- Thurmond, V.A. 2001. The point of triangulation. *Journal of nursing scholarship*, **33(3)**: 253-258.
- Udimal, B.T., Emmanuel, Z.J., Ayamba, E.C., & Owusu, S.M. 2017. China's water situation; the supply of water and the pattern of its usage, *International Journal of Sustainable Built Environment* (**6**): 491-500.
- United Nations Educational Scientific and Cultural Organisation (UNESCO). 2018. United Nations World Water Development Report 2018: Nature-based solutions for water. Available at https://worldwaterday.org/app/uploads/2018/02/fact_sheet_WWD2017_EN_2.pdf, Retrieved on 2 July 2018
- Vhembe District Municipality .2017. Final Intergrated Development Plan 2017/2018-2021/2022.

Available at
<http://mfmamirror.s3.amazonaws.com/Documents/01.%20Integrated%20Development%20Plans/201718/02.%20Final/03.%20District%20municipalities/DC34%20Vhembe/DC34%20Vhembe%20Final%20IDP%202017-18.pdf> Retrieved on 18/06/2018

- Wagner, P., Malisz, Z. & Kopp, S. 2014. Gesture and speech in interaction: An overview. *Speech Communication* **57**: 209-232
- Wallerstein, N., & Bernstein, E. 1988. Empowerment education: Freire's ideas adapted to health education. *Health Education and Behaviour*, **15(4)**: 379-394.
- Webb, E. J., Campbell, D. T., Schwartz, R. D., & Sechrest, L. 1966. Unobtrusive Measures: Nonreactive Measures in the Social Sciences. Chicago: Rand McNally.
- WHO (World Health Organization). 2004. Guidelines for drinking-water quality. Section 11.6.1, Total Coliform Bacteria. Geneva: World Health Organization.
- Yeasmin, S. & Rahman, K.F. 2012. Triangulation research method as the tool of social science research. *BUP journal*, **1(1)**: 154-163.

CHAPTER 4 RURAL HOUSEHOLD COPING STRATEGIES FOR INADEQUATE DOMESTIC WATER

4.1 Abstract

Inadequate availability of water is a common challenge in many parts of the world which makes it difficult for development to thrive. In South Africa, some communities have challenges securing adequate water for basic domestic uses. A study was conducted to identify the strategies that community members in Mabayeni village used to cope with inadequate availability of water for domestic use. A qualitative exploratory design was used. Focus group discussions guided by a semi-structured interview guide, photo voice, transect walks, key informant interviews and storytelling were used to collect data on the major coping strategies to water scarcity in the village. In addition, seasonal diagrams were used to collect data on the different coping strategies that were available across months. Participants were categorised into different interest groups according to age and gender. These were; children (boys and girls), youth (male and female), adult (men and women), and the elderly. Participatory data analysis methods such as matrix ranking, seasonal diagram matrices, as well as thematic content analysis through the use of ATLAS.ti version 7.5.7 software were used to analyse data. The coping strategies that were used in Mabayeni village were autonomous and season-specific. During the rainy season, community members relied mainly on RWH while strategies such as buying water, walking long distances to fetch water, using dirty water from small dams and fetching water from the river were used during the dry season. Coping strategies were also risky, expensive and unhygienic. The most preferred coping strategies, which were also regarded as effective were harvesting rainwater, buying *Jojo* tanks to store water for later use, as well as hiring donkey-drawn carts to fetch water from municipal taps. It was therefore imperative to understand what communities were already doing in order to identify opportunities that could be exploited. The Asset-Based Community Development approach emphasizes building on existing community assets and strengths or activities when facilitating community interventions. Therefore, initiatives meant to develop communities should focus on expanding on already existing assets.

Keywords

Coping strategies; Domestic use; Rainwater harvesting; Rural households, Water shortages, Water scarcity,

4.2 Introduction

Identifying the strategies that Mabayeni community members used to cope with inadequate availability of water was important in building a deeper understanding of the resources and intervention strategies that were already in place. This exercise was crucial given that more devastating effects of climate change are expected in the near future (Ogundeji & Jordaan, 2017). Understanding the state of affairs with regards to coping mechanisms was part of the first steps towards building community resilience to water scarcity induced by climate change and other causes. The impact of water scarcity has been felt in different communities across the globe (Hanasaki *et al.*, 2012). It has also been felt in many sectors such as agriculture (Ran *et al.*, 2016), mining (Northey *et al.*, 2017), as well as just for domestic use (Fisher-Jeffes *et al.*, 2017). More than one billion people in the world lack access to safe clean water for domestic use, which often results in catastrophic health impacts (Takacs, 2016). Inadequate availability of clean water thus originates from natural and man-made factors, and sometimes a combination of the two.

Natural causes include climatic conditions such as low or irregular rainfall, high temperatures and evapotranspiration, and hydrological characteristics, viz. topography, vegetation cover, soils and geology (Pereira *et al.*, 2002; Distefano & Kelly, 2017). Man-made causes include over-exploitation and poor governance of water resources, among others. Although water scarcity affects all people irrespective of status, Basu *et al.* (2015) argue that the poor and marginalized often suffer more due to lack of proper infrastructure, and governance to manage, store and supply water. The impacts are said to be more pronounced in rural communities because they depend on rain-fed agriculture (Rijsberman, 2006). Given that aridity in many African communities has increased (Alcamo *et al.*, 2007), successful subsistence agriculture is now impossible to achieve. In some South African villages, households find it difficult to access adequate water even for basic domestic use.

Wilbanks & Kates (1999), and van Aalst *et al.* (2008) highlight the significance of grassroots community understanding and response to water scarcity. Many studies (Mehta, 2007; Alessa *et al.*, 2008; Haldar *et al.*, 2012; Adeniji-Oloukoi *et al.*, 2013; Murtinho *et al.*, 2013) have shown the importance of perceptions. They acknowledged that people's decisions are based on perceptions rather than measured variables. However, Alessa *et al.* (2008) contend that most predictive models dealing with use of water resources never take into account social and sociological imperatives. Yet such perceptions influence both short and long-term decision making on planning

and management of water resources, and, are key components of adaptation (Basu *et al.*, 2015). There is therefore need to consider community perceptions and their interactions with a variety of water resources in order to understand their selection of coping strategies. This information would be vital in informing intervention strategies.

The issues raised above informed the current study in which the strategies that rural households in Mabayeni village of Collins Chabani Local Municipality relied on to cope with inadequate water for domestic use were examined. Participatory research techniques were used to identify and rank what local residents preferred and regarded as effective strategies to cope with water scarcity during the course of each year.

4.3 Methodology

4.3.1 Research design

As already indicated, the research philosophies, designs and approaches adopted in Chapter 3 were used in this study. They were appropriate because the intention of the study was to build a profound understanding of Mabayeni residents' water concerns through exploring and examining the strategies they used to cope with water scarcity.

4.3.2 Population and sampling procedures

The population of the study was all Mabayeni community members who were willing and available to participate in the planned research engagements. In other words, invitation to participate was open to everyone. An invitation was sent through the headman as well as leaders of community-based structures such as the South African National Civic Organisation, Community Policing Forum, Community Works Programme, Community Development Forum, Ward committee, Home-based Carers, Mabayeni Society for the Aged and local traditional leadership Cabinet, Malamulele Adopt a River Forum and the Water Committee. The last two community-based organisations were already dealing with the village's water affairs. In addition, reminder calls were made three days before each engagement. Information was disseminated to community members using local community gatherings, word of mouth, phone calls as well as WhatsApp messages.

A multi-stage sampling technique was used in this study. As indicated in the previous chapter, participants were grouped according to gender and age so as to triangulate responses. This was important so as to ascertain the accuracy and completeness of responses. Community members

were clustered into children, youth and adult groups. Two groups of key informants were formed out of the representatives of the eight leadership structures explained above. One portion of the village was said to be most affected by water scarcity because it did not have access to piped water. Residents of that sub-area of the village named Magangeni, had to walk longer distances irrespective of whether municipal supplies were available elsewhere. This situation justified engaging them separately in order to record their unique experiences. The groups engaged were separated by age and gender such that there were two groups per age group namely; children (boys and girls), youth (male and female) and adult (men and women). With the elderly, only the women were available. The Magangeni was a mixed group consisting of adult men and women. In total, eight groups were engaged. Separating groups considering age and gender was also done in order to check if there were any gender or age-based differences in responses. More detailed information on sampling procedures is provided in Chapter 3.

4.3.3 Data collection

Both primary and secondary data were collected. Interviews were conducted with children, youth, adults and local leaders in Mabayeni village. Secondary data was collected from various sources stored in the University of Venda Library. Sources included books, journal articles, newspapers, conference proceedings, postgraduate theses and credible scientific materials from the internet. Data triangulation (Denzin, 1970) was carried out in this study. This entailed gathering data through multiple sampling strategies as well as consulting a variety of sources of data. This was done in order to gain confidence in the reliability of the data. In addition, data was collected through a variety of methods and techniques (methodological triangulation) for the same reasons. Triangulation in this instance added a sense of richness and complexity to the study and enhanced the credibility of results. Although different methods and techniques used in the study tapped different types of data, their use resulted in what Denzin (1970) regards as convergent validity which is also important for validating results.

Various participatory rural appraisal (PRA) techniques were used to collect primary data. They included focus group discussions, photo voice, key informant interviews, storytelling, priority ranking and a combination of participatory mapping and transect walks were used to collect primary data. Data collection tools such as flip charts, markers, camera, bean seeds, tape recorders, pictures, notebooks and pens were also used. Collected data was qualitative in nature. With regard to participatory mapping and transect walks, participants were requested to draw a map of their village showing all water-related features. These included rivers, boreholes, dams,

municipal tap, water tanks, among others. Like all the other data collection techniques, participatory mapping was done in different interest groups divided according to gender and age as already explained. After that, participants were requested to choose one map that best represented the village. Before commencing with the transect walks, community members agreed on the transect route to be followed in order to make sure that the whole village was covered. On the selected map (shown in Figure 3.4), a marker was used to highlight the route that guided the transect walks. During transect walks, photographs were taken to illustrate the strategies that community members used to cope with water scarcity in the village. Transect walks were important because they offered an opportunity to observe landscape features relating to water issues and understand the community topography. According to Freudenburger (2011), transect walks are a good way of verifying and expanding on information obtained from mapping exercises. This exploratory inquiry through direct observation was imperative for triangulation purposes. During the transect walks, photographs of coping strategies were also taken as confirmation of what the participants were saying.

Data that were collected were qualitative in nature. Participants were given a prepared flipchart with a list of coping strategies that they used on the vertical axis, and columns of preference, effectiveness, and calendar months on the horizontal axis. Firstly, participants were requested to distribute 60 bean seeds amongst the coping strategies showing the ones regarded as most preferred, as well as most effective. Then, for each coping strategy, each group of participants was requested to distribute 60 bean seeds across the year. The instruction was that each box had to have at least one seed. In addition, the higher the number of seeds allocated to a coping strategy, the more it was preferred and also effective. Similarly, the higher the number of seeds allocated to a coping strategy in a particular month, the more the coping strategy was relied on in that particular month.

Freudenburger (1999) expounds that seasonal diagramming helps to avoid seasonality bias which is related to the time of the year that the study is conducted. Seasonal calendars, were therefore used to understand how reality changed with regard to coping strategies to water scarcity during different seasons as conditions changed in Mabayeni village. Figure 4.1 shows participants carrying out a combination of seasonal diagramming and matrix scoring. Seasonal diagramming and matrix scoring were carried out to produce seasonal calendars reflecting the extent to which the respective strategies were used to cope with water scarcity across months.



Figure 4.1 An illustration of a combination of seasonal diagramming and matrix scoring

4.3.4 Data analysis

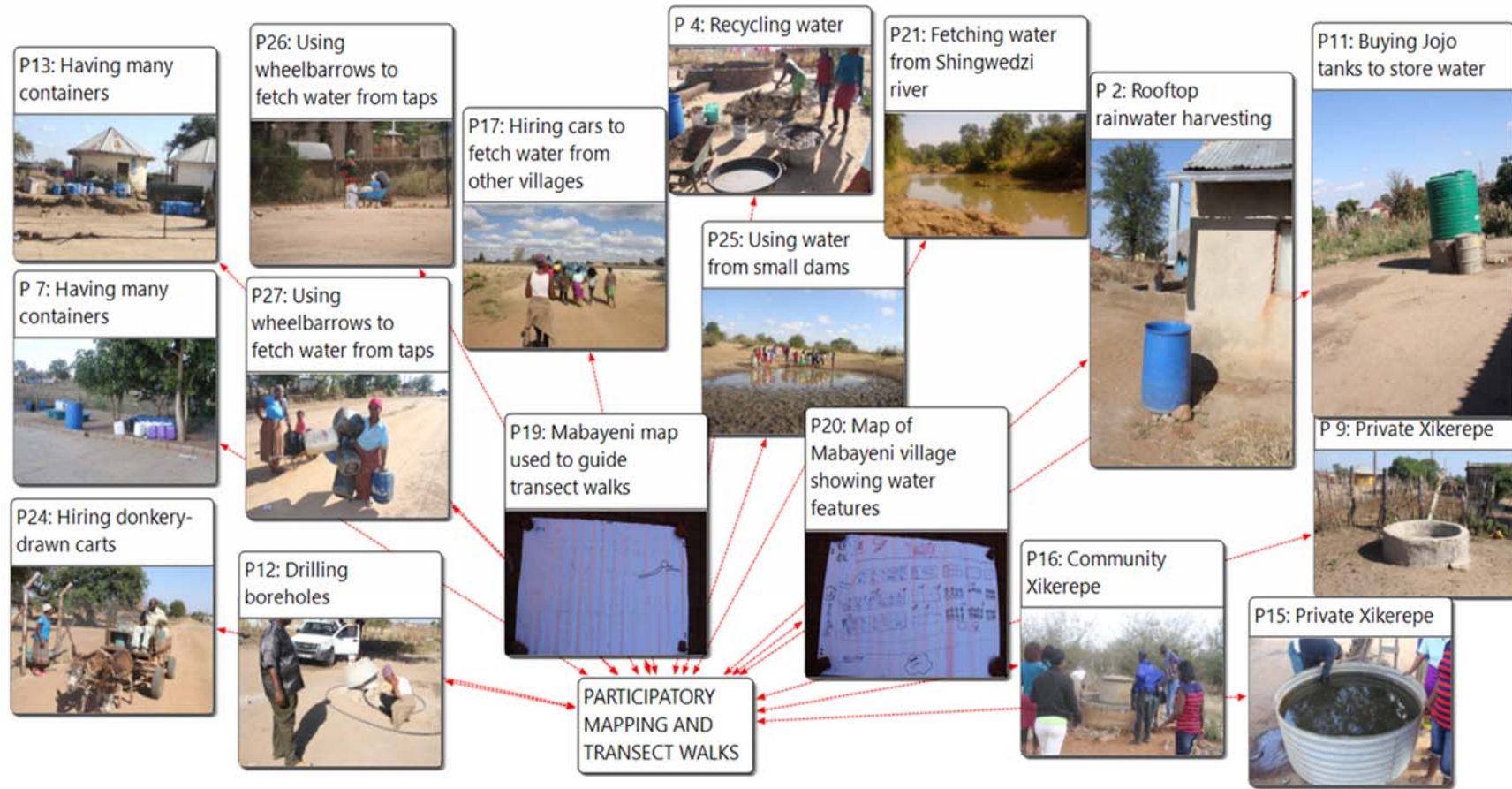
A list of the commonly used coping strategies was compiled from the interview data. Matrix scoring was then used to analyse the data (as illustrated in Sinuany-Stern, 2000). The seed technique was used to rank the coping strategies taking into account the community-perceived preferences and effectiveness. The rich data gathered through story-telling, focus group discussions, key informant interviews and photo voice were analyzed through thematic content analysis using ATLAS.ti software version 7.5.7. In Atlas.ti, the data were coded and organised into themes. Using the linking and related functions under the Network View Manager, nodes were imported to link sub-categories emerging under the broad coping strategies theme. In addition, through reference to memos, comments and verbatim transcripts, relationships among themes were established and demonstrated through a process called network analysis. Only the major themes and their linkages or relationships with other codes and quotations are discussed. Photographs of coping strategies were also presented using Atlas.ti (Figure 4.2).

4.3.5 Ethical considerations

During field visits, ethical issues such as informed consent, voluntary participation and non-discrimination were adhered to as explained in the previous chapter. Respect and integrity were upheld through making sure that participants selected engagement dates and venue that they were comfortable with. In order to manage respondents' expectations, the nature and purpose of the study were explained repeatedly during each data collection session. Participants were encouraged not to expect immediate solutions to their water challenges as the study was primarily academic. It was highlighted that if solutions were to come, it would take some time.

4.4 Results

The number of participants per data collection technique across interest groups are presented in Table 4.1. Children could not participate during transect walks as they were attending school on the day. They were also absent during photo voice discussions which were held with key informants who were community-based leaders. As for Magangeni group, they indicated that they were not available to participate as they were busy with collecting water and other house chores. Table 4.2 illustrates the number of quotations for each code across data collection techniques. It is revealed that transect walks and focus group discussions yielded the highest number of quotations out of a total of 78. Conversely, storytelling and photo voice discussions yielded the least number of quotations.



(Poor quality photographs were removed during processing in Atlas.ti version 7.5.7)

Figure 4.2 Coping strategies to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 4.1 Number of quotations for each data collection technique used in investigating rural household coping strategies for inadequate domestic water in Mabayeni Village of Collins Chabane Local Municipality

Data collection technique	Children		Youth		Adult		Elderly people	Magangeni sub-village	Total
	Boys	Girls	Male	Female	Men	Women			
a) Photo voice with key informants	0	0	2	2	4	6	3	1	18
b) Focus group discussions	8	7	9	11	7	9	6	9	66
c) Storytelling	12	17	7	15	6	11	8	12	88
d) Participatory mapping	8	10	15	16	6	8	7	0	70
e) Transect walks	0	0	2	4	3	4	1	2	16
f) Priority ranking (Matrix scoring)	8	12	9	14	5	10	7	0	65
g) Matrix scoring and Seasonal diagramming	8	12	9	14	5	10	7	0	65

Table 4.2 Consolidated results for codes and quotations generated for each data collection technique used in investigating rural household coping strategies for inadequate domestic water in Mabayeni village of Collins Chabane Local Municipality

Coping strategies (Codes)	Number of quotations per data collection technique						Totals
	Key Informant Interviews	Photo Voice	Focus Group Discussions	Story telling	Participatory mapping	Transect Walks	
	a) Buying <i>Jojo</i> tanks to store water	0	0	1	0	0	
b) Building water holding structures (private <i>Xikerepe</i>)	1	0	0	0	2	4	7
c) Buying water from borehole owners	2	0	0	1	0	2	5
d) Hiring cars to fetch from Malamulele	1	0	1	0	1	1	3
e) Fetching from neighbouring villages	0	0	0	1	1	0	2
f) Having many storage containers	2	0	1	1	0	2	6
g) Illegal water connection	0	0	0	0	0	1	1
h) Rainwater harvesting	1	2	4	0	0	4	11
i) Recycling water	0	0	1	0	0	1	2
j) Hiring donkey-drawn carts to fetch water from outside the village	0	1	0	0	1	0	2
k) Hiring donkey-drawn carts to fetch water from municipal taps	3	1	2	0	2	1	9
l) Fetching water from Shingwedzi river	2	1	5	2	1	1	12
m) Use of water from small dams (<i>Magraveleni</i>)	0	0	0	0	2	4	6
n) Use of wheelbarrows to fetch from local taps	0	1	2	0	1	0	4
TOTALS:	12	6	17	5	11	24	78

In addition, the codes that yielded the highest number of quotations were “Rainwater harvesting” and “Fetching water from Shingwedzi River”.

4.4.1 Preferred coping strategies for water scarcity

Groups of children, youth, adults and local leaders in Mabayeni village of Collins Chabani Local Municipality in Limpopo Province reported that they used 13 strategies to cope with water scarcity (Table 4.3). The strategies were categorized into four themes, namely internal (community) water sources, external (out of community) water sources, water-related expenses, and water purification. Water purification and external water sources were the least preferred. Convenient strategies that enabled the residents to fetch and store water in large quantities were preferred.

As shown in Table 4.3, the strategies that the eight interest groups preferred most were “using donkey-drawn carts to fetch water from public municipal taps”, “harvesting rainwater from roof tops” and “buying *Jojo* tanks to store water”. Figure 4.3 shows some *Jojo* tanks used at household level in Mabayeni village. The preceding results were confirmed when data collected through key informant interviews, photo voice-based discussions, focus group discussions guided by a semi-structured interview guide, story-telling and transect walks were analysed using the ATLAS.ti 7.5.7 software (Figure 4.4).

Even though the community members had to pay owners of donkey-drawn carts to transport water to their homesteads, this was a preferred coping strategy because it enabled them to use many containers at the same time. Rainwater harvesting was preferred because the local population said it was free and convenient, apart from the quality of the water being perceived to be high. A respondent in one focus group discussion explained this as follows:

“We use rainwater for drinking, bathing, cooking and washing. We use it for everything”

Jojo tanks were preferred because of their large storage capacities, which ranged from 2 500 to 5 000 litres.

Table 4.3 The most preferred coping strategies for water scarcity as perceived by residents of Mabayeni Village of Collins Chabane Local Municipality in Limpopo Province

Coping strategies	Adult male	Youth female	Youth male	Adult female	Girl children	Magangeni	Boy children	The elderly	Total
Internal (Community) water sources									
a) Using water from small dams (<i>Magraveleni</i>) for various household uses	4	2	3	1	2	1	1	1	15
b) Creating small water-holding structures (<i>Xikerepe</i>) for livestock drinking	3	4	3	4	3	4	4	4	29
c) Using wheelbarrows to fetch water from municipal taps	5	3	6	5	6	8	8	5	46
d) Harvesting rainwater from rooftops	8	11	11	7	8	8	8	10	71
External (Out of community) water sources									
a) Fetching water from neighbouring villages e.g. Merwe	2	1	2	2	1	3	3	1	15
b) Digging wells in the rivers	2	3	2	4	2	3	2	4	22
c) Fetching water from rivers	5	3	1	4	2	3	2	4	24
Water-related expenses									
a) Hiring cars to fetch water from Malamulele	4	2	3	4	2	4	1	4	24
b) Buying from those with boreholes	6	2	5	3	4	5	5	5	35
c) Buying <i>Jojo</i> tanks to store water	11	11	12	7	6	9	10	4	70
d) Using donkey-drawn carts to fetch water from taps	8	10	10	10	15	7	10	9	79
Water treatment									
a) Boiling river water	1	2	1	3	3	1	1	3	15
b) Sterilizing water with jik (Sodium hypochlorite)	1	4	1	3	2	1	3	3	18

Respondents revealed that they preferred to use large tanks, which enabled them to store water for a long time (Figure 4.3). However, the tanks were reported to be expensive. In Figure 4.4, under themes “preferred coping strategies”, “solutions to water scarcity,” and “challenges with current water storage” emphasis was placed on the desperate need for the community to have large water storage containers. The following views that a woman expressed during a focus group discussion lend weight to this argument:

“The containers that we have (drums, dishes and buckets) are too small. The water doesn’t last. We wish to have big tanks like Jojo tanks for each household to store water for longer periods”

Apart from the findings articulated above, the residents of Mabayeni expected outsiders such as the local Municipality, national or provincial government and university researchers to assist them (Figure 4.4). They did not seem to regard themselves as central to finding solutions to the water scarcity that they faced. Figures 4.5 (a-e) are seasonal calendars showing the extent to which each strategy was used to cope with water scarcity across months. Only the results illustrating the most and least preferred coping strategies are presented. The rest of the results are presented in Appendices 4.1-4.8. All the interest groups except for the female youth reported that from late April to end of August, use of donkey-drawn carts to fetch water from public municipal taps was high. An almost exponential increase in the use of the carts was observed from late April and peaked in June. Thereafter, it decreased gradually to reach the least extent of use in October.

In contrast to the rest of the interest groups, female youth reported that the use of donkey-drawn carts to fetch water did not change throughout the year. They pointed out that the local community relied mostly on tap water over the whole year. Moreover, they explained that this trend was mainly due to relatively reliable availability of clean tap water. Even though this was the case, the female youth noted that rainwater and other sources provided relief during times of dire water scarcity, with the former being regarded as a significant source (Figure 4.5a).

All the interest groups that participated in the current study indicated that from September to April they relied on “harvesting rainwater from rooftops” to meet water demands for domestic use (Figure 4.5b). Figure 4.5(c) shows the period when they resorted to “buying Jojo tanks to store water.”



Figure 4.3 Photographs of various sizes of water storage containers (*jojo* tanks) taken from some homesteads in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

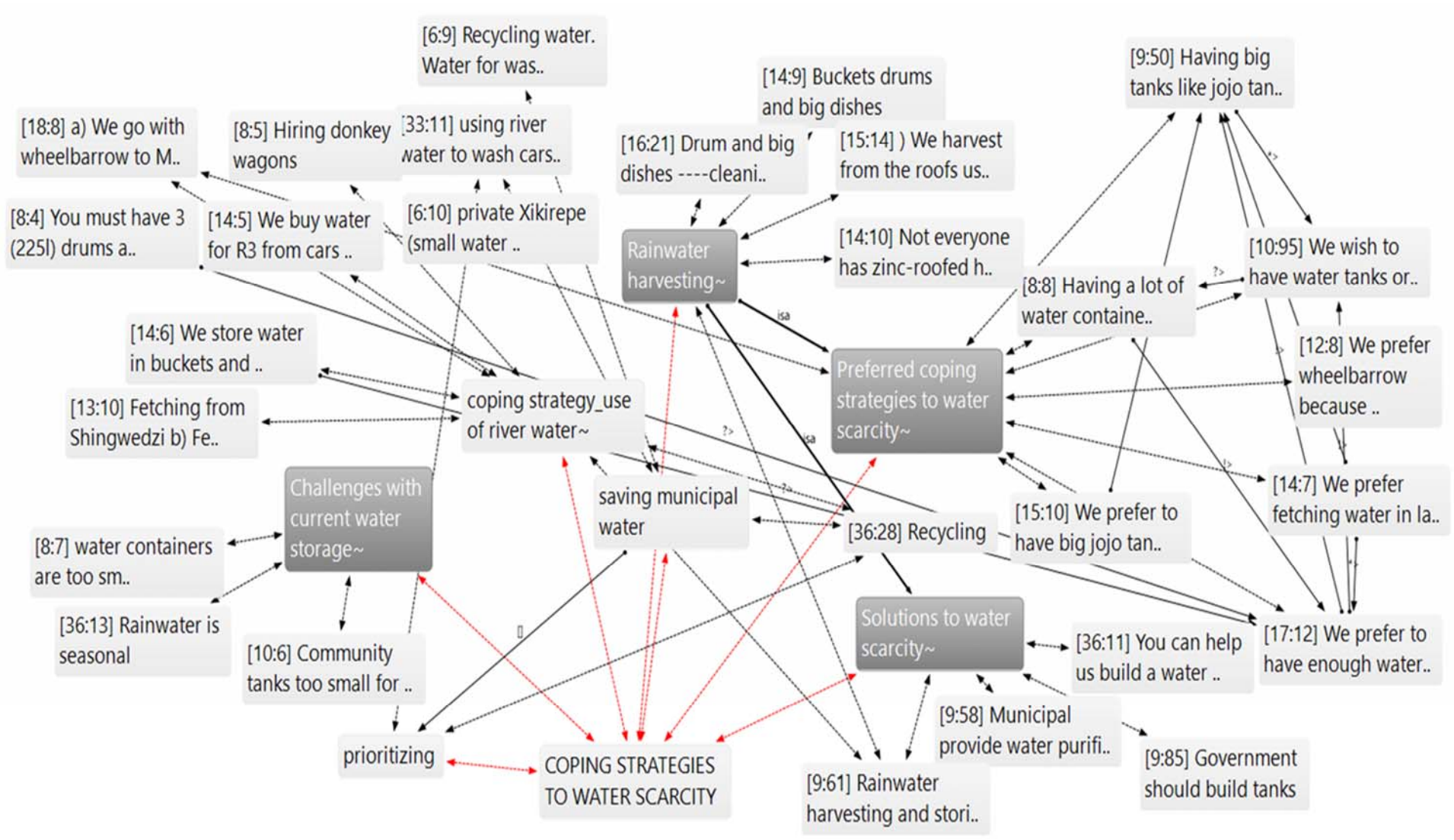


Figure 4.4 Preferred strategies for coping with water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

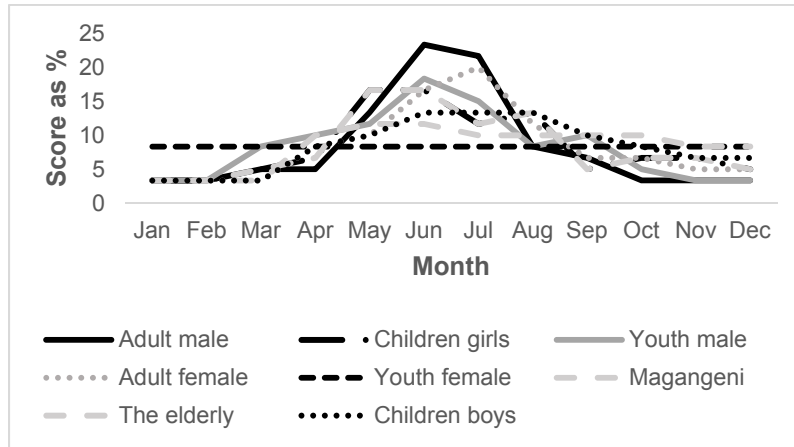


Figure 4.5.1 Using donkey-drawn carts to fetch water from municipal taps as a coping strategy to water scarcity in Mabayeni village

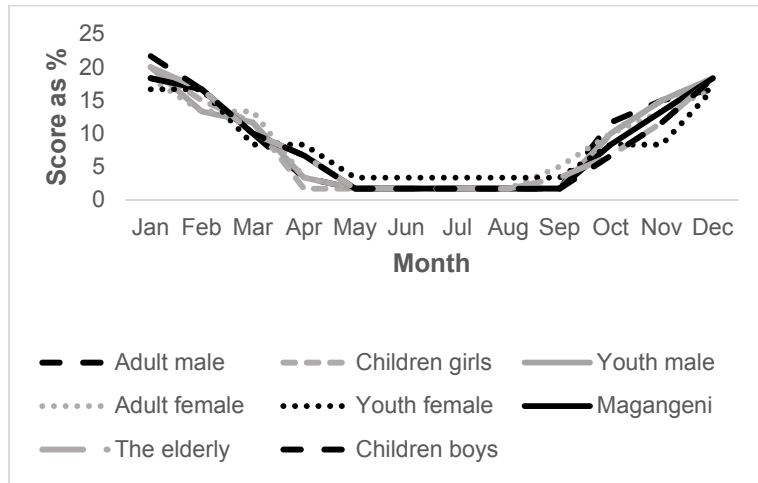


Figure 4.5.2 Harvesting rainwater from rooftops as a coping strategy to water scarcity in Mabayeni village throughout the year as perceived by interest groups

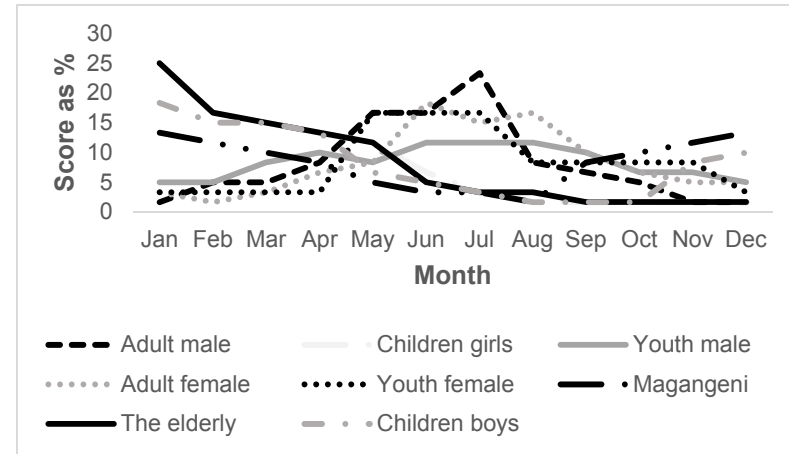


Figure 4.5.3 Buying Jojo tanks as a coping strategy to water scarcity in Mabayeni village

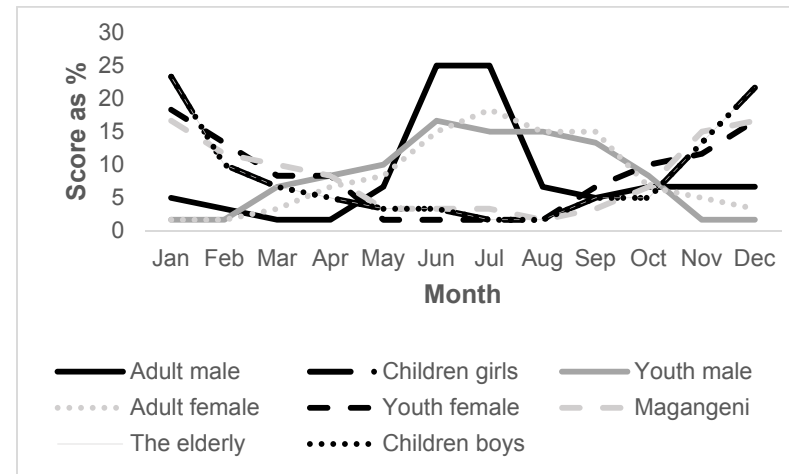


Figure 4.5.4 Using water from small dams for different household uses as a coping strategy to water scarcity in Mabayeni village

Both boy and girl children groups, the residents of Magangeni sub-village where thatched roofs for dwellings were predominant, and the group made up of the elderly indicated that they relied on this strategy between January and April, and also from September to December. The rest of the interest groups revealed that they bought *Jojo* tanks, which they used to store water during the dry season that extended from May to August. It has already been reported in this chapter that *Jojo* tanks were the most preferred containers, mainly due to their capacity to store large volumes of water.

The least preferred coping strategies for water scarcity were, “Using water from small dams for various household uses” and “Boiling river water”. Water from small dams was said to be dirty and, thus, unsuitable for cooking, drinking, washing dishes and even for laundry. A woman from Magangeni clarified this, presenting her views on why water drawn from small dams was unsuitable for washing clothes.

“Do you see my children’s clothes on the line? They are no longer neat because we are using this dirty water to wash” This water damages our children’s clothes and thus are no longer as bright as they were”

Shingwedzi River, which had flowing water throughout the year, was located about 5 km from Mabayeni village. The long distance that the residents had to travel to reach the river made it difficult for them to access water from it. Furthermore, river water was least preferred because its quality was very poor for domestic use. In a focus group discussion, one elderly woman expressed her displeasure with the quality of water from the river in the following way:

“These days the river bank is full of diapers and other dirt. Would you drink such water?”

As shown in Figure 4.5(d), the residents of Magangeni sub-village, female youth and boys preferred using water from small dams during the rainy season. They explained that during that period, the small dams were full and had clearer water, which they believed was clean.

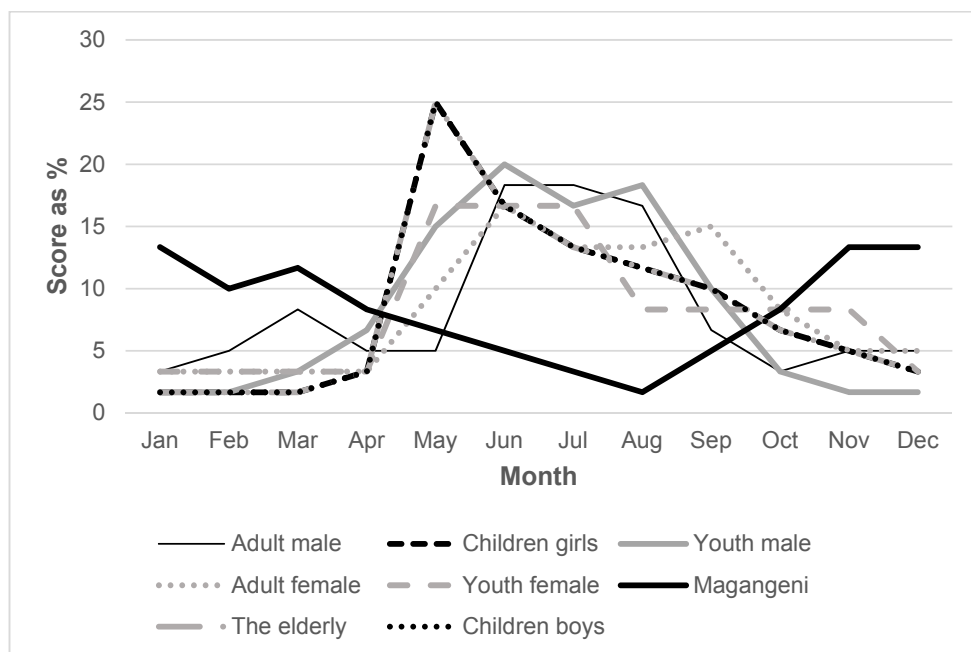


Figure 4.5.5 Boiling river water as a coping strategy to water scarcity in Mabayeni village throughout the year as perceived by interest groups

The foregoing views contrasted considerably with those of the rest of the groups which revealed that water from small dams and rivers was used more during the driest months of the year, namely May-August. In Figure 4.5(e), it is shown that all the interest groups apart from the Magangeni residents boiled river water for domestic use between May and September.

4.4.2 Effective strategies for coping with water scarcity

The various interest groups in Mabayeni village ranked the thirteen strategies used to cope with water scarcity based on effectiveness (Table 4.4). As explained already, the coping strategies were categorized into four themes. Strategies relating to water treatment and external water sources were the least effective. This was in contrast to those relating to water-related expenses. To some extent, local water sources were regarded as the most effective strategies.

“Buying *Jojo* tanks to store water”, “Using donkey-drawn carts to fetch water from public municipal taps”, and “Harvesting rainwater from roof tops” were perceived to be the most effective. In contrast, “Boiling river water”, “Digging wells in the river”, and “Using water from small dams for different household uses” were regarded the least effective. These results are the same as those obtained for the most preferred coping strategies in Table 4.3.

The women and children groups indicated that they preferred using wheelbarrows to fetch water from municipal taps because it was cheap (Table 4.4). However, using donkey-drawn carts was reported to be more effective for water collection. Even though the residents paid a fee to owners of carts, the fact that this accorded them the opportunity to fetch water in large quantities helped reduce physical harm and time devoted to this activity.

All the groups of residents of Mabayeni village had similar views on the coping strategies they regarded to be the least effective. However, as illustrated in Table 4.4, the residents of Magangeni sub-village disagreed with all the other seven interest groups with respect to the view that “Using water from small dams for different household uses” was the least effective coping strategy. In support of this, Figure 4.4 also shows “prioritizing” and “saving municipal water” as other ways of coping with water scarcity.

Table 4.4 The most effective coping strategies to water scarcity as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Coping strategies	Men	Youth female	Youth male	Women	Girl children	Magangeni	Boy children	The elderly	Total
Internal (Community) water sources									
a) Using water from small dams (<i>Magraveleni</i>) for various household uses	3	2	1	2	2	7	1	1	19
b) Creating small water-holding structures (<i>Xikerepe</i>) for livestock drinking	2	8	1	2	2	8	5	4	32
c) Using wheelbarrows to fetch water from municipal taps	2	2	6	7	7	2	7	5	38
d) Harvesting rainwater from rooftops	8	8	13	9	7	8	8	11	72
External (Out of community) water sources									
a) Digging wells in the rivers	2	3	1	2	2	3	2	3	18
b) Fetching water from the rivers	4	4	2	1	2	3	2	2	20
c) Fetching from neighbouring villages e.g. Merwe	2	2	3	2	2	5	2	3	21
Water-related expenses									
a) Hiring cars to fetch water from Malamulele	8	1	3	6	2	1	2	1	24
b) Buying from those with boreholes	9	5	5	6	5	2	5	2	39
c) Using donkey-drawn carts to fetch water from taps	8	7	11	8	15	8	10	7	74
d) Buying <i>Jojo</i> tanks to store water	10	10	12	10	9	9	10	14	84
Water treatment									
a) Boiling river water	1	3	1	1	3	2	2	3	16
b) Sterilizing water with Jik (Sodium hypochlorite)	1	5	1	4	2	2	4	4	23

4.5. Discussion

The study could have benefitted more from having children participate in the transect walks. However, all the dates that community members indicated their availability were during the week when children were in school. This made it impossible for children to participate in the transect walk. In addition, the failure of Magangeni sub-village participants to come for some engagements confirmed that that section of the village was disproportionately affected by water shortages. They therefore always had extra chores compared to their counterparts. Moreover, the fact that transect walks and focus group discussions yielded the highest number of quotations across subthemes reveal their importance in collecting qualitative data. However, although storytelling and photo voice discussions yielded the least number of quotations, they were also valuable as they complemented results. Such is the essence of triangulation (Thurmond, 2001; Yeasmin & Rahman, 2012). Schoonenboom & Johnson (2017) add that complementarity in research is about elaboration, enhancement, illustration, clarification of results from one method with the results from another. Thus, the use of multiple data collection techniques in the current study enhanced the credibility of findings.

As water scarcity worsened and internal sources shrunk, community members sought water outside their village. Buying water from those with private boreholes was the least desirable coping strategy because of the extra financial burden it imposed on community members. This caused what Eakin *et al.* (2016) refer to as a poverty trap, as they were already economically marginalized. Unclean water from small dams (Magraveleni) and Shingwedzi River was purified before it was used for different household uses. This coping strategy was least preferred because of the long distance (about 5 km) travelled to fetch water. In addition, the extra energy costs, as well as costs related to purchasing water purification chemicals, made this coping strategy less desirable. The most widely used purification method in the village was boiling. The purification method was regarded as time-consuming. These results confirm the Nastiti *et al.* (2017) findings on a study undertaken in Indonesia. The authors discovered that water from dug wells was boiled before use. On the contrary, results of the study carried out by Abedin & Shaw (2018) revealed that community members in Bangladesh used more sophisticated water purification strategies such as passive sedimentation, Alkan-activated aluminum filter and SONO-3 kolshi. They were able to afford and access these strategies through support obtained from research institutions in the country. In the current study, although boiling was one of the least preferred coping strategies, it was the dominant method of purifying water since it was viewed the cheapest.

All the strategies that Mabayeni residents used to cope with water scarcity appeared to be spontaneous. Decisions on coping strategies depended on the next available water source. These results resonate with findings from the Pandey *et al.* (2018) study on adaptation to climate change. The scholars discovered that potential responses did not require long periods of planning. The authors added that lack of long term strategies was caused by lack of resources. This was the case in Mabayeni village. Community members expressed lack of financial support as an obstruction to implementation of long term water access solutions.

Mabayeni residents preferred coping strategies that involved fetching water from internal sources more than external sources; allowed fetching and storing water in large volumes; provided clean potable water; did not include extra expenses for water purification; and involved minimal or no payment for water and water transportation. They also preferred using donkey-drawn carts to fetch water from taps because they could fetch water in large quantities although they had to pay a fee for transportation. Although regarded as expensive, buying *Jojo* tanks for storing water was preferred because of the *Jojo* tanks' huge capacity. This coping strategy was viewed as a solution to water scarcity since large quantities of water would last for many days. This shows that although they had to pay for it, community members preferred investing in long term water infrastructure. Holloway's (1977) concepts of value addition and relative advantage can be borrowed to explain this. A bigger storage tank was believed to provide relief against water scarcity making it a preferred option.

Rooftop RWH was preferred and viewed as an effective coping strategy, as well as a solution to water scarcity. This was because it was seen to be convenient, cheap and easy, and the water was believed to be clean and safe for drinking. This coping strategy was also preferred because it was carried out at household level. This meant that water was not shared with other community members. A household-level coping strategy was preferred because it reduced conflicts amongst community members. In the Nastiti *et al.* (2007) study, community piped water was also seen as a potential source of conflict. In fact, community members preferred having wells around their yards to sharing piped water. This diverges from the results of a study carried out in Uganda by Pearson *et al.* (2015). The latter authors identified a high level of water sharing and reciprocity between wealthy and poor community members which indicated a strong reliance on social capital. This bridged the gap between the wealthy and poor. In Mabayeni village, participants did not like sharing a water source and those who could afford to drill boreholes sold water to the poor for amounts ranging from R1 to R3.50. This actually widened the gap between the rich and

the poor. Ahile *et al.* (2015), and Abedin & Shaw (2018) also found RWH as a coping strategy in their studies in Nigeria and Bangladesh, respectively.

