



University of Venda

# **DEVELOPMENT OF PRODUCT QUALITY MANAGEMENT GUIDELINES FOR INFORMAL SMALL-SCALE BRICK MANUFACTURING ENTERPRISES IN DIDIDI, LIMPOPO PROVINCE, SOUTH AFRICA**

Name : Khensani Eullen Matsiketa  
Student No : 11593215

Supervisor : Dr. F. Amponsah-Dacosta  
Co-supervisor : Mr. Sphiwe Emmanuel Mhlongo

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## DEDICATION

This work is dedicated to my parents,

Mr Mzamani Samuel and Mrs Khubani Maria Hobyane for their love, support and prayers;

And

To my sister, Dr Katekani Chauke for the motivation, inspiration and for always believing in me and encouraging me to remain positive throughout my studies.

## DECLARATION

I, **MATSIKETA KHENSANI EULLEN**, do hereby declare that this research project for master of Earth Sciences in Mining and Environmental Geology at the University of Venda, hereby submitted by me, is my own original work; has not been previously submitted for masters' work at this or any other university; and, that all reference material contained therein has been duly acknowledged.

Undersigned

Student's signature: .....

Date: .....

We, the supervisors, certify that this declaration is correct

Supervisor.....

Date.....

Co-Supervisor.....

Date.....

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## ABSTRACT

Although clay brick manufacturing has been going on for many years in South Africa, informal small-scale clay brick manufacturing enterprises are not officially regulated. Consequently, informal brick makers in the study area do not adhere to the demanding requirements of the South African National Standards for burnt clay masonry. Therefore, their clay bricks lack uniformity in terms of quality. Preliminary work revealed that over time, buildings constructed with these bricks develop cracks, thereby compromising safety. The importance of product quality management is not well understood in the informal brick manufacturing enterprises. As a result, they do not have any product quality management guidelines.

The main purpose of this research was to develop the product quality management guidelines for ensuring quality in small-scale brick making enterprises in Dididi area. The specific objectives were to characterize the raw materials for clay brick manufacturing, identify and assess the technical problems of clay brick production, analyse the process of clay brick production and determine areas where product quality improvement is warranted. The research involved fieldwork which included soil sampling, analysis of clay brick production through the use of questionnaires and onsite observation of the production process, collection of samples of burnt bricks which were examined for compressive strength, water absorption as well as dimension measurements. These were then compared with the prescribed quality standards. Laboratory analyses of samples of raw materials were conducted and these included sieve analysis which was conducted in order to establish the particle size distribution of the raw materials; Atterberg limit tests were conducted in order to establish the physical characteristics of the soil. Chemical and mineralogical analyses were carried out to determine the chemical and mineralogical composition of the soil using XRF and XRD respectively.

The textural characterisation of the material revealed abundance of sand sized particles and significantly low amounts of clay and silt. The plasticity of the soil used for bricks manufacturing in the study area was found to be ranging from slight to medium plasticity. Chemical analysis showed elevated silica contents with minor amounts of alumina and iron oxide. XRD analysis revealed the dominance of non-clay minerals with the highest concentration of quartz. The average compressive strengths of the tested brick samples for site A was 3.8, and 2.9 and 3.8 MPa for sites B and C respectively. The water absorption of the bricks was 13.5, 15.0 and 16.1% for samples from Site A, B and C respectively. The bricks dimensions met the recommended standards although their sizes were not uniform.

The survey conducted on brick manufacturing process revealed that the technical inefficiencies were mostly influenced by human and mechanical factors as well as the material inappropriateness. The production process was found to be too manual and labour intensive. Selection of the raw materials for brick manufacturing was based on indigenous knowledge and experience and most of the brick manufacturers lacked the prerequisite experience for making quality bricks.

On the basis of the results of this research, it can be concluded that the materials used for manufacturing of clay bricks in Dididi are not well suited for making good quality bricks due to the reduced plasticity of the soil and the high concentration of quartz. These render the bricks brittle. It was also concluded that the production process also contributes to the poor quality of the bricks as the nature of the process was too manual. Selection of materials based merely on knowledge and experience and no scientific tests resulted in selection of inadequate materials which in turn affect the quality of the final bricks.