Harvested rainwater was stored in containers ranging from 10 to 110 litres. However, the noted water storage challenges at both community and household levels were related mostly to the size of containers. This concurs with results from the Ishaku *et al.* (2013) study. The authors also indicated that the majority of their respondents stored water in 100 litre drums, pots, jerry cans and buckets that lasted a few days. In fact, lack of big storage facilities was identified as one of the biggest challenges of water harvesting. Although respondents knew about RWH and liked the idea, they were discouraged by having to use small containers. In Mabayeni village, the buckets and drums used to harvest rainwater could not collect adequate water. Neither could it keep the water clean for a long time. Even the two community tanks that stored municipal water were said to be too small to store adequate water for the whole village. Another challenge was that rainfall was seasonal making it difficult for community members to cope during the dry season. Therefore, participants suggested harvesting rainwater from rooftops and getting external help to build large water storage reservoirs as possible solutions.

Adeniji-Oloukoi *et al.* (2013) explain two types of coping strategies which are soft and hard solutions. According to the authors, hard solutions entail the technical innovations for resource development while soft solutions are those that require behavioural changes to cope with water supply shortages for instance, water reuse. Mabayeni community members also reused water as another strategy to cope with water shortages during the dry season. For instance, after bathing, water was saved for cleaning floors and yard decorations using cow dung. Although participants confessed that some community members used water wastefully, they explained that efforts were made to save municipal water. To this end, municipal water was only used for potable uses while other water sources such as river and *Magraveleni* were for no-potable uses such as washing cars, sanitation (pouring in toilets), cow dung plastering, among others. In a study carried out in Nigeria, Adeniji-Oloukoi *et al.* (2013) also recorded soft coping strategies such as alternating bathing days in the week instead of bathing every day, minimizing the amount of water used for bathing, cleaning, washing and controlling children's bathing by disallowing them to bath on their own.

Seasonal calendars revealed the driest months of the year to be between May and September when there was no rain. This was the period in which donkey-drawn carts were used the most to fetch water from municipal taps within and outside the village. Water from small dams (*Magraveleni*) and Shingwedzi dam was mostly used during this period. The dry season was confirmed by 10-year rainfall data (2007-2017) obtained from the Agricultural Research Council (ARC) Institute for Soil and Water. Although participants explained that the seasons were shifting, the observed general trend showed the rainy season in the area to be between October and April. However, the difference in perceptions regarding the period in which donkey-drawn carts were used could have been due to the fact that the primary source of water in Mabayeni village was municipal tap water. This water was available a few days in a week throughout the year. Many people hired donkey-drawn carts to fetch water from these taps, making it a common activity throughout the year. Regarding buying *Jojo* tanks for water storage, the mixed perceptions on the period this coping strategy was mainly used could have been because the *Jojo* tanks were not only used to store municipal tap water, but also collected rainwater thus, varying the time the tanks were bought. Nonetheless, less than a quarter of Mabayeni residents actually owned *Jojo* tanks owing to the fact that they were pricey. Having this in mind, it is likely that these tanks were bought when money was available.

Seven small dams (*Magraveleni*) of different sizes and depth were found in the village. The mixed perceptions on the particular seasons this source was used to cope with water scarcity could have been due to the sizes of these small dams. This translated into different water holding capacities. Participants who had access to a smaller *Magraveleni* would have a smaller supply period compared to those with access to relatively larger dams. Although water from *Magraveleni* was regarded as dirty, during the rainy season, it was used for non-potable domestic uses such as washing clothes and cleaning the house since it was clearer. As is the case in the Nastiti *et al.* (2017) study, water from *Magraveleni* and Shingwedzi River was not desired due to its perceived poor water quality based on its smell, colour and taste. This water was used during the dry season when water sources were limited.

The period between May and September was evidently the most critical period which required attention. This information was important because it helped inform intervention strategies that targeted the real challenge. In this case, intervention strategies focused on augmenting water access in the dry season. Scarcity of water during the dry season echo the Kelly *et al.* (2018) findings in Kenya, Ghana and Zambia. The authors found out that in Zambia, people collected

water less frequently, walked shorter distances and spent less time collecting water during the rainy season because water was readily available. Water sources such as shallow wells, earth dams and seasonal springs dried up during the dry season pushing people to use groundwater sources. It was also reported that one community in Ghana supplemented water from their single borehole with drums purchased from a water vendor truck which would come from the nearest urban centre (Kelly *et al.*, 2018). Apart from affecting water yield for domestic use (Wang *et al.*, 2016), seasonal water scarcity is believed to impact agricultural production (Gaydon *et al.*, 2012) as well as the energy production (Goudard *et al.*, 2018).

It was discovered that the most preferred coping strategies were the same as the most effective strategies. Buying *Jojo* tanks, using donkey-drawn carts and harvesting rainfall from rooftops were regarded as the most effective strategies for coping with inadequate water availability because they provided clean water in large quantities and were convenient. However, although *Jojo* tanks were regarded as expensive, they were considered effective because they offered a long term solution to seasonal water unavailability. Even so, participants indicated that they could not afford to buy these tanks. They expressed that they needed help from the government to buy large water storage tanks. As indicated above, Mabayeni residents chose coping strategies that required financing because they were believed to present long term solutions. This also finds support in Holloway's (1977) argument as well as the Kelly *et al.* (2018) findings explained above.

4.6. Conclusion

It was apparent from the study that the strategies that residents of Mabayeni used to cope with inadequate availability of water were autonomous. Responses were implemented by individual households depending on resource availability, without intervention or coordination by the community itself, government or other external stakeholders. Available resources in a household also determined the range of coping options available, for instance, having borehole water, buying from those with water, or travelling long distances to fetch dirty water. Coping strategies were also not planned in advance. Residents would only switch from one coping strategy to another when the former proved challenging. The coping strategies that participants preferred were closely related to those regarded as effective. It was revealed that community members preferred coping strategies that were cheap, convenient, provided clean water, and allowed them to collect large volumes of water. They disliked coping strategies that involved incurring extra expenses, involved sharing water and that were distant. In addition, severe water scarcity was experienced in the period between May and September where desperate coping strategies such as boiling water

from the river, buying water, fetching water from the river and other villages were used. With regard to solutions to water scarcity, Mabayeni residents suggested harvesting rainwater from rooftops and building or buying large water storage containers. This would assist them in harvesting and storing water in large quantities which would last for longer periods, unlike the small containers they used. Since RWH emerged as a possible option for alleviating water scarcity, the RWH techniques that Mabayeni residents used were documented.

4.7 References

- Abedin, M. A., & Shaw, R. 2018. Constraints and coping measures of coastal community toward safe drinking water scarcity in Southwestern Bangladesh. *Science and Technology in Disaster Risk Reduction in Asia* **29(1)**:431-452.
- Adebo, S., (2000). Training Manual on Participatory Rural Appraisal. Addis Ababa. Available at <http://www.myfirecommunity.net/discussionimages/NPost8220Attach1.pdf> Retrieved from 12 May 2018
- Adeniji-Oloukoi, G., Bob, U., & Moodley, V. 2013. Household coping strategies to address water shortages related to climate variability in Oke-Ogun, Nigeria. *Environmental Development*, **5**:23-38.
- Ahile, S. I., Udoumoh, E.F. & Adzande, P. 2015. Residents' coping strategies with water scarcity in Makurdi town Nigeria, *Mediterranean Journal of Social Science* **6(4)**: 100-108
- Alcamo, J., Moreno, J. M., & Shvidenko, A. 2007. Europe. Climate Change 2007: Impacts, adaptation and vulnerability.
- Alessa, L.N., Kliskey, A.A., Williams, P. & Burton, M. 2008. Perception of change in freshwater in remote resource-dependent Arctic communities. *Global Environmental Change* **18**: 153-164
- Basu, M., Hoshino, S. & Hashimoto, S., 2015. Many issues, limited responses: coping with water insecurity in rural India. *Water Resources and Rural Development*, **5**: 47-63.
- Denzin, N. K. 1970. *The Research Act in Sociology*. Chicago. Aldine.
- Distefano, T., & Kelly, S. 2017. Are we in deep water? Water scarcity and its limits to economic growth. *Ecological Economics*, **142**: 130-147.
- Eakin, H., Lerner, A.M., Manuel-Navarrete, D., Aguilar, B.H., Martínez-Canedo, A., Tellman, B., Charli-Joseph, L., Álvarez, R.F. & Bojórquez-Tapia, L., 2016. Adapting to risk and perpetuating poverty: Household's strategies for managing flood risk and water scarcity in Mexico City. *Environmental Science & Policy*, **66**: 324-333.
- Fisher-Jeffes, L. N., Armitage, N. P., & Carden, K. 2017. The viability of domestic rainwater harvesting in the residential areas of the Liesbeek River Catchment, Cape Town. *Water South Africa*, **43(1)**: 81-90.
- Freudenberger, K.S., Rapid Rural Appraisal and Participatory Rural Appraisal: A Manual for Catholic Relief Services Field Workers and Partners. Available at <http://www.crsprogramquality.org/publications/2011/1/17/rapid-rural-appraisal-and-participatory-rural-appraisal.html>. accessed on 12 February 2017

- Gaudard, L., Avanzi, F., & De Michele, C. 2018. Seasonal aspects of the energy-water nexus: The case of a run-of-the-river hydropower plant. *Applied Energy*, **210**: 604-612.
- Gaydon, D. S., Meinke, H., & Rodriguez, D. 2012. The best farm-level irrigation strategy changes seasonally with fluctuating water availability. *Agricultural water management*, **103**: 33-42.
- Halder, P., Sharma, R., & Alam, A. 2012. Local perceptions of and responses to climate change: experiences from the natural resource-dependent communities in India. *Regional environmental change*, **12(4)**: 665-673.
- Hanasaki, N., Fujimori, S., Yamamoto, T., Yoshikawa, S., Masaki, Y., Hijioka, Y., Kainuma, M., Kanamori, Y., Masui, T., Takahashi, K. & Kanae, S., 2012. A global water scarcity assessment under shared socio-economic pathways – part 2: Water availability and scarcity. *Hydrology and Earth System Sciences*, **9**: 933-994
- Ishaku, H.T., Abayomi, A. P., Sahabo, A.A. & Dama, F.M. 2013. Complementing water supply through rainwater harvesting in some selected villages of Sahel savannah ecological zone in Borno state Northe-eastern Bigeria, *Journal of Water Resource and Protection* **5**: 200-207.
- Islam, M.M., Chou, F.N.F., & Kabir, M.R. 2011. Feasibility and acceptability study of rainwater use to the acute water shortage areas in Dhaka City, Bangladesh. *Natural Hazards*, **56**: 93–111.
- Karnataka-Tamil Nadu (2005). Participatory Monitoring and Evaluation: Field Experiences. NGO Programme KTN Series. Hyderabad: Intercooperation.
- Kelly, E., Shields, K. F., Cronk, R., Lee, K., Behnke, N., Klug, T., & Bartram, J. 2018. Seasonality, water use and community management of water systems in rural settings: Qualitative evidence from Ghana, Kenya, and Zambia. *Science of the Total Environment*, **628**: 715-721.
- Mehta, L. 2007. Whose scarcity? Whose property? The case of water in western India. *Land Use Policy*, **24(4)**: 654-663.
- Murtinho, F., Tague, C., de Bievre, B., Eakin, H., & Lopez-Carr, D. 2013. Water scarcity in the Andes: a comparison of local perceptions and observed climate, land use and socioeconomic changes. *Human ecology*, **41(5)**: 667-681.
- Nastiti, A., Muntalif, B. S., Roosmini, D., Sudradjat, A., Meijerink, S. V., & Smits, A. J. M. 2017. Coping with poor water supply in peri-urban Bandung, Indonesia: towards a framework for understanding risks and aversion behaviours. *Environment and Urbanization*, **29(1)**: 69-88.
- Northey, S. A., Mudd, G. M., Werner, T. T., Jowitt, S. M., Haque, N., Yellishetty, M., & Weng, Z.

2017. The exposure of global base metal resources to water criticality, scarcity and climate change. *Global Environmental Change*, **44**: 109-124.
- Ogundeji, A. A., & Jordaan, H. 2017. A simulation study on the effect of climate change on crop water use and chill unit accumulation. *South African Journal of Science*, **113(7-8)**: 1-7.
- Pandey, R., Kumar, P., Archie, K.M., Gupta, A.K., Joshi, P.K., Valente, D. & Petrosillo, I. 2018. Climate change adaptation in the western-Himalayas: Household level perspectives on impacts and barriers. *Ecological Indicators* **84**: 27-37.
- Parsons, D., Goodhew, S., Fewkes, A., & De Wilde, P., 2010. The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. *Urban Water Journal*, **7(4)**: 257–265
- Pearson, A. L., Mayer, J. D., & Bradley, D. J. 2015. Coping with household water scarcity in the savannah today: implications for health and climate change into the future. *Earth Interactions*, **19(8)**: 1-14.
- Pereira, L. S., Cordery, I., & Lacovides, I. 2009. *Coping with water scarcity: Addressing the challenges*. Springer Science & Business Media.
- Ran, Y., Lannerstad, M., Herrero, M., Van Middelaar, C.E. & De Boer, I.J.M., 2016. Assessing water resource use in livestock production: A review of methods. *Livestock Science* **187**: 68–79. <https://doi.org/10.1016/j.livsci.2016.02.012>
- Rijsberman, F. R. 2006. Water scarcity: fact or fiction? *Agricultural water management*, **80(1-3)**: 5-22.
- Savenije, H. H. G. 2000. Water scarcity indicators; the deception of the numbers. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere*, **25(3)**: 199-204.
- Schoonenboom, J. & Johnson, R.B. 2017. How to construct a mixed methods research design. *Cologne Journal of Sociology and Social Psychology*, **69**: 107-131
- Shadeed, S., & Lange, J. 2010. Rainwater harvesting to alleviate water scarcity in dry conditions: a case study in Faria Catchment, Palestine. *Water Science and Engineering*, **3(2)**: 132-143.
- Sinuany-Stern, Z., Mehrez, A. and Hadad, Y., 2000. An AHP/DEA methodology for ranking decision making units. *International Transactions in Operational Research*, **7(2)**: 109-124
- Takacs, D. 2016. South Africa and the Human Right to Water: Equity, Ecology, and the Public Trust Doctrine. *Berkeley Journal of International Law*, **34(2)**: 55-108
- Thurmond, V.A. 2001. The point of triangulation. *Journal of nursing scholarship*, **33(3)**: 253-258.
- Van Aalst, M. K., Cannon, T., & Burton, I. 2008. Community level adaptation to climate change:

- the potential role of participatory community risk assessment. *Global environmental change*, **18(1)**: 165-179.
- Wang, C., Wand, S., Fu, B., Zhang, L., 2016. Advances in hydrological modelling with the Budyko framework: a review. *Progress in Physical Geography*, **40(3)**: 1–22
- Ward, S., Butler, D., & Memon, F.A. 2011. Benchmarking energy consumption and CO2 emissions from rainwater harvesting systems: an improved method of proxy. *Water and Environment Journal*, **26(2)**:184–190.
- Wilbanks, T. J. & Kates, R. W. 1999. Global change in local places: how scale matters. *Climatic change*, **43(3)**: 601-628.
- Yeasmin, S. & Rahman, K.F. 2012. Triangulation research method as the tool of social science research. *BUP Journal*, **1(1)**: 154-163.

CHAPTER 5 CURRENT RAINWATER HARVESTING PRACTICES USED IN RURAL COMMUNITIES OF LIMPOPO PROVINCE: A CASE STUDY OF MABAYENI VILLAGE

5.1 Abstract

Rainwater harvesting has become the next plausible alternative to ensuring availability of water for multiple domestic uses. This opportunity has however been underexploited especially in South Africa. A study was therefore carried out to document the current RWH practices used in Mabayeni village of Collins Chabane Local Municipality. The objectives of the study were to determine the most preferred and effective RWH practices in the area. The study employed a qualitative and exploratory design. Data collection techniques such as focus group discussions, transect walks, key informant interviews and storytelling were used to collect data. The data were analysed through matrix ranking, and ATLAS.ti software (version 7.5.7) aided thematic content analysis. There were no existing technologies that were purposely designed for harvesting rainwater. Instead, community members collected water from their rooftops using containers of different sizes. The RWH practices that were regarded as most preferred were those that were regarded as cheap and easily accessible such as 25 litre buckets and containers (*Swigubu*). On the contrary, RWH techniques that were regarded as most effective were those that involved using large water storage containers such as *Jojo* tanks of sizes between 2 500 litres and 10 000 litres and 225 litre drums. This shows that with regards to RWH, size, affordability and accessibility were key to community members. Having this understanding was essential. It provided background information on existing RWH activities in Mabayeni village. Apart from this, it informed the design of a RWH technology with best potential to reduce water scarcity in the village. The study was crucial because it provided a unique dimension to exploratory studies. A community-based analysis of available coping strategies based on preference and effectiveness helped expose the differences between coping strategies that were preferred and those that were effective. This translated into gaps that existed between what was within reach and what was desired.

Key words

Mabayeni village, rainwater harvesting technique, rural community, water scarcity, water shortages

5.2 Introduction

Rainwater harvesting is an old water technology dating back to more than a thousand years ago (Alamdari *et al.*, 2018; Oweis, 2017; AbdelKhaleq & Ahmed, 2007). Its practice has gained popularity due to growing scarcity of water caused by a variety of factors (United Nations Settlements Programme – [UN-Habitat], 2012) such as, rising desire for decentralisation of water sources (Helmreich & Horn, 2009) and notable improvements in the technology of water harvesting itself (Thomas, 1998). Rainwater harvesting can either be used as a principal or supplementary source of water (Haque *et al.*, 2016). Four major categories of RWH have emerged from literature. These are in-field, ex-field, macro-catchment and domestic RWH systems (De Kwaadsteniet *et al.*, 2013; Saladin & Bohara, 2016). In field, ex-field and macro-catchment RWH systems are popular in agriculture-related water conservation activities.

According to Terencio *et al.* (2018), rainwater can be stored in the soil (in-field) or behind manufactured dams, as well as in tanks or containers (ex-field), for different uses. In-field RWH makes use of part of the target area or cultivated basin as the catchment area. On the other hand, with ex-field RWH, there is a distinct division between the catchment area and the cultivated basin although the two are adjacent to each other (Gowing *et al.*, 1999). *In-situ* RWH is also called “green water” harvesting (Oweis, 2017). Macro-catchment RWH is characterised by large catchment areas located outside the cropped area, where individual farmers have little or no control over them. The systems include intermediate components for collecting, transferring and storing runoff. Gowing *et al.* (1999) posits that such systems are difficult to differentiate from conventional irrigation systems but it is referred to as RWH as long as the harvested water is available beyond the rainy reason.

Domestic RWH which is the focus of this study, utilizes rooftops, courtyards, or treated systems for the collection of rainwater into storage tanks for domestic purposes (Mwenge Kahinda *et al.* 2008). According to Saladin & Bohara (2016), RWH can also be further categorised based on storage options that is, above ground or underground. Pandey *et al.* (2003) and Salas *et al.* (2009) explain the potential of RWH to strengthen community adaptation to climate change, and also enhancing ecosystem and livelihood resilience (Muller, 2007). The main advantage of domestic RWH is that it provides water right near the household, reducing the long distance walks which are a burden for communities when collecting water (Musayev *et al.*, 2018; Helmreich & Horn, 2009).

Success stories of domestic RWH have been recorded in rural communities of Ethiopia (Eggens & Patrick, 2015), Kenya and Western Uganda (UN-Habitat, 2012), Ghana (Gould & Nissen-Petersen, 2006), Tanzania (National Peace Corps Association, 2016) and South Africa in Limpopo, Free State and Eastern Cape provinces (WRC Technical Brief, 2008; WRC Technical Brief, 2013; Mannel *et al.*, 2014). This is enough evidence to show that domestic RWH is a not just as promising alternative to augment available water supplies, but also that it has been tried and tested in different parts of the world. However, in spite of the promise provided by domestic RWH, less than 1 % of rural households in South Africa used a rainwater storage tank as their main water source by 2010 (Mwenge Kahinda *et al.*, 2010). The authors added that domestic RWH was the least used water source in South Africa with existing domestic rainwater storage tanks having been built by non-governmental organisations. Nonetheless, with water scarcity becoming more and more severe, especially in rural communities such as Mabayeni village, there was need to document the current RWH practices.

Since community members highlighted RWH as one of the most promising coping strategies with potential to provide clean water at very limited costs, attention was given to this coping strategy. Examining available RWH techniques and technologies was also vital so as to build on these and strengthen community adaptation to water scarcity. In addition, existing RWH practices were ranked according to preference and effectiveness to determine what is preferred and what works best for the community. This investigation was believed to be one of the important aspects forming the basis of a long-lasting community development intervention strategy.

5.3 Methodology

5.3.1 Research design and sampling procedures

The research design and sampling procedures followed in this chapter were the same as those explained in the previous chapters. A total of seven focus group discussions were conducted. In addition, two-group key informant interviews were held. The key informant interview groups were made up of Mabayeni village leaders. The two groups had eight and nine members each. As for transect walks, two representatives of each interest group and two community leaders were requested. Volunteers registered their names. The expected number was 16 but 19 participants actually participated. This showed growing interest of community members to participate in the study.

5.3.2 Data collection

Primary data was collected through conducting a combination of PRA techniques explained in the previous chapters. These were key informant interviews, focus group discussions, storytelling and transect walks. Secondary data was collected from books, internet-based journal articles, other credible internet sources and newspapers. In their different interest groups, participants were requested to list and explain the current RWH techniques carried out in their village. All the RWH techniques were consolidated on a flip chart.

Matrix ranking, which is both a data collection and analysis technique was used. This involves collecting data and analysing it simultaneously with the participants in the field. On a prepared flip chart, participants were requested to rank the RWH techniques according to preference and effectiveness. Matrix scoring, particularly the seed technique was used to determine the most preferred and most effective RWH techniques. Each interest group was given 60 seeds to distribute among the listed RWH techniques ensuring that the more the number of seeds allocated, the more preferred or effective a technique was regarded to be. Results of all the interest groups were then consolidated per RWH practice or technique.

5.3.3 Data analysis

The matrix ranking procedure has been described above. It should be noted that before scores were entered on the flip charts, participants discussed the reasons for their ranking patterns until they agreed on a common score. Discussions were captured through voice recording to ensure that reasons for ranking were properly understood. In addition, thematic content analysis was carried out using the ATLAS.ti software version 7.5.7. In ATLAS.ti software, quotations were categorised based on common sub-themes or codes. Related codes were then further grouped into different families (or themes). ATLAS.ti was also used to consolidate the photographs of common RWH practices in Mabayeni village.

5.4. Results

5.4.1 Rainwater harvesting practices used in Mabayeni village

Mabayeni people used dishes, drums, buckets and other containers of different sizes to harvest rainwater. Participants reported that they stored harvested rainwater in *Jojo* tanks. In addition, water holding structures (*Swikerepe*) that were constructed for watering animals were also used

to capture and store rainwater. Community members also stated that they collected rainwater from roofs through placing containers on top of traditional benches made from mud (*Maguvha*) to reduce contamination of rainwater by soil and small animals.

5.4.2 Most Preferred Rainwater Harvesting Practices

Seven RWH practices were used in Mabayeni village (Table 5.1; Figure 5.1). The most preferred RWH practices were “Using 225 litre drums to collect and store water,” “Using buckets with a storage capacity of up to 30 litres” and “using 25 litre containers (*Swigubu*)” (Figure 5.1). It was explained that these practices were preferable because the containers were readily available in the village. Although female youth, adult men and women, Magangeni residents, and boy children and girls preferred “using 25 litre containers (*Swigubu*)” to harvest rainwater, the male youth and the group made up of the elderly people disagreed. The latter groups argued that the 25 litre containers were too small for use in collecting rainwater. The foregoing results were also confirmed when data collected through key informant interviews, photo voice-based discussions, focus group discussions guided by a semi-structured interview guide, story-telling and transect walks were analysed using the ATLAS.ti 7.5.7 software. Men and elderly people preferred “Storing water in *Jojo* tanks” because the water containers that were used in Mabayeni village were very small. One respondent explained:

“We prefer to have big Jojo tanks to store rainwater or water from the municipal taps to use for a long time”.

The above sentiments have already been firmly expressed in the previous Chapter. However, the youth male and female, boy children and girls, women and residents of Magangeni sub-village did not prefer the *Jojo* tanks because they were very expensive.

Table 5.1 The most preferred rainwater harvesting practices as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Rainwater harvesting practices	Youth		Adult		Elderly people	Magangeni group	Children		Total
	female	male	female	male			boys	Girls	
a) Using 225 litre drums to collect and store water	16	18	19	12	10	9	13	13	112
b) Using buckets with a storage capacity of up to 30 litres	11	9	15	15	9	11	11	12	95
c) Using 25 litre containers (<i>Swigubu</i>)	11	12	5	10	7	9	12	10	77
d) Using 150 litre basins (<i>Bhavhu</i>)	10	10	5	4	6	8	11	9	68
e) Storing water in <i>Jojo</i> tanks	6	7	5	12	15	7	4	6	62
f) Constructing water holding structures (<i>Xikerepe</i>) for animals to drink	5	3	10	4	11	8	6	8	58
g) Placing zinc on top of a wall (<i>Guva</i>) to collect rainwater into buckets and dishes	1	1	1	3	2	8	3	2	21

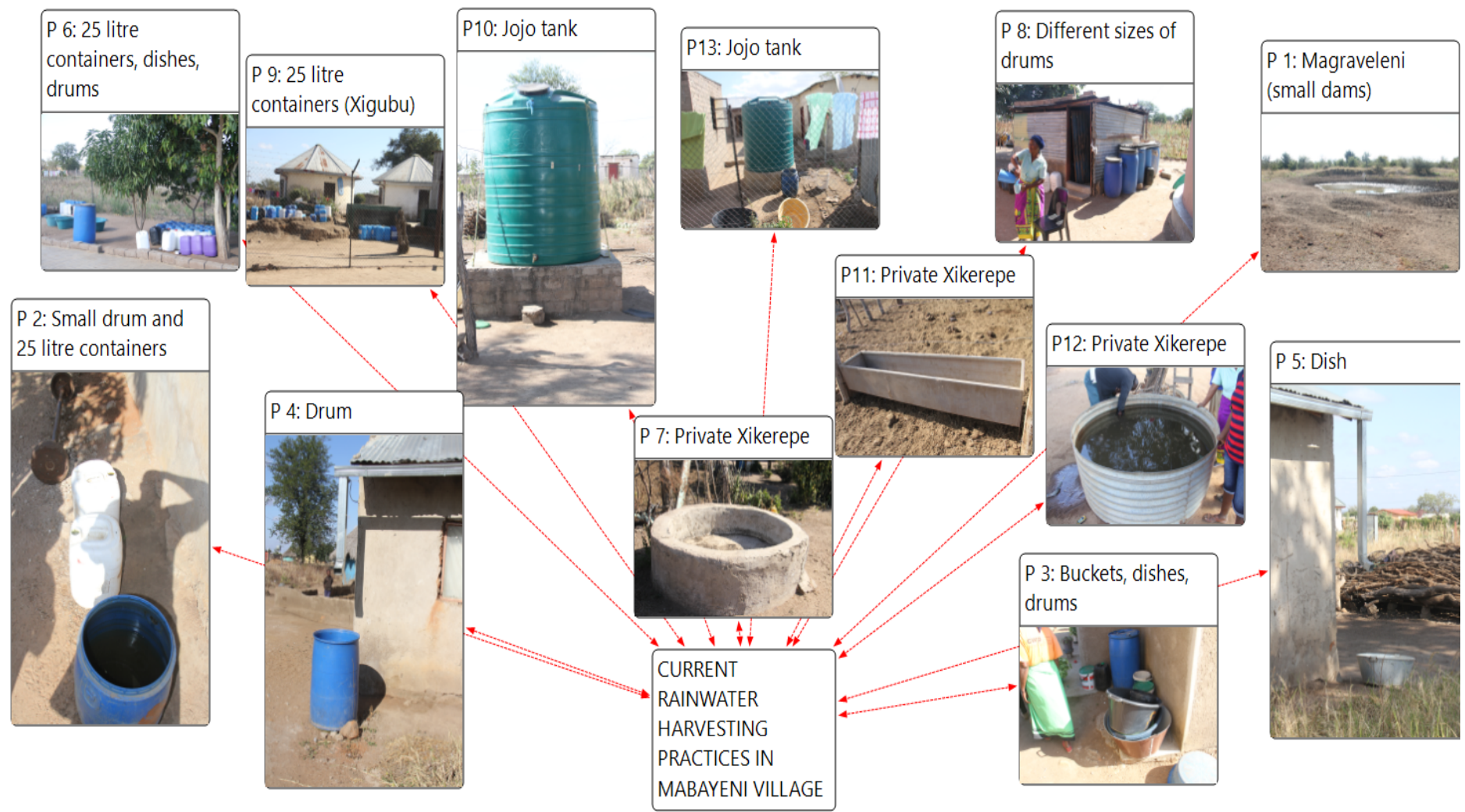


Figure 5.1 Photographs of common rainwater harvesting practices in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Results revealed the challenges faced with RWH as well as water storage (Figure 5.2). Deterioration of water quality and the seasonality of rainwater were some of the challenges that were highlighted. The small size of water containers at both village and household levels was the most common challenge regarding water storage. In addition, RWH was seen as a potential solution to water scarcity provided the storage facilities were large enough to last families for about three to four months. However, participants predicted that theft of water tap heads would likely hinder RWH efforts (Figure 5.2). Furthermore, the fact that some community members did not have houses with zinc roofing was a major concern. It meant that they would not be able to harvest clean rainwater. The expressions below were given by some participants to qualify the latter assertion.

“I don’t go to my neighbour since I do not have zinc roofing, besides I wouldn’t want to wake my neighbour’s children just because I want to fetch water at night” [adult women]

“I don’t want to bother anyone because I can’t go and wake young men with their young families, as old as I am, I can’t do that!” [elderly women]

“Some people lock their gates at night so it is difficult for some of us with thatched roofs to collect rainwater” [adult women]

5.4.3 Most Effective Rainwater Harvesting Practices

Table 5.2 shows the seven RWH practices based on how effective the interest groups in Mabayeni village regarded them to be. In general, the perceptions of all the interest groups were the same. “Storing water in *Jojo* tanks”, “Using 225 litre drums to collect and store water”, and “Using 25 litre containers (*Swigubu*)” were said to be the most effective RWH practices. “Placing zinc on top of a wall (*Guva*) to collect rainwater into buckets and dishes” and “Creating water holding structures (*Swikerepe*) for animals to drink” (shown in Figure 5.1) were regarded as the least effective practices. In contrast to the rest of the interest groups, female youth, and all the groups of children perceived “Using buckets with a storage capacity of up to 30 litres” as one of the least effective RWH practices. It was pointed out that even though buckets were small, virtually everyone in the village owned them. Moreover, the buckets were used to fetch and store water from various sources and thus, were readily available for use.

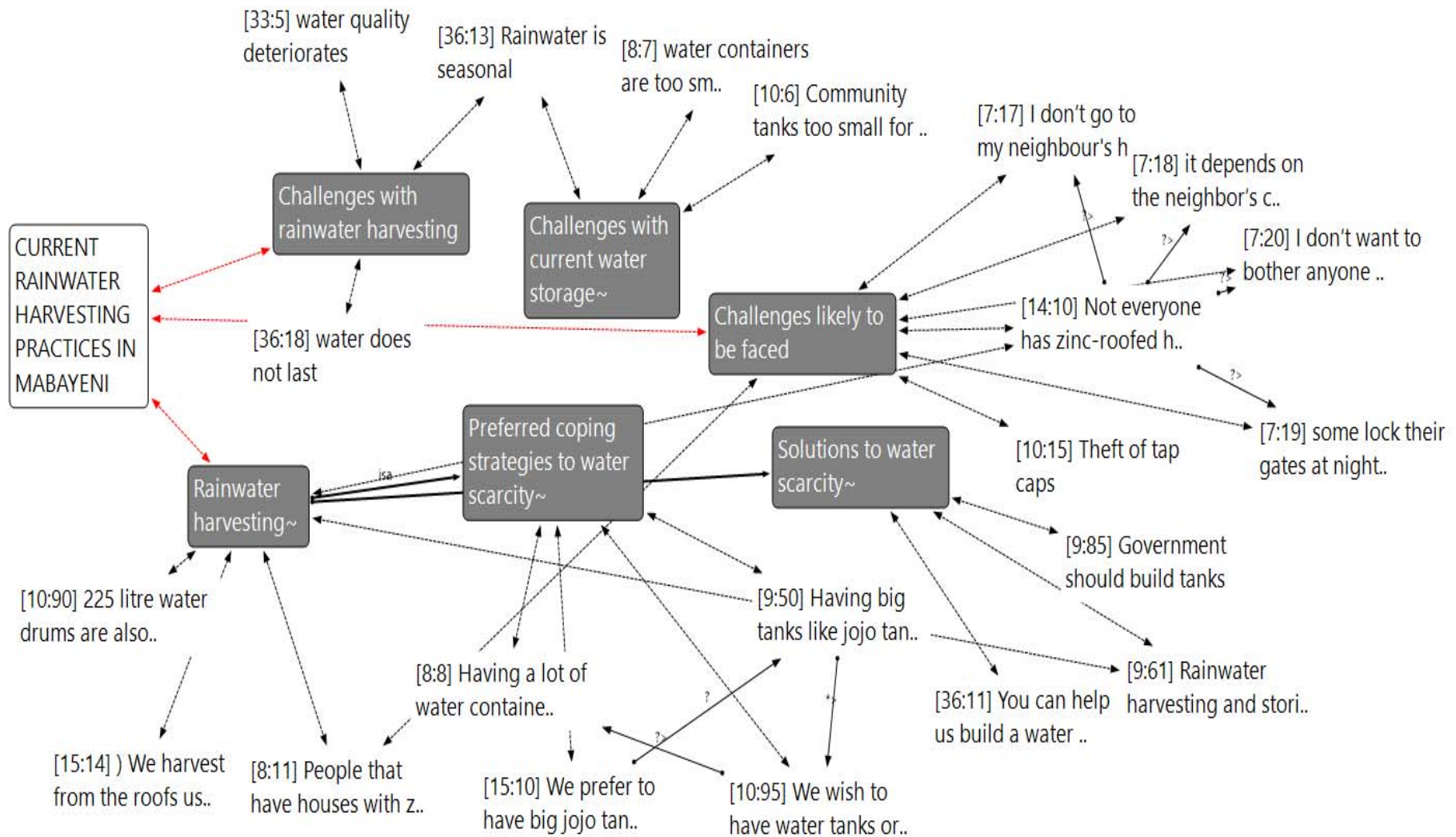


Figure 5. 2 Rainwater harvesting practices in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 5.2 the most effective rainwater harvesting practices as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Rainwater harvesting practices	Youth		Adults		Elderly people	Magangeni sub village	Children		Total
	Female	Male	Female	Male			boys	girls	
a) Storing water in <i>Jojo</i> tanks	20	21	6	12	20	10	17	20	126
b) Using 225 litre drums to collect and store water	15	15	18	11	10	10	15	10	104
c) Using 25 litre containers (<i>Swigubu</i>)	10	7	10	10	10	10	10	10	77
d) Using buckets with a storage capacity of up to 30 litres	5	9	15	10	10	11	3	5	68
e) Using 150 litre basins (<i>Bhavhu</i>)	5	5	5	9	4	9	9	7	55
f) Constructing water holding structures (<i>Xikerepe</i>) for animals to drink	4	2	3	5	4	5	4	5	45
g) Placing zinc on top of a wall (<i>Guva</i>) to collect rainwater into buckets and dishes	1	1	3	3	2	5	2	3	20

Results obtained show that most of the perceptions on RWH practices regarding preference and effectiveness were the same across interest groups. However, “Storing water in *Jojo* tanks” which was least preferred was regarded as the most effective RWH practice. As already explained, residents of Mabayeni explained that *Jojo* tanks were effective because they were big enough to store water that lasted for longer periods though less than 10 households actually used these tanks.

5.5. Discussion

It was evident from the results that there were no technologies or systems specifically designed for harvesting rainwater in Mabayeni village. The structures or containers that were used to harvest water were primarily meant for other uses such as animal watering, fetching and storing water from municipal taps, washing clothes, washing dishes, among others. The absence of a RWH technology was attributed to lack of knowledge on how to design such a technology. This concurs with results of a study done by Kisakye *et al.* (2018) in Uganda. The author discovered that although formal RWH systems were ideal and provided the safest water for domestic use compared to informal systems, only 23 % of the households in their study practiced formal RWH. This was attributed to the high initial investment costs required especially for large storage volume. Participants however admitted that they had seen a RWH technology in one of the villages near Kruger National Park and they wished to have a technology similar to that. However, lack of financial resources discouraged them. Similar findings were obtained from the Murgor *et al.* (2013) study carried out in Kenya. The authors learnt that poor financial status, lack of awareness about the RWH technology, as well as lack of technical assistance influenced farmers’ decisions to adopt RWH technologies. Baguma & Loiskandl (2010) thus concluded that subsidy provision determined successful adoption of formal RWH technologies in Uganda. Nonetheless, community members should be applauded for using the resources within their means to collect rainwater and relieve water scarcity.

Even Barthwal *et al.* (2014) mention the incentives and costs involved in a water management scheme as determinants of its implementation and success. Fisher-Jeffes *et al.* (2017) argue that RWH is a relatively expensive alternative water source which may make it inappropriate for poor communities. Nonetheless, Helmreich & Horn (2009) maintain that although capital costs are high, neither operation nor maintenance usually involves significant expenditure making RWH a cheaper option in the long run. This suggests the need for subsidizing or funding RWH technologies especially in rural communities. Unlike in developed countries such as China,

Germany and Australia where the government has policies to support RWH and provides funding for decentralised water management systems such as RWH systems (Musayev *et al.*, 2018), that kind of support has been lacking in South Africa (De Lange, 2006; Mwenge-Kahinda *et al.*, 2010).

The most common RWH practice in Mabayeni village was rooftop rainwater harvesting (RRWH). This was because unlike the water holding structures (*Swikerepe*) and *Jojo* tanks which were owned by a few people, all the community members owned containers of varying sizes which were used for other household uses. This made it cheaper for them to use already existing containers to harvest rainfall from their rooftops. This is in line with the Barthwal *et al.* (2014) argument that availability of resources influences adoption of a RWH technology. In this case, containers for collecting and storing rainfall (although regarded as small), were readily available. In addition, unlike water holding structures, rooftop RWH yielded water that was regarded as safe for drinking. In fact, Mabayeni community members attested to using rainwater for potable uses such as drinking and cooking without purifying it. According to Abdulla & Al-Shareef (2009), harvested rainwater is a renewable clean source of water that is ideal for domestic and landscape uses. Peters (2016) adds that rainwater has traditionally been the main source of potable water particularly in remote and isolated communities. Jones & Hunt (2010) maintain that although rainwater may need to be treated in some instances, a high level of treatment is not necessary. Therefore, rooftop RWH presented a number of advantages for Mabayeni residents.

An examination of the preferred RWH practices revealed that residents of Mabayeni preferred practices that were available and accessible to them. Participants did not prefer *Jojo* tanks because they were too expensive. This shows that preference of a particular rooftop RWH practice was influenced by convenience, and affordability of resources needed to implement it. Oweis & Hachum (2006), de Kwaadsteniet *et al.* (2013) and Ishaku *et al.*'s (2013) have also noted financial constraints of people in rural communities as a limitation for successful implementation of RWH.

The order in which the RWH practices were ranked indicated that although not preferred because of limited resources, larger storage containers were perceived as effective in storing large amounts of water. This showed that size of storage was also regarded as key for harvesting rainwater from rooftops. Even Mwenge-Kahinda *et al.* (2010) discovered a relationship between water storage tank size and water scarcity in a study carried out in South Africa. However, it was interesting to note that the 150 litre basins (*Mabhavhu*) were seen to be less effective when

compared with 25 litre containers. The reason given for this was that as much as the 150 litre basins could collect more rainwater, it was difficult to keep collected water clean because they did not have lids. It can, therefore, be deduced that in addition to the volume of water that could be collected, the quality of harvested water also determined the effectiveness of RWH in Mabayeni. This complements findings of Lasage & Verbug (2015) who discovered the importance investment costs of the RWH structure (in terms of water yield) in the adoption of RWH technologies. By extension, community members were likely to adopt a RWH technique that enabled them to collect more volumes of water. De Kwaadsteniet *et al.* (2013), and Lasage & Verbug (2015) also highlight the importance of water quality in RWH systems especially if water is for potable domestic uses.

The seasonality of rainfall necessitated having large storage containers to store water for use in the dry season while the deterioration of rainwater quality after some weeks demanded purification. Worm & Hattum (2006), Hemlreich & Horn (2009) and Li *et al.*, (2010) postulated that in rural areas, rainwater from well-maintained roof catchments is generally safe to drink without treatment because rainwater is generally unpolluted and pure before reaching the ground. However, scholars such as Fujioka (2002), Aladenola & Adeboye (2010) and de Kwaadsteniet *et al.* (2013) have emphasized the need to purify rainwater. This is because of the discovery of microbial and chemical contaminants in untreated rainwater storage tanks. These were believed to originate from raindrops that traverse through polluted air, the catchment areas, and storage containers (Kwaadsteniet *et al.*, 2013). This means that although rainwater may be safe for potable uses immediately after collection, it needs to be treated if it has to be stored for a long period.

Not having zinc roofs was a barrier to harvesting clean rainwater. Harvested rainwater from thatch roofs was said to have colour (from kitchen smoke, grass, leaves and dust). This discouraged community members with thatch roofs to harvest rainwater. To community members, this meant that water was contaminated and unfit for most domestic uses, making it useless. The fact that thatch roofs soak or absorb rainwater also reduced the runoff coefficient (that is, the amount of water that could be collected). This concurs with results of a study conducted by Opare (2012) in Ghana. The author observed that thatch roofing discouraged people from harvesting rainwater because of the difficulty in fixing gutters on the edges of the roof, colouring of rainwater which increased the extent of contamination, as well as limited quantities of water that could be harvested. On the contrary, drawing from the results of a study undertaken by, Efe (2006),

collection, storage and use of rainwater harvested from thatch roofs is recommended. The author's research focused on assessing the level of potability of rainwater samples from different catchments including thatch, in some rural communities of Nigeria. The recommendation was based on the results of the study which revealed a satisfactory concentration of chemical elements in various rainwater samples which included thatch. However, Efe (2006) suggested little treatment in terms of acidity, colour and iron, to bring them to WHO level of potability. Nonetheless, residents of Mabayeni maintained that they would not collect water from thatch roofs. Instead, they suggested covering the roofs with polythene plastic so as to harvest clean, potable water.

5.6 Conclusion

Community members in Mabayeni village did not have any technology that was designed to harvest rainwater. Instead, they collected and stored rainwater using the available containers of varying sizes. However, this was a challenge since some of the containers that were used for collecting rainfall did not have lids resulting in the water getting contaminated before it was used. It was also clear that rooftop RWH was the most common RWH practice as it presented a number of advantages. In addition, Mabayeni residents preferred RWH practices that they could afford, or were within their comfort zone. On the other hand, RWH practices such as use of *Jojo* tanks and drums to collect rainwater were perceived as effective due to their size of storage and the possibility of storing good quality water. It was clear that the practices that were preferred (affordable) were not effective suggesting the need for support from the government, non-governmental organisations and other institutions to install effective RWH technologies. The seasonality of rainfall, and deterioration of quality of rainwater, the small sizes of available containers, contamination of water harvested from thatch roofs were the main challenges hindering successful RWH. With regard to solutions to the existing challenges, purifying rainwater, buying large water storage containers, and covering thatch roofs in order to collect clean rainwater were suggested. It was vital to take note of, and learn from what local people were already doing so as to build on this in coming up with intervention strategies. As a next step to the intervention strategy, the preferred features of a rooftop RWH technology with the best potential to reduce water scarcity were documented.