It is therefore recommended that plastic clays be added to the raw clay materials to enhance its moulding property. In addition, materials such as internal fuels and anti-shrinkage materials should be incorporated into the process cycle to prevent cracking during drying and firing. Based on the findings of the analysis of the production process, it is recommended that mechanized techniques be employed in the operation and awareness training conducted to improve the understanding and skills of the brick manufacturers and to ensure production of good quality bricks.

**Key Words:** Clay Bricks, Soil Characterisation, Brick Manufacturing, Product Quality, Management Guidelines.

## TABLE OF CONTENT

<b>DEDICATION.....</b>	<b><i>i</i></b>
<b>DECLARATION.....</b>	<b><i>ii</i></b>
<b>ACKNOWLEDGEMENTS.....</b>	<b><i>iii</i></b>
<b>ABSTRACT .....</b>	<b><i>iv</i></b>
<b>TABLE OF CONTENT.....</b>	<b><i>vi</i></b>
<b>LIST OF FIGURES.....</b>	<b><i>ix</i></b>
<b>LIST OF TABLES .....</b>	<b><i>x</i></b>
<b>LIST OF ACRONYMS AND ABBREVIATIONS .....</b>	<b><i>xi</i></b>
<b>CHAPTER ONE.....</b>	<b><i>1</i></b>
<b>INTRODUCTION.....</b>	<b><i>1</i></b>
1.1 Background of the Study.....	1
1.2 Problem Statement .....	4
1.3 Objectives of the Research .....	4
1.4 Research Questions .....	4
1.5 Justification of the Research .....	5
1.6 Study Area.....	5
1.6.1 Location of the study area.....	6
1.6.2 Climate .....	6
1.6.3 Regional geology of the study area.....	7
<b>CHAPTER TWO.....</b>	<b><i>8</i></b>
<b>LITERATURE REVIEW .....</b>	<b><i>8</i></b>
2.1 The Importance of Clay Brick Industry .....	8
2.2 Raw Materials for Burnt Clay Brick Manufacturing .....	9
2.3 Selection of Materials for Making Burnt Clay Bricks .....	10
2.3.1 Textural properties of brick making soils.....	10
2.3.2 Clay minerals.....	11
2.3.3 Chemical composition of brick making soil .....	12
2.4 Clay Brick Manufacturing Process .....	13
2.4.1 Clay mining.....	13
2.4.2 Clay preparation .....	14

2.4.3	Moulding of bricks .....	14
2.4.4	Drying of bricks.....	15
2.4.5	Firing .....	16
2.5	Standards for Burnt Clay Masonry Units .....	17
2.5.1	Classification of burnt bricks .....	17
2.5.2	Overall dimensions and tolerances .....	18
2.5.3	Compressive strength of bricks.....	19
2.6	Properties of Burnt Clay Bricks .....	19
2.6.1	Physical properties .....	19
2.6.2	Mechanical properties of clay bricks .....	22
2.6.3	Chemical composition of clay bricks .....	22
2.7	Overview of Product Quality Management .....	23
2.7.1	Quality of product .....	23
2.7.2	Product quality management .....	25
2.7.3	Adoption of quality management.....	26
2.7.4	Cost of poor quality .....	27
<b>CHAPTER THREE.....</b>		<b>29</b>
<b>RESEARCH METHODOLOGY.....</b>		<b>29</b>
3.1	Preliminary Work .....	30
3.2	Fieldwork .....	30
3.2.1	Soil sampling.....	30
3.2.2	Collection of samples of clay bricks .....	31
3.2.3	Analysis of clay brick production .....	31
3.3	Laboratory Tests.....	32
3.3.1	Sieve analysis .....	33
3.3.2	Atterberg Limit tests .....	34
3.3.3	Chemical and mineralogical analyses.....	36
3.3.4	Compressive strength test .....	37
3.3.5	Water absorption test.....	37
3.4	Development of Product Quality Management Guidelines .....	38
<b>CHAPTER FOUR.....</b>		<b>39</b>
<b>RESULTS AND DISCUSSION .....</b>		<b>39</b>
4.1	Characteristics of the Brick Manufacturing Materials.....	39
4.1.1	Textural properties of the soil.....	39
4.1.2	Atterberg limit tests results .....	41
4.1.3	Chemical properties of the soil used to manufacture clay bricks.....	43
4.1.4	Mineralogical composition of the soil used to manufacture clay bricks .....	44
4.2	Assessment of the Technical Problems of Clay Brick Production.....	47
4.2.1	The compressive strength of bricks produced in the study area .....	47
4.2.2	Water absorption property of the bricks .....	49
4.2.3	Brick dimensions .....	50

4.2.4 Process efficiency analysis .....	51
4.3 Analysis of Clay Brick Production Process .....	51
4.3.1 Demographic analysis .....	52
4.3.2 Resources for brick manufacturing .....	55
4.3.3 Analysis of production and soil testing methods .....	57
<b>CHAPTER FIVE.....</b>	<b>67</b>
<b>PRODUCT QUALITY MANAGEMENT GUIDELINES.....</b>	<b>67</b>
5.1 .The Need for the Guidelines .....	67
5.2 Objectives of the Guidelines .....	67
5.3 Guidelines for Ensuring Product Quality.....	68
5.3.1 Establishment of quality management team and training activities .....	68
5.3.2 Analysis of suitability of raw materials prior to selection .....	68
5.3.3 Preparation of the materials for brick making .....	69
5.3.4 Guidance for moulding of bricks .....	69
5.3.5 Guidelines for drying of bricks.....	70
5.3.6 Guidelines for firing of bricks.....	70
5.3.7 Product quality measurement .....	71
5.3.8 Formalization of the brick manufacturing enterprises .....	71
<b>CHAPTER SIX.....</b>	<b>72</b>
<b>CONCLUSIONS AND RECOMMENDATIONS.....</b>	<b>72</b>
6.1 Summary of the Study .....	72
6.2 Conclusions .....	74
6.3 Recommendations .....	76
<b>REFERENCES.....</b>	<b>77</b>
<b>APPENDICES.....</b>	<b>84</b>

## LIST OF FIGURES

<b>Figure 1.1:</b> A map showing the location of the study .....	6
<b>Figure 2.1:</b> Diagrammatic representation of the clay brick manufacturing process .....	13
<b>Figure 2.2:</b> Placing the clay in a mould to form bricks .....	15
<b>Figure 2.3:</b> Clay bricks arranged on the ground to allow drying .....	16
<b>Figure 2.4:</b> Fire Boxes around the sides of the clamp .....	17
<b>Figure 3.1:</b> A map showing the extent of the study area and sampling points .....	31
<b>Figure 4.1:</b> Grain size distribution curve of the soil used to manufacture fired bricks in Dididi ..	40
<b>Figure 4.2:</b> The flow curves of the liquid limit of the soil samples from Dididi.....	42
<b>Figure 4.3:</b> Comparison of the comparative strength of the bricks and their masses .....	48
<b>Figure 4.4:</b> Gender of the respondents.....	52
<b>Figure 4.5:</b> Age and educational background of the respondents.....	53
<b>Figure 4.6:</b> Experience of the respondents in brick making .....	54
<b>Figure 4.7:</b> Motivation of the respondents for entering the brick manufacturing enterprise .....	55
<b>Figure 4.8:</b> Resource availability .....	56
<b>Figure 4.9a:</b> Drying period.....	60
<b>Figure 4.9b:</b> Firing period.....	60
<b>Figure 4.10:</b> Number of bricks made per day.....	61
<b>Figure 4.11:</b> Number of respondents who have received complaints from customers .....	62
<b>Figure 4.12:</b> The operations of extraction of raw material for bricks manufacturing .....	63
<b>Figure 4.13:</b> Mixing of soil used for brick making done using legs and shovels in Dididi.....	64
<b>Figure 4.14:</b> Material preparation and brick moulding in one of the selected areas in Dididi .....	65