5.7 References

- AbdelKhaleq, R. A., & Ahmed, I. A. 2007. Rainwater harvesting in ancient civilizations in Jordan. *Water Science and Technology: Water Supply*, **7(1)**: 85-93.
- Abdulla, F. A., & Al-Shareef, A. W. 2009. Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, **243(1-3)**: 195-207.
- Aladenola, O. O., and Adeboye, O. B. 2010. Assessing the potential for rainwater harvesting. *Water Resources Management*, **24(10)**: 2129-2137.
- Alamdari, N., Sample, D. J., Liu, J., & Ross, A. 2018. Assessing climate change impacts on the reliability of rainwater harvesting systems. *Resources, Conservation and Recycling*, **132**: 178-189.
- Baguma, D.; Loiskandl, W. 2010. Rainwater harvesting technologies and practises in rural Uganda: A case study. *Mitigation and Adaptation Strategies for Global Change*, **15**: 355–369
- Barthwal, S., Chandola-Barthwal, S., Goyal, H., Nirmani, B., & Awasthi, B. 2014. Socio-economic acceptance of rooftop rainwater harvesting—A case study. *Urban Water Journal*, **11(3)**: 231-239.
- De Kwaadsteniet, M., Dobrowsky, P. H., Van Deventer, A., Khan, W., & Cloete, T. E. 2013. Domestic rainwater harvesting: microbial and chemical water quality and point-of-use treatment systems. *Water, Air, & Soil Pollution*, **224(7)**: 1629.
- De Lange, Marna. 2006. War on hunger: some impacts of the DWAF Rainwater Harvesting Pilot Programme. Report to the Water Resources Finance and Pricing DWAF directorate. Department of Water Affairs and Forestry, Pretoria, South Africa. Department of Health (DOH), 2003a. Malaria. <<http://www.doh.gov.za/>
- Efe, S. I. 2006. Quality of rainwater harvesting for rural communities of Delta State, Nigeria. *Environmentalist*, **26(3)**: 175-181.
- Eggen, L. and Patrick, S. (Eds), Meerman, R., Boelee, E. & Chavez, T.J. 2015. Rainwater champions: Stories from Ethiopia, Kenya and Uganda, Amsterdam, The Netherlands.
- Fisher-Jeffes, L. N., Armitage, N. P., & Carden, K. 2017. The viability of domestic rainwater harvesting in the residential areas of the Liesbeek River Catchment, Cape Town. *Water South Africa*, **43(1)**: 81-90.
- Fujioka, R.S., 2002. Rainwater roof catchment systems, Microbial Quality of roof-harvested rainwater. *Encyclopedia of Environmental Microbiology*, **5(6)**:2674 - 2685.
- Gowing, J.W., Mahoo, H., Mzirai, O.B., & Hatibu, N. 1999. Review of rainwater harvesting

- techniques and evidence for their use in semi-arid Tanzania. *Tanzania Journal of Agriculture Science* **2(2)**:171-180.
- Helmreich, B., & Horn, H. 2009. Opportunities in rainwater harvesting. *Desalination*, **248(1-3)**: 118-124.
- Ishaku, H.T., Abayomi, A. P., Sahabo, A.A. & Dama, F.M. 2013. Complementing water supply through rainwater harvesting in some selected villages of Sahel savannah ecological zone in Borno state Northe-eastern Bigeria, *Journal of Water Resource and Protection* **5**: 200-207.
- Jones, M. P., & Hunt, W. F. 2010. Performance of rainwater harvesting systems in the southeastern United States. *Resources, Conservation and Recycling*, **54(10)**: 623-629.
- Kisakye, V., Akurut, M., & Van der Bruggen, B. 2018. Effect of Climate Change on Reliability of Rainwater Harvesting Systems for Kabarole District, Uganda. *Water*, **10(1)**: 71.
- Lasage, R. & Verburg, P.H. 2015. Evaluation of small scale water harvesting technologies for semi-arid environments. *Journal of Arid Environments* **118**: 48-57.
- Li, Z., Boyle, F. & Reynolds, A. 2010. Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination*, **260(1-3)**: 1-8.
- Murgor, F.A., Owino, J.O., Cheserek, G.J. & Saina, C.K. 2013. Factors influencing farmers' decisions to adapt rain water harvesting techniques in Keiyo District, Kenya. *Journal of Emerging Trends in Economics and Management Sciences*, **4(2)**: 133-139.
- Musayev, S., Burgess, E., & Mellor, J. 2018. A global performance assessment of rainwater harvesting under climate change. *Resources Conservation and Recycling*, **132(1)**: 62-70.
- Mwenge Kahinda, J., Taigbenu, A. E., & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35 (13)**: 742-751.
- Mwenge Kahinda, J., Lillie, E. S. B., Taigbenu, A. E., Taute, M., & Boroto, R. J. (2008). Developing suitability maps for rainwater harvesting in South Africa. *Physics and Chemistry of the Earth*, **33**:788–799.
- Mwenge Kahinda, J., Taigbenu, A. E., & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.
- National Peace Corps Association. 2015. Success stories: Katie Difilippo and water security in rural Karagwe, Tanzania. Available at <http://www.peacecorpsconnect.org/karagwesuccess>, Retrieved on 27 January 2016
- Opare, S. 2012. Rainwater harvesting: an option for sustainable rural water supply in

- Ghana. *GeoJournal*, **77**: 695-705.
- Oweis, T. Y. 2016. Rainwater harvesting for restoring degraded dry agro-pastoral ecosystems: A conceptual review of opportunities and constraints in a changing climate. *Environmental Reviews*, **25(2)**: 135-149.
- Oweis, T., & Hachum, A. 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management*, **80(1-3)**: 57-73.
- Pandey, D. N., Gupta, A. K., & Anderson, D. M. 2003. Rainwater harvesting as an adaptation to climate change. *Current science*, **81(1)**: 46-59.
- Peters, E. J. 2016. Success and Success Factors of Domestic Rainwater Harvesting Projects in the Caribbean. *Journal of Sustainable Development*, **9(5)**: 55-69.
- Saladin, M. and Bohara, C. 2016. Difficulties in replicating success stories: The case of domestic rainwater harvesting. Paper presented in the 7th Rural Supply Water Network (RWSN) Forum themed "Water for everyone" from the 29th of November to the 2nd of December in Abidjan, Cote d'Ivoire
- Salas, J.C., König, K.W. & Lo, A. 2009. Rainwater harvesting providing adaptation opportunities to climate change. In: Barron, J. (Ed.), *Rainwater Harvesting: A Lifeline for Human Well-being*. A Report Prepared for UNEP by Stockholm Environment Institute Y York, UK/Stockholm Resilience Centre, Stockholm, Sweden. ISBN: 978-92-807-3019-7.
- Thomas, T. 1998. Domestic water supply using rainwater harvesting. *Building Research & Information*, **26(2)**: 94-101.
- Terêncio, D. P. S., Fernandes, L. S., Cortes, R. M. V., Moura, J. P., & Pacheco, F. A. L. 2018. Rainwater harvesting in catchments for agro-forestry uses: A study focused on the balance between sustainability values and storage capacity. *Science of the Total Environment*, **613**: 1079-1092.
- The United Nations Human Settlements Programme (UN-Habitat). 2012. Rainwater harvesting and utilization. Blue Drop Series: Book 2: Beneficiaries and capacity builders.
- Worm, J. & van Hattum, T. 2006. Rainwater Harvesting for Domestic Use, Agrodok 43, Agromisa Foundation and CTA, Wageningen. Accessed from: www.rainfoundation.org/fileadmin/PublicSite/Manuals/AGRODOK_RWH_43-e-2006-small.pdf on the 13th of March 2018

CHAPTER 6 FEATURES OF ROOFTOP RAINWATER HARVESTING TECHNOLOGY AS PERCEIVED BY RESIDENTS OF MABAYENI VILLAGE

6.1 Abstract

Despite the potential presented by rooftop RWH as a convenient household water source, there are still challenges regarding adoption of this opportunity. This is mainly a result of limited or no participation of the end users in the technology implementation process. This has in turn, resulted in development of technologies that do not meet recipients' expectations or fail to address their needs. Therefore, the current study was conducted to engage Mabayeni community members on their specific needs with regard to the features of a rooftop RWH technology. The objective of the study was to determine the most preferred features of the RWH technology as perceived by children, youth and adults in Mabayeni village. A qualitative approach was adopted. Data was collected mainly through focus group discussions. Within focus groups, participants were further subdivided according to age and gender to check for any differences in preferred features across interest groups. Thematic content analysis through ATLAS.ti version 7.5.7 software and preference ranking were used to analyse data. Community members were able to put together the major features of the rooftop RWH. They also customized the technology to accommodate accessibility by groups such as children, the elderly and the disabled. In addition, features related to water quality, construction material and security were the most preferred across groups. The study was significant as it was a preparatory step towards developing a rooftop RWH technology best suited to mitigate the water challenges in Mabayeni. In addition, community members were involved in the idea-generation phase of the design process, something that's unusual in engineering design. Thus community members should participate in the designing of products and services that are meant to improve their lives. Their participation is vital because it provides them with an opportunity to think, learn and tailor-make products and services to suit their needs.

Key words

Household water source, Mabayeni village, rooftop rainwater harvesting technology, water scarcity

6.2 Introduction

Although a number of RWH practices were considered, rooftop RWH was the most preferred as it presented a number of advantages. This justified concentrating on the features of this technology as it was believed to be the best intervention for inadequate availability of water in Mabayeni village. Developing a rooftop RWH technology for any community requires adequate and relevant information. This information should relate to resources that are available as well as the needs and preferences of that particular community. Needs and preferences of the end user should primarily inform the type of RWH system that is developed. Success stories on RWH technologies (Gould & Nissen-Petersen, 2003; Deffner & Mazambani, 2010; Waltersdorf *et al.*, 2014; Eggens & Patrick, 2015; National Peace Corps Association, 2015) highlight the importance of active community involvement in the process of developing RWH technologies. In fact, it is the expert-oriented approach that led to failure of some RWH systems even in South Africa for instance, the Kleinmond Housing Scheme (Van Vuuren, 2013). When community members are not involved, the chances that the technology will be appropriate for them are slim. In addition, there will be little incentive for them to take care of the technology. Therefore, it is essential for beneficiaries to take up active roles in the designing of technologies that are meant to benefit them. That way, the end users assume ownership and become confident with taking care of the technologies that are meant to improve their lives.

Emphasis in the current study was on having end users participate in a process of designing a RWH technology from the beginning until the end, and decide on the components that make up RWH technologies suiting their circumstances. However, some basic features of rooftop RWH technology are available in literature. These features have been used by engineers to guide the designing of RWH technologies for individual households, industries and communities in different locations. The most basic components of a RWH system are the catchment, delivery system or guttering, and the storage reservoir (Thomas, 1998; Sturm *et al.*, 2009). Additional features such as the gutter screen, first flush device and filtration unit are mainly meant to improve the quality of harvested water (Morey *et al.*, 2016) and to minimize rainwater loss such as flow deflectors and splash guards (Smet *et al.*, 2005). However, Mabayeni community members had to define and prioritise the components of features that would make up a RWH technology that would be suitable for their village.

Authors such as Mwenge-Kahinda *et al.* (2010), Haque *et al.* (2016) and Campisano *et al.* (2017) provide definitions of the main components of RWH system. A catchment or collection area is the surface on which rainwater falls. Delivery system or guttering which is also called the conveyance system, is used to transfer collected rainwater to the storage tank. It comprises of gutters or flat roof drainage holes, downspouts and piping (Campisano *et al.*, 2017). The storage reservoir may be positioned above or below ground. It can consist of single or multiple containers. Gutter screen, which is also called coarse mesh or leaf screen is provided at the mouth of the inflow pipe. It is meant to prevent the entry of leaves and other debris into the system (Indian Railways Institute of Civil Engineering [IRICEN], 2006; Ferrand & Cecunjanin, 2014). The first flush device is a device that dispose of the first spell of dirty rainwater so that it does not enter the system (Ferrand & Cecunjanin, 2014). A filtration unit is required if the collected water from rooftop is to be used for human consumption directly. This filter is used to remove suspended pollutants from rainwater collected from the roof. The filter unit is a chamber filled with filtering media such as fiber, coarse sand and gravel layers to remove debris and dirt from water before it enters the storage tank (IRICEN, 2006).

The features described above are the most common and not necessarily an exhaustive list. Other optional features may be added depending on the characteristics of a locality. It is for this reason that the study was aimed at describing and explaining community-preferred features of a RWH technology with the best potential to increase access to water for multiple domestic uses in Mabayeni village. The objectives of the study were to determine the most important components or features that would make up the RWH system as perceived by community members, to compare the technology features that people of different age groups preferred, and to determine the RWH technology option believed to have the best potential to increase access to water in the village. As indicated in the previous chapter, Mabayeni community members specified that they preferred the rooftop RWH technology mainly because it enabled them to collect clean water. This study extended the conversation by allowing community members to come up with the RWH features that would satisfy their circumstantial needs. This needs-based approach was adopted to ensure that the technology was tailor-made for community needs. This eliminated the possibility of designing a technology that would fail to meet community needs.

6.3 Methodology

6.3.1 Research design

A combination of case study and action research designs (Figure 6.1) were used in this chapter. The case study design together with research philosophy have been explained in Chapter 3 and thus are not explained further in this chapter. With respect to action research design, Pearson & Bacon (2007) reveal that it follows a characteristic cycle whereby initially an exploratory stance is adopted. This involves building an understanding of a problem and developing an intervention strategy. During this process, observations regarding the intervention are collected in various forms. After implementing the intervention strategies, the cyclic process is repeated until a sufficient understanding of the problem is achieved (Pearson & Bacon, 2007). In this study, the preferred features were extensively explored with the aim, and in preparation for designing a community-informed RWH technology option.

6.3.2 Population and sampling procedures

The sampling procedures followed in this study were the same as those described in the previous chapters. Three focus group discussions focusing on the features of RWH technology were held with the eight interest groups referred to in the Chapters 3-5. Gender and age were taken into account when establishing the focus groups. As already explained in Chapters 4 and 5, residents of the driest section of the village constituted their own group. This was maintained to check if their preferred features would be the same as those of participants coming from the other parts of the village.

6.3.3 Data collection

Secondary data on components of rooftop RWH technologies was collected from credible internet sources such as peer reviewed online journal articles, books and book chapters, technical guides, handbooks and relevant manuals. Primary data was collected through focus group discussions. Within the focus groups, respondents engaged in data collection techniques such as brainstorming, paper illustrations and drawing to visualise the RWH technology of choice. Tools such as pencils, pens, plain paper and flip charts were used for illustrations, while proceedings of engagements were recorded using tape recorders and a camera.

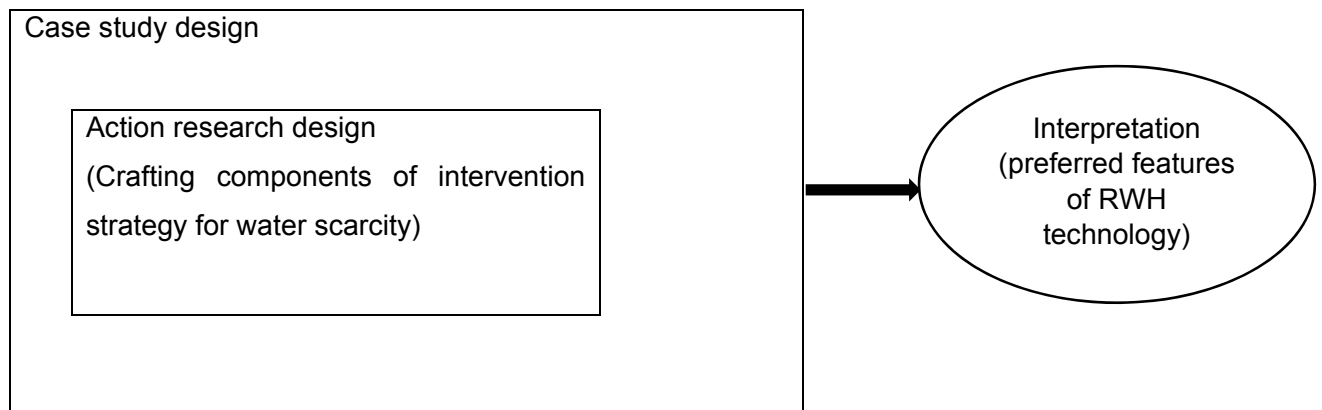


Figure 6.1 A depiction of the embedded research design used in the study

6.3.4 Data analysis

Various data analysis techniques were used. Qualitative data was entered into ATLAS.ti version 7.5.7 software for analysis and code-based networks were developed to summarize emerging themes. The component features of the RWH technology which emerged from the ATLAS.ti analysis were ranked according to preference using the matrix scoring. This was done to understand the components which were perceived by community members as most important. When ranking, 1 indicated the most important feature while 8 represented least important. The results were consolidated per component and ranks were combined for all interest groups. The reason being to ascertain the components that were generally considered to be the most important. A separate column was created to display their order of importance. In addition, the rooftop RWH tank options which emerged from thematic content analysis were also ranked according to preference. This was done in order to establish the rainwater storage tank option which suited community needs the most. Regarding rooftop rainwater storage tank options, a low rank indicated a feature that was most preferred. Similarly, a column was created to show the technology options in their order of preference. Participants provided descriptions to justify the most preferred RWH technology option.

6.3.5 Ethical clearance

Ethical clearance procedures were appropriately adhered to as explained in Chapter 3. Issues to do with voluntary and informed consent were addressed and bias and deception were avoided. This was achieved through explaining in detail how the study stood to benefit both the researcher and the community. The concept of beneficence (Churchill, 1995) was widely observed. The purpose of the study and the benefits that would accrue from it were explained in detail to participants without exaggerating or underestimating the benefits. Participants were updated on the progress of the research at every stage of data collection and also the ultimate goal of designing a technology that would help increase water access as a long term benefit for the community.

6.4 Results

Nine main features of a rooftop RWH technology suitable for Mabayeni village emerged (Figure 6.2). These were shape of tank, capacity of storage tank, construction material, the delivery system, security, tank housing, water access, water quality as well as water conservation. In addition, participants highlighted the challenges that were experienced with RWH. Furthermore,

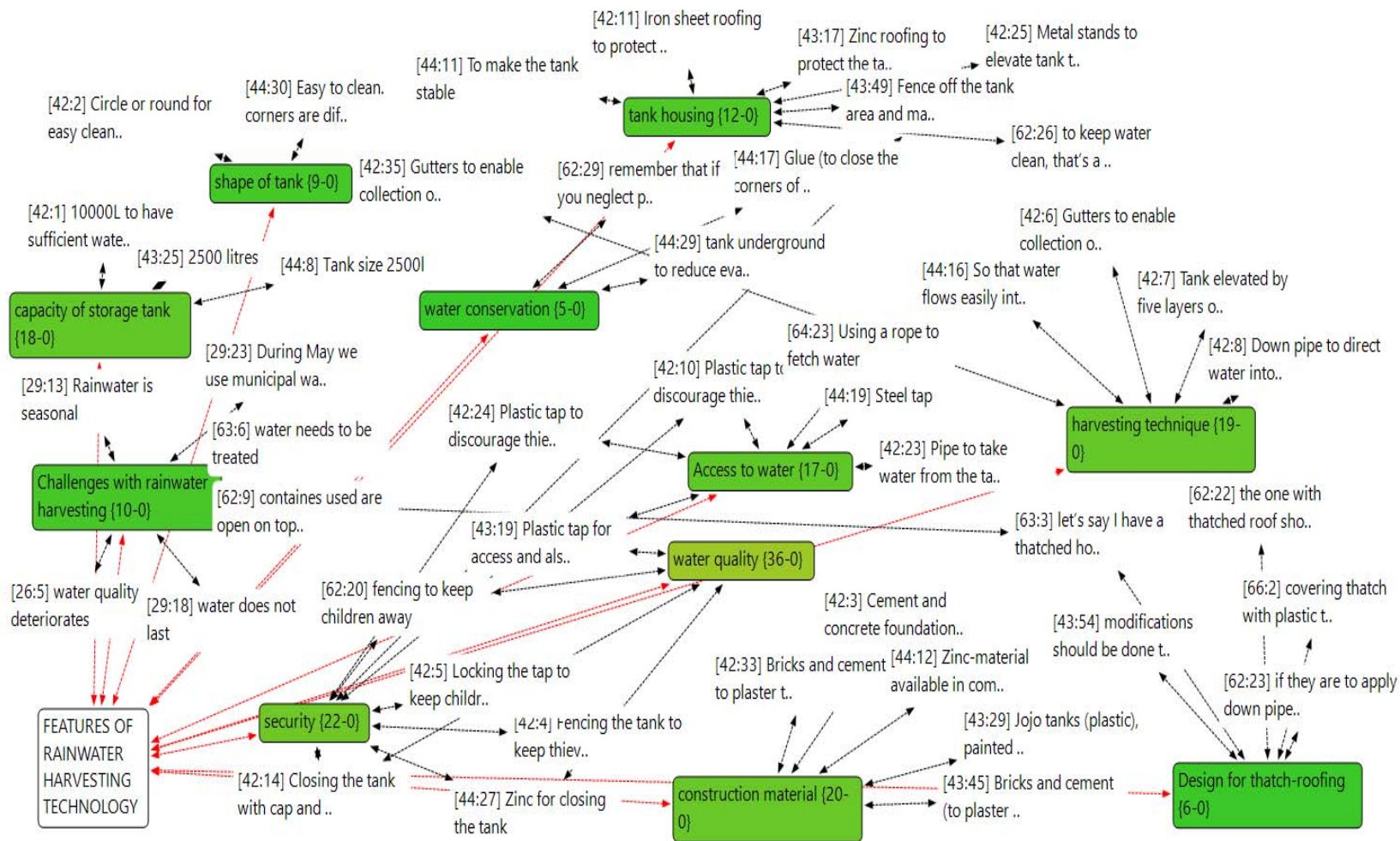
they emphasized the need for designing a technology for harvesting water for residents who stayed in thatch-roofed houses. As shown in Table 6.1, the most important features were water quality, construction material and security. Delivery system, shape of tank, and access to water were regarded as least important. All the interest groups unanimously indicated that water quality was the most important issue to consider when designing a rainwater RWH. This was also confirmed in Figure 6.2. Water quality had the highest density score of 36, indicating that it was the most discussed theme out of the eleven. Participants also indicated that they preferred different sizes of storage tanks. The volumes that were given ranged between 2 500 and 10 000 litres as these amounts were believed to be sufficient for the important household uses.

The elderly people also placed more importance on access to water and security, but did not view construction material as important. While the adult groups, residents of Magangeni sub-village, female youth, the group of elderly people, and girls viewed security as one of the important components to consider when designing a RWH technology. The male youth and boys disagreed with the views. In fact, boys and male youth regarded water conservation and tank housing respectively, as more important than security. For residents of Magangeni sub-village and boys, water conservation was the second most important issue to consider when designing a technology for harvesting rainwater from the rooftops.

Four rooftop RWH technology options also emerged (Table 6.2). The first option was “slightly elevated brick and mortar tank”, followed by “*Jojo* tank elevated by metal stands”, then “zinc tank elevated by metal stands” and lastly, “underground tank.” For the first option, the construction materials were brick and mortar with concrete foundation. Respondents suggested that the tank should be elevated with five layers of bricks to increase water pressure. For option two, participants proposed having a *Jojo* tank elevated with metal stands raised on cement foundation. The tank for the third option was to be made of zinc material and elevated with metal stands raised on cement foundation. Lastly, community members proposed using brick and mortar to build the water tank underground. This tank would have a concrete foundation and reinforced with wire mesh or brick force. Details of each option are described in Table 6.2.

Table 6.1 The most important features of rainwater harvesting technology as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Component	Adults		Elderly people	Youth		Children		Magangeni sub-village	Total rank	Overall rank
	Men	Women		Female	Male	boys	girls			
a) Water Quality	1	1	1	1	1	1	1	1	8	1
b) Construction material	2	5	6	2	2	2	1	2	22	2
c) Security	3	2	1	4	6	6	4	5	31	3
d) Tank housing	5	4	8	5	3	4	1	7	37	4
e) Water conservation	8	5	6	6	4	2	5	2	38	5
f) Shape	7	2	4	3	6	7	8	5	42	6
g) Access to water	5	7	1	7	5	4	6	7	42	6
h) Delivery System	4	8	4	8	6	8	7	4	49	8



*Brighter background colours indicate most discussed themes

Figure 6.2 Features of rainwater harvesting technology as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 6.2 The different rooftop rainwater harvesting technology options emerging in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Variable considered	Option 1: Tank on the ground (slightly elevated with five layers of bricks)	Option 2 and 3: Tank elevated by metal stands		Option 4: Underground tank
a) Shape:	Circle or round for easy cleaning	Circle or round for easy cleaning	Circle or round for easy cleaning	Circle or round for easy cleaning
b) Construction material:	Brick and cement for tank and concrete for foundation	Elevated <i>Jojo</i> tank with cement foundation for metal stands	Tank made of zinc, use of glue to seal and paint to prevent rusting	Underground concrete and cement tank
c) Harvesting technology:	Gutters, tank and downpipe	Gutters, tank and downpipe	Gutters, tank and downpipe	Gutters, tank and downpipe
d) Security:	Fencing, locking, use of plastic tap	Tank elevated about 6 metres for security reasons	Fencing, locking, use of plastic tap	Fencing and locking
e) Tank housing:	Iron sheet roofing	Metal stands to elevate tank to increase water pressure, to stabilize tank and protect it from wind and rain. Also durable, would not be affected by termites	Zinc roofing because it is cheap and locally available	Not needed.
f) Water access:	Pipe to take water from the tank into the house for disabled, children and elderly people; tap to access water from the tank	Pipe to take water from tank to house for disabled, children and elderly	Pipe to take water from the tank into the house for disabled, children and elderly people,	Using buckets to fetch water using a rope
g) Water quality:	Use of gutter screens; closing the tank with cap and locking for cleaning and maintenance	Gutter screens and cleaning the tank	Gutter screens and cleaning the tank	Elevated paving to keep dirty water from flowing into the tank. Covering the tank with zinc cap
h) Water conservation:	Creating a cement water holding structure to collect excess water from the tank	No need to conserve water. Once the tank is full there is no need for more water	Creating a cement water holding structure to collect excess water from the tank	Creating a channel to direct water outside the tank when full

Local residents of Mabayeni were also given the four rooftop RWH technology options to rank in order of preference. As shown in Table 6.3, the most preferred RWH technology was the option using the “slightly elevated brick and mortar tank”. Only boy children preferred a rooftop RWH technology option using *Jojo* tank elevated by metal stands. The boys indicated that they preferred a *Jojo* tank for water storage because they argued that it was durable. However, the rest of the interest groups preferred a RWH technology using a storage tank constructed using brick and mortar and slightly elevated from the ground. It should also be noted that there were no differences in preferences observed between Mabayeni residence and Magangeni sub-village. Results of the ranking exercise and the explanations for rooftop RWH technology choice are presented in Table 6.3.

Participants also gave details on the selected RWH technology option which was the slightly elevated brick and mortar tank. They provided the preferred materials that would be used to construct each component giving reasons (Figure 6.3). As indicated in Table 6.2, a round shape was preferred for the tank because it was easy to clean. Its location was at least 2 metres away from the house. As already indicated, the preferred construction material was brick and mortar reinforced with wire mesh or brick force for strength. The tank would also have a concrete foundation to stop water from seeping away. With regard to the conveyance system, locally available zinc material would be used to make gutters.

In order to prevent rusting, paint coating was suggested. For down pipes, Mabayeni residents recommended Polyvinyl chloride (PVC) pipes which would be bought from local hardware stores. Community members also preferred slightly raising the tank from the ground with five layers of brick to increase water pressure. For security reasons, the tank would be fenced using razor wire. This was done to keep children, thieves and animals away. They further explained that children would be warned about the dangers of razor wire so that they avoid playing near it. One respondent explained:

“We want razor wire because we would want to protect our water tanks even from thieves...even children will know that it is dangerous therefore they will not play near it.”
[adult woman]

Table 6.3 The most preferred rooftop rainwater harvesting technology option in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Technology Option	Adults		Elderly people	Youth		Magangeni sub-village	Children		Total rank	Overall rank	Explanation for choice
	Men	Women		Female	Male		Boys	Girls			
1. Slightly elevated brick and mortar tank	1	1	1	1	1	1	2	1	9	1	It is durable, affordable, building materials are locally available, can harvest clean water, tank is easy to clean
2. Jojo tank elevated by metal stands	2	3	2	3	2	2	1	2	17	2	Tank is expensive and difficult to clean
3. Zinc tank elevated by metal stands	3	2	3	2	4	3	3	3	23	3	Zinc material does not last long, risk of rusting and contaminating water
4. Underground tank	4	4	4	4	3	4	4	4	31	4	Risk of children drowning, and water can easily be contaminated by fetching with buckets. It would also be difficult to fetch water when water level drops.

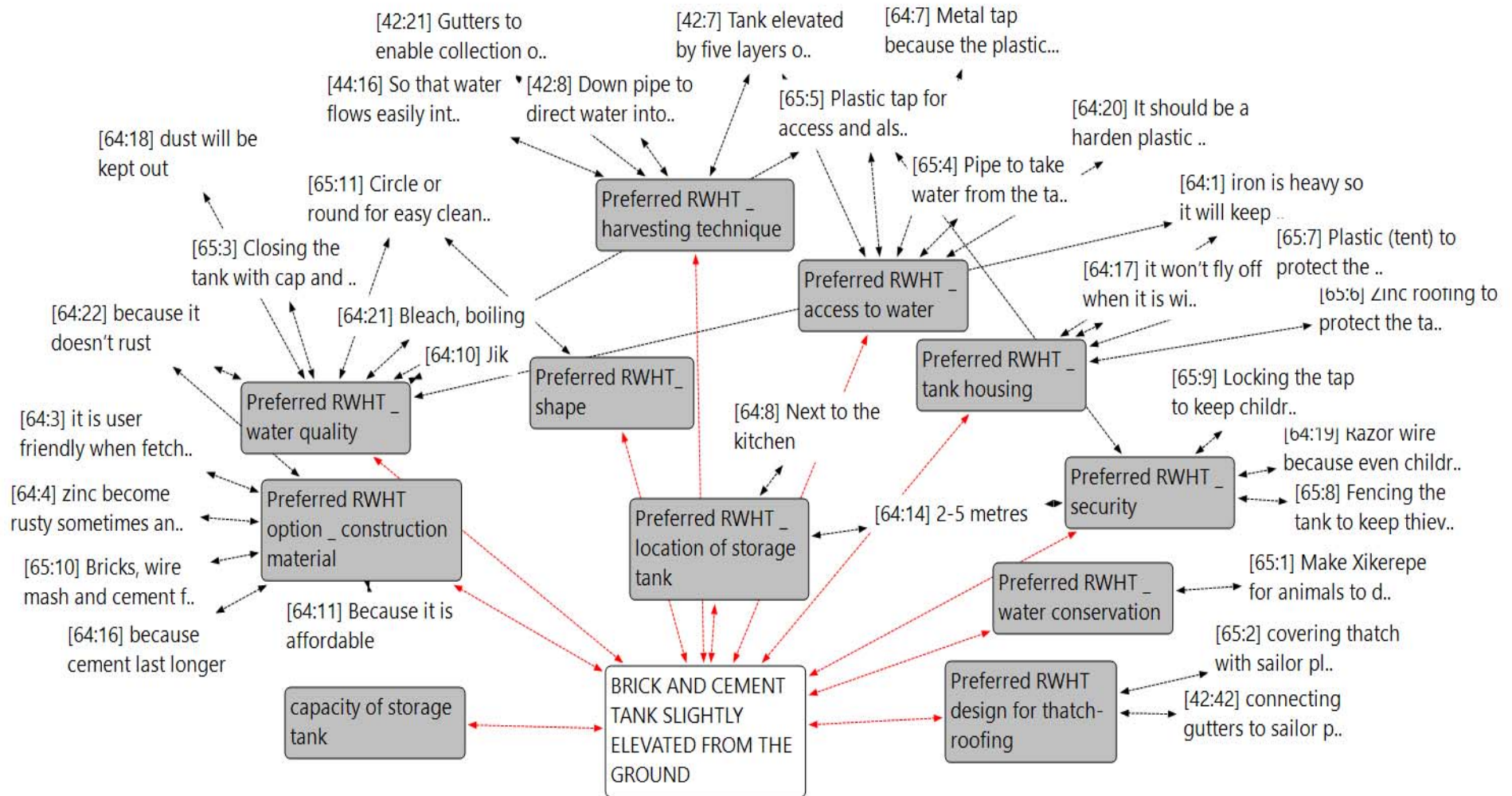


Figure 6.3 Preferred features of rainwater harvesting technology and their explanations as perceived by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

It was further recommended that the taps be kept under lock and key to prevent children from playing with water. In addition, because a lot of the public municipal taps in the village were stolen, residents of Mabayeni preferred using plastic taps on the RWH storage tank to discourage thieves. In addition, the different groups of participants in Mabayeni village preferred to have two water access outlets that is, one that would be split into two for different household uses. One pipe would go into the kitchen for the convenience of old people, children and people with disabilities. This water would be used for indoor potable uses such as cooking and drinking. The other outlet would be left outside to fetch water for uses such as bathing, washing clothes and washing dishes to avoid untidiness in the house.

To ensure that harvested rainwater was of good quality, participants suggested the use of gutter screens to prevent leaves, bird droppings and other physical dirt from entering the system through the downpipe. In addition, community members suggested closing the tank with a cap and lock it to allow for easy opening to clean the tank. It was also proposed that the opening into the tank be at the top of the tank from which a person would get in to clean the tank properly. A filtering system was also added above the tank to filter small physical particles before water enters the storage tank. A mechanism was also proposed to conserve water after the RWH tank gets full. Participants suggested linking the RWH storage tank with a water holding structure such as a well or *Xikerepe* through an overflow pipe to avoid water loss. This water would be used for other non-potable uses such as laundry, gardening or animal drinking depending on the size of the water holding structure, and the size of the family. This was also a security feature since overflowing water from the tank would cause flooding which could become a breeding site for mosquitoes.

6.5 Discussion

Results indicated that residents of Mabayeni managed to come up with all the critical components of the desired RWH system although they were not harvesting rainwater systematically from their roofs. The identified features captured the main components of RWH technology which are catchment area, transportation or delivery system, as well as storage (Sturm *et al.*, 2009; Li *et al.*, 2010; Haque *et al.*, 2016; Morey *et al.*, 2016). Participants should be applauded for managing to customise the design of the rooftop RWH technology to suit their needs. They incorporated additional features relating to water quality, safety and security of the residents, water access, and water conservation which they found relevant to their everyday needs.

Participants explained that it would not make sense to build a rooftop RWH technology that would collect unclean water and was inaccessible to the elderly and disabled people. The water quality-

related features revealed how determined community members were in getting clean potable water. Apart from using purification chemicals such as Sodium Hypochlorite (jik), participants found it necessary to physically clean the tank thus warranting the need for a manhole to enable access for maintenance and cleaning. The need for a manhole has also been recommended by Chidi (2010). As advised by The Texas Manual on Rainwater Harvesting, a filtration device is regarded important for removal of small physical particles before water enters the storage tank. Other water purification options that could be used are ozonation, reverse osmosis, ultraviolet (UV) light as explained in the Virginia Rainwater Harvesting Manual (2007).

Participants also highlighted that they could not afford to waste any drop of water since it was a scarce resource. This justified adding another structure (water holding structure) to tap excess collected water. This is one technology feature that can easily be missed by an outside designer. Nonetheless, this is a critical element that may contribute to adoption of the RWH technology. Thus employing a needs and demand-based approach in deciding the components that would make up the desired rooftop RWH technology offered the best chance of ensuring the appropriateness of the technology (Tayal, 2013). In fact, it is regarded as one of the success factors in RWH systems (Worm & Hattum, 2006).

The rough estimates of the preferred sizes of water storage containers varied greatly amongst groups. A huge difference in the proposed volumes could have been influenced by community members' exposure to different sizes of *Jojo* tanks. This difference could also have been due to the variation in household sizes which translated to the demand of water in a household. However, according to Worm & Hattum (2006), and Mwenge-Kahinda (2007), in addition to water demand, RWH tank size is determined by the amount of rainfall received in an area, the catchment area and the runoff coefficient as well as available resources. Pelak & Porporato (2016) added availability of resources as another important determinant of storage tank size.

Regarding the shape of tank, Mabayeni residents' shape preference finds support in Mati's (2005) work. A round or cylindrical shape was preferred because it would be easy to clean. Participants explained the difficulties associated with cleaning a tank with corners. Mati (2005) argues that rectangular and square-shaped tanks also have a tendency of cracking. Mati (2005) and Manual (2007) recommend spherical, hemi-spherical or cylindrical shapes when constructing water storage tanks because they distribute load uniformly on the walls of the tank, reducing uneven tension and the possibility of cracking. With regard to the distance of the tank from the house,

Mabayeni residents suggested a distance of at least two metres from the house in order to enable them to hear thieves at night. The other reason was safety. A two-metre distance was regarded as a safe distance in case of a disaster (collapse of the tank). This is supported by Macomber (2001) who also recommends a minimum distance of 90 cm between the storage tank and the house. The latter author also suggests that overflow water must be diverted away from the house to maintain the foundation's integrity.

Water quality, construction material, and security emerged as the most valuable components because they ensured that harvested water was safe for drinking, the tank was durable and secured (especially the taps) from thieves. Participants openly indicated that they wanted to use rainwater for potable uses in order to avoid purification costs. They also wished to save time and energy associated with fetching unclean water from distant sources and boiling it. Thomas (1998) and Chidi (2010) indicate that specifications about water quality depend on intended water use. Unlike in some developed countries especially in Europe where RWH is motivated by environmental reasons (Yan *et al.*, 2018), in Africa especially SSA, RWH is motivated by shortage of water for household use including potable use. In Europe, harvested rainwater is mainly for uses such as flushing toilets, irrigation, washing cars and for ground seepage (Thomas, 1998; Salas, 2007). In Mabayeni village, rainwater was used to meet potable supply needs. The expectation in Mabayeni village was therefore to use water for potable domestic uses. This concurs with Abdulla & Al-Shareef (2009), Yeasmin (2013) and Peters (2016) who indicated that rainwater is generally safe to drink and may not require treatment. However, Malema *et al.* (2018) and Chubaka *et al.* (2018) insist that rainwater be treated following the detection of various pathogenic organisms in rainwater samples.

Construction material for the storage tank was also regarded as a critical component of the RWH system because participants wanted a durable RWH tank. Since the expectation was to have a system that would last them more than 15 years, Mabayeni residents emphasized construction material that would meet their expectation. They also wanted a technology that would last longer than the perceived lifespan of a *Jojo* tank. This shows that they were preparing for a long term solution. Moreover, the construction materials identified did not only address durability issues. They also addressed affordability and water quality issues. Most respondents valued construction material of the tank because it would store all the harvested rainwater making it a high risk component that demanded great care. Thomas (1998), Parsons *et al.* (2010), Morey *et al.* (2016), Khoury-Nolde (2016) and Compisano (2017) also postulate that the tank is the most expensive

of all the components of a RWH system. Mati (2005) therefore, cautioned that care be taken when building the tank. This is because any mistakes resulting in cracks are difficult to repair. At worst, poor investment into construction of the storage tank can lead to loss of all the harvested water. Chidi (2010) recommends brick and mortar tanks as long as the materials are locally available and affordable. Mati (2005) on the other hand, emphasizes that tanks should be adequately reinforced and plastered to avoid cracks.

Security was also selected as one of the most important components of a RWH system. Participants explained that the water tank needed security features to protect water from thieves and children. There is a dearth of information from literature supporting the need to secure water from thieves. Stealing of water could have been an exceptional occurrence in Mabayeni village because the area was experiencing severe water scarcity. However, securing water access points has been recommended to prevent children from wasting the scarce but valuable resource, as well as preventing contamination (The Texas manual on Rainwater Harvesting, 2005; Khoury-Nolde, 2016). Apart from water quality, the elderly people were more concerned about security of water probably because they felt they were no longer physically strong to protect their household resources, including harvested rainwater. They actually indicated that thieves targeted households that only had women or the elderly. Therefore, in the event that the RWH technology was installed, it would need some form of security. On the contrary, boy children and male youth did not value security but water conservation and tank housing. With security, it could have been because they did not see water theft as a threat.

With regards to water conservation, it is likely that these groups valued conserving water since fetching water was not one of their favourite chores. During focus group interviews males indicated that fetching water was a chore for women. But due to the water shortages in the village, they were forced to help out. Therefore, conserving water through channelling it to a watering trough would mean that water would be available for longer, and they would not have to help with collection of water from other distant sources. Baguma *et al.* (2010) and Baguma *et al.* (2013) acknowledged the gender roles associated with water collection in rural communities.

Regarding water access, the elderly also felt that they were not strong enough to fetch water for cooking from outside. This would particularly be a challenge to those elderly people staying on their own as well as people living with disability. Suggested water access features would therefore, allow them to fetch water from inside the house. Halloway (1977) and Rogers (2004)

describe image and relative advantage as important factors determining adoption of a RWH technology. The authors note that improvement of social status is one goal that should be achieved if a technology is to be valued and adopted. Critchley & Siegert (1991) add that the technology should also go hand in hand with people's priorities and infrastructure should meet the needs of the individuals meant to use it. The elderly people therefore, came up with a simple way of customizing the technology which increased their net benefit (Castonguay *et al.*, 2018) and chances of adopting it. This is yet another feature that could have been missed by an outside designer with no knowledge of end-user community priorities. Yet it is very crucial.

After going through a process of brainstorm-design-review, and imagining the four proposed technology solutions, residents of Mabayeni village selected the technology option that they believed was the best. Tayal (2013) argues that brainstorming is an important process which ensures that participant designers interrogate all the possible solution options and come up with the best. Mabayeni residents unanimously chose a technology using the above ground tank. The tank would be slightly elevated with five layers of bricks. This technology option was preferred the most because it was believed to be durable, affordable, the building materials were locally available, could harvest clean water, and tank could be physically cleaned. Furthermore, this option was regarded as flexible in terms of sizing since it allowed households to design tanks according to their preference. This was unlike *Jojo* tanks that came in specific sizes. However, as indicated above, the size of a storage tank is dictated by the roof area, amount of water required by the users, or the costs associated with installing the tank (Worm & Hattum, 2006; Kinkade-Levario, 2007; Pelak & Porporato, 2016). Otherwise, it would be a waste of resources to build a tank bigger than the rainfall supply in the area. The same applies for use, there would be no point in building a tank that harvests more than the required water.

The remaining three options (*Jojo* tank, zinc tank and underground tank) were rejected for different reasons. The *Jojo* tank was rejected because it was said to be expensive and difficult to clean. As indicated above, participants were very clear that they wanted clean water through incorporating pre-storage water safety features and post-storage rainwater treatment (Campisano *et al.* (2017). They emphasized their preparedness to physically clean the tank. Kinkade-Levario, (2007) also emphasizes that the tank should be accessible for cleaning, inspection and maintenance. The zinc tank was overruled because zinc material would not last longer and presented the risk of rusting and contaminating the water. This perception finds support in the Gwenzi *et al.*'s (2015) work. The author argues that the nature and concentrations of the

contaminants in roof water largely depends not only on the source and anthropogenic activities, but also on the flow pathways and interactions with the environment. In addition, a study done in Nigeria by Adeniji & Olabanji (2005) revealed that direct leaching of roof materials by chemical reactions was the main source of contamination on iron, aluminium and zinc sheets.

The underground tank was dismissed due to a number of reasons. It was meant to be closed with a light moveable lid. This presented the risk of drowning especially for children. Another reason was that it would be difficult to fetch water from the underground tank when the water level dropped. In addition, drawing water with buckets also presented a health risk as water would easily be contaminated through fetching with buckets. Sazakli *et al.* (2007) propound that in addition to catchment characteristics, weather, topography and proximity of harvesting area to pollution sources, harvested rainwater quality can be compromised during handling and management. Handling and management of water involves contamination at point of fetching, which should be avoided at all costs. Authors such as Thomas (1998) and Helmreich & Horn (2009) argue that underground tanks possess significant disadvantages such as the need for pumps, the difficulty in monitoring leakage flows, as well as the possibility of contamination from human, animal or other environmental contaminants.

An examination of the materials that were preferred for use in developing the selected rooftop RWH technology revealed that community members valued materials that possessed a combination of characteristics. Selected materials were affordable, locally available, durable, and ensured collection of good quality water. These conditions were consistently raised since the commencement of discussions on RWH. However, in some cases, these characteristics were found to be conflicting. Some of the available materials could not guarantee the other desired qualities. For example, while locally available materials such as brick, mortar and wire mesh would guarantee a durable storage tank, zinc material though locally available, would present issues such as rusting which would contaminate the water.

Lee *et al.* (2010) maintain that the quality of harvested water depends largely on the materials used to construct the RWH system. Zinc material was recommended in constructing the gutters. Mabayeni residents suggested applying protective coating (such as paint) inside the gutters to prevent rusting (also recommended by Ward *et al.*, 2010). However, Practical Action (2009) discourages the use of paint in the RWH systems since it releases toxic substances when it peels off. Participants also suggested the use of plastic taps to discourage thieves and also prevent

rusting. Although plastic taps would be a possible solution to these risks, their durability was questioned. The Texas Manual on Rainwater Harvesting (2005) recommends good quality taps that are durable. Otherwise, cheap or malfunctioning taps would present a bigger risk of losing all the harvested water. Plastic taps are also discouraged because they don't dispense water efficiently (Practical Action, 2009). In light of these complications, participants had to prioritize features based on their expected performance of the technology.

6.6 Conclusion

Community members were able to come up with the basic features of a RWH system. These were shape of tank, size of tank, delivery system, access to water, water conservation, tank housing, construction material, security, and water quality. Out of these components, those ranked as important were water quality, construction material and security-related features. The selected RWH option and the reasons given by community members confirmed the preferred features of the rooftop RWH technology needed in Mabayeni village as a whole, including Magangeni area. No differences in preferred features or technology for harvesting rainwater from rooftops were observed between Mabayeni village and Magangeni sub-village. Participants desired a rooftop RWH technology that could; harvest clean water, would not pose excessive additional costs, had safety and security features, was convenient, durable, and could be built using locally available materials. However, in some cases, the available materials could not meet the technology standards that satisfied community members. This present a gap that other outside stakeholders such as the government, NGOs and private sector should fill. The process followed in developing a rooftop RWH technology is presented in the next chapter.