## LIST OF TABLES

<b>Table 2.1:</b> Definition of particle sizes in brick making.....	11
<b>Table 2.2:</b> Classification of burnt bricks [SANS 227 (2007)]......	18
<b>Table 2.3:</b> Tolerances on work size by SABS 227 (2007) .....	18
<b>Table 2.4:</b> Required compressive strengths of burnt clay masonry units by SANS 227(2007) ..	19
<b>Table 3.1:</b> Methods and techniques of data acquisition.....	29
<b>Table 3.3:</b> Method and formulae for the analysis of the geo-engineering, chemical and mineralogical properties of the soil. ....	33
<b>Table 4.1:</b> Particle size distribution of the raw materials obtained from sieve analysis. ....	40
<b>Table 4.2:</b> Atterberg Limit Results.....	41
<b>Table 4.3:</b> Major element composition of the clay bricks making material from Dididi .....	44
<b>Table 4.4:</b> Trace element composition.....	44
<b>Table 4.5:</b> Mineralogical composition of the raw materials. ....	46
<b>Table 4.6:</b> The comparison of the compressive strength of the tested bricks with standards ....	48
<b>Table 4.7:</b> The water absorption of the bricks from Dididi area .....	49
<b>Table 4.8:</b> Measured dimensions of the bricks.....	50
<b>Table 4.9:</b> Quality efficiency.....	51
<b>Table 4.10:</b> Moulds and fuel used.....	56
<b>Table 4.11:</b> Methods used to manufacture burnt bricks in Dididi.....	59
<b>Table 4.12:</b> Respondents' awareness of SANS 227:2007 for burnt brick.....	62

## LIST OF ACRONYMS AND ABBREVIATIONS

**ASTM** : American Society for Testing and Materials

**BC** : Before Christ

**ISO** : International Organization for Standardization

**PQM** : Product Quality Management

**SABS** : South African Bureau of Standards

**SANS** : South African National Standards

**SMEs** : Small-Medium Enterprises

**LL** : Liquid Limit

**PL** : Plastic Limit

**PI** : Plasticity Index

**ppm** : Parts per millions

### CHEMICAL COMPOUNDS

**SiO<sub>2</sub>** : Silica

**Na<sub>2</sub>O** : Sodium Oxide

**MnO** : Manganese

**MgO** : Magnesia

**CaO** : Lime

**K<sub>2</sub>O** : Potassium Oxide

**Fe<sub>2</sub>O<sub>3</sub>** : Ferric Oxide

**Al<sub>2</sub>O<sub>3</sub>** : Alumina

**Ba** : Barium

**Cu** : Copper

**Cr** : Chromium

**Ga** : Galium

**Ni** : Nickel

**Rb** : Rubidium

**Sr** : Strontium

**V** : Vanadium

**Zr** : Zirconium

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the Study

Clay brick is the simplest and the most ancient of all building materials (Clay Brick Technical Guide, 2007). Bricks are among the most durable construction materials (Mortar Industry Association, 2013). They are therefore one of the world's most widely used building materials. SABS 227 (2002) defines a clay brick as a masonry unit made basically from clay or shale (with or without an admixture of other materials), molded or extruded into a rectangular form, hardened by firing at high temperature in kilns, with or without frogs, perforations or cavities.

Clay bricks were formerly based on dried mud and were used for the first time around 8000 BC in Mesopotamia (Pacheco-Torgal and Jalali, 2011). As cited by Pacheco-Torgal *et al.* (2015), the use of clay bricks goes back to around 3000 BC. Burnt clay bricks usage is also recorded in Genesis 11 verse 3 in the Bible story of "The Tower of Babel" where the people began saying to each other "Let's make bricks and harden them with fire." Bricks were used instead of stone, and tar was used for mortar (The New Living Translation, 2013).