6.7 References

- Abdulla, F.A. & Al-Shareef, A. 2009. Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, **243(1)**:195-207
- Adeniyi, I.F. & Olabanji, I.O. 2005. The physico-chemical and bacteriological quality of rainwater collected over different roofing materials in Ile-Ife, southwestern Nigeria. *Chemistry Ecology*, **21**: 149-166.
- Akpinar Ferrand, E., & Cecunjanin, F. 2014. Potential of rainwater harvesting in a thirsty world: a survey of ancient and traditional rainwater harvesting applications. *Geography Compass*, **8(6)**: 395-413.
- Baguma, D., Loiskandl, W. & Jung, H. 2010. Water management, rain water harvesting and Predictive Valuables in Rural Households, *Journal of Water Resource Management*, **24**: 3333- 3348.
- Baguma, D., Hashim, J. H., Aljunid, S. M., & Loiskandl, W. 2013. Safe-water shortages, gender perspectives, and related challenges in developing countries: The case of Uganda. *Science of the Total Environment*, **442**: 96-102.
- Campisano, A., Butler, D., Ward, S., Burns, M.J., Friedler, E., DeBusk, K., Fisher-Jeffes, L.N., Ghisi, E., Rahman, A., Furumai, H. & Han, M. 2017. Urban rainwater harvesting systems: Research, implementation and future perspectives. *Water research*, **115**: 195-209.
- Castonguay, A. C., Urich, C., Iftekhar, M. S., & Deletic, A. 2018. Modelling urban water management transitions: A case of rainwater harvesting. *Environmental Modelling & Software*, **105**: 270-285.
- Chidi, M. C. 2010. Rainwater harvesting: a technical guide available on <https://researchspace.csir.co.za/dspace/bitstream/handle/10204/3944/Chibi.pdf?sequence=1> Retrieved on 10 February 2018
- Chubaka, C. E., Whiley, H., Edwards, J. W., & Ross, K. E. 2018. A Review of Roof Harvested Rainwater in Australia. *Journal of Environmental and Public Health*, **2018**: 1-14.
- Churchill, L.R. 1995. Beneficence. *Encyclopedia of Bioethics*. New York: Simon & Shuster Macmillan
- Critchley, W., Siegert, K., & Chapman, C. 1991. Water harvesting. *FAO, Rome*.
- Deffner, J. & Mazambani, C. 2010. Participatory empirical research on water and sanitation demand in Central-Northern Namibia: a method for technology development with a user perspective. CuveWaters Papers, No. 7, Institute for Social-Ecological Research (ISOE), Frankfurt/Main, Germany.

- Eggens, L. & Patrick, S. (Eds), Meerman, R., Boelee, E. and Chavez, T.J. 2015. Rainwater champions: Stories from Ethiopia, Kenya and Uganda, Amsterdam, The Netherlands.
- Gould, J. & Nissen-Petersen, E. 2003. Rainwater Catchment Systems for Domestic Supply – Design, Construction and Implementation. ITDG Publishing, London.
- Gwenzi, W., Dunjana, N., Pisa, C., Tauro, T., & Nyamadzawo, G. 2015. Water quality and public health risks associated with roof rainwater harvesting systems for potable supply: Review and perspectives. *Sustainability of Water Quality and Ecology*, **6**: 107-118.
- Haque, M. M., Rahman, A., & Samali, B. 2016. Evaluation of climate change impacts on rainwater harvesting. *Journal of Cleaner Production*, **137**: 60-69.
- Helmreich, B., & Horn, H. 2009. Opportunities in rainwater harvesting. *Desalination*, **248(1-3)**: 118-124.
- Holloway, R. E. 1977. Perceptions of an innovation: Syracuse University's Project Advance. PhD thesis, in Rogers, E. M. 2003. Diffusion of Innovations (5th edition). New York: Free Press.
- Indian Railways Institute of Civil Engineering (IRICEN). 2006. Rain Water Harvesting. A Publication of Indian Railways Institute of Civil Engineering, Pune. Available at http://www.sswm.info/sites/default/files/reference_attachments/IRIC... Retrieved on 12 January 2017
- Khoury-Nolde, N. 2016. Rainwater harvesting. *Zero M. Germany*. Available at [http://www.ercsa.eu/uploads/media/Rainwater Harvesting - an overview .pdf](http://www.ercsa.eu/uploads/media/Rainwater_Harvesting_-_an_overview_.pdf) Retrieved on 20 May 2018
- Kinkade-Levario, H. 2007. *Design for water: Rainwater harvesting, stormwater catchment, and alternate water reuse*. New society publishers.
- Li, Z., Boyle, F., & Reynolds, A. 2010. Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination*, **260(1-3)**: 1-8.
- Malema, M. S., Abia, A. L. K., Tandlich, R., Zuma, B., Kahinda, J. M. M., & Ubomba-Jaswa, E. 2018. Antibiotic-Resistant Pathogenic Escherichia Coli Isolated from Rooftop Rainwater-Harvesting Tanks in the Eastern Cape, South Africa. *International journal of environmental research and public health*, **15(5)**: 1-14
- Mati, B. M., Malesu, M. & Oduor, A. 2005. Promoting rainwater harvesting in Eastern and Southern Africa: The RELMA experience, Working Paper no. 24, World Agroforestry Centre.
- Morey, A., Dhurve, B., Haste, V., & Wasnik, B. 2016. Rainwater harvesting system. *International Research Journal of Engineering and Technology*, **3(4)**: 2158-2162.
- Mwenge-Kahinda, J.M.; Taigbenu, A.E.; Boroto, J.R. 2007. Domestic rainwater harvesting to

- improve water supply in rural South Africa. *Physics and Chemistry of the Earth*, **32**: 1050–1057
- Mwenge Kahinda, J., Taigbenu, A. E., & Boroto, R. J. 2010. Domestic rainwater harvesting as an adaptation measure to climate change in South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* **35(13)**: 742-751.
- National Peace Corps Association. 2015. Success stories: Katie Difilippo and water security in rural Karagwe, Tanzania. Available at <http://www.peacecorpsconnect.org/karagwesuccess>, Retrieved on 27 January 2016
- Parsons, D., Goodhew, S., Fewkes, A., & De Wilde, P. 2010. The perceived barriers to the inclusion of rainwater harvesting systems by UK house building companies. *Urban Water Journal*, **7(4)**: 257-265.
- Pelak, N., & Porporato, A. 2016. Sizing a rainwater harvesting cistern by minimizing costs. *Journal of Hydrology*, **541**: 1340-1347.
- Peters, E. J. 2016. Success and Success Factors of Domestic Rainwater Harvesting Projects in the Caribbean. *Journal of Sustainable Development*, **9(5)**: 55-69
- Rogers, E. M. 2004. A prospective and retrospective look at the diffusion model. *Journal of health communication*, **9(1)**: 13-19.
- Salas, J. C. 2007. Rainwater harvesting: A community's technology for coping with climate change. *Rainwater and Urban Design* **18(2)**: 952-968.
- Sazakli, E., Alexopoulos, A., Luotsinidis, M. 2007. Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Resources*, **41**:2039-2047.
- Smet, J. 2005. Domestic rainwater harvesting; WELL fact sheet. Available at <http://www.iboro.ac.uk/well/resources/factsheets/fact-sheets.pdf> Retrieved on 17 June 2017
- Sturm, M., Zimmermann, M., Schütz, K., Urban, W., & Hartung, H. 2009. Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia. *Physics and Chemistry of the Earth, Parts A/B/C*, **34(13-16)**: 776-785.
- Tayal, S. P. 2013. Engineering design process. *International Journal of Computer Science and Communication Engineering, IJCSCE Special issue on "Recent Advances in Engineering & Technology" NCRAET*: 1-5.
- Thomas, T. 1998. Domestic water supply using rainwater harvesting. *Building Research & Information*, **26(2)**: 94-101.
- Van Vuuren, L. 2013. Rainwater harvesting from tanks-Useful yes, but can you drink it? The Water Wheel. Available at <http://www.thewaterwheel.com> Retrieved on 12 May 2015.

- Woltersdorf, L., Jokisch, A. & Kluge T. 2014. Benefits of rainwater harvesting for gardening and implications for future policy in Namibia, *Water Policy* **16**:124-143.
- Worm, J. & Hattum, T. 2006. Rainwater Harvesting for Domestic Use [online], Agrodok 43, Agromisa Foundation and CTA, Wageningen. Available at: www.rainfoundation.org/fileadmin/PublicSite/Manuals/AGRODOK_RWH_43-e-2006-small.pdf Retrieved on 26 February 2017.
- Yan, X., Ward, S., Butler, D., & Daly, B. 2018. Performance assessment and life cycle analysis of potable water production from harvested rainwater by a decentralized system. *Journal of Cleaner Production*, **172**: 2167-2173.
- Yeasmin, S., & Rahman, K. F. 2013. Potential of rainwater harvesting in Dhaka City: An Empirical Study. *ASA University Review*, **7(1)**: 143-150.

CHAPTER 7 DEVELOPING COMMUNITY-INFORMED PROTOTYPES OF ROOFTOP RAINWATER HARVESTING TECHNOLOGY WITH BEST POTENTIAL TO REDUCE WATER SCARCITY

7.1 Abstract

Developing technologies with the end users although recommended, has not been very common across disciplines. Where this has taken place, information on the processes followed has not been fully documented and reported. A study was therefore carried out to develop community-informed prototypes of rooftop RWH with best potential to mitigate water scarcity in Mabayeni village. The objective of the study was to document the process followed as well as the user experiences during the process. A combination of participatory action and experimental research designs were used. Participants were divided according to gender and age to observe the differences in creative capabilities. Qualitative data was collected through the use of focus group discussions in design workshop setups. A total of seven focus groups were constituted and each group developed two prototypes (one for thatch and another for zinc roof). The elements engineering design process was also used to guide the prototyping process in each of the seven focus groups. Photographs of prototypes were processed and presented using ATLAS.ti version 7.5.7. The verbatim expressions of different groups were recorded and tabulated. Thematic content analysis was used to analyse verbatim expressions while verbal protocol analysis was used to analyse the processes followed during prototyping. In addition, two mathematical calculations were used to determine water demand as well as rainfall potential in Mabayeni village. A total of 14 prototypes were developed by the seven interest groups. The elements engineering design process was modified to give room for more end-user participation. Engaging the community members in the prototype production process ensured that the end product met community expectations. Recording the process and experiences was important as it provided context and reflected on the psychology of the people and the environment they lived in. In order to ensure appropriateness, products and services should be developed with the prospective end users.

Key words

Community-informed, prototype, rooftop rainwater harvesting technology, water scarcity, water shortage

7.2 Introduction

A prototype can simply be defined as an artefact that approximates a feature or multiple features (Camburn *et al.*, 2017). Prototyping is a process very popular especially in engineering and business fields, and has long been acknowledged as an important part of the product development process. Prototypes serve numerous purposes both from engineering and business standpoints (Christie *et al.*, 2012). Businesses use prototypes to gather detailed customer feedback on issues like aesthetics, ergonomics, marketing research and cost analysis, while engineers use prototyping to provide manufacturing and assembly data, to investigate system integration issues and to develop analysis and testing strategies (Christie *et al.*, 2012). In some cases, prototyping is used in the concept generation phase of the design process to assist designers to either expand or contract the set of possible concepts.

Camburn *et al.* (2017), summarizes the main objectives of prototyping in four points namely; refinement (a process of gradually improving a design), communication (the process of sharing information about the design and its potential use), exploration (the process of seeking out new design concepts) and learning (the process of gaining knowledge about the design space or relevant phenomena). The prototypes that were developed in this study touched on all the four purposes explained above. This was because it was an opportunity for community members to refine the main features of the technology they had suggested, create visual representations of the technology and use them (as a tool of expression) to communicate their ideas and explore different ways of putting together the components. Prototyping also presented a learning platform to participants as they learnt more about the technology and how it would work through interrogating the components and explaining the purpose of each one of them.

Several categories of prototypes have been suggested in literature. Ullman (2003) introduced classified models based on their functionality and stage of design process which is proof of concept, proof of product, proof of process and proof of production. Another division is between prototypes that address form and those that address function (Otto & Wood, 2001; Pei & Campbell, 2011). An additional distinction is based on the level of fidelity of prototype that is, the level of resemblance of the prototype compared to the actual product or technology (Stowe, 2008). Moreover, a distinction is also made between virtual (simulations, visualization or computational approximations of behaviour) and physical models (Stowe, 2008). Evidence in literature seem to suggest physical models as more preferred to virtual models as tools for solving

design problems (Marks, 2000; Kelley, 2001; Green & Smrcek, 2006). According to Hallgrimsson (2012), physical prototypes are still leading and getting more acknowledgement than 3D computer rendered and animation models. This is mainly because physical prototypes assist in face to face interaction among different stakeholders.

Although prototyping has been an engineering and business practice, Avrahami & Hudson (2002) acknowledge some changes in design practice in the last quarter of the 20th century. One of the main changes was a shift to place the customer instead of the product at the centre of the design process. The approach, known as user-focused or user-centred design requires that the user needs, goals and desires are satisfied (Isa, 2014). This entails a design process that involves users in designing from understanding the nature of the problem, the needs of the people until the finalization of the design. Within the framework of user-centred design underlie four key principles namely; early focus on users and task, prototyping and user testing and iterative design (Gould & Lewis, 1985). The user-centred approach is important for usability as it is essential to capture the voice of the customers (Carulli *et al.*, 2013) who are the direct beneficiaries or end users of the product. However, this approach is not commonly used by designers.

Most designers adopt solution-focused strategies whereby solutions are generated first, then evaluating the extent to which the generated ideas present a satisfactory solution for the problem. For example, Coughlan *et al.* (2007) describe the design process at IDEO. IDEO is an international product design and consulting firm founded in Palo Alto in California. The authors explain that instead of starting with detailed analyses of technical and user requirements and development of specifications, a typical design process at IDEO involved at quite an early stage, a wide range of low fidelity prototypes from which to learn. The idea here is to explore many different possibilities with respect to physical form, human interactions and how mechanical elements might work. Christie *et al.* (2012) has shown three categories of participants in design practice. All three of them have different specific interests towards the design process. These are engineers, business people or project managers and end users. For engineers, the focus seem to be more on the product while project managers worry mostly about the economic viability of the design project. For end users, it is their needs and preferences that influence their design choices. It is this last group of participants that is of concern to this study. Although there have been acknowledgements of the importance of end user participation in technology design, there is a dearth of information on actual cases where end users have taken part in the process from investigating their needs, all the way until finalization of a design.

Johns & Richey (2000) posit that the use of prototypes early in the development process stands in contrast to many development projects where the customer does not see the product until it is nearly completed. The cost of making changes to a nearly finished project is often prohibitive resulting in a limited role for the customer's input. Limited role of end user input often results in failure to meet their needs, which may in turn, result in failure or non-adoption of technologies. In this study, the aim was, therefore, to develop community-informed prototypes of rooftop RWH technology with best potential to increase access to water for multiple domestic uses. Community members who were prospective users, decided on the most important features of the rooftop RWH technology that they wanted as presented in the previous chapter. They were then given the chance to participate in all stages of the design process, and come up with a rooftop RWH technology that served as an intervention for severe water scarcity in the village. Due to climate change, rainfall amounts dropped, and the dry season was reported to have increased to about five months. It was believed that involving them in the design process would likely make the technology responsive to community or end users' needs.

7.3 Methodology

7.3.1 Research design

Apart from the research design employed being a case study, a combination of experimental and action research designs were used in the current study. Case study design and action research designs have been explained in detail in the previous chapters. The prototyping process was regarded as an experiment. Bradac *et al.* (1993) also describes prototyping as a process-monitoring experiment; reason being that an experiment is a try and re-try process carried out to discover the unknown, to test or establish a hypothesis or to illustrate a known (Bradac *et al.*, 1993). Experimental design is regarded as critically important in the scientific and engineering world for driving innovation in the product realization process (Montgomery, 2017). In this study, participants were given simple, easy to use materials to make physical sketches of a rooftop RWH technology. Following a general engineering design process, participants were observed throughout the course of the technology development and their group experiences recorded.

7.3.2 Sampling procedures

Participants were divided into different groups based on age and gender as explained in previous chapters. This was done in order to observe possible differences in understanding, imagination

and creativity amongst groups. In total, three engagements focusing on prototyping were held. For convenience, a separate prototyping engagement was done with children at a local primary school. Community perceptions were considered when calculating water demand for Mabayeni village. For the selected domestic uses, participants in their respective groups were requested to provide estimates on frequency and amount of water used in a day or week. During this exercise, although the grouping criteria for focus groups was maintained, the participants provided water demand responses for an additional category, which was, children under five years of age. This was done to check if children who were five years old consumed the same amount of water as those below five.

When measuring roof catchment area for estimation of RWH potential in the area, cluster sampling was used. Households in Mabayeni village were grouped into four clusters based on the size of the house (roof) and the type of material used for roofing. Clusters descriptions were: the small (which comprised of one roomed thatch and zinc-roofed houses), the medium (which comprised of a range of houses build under the Rural Development Programme (RDP) ranging from three to six rooms), and the large (comprising big houses with seven rooms and above). A total of 16 roof catchments were measured with at least three houses measured per cluster. This was done in order to calculate the potential for harvesting rainwater for houses of different sizes.

7.3.3 Data Collection Process

Secondary data was collected from accredited journal articles, internet-based design manuals, RWH guides and manuals, and other credible internet sources. The main primary data collection methods used were interviewing and experimentation. Participatory designing or prototyping was done in different focus groups. A combination of parallel and competitive prototyping techniques were employed. Parallel prototyping is defined as a process whereby multiple design concepts are embodied and compared concurrently (Camburn *et al.*, 2017). Cristie *et al.* (2012) adds that parallel prototyping can help provide critical feedback for concept selection. In this study, except for the groups of children which were engaged separately, the rest of the groups did their prototyping at the same venue concurrently. Competitive prototyping is a form of prototyping where separate teams independently develop concepts in parallel to solve a common problem. According to Borowski (2012), employing separate teams allows for high design divergence, even within tight requirements.

As explained above, age and gender were used to disaggregate participants. Tools such as sketch modelling or prototyping kit comprising cheap, easy-to-use materials (such as molding clay, paper glue, wood glue, scissors, sellotape, wooden sticks, straws, plastic cups, cardboard boxes, old pipes of different sizes, refuse bags, blades, small hack saw and blades, pencils, plain paper, staplers, wires, plastic paper, scissors among others) were used to design prototypes for rooftop RWH technology. Cameras, tape recorders, pens and notebooks were also used to record the engagement proceedings. A tape measure was used to take measurements of different roof catchments which were needed for calculation of rainwater potential. Participants used a list of structural components (technology features) that had been collectively developed in the previous engagement. This document served as a guide for the prototype development exercise. In this process, participants started by brainstorming, imagining and creating visuals of the prototype, then incorporating the preferred features of RWH system. Illustrations were then made using the provided prototyping materials.

The prototyping process followed a six-step engineering design cycle. The process started with defining the problem, collecting information, brainstorming and analysing ideas, developing solutions, presenting ideas to others for feedback and finally improving the design (Hubka & Eder, 2012). Discussions took place in different social groups (focus groups) working in participatory design workshops (Mukherjee, 1995). A presentation and analysis (Chambers, 1994) session was held at the end of each session to get the participants' design experiences in their respective focus groups. Moreover, in their respective interest groups, participants were then requested to give estimates of the frequency and amount of water used for each use per person per day. In addition, participants were requested to provide overall estimates of water use per household per day. Making estimations for water use per household helped compare household and individual amounts to validate the figures.

7.3.4 Data Analysis

Pictures of completed prototypes per group were processed and presented using ATLAS.ti version 7.5.7. In addition, two mathematical calculation methods were used to obtain estimates of water demand for the dry season in Mabayeni village (Worm & Hattum, 2006), as well as to determine the rainfall potential which was crucial for sizing the storage tank (Kalimuthu, 2016). Using Microsoft Excel packages, averages were then calculated for each of the selected water uses.

With regard to calculation of the size of storage reservoir, the dry-season demand versus supply approach (Worm & Hattum, 2006) was employed. The authors define water demand as the volume of water requested by users to satisfy their needs. Community water uses that were prioritized for purposes of developing the rooftop RWH technology were drinking, cooking, bathing, washing dishes, washing clothes and sanitation (Chapter 3). Therefore when water demand calculations were done, only these water uses were considered. All relevant ethical clearance procedures were adhered to.

Verbal protocol analysis was used to analyse design behaviour in different interest groups. According to Atman & Bursic (1998), verbal protocol analysis is a research method in which research participants think aloud as they solve problems or perform a task. As they do this, their thought-processes are captured on audio tape. In this study, the transcribed text from tape recorders was then coded and themes generated using thematic content analysis. Comparison of verbal protocol data was done to evaluate the approaches and processes that different interest groups used when developing prototypes.

7.4 Results

7.4.1 Description of the Selected Rainwater Harvesting Technology Option

The research participants explained the details of the selected rooftop RWH technology option before commencing with the actual prototyping exercises. They also detailed the most preferred construction materials for each component and giving reasons (Table 7.1). The main structural components, the preferred design characteristics, and the reasons stated during focus group discussions were indicated. It should be noted that this set of components which was developed by participants themselves, was used as a checklist or design guide in the prototyping process. The participatory design process which was used in the development of prototypes as well as the engineering design process which was used as a reference point are illustrated in Figures 7.1 and 7.2. Using the design guide, community members were able to construct two prototypes per interest group (one for zinc and another for thatch roof) in three days. A total of 14 prototypes were developed, a shortfall of two because the Magangeni part of the village did not turn up due to other commitments.

Table 7.1 The Description of a Rooftop Rainwater Harvesting Technology Developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Structural component	Design characteristics	Reasons
a) Shape and location	a) Round or circle	For easy cleaning
	b) Two metres away from the house	Safety and security
b) Construction material	a) Reinforced brick and cement	Durability
	b) Plastering with cement	To ensure good water quality
	c) Concrete base	Avoid water seepage
c) Conveyance system	a) Painted zinc gutters	Collection of clean water
	b) Downpipe	Water transportation
	c) Elevating tank from the ground by five layers of bricks	Obtaining water pressure through gravity
d) Security	a) Fencing the tank with razor wire	Secure the tank from thieves
	b) Securing the tank with lock and key	Secure the tank from children
	c) Use of plastic taps	To discourage thieves
e) Tank housing	a) Creating a shade	To avoid exposure to direct sunlight which promotes algae growth
	b) Housing the tank with iron sheets	Protect the tank from physical damage and ensure water quality
f) Water access	a) Having two water access taps	Convenience (children, the elderly, disabled)
g) Water quality	a) Gutter screens	To get clean, potable water
	b) Lock tank with cap	To keep small organisms from entering the water tank
	c) Physically cleaning the tank	To get rid of dirt
	d) Filtering system at mouth of tank	To trap suspended particles
	e) Draining water from the tank	To remove organic debris build up
	f) Treating water (chlorination or boiling)	To treat microbial contaminants
h) Water conservation	a) Creating water holding structures	To collect water when the tank is full
	b) Creating drains	To direct overflow and get rid of standing water

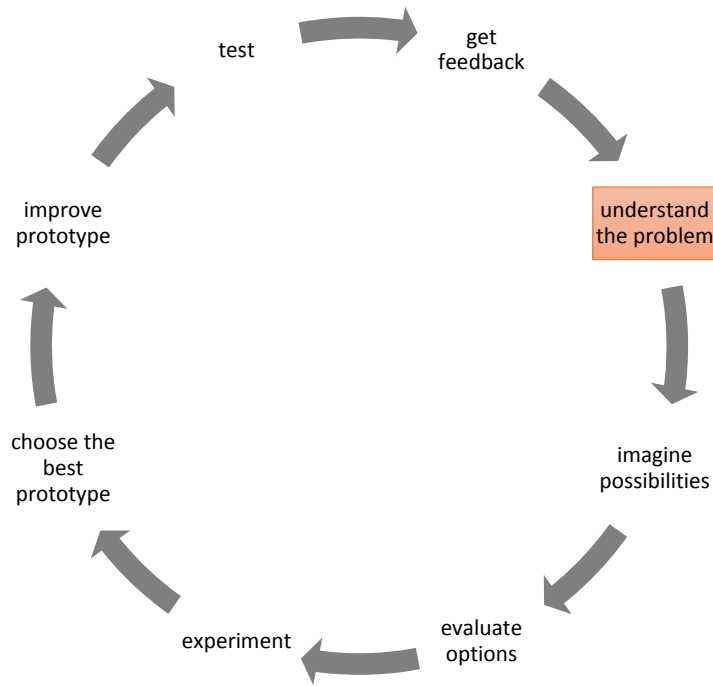


Figure 7.1 An illustration of the participatory design process followed in developing the prototypes of a rooftop rainwater harvesting technology in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

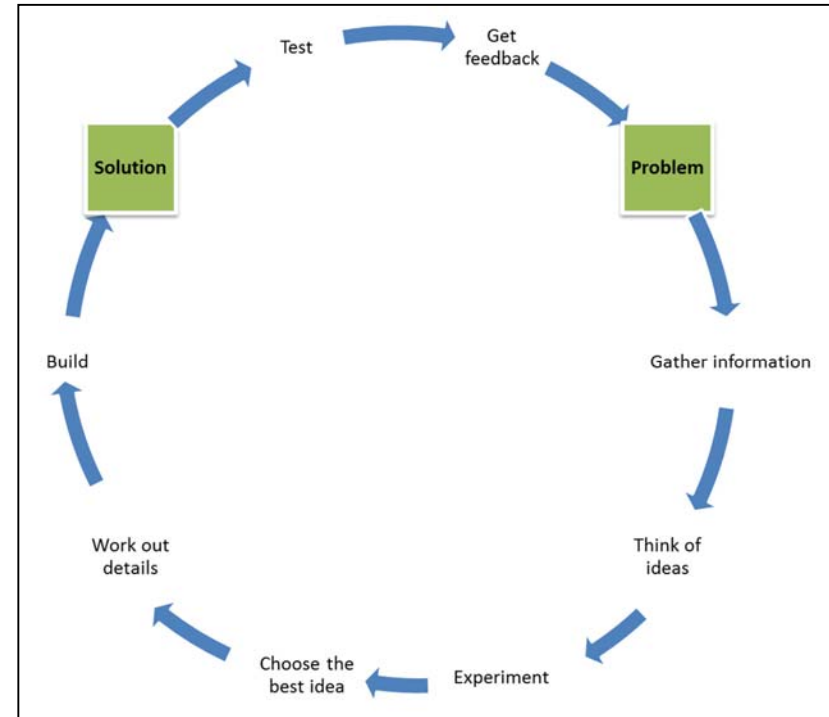


Figure 7.2 An illustration of the engineering design process used as reference in the development of prototypes of rooftop rainwater harvesting technology in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Source: Adapted from (Hubka & Eder, 2012)

After deliberations, it was agreed that the design for RWH for thatch roofing would be similar to that of zinc. The only difference was that the thatch would be covered with a hard plastic in order to collect clean water. The hard plastic would be folded into a gutter and downpipes connected. The rest of the technology would be the same as that of the zinc roofing with similar details as explained above. Figure 7.3 shows the photographs of prototypes produced by different groups in Mabayeni village.

On completion of the experimentation process, participants reflected on their first impressions and experiences in developing the sketches. The results are presented in Table 7.2. Results of verbal protocol analysis showed that groups of children and men were the fastest in completing their tasks as they finished in one session. They were followed by male and female youth groups who finished in two sessions. Women and the elderly people were the last groups to complete their task in three sessions. Each session was roughly three hours long. In addition, results also showed different forms of team work within groups. In the groups of children, all team members focused on one aspect of the prototype at a time. The boy children quickly delved into the technical decisions such as shapes and sizes of houses and storage tanks.

As for women, there was division of tasks which was meant to keep everyone busy so as to complete the task quicker. However, lengthy disagreements delayed their progress. In the female youth group, one lady rose to become a leader. She was responsible for keeping time and identifying materials needed. Men examined all the prototyping materials first and drew sketches of the prototypes. The sketches were used to aide discussions on the shapes and materials to be used for each prototype. Then, they distributed roles and commenced with prototyping. With the male youth, they identified one talented member whom they called “the architect” because he was knowledgeable and experienced in craftwork. He was responsible for the actual designing while the rest of the group members helped with gathering, cutting shapes and gluing pieces under his instruction. In elderly group, only two women were involved with actual building of prototypes. The rest were seated around busy with their beadwork while contributing ideas to the process. It was also evident from the conversations that all groups were excited about the exercise, and were motivated by the desire to win since it was a competition.



Figure 7.3 Prototypes of rainwater harvesting developed by residents of Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 7.2 Experiences of community members on prototyping exercises for developing a technology for harvesting rainwater in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Group	Verbatim quotes
a) The elderly	“This exercise was good. It helped us think. We also understood how this technology will work because we made it. But we got tired. We asked one of the boys to finish for us when we were tired. We told him what to do”
b) Men	<p>“At first, we felt that we were too old for the exercise, it needed patience and strategizing...we examined materials first before deciding on size, then how to build the prototypes”</p> <p>“We wanted to show these women that we are not just drunkards. Our prototypes are way better than all the others’. This is our thing!”</p>
c) Women	<p>“I was amazed by the many different and useful ideas we all contributed, it was exciting although ours are not so nice...our house looks like a big church. We also divided tasks”</p> <p>“We spend some time discussing and disagreeing. But we eventually agreed and moved forward. We learnt how to work in a team”</p>
d) Male youth	<p>“We learnt a lot, we brainstormed first then gave the talented guy the task to put the pieces together as we helped with cutting and gluing pieces.”</p> <p>“it feels good to produce something nice from sketch, we now have a solution to our problem”</p>
e) Female youth	<p>“...in order to learn, one has to be humble and accept that s/he does not know everything”.</p> <p>“We learnt that we have to be patient and listen to each other, everyone knows something”</p>
f) Children (boys)	<p>“Some of the materials were difficult to work with but we improvised..., for instance, we used fire to create holes on plastics...”</p> <p>“We are now thinking about storing rainwater...”</p>
g) Children (girls)	“It was tough but we built a nice sketch, we can compete with the boys”

7.4.2 Sizing of Storage Tank

The process of designing the RWH technology is demand driven and related to the size of a storage facility. This technology rests upon a number of variables such as water demand, water supply as well as the catchment area. In order to make sure that harvested rainwater would meet the demand of households, the water demand of the area was calculated using the following formula from Worm & Hattum (2006):

$$\text{Water demand} = \text{Water use} \times \text{household members} \times 365$$

Mabayeni participants indicated that the average household size for their village was eight. The period regarded as critically dry in Mabayeni village was five months (from May to September) as illustrated in Chapters 3 and 4. The estimated daily average amounts of water used in a household are displayed in Table 7.3. However participants indicated that during periods of scarcity (when there was no running water on taps for a week or so), they used water sparingly such that 400 litres (16 x 25 litre containers) was sufficient to cater for a household of eight in a week. In addition, the frequency of no-water-at-all situations wherein water was not running on municipal taps for about a week was indicated to be at least once a month. This was the time they relied on buying, fetching from other villages as well as Malamulele town. This meant that community members needed water to augment municipal water during the no-water-at-all situations. Using the water demand equation above, the amount of water needed in Mabayeni village to cater for the prioritized uses during the period when there was no municipal water for about a week was therefore:

$$400 \text{ litres} \times 1 \times 5 \text{ months} = 2000 \text{ litres}$$

As for the water supply, the amount of rainwater that could realistically be collected in the village was also determined. Rainwater harvesting potential was calculated using the following formula from (Kalimuthu, 2016):

$$Q = A \times C \times P$$

Where: Q = the quantity of harvested rainwater in litres;

A = catchment area in square metres;

C = runoff coefficient; and

P = the mean annual rainfall

Table 7.3 Averages of estimated water demand per day in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

All amounts are in litres							
Consumption	Drinking	Cooking	Bathing	Washing dishes	Washing clothes	Sanitation	Total amount
Individual consumption	1.9	1.25	15	1.5	5	0.25	24.9
Household consumption	15	10	120	12	40	2	199

7.4.3 Runoff coefficient and catchment area

A catchment area is an area from which rain falls. The runoff coefficient of a catchment area is important for calculating the rainfall potential. Runoff is the water that flows away from a catchment after falling on its surface in the form of rain. The runoff coefficient is, therefore, the value that represents the ratio of runoff to rainfall. Pacey & Cullis (1989) outline the different types of catchments and their runoff coefficients. The authors indicate that while the runoff coefficient for tiles range from 0.8 to 0.9, the range for corrugated metal sheets is between 0.7 and 0.9. As for organic thatch roofs, the runoff coefficient was estimated at 0.2. However, a number of households in Mabayeni village had thatch-roofed houses and wished to harvest clean rainwater. To this end, they suggested using plastic sheet to cover roofs (Chapter 5). Using polythene plastic to cover the thatch roof significantly raises the runoff coefficient to a range between 0.7 and 0.8 (Pacey & Cullis, 1989). For purposes of this study, runoff coefficients of 0.7 and 0.8 were adopted for thatch and zinc-roofed houses respectively. A lower coefficient for thatch roofs was adopted because polythene plastic lacks rows which help in channelling water to the gutter.

7.4.4 Rainfall characteristics and harvesting potential

In order to estimate rainfall harvesting potential, a number of issues were considered. Among the several factors that influence the RWH potential of a site, climatic conditions especially rainfall, and the catchment characteristics were considered to be the most important (Morey *et al.*, 2016). Rainfall potential depends on the rainfall amounts, seasonal patterns and intensities. Morey *et al.* (2016) encourage that in order to determine the potential rainwater supply for a given catchment, reliable rainfall data are required preferably for a given period for at least 10 years. Malamulele daily rainfall data for the period between 2007 and 2017 were obtained from the Agricultural Research Council (ARC) – Institute for Soil, Climate and Water. Daily rainfall figures were averaged monthly, then yearly. An average amount for the 10 year period was also calculated. Due to the fact that the rooftop RWH technology was meant to harvest rainwater during the rainy season, only rainy season months (October to March) averages were considered for calculating the RWH potential. Mabayeni areas received at least 99 mm of rainfall per annum. Different sizes of roofs that were measured in Mabayeni village were categorized into small, medium and large as already explained (also see Appendices 7.1-7.4). Using the RWH potential equation already stated, the rainfall potential of different rooftops in Mabayeni village ranged from 1386 to 45 619 litres (Table 7.4) depending on the size of the catchment area. It was observed that the size of household was somewhat directly proportional to catchment size in small and medium houses.

Table 7.4 Rainwater harvesting potential for different roof sizes in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

	Sample	Catchment (m ²)	Household size	Estimated Run off Coefficient	Mean rainfall (mm)	Mean Rainfall (m)	Potential harvested rainwater (l)	Individual water use (l/day)	Individual duration (months)	Household water use (l/day)	Household duration (months)
Small Thatch	1	20	2	0.7	99	0.099	1386	24.9	1.9	199	0.23
	2	17	2	0.7	99	0.099	1178	24.9	1.58	199	0.20
	3	20	2	0.7	99	0.099	1386	24.9	1.86	199	0.23
	4	15	3	0.7	99	0.099	1040	24.9	1.39	199	0.17
	5	25	1	0.7	99	0.099	1733	24.9	2.32	199	0.29
Small Zinc	1	11	1	0.8	99	0.099	871	24.9	1.17	199	0.15
	2	24	2	0.8	99	0.099	1900	24.9	2.54	199	0.32
	3	18	1	0.8	99	0.099	1426	24.9	1.91	199	0.24
Medium Zinc	1	37.2	4	0.8	99	0.099	2946	24.9	3.94	199	0.49
	2	43	4	0.8	99	0.099	3406	24.9	4.56	199	0.57
	3	40.2	3	0.8	99	0.099	3184	24.9	4.26	199	0.53
	4	44.4	2	0.8	99	0.099	3517	24.9	4.71	199	0.59
	5	44.3	4	0.8	99	0.099	3510	24.9	4.70	199	0.59
Large Zinc	1	150	7	0.8	99	0.099	11880	24.9	15.90	199	1.99
	2	102	3	0.8	99	0.099	8078	24.9	10.81	199	1.35
	3	576	4	0.8	99	0.099	45619	24.9	61.07	199	7.64

7.5 Discussion

In literature, there is a dearth of information on the processes that have been used in developing various technologies. With respect to RWH technologies, previous studies have shown that technologies that have been developed with the participation of community members or end users (Waltersdorf *et al.*, 2014; Eggens & Patrick, 2015; Gould & Nissen-Petersen, 2016) have been more successful than those developed without (van Vuuren, 2013). However, not much is revealed on the extent to which end users participated. In addition, experiences of the community members as designers have either not been documented at all, or have been underreported. As a result of this, there is not much to compare results of this study with, in terms of the prototypes, the process followed, or the experiences. Nonetheless, effort is made to discuss the process that was followed in developing the rooftop RWH technology. This is done in comparison with the traditional engineering design processes. Further, the implications of community members' experiences during prototyping are discussed.

The ability to construct a potential solution to a common community challenge displayed by Mabayeni community members is proof that rural communities are a strong resource, and not helpless victims waiting for outsiders to rescue them. This confirms Sanders & Simons' (2009) belief that all people are creative and will participate in a creative process if they are motivated and are provided the tools to do so. Successful development of prototypes revealed the importance of co-creation of solutions as opposed to just participation of communities. According to Voorberg *et al.* (2015), co-creation refers to the active involvement of end users in various stages of the production process. This is more specific than a broad concept of participation which could also refer to passive involvement. Sanders & Jan Stappers (2008) describe an evolution in design research from user-centred approach to co-designing. The latter authors also explain the changing roles of the designer, the researcher and the person formerly known as the user.

In this study, the end users were empowered to become designers thereby closing the gap which traditionally existed between the two groups. Although the researcher participated as a co-designer, the traditional role of being an expert was relinquished to become more of a facilitator. This involved leading, guiding and providing resources to the designers. The success of co-creation of prototypes of a rooftop RWH technology underscores the need to change the way design research is undertaken to accommodate community members. Community members should be regarded as experts primarily in understanding their challenges. On this basis, they

should also be trusted with taking the lead role in crafting appropriate solutions (Chambers, 1994). Voorberg *et al.* (2015) therefore, suggest that policy makers and politicians should consider co-creation or co-production of solutions with citizens as a necessary condition to create innovative public services that meet the needs of citizens.

As indicated above, the process used in developing prototypes for a technology for harvesting rainwater in Mabayeni village was borrowed from the engineering design processes. Engineering design process is the process of devising a system, component, or process to meet desired needs (Kamrani & Nasr, 2010). It is a sequence of events and a set of guidelines that helps a designer define a clear starting point from visualizing a product in the designer's imagination to realizing it in real life (Haik *et al.*, 2018). Unlike in the traditional engineering processes wherein evaluation is done after making the prototype, evaluation in this study was done before, during and after prototyping to ensure that the incorporation of feedback was done as a continuous process. This addressed one of the common engineering design challenges in product prototyping whereby conflicts emerge between developers and customers. According to Liou (2007), conflicts emanate because customers request excessive changes during feedback sessions. Involving the customers or end users in the whole design process avoided this kind of conflicts. Haik *et al.* (2018) add that the most important step of the design process is identifying the requirements of the customer. This was taken care of through allowing "the customer" to ideate as well as design (put together the components of the technology).

The argument arising from this study is that there is no need to rush into prototyping before ascertaining the best possible product option for any technology. Only after acquiring an in-depth understanding of the problem, the need, and available options, should designers embark on a process of evaluating the options together with the end user. Then, development of the product can commence. This is crucial in ensuring that the best option is taken up for experimentation. Hartman (2009) posits that designers adopt solution-focused strategies by generating solutions first, then checking to what extent the generated ideas are adequate for the problem. In this way, creation comes before analysis. Only through creation of prototypes and other representations is it possible to test the extent to which an idea fulfils the design goals. The weaknesses of this "best-guess approach" frequently used by engineers and scientists is explained by Montgomery (2017). Therefore engaging in rapid prototyping with end users and having frequent evaluation sessions saved time and resources, and guaranteed production of a solution that best suited end users' needs. In addition, the approach used in the prototyping process encouraged transparency

and established authenticity of the technology (Leavy, 2012). Considering the arguments above, the engineering design process (summarized in Figure 7.2) was therefore slightly modified (summarized in Figure 7.1) to make sure the approach became user-centred (Carulli *et al.*, 2013).

Product development has historically been a field reserved for engineers. However, Avrahami & Hudson (2002) and Kamrani & Masr (2010) acknowledge that product development is evolving from a sequential process carried out primarily by engineers to an integrated process incorporating a cross-functional team. In this study, engineering involved community members who were prospective end users of the technology which is an unusual occurrence. As described in the Lepine *et al.* (2008) study on teamwork processes, all interest groups in Mabayeni village displayed different types of team work. Men and boy children displayed a type of transition process analysis called mission analysis. This process involves identification and evaluation of team tasks, challenges, environmental conditions, and resources available before performing the teams' work (Lepine *et al.* 2008).

The explanations for these groups of males' strategy can be explained using evidence from psychology and sociology studies. According to Lorber (1994), societal role assignments and self-selection into social roles are some primary determinants of behavioural sex differences. In addition, Wood & Eagly (2002) argue that gender is constructed within cultures. Men are therefore culturally socialised to become problem solvers and have naturally acquired skills of practical problem solving as part of their upbringing. This made it easy for them to strategize accordingly and execute the task with ease. Moreover, cooperation and workload sharing observed within girl children, women as well as male youth groups could have been because participants in these groups learnt that working together was important in order to finish the prototyping task faster. They therefore figured that breaking down the task into smaller parts and sharing responsibilities would help them complete the design task more quickly.

The youth groups' strategy of identifying leaders or experienced people before commencing with prototyping could have been as a result of awareness on the importance of team leadership. According to Morgeson *et al.* (2010), team leadership is a critical component of team effectiveness (that is, delivering quality results in a timely manner). An examination of the processes followed in the group prototyping sessions showed that the processes used mirrored the broad engineering design process. As displayed by men and boy children, proper problem formulation, formulation of assumptions and examination of strengths, constraints and resources before actual prototyping

results in effective product development. It also reflected the differentiated social roles that exist in many African societies and their effect on development activities. Fosmire & Redcliffe (2014) summarise prototyping as a learning activity; as critical thinking and as lived experience. Participants confirmed that they deeply exercised their minds, and learnt a lot about the different components of the rooftop RWH technology. They also learnt about behavioural traits and skills that are required for successful group prototyping. Without skills such as conflict management, team work, leadership, tolerance, and behavioural traits such as patience, respecting contributions and encouraging participation, any group design endeavours would be unsuccessful. Most of these lessons were applicable to community members' daily lives. This displays an extension of engineering which goes beyond the current practice of only inviting end-user input when the product is completed in order to get feedback comments. True engineering and participation entails giving the end user the opportunity to interact fully, think critically and learn from the process.

An analysis of the water demand and rainfall potential exposed that it was difficult to estimate an overall storage tank size for the whole community considering the multiple variables such as household size (which translates to water demand), catchment area (Worm & Hattum, 2006; Mwenge-Kahinda *et al.*, 2007; Pelak & Porporato, 2016), among others. In addition, the water demand and supply figures revealed that it was possible to collect and store rainfall sufficient to augment municipal tap water during periods when water was not running on taps. It was also possible for all community members irrespective of catchment area size, to have a continuous supply of water throughout the year since the size of household was directly proportional to the size of catchment. Successful implementation of the rooftop RWH technology in this community would therefore eliminate security risks associated with fetching water at night and travelling long distances to fetch water. With proper water purification measures, health risks emanating from the use of contaminated water could also be eliminated. Apart from having continuous water supply, community members would also afford to have small home gardens in which they would grow vegetables, thereby improving food security. Those with bigger catchment would also share water or sell to those with smaller catchments in case there is a need.

7.6 Conclusion

The aim of the study was to develop community-preferred prototypes of a rooftop RWH technology with best potential to reduce water scarcity. Community members of Mabayeni were

able to make simple sketches of the technology using cheap locally available materials. The ability of community members to develop prototypes is evidence that they are a crucial resource which should be considered in any development initiatives that affect their lives. In addition, the traditional engineering design process was modified to create more space for community members to create, interrogate their ideas, and come up with the best possible intervention. Moreover, although Mabayeni residents were prototyping for the first time, they enjoyed the whole process and indicated that they had learnt a lot of skills which were also applicable in their daily lives. It was also discovered that water demand, household size and catchment area were critical aspects when determining rainfall harvesting potential as well as tank size. The study was important as it explored a number of aspects that were critical in developing a community-informed RWH system. It became clear that when developing a community-informed technology, attention should be paid on both the process and the product. After prototyping, two representations which best represented community needs were selected through an evaluation process. The prototypes and the process followed are presented in the next chapter.