In South Africa, clay bricks have been in use for centuries. In Limpopo province, especially rural areas, many people rely on clay bricks for housing. Despite the fact that clay bricks have been in use for many years in South Africa, most informal small-scale burnt brick manufacturers in rural Limpopo province have very limited information about the characteristics of the soil they use for brick manufacturing. A report by Mueller *et al.* (2008) on "Green Brick Making" indicates that clay brick manufacturers use whatever soil is available nearby without taking into consideration the characteristics of the soil, therefore reducing the quality of the bricks.

The quality of the soil depends on the soil characteristics which in turn affect the quality of the final brick products. It is therefore crucial to determine the characteristics of the soil before using it for brick manufacturing. According to Fernandes *et al.* (2009), the quality of the raw materials used for brick manufacturing, together with the manufacturing process technology determine the properties of the final brick product. Informal small-scale brick manufacturers usually use poor manufacturing techniques, which in turn affect the quality of the end product.

Fernandes *et al.* (2009) emphasized that the analysis of clay brick production and final properties are fundamental in determining the quality of the bricks and further stated that it is important to obtain information on the main physical, chemical and mechanical properties of clay bricks as well as the characteristics of the soil and their manufacturing process. Brick making technology used by small-scale clay brick manufacturers differs from that of formalized brick manufacturers. Hence analysis of clay brick production is necessary for this study in order to understand and possibly identify the potential effects of the production process used for the manufacture of bricks on the final brick quality.

Determining the final brick properties is also very important before using or selling the bricks. Knowing the quality of the bricks helps prevent the dangers such as cracking of buildings that may be caused by using poor quality bricks for construction purposes. This also improves reliability of the bricks and safety of the people relying on these bricks for building homes. A study by Koroth (1997) shows that porosity, absorption and durability are the major properties affecting the quality of burnt clay bricks.

According to Fernandes *et al.* (2009), porosity influences other properties such as chemical reactivity, mechanical strength, durability and the general quality of the bricks. The amount of water that is absorbed by a brick while in contact with water depends on the porosity and pore size distribution of bricks (Koroth, 1997). Furthermore, Koroth (1997) stated that an increase in porosity is normally accompanied by a decrease in compressive strength. Compressive strength measures the ability of the brick to support weight without crumbling.

A report by Cermalab (2014) on the Survey of the Status of the Informal Clay Brick Making sector in the Eastern Cape of South Africa shows that informal clay brick manufacturers in South Africa are not officially regulated and registered as businesses. Consequently, they are not adhering to the requirements of the South African National Standards for clay bricks. Hence it is imperative in this study to examine the characteristics of the final bricks manufactured by informal brick manufacturers in Dididi and compare them with the prescribed burnt bricks standards. Comparing the brick properties with the standards will help in identifying the differences between the characteristics of the bricks produced by informal brick makers in Dididi with the required standards. This will assist in identifying areas where product quality improvement is required.

Studies show that the adoption of quality management techniques has helped enterprises to improve the quality of their products. Contrarily, a study by Wanjau *et al.* (2013) shows that most small and medium scale enterprises lose between 5 to 15% of sales revenue due to lack of attention to quality management. Ramos *et al.* (2007) define product quality management as coordinated activities to direct and control an organization with regard to quality. Product quality management is also understood as a comprehensive set of tools that enable organizations to control and manage the data related to product quality across enterprises. This product data includes product and manufacturing defects, field failures, customer complaints, product improvements and corrective and preventive actions requests. Product Quality Management ensures that a product is consistent and it has four main components, namely: quality planning, quality assurance, quality control and quality improvement.