7.7 References

- Atman, C.J. & Bursic, K.M. 1998. Verbal protocol analysis as a method to document engineering student design processes. *Journal of Engineering Education*, **87(2)**:121-132.
- Avrahami, D., & Hudson, S. E. 2002. Forming interactivity: a tool for rapid prototyping of physical interactive products. In *Proceedings of the 4th conference on Designing interactive systems: processes, practices, methods, and techniques*. ACM.
- Borowski, S. M. 2012 Competitive prototyping in the department of defense: suggestions for a better approach. In *The Defense Acquisition University Research Symposium*, Fort Belvoir, VA.
- Bradac, M. G., Perry, D. E., & Votta, L. G. 1993. Prototyping a process monitoring experiment. In *Proceedings of the 15th international conference on Software Engineering*, IEEE Computer Society Press.
- Camburn, B., Viswanathan, V., Linsey, J., Anderson, D., Jensen, D., Crawford, R., Otto, K., & Wood, K. 2017. Design prototyping methods: state of the art in strategies, techniques, and guidelines. *Design Science* **3**: 1-33
- Carulli, M., Bordegoni, M., & Cugini, U. 2013. An approach for capturing the voice of the customer based on virtual prototyping. *Journal of Intelligent Manufacturing*, **24(5)**: 887-903.
- Chambers, R. 1994. The origins and practice of participatory rural appraisal. *World development*, **22(7)**: 953-969.
- Christie, E. J., Jensen, D. D., Buckley, R. T., Menefee, D. A., Ziegler, K. K., Wood, K. L., & Crawford, R. H. 2012. Prototyping strategies: literature review and identification of critical variables. In *American Society for Engineering Education*. American Society for Engineering Education.
- Coughlan, P., Suri, J. F., & Canales, K. 2007. Prototypes as (design) tools for behavioral and organizational change: A design-based approach to help organizations change work behaviors. *The journal of applied behavioral science*, **43(1)**: 122-134.
- Daly, S. R., Yilmaz, S., Christian, J. L., Seifert, C. M., & Gonzalez, R. 2012. Design heuristics in engineering concept generation. *Journal of Engineering Education*, **101(4)**: 601-629.
- Fosmire, M., & Radcliffe, D. F. (Eds.). 2013. Integrating information into the engineering design process. Purdue University Press.
- Gould, J. D., & Lewis, C. 1985. Designing for usability: key principles and what designers think. *Communications of the ACM*, **28(3)**: 300-311.
- Gould, J., Nissen-Petersen, E. 2003. Rainwater Catchment Systems for Domestic Supply –

- Design, Construction and Implementation ITDG Publishing, London
- Green, G., & Smrcek, L. 2006. On the developing role of physical models in engineering design education. *European journal of engineering education*, **31(2)**: 191-200.
- Haik, Y., Sivaloganathan, S., & Shahin, T. 2018. The engineering design process, 3rd Edition, Cengage, Boston, USA.
- Hallgrimsson, B. 2012. Prototyping and model making for product design. London, England: Laurence King Publishing.
- Hartmann, B. 2009. *Gaining design insight through interaction prototyping tools*. PhD Thesis, Department of Computer Science, University of Stanford, USA
- Isa, S. S., & Liem, A. 2014. Classifying Physical Models and Prototypes in the Design Process: A study on the Economical and Usability Impact of Adopting Models and Prototypes in the Design Process. In *DS 77: Proceedings of the DESIGN 2014 13th International Design Conference*.
- Jones, T. S. & Richey, R. C. 2000. Rapid prototyping methodology in action: a developmental study. *Educational Technology Research and Development*, **48(2)**: 63–80.
- Kalimuthu, A. 2016. A practical guide on rooftop rainwater harvesting, WASH Institute, New Delhi, India
- Kamrani, A. K., & Nasr, E. A. 2010. Engineering design and rapid prototyping. Springer Science & Business Media.
- Kelley, T. 2001. Prototyping is the Shorthand of Innovation. *Design Management Journal Summer*, **12(3)**: 35-42.
- Kinkade-Levario, H. 2007. Design for water: Rainwater harvesting, stormwater catchment, and alternate water reuse. New society publishers.
- Leavy, B. 2012. Collaborative innovation as the new imperative—Design thinking, value co-creation and the power of “pull”. *Strategy & Leadership*, **40(2)**: 25-34.
- LePine, J.A., Piccolo, R.F., Jackson, C.L., Mathieu, J.E. & Saul, J.R. 2008. A meta-analysis of teamwork processes: tests of a multidimensional model and relationships with team effectiveness criteria. *Personnel Psychology*, **61(2)**: 273-307.
- Liou, F. W. 2007. Rapid prototyping and engineering applications: a toolbox for prototype development. CRC Press.
- Lorber, J. 1994. *Paradoxes of gender*. New Haven, CT: Yale University Press.
- Marks, P. 2000. Faster times for Rapid Prototyping. Computer Aided Engineering
- Morgeson, F.P., DeRue, D.S. & Karam, E.P., 2010. Leadership in teams: A functional approach

- to understanding leadership structures and processes. *Journal of management*, **36(1)**: 5-39.
- Montgomery, D. C. 2017. *Design and analysis of experiments*. John Wiley & Sons.
- Morey, A., Dhurve, B., Haste, V., & Wasnik, B. 2016. Rainwater harvesting system. *International Research Journal of Engineering and Technology*, **3(4)**: 2158-2162.
- Mukherjee, N. 1995. *Participatory rural appraisal and questionnaire survey*. Concept Publishing Company.
- Mwenge-Kahinda, J.M., Taigbenu, A.E. & Boroto, J.R. 2007. Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth*, **32**: 1050-1057
- National Peace Corps Association. 2015. Success stories: Katie Difilippo and water security in rural Karagwe, Tanzania. Available at <http://www.peacecorpsconnect.org/karagwesuccess>, Retrieved on 27 January 2016
- Otto, K., & Wood, K. 2001. Product design: techniques in reverse engineering and new product design. Prentice-Hall.
- Pacey, A. & Cullis, A. 1989. *Rainwater Harvesting: The Collection of Rainfall and Runoff in Rural Area*. International Technology Publications, London, United Kingdom
- Pei, E., Campbell, I., & Evans, M. 2011. A taxonomic classification of visual design representations used by industrial designers and engineering designers. *The Design Journal*, **14(1)**: 64-91.
- Pelak, N., & Porporato, A. 2016. Sizing a rainwater harvesting cistern by minimizing costs. *Journal of Hydrology*, **541**: 1340-1347.
- Petroski, H. 1985. *To engineer is human*. New York: St. Martin's Press.
- Sanders, L., & Simons, G. 2009. A social vision for value co-creation in design. Open Source Business Resource.
- Sanders, E. B. N., & Stappers, P. J. 2008. Co-creation and the new landscapes of design. *Co-design*, **4(1)**: 5-18.
- Stowe, D. T. 2008. Investigating the Role of Physical Prototyping in Engineering Design Using Case Study Validation, PhD thesis, Clemson University.
- Ullman, D.G. 2003. *The mechanical design process*. McGraw-Hill, New York, NY
- Voorberg, W. H., Bekkers, V. J., & Tummers, L. G. 2015. A systematic review of co-creation and co-production: Embarking on the social innovation journey. *Public Management Review*, **17(9)**: 1333-1357.
- Woltersdorf, L., Jokisch, A., & Kluge, T. 2014. Benefits of rainwater harvesting for gardening and

- implications for future policy in Namibia. *Water Policy*, **16(1)**: 124-143.
- Wood, W. & Eagly, A.H., 2002. A cross-cultural analysis of the behavior of women and men: Implications for the origins of sex differences. *Psychological bulletin*, **128(5)**: 699-726
- Worm, J. & Hattum, T. 2006. Rainwater Harvesting for Domestic Use [online], Agrodok 43, Agromisa Foundation and CTA, Wageningen. Available at: www.rainfoundation.org/fileadmin/PublicSite/Manuals/AGRODOK_RWH_43-e-2006-small.pdf retrieved on 26 February 2017.

CHAPTER 8 SELECTING THE MOST PREFERRED PROTOTYPES OF THE RAINWATER HARVESTING TECHNOLOGY WITH BEST POTENTIAL TO IMPROVE ACCESS TO WATER IN MABAYENI VILLAGE

8.1 Abstract

Every technology that is developed has to be evaluated in order to make sure that it satisfies all the user requirements. Ignoring this step in the design process can result in developing a technology that is not appropriate for the customers or end users, rendering it useless. Thus, a study was carried out to select the most preferred prototypes of a rooftop RWH technology in Mabayeni village. The objective of the study was to evaluate available options and select the best prototypes for improvement using community feedback. Participants selected the best two prototypes out of the 14 that were developed by the seven interest groups. Respondents were grouped using gender and age to establish any differences in preference of prototypes. The study adopted a mixed method approach. Quantitative data (scores) were collected to select the best prototypes while qualitative data provided an in-depth understanding on the reasons considered when choosing. Thematic content analysis was used to analyse qualitative data while statistical software such as SPSS version 25 and R version 3.3.0 were used to analyse quantitative data. The Kruskal Wallis test was carried out to establish the prototypes that were regarded as the best. The Dunn's test in R was carried out to check if prototype component ratings differed across prototypes. Results indicated that Mabayeni residents were able to evaluate their prototypes and select the best using a design manual they created. The prototypes that were selected as the best were those made by boy children and men for zinc and thatch roofs respectively. This was based on the appearance and execution of the eight components namely; shape, construction material, delivery system, security, tank housing, access to water, water quality and water conservation. The study proved that with support, community members are able to develop, evaluate and propose improvements meant to provide solutions to their challenges. Thus, community members should be viewed as "experts" in designing and evaluating interventions for their societal challenges. This is because they understand their needs and capabilities better than outsiders.

Key words: Design evaluation; prototyping; rooftop rainwater harvesting, water scarcity

8.2 Introduction

In order to ensure that developed prototypes met all the requirements of participants, they were subjected to an evaluation process. Community members were at the centre of this process. They compared the different products (prototypes) with the expected components outlined in the design manual. Design evaluation presented an opportunity for participants to critically analyse the prototypes and improve them. According to Gupta *et al.* (2018), recent research has focused on the value of evaluation in improving design products and services. After solution alternatives are analysed, a decision is made on the solution best suited for implementation (Khandani, 2005). In addition, it is a stage where technical knowledge is applied to decide which solution to carry out (Khandani, 2005; Cockton, 2008). In other words, the design evaluation stage can be understood as both a confirmation stage (Gupta *et al.*, 2018) and a solution refinement stage (Fosmire & Radcliffe, 2014). This is because the main objective is to confirm if rhetoric suggestions made in the planning stage match with the actual prototype or artefact. Moreover, using feedback from end users or stakeholders on areas needing improvement helps in refining the proposed solution into its best possible condition. This ensures that it becomes usable.

Khandani (2005) argues that design analysis is a highly subjective step and should be made by a group of experienced people using a systematic methodology. In addition, Cockton (2008) contends that usability inspection has typically been carried out by trained usability experts. On the contrary, authors such as Bhagwat and Sharma (2007), Folstad *et al.* (2010), Folstad (2017) and Gupta *et al.* (2018) recommend that this exercise should be done by the end users. According to Gupta *et al.* (2018), it is vital to get the end users' requirements before the finalization of the design, and their satisfaction after experiencing the product because the customers are the ones who will use the product. Folstad (2007) highlights interaction and reflection as important aspects of obtaining design feedback from end users. This is because the two aspects lead to findings formulated as usability problems, or to quantitative summaries such as success rate. These among others, provide the designer(s) with an indication of areas needing improvement which in turn, makes the product acceptable.

Abras *et al.* (2004) encourages proper definition of the end users and how to involve them in the design process before the actual evaluation is done. The latter authors explain the three types of end users which are primary, secondary and tertiary. Primary users are defined as the people who actually use the artefact while secondary users are those who will occasionally use the artefact, or use it through an intermediary. Tertiary users are the people who will be affected by

the use of the artefact or make decisions about its purchase. Abras *et al.* (2004) argues that the successful design of a product must take into account the wide range of stakeholders of the artefact. This is because these stakeholders may provide important insights that can benefit the product. However, according to Preece *et al.* (2002), not everyone who is a stakeholder needs to be represented in the design team, but their contribution must be considered.

Khandani (2005) urges that before deciding which design solution to implement, one needs to analyse each alternative solution against a defined selection criteria. Although every design problem is unique and requires different types of analyses, Khandani (2005) gives examples of common design analyses that are carried out in engineering and business fields. These are functional analysis, industrial design (ergonomics), mechanical (strength analysis), electrical (electromagnetic), manufacturability (testability), product safety and liability, economic and market analysis, among others. These are some of the technical issues whose feasibility are examined during the design analysis or design evaluation stage.

In this study, 14 prototypes of a technology for harvesting rainwater for domestic use were evaluated in Mabayeni village. Firstly, the prototypes with best potential to improve water availability were selected. Secondly, feedback gathered from community members, who were also the prospective primary users was used to refine the prototypes. Mabayeni residents, who also took part in the designing of prototypes were the expert design evaluators. Design evaluation was a very important step. It helped the designers (community members) to get useful feedback for the improvement of the rooftop RWH technology. Without it, there was no guarantee that the final product fulfilled their expectations. In other words, this exercise was done to check if the prototypes that were developed by community members were an accurate representation of the RWH technology that they desired. The technology was believed to have the potential to assist in tapping rainwater and bridge the gap between the rainy season and dry season.

8.3 Methodology

8.3.1 Research design

The current study adopted the view that both the positivist and interpretivist philosophies can be understood as a continuum rather than opposite positions (Tashakkori & Teddlie, 1998). Consequently, the pragmatist's view, which combines the two philosophies was assumed since the nature of the study was exploratory, explanatory and included hypothesis testing. This justified the use of the explanatory sequential mixed method design. This entailed simultaneous collection

and analysis of quantitative and qualitative data and giving equal weight to both types of data (Palinkas *et al.*, 2010). A combination of qualitative data from a variety of PAR techniques and quantitative data from a survey were used to evaluate prototypes and improve the selected ones using participants' feedback. In other words, while quantitative data indicated the most preferred prototypes out of the 14, qualitative data provided explanations for those decisions. This made qualitative data dependent on quantitative data. The main purpose of using a mixed method design was therefore to complement and illustrate results. This means that qualitative data was used to illustrate or justify quantitative data.

8.3.2 Population and sampling procedures

Five volunteers from each of the seven interest groups individually completed a one-page questionnaire with eight components of the RWH technology. A total of 35 respondents took part in the exercise. In this engagement, none of the Magangeni group members participated and no apology was received from any resident of this part of the village. As already mentioned, this group was disproportionately affected by water scarcity. As a result, they were busy most of the time.

8.3.3 Data collection

Data was collected through surveys. Surveys were used to determine the preferences of prototypes and prototype components developed by different interest groups. A questionnaire (assessment sheet) with open and closed ended questions was used. The prototypes were broken down into eight components namely; shape, construction material, delivery system, security, tank housing, access to water, water quality, and water conservation. For each prototype component, participants were given an instruction to give a score out of 10 (1 being poor and 10 being very good). In addition, some space was provided in the questionnaire to give comments and suggestions for improvement of the prototypes. The research questions that were answered were (a) Which two prototypes (one zinc and one thatch) were regarded as the best, (b) Did different interest groups prefer the same prototypes?, and (c) Are there any statistically significant differences in the ranking of prototype components? The latter objective was determined through carrying out statistical tests. The main tools used for collecting data through both focus group discussions and survey were the 14 prototypes, and a two-page assessment tool. Other tools included pencils, pens, markers, stickers, flipcharts, notebooks and camera.

8.3.4 Data analysis

Participants followed a process called design evaluation or design analysis to interrogate the different prototypes. A combination of the Statistical Packages for Social Sciences (SPSS) version 25 and R software for statistical analysis version 3.3.0 were used to analyse data. The Kruskal Wallis test was used to determine first, the two prototypes (one for zinc roof and another for thatch roof) that were regarded as the best; and second, if prototype component ratings differed across prototypes. The Kruskal Wallis test is the non-parametric equivalent of Analysis of Variance (ANOVA) procedure. The Kruskal Wallis test was used because the data did not meet some assumptions of ANOVA (Mann & Lacke, 2011). Out of the three assumptions of ANOVA, normality and homogeneity were not met. The assumption of normality was tested using the Kolgomorov-Smirnov test (D' Agostino & Stephens, 1986) while the equality for variance assumption was tested using the Bartlett's test (Montgomery, 2007). Non-parametric tests such as the Kruskal Wallis test do not have such requirements. Efforts to transform data to normality using a variety of recommended transformation methods were unsuccessful.

The null hypothesis for the Kruskal Wallis test was:

H₀: The distribution of scores for a component (e.g. shape) are the same across prototypes.

However, the Kruskal Wallis test on its own could not give an indication of the specific groups that differed. When the null hypothesis was rejected, pairwise comparisons had to be conducted to compare the groups in pairs. However, there were many groups to compare (seven in this study), making it difficult to categorize the comparison groups (for example, prototype components). The Dunn's test in R statistical software version 3.3.0 was therefore used for pairwise comparisons. The reason being that the output that it gives makes categorizing the comparison groups easier. Significance was determined at $P < 0.05$. Box and Whisker plots were used to give a visual comparison of the scores across prototypes as well as prototype components. Box and Whisker Plots produced for prototypes are shown under the results section. The corresponding plots for prototype components are presented under Appendices 8.2 and 8.3. Figure 8.1 is an illustration of a Box and Whisker Plot. All the quartile sections represent about a quarter of the data.

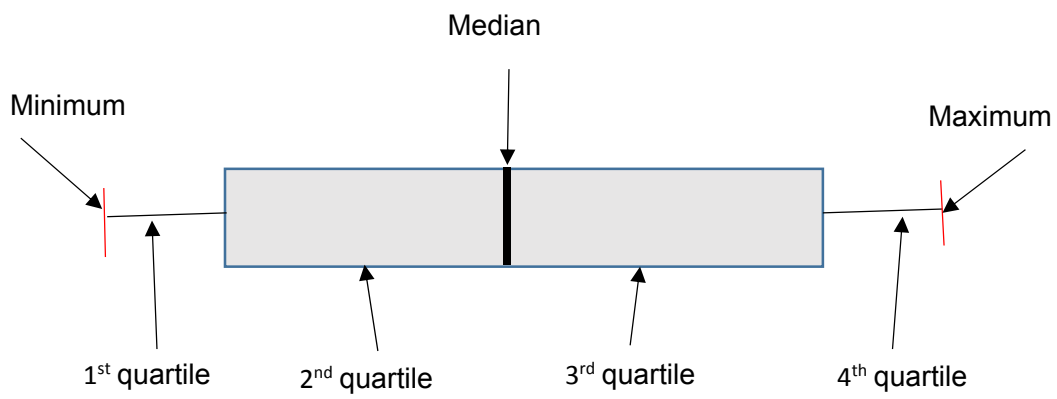


Figure 8. 1 An illustration of the Box and Whisker Plot

8.3.5 Ethical considerations

Ethical issues relating to engineering design such as truthfulness (Fosmire & Radcliffe, 2014) and intellectual property ownership were taken into consideration. Truthfulness was upheld through communicating correct and relevant information to community members. Furthermore, possible products and benefits accruing to the RWH technology were communicated to community members.

8.4 Results

Participants' scores enabled the selection of the two best RWH prototypes out of the fourteen. As already indicated, seven of them were meant for thatch roofing, while the remaining were for zinc. Results for zinc and thatch are therefore presented separately. The distribution of scores among the seven zinc prototypes is displayed in Table 8.1.

As shown in Table 8.1, the prototype that was made by boy children had the highest mean rank, of 1269. This was followed by the one that was developed by male youth with a mean rank of 1046. The least ranked prototypes were those built by women and female youth with mean ranks of 842 and 856 respectively. These results are confirmed by an illustration of the distribution of scores across prototypes presented in Figure 8.2. The prototype made by boy children had a minimum score of six and a maximum of 10. A huge number of scores for this prototype were concentrated between the range of eight and 10. The prototype designed by male youth recorded a minimum score of one and a maximum of 10. As for women, female youth and girls, their lowest score was one while the highest was nine.

This was further reinforced by the results on the distribution of scores among prototypes according to prototype component presented in Table 8.2. The prototypes with the highest number of components that were highly ranked were boy children's with seven components. It was followed by the one designed by male youth with three components out of eight.

Table 8.1 The Distribution of Scores According to Prototypes across Groups in Mabayeni Village of Collins Chabane Local Municipality in Limpopo Province

Prototype for zinc roof	Mean rank	Rank
Boy children	1269 ^c	1
Male youth	1046 ^b	2
Elderly people	1031 ^b	3
Girl children	929 ^{ab}	4
Men	888 ^a	5
Female youth	856 ^a	6
Women	842 ^a	7

^{a,b,c} Mean ranks with similar superscripts within columns are not significantly different

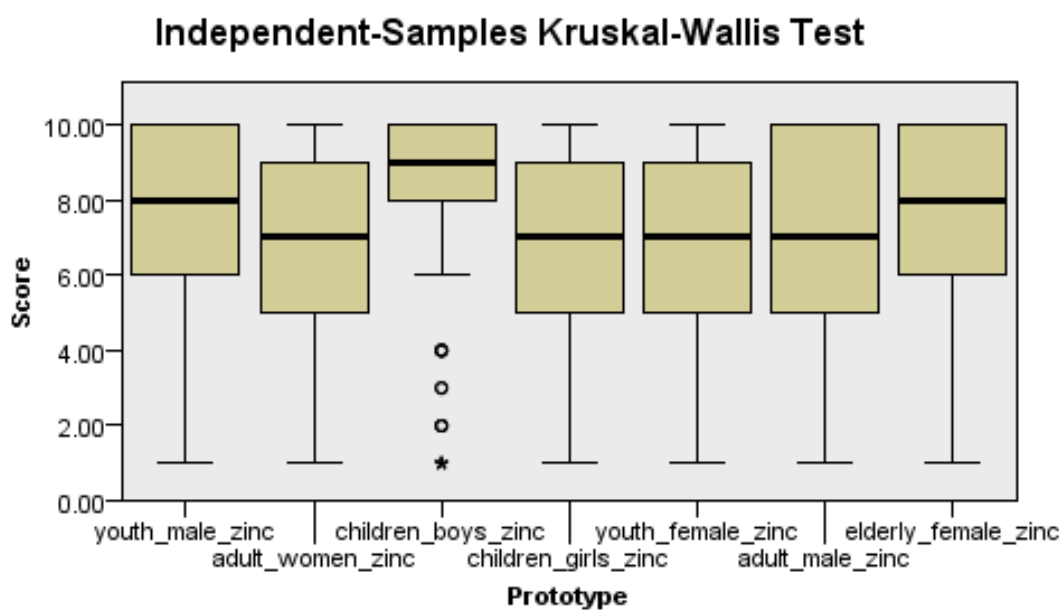


Figure 8.2 Box and whisker plot showing the distribution of scores for zinc prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 8.2 The distribution of scores according to prototype component across groups in Mabayeri village of Collins Chabane Local Municipality of Limpopo Province

Components for zinc prototype	Children		Youth		Adults		Elderly people
	Boys	Girls	Male	Female	Men	Women	
a) Shape	145 ^b	134 ^{ab}	107 ^{ab}	108 ^{ab}	131 ^{ab}	96 ^a	140 ^{ab}
b) Construction material	162 ^{bc}	104 ^a	118 ^{ab}	100 ^a	106 ^a	100 ^a	171 ^c
c) Delivery system	134 ^{ab}	126 ^{ab}	166 ^b	125 ^{ab}	97 ^a	104 ^a	110 ^{ab}
d) Security	163 ^b	97 ^a	129 ^{ab}	122 ^{ab}	115 ^{ab}	121 ^{ab}	113 ^{ab}
e) Tank housing	183 ^b	126 ^{ab}	114 ^a	97 ^a	119 ^a	92 ^a	130 ^{ab}
f) Access to water	160 ^c	136 ^b	150 ^b	84 ^a	100 ^{ab}	117 ^{abc}	113 ^{ab}
g) Water quality	144 ^b	100 ^a	144 ^b	117 ^{ab}	121 ^{ab}	111 ^{ab}	124 ^{ab}
h) Water conservation	178 ^b	111 ^a	131 ^{ab}	109 ^a	98 ^a	105 ^a	129 ^{ab}

^{a, b, c} Mean ranks with similar superscripts within rows are not significantly different

On the other hand, the prototype that was constructed by women had the highest number of components (four out of eight) which were ranked the lowest

With respect to thatch prototypes, the prototype that was built by men had the highest mean rank of 1279. It was followed by the one developed by female youth with a mean rank of 1165 (Table 8.3). The prototype developed by elderly people had the lowest mean rank of 660. This was also confirmed by the distribution of scores displayed in Figure 8.3. Although the lowest score for all prototypes was one, the majority of scores for the prototype that was developed by men fell between five and 10. On the contrary, the majority of scores for the prototype that was developed by the elderly people fell between one and six. Results of the analysis of prototypes based on components also reinforced the fact that the prototype made by men was the best (Table 8.4). This prototype obtained the highest mean ranks for all components except for water conservation. Regarding the latter component, it was the prototype that was developed by female youth which had the highest mean rank (of 161). For female youth, this was the only component they scored the best. On the contrary, the prototype developed by the elderly had five components that were ranked the lowest, making their prototype the least preferred. Scores for the rest of the prototypes fell in between.

The comments that were given by participants to justify their score allocations were used to finalize the selected prototypes. For the zinc prototypes, the most common comment given for the boy children was absence of gutter screens and the water holding structure's closeness to the house (Table 8.5). For men, most of the comments for both zinc and thatch prototypes (Table 8.6) were about the absence of a water holding structure for storage of excess water from the storage tank. In addition, the boy children's prototype lacked gutter screens and fencing for security among other components. For the rest of the groups, the prototypes were either missing a number of components, or the components were not properly put together. The feedback indicated above was used to improve the selected two rooftop RWH prototypes. Figures 8.4 and 8.5 illustrate the improved versions of the zinc and thatch prototypes respectively.

Table 8.3 The distribution of scores according to prototype across groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Prototype for thatch roof	Mean rank	Rank
Men	1279 ^d	1
Female youth	1165 ^c	2
Women	1082 ^c	3
Girl children	932 ^b	4
Male youth	889 ^b	5
Boy children	856 ^b	6
Elderly people	660 ^a	7

^{a,b,c,d} Mean ranks with similar superscripts within columns are not significantly different

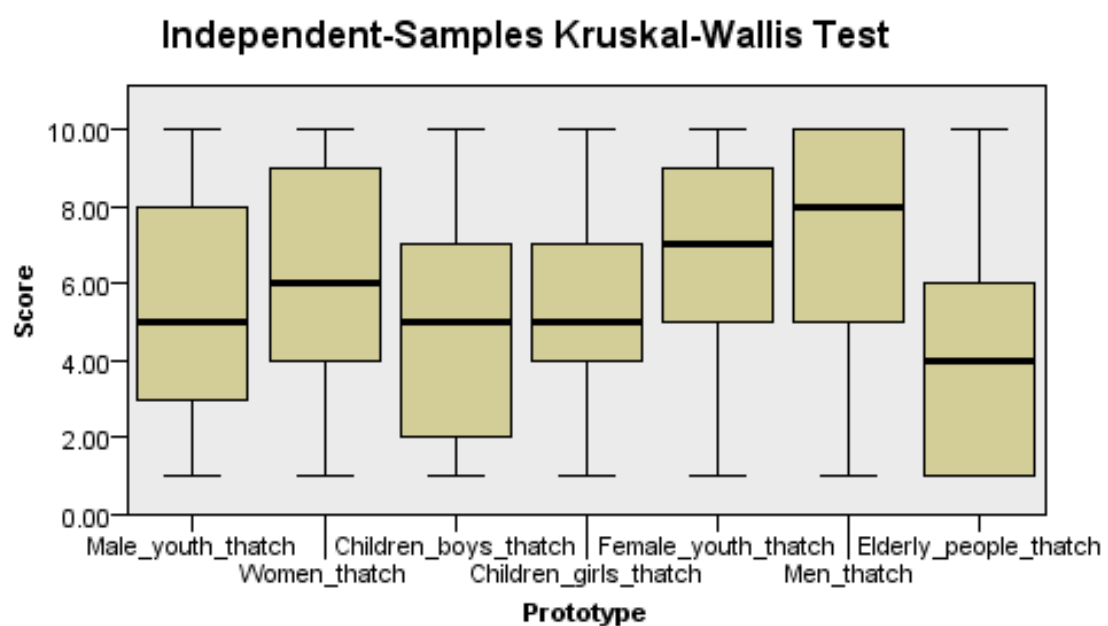


Figure 8.3 The box and whisker plot showing the distribution of scores for thatch prototype developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Table 8.4 The distribution of scores according to prototype across groups in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Components for thatch prototype	Children		Youth		Adults		Elderly people
	Boys	Girls	Male	Female	Men	Women	
a) Shape	146 ^c	82 ^a	99 ^{ab}	134 ^{bc}	148 ^c	112 ^b	140 ^{bc}
b) Construction material	144 ^c	91 ^a	139 ^c	130 ^{bc}	148 ^c	130 ^{bc}	81 ^a
c) Delivery system	104 ^a	110 ^{ab}	110 ^{ab}	162 ^c	180 ^d	116 ^b	79 ^a
d) Security	63 ^a	122 ^{ab}	132 ^b	141 ^c	175 ^d	141 ^c	88 ^a
e) Tank housing	71 ^a	132 ^b	137 ^{bc}	149 ^{bc}	174 ^c	141 ^{bc}	58 ^a
f) Access to water	103 ^b	123 ^{bc}	136 ^{bc}	140 ^{bc}	153 ^c	147 ^{bc}	60 ^a
g) Water quality	90 ^a	131 ^b	81 ^a	153 ^{bc}	180 ^c	151 ^{bc}	74 ^a
h) Water conservation	131 ^b	145 ^b	67 ^a	161 ^b	128 ^{ab}	154 ^b	75 ^a

^{a,b,c,d} Mean ranks with similar superscripts within rows are not significantly different

Table 8.5 Design feedback for zinc prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Prototype	Boy children	Girl children	Men	Women	Male youth	Female youth	Elderly people
a) Male youth	no gutter screen, tank housing not properly designed,		no tank housing		zinc material closing tank will make water hot	tank too close to the house	
b) Women	no gutters on other side, roofing not properly done	no gutters on the other side		no gutters on the other side	roofing not well done	gutters are on one side, no space for cleaning the tank	
c) Boy children	no gutter screen	no fencing for animals and thieves		<i>Xikerepe</i> too close to the house	tank is completely closed with housing	tank and <i>Xikerepe</i> too close to the house	no gutter screen
d) Girl children	tank not elevated	no gutters, tank not protected	no gutters	tank not elevated	tank completely covered, unable to see what's inside		
e) Female youth	no fencing	<i>Xikerepe</i> missing				no fencing	water pipes not well connected
f) Men	<i>Xikerepe</i> missing	<i>Xikerepe</i> missing	<i>Xikerepe</i> missing	<i>Xikerepe</i> missing	no security		<i>Xikerepe</i> missing
g) Elderly Female	tank not round		no gutters	no gutters		no specification whether tank is for people or animals	

Table 8.6 Design feedback for thatch prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Prototype	Boy children	Girl children	Men	Women	Male youth	Female youth	Elderly group
a) Male youth	storage tank not round, missing gutter screen and water holding structure (<i>Xikerepe</i>)	shape not round, missing gutter screen, no <i>Xikerepe</i>	no fence, tank housing missing		no <i>Xikerepe</i> and gutter screen	no gutter screens, tank not fastened	no <i>Xikerepe</i> , plastic wears off easily
b) Women	no gutter screens	no gutters and cap to close tank, no fencing	no fence	gutters not well designed		zinc material for closing tank will make water hot	tank too close to the house, <i>Xikerepe</i> is in front of the house
c) Boy children	<i>Xikerepe</i> too high, no fence	no fencing, gutters and gutter screens, tank not closed		no gutters, no tank housing	not finished	no gutter screens, fencing and roofing to protect the tank	
d) Girl children	no <i>Xikerepe</i>	not finished		no gutters no gutter			
e) Female youth	no gutters	no downpipes		screens, no <i>Xikerepe</i>			
f) Men	no tank housing, tank not round	no <i>Xikerepe</i> and gutters		no <i>Xikerepe</i>	no <i>Xikerepe</i>	tank, zinc roofing and tent too close to the house	no <i>Xikerepe</i>
g) Elderly female	no gutters, gutter screen and <i>Xikerepe</i> , tank not round	no gutters, gutter screen and <i>Xikerepe</i>	no gutters and gutter screen		no gutters	prototype not complete	

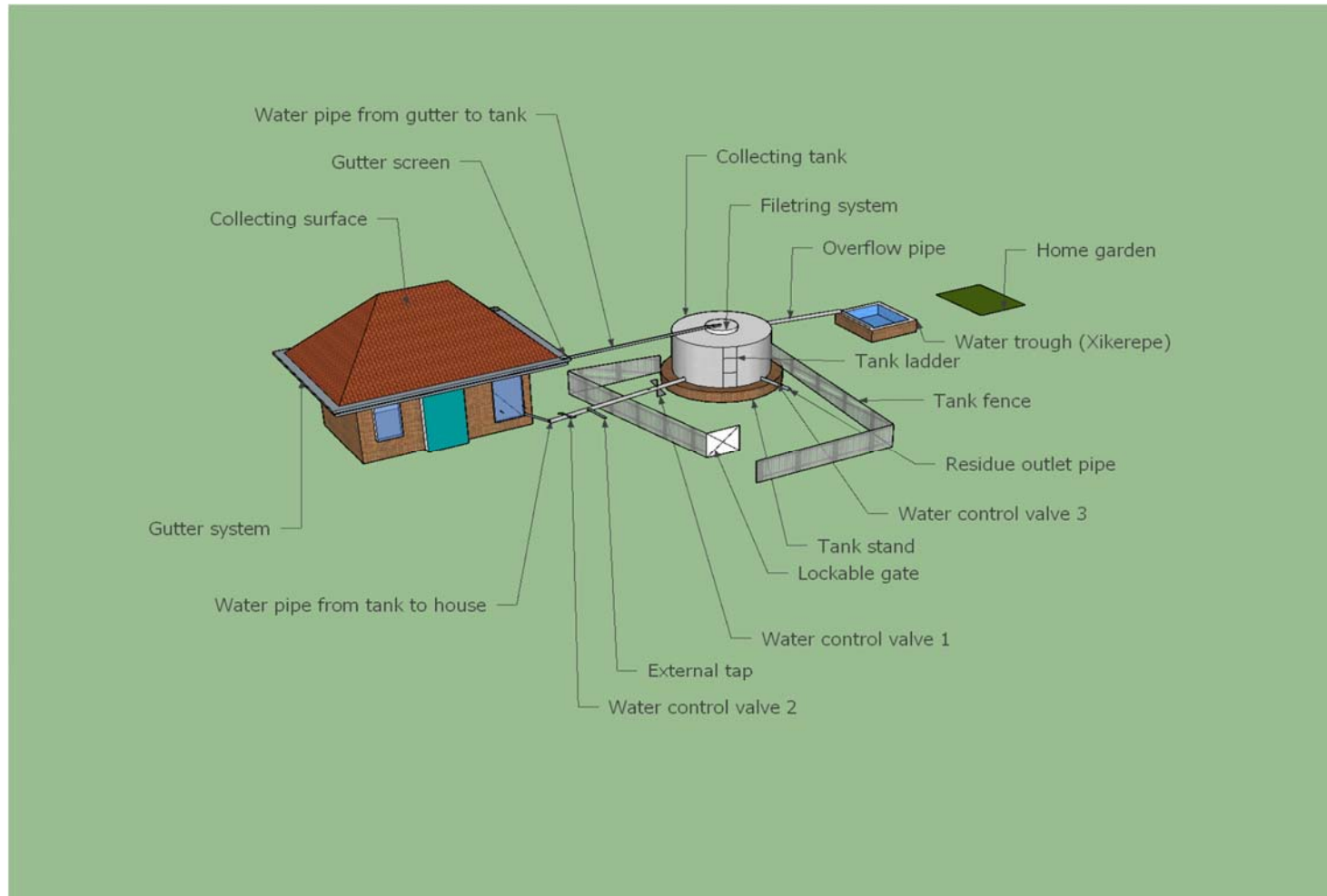


Figure 8. 4 An improved pictorial view of the rooftop rainwater harvesting technology for zinc roof developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

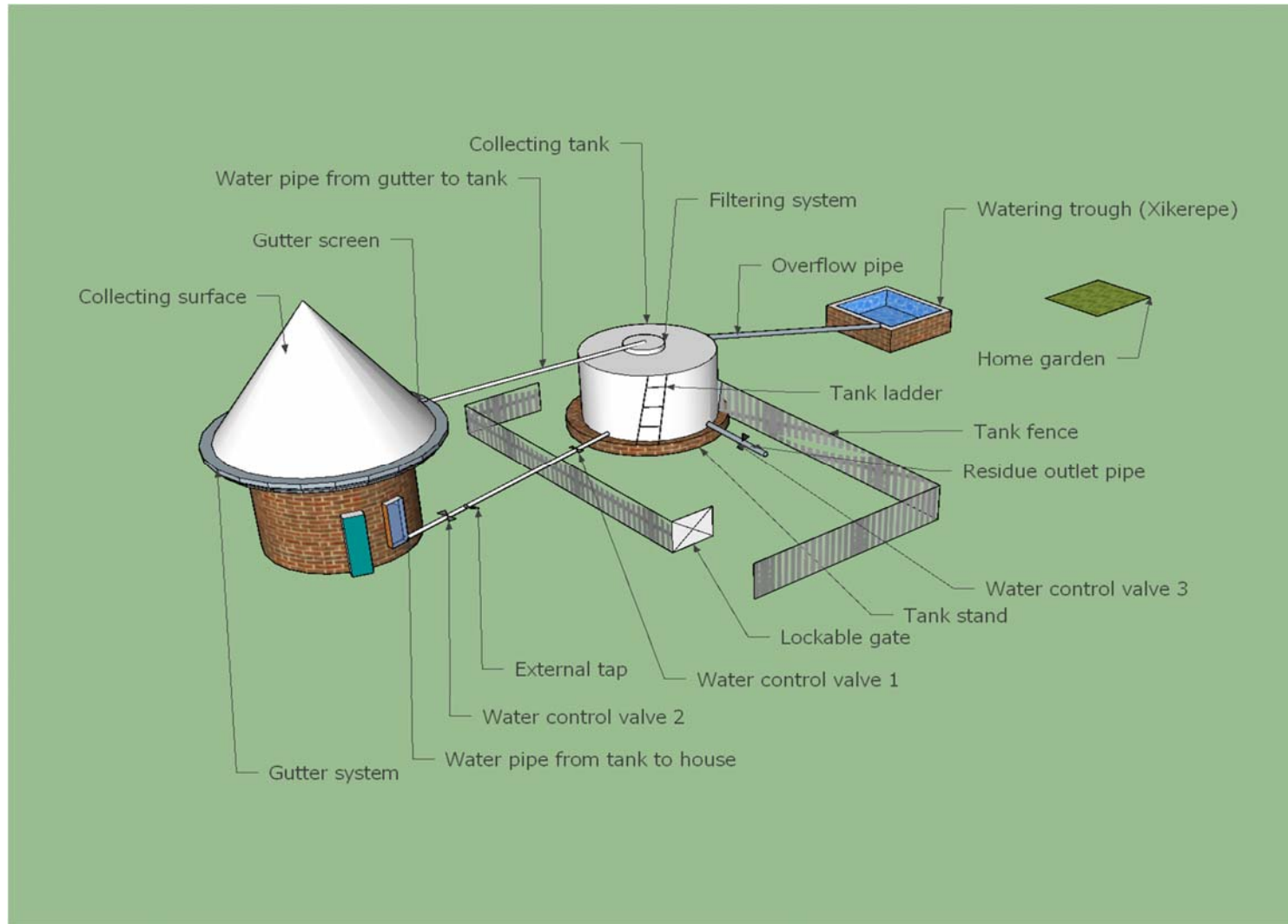


Figure 8. 5 An improved pictorial view of the rooftop rainwater harvesting technology for thatch roof developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

8.5 Discussion

Prototype, component and score distribution-based results indicate that groups of children, youth, adults and the elderly unanimously agreed on the best prototypes for both zinc and thatch roofs. Boy children's and men's prototypes were chosen as the best for zinc and thatch roofs, respectively. The reasons given for this selection were related to structural arrangement or assembling of prototype components, and the ability to capture all the required components as specified in the concept description or design guide. This is evidence that Mabayeni residents were able to systematically adhere to a design manual they created, and used it to assess their prototypes. The importance of using pre-prototype documentation such as concept descriptions when performing user-reflection tasks is highlighted by Folstad (2017). Developing the design manual also portrayed the community's domain knowledge regarding water scarcity in the area and addressed their contextual needs.

While Preece *et al.* (2002), Robertson & Simonsen (2012) and Folstad (2017) recognize understanding a system's context as critical in design evaluation as well as in the ultimate success of design products, Cockton *et al.* (2008) emphasizes the significance of domain knowledge as an evaluation resource. In addition, Cross (2000) stresses the evaluation of design alternatives through considering the objectives that the design is supposed to achieve. This converges with Siddall's (1982) emphasis on the role of value in generating the best possible product in design. The author underscores the importance of developing a value criterion in determining best design choice. According to Siddall (1982), it is the ability to define values of society that can help designers to shape technologies in response to these values. Kerr (2014) adds that all group members should be satisfied with the selected idea if a design project is to be successfully completed. Abras (2004) even recommends that design evaluation should take place in the environment in which the product being designed would be used. In the current study, end users were portrayed as a central to the development process (Aitamurto *et al.*, 2015) and satisfied all the other requirements and suggestions as explained above. Therefore, as experts of their experiences, Mabayeni residents were able to use their knowledge and expertise to select the technologies with the best potential to address inadequate availability of water in their community.

The fact that prototypes developed by boy children for zinc and thatch roofs were ranked as best and worst, respectively reveals the importance of having different groups develop the same prototype. In addition, men only did well with the thatch prototype but not the zinc one. Even so, an examination of the prototype components exposed that the prototypes that were selected as

the best were not perfect and needed improvement. The female youth for example, made the best water conservation component although the rest of the components were least ranked. The evaluation method which was used enabled consolidation of a variety of strengths from different design groups. Spiller *et al.* (2015) terms this robustness of design. This method of design evaluation also finds support in the work of Khandani (2005). This is a confirmation of the need and importance of engaging a wide range of stakeholders during product design in order to come up with the best possible product. The prototype developed by men was improved by adding a water holding structure while that of boy children had the delivery system component improved to meet the community's requirements.

It was also amazing that the boy children group created the best zinc prototype. During the design evaluation engagement, groups of adults and elderly were left perplexed, and attested that they did not expect boy children to construct one of the best prototypes. Available literature on involvement of children in research is found mainly in health care services (Bell, 2005; Mc Laughlin, 2010; Moore & Kirk, 2010). According to Moore & Kirk (2010), children have often been viewed as an innocent group needing protection from society's evils. Children have also been seen to exist outside politics. Bell (2005) explains a traditional approach in which children are viewed as citizens of the future. Focus is therefore limited to discovering how to develop appropriate skills for their future roles as citizens.

Such notions are contested in this study. It is revealed that children are citizens in their own right, can contribute meaningfully to any activities taking place in their space. Therefore, they should be given the opportunity to learn and understand their environment, as well as participate in political and civic activities in their everyday lives. This will ensure that any initiatives that take place in their locality are relevant to their needs. Children and youth have been neglected when it comes to participating in activities taking place in their localities (Lekies (2007). Guyot (2007) argues that when children and youth participate, they change the world around them. Depriving these groups the opportunity to participate means depriving them of the opportunity to think, learn and change their worlds. It is this exclusion which later on builds resentment. This negative energy is not good for development. Thus younger community groups should be involved in any community activities so as prepare them to become active and responsible citizens.

It is worth noting that men deliberately excluded water conservation features in their prototypes. They argued that there would be no need for capturing excess water into another water holding

structure (*Xikerepe*) once the storage tank fills up. This is because each household would design a tank with a storage capacity sufficient for all its water needs. It was thus, unnecessary for this group to consider an extra water holding structure. However, data from design evaluation, revealed that all groups (including men's) found the water holding structures to be a necessity since they would store water for other uses such as washing clothes or animal drinking. Mulder & Jan Stappers (2009) argue that design evaluation is also a procedure of letting participants go through a process of reflection in order to deepen insights on the product under design. It is possible that during group discussions, men got convinced that extra water holding structures were necessary. This put all the design groups in agreement on all the prototype features, satisfying Kerr's (2014) requirement explained above. Other advantages of channelling excess overflow water (Krishna *et al.*, 2005; Mati, 2005; Chidi, 2010) have already been explained in Chapters 6 and 7.

Also worth noting is the fact that the best prototypes were developed by males. From the prototyping experiences, it was observed that males found the task easy to do and seemed familiar with manipulating prototyping material into different shapes. On the other hand, although females found the exercise exciting, it was practically challenging for them to produce the prototypes. There is a dearth of recent literature on any relationships between gender and (creative) psychomotor skills. Although scholars like Vernon (1989) find logical grounds for speculating that genetic differences must account for some gender differences in creative achievement, specific genetic or other biological theories of gender differences in creativity are difficult to find. Abra & Valentine-French (1991) consider both nature and nurture arguments for the observed gender differences in creative accomplishments in their study. The latter authors noted the problem of disentangling the two. Helson (1990) argues that cultural values, social roles and sexist thinking are now recognized as key reasons for the comparative lack of creative accomplishment by women. The latter author adds that the differences between men and women in biology and early socialization experience are exaggerated by culture. In this study, it is possible that the males developed the best prototypes because they were used to working with objects as part of their social and cultural upbringing.

8.6 Conclusion

The prototype alternatives for a technology for harvesting rainwater for domestic use in Mabayeni village were evaluated and the best two chosen. Prototypes that were made by boy children and men were chosen as the best for zinc and thatch roofs, respectively. Although this was the case,

both prototypes needed some improvements in order to meet community requirements. On the boy children's prototype, the delivery system needed reworking while the men's prototype lacked water conservation features. The study also exposed that in engineering and participatory designs, the process is as important as the product. Prototypes were chosen using a pre-prototype documentation (design guide) which was developed by the community members themselves. This ensured that the selected prototypes met the community's exact needs. Prototypes that were developed by males were regarded as the best, likely owing to differentiated exposure, culture or environment due to gender. In a nutshell, Mabayeni community members managed to follow a process which helped them design an intervention strategy for water scarcity in their area.

8.7 References

- Abra, J., & Valentine-French, S. 1991. Gender differences in creative achievement: A survey of explanations. *Genetic, Social, and General Psychology Monographs*, **117**: 235-284
- Abras, C., Maloney-Krichmar, D. & Preece, J. 2004. User-Centered Design. In Bainbridge, W. *Encyclopedia of Human-Computer Interaction*. Thousand Oaks: Sage Publications. (in press)
- Aitamurto, T., Holland, D. & Hussain, S. 2015. The Open Paradigm in Design Research. *Design Issues*, **31(4)**: 17-29
- Bell, B., 2005. Children, youth, and civic (dis) engagement: Digital technology and citizenship. Available at <https://tspace.library.utoronto.ca/bitstream/1807/32142/1/CRACIN%20Working%20Paper%20No%205.pdf>, Retrieved on 26 May 2018
- Bhagwat, R. & Sharma, M.K. 2007. Performance measurement and supply chain management: A balanced score card approach. *Computers and Industrial Engineering* **53(1)**: 43-62
- Chidi, M. C. 2010. Rainwater harvesting: a technical guide available on <https://researchspace.csir.co.za/dspace/bitstream/handle/10204/3944/Chibi.pdf?sequence=1> retrieved on 10 February 2018
- Clavering, E.K. & McLaughlin, J. 2010. Children's participation in health research: from objects to agents?. *Child: care, health and development*, **36(5)**: 603-611.
- Cockton, G., Woolrych, A., Lavery, D. & Sears, A. 2009. *Inspection-based evaluations*. CRC Press.
- Cowley, J.A. & Radford-Davenport, J. 2011. Qualitative data differences between a focus group and online forum hosting a usability design review: a case study. *Proceedings of the human factors and ergonomics society annual meeting* **55(1)**: 1356–1360
- Cross, N. 2000. *Engineering design methods, strategies for product design*, Third Edition. John Wiley and sons, West Sussex, England
- D' Agostino, R.B. & Stephens, M.A. (Eds). 1986. *Tests based on EDF statistics: Goodness of fit techniques*, M. Dekker. New York
- Følstad, A., Anda, B.C., Sjøberg, D.I.K. 2010. The usability inspection performance of work-domain experts: an empirical study. *Interacting with Computers* **22**:75–87
- Følstad, A. and Hornbæk, K. 2010. Work-domain knowledge in usability evaluation: Experiences with cooperative usability testing. *Journal of systems and software* **83(11)**: 2019–2030

- Folstad, A. 2017. User's design feedback in usability evaluation: A literature review. *Human-centric computing and information sciences*, **7**: 1-9
- Fosmire, M. and Radcliffe, D. 2014. Integrating information into the engineering design process, Purdue University, USA.
- Gupta, R.K., Belkadia, F., Buergyb, C., Bitted, F., Da Cunhaa, C., Buergine, J., Lanzae, G. and Bernarda, A. 2018. Gathering, evaluating and managing customer feedback during aircraft production. *Computers and Industrial Engineering*, **115**: 559-572
- Guyot, J. 2007. Child and youth participation in protracted refugee situations. *Children, Youth and Environment*, **17(3)**: 159-178
- Helson, R. 1990. Creativity in women: Outer and inner views over time. In Runco, M. A., & Albert, R. S., *Theories of creativity*. Newbury Park, CA: Sage.
- Henderson, R., Podd, J., Smith, M.C. & Varela-Alvarez, H. 1995. An examination of four user-based software evaluation methods. *Interacting with Computers* **7(4)**:412–432
- Kano, N., Seraku, N., Takahashi, F. & Tsuji, S. 1984. Attractive quality and must-be quality. *Hinshitsu: The journal of the Japanese Society for Quality Control* **14(2)**: 39-48
- Kerr, J.M. 2014. Making engineering design relatable for all students – feature activity. *Children's Technology and Engineering*: 12 -14
- Khandani, S. 2005. Engineering design process: Education transfer plan available on <https://www.scribd.com/document/174690096/Engineering-Design-Process> Retrieved on 23 April 2018
- Krishna, H. J., Brown, C., Gerston, J., and Colley, S. 2005. The Texas manual on rainwater harvesting. *Texas Water Development Board, 3rd Edition, Austin, Texas, United States of America*.
- Lekies, K.S., Eames-Sheavly, M., MacDonald, L. & Wong, K.J. 2007. Greener voices: Strategies to increase the participation of children and youth in gardening activities. *Children Youth and Environments*, **17(2)**: 517-526.
- Mann, P.S. & Lacke, C.J. 2011. *Introductory statistics: International student version*, 7th Edition. John Wiley & Sons
- Mati, B. 2015. Roof water harvesting with above ground tank available on <http://www.jkuat.ac.ke/departments/warrec/wp-content/uploads/2015/07/ROOF-WATER-harvesting-with-above-ground-tank1.pdf> Retrieved on 13 March 2018
- Montgomery, D.C., 2007. *Introduction to statistical quality control*. John Wiley & Sons.

- Moore, L. & Kirk, S., 2010. A literature review of children's and young people's participation in decisions relating to health care. *Journal of clinical nursing*, **19(15-16)**: 2215-2225.
- Mulder, I. & Stappers, P.J. 2009. Co-Creating in Practice: Results and Challenges, Proceedings of the 15th International Conference on Concurrent Enterprising, ICE'2010 "Collaborative Innovation: Emerging Technologies, Environments and communities", Leiden, The Netherlands, June 2009
- Palinkas, L. A., Horwitz, S. M., Chamberlain, P., Hulburt, M., & Landsverk, J. 2010. Mixed method designs in mental health services research. *Psychiatric Services* (in press)
- Preece, J., Rogers, Y., & Sharp, H. 2002. *Interaction design: Beyond human-computer interaction*. New York, John Wiley and Sons.
- Robertson, T. & Simonsen, J. 2012. "Challenges and Opportunities in Contemporary Participatory Design," *Design Issues* **28(3)**: 3–9
- Siddall, J.N. 1982. Optimal Engineering design principles and applications. Mechanical engineering 14. Marcel Dekker Inc., New York and Basel
- Spiller, M., Vreeburg, J.H.G., Leusbrock, I. and Zeeman, G. 2015. Flexible design in water and wastewater engineering – definitions, literature and decisions guide. *Journal of Environmental Management* **149**: 271-281
- Steen, M. 2013. Co-design as a process of joint enquiry and imagination. *Design Issues* **29(2)**: 16-28
- Tashakkori, A., Teddlie, C. & Teddlie, C.B., 1998. *Mixed methodology: Combining qualitative and quantitative approaches* (Vol. 46). Sage. London
- Vermeeren, A.P., Law, E.L.C., Roto, V., Obrist, M., Hoonhout, J. & Väänänen-Vainio-Mattila, K. 2010. User experience evaluation methods: current state and development needs. In: Proceedings of the 6th Nordic conference on human-computer interaction: extending boundaries, ACM, New York
- Vernon, P. E. 1989. The nature-nurture problem in creativity. In Glover, J. A., Ronning, R. R. & C. R. Reynolds (Eds.), *Handbook of creativity: Perspectives on individual differences*, New York: Plenum Press.

CHAPTER 9 SYNTHESIS OF THE STUDY ON COMMUNITY-INFORMED RAINWATER HARVESTING TECHNOLOGY IN RURAL AREAS

9.1 Introduction

In this study, developing a rooftop rainwater harvesting technology with the community involved the use of a combination of various research designs, assorted data collection and analysis techniques and tools borrowed from different disciplines. It involved a blend of research and engineering processes. The specific objectives of the study were to: (1) determine the extent of water scarcity in Mabayeni village; (2) identify the strategies that were used to cope with inadequate availability of water for domestic use; (3) document the rainwater harvesting techniques that rural communities used; (4) compare the features of rainwater harvesting technology that people of different age groups preferred; (5) develop community-preferred prototypes of rainwater harvesting technology with the best potential to increase access to water for domestic uses; and (6) evaluate the prototypes of rainwater harvesting technology through an inclusive participatory community feedback approach. In this chapter, a summary of the major results of the study is provided. Many aspects of originality and contribution to knowledge emerging from the study are discussed within the context of the different types of scholarship that Boyer (1990) advocated. All this is aligned with the body of knowledge that is used to assess doctoral work. Conclusions are then drawn and recommendations for further research, policy and practice made.

9.2 Methodological aspects

Multiple research designs were used owing to the nature of the current study (Figure 9.1). The exploratory nature of the study justified the use of a multi-method research design in the beginning of the study. As the study progressed, the multi-method design was complemented with participatory action research design. The latter design was necessary because of the practical activities involved such as sketch modelling and prototyping. In addition, the engineering design process was borrowed to guide design activities. All the prototypes were evaluated using an explanatory-sequential mixed method design. The mixed method design was essential because neither qualitative nor quantitative approaches were sufficient to effectively evaluate the prototypes. The quantitative approach provided scores for each prototype while the qualitative approach provided explanations and validated given scores. The mixed method approach enabled comparison of results from interest groups through testing of hypotheses.

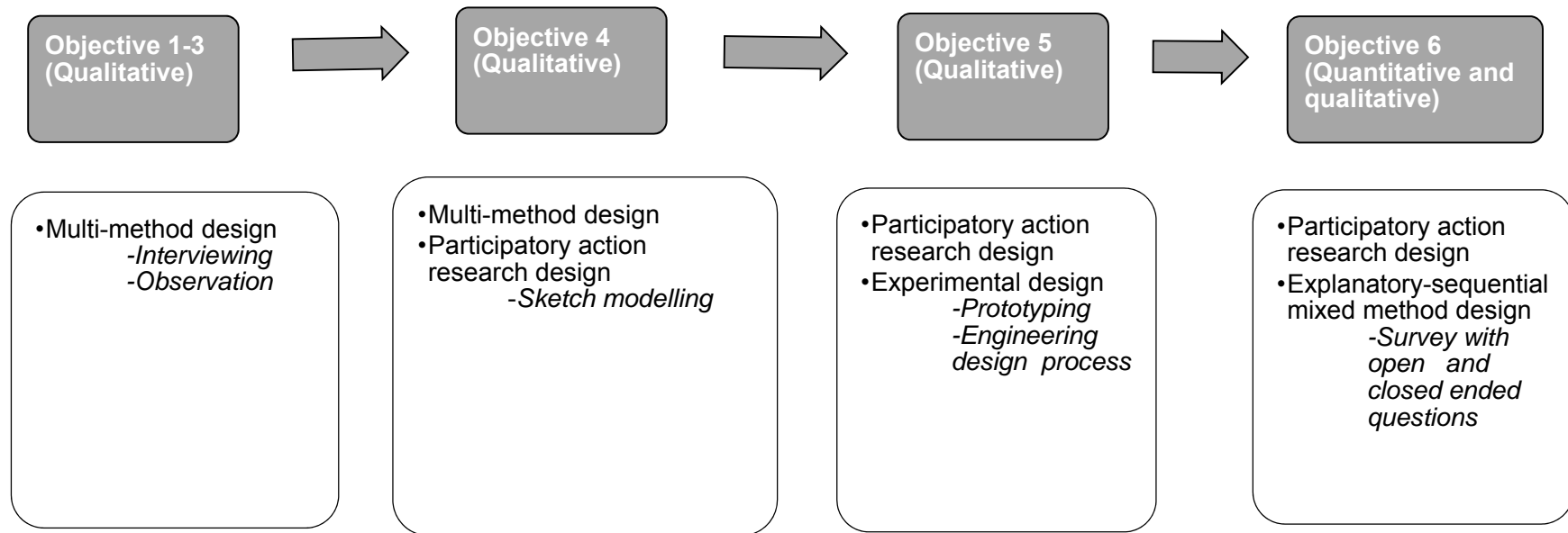


Figure 9.1 The hybrid research design used in the study on developing community-informed technologies for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Thus, an explanatory sequential mixed method design was best suited for discovery and confirmation purposes. Multiple research designs were carefully interwoven (into a hybrid design) in order to appropriately respond to research questions that underpinned the study. Boyer (1990) argues that it is through connectedness that research is ultimately made authentic. Thus, the aspects of authenticity and practicality were fulfilled in the current study.

A variety of primary and secondary data sources were consulted. The reason for this was to expand or extend the breadth and range of inquiry. In addition, multiple sampling strategies that were carried out allowed collection of data from different interest groups based on age and gender. Bryman (2012) calls this data triangulation. This was important for convergence and corroboration of data from different groups (Schoonenboom & Johnson, 2017). In addition, data triangulation was also important for checking any diversity of views among sample groups. Moreover, 11 data collection techniques were used (Table 9.1). This is called methodological triangulation (Denzin, 1970). In the current study, methodological triangulation existed within and between methods. This ensured validity of findings through convergence. However, even though the triangulation exercise may yield convergent findings, Bryman (2012) cautions that this does not necessarily mean that findings are unquestionable. On the contrary, it may be that both sets of data are flawed. Even so, at least four data collection methods and eight associated techniques were used in the current study. This reduced the possible flaws associated with using a couple of methods and/or techniques. This consequently, enhanced credibility and persuasiveness of research results.

About four data analysis methods and 10 associated techniques (Table 9.2) were used to analyse data. Webb *et al.* (1966) regard this as triangulation of measurement processes. Analysing data using a variety of analysis methods and techniques reduced interpretation error. Webb *et al.* (1966: 3) argue, "Once a proposition has been confirmed by two or more independent measurement processes, the uncertainty of its interpretation is greatly reduced. The most persuasive evidence comes from triangulation of measurement processes." This also increased credibility of, and confidence with research results. The use of a variety of data collection and analysis techniques also facilitated reaching a point of saturation. This was crucial for completeness of data. Thus, a variety of triangulation aspects explained above strengthened the integrity, validity as well as reliability of study results. Reducing errors meant that results that were produced were accurate, or as closest to ground realities as possible.

Table 9.1 Data collection techniques used in developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo province

Data collection techniques	Objectives					
	1	2	3	4	5	6
1. Photo voice with key informants	1	1	1			
2. Key informant interviews	1	1	1			
3. Focus group discussions with community	1	1	2	3	3	1
4. Non-participant observation	1	1	1			
5. Participatory mapping	1	1	1			
6. Transect walks	1	1	1			
7. Story telling	1	1	1			
8. Seasonal diagramming*	2	2	1			
9. Matrix scoring*	3	2	2	2		1
10. Prototyping					3	
11. Survey (questionnaire with open and closed-ended questions)						1
Total number of techniques	9	9	9	2	2	1

Table 9.2 Data analysis techniques used in developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo province

Data collection techniques	Objectives					
	1	2	3	4	5	6
1. Card sorting	x	x				
2. Thematic content analysis				x	x	x
3. Map ranking	x					
4. Conversation analysis	x	x	x			
5. Atlas.ti (version 7.5.7) - aided thematic content analysis	x	x	x	x	x	
6. Verbal protocol analysis					x	
7. Mathematical calculations					x	
8. Presentation and analysis	x			x	x	
9. Kruskal Wallis test in SPSS version 25						x
10. Dunn's test in R version 3.3.0						x
Total number of techniques	5	3	2	3	5	3

The range of techniques used originated from different disciplines such as Engineering (engineering design process and prototyping), Statistics (Kruskal Wallis and Dunn's tests), Mathematics (water demand and RWH potential equations), Anthropology (storytelling, transect walks and conversation analysis), Psycholinguistics (verbal protocol analysis) and Humanities (PRAs). This made the enquiry transdisciplinary in nature. This also expanded the study in terms of breadth and range while at the same time benefitting from different disciplinary perspectives. Borrowing techniques from other disciplines added sense of richness and complexity to the inquiry. Complexity, methodological rigour and focus are some of the critical elements expected from doctoral work. All the three characteristics were displayed in the current study. A variety of research designs, sampling strategies, data collection and data analysis methods and techniques were systematically coordinated in a deep-searching process which enabled the development of a practical intervention for water scarcity in Mabayeni village.

9.3 Enablers and challenges faced during the study

A number of activities and procedures that were followed enabled successful completion of the study. These included, proper development and cleaning of data collection tools, training of research assistants, well-planned and executed community entry process, having reflection sessions after each engagement, among others. Data collection tools were pre-tested and pilot tested with groups of community members to check the accuracy, clarity and sequence of questions. Unclear questions were clarified and unnecessarily long questions rephrased. This reduced engagement time and ensured collection of high quality data. Research assistants were trained on basic facilitation procedures. They were also orientated on the nature, background and purpose of the study. All the research assistants spoke the local language (Xitsonga). Thus, they were able to assist with translation when needed. The community entry process that was followed is described in Box 1. The research team was also innovative as they manoeuvred through emerging challenges. Box 2 illustrates once such instance.

The lesson learnt from the experience described in Box 1 was that informed consent play a vital role in promoting voluntary participation. Mabayeni village leaders appreciated the openness and transparency displayed by the team of researchers. Because they also understood how their community would benefit from the study, and their expected roles, it was easy for community leaders to show commitment and provide support throughout the study. Participating in the planning process through setting engagement dates and choosing community representatives made them feel responsible for contributing to the success of the research project.

Box 1 “Community entry: A requisite for the success of research projects”

Firstly, a meeting was held with the Councillor of Ward 35 of Collins Chabane Local Municipality where Mabayeni village is located. Permission was sought to carry out the study. In addition, the nature of the study, purpose, objectives and expected duration were clarified. Contact details of the village Headman were obtained from the Ward Councillor. Next, a visit was paid to the Vhembe District Water and Sanitation Department. The purpose was to seek, support and permission since water-related issues fall under the jurisdiction of the District Municipality. A representative was assigned to participate in the research project. Another meeting was held with the village headman and community leaders. During this meeting, permission to carry out the study in the village was sought. The purpose and objectives of the study were also explained. Moreover, consent to engage children from ages seven to 14 was also obtained. The expected duration of the study and expected support were outlined. The headman verbally gave permission. Three village representatives were selected to work directly with the research team. Their roles were to assist with mobilisation, offer advice where necessary, and communicate with researchers on behalf of the community. Community leaders warmly welcomed the team of researchers. They also showed gratitude towards the researchers because they were hopeful that the research would come up with a solution to water challenges in their community. In his words, the headman said, “Finally, we have research that will benefit us in a way that we can see. All we have to do is support you because the success of this project means our success as a community. Water is really a serious challenge here. This is a legacy for you even when you go back to Zimbabwe, there will be evidence that you did something good for this community.” Commitment to participate was secured through collectively indicating dates for engagement each week. The traditional leader pledged to mobilise people and take advantage of gatherings such as monthly village gatherings, churches and funerals.

Box 2 “The discovery of the *Swidhakwa* group”

As the engagement progressed, the group of men got smaller and smaller. None of them turned up on the first day of the prototyping exercises. On the second day, a large group of men was seen drinking traditional beer at one household. A short meeting was held with research assistants to explore the possibility of inviting these men. Another meeting was held with a few community leaders about the same issue. It was agreed that “the drunkards” could be invited provided that they would not cause problems. On invitation, the men agreed to participate in the prototyping exercises as long as they would be allowed to drink. They brought their bucket of alcohol and made their prototypes while drinking. They did this under a tree, away from the other groups. It was evident from their conversations that men were excited to participate. They wanted to prove a point to the rest of the groups. “They look down upon us. We know that they don’t take us seriously because we are drunk. We will show them. This is our thing,” they were heard saying. They even proudly named their group “Swidakwa” meaning drunkards. This group of men worked together very well. They did not cause any problems, and finished constructing their two prototypes in one session. The other groups took two to three sessions to complete. The rest of the groups unanimously agreed that Swidakwa group produced the best thatch prototype. This was amazing because other participants did not expect “the drunkards to produce meaningful prototypes.”

The experience displayed in Box 2 reveals the need to be innovative and “think on your feet” when carrying out community-based research. Men were invited to take part in research activities regardless of the fact that they were drinking alcohol. Though unusual, this was a success. Although participants from other groups were skeptical about the approach in the beginning, they confessed to have learnt not to underestimate other community members. Caution was taken through seeking advice and permission from the local community leaders before engaging men to avoid trouble. In addition, the group of men was isolated from other participants to ensure that they remained focused. Thus, even when pushing boundaries, care should be taken to avoid infringing other community rights, norms and values.

A number of challenges were also faced throughout the research process. These included delays in starting engagements due to participants’ late arrival, poor turn out of participants despite efforts made to mobilize, poor service from the catering company, among others. The catering company which provided lunch was a local company recommended by community members. On several occasions, the caterer brought food late which frustrated research participants. Efforts were made to resolve this challenge through having discussions with the service provider and community leaders. However, the challenge persisted. Boxes 3 and 4 present some of the challenges faced in detail. The lesson learnt from the experience described in Box 3 was that it takes time for community members to understand the intentions of a researcher. Likewise, it takes time for a researcher to understand the community psychology of any particular community. Thus, trust is a process built through patience, honesty and consistency. In addition, it is advisable to avoid scheduling events on national holidays because some people may be committed on such days. It became clear to the researchers that there was need to explain the background and purpose of the study on each engagement so as to make sure that participants understood why they were participating and its significance.

The lesson learnt from the experiential story in Box 4 was that it is risky to rely on one person when making arrangements for community engagements. Despite indicating that everything was under control, the headman failed to mobilise participants. The researchers could have insisted on getting another contact person to work with the headman. It is therefore advisable to work with a number of community representatives to avoid similar inconveniences.

Box 3 “The inopportune engagement”

The agreement was to start engagements at 7 am since it was a National Youth Day holiday. The research team arrived at 6:45 am. It was not until 8 am that a few community members started arriving. By 9 am, only seven people had arrived. The engagement only started at 10:30 with 30 participants. Others arrived very late. Out of the expected 120, only 49 participants turned up on the day. Refreshments had already been organised and last minute cancellations were unsuccessful. It was a very cold winter day. Were participants discouraged by the weather? Was it the holiday or was it something else? We couldn't help but wonder. We had agreed to start earlier than our normal 9 am meeting time to give people time to go for Youth Day celebrations after the engagement. We had reminded our community-based research team to mobilize as we had planned. We could not figure out what had gone wrong. Therefore, before commencing with the day's programme we devoted some time to understand what had gone wrong. It emerged from the discussion that one of the community-based research team members had discouraged community members from participating because “there was no proper food but only bread”. It had been communicated to this team member that due to the large numbers of people that were expected, only refreshments and not the usual standard lunch would be provided due to financial constraints. The feeling among the community members was that the researchers “were using people, and saving money for their enjoyment at the expense of community members”. The person whose responsibility was to mobilize participants had on the contrary, discouraged them to participate. We felt betrayed. After the discussion session, the project leader apologized for the misunderstanding and took some time to clarify some issues related to budget, purpose of the research and ways in which the researchers and community would benefit. Then, engagement proceeded with the few people that were available.

Box 4 “The leader that failed to deliver”

Prototypes that were developed in Mabayeni village were supposed to be evaluated by Mabayeni community members together with members from an external community which had not participated in design process. The neighbouring village (Jilongo) was selected because it was also experiencing severe water shortages. A meeting was held with the village headman and the background and purpose of the study explained. Permission was sought to engage community members in his village. About 35 participants (at least five per interest group) were requested to join the prototype evaluation session which was taking place in Mabayeni village. Headman Jilongo was very supportive and indicated that he would call a meeting and make sure that the required representatives would participate. Three days before the engagement, reminder calls were made to the headman who indicated that he had already mobilised and everything was under control. On the day of the engagement, participants from Jilongo village did not turn up. On making follow-up calls, the headman indicated that the participants were on their way. Towards the end of the engagement, only four elderly women arrived. They indicated that they had received communication about the engagement the same morning. Efforts to establish what had happened from the headman after the event were fruitless.

9.3 Major Findings

A summary of findings and implications of the study per objective are displayed in Table 9.3. Mabayeni village experienced what is termed economic water scarcity. This is because although water resources were available in the area, lack of and poor management of existing public water infrastructure, and lack of big storage containers to tap rainwater, among others contributed to prevailing water scarcity. Out of the eight data collection techniques used, storytelling and transect walks emerged as the most informative techniques for collecting data. Any qualitative research seeking to obtain a deep understanding of a phenomenon should consider using the latter techniques. In addition, the strategies that were used to cope with water scarcity were random, inadequate, and unsafe especially for girls and women. Moreover, no formal rainwater harvesting technology was used in Mabayeni village. Instead community members used available containers to collect rainwater. Because of this, water got easily contaminated and could not last. All interest groups preferred features related to water quality and security, while the elderly preferred convenient access-related features. Community members displayed their ability to develop and evaluate prototypes. This is a clear testimony that given the necessary support, communities have the potential to become experts in solving their own problems.

9.4 Characteristics of a PhD

Scholars have for years grappled with coming up with a standard criteria for assessing PhD theses. With the growing diversity of types of PhDs (for example, PhD by publication, Hybrid PhDs as well as PhDs with publications appended), inconsistencies in assessment have been reported (Sharmini *et al.*, 2015). The disparities have also been influenced by disciplinary diversity. In some cases, there has been overlaps in criterion features making it difficult to single out distinct features (Clarke & Lunt, 2014). In addition, the interpretation of criterion features still varies according to institutions, disciplines and individual examiners. Scholars have confirmed that there is no universally agreed criteria for assessing PhDs (Holbrook *et al.*, 2008; Clarke & Lunt, 2014). However, there is consensus on the need for doctoral work to be original (Tinkler & Jackson, 2000; Park, 2005; Clarke & Lunt, 2014; Casanave, 2018), as well as to advance knowledge of the subject, field or discipline of focus (Alpert & Kamins, 2004; Clarke & Lunt, 2014; Casanave, 2018).

Table 9.3 Summary of major findings on developing a technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Objective	Problem	Methods	Key results	Implications
1. To determine the extent of water scarcity in Mabayeni village	Water scarcity	Mixed method design PRA, thematic contents analysis with Atlas.ti	-water scarcity is seasonal -economic water scarcity -storytelling and transect walks had highest number of responses across themes	-storytelling and transect walks the most informative data collection techniques that should be used in research -intervention strategies should target the dry season -need for enhancing capacity to enable access to water
2. To identify strategies households use to cope with inadequate availability of water for domestic use	Coping strategies were unknown	Qualitative, PRA, contents analysis with Atlas.ti	-coping strategies are random, inadequate and unsafe	- intervention efforts should ensure that coping strategies are safe and sustainable
3. To document the rainwater harvesting techniques that rural communities use	Rainwater harvesting strategies not known	Qualitative, PRA, contents analysis with Atlas.ti	-no formal RWH technology -available containers are small	-need for formal RWH technology that uses larger storage containers
4. To compare the features of rainwater harvesting technology that people of different age groups prefer	Lack of community decision making on features of appropriate RWH technologies	Qualitative, matrix ranking	-all groups preferred water quality, construction materia and security-related features -elderly people preferred access-related features	-water quality, construction material and security-related features should take priority in the construction of the RWH technology -access-related features should be included to accommodate the elderly, disabled people and children
5. To develop community-preferred prototypes of rainwater harvesting technology with the best potential to increase access to water for domestic uses	Lack of community participation in actual construction of RWH technologies	Qualitative experimental design, verbal protocol analysis	Community members were capable of developing RWH technology prototypes with guidance	-community members should be given an opportunity to create or formulate intervention strategies to their challenges
6. To select the most preferred prototypes of rainwater harvesting technology using community feedback	Lack of feedback engagements to ascertain if RWH technologies meet community requirements	Sequential explanatory mixed method, Kruskal Wallis tests, Dunn's tests and thematic content analysis	Prototypes made by boy children and men were selected and improved using community feedback	-community members should also be given the chance to evaluate strategies and services meant to benefit them so as to confirm if their needs and expectations are met
Contribution to body of knowledge			- a community-informed rooftop rainwater harvesting technology - a seasonal approach to assessing water scarcity - a process that can be followed in formulating, executing and evaluating an intervention strategy with community members	

Other assessment criteria that are used either as independent features, or indicators of originality and contribution to knowledge include substantial coherence of work and student autonomy (Mullins & Kiley, 2002; Clarke & Lunt, 2014), teaching and training or apprenticeship (Park, 2005), innovation and applicability, as well as engagement (Jacelon *et al.*, 2010; Mtawa *et al.*, 2016). Although these characteristics are closely related and sometimes overlapping, a separate section is devoted for each of them. This is done in order to decipher the unique aspects of the study that are associated with each characteristic. Table 9.4 shows a summary of the doctoral characteristics identified in this study.

9.4.1 Originality and contribution to knowledge

The concept of originality in research dates back to as far as the 1980s (Nightingale, 1984; Committee of Vice Chancellors and Principals, 1988). Many scholars (Kiley & Mullins, 2003; Park, 2005, 2007; Sharmini *et al.*, 2015; Casanave, 2018) regard originality and contribution to knowledge as a fundamental criterion of doctoral success. However, Clarke & Lunt (2014) argue that there is no universally agreed definition of originality. According to Lovitts (2007) original simply means producing something new and would be easy to do. However, the problem comes when the thesis does not contribute significantly to the body of knowledge. According to the latter author, it would therefore make more sense to couple originality with contribution to knowledge. Some respondents in Clarke & Lunt's (2014) study even rejected the idea that researchers in their discipline could make original contributions.

This belief could have been influenced by lack of clear clarification on originality and its application as a criterion for assessing PhD work. Questions have also been raised on what constitutes adequate and significant contribution to knowledge (Mullins & Kiley, 2002; Wellington *et al.*, 2005; Gill & Burnard, 2012). Nonetheless, originality in this context has been defined as slant or inventiveness in the topic, discovery of new facts arising from the thesis (Clarke & Lunt, 2014), application of existing knowledge from any discipline to provide new insights into the subject in a way that has not been done before (Lovitts, 2007), finding new ways of analysing and/ or theorising a known body of information and proposing a new method and /or theory and applying it to a new range of data (Park, 2005). Doctoral work is regarded as having contributed knowledge if it broadens or provides a different way of understanding the field (Wellington *et al.*, 2005) and help move the discipline forward in terms of knowledge and methodology.

Table 9.4 Criteria for assessing doctoral work

Criteria	Evidence of PhD in the current thesis
a) Originality and advancement of knowledge (Lovitts, 2007; Clarke & Lunt, 2014; Casanave, 2018)	<ul style="list-style-type: none"> - Developing community-informed technologies for harvesting rainwater - Contributing a seasonal approach to assessing water scarcity - Contributing a procedure that can be followed in formulating, executing and evaluating an intervention strategy with community members
b) Substantial, coherence and student autonomy (Wellington <i>et al.</i> , 2005; Bourke & Holbrok, 2013; Clarke & Lunt, 2014)	<ul style="list-style-type: none"> - Synchronization of a wide range of approaches and processes borrowed from different disciplines to come up with a consistent research methodology and practical solution to water scarcity
c) Training or apprenticeship (Boyer, 1990; Anon, 2002; Park, 2005, 2007)	<ul style="list-style-type: none"> - Self-taught data analysis using different software (Atlas.ti, SPSS, R statistical software) - Mentoring postgraduate students on Atlas.ti - Acquiring practical experience on participatory data collection and analyses techniques - Teaching and mentoring research assistants on field data collection and analysis procedures, facilitation, transcribing, report writing. - Co-supervising Honours students' dissertations
d) Application or innovation (Boyer, 1990, 1996; Prasad, 2015; Clarke & Lunt, 2014)	<ul style="list-style-type: none"> - Applying a variety of concepts from different disciplines such as engineering, anthropology and maths sciences to co-design, and co-evaluate rainwater harvesting technologies.
e) Engagement (Boyer, 1996; Jacelon <i>et al.</i> , 2010; Mtawa <i>et al.</i> , 2016)	<ul style="list-style-type: none"> - Co-designing the technology with the community members - Teaching community members on prototyping, and prototyping evaluation processes - Providing practical training on team management processes to community members

In the current study, the focus was on developing a tangible intervention (RWH technology prototypes) to an existing societal problem (water scarcity). The focus on its own is rare in the Human and Social Sciences discipline. Typical research in the field concentrate on identifying problems, investigating and recommending possible solutions through crafting frameworks. Not many researchers have attempted to take the next step of implementing designed frameworks or suggested solutions. Doing this helps in validating the feasibility of recommended solutions. In addition, the process that was followed in developing the RWH technologies was also very significant. Starting from understanding the problem, coming up with possible intervention options, selecting the best option, prototyping, evaluating prototypes and choosing the best – all done with community members, deepened the understanding of the water scarcity problem. The process used was also novel as it demonstrated the possibility of co-creating appropriate technologies with communities. This is a crucial element of Boyer's (1990) scholarship of discovery. The author notes that in contributing to human knowledge and also to the intellectual climate, it's not just the outcomes that matter, but the process and especially the passion that give meaning to the effort. The process used in developing the RWH technology is an important product that can be used to guide any community-based work.

9.4.2 Substantial coherence and student autonomy

Another set of characteristics of doctoral work found in literature relates to substantial coherence of work and evidence of student autonomy (Mullins & Kiley, 2002; Wellington *et al.*, 2005). According to Mullins & Kiley (2002) examiners expect a doctoral thesis to be a coherent piece of work with evidence of professionalism. This is demonstrated by mature comments and accuracy of logic. Clarke & Lunt (2014) term this intellectual rigour. The expectation of intellectual rigour is based on the premise that after attainment of the qualification, the candidate must be able to independently conduct and disseminate scientific research (Bourke & Holbrok, 2013). This characteristic resonates with the scholarship of integration as illustrated by Boyer (1990). According to the author, scholarship of integration underscores the need for scholars who give meaning to isolated facts and putting them into perspective. This also means making connections across disciplines, placing the specialties in larger context, illuminating data in a revealing way and educating non-specialists in the process. Authentic arguments have been made in the study and conclusions drawn based on credible findings. As already indicated, a variety of research methods and techniques were borrowed from different disciplines and synchronised to produce a hybrid research design. This design was appropriate for adequately responding to the research questions.

9.4.3 Training and apprenticeship

In countries such as United Kingdom, Australia and United States of America, the Doctorate has been redefined to meet the changing demand of students and employers. According to Park (2005), doctoral studies have been reconceptualised as a training period for future researchers rather than a piece of work that changes the course of human knowledge. In support of this assertion, Pole (2000) views a PhD student as a blend of technician and scholar. Traditionally, the function of the PhD has been to train future academic workers. According to Anon (2002), the research content, not the training of the researcher has been the main outcome. This is changing due to the growing need to develop autonomous researchers but with a broader skills base for the majority of doctoral candidates whose careers will be outside academia. Therefore, universities in the above mentioned countries have included an aspect of training or apprenticeship as part of the key criteria for assessing doctoral work. Park (2005, 2007) argues that this new way of framing doctoral study paint the qualification as achievement of a combination of training (the person) and writing the thesis. One of the descriptors of successful Doctorate is that in addition to the thesis, holders will have the qualities needed for employment requiring the ability to make informed judgements on complex issues in specialist fields and innovation in tackling and solving problems (Quality Assurance Agency, 2001; Walters & Misra, 2013). Even within the academia, Alpert (2004) and McAlpine (2015) suggest the need for PhD training to develop a range of abilities and qualifications expected of an independent researcher. Although available literature reflect concerns and changes in the developed world, the same changes are taking place in African countries, warranting the need to transform the course and assessment criteria to accommodate the changing needs.

Throughout the duration of the study, a number of skills were attained through workshops, self-teaching as well as practice (Figure 9.2). These included facilitation skills, project management skills, team management skills, data collection and analysis skills, as well as, training and mentoring skills. The above mentioned skills were obtained as part of the research project from making the necessary planning arrangements, training research assistants and carrying out data collection and analysis. According to Aristotle, teaching is the highest form of understanding (Shulman, 1986). Boyer (1990) adds that in order to teach, one must be well informed in the knowledge of their field. This shows that in as much as learning took place within the candidate, it was applied through teaching and mentoring others. Smith & Hatmaker (2014) also acknowledge the importance of mentoring, socialization, and professional identity development for doctoral students. In addition, during the actual mentoring, learning was promoted as knowledge was transformed and extended in both the participants and the candidates.

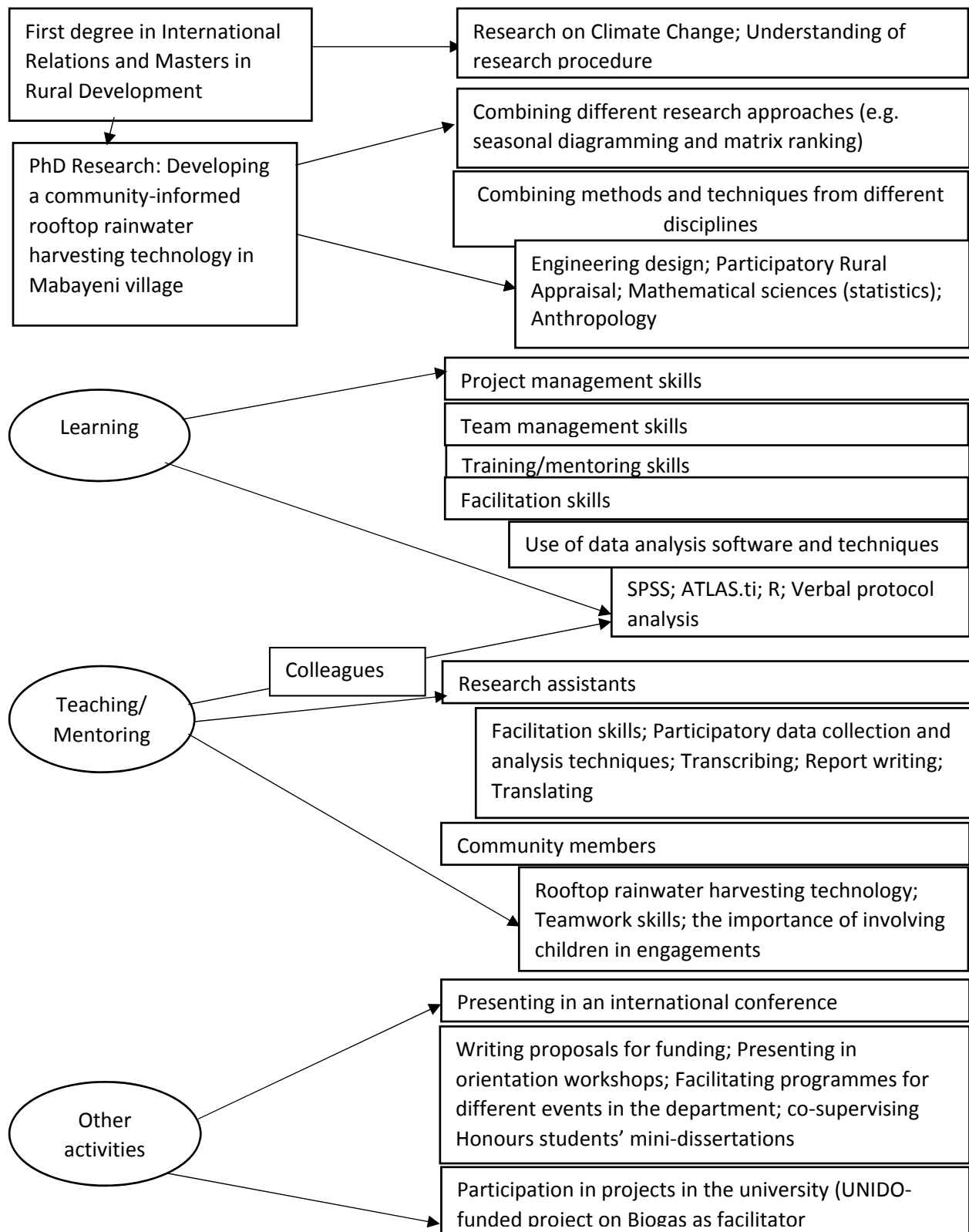


Figure 9.2 Teaching and learning process throughout the PhD training

Research assistants confirmed that they attained skills such as participatory data collection and analysis, facilitating group discussions, transcribing, and report writing as well as translation skills throughout the duration of the study. A number of colleagues within the Institute for Rural Development and the University were trained on the use of data analysis software such as Atlas.ti. Involvement in other activities such as presentation in international conferences, facilitating events in the Institute for Rural Development, and co-supervising Honours students' dissertations transformed the candidate into a professional with the abilities to make informed judgements on complex issues, and innovative in tackling problems. The above training provide evidence to development of the autonomous academic researcher with a broader skills base as recommended by Park (2005, 2007). Even community members from Mabayeni village attested to have learnt about the rooftop rainwater harvesting technology, and team work skills during prototyping.

They indicated that they would apply some of these skills in their daily lives. In addition, after seeing the significant contributions made by children and youth, Mabayeni leaders vowed that they would have these two groups represented in their leadership structures. This is confirmation that as part of the study, transformation took place within the candidate, the research assistants, some colleagues within the University, as well as the target community itself. The learning experience described above also fulfils the University of Venda's mission, "to produce graduates imbued with knowledge, skills and qualifications which are locally relevant and globally competitive". Therefore, the candidate obtained the necessary skills in preparation for roles in and outside academia.

9.4.4 Innovation and applicability

Applicability of doctoral work or its aspects to real-life circumstances or societal challenges is yet another crucial characteristic of a successful PhD project (Clarke & Lunt, 2014). This echoes the scholarship of application established by Boyer (1990). According to the author, application of knowledge moves toward engagement as scholar finds out ways of responsibly applying knowledge to existing problems as well as creating space for social problems to define the agenda for scholarly investigation. Prasad (2015) argues that scholars must take the necessary risks to transgress from the status quo that presently constrains the field. As already indicated, the knowledge of research was applied in the development of a solution for water scarcity in Mabayeni village. Boyer (1996) established that when scholars are engaged in their field, moving from theory to practice and back, they increase the application and authenticity of their work. Boyer (1990) discovers a gap between values in the academy and the needs of the bigger world. He explains that Higher Education Institutions (HEIs) are more academic and less practical.

In essence, Boyer (1990) meant that discovery alone was not complete without application to improve lives of people. This interaction between theory and practice is needed in a world in which intractable problems call for the skills and insights that can only be provide by the academy. Thus, the study responded to an existing societal challenge (water scarcity) and made an attempt to bring a practical solution for it. The study fills in that gap to show the true relevance of HEIs in serving the interest of the larger community as advocated by Sawye (2004) and Olowu (2012).

The methodological process followed in this study was systematic and vigorous as already explained. A blend of designs, methods and techniques were used to get an in-depth understanding of the problem as well as in the development of prototypes. However, the knowledge of these and how to use them would be meaningless if they were not applied in a manner that contributed to improvement of lives. Goal 4 of the SDGs talks about ensuring that learners acquire knowledge and skills needed to promote sustainable development. This shows that knowledge on its own is useless if it cannot be applied to improve lives. Regulatory frameworks such as the White paper on Higher Education of 2014, The National Plan for Higher education 2015/2016-2019/2020 and The Transformation Agenda for Higher Education developed by the Development Bank of South Africa (Soudien, 2010), have also emphasized the importance of HEIs in transforming society. The White Paper on Science, Technology and Innovation also emphasizes the importance of collaborative research in reducing unemployment, poverty and inequality. Even the University of Venda aspires “to be at the centre of tertiary education for rural and regional development in Southern Africa.” This study therefore serves as a model for application of academic knowledge to solve societal problems. It also displays the relevance of HEIs to communities around them as outlined in the regulatory frameworks above. According to Schon (1995), mainstream academic scholarship has less epistemological legitimacy because its claims to knowledge are made in isolation from social practices and public practices. In the current study, an attempt was made to close this gap.