Quality planning refers to activities that are performed to establish quality objectives. This includes establishment of both short-term and long-term quality improvement objectives that ensure that customer needs are met by the final products (Nanda, 2005). Quality assurance is a part of quality management that is focused on providing confidence that quality requirements will be fulfilled (WMO, 2011). According to ISO 9000, quality control is a part of quality management focused on fulfilling requirements for quality. Quality improvement involves systematic and continuous actions that lead to measurable improvement in product quality. According to American Society for Quality (2005), quality is a product's ability to satisfy stated or implied needs, and quality product should be free of deficiencies. In a nutshell, quality is the degree to which a set of inherent characteristics fulfill requirements.

Product quality management is critical in manufacturing because it assists in improving production processes as well as ensuring production of quality products. However, its importance in small-scale enterprises, especially in informal sectors is not emphasized. This is due to lack of either management involvement or management team to develop quality management strategies for improving production processes and ensuring quality of the products. Consequently, small-scale enterprises are normally associated with inadequate manufacturing techniques, low productivity rate and inadequate product quality. Therefore, the main focus of this study is to develop product quality management guidelines for ensuring product quality in the informal small-scale clay brick manufacturing enterprises in Dididi.

## 1.2 Problem Statement

Clay brick manufacturing has been going on for many years in Dididi. However, informal small-scale brick manufacturing enterprises in South Africa are not officially regulated. Consequently, they do not adhere to the demanding requirements of the South African National Standards for burnt clay masonry units. As a result, the bricks produced by informal small-scale brick manufacturers in Dididi lack uniformity in terms of quality. The immediate purchasers of the bricks manufactured by informal small-scale brick manufacturers in Dididi are the people from the surrounding areas. They normally use these burnt bricks for building houses. Preliminary work revealed that with time, the buildings constructed with these bricks tend to develop cracks, thereby compromising safety. Despite the need for product quality improvement in small-scale brick manufacturing enterprises in Dididi, the concept of quality and importance of product quality management is not well understood. As a result, they still lag behind when it comes to adopting quality management. Thus they do not have any product quality management guidelines for improving manufacturing operations and to ensure product quality. For this reason, this study aims to develop product quality management guidelines for ensuring quality of products in the informal small-scale clay brick manufacturing enterprises in Dididi.

## 1.3 Objectives of the Research

The main objective of this study was to develop product quality management guidelines for the informal small-scale clay brick manufacturing enterprises in Dididi.

The specific objectives were to:

- Characterise the raw materials for clay brick manufacturing.
- Identify and assess the technical problems of clay brick production.
- Analyse the process of clay brick production and determine areas where product quality improvement is warranted.
- Come up with product quality management (PQM) guidelines for the informal small-scale clay brick manufacturing enterprises in Dididi.

## 1.4 Research Questions

- What are the characteristics of soil used for brick manufacturing in Dididi?
- What are the technical problems associated with clay brick production in the study area?
- How are clay bricks produced in the study area?

- How will development of product quality management guidelines benefit small-scale brick manufacturing enterprises in the study area?

## **1.5 Justification of the Research**

Characterisation of the raw materials plays a significant role in determining the suitability of materials for brick manufacturing. This study will contribute to informal small-scale clay brick manufacturers understanding of the importance of considering the characteristics of raw materials before using them for brick making.

The study is also significant in that analysis of clay brick production will shed light on how the brick manufacturing process technology used in the study area affects the quality of clay bricks. This will help informal clay brick manufacturers to improve production processes to ensure production of quality bricks.

Determination of the properties of burnt clay bricks and comparing the properties with the standards will help the clay brick manufacturing enterprises to identify the technical problems associated with their bricks and ensure that the properties of their products meet the demanding requirements of the standards and thereby improving product quality. Identification of the areas where product quality improvement is warranted will help the burnt brick manufacturing enterprises will assist in developing strategies for improving quality.