The approach used in the current study helped in the operationalisation of a variety of policies at, international, regional and local level. As already indicated, these include the UN SGD 6 (targeting universal and equitable access to safe and affordable drinking water for all by 2030), Aspiration 6 of the AU’s AGENDA 2063 (highlighting people-driven development), the Science, Technology and Innovation for Africa (STISA-2014) (stressing collaboration of different stakeholders to achieve an innovation-led, knowledge-based economy), The White Paper on Science, Technology and Innovation (underscoring engagement of all societal actors throughout the process of framing societal challenges and developing joint solutions), among others. In the current study, a technology for harvesting rainwater was developed with active participation of the (end user) community in its entirety. All community groups including children and women were

given an equal space to contribute their thoughts and aspirations. This was a first step in the collaboration process wherein civil society was put in the forefront in defining appropriate solutions for the water challenge. This process paved way for scientists/engineers to contribute technical expertise to the technology, fulfilling the need for collaboration of different sectors as stipulates in the AU's STISA-2024. These efforts contributed to provision of universal and equitable access to safe water for drinking (as stipulated in the UN SDG 6), as well as other domestic uses.

9.4.5 Engagement

Engagement is another critical feature of doctoral work. Although this is closely related to application, engagement extends to include a reciprocal collaborative relationship with a public entity (Barker, 2004). The scholarship of engagement consists of research, teaching, integration and application that incorporate reciprocal practices of civic engagement into the production of knowledge Boyer (1996). Through this approach, insights and possibilities are deepened and knowledge is expanded as scholars are exposed to new sources of data and have access to opportunities for greater experimentation. Barker (2004) argues that engagement requires not only communication to public audiences, but also collaboration with communities in production of knowledge. Instead of seeing communities as passive recipients of expert knowledge, engaged scholarship stresses that the communities can themselves contribute to academic knowledge. This broader understanding of engagement often lacks in practices associated with civic engagement. The South African National Research Foundation's Science Engagement Strategy (2015) focuses on three aspects of engagement namely; promoting science education, science communication and science outreach and awareness. Within this framework, dialogue of science is enhanced in order to create greater confidence, improve the understanding of science as well as promote co-creation of technologies with communities.

The process followed in the current study focusing on community-informed technology for rainwater harvesting resembled a broader level of engagement as Schon (1995), Boyer (1996), Jacelon *et al.* (2010) and Mtawa *et al.* (2016) suggest. The development of rooftop RWH technologies was done in the target community, together with the community members. Unlike other studies or engineering products wherein community members are only engaged at certain stages of the engineering design cycle (that is, only to collect data or just to get feedback on product usability), community members took part in the whole process from the beginning until the end. They participated in problem framing, imagining possibilities, selecting the best options, putting together a design manual, prototyping and evaluating prototypes so as to choose the best ones. However, testing and implementation of the technology fell outside the scope of the PhD project. This will be done as part of Post-doctoral studies. The full design process is shown in Figure 9.4.

Although data were also analysed using statistical software, most of it was examined together with community members. This reduced the chances of misinterpreting data. Participating in the entire process resulted in co-creation of a solution with higher chances of addressing their needs. For instance, participants included specific features relating to safety, security and access. Without this type of engagement, it would have been difficult to develop a technology that would meet community expectations. The platform became a profitable learning process for the researchers as well as the community members (as indicated above), making it a mutually beneficial partnership as recommended by Jacelon *et al.* (2010). In fact, Gothelf (2016) maintains that collaborating with end users builds a shared understanding of the problem space, and the proposed solutions, creates consensus behind decisions which results in real involvement in product making and team investment in validated learning. All these elements were achieved through the co-designing and co-creation processes which took place in the community.

9.5 Critique of study

This study, like any other piece of academic work, had some flaws. A case study approach was used to guide the research activities in the study because of its appropriateness to the nature and objectives of the study. In order to get an in-depth understanding of the water scarcity situation and come up with possible interventions to be problem, the case study design was deemed most appropriate. Schell (1992) supports that a case study deals with the how and why aspects of a phenomenon. However, the case study design has been criticized by scholars such as Miles (1979) for its inherent researcher bias. The latter author argues that there are few conventions that the researcher can rely upon to defend him/herself against self-delusion or the presentation of unreliable or invalid conclusions. Nevertheless, this was addressed through triangulation of data collection and analysis methods and techniques most of which were participatory in nature. A variety of data collection techniques such as photo voice, participatory mapping, transect walks and focus group interviews were used to confirm and complement data. As already indicated, most of the data were analysed using participatory methods such as seasonal diagramming and matrix ranking (for instance, preference scoring) so as to minimize misinterpretation of results. In addition, other research designs such as survey, participatory action research design and experimental design were used to complement the case study design. This helped in strengthening the overall research methodology.

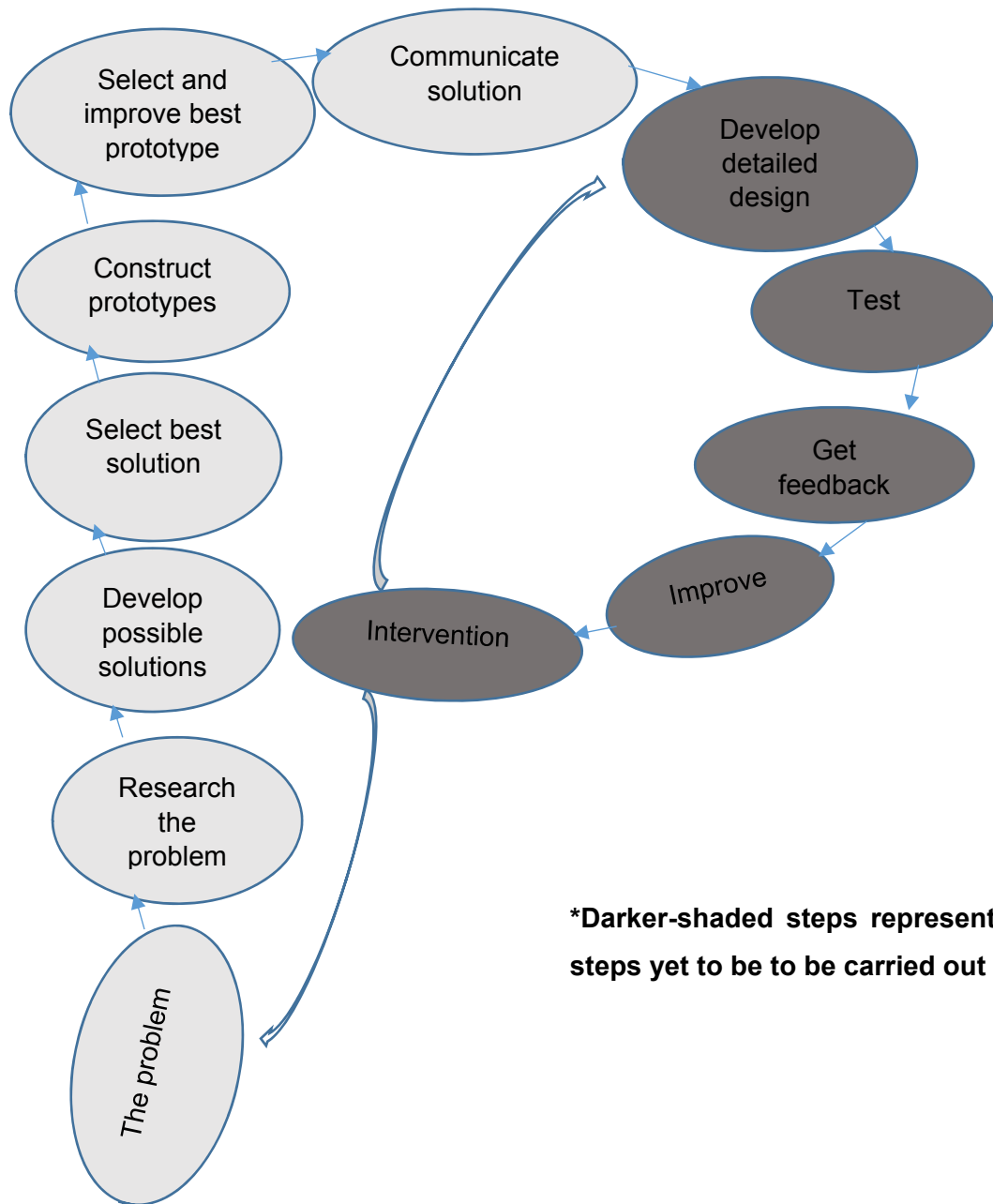


Figure 9.3 An illustration of the full design process for developing a community-informed technology for harvesting rainwater for domestic use in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

The study could have benefitted more from having a cross-case study. Comparing cases from different locations for instance, could have provided a broader framework for analysis of results. Alternatively, including a different community during prototype evaluation could have resulted in consideration of feedback from a wider spectrum thus, increasing reliability and relevance of the rooftop RWH technology in other areas. However, the fact that a constructivist approach to knowledge and reality was adopted in the study already defined the study's focus to the context of a specific area. Although there is a high level of confidence in the validity of methods and techniques employed in the study, consistence in this context does not necessarily translate to production of similar or generalizable results. On the contrary, reliability in the context of this study means that a similar methodological process in a different location would result in a technological solution that is relevant to that particular community.

This could have been projected through examining feedback from other communities. However, due to limited resources and time, the focus of the study was limited to one case study. Miles (1979) also criticizes a case study approach because it is labour intensive and time consuming resulting in generating much researcher stress. Considering the timeframe for completion of a PhD qualification (three years) and the required resources (including transport, subsistence for research assistants, refreshments for research participants, prototyping material, among others) it was not possible to carry out a cross-case study. It is thus recommended that similar studies focus on or involve at least two case studies for purposes of broadening applicability of study results to a broader area. Nonetheless, the single case study approach coupled with other designs provided satisfactory ground for developing a community-informed technology for harvesting rainwater in the specified study area.

Low-fidelity prototypes were the major products of the study. Although they may constitute a substantial contribution to the body of knowledge, low-fidelity prototypes are an incomplete contribution to a community experiencing water scarcity. As indicated above, due to time and resource constraints, the whole design process could not be completed. However, the construction of a high-fidelity prototype (actual rooftop RWHT) will be done subject to availability of resources. In addition, scholars such as Rudd *et al.* (1996) and Stone *et al.* (2005) argue that some of the disadvantages of low-fidelity prototypes are that they lack functionality, and the ability to check errors is limited. In addition, there is limited utility of the prototype after requirements are established. In other words, prototypes become useless once requirements are established. Even so, the aim of the study was to come up with a community-informed technology (representation) for harvesting rainwater for multiple domestic uses. Through prototyping, all requirements of the technology were outlined and explained, paving way for the testing and implementation phase.

9.6 Conclusions

The study revealed that Mabayeni village was experiencing economic water scarcity. In addition, the nature of the scarcity was seasonal. Water scarcity was severe during the dry season when there was no rain and water sources such as wells and small dams had dried up. In addition, the community was also experiencing economic water scarcity since water was available. What lacked was the economic capabilities or expertise to access the water. This manifested in the form of poor water infrastructure management and abuse of water infrastructure. Moreover, storytelling and transect walks emerged as the most informative techniques for collecting qualitative data.

Furthermore, the coping strategies that community members relied on were random, inadequate and unsafe. Although community members harvested rainwater using available containers, they did not use any formal technology. This was due to lack of knowledge of the technology as well as lack of finances. Regarding features of a desired RWH technology, community members preferred water quality, construction material and security-related features. Moreover, Mabayeni residents were able to develop a customised RWH technology (prototypes) using cheap easy-to-use materials.

The prototypes that were constructed by boy children and men were selected as the best for zinc and thatch roofs respectively. The two prototypes were improved to meet community needs and expectations using community feedback. Apart from the technology itself, the process which was followed when developing the technologies (an amalgamation of research science and engineering) should be recognised as another major product of the doctoral work.

9.7 Recommendations

In light of the discussion given above, some recommendations are made with regard to research, policy and practice. This is done with the view of improving the way scientific research is carried out, policies and policy instruments are administered, as well as rural development is practiced.

9.7.1 Research

In the current study, the importance of using multi-disciplinary research approaches in order to comprehend deep seated societal issues was exposed. A number of complementary methodological techniques were also employed. In as much as this was vital for triangulation purposes and building confidence in findings, it is one of the best ways of creating a strong foundation for understanding a problem so as to come up with appropriate interventions. In addition, although most HEIs' primary focus is on teaching and learning, it is possible to embed

elements of innovation and applicability in their work. As argued above, research production is worthless if it does not contribute to solving societal challenges. Therefore, there is need for the academy to expand its focus from serving only its primary needs to accommodate the needs of the society. In order to do this, institutions should make sure that postgraduate research topics are informed by compelling societal issues.

Next, instead of the prevailing norm of investigating causes of problems and suggesting possible solutions, effort should be made to try and co-create interventions for these problems with the communities. This would make academic research more relevant, meaningful and beneficial to both the academy and society. This would also mean a transformation of focus from research for development to research and development as these two will be undertaken concurrently. The engagement approach used in the study can be borrowed by government sectors, non-governmental organisations, and the private sector to produce products and services that are relevant to end users. Academics can also adapt the same approach in their research in order to promote collaboration between researchers and communities in coming up with lasting solutions to real societal challenges around them.

9.7.2 Policy

Water policies in South Africa such as the White Paper on water Supply and Sanitation of 1994, National Water Act of 1998 and the Water Research Act of 1971 outline the significance of “public participation”, “empowering communities” and getting “community buy in” in ensuring sustainable water resources management and development. However, there is lack of a clear definition of what constitutes public participation, which in turn, hinders effective implementation. There is therefore need for specification and prioritization of active involvement of communities in projects, programmes, or services meant to improve their lives. In actual fact, policy instruments such as the Water Research Commission should be adjusted to create more space for involvement of community members. For example, in government, non-governmental organisations and the private sector, there should be an emphasis collaboration with communities in design and implementation of various solutions. This is one of the most effective ways of ensuring sustainable development. In addition, monitoring should be done to ensure that all the members of the communities are represented for instance, children, youth and the elderly that are often neglected.

As has been proven, participation of these groups provide significant insights that help in tailoring services to communities according to their needs. This all-inclusive approach will ensure that programmes become relevant to all community members. A shared understanding of the problems and solutions, as well as creating consensus behind decisions eliminates the chances of abuse of services that are seen in many South African communities today. A community-centred approach may also be a suitable way of addressing the prevailing service delivery

protests. It was exposed in the current study that there is lack of communication between the water service provider and the citizens regarding the right to water, its extension as well as limitations. It is therefore recommended that there be a clear communication strategy so that rural communities understand their roles and responsibilities in safeguarding this resource.

9.7.3 Practice

When it comes to rural development practice, practitioners should focus on real community empowerment not just participation. Real community empowerment entails providing a platform for communities to come together to interrogate their challenges, and discover their strengths and opportunities which they can use to solve their own problems. Children are rarely involved in community development initiatives. The fact that one of the best prototypes was developed by boy children is evidence that they are a critical and underutilized resource. It is therefore crucial to do objective stakeholder mapping and analysis before carrying out any development initiatives. An inclusive approach informed by the results of the analysis should then be used in order to develop strategies and services that are relevant to different community stakeholders.

The experiences that have been shared points to the birth pains of a good research product. They also reveal the need for researchers to be resolute, patient and innovative when carrying out community-based research. There is also need to take considerable time at the community entry stage to as to establish trust and mutual understanding between the researcher and community members. In addition, true rural development does not require doing things for communities, but doing things with them so that they learn to do things for themselves. As revealed in the study, true engagement should ignite a process of learning and a drive towards bringing positive change. The study also exposed that communities are experts in designing solutions for their challenges and should be regarded as such. Therefore, the focus of external interventions should be on supporting community-led activities.

9.8 Dissemination plan

The thesis will be disseminated through various scholarly media such as international and local conferences. Scientific publications for example empirical research papers and review papers will be prepared for publication in accredited peer reviewed journals and popular research and policy magazines. In addition, pamphlets or copies of summaries from the thesis will be distributed to community members. Stories on water scarcity that were harvested from Mabayeni will also be compiled into a booklet and shared with community members. A copy of the dissertation will also be given to the community leadership to thank the community for their support. The pamphlets, booklets and dissertation will serve as community resources.

Moreover, a workshop will be held on campus to train postgraduate students on the application of participatory research techniques. This is because not many of them are exposed to these tools yet they could improve their research. A procedure manual on the research activities carried out per objective will also be packaged for dissemination in the university and other scholarly media. Lastly, a policy brief will be developed with recommendations for local level policies or by-laws on water scarcity and conservation.

9.8 References

- Alpert, F. & Kamins, M.A. 2004. Doctoral coursework is needed in Australasia. *Australasian Marketing Journal (AMJ)*, **12(1)**: 66-72.
- Anon 2002. Profiting from postgraduate talent. Report of a conference held on 11 June 2002, in London. Cambridge: CRAC.
- Barker, D. 2004. The scholarship of engagement: A taxonomy of five emerging practices. *Journal of Higher Education Outreach and Engagement*, **9(2)**: 123-137.
- Bourke, S., and A. Holbrook. 2013. "Examining PhD and Research Masters Theses." *Assessment & Evaluation in Higher Education* **38(4)**: 407-416.
- Boyer, E.L. 1996. The scholarship of engagement. *Bulletin of the American Academy of Arts and sciences*, **49(7)**: 11-20
- Boyer, E. L. 1990. *Scholarship Reconsidered: Priorities of the Professoriate*. Princeton, N.J.: Carnegie Foundation for the Advancement of Teaching.
- Bryman, A., 2004. Triangulation and measurement. Available at Department of Social Sciences, Loughborough University, Loughborough, Leicestershire: [www. referenceworld. com/sage/socialscience/triangulation. pdf](http://www.referenceworld.com/sage/socialscience/triangulation.pdf). Retrieved on 19 June 2018
- Casanave, C.P., 2018. Performing expertise in doctoral dissertations: Thoughts on a fundamental dilemma facing doctoral students and their supervisors. *Journal of Second Language Writing*. (In press)
- Clarke, G. & Lunt, I. 2014. The concept of 'originality' in the Ph. D.: how is it interpreted by examiners? *Assessment & evaluation in higher education*, **39(7)**: 803-820.
- Committee of Vice-Chancellors and Principals. 1988. The British Ph.D. London: Committee of Vice-Chancellors and Principals.
- Gill, P. and Burnard, P., 2012. Time to end the vagaries of PhD examining? *Nurse education today*, **32(5)**, pp.477-478.
- Gothelf, J. and Seiden, J., 2016. *Lean UX: Designing Great Products with Agile Teams*. O'Reilly Media, Inc.
- Holbrook, A., S. Bourke, T. Lovat, and H. Fairbairn. 2008. Consistency and Inconsistency in PhD Thesis Examination. *Australian Journal of Education* **52(1)**: 36-48.
- Jacelon, C.S., Donoghue, L.C. & Breslin, E., 2010. Scholar in residence: An innovative application of the scholarship of engagement. *Journal of Professional Nursing*, **26(1)**: 61-66.
- Kiley, M. & Mullins, G. 2003. Why conceptions of research might be significant in postgraduate education. In *10th European Conference for Research on Learning and Instruction, Padua, Italy*.
- Lovitts, B. 2007. *Making the implicit explicit: Creating performance expectations for the dissertation*. Sterling, VA: Stylus Publishing.

- McAlpine, L. 2015. Doctoral education. University of Oxford. Oxford, UK
- Miles, Matthew B. 1979. Qualitative Data as an Attractive Nuisance. *Administrative Science Quarterly*, **24**: 590-601
- Mtawa, N.N., Fongwa, S.N. and Wangenge-Ouma, G., 2016. The scholarship of university-community engagement: Interrogating Boyer's model. *International Journal of Educational Development*, **49**: 126-133.
- Mullins, G. & Kiley, M. 2002. 'It's a PhD, not a Nobel Prize': How experienced examiners assess research theses. *Studies in higher education*, **27(4)**: 369-386.
- Nightingale, P. 1984. Examination of research theses, *Higher Education Research and Development*, **3**: 137-150.
- Olowu, D. 2012. University–community engagement in South Africa: Dilemmas in benchmarking. *South African Review of Sociology*, **43(2)**: 89-103.
- Park, C. 2005. New variant PhD: The changing nature of the doctorate in the UK. *Journal of Higher Education Policy and Management*, **27(2)**: 189-207.
- Park, C. 2007. Redefining the Doctorate. Discussion Paper, Higher Education Academy. Available at. <http://eprints.lancs.ac.uk/435> Retrieved on 15 May 2018
- Pole, C. 2000. Technicians and scholars in pursuit of the PhD: Some reflections on doctoral study. *Research Papers in Education*, **15(1)**: 95-111.
- Prasad, A. 2015. Liminal transgressions, or where should the critical academy go from here? Reimagining the future of doctoral education to engender research sustainability. *Critical Perspectives on Accounting*, **26**:108-116.
- QAA (Quality Assurance Agency for Higher Education). 2001. Framework for Higher Education Qualifications in Scotland. Gloucester: QAA.
- Rudd, J., Stern, K. & Isensee, S. 1996. Low vs. high-fidelity prototyping debate. *Interactions*, **3(1)**: 76-85.
- Sawyerr, A., 2004. Challenges facing African universities: Selected issues. *African Studies Review*, **47(1)**:1-59.
- Schell, C., 1992. The value of the case study as a research strategy. *Manchester Business School*, **2**: 1-15.
- Schon, D. A. 1995. The new scholarship requires a new epistemology. *Change* **27(6)**: 26–35.
- Schoonenboom, J. & Johnson, R.B. 2017. How to construct a mixed methods research design. *Cologne Journal of Sociology and Social Psychology*, **69**: 107-131
- Sharmini, S., Spronken-Smith, R., Golding, C. & Harland, T. 2015. Assessing the doctoral thesis when it includes published work. *Assessment & Evaluation in Higher Education*, **40(1)**: 89-102.
- Shulman, L.S. 1986. Those who understand: Knowledge growth in teaching. *Educational researcher*, **15(2)**: 4-14.

- Smith, A.E. & Hatmaker, D.M. 2014. Knowing, doing and becoming: Professional identity construction among Public Affairs Doctoral students. *Journal of Public Affairs Education*, **20(4)**:545-564
- Soudien, C., 2010. Transformation in higher education: A briefing paper. *Development Bank of Southern Africa*.
- South African National Research Foundation's Science Engagement Strategy (2015) Science and society engaging to enrich and improve our lives (2015-2020) Available at https://www.saasta.ac.za/saasta_wp/wp-content/uploads/2017/11/Science_Engagement_Strategy-11.pdf Retrieved on 30 May 2018
- Stone, D., Jarrett, C., Woodroffe, M. and Minocha, S., 2005. *User interface design and evaluation*. Elsevier.
- Tinkler, P., & Jackson, C. 2000. Examining the doctorate: Institutional policy and the Ph.D. examination process in Britain. *Studies in Higher Education*, **25(2)**: 67-180.
- Walters, K. & Misra, J. 2013. Bringing collaborative teaching into Doctoral programmes: Faculty and graduate student co-teaching as experiential training. *The American Sociologist*, **44**:292-301
- Webb, E. J., Campbell, D. T., Schwartz, R. D., & Sechrest, L. 1966. *Unobtrusive Measures: Nonreactive Measures in the Social Sciences*. Chicago: Rand McNally.
- Wellington, J.J., Bathmaker, A.M., Hunt, C., McCulloch, G. & Sikes, P. 2005. *Succeeding with your Doctorate*. Sage. London

APPENDICES

Appendix 3.1 Ethical Clearance Certificate

**RESEARCH AND INNOVATION
OFFICE OF THE DIRECTOR**

NAME OF RESEARCHER/INVESTIGATOR:

**Ms P Nyamukondiwa
Student No: 11576183**

**PROJECT TITLE: Developing community-informed
technology for harvesting rainwater for domestic
use in semi-arid areas of South Africa.**

PROJECT NO: SARDF/16/IRD/07/2904

SUPERVISORS/ CO-RESEARCHERS/ CO-INVESTIGATORS

NAME	INSTITUTION & DEPARTMENT	ROLE
Prof J Francis	University of Venda	Supervisor
Dr M Manjoro	University of Venda	Co-Supervisor
Dr PF Kapila	University of Venda	Co-Supervisor
Ms P Nyamukondiwa	University of Venda	Investigator - Student

ISSUED BY:

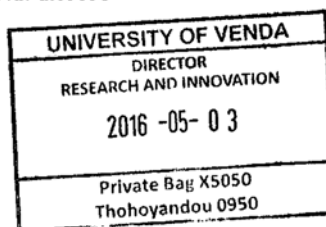
UNIVERSITY OF VENDA, RESEARCH ETHICS COMMITTEE

Date Considered: April 2016

Decision by Ethical Clearance Committee Granted

Signature of Chairperson of the Committee:

Name of the Chairperson of the Committee: Prof. G.E. Ekosse



University of Venda

PRIVATE BAG X5050, THOHOYANDOU, 0950, LIMPOPO PROVINCE, SOUTH AFRICA
TELEPHONE (015) 962 8504/8313 FAX (015) 962 9060

"A quality driven financially sustainable, rural-based Comprehensive University"

Appendix 3.2 Data collection and ethical clearance tools

Structured Interview guide

DEVELOPING COMMUNITY-INFORMED TECHNOLOGY FOR HARVESTING RAINWATER FOR DOMESTIC USE IN SEMI-ARID AREAS OF SOUTH AFRICA

Introduction

My name is Pertina Nyamukondiwa. I am a student at University of Venda registered for the PhD in Rural Development (PhDRDV) programme within the Institute for Rural Development. I am conducting research focusing on ***Developing Community-informed Technology for Harvesting Rainwater for Domestic use in Semi-arid areas of South Africa***

Through this communication, I am requesting you to participate in this study. Any information you will provide will be used solely for academic purposes. Please note that your participation is strictly voluntary. This means you can opt to pull out any time should you feel uncomfortable. I would also like to request permission to take photographs that will be used as evidence solely for the purpose of the study.

Signature of Researcher _____ **Date** _____

I.....have read and understood the contents of this invitation to participate in the study. Thus, I hereby voluntarily consent to participate in the research.

Respondent signature _____ **Date** _____

Appendix 3.3 Preferences for water sources and use as perceived by boy children in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	4	3	1	5	6
2. Cooking	2	3	4	1	5	6
3. Bathing	2	4	3	1	5	6
4. Washing clothes	2	4	3	1	5	6
5. Washing dishes	2	4	3	1	5	6
6. Sanitation	2	3	4	1	5	6

Appendix 3.4 Preferences for water sources and use as perceived by girl children in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	4	3	1	5	6
2. Cooking	2	4	3	1	5	6
3. Bathing	2	4	3	1	5	6
4. Washing clothes	1	4	3	2	5	6
5. Washing dishes	2	3	4	1	5	6
6. Sanitation	2	3	4	1	5	6

Appendix 3.5 Preferences for water sources and uses as perceived by youth male in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	4	3	1	5	6
2. Cooking	2	4	3	1	5	6
3. Bathing	3	4	2	1	5	6
4. Washing clothes	2	4	3	1	5	6
5. Washing dishes	2	3	4	1	5	6
6. Sanitation	2	3	4	1	5	6

Appendix 3.6 Preferences for water sources and use as perceived by youth female in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	3	2	4	1	5	6
2. Cooking	3	2	4	1	5	6
3. Bathing	2	4	3	1	5	6
4. Washing clothes	3	4	1	2	5	6
5. Washing dishes	1	4	3	2	5	6
6. Sanitation	1	3	4	2	5	6

Appendix 3.7 Preferences for water sources and uses as perceived by adult women in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	3	4	1	5	6
2. Cooking	2	4	3	1	5	6
3. Bathing	1	4	2	3	5	6
4. Washing clothes	1	4	2	3	5	6
5. Washing dishes	1	4	3	2	5	6
6. Sanitation	2	3	4	1	5	6

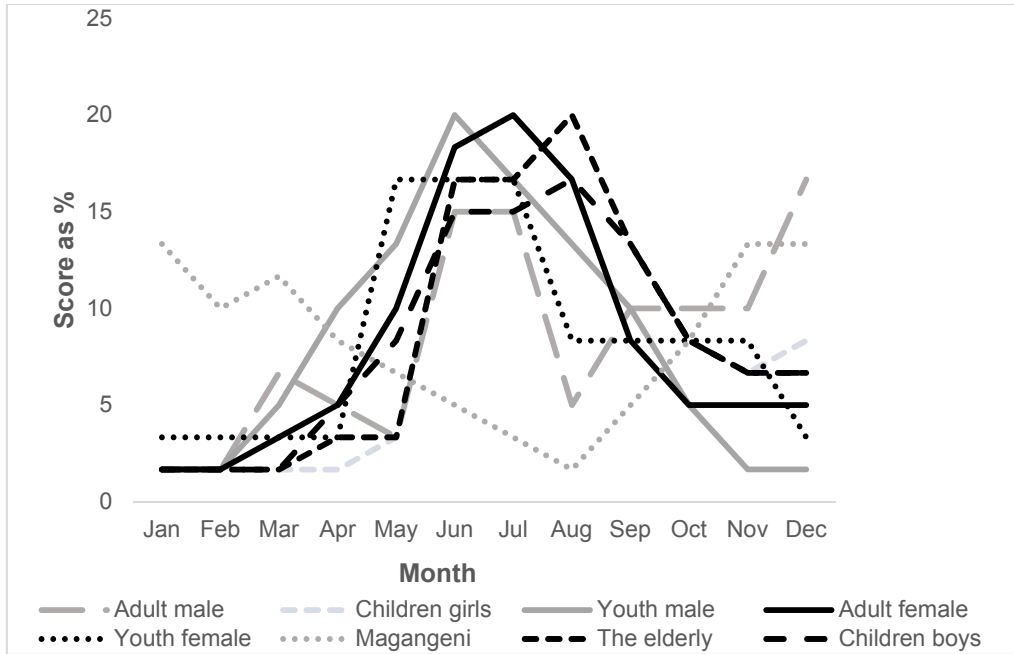
Appendix 3.8 Preferences for water sources and uses as perceived by adult male in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	4	3	1	5	6
2. Cooking	2	4	3	1	5	6
3. Bathing	3	4	2	1	5	6
4. Washing clothes	3	4	2	1	5	6
5. Washing dishes	3	4	2	1	5	6
6. Sanitation	3	4	2	1	5	6

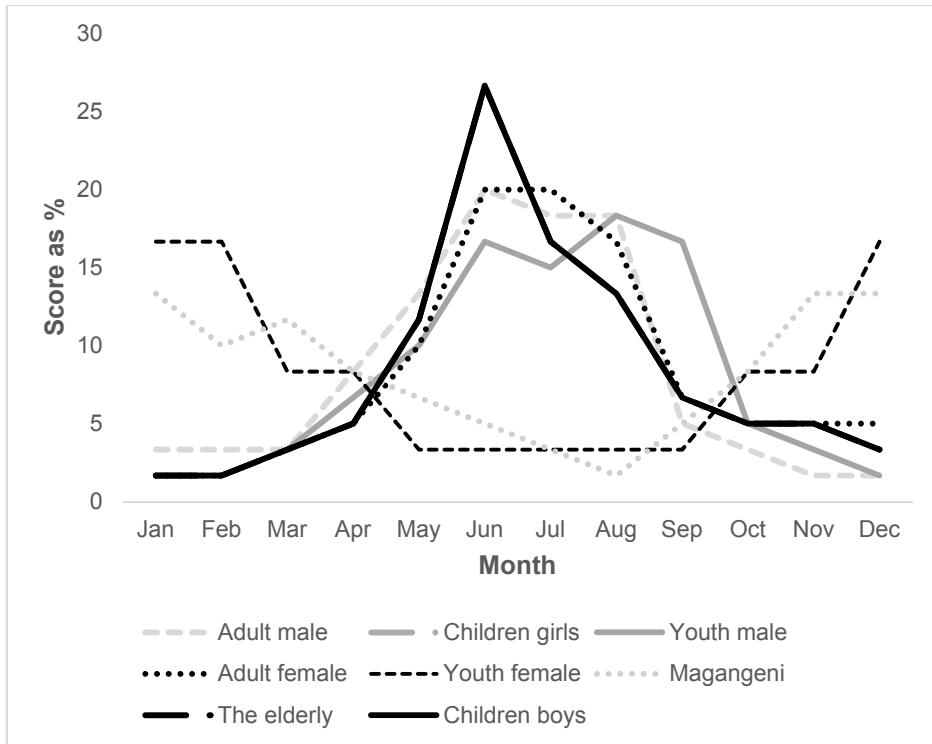
Appendix 3.9 Preferences for water sources and use as perceived by the elderly in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

Water use	Preferred sources					
	Rainwater	Borehole	River	Municipal tap water	Small dams (<i>Magraveleni</i>)	Xikerepe
1. Drinking	2	4	3	1	5	6
2. Cooking	2	4	3	1	5	6
3. Bathing	2	4	3	1	5	6
4. Washing clothes	2	4	3	1	5	6
5. Washing dishes	2	4	3	1	5	6
6. Sanitation	2	4	3	1	5	6

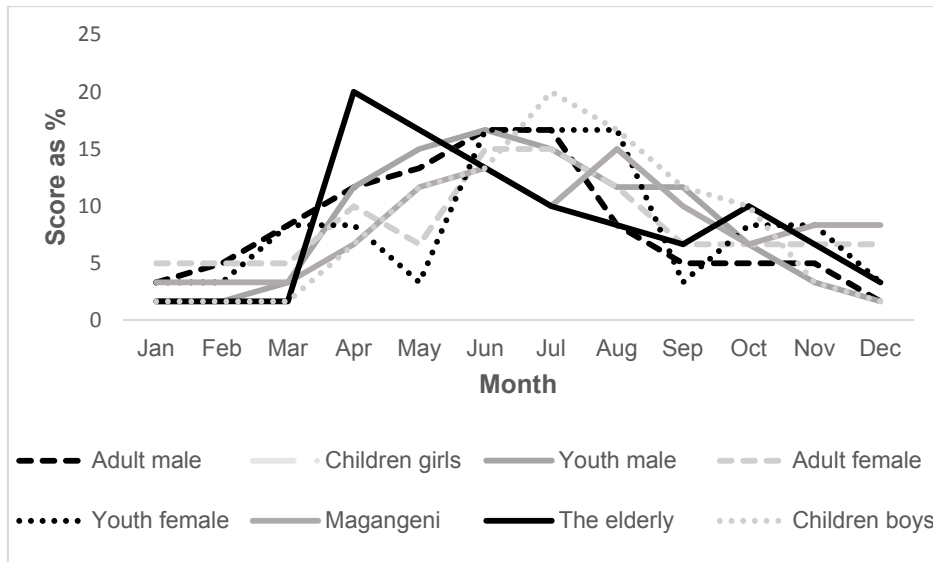
Appendix 4.1 Fetching water from the river as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



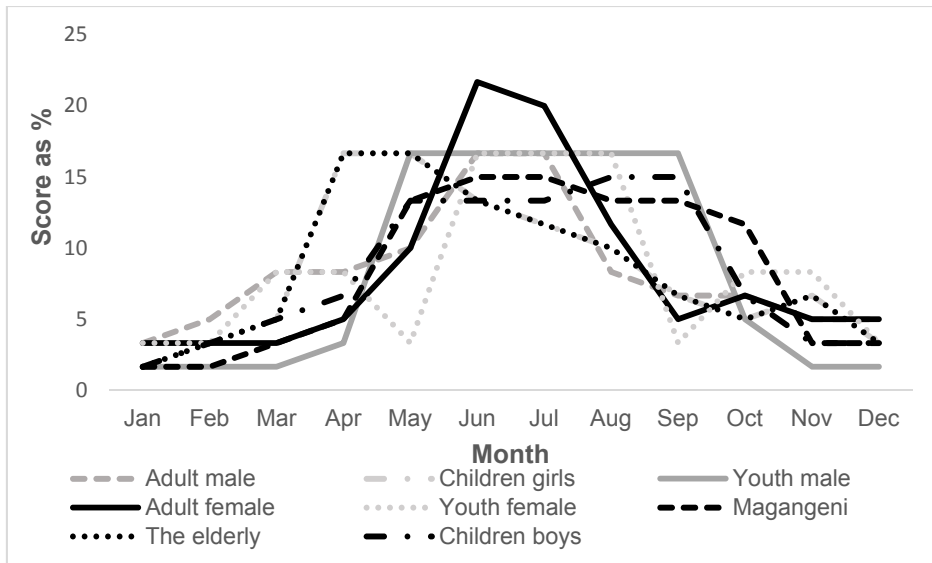
Appendix 4.2 Digging wells in the river as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



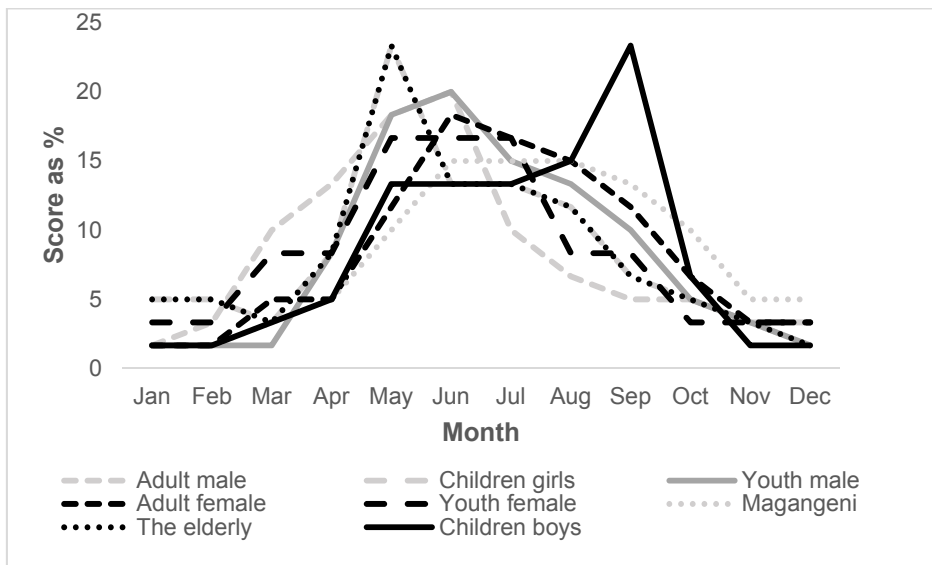
Appendix 4.3 Fetching water from neighbouring villages as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



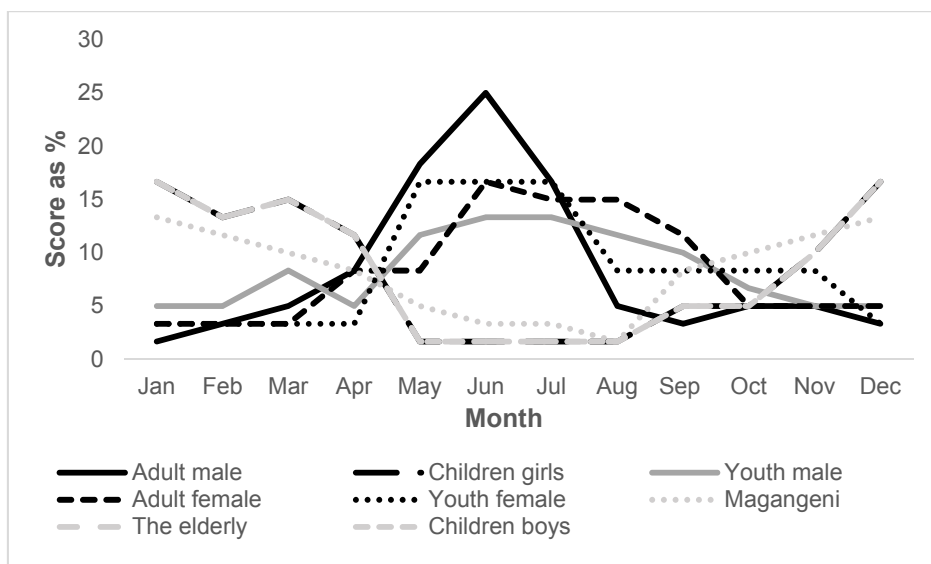
Appendix 4.4 Hiring cars to fetch water from Malamulele town as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



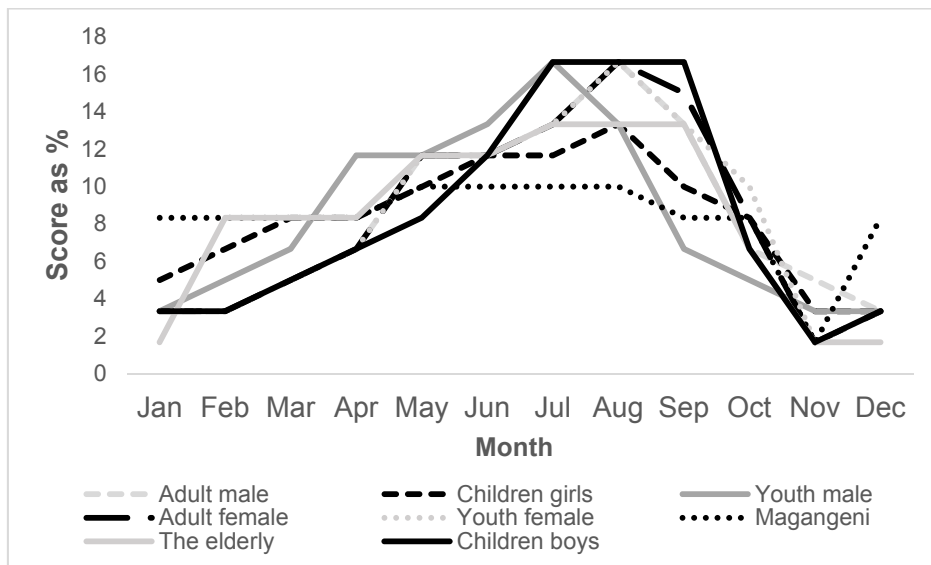
Appendix 4.5 Buying from those with boreholes as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



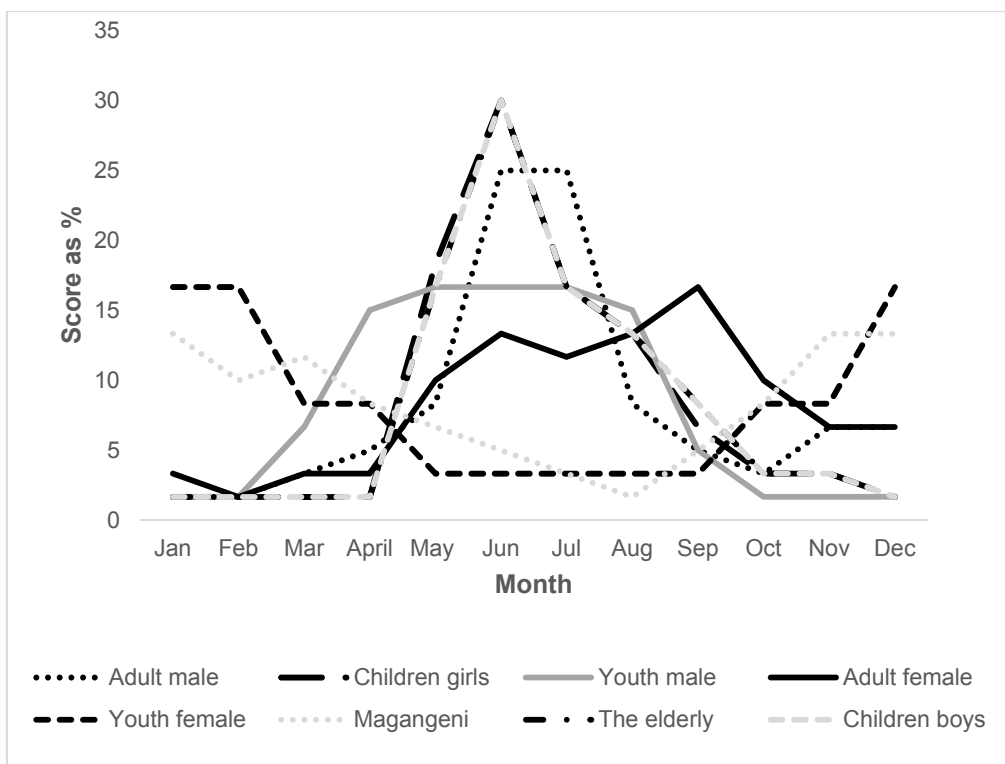
Appendix 4.6 Creating water holding structures (*Xikerepe*) for livestock drinking as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