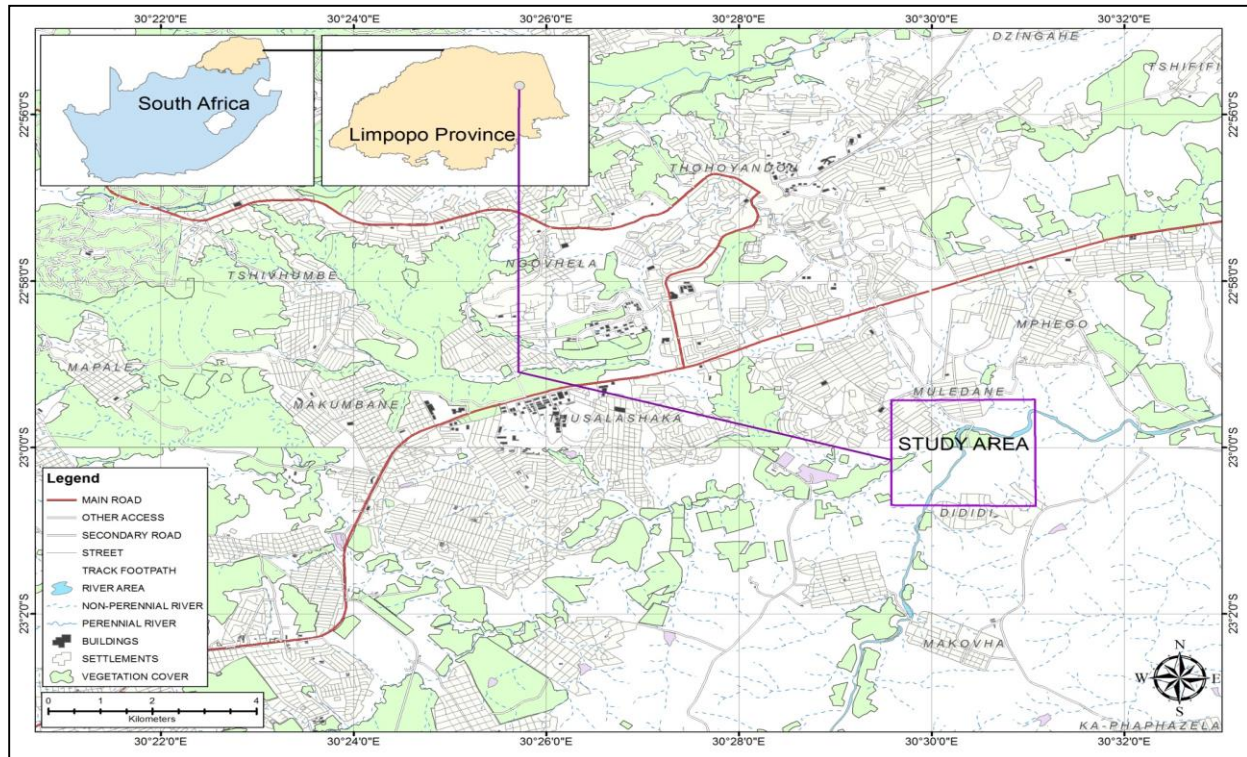
This study focuses on development of product quality management guidelines for informal small-scale clay brick manufacturing enterprises in Dididi. These guidelines will highlight the recommendations for ensuring effective and efficient production process and for ensuring quality of the bricks. Improvement of production processes will also contribute to improved skills of the brick manufacturers. The study will also highlight the importance of product quality management, with the purpose of improving the brick manufacturers understanding of the issues regarding quality and product quality management. Pursuing the objectives of this study will also benefit the consumers as improved quality of the bricks will also reduce the negative effects associated with building houses using poor quality bricks.

## **1.6 Study Area**

This section provides the description of the study area. It describes the geographical location of the study area, climate and regional geology of the area.

### 1.6.1 Location of the study area

The study was undertaken in Dididi village. Dididi is located in the Vhembe district municipality in the Limpopo province of South Africa. The geographic coordinates of the study area are between 23°00”S and 30°30’0” E. The location of the study area is shown in Figure 1.1.