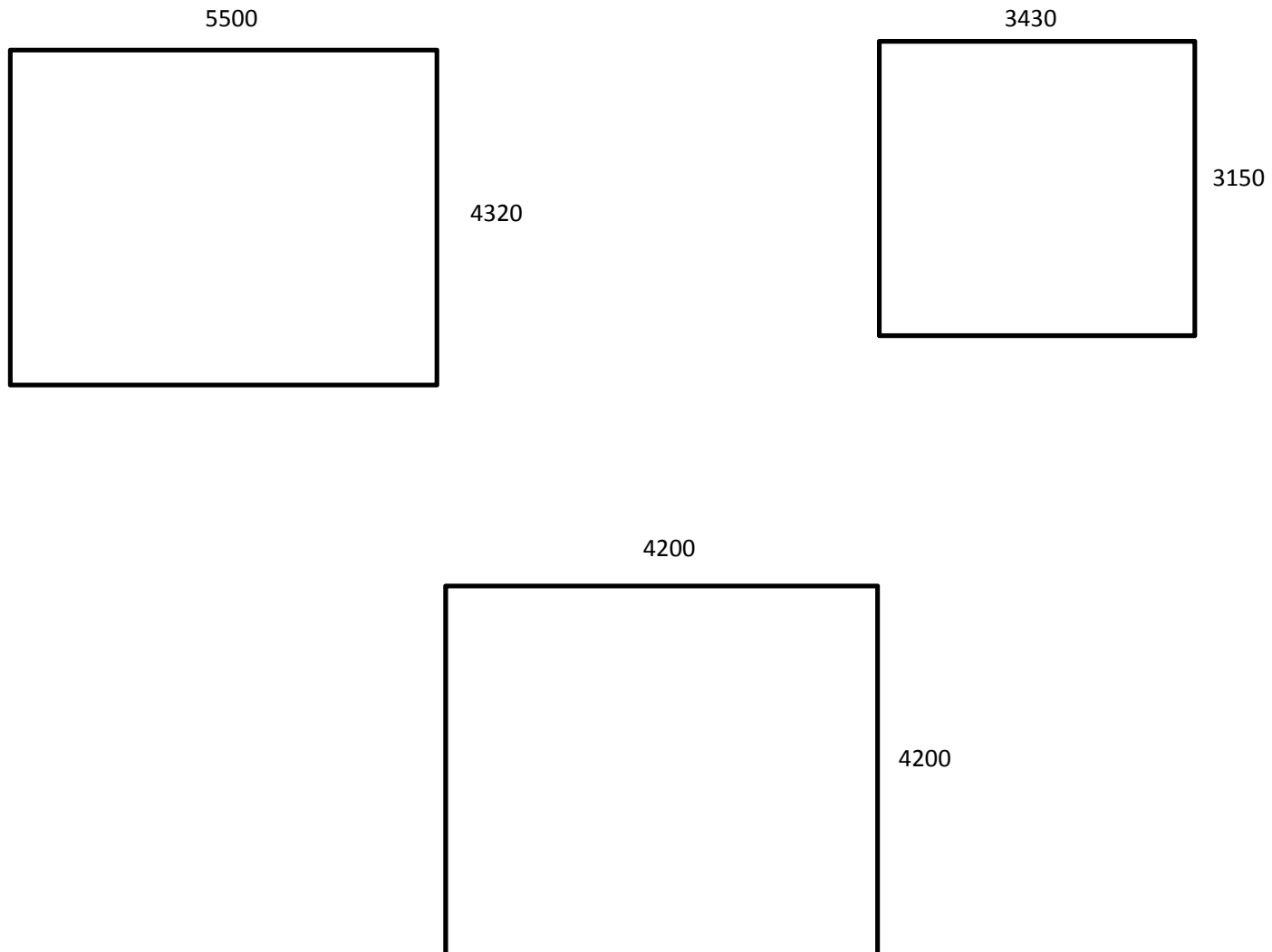
Appendix 4.7 Using wheelbarrows to fetch water from municipal taps as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



Appendix 4.8 Sterilizing water with Sodium Hypochlorite (Jik) as a coping strategy to water scarcity in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

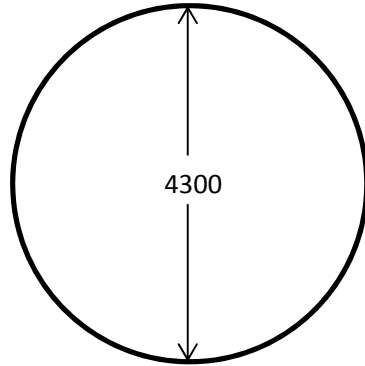


Appendix 7.1 Small Zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

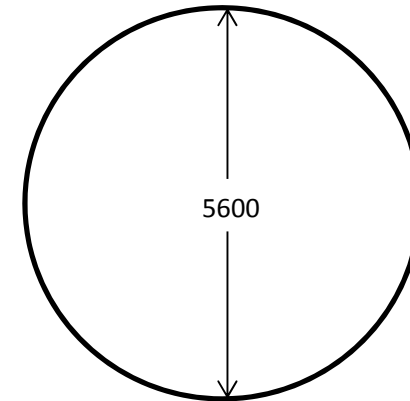


Appendix 7.2 Small thatch-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

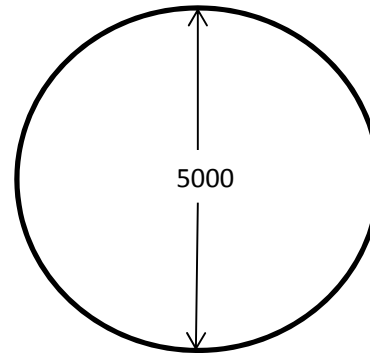
Thatch A



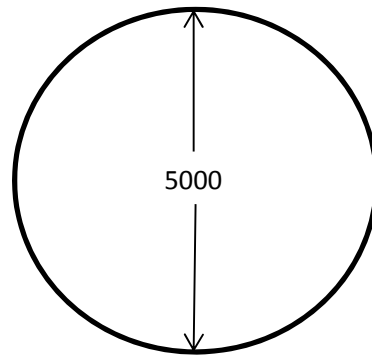
Thatch B



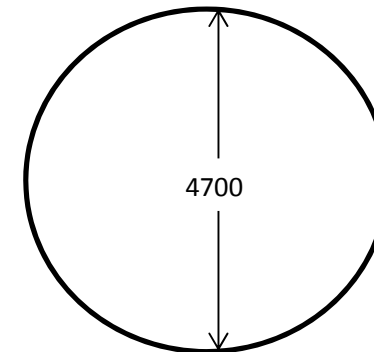
Thatch D



Thatch C

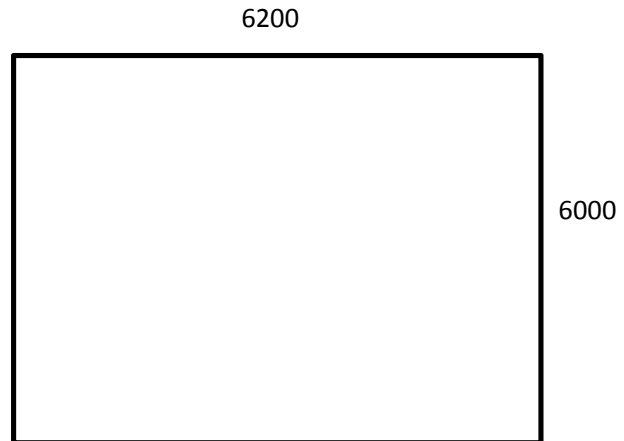


Thatch E

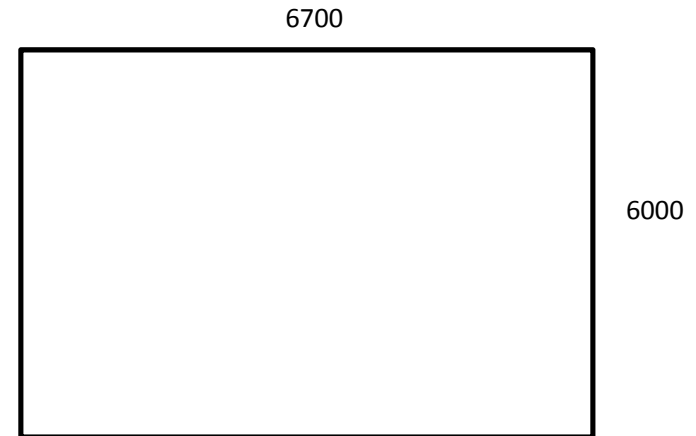


Appendix 7.3 Medium zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

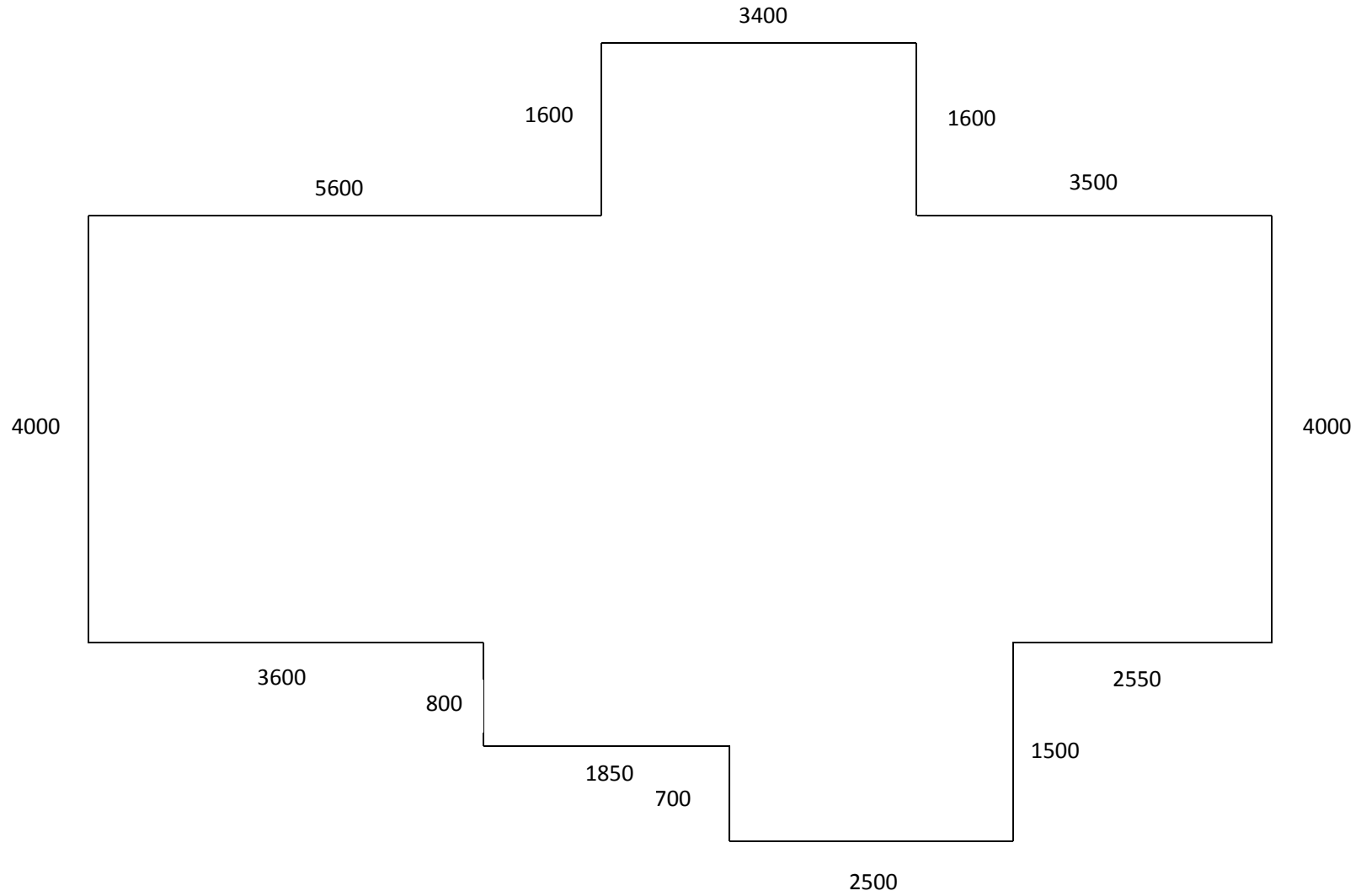
Sample 1



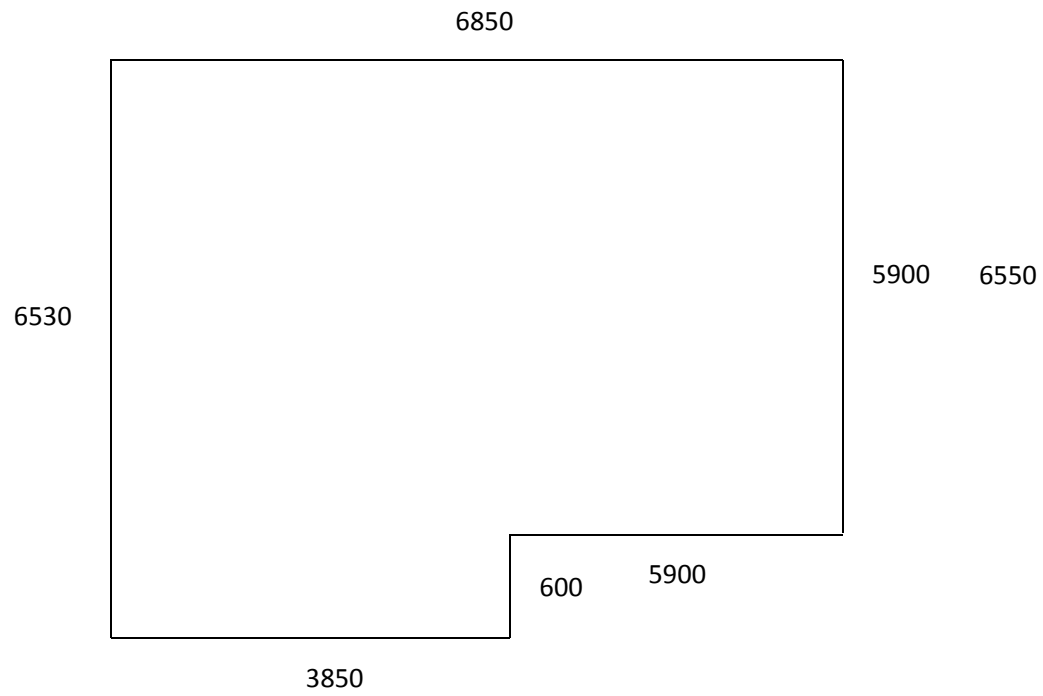
Sample 2



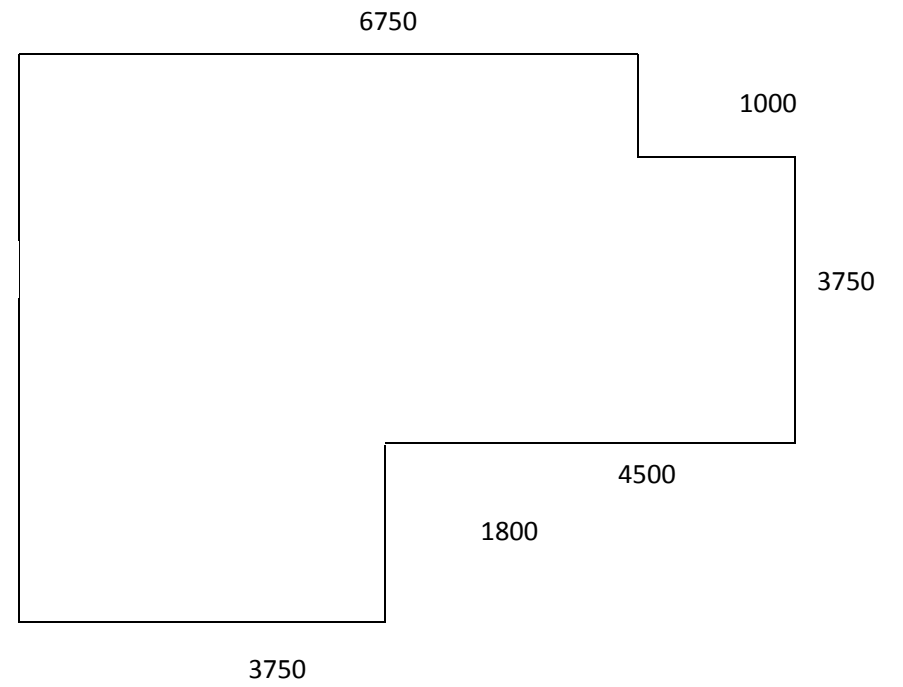
(Sample 3)



Sample 4

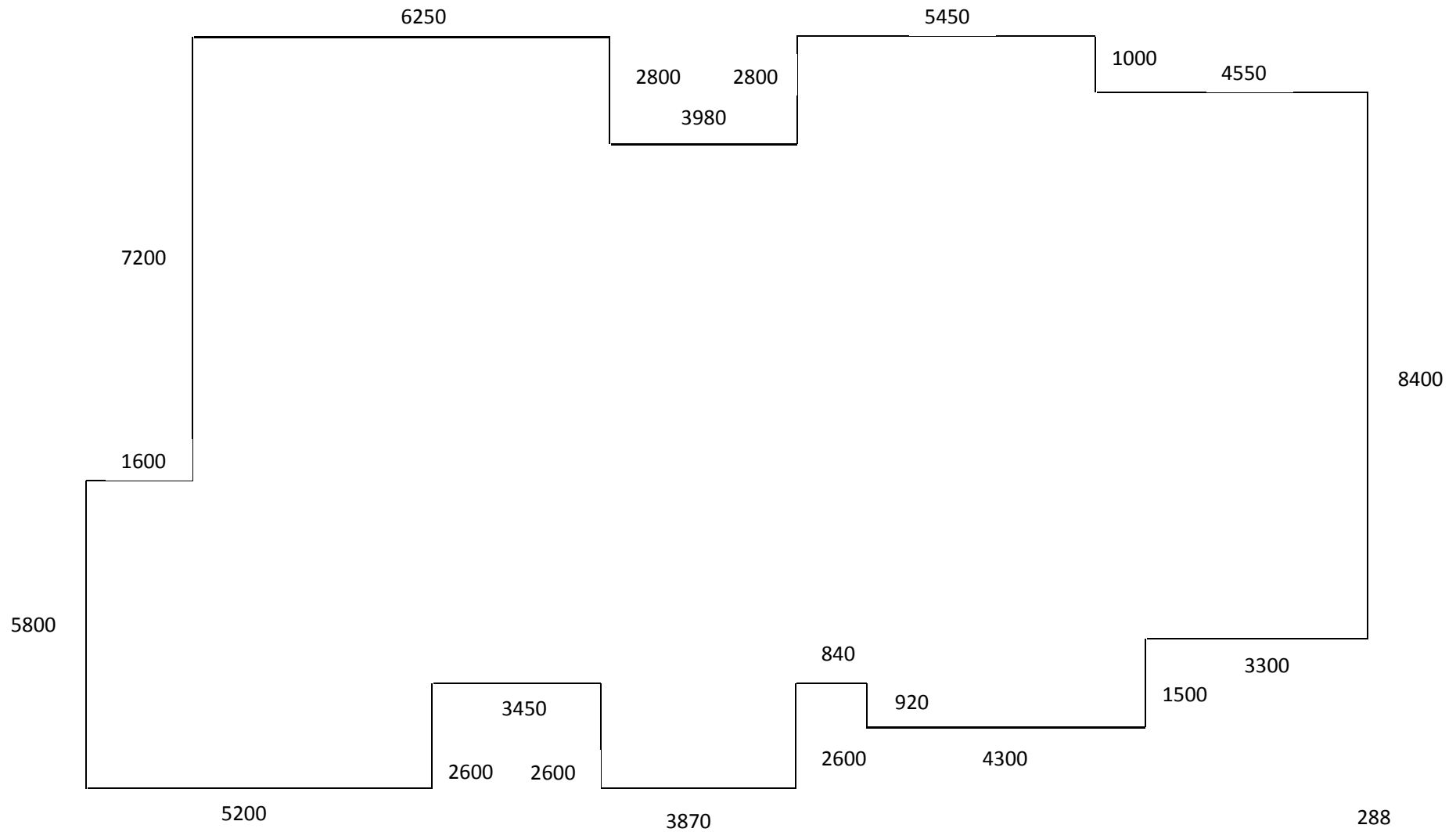


Sample 5

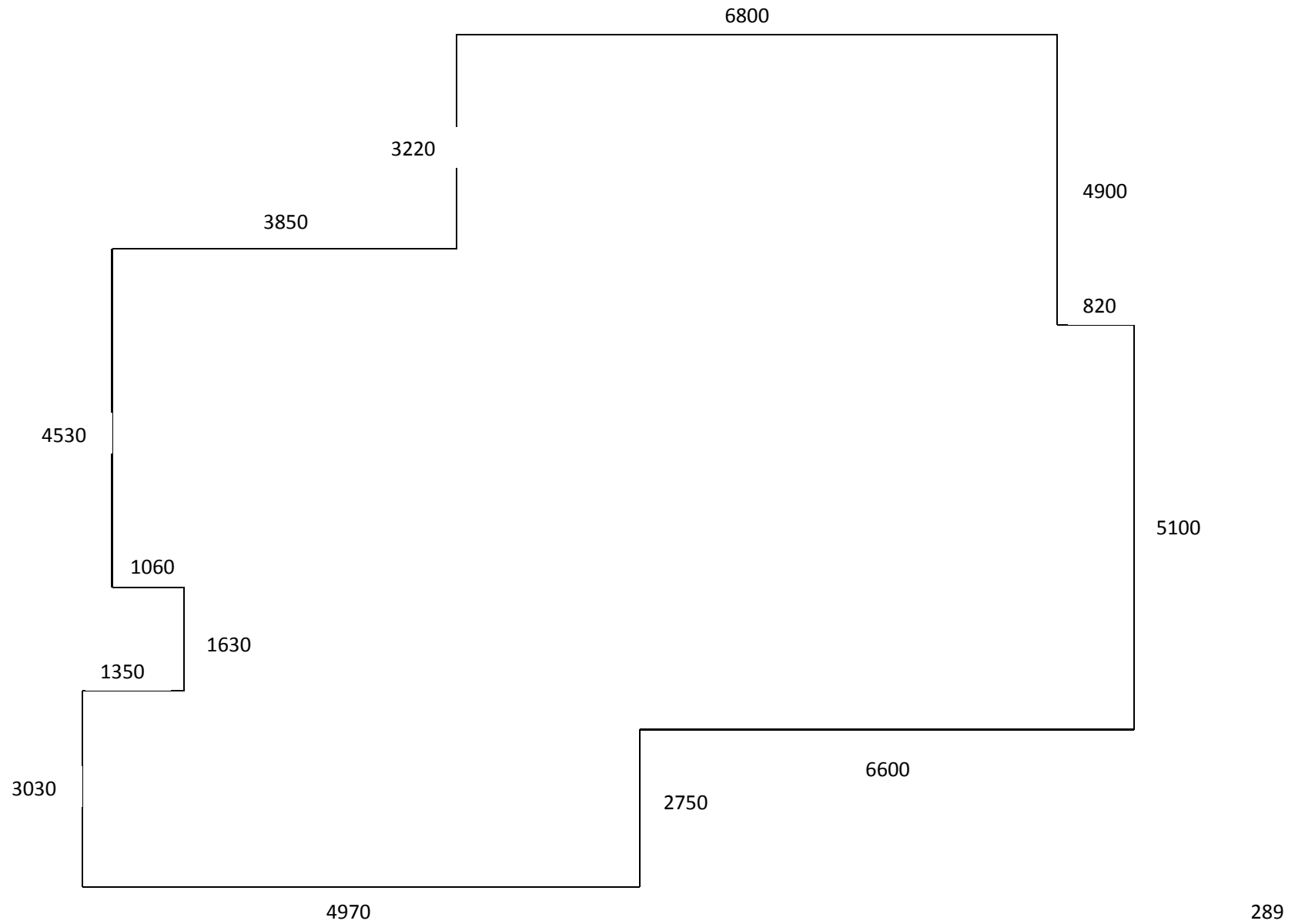


Appendix 7.4 Large zinc-roofed house samples taken from Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

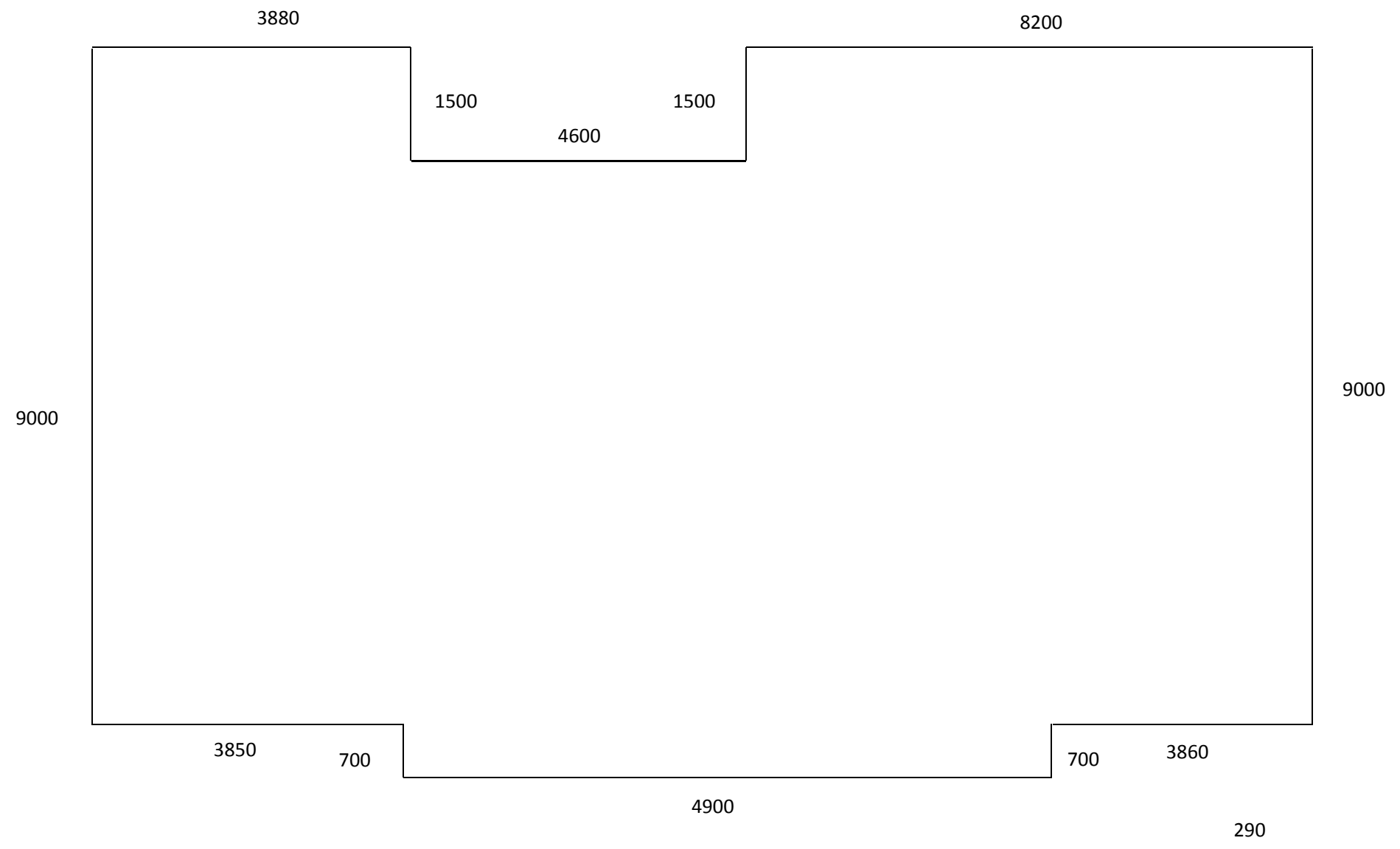
Sample 1



Sample 2



Sample 3

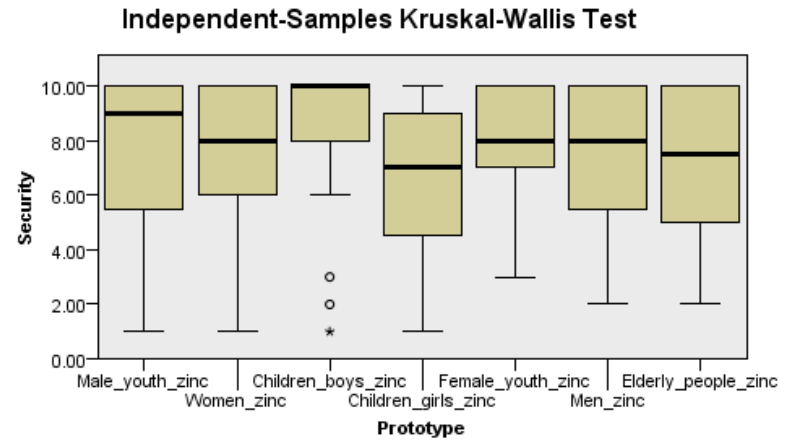
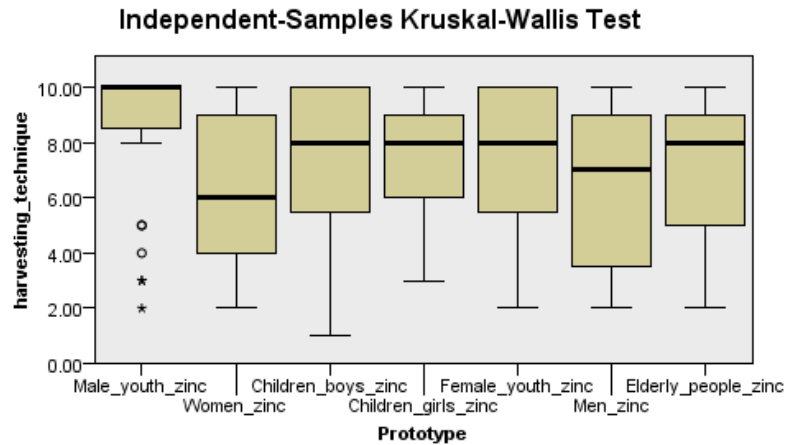
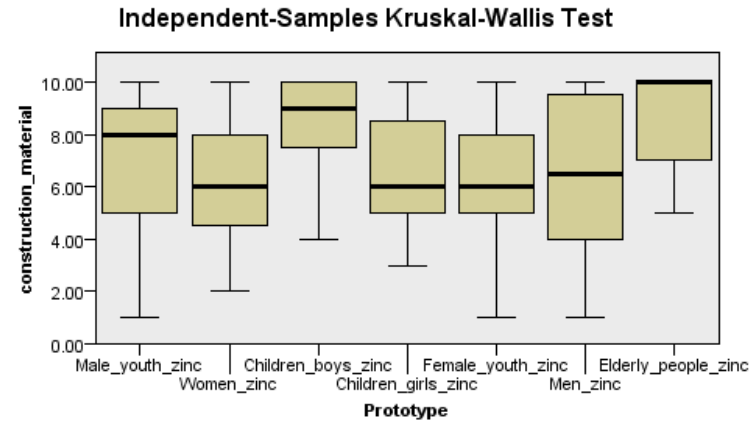
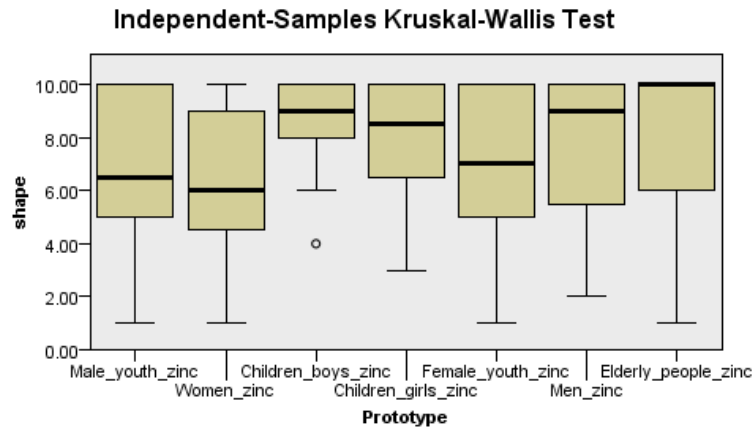


Appendix 8.1 Questionnaire or assessment sheet used to evaluate the prototype for harvesting rainwater in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province

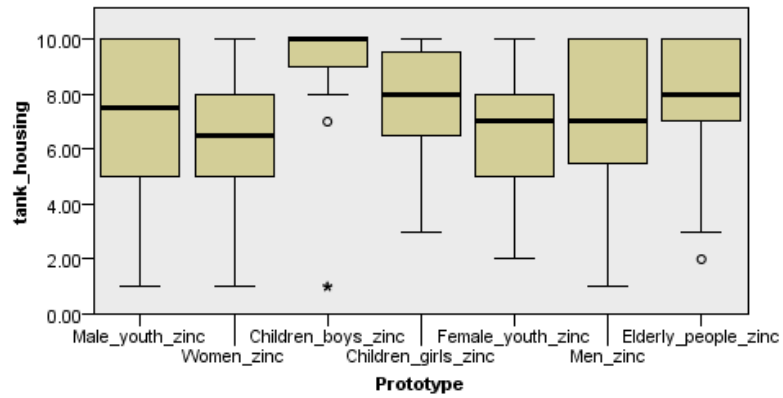
Assessor name: **Interest group.... Village.....Educational background****Instruction:** *Kindly go through the 14 prototypes and use this sheet to give a score for each prototype per structural component out of 10 (1 being poor and 10 being very good). Use provided descriptions to guide your decision. Also, give comments and suggestions for improvement*

Structural component	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
1. Shape: Circle or round for easy cleaning														
2. Construction material: Bricks, wire mash and cement for tank and concrete for foundation														
3. Delivery system: -Gutters for collection of water from the roof; Tank elevated by five layers of bricks to increase water pressure; Down pipe to direct water into the storage tank														
4. Security: Fencing the tank to keep thieves or animals away; Locking the tap to keep children from playing with water, and using plastic tap to discourage thieves														
5. Tank housing: Zinc roofing to protect the tank from weather damage and algae growth; Plastic (tent) to protect the tank from weather damage and algae growth														
6. Water access Pipe to take water from the tank to the house for easy access especially for old people, children and people with disabilities Plastic tap for access and also to prevent rusting														
7. Water quality Gutter screens to keep debris out of the system Closing the tank with cap and locking to allow for easy opening to clean the tank;(covering thatch with plastic to get clean water)														
8. Water conservation make Xikerepe for animals to drink or use the water for gardening or washing clothes														
TOTAL SCORE														

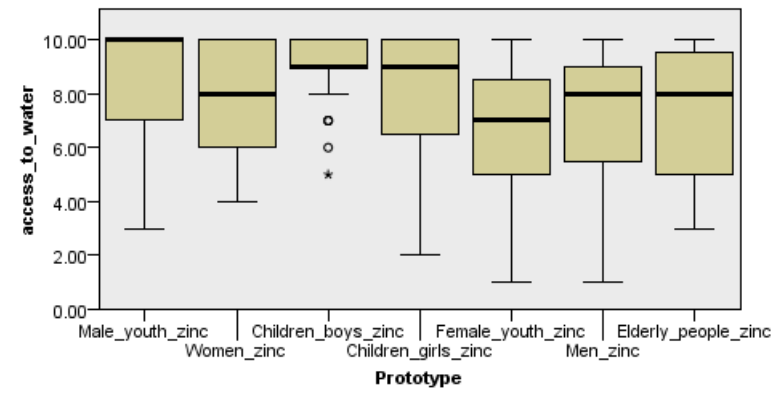
Appendix 8.2 The distribution of scores for prototype components for zinc prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



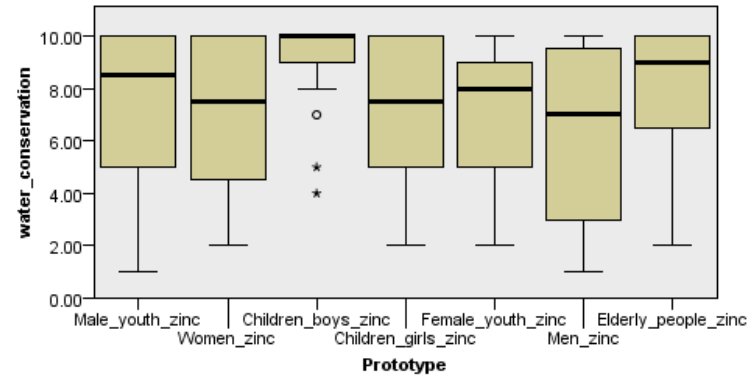
Independent-Samples Kruskal-Wallis Test



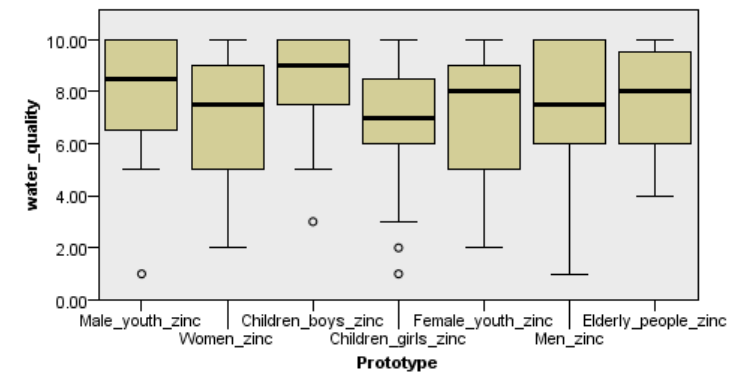
Independent-Samples Kruskal-Wallis Test



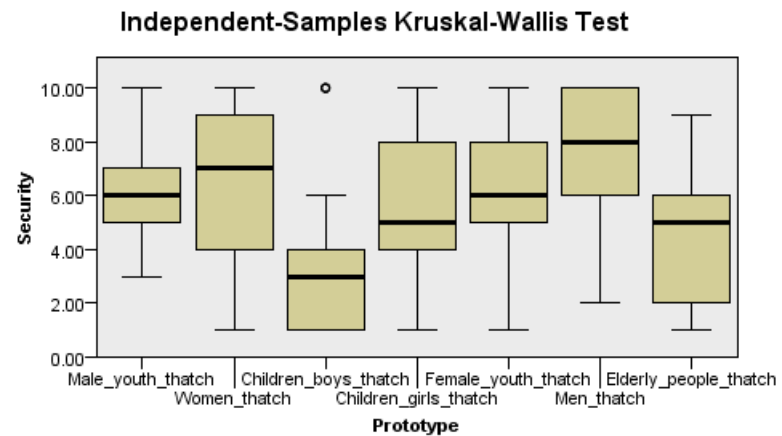
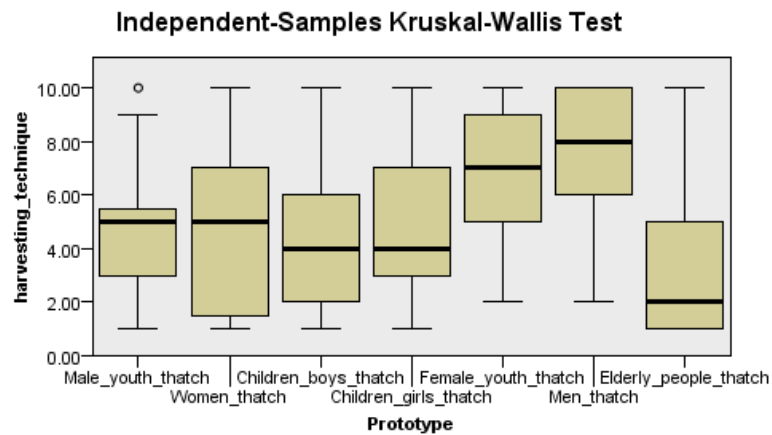
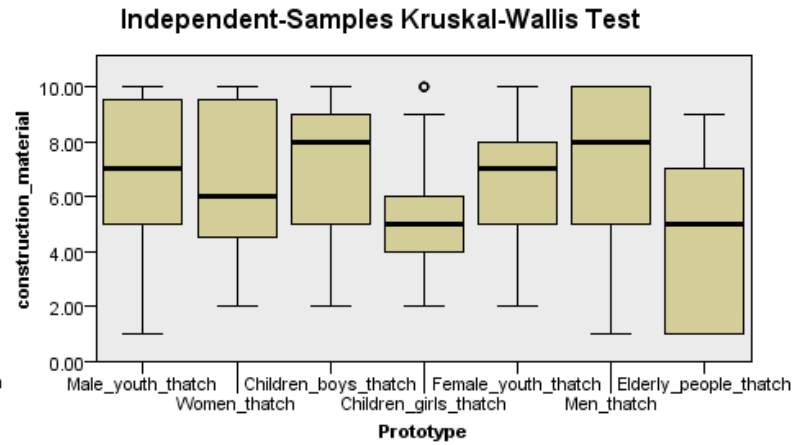
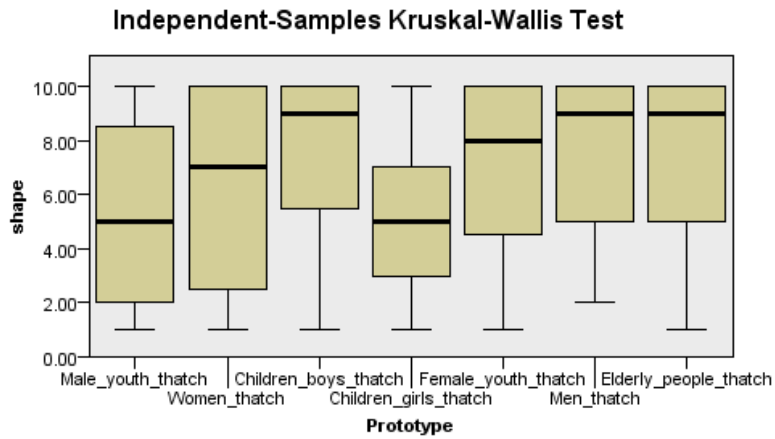
Independent-Samples Kruskal-Wallis Test



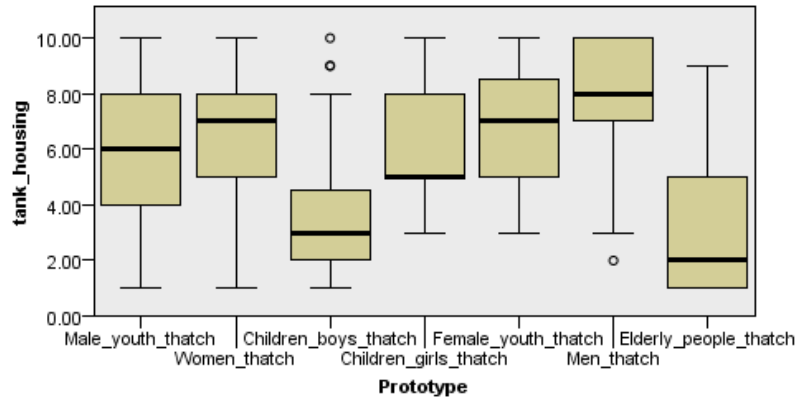
Independent-Samples Kruskal-Wallis Test



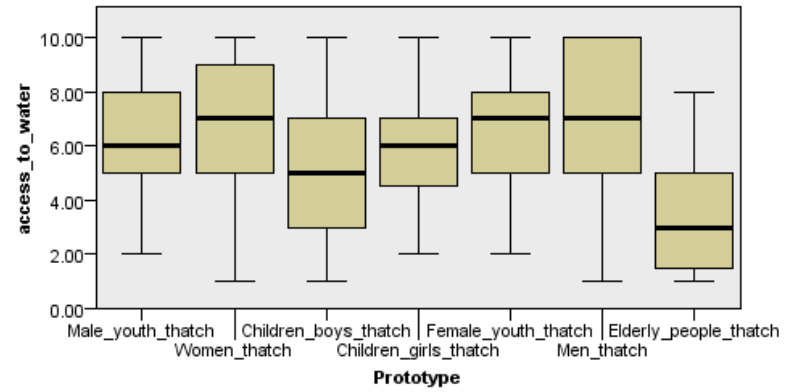
Appendix 8.3 The distribution of scores for prototype components for thatch prototypes developed in Mabayeni village of Collins Chabane Local Municipality in Limpopo Province



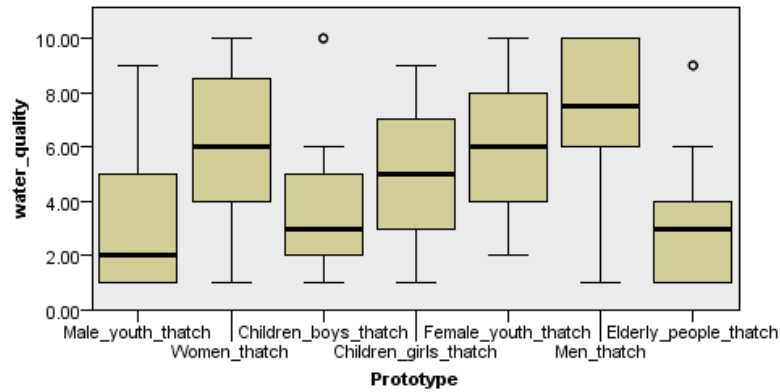
Independent-Samples Kruskal-Wallis Test



Independent-Samples Kruskal-Wallis Test



Independent-Samples Kruskal-Wallis Test



Independent-Samples Kruskal-Wallis Test