**Figure 1.1:** A map showing the location of the study

### 1.6.2 Climate

The climate in Dididi varies from subtropical to semi-arid. The area is characterized by typically subtropical temperatures with fairly high humidity. Based on Integrated Development Planning (IDP) Review, the area experiences annual rainfall of approximately 500 mm per annum, with about 87.1% falling between October and March. The rainfall pattern decreases from east to the west of the district (Vhembe district) due to the orographic rain effect of the Drakensberg Mountains joining the Soutpansberg perpendicularly (Thulamela Municipality IDP Review, 2015/2016).

### 1.6.3 Regional geology of the study area

The study area is overlain by Precambrian basalts of the Soutpansberg Group. The Soutpansberg Group comprises a volcanic and sedimentary rock succession that is presently subdivided into six formations, namely the basal, discontinuous Tshifhefhe Formation, Sibasa Formation, Fundudzi Formation, Willie's Poort Formation, Musekwa Formation and Nzhelele Formation (Barker *et al.*, 2006). The volcanic and Sedimentary rocks of the Soutpansberg group occupy an East-South-East trending graben within the previously uplifted and eroded high-grade gneiss terrain of the Limpopo Mobile Belt (Bristow, 1986).

## CHAPTER TWO

### LITERATURE REVIEW

This chapter aims at reviewing the available literature in the study of the development of product quality management guidelines for informal small-scale clay brick manufacturing enterprises in Dididi. The literature review covers the importance of clay brick industry, raw materials for brick manufacturing, selection of raw materials, clay brick manufacturing process, standards for burnt clay masonry units, properties of clay bricks and overview of product quality management.

#### 2.1 The Importance of Clay Brick Industry

In South Africa, informal small-scale clay brick manufacturing is a major socio-economic contributor in the building sector. Although the informal brick making employees earn less income, informal brick manufacturing in rural areas help reduce poverty by providing employment to local communities. According to Clay Brick Association of South Africa (2014), about 20 000 people are directly employed in brick manufacturing through both formal and informal brick makers.

A report by Cermalab (2014) on “Survey of the Status of the Informal Clay Brick Making in the Eastern Cape of South Africa indicates that the estimated number of informal brick making operations in the Eastern Cape is 1042, producing around 118,6 million saleable bricks per annum. At an estimated average selling price of R1046 per 1000 bricks, meaning that informal brick makers in the Eastern Cape generate a total of R124, 055 million. The report further shows that the informal clay brick manufacturing operations in the Eastern Cape give employment to around 5210 people who support a further 30,218 dependents, with an average monthly income per worker of R826, meaning the informal brick makers contribute a further R4,3 million in wages to the Eastern Cape economy (Cermalab, 2014).

Bricks are significant materials required for buildings, civil engineering work, and landscape designs. The demand for bricks has been increasing with increased building construction activities in both private and government sectors. According to the Clay Brick Association of South Africa (2014), the demand for clay bricks in South Africa is increasing rapidly with increasing population. Clay brick industry plays a significant role in the economy of many developing countries.

In some countries, clay brick manufacturing enterprises are considered the foundation of the economy. According to Saidapur (2012), the economy of India which is the second largest producer of clay bricks following China depends largely on small-scale industries. In the study of “Informal Brick Industry in the North Karnataka”, Saidapur (2012) indicates that Indian brick industry runs as an unorganized small sector with more than 10000 brick kiln units spread throughout the country, each manufacturing about 1 million clay bricks per year.

Croitoru and Sarraf (2012) showed that the informal sector in India absorbed more than 70% of total workforce in 2000. According to the Asian Development Bank (2012), brick making sector in Bangladesh contributes about 1% to the country’s gross domestic product and generates employment for about 1 million people. United Nations Development Programme (2012) indicates that the trend data of the last decade shows that the demand for bricks is rising steadily at about 5.28% annually.

## **2.2 Raw Materials for Burnt Clay Brick Manufacturing**

The principal raw material for brick making is clay. Clay is an abundant raw material with an amazing variety of uses and properties that depend largely on their mineral structure and composition (Murray, 2007). To be suitable for brick making, clay must possess properties such as plasticity, which permits the clay to be moulded when mixed with water, and must have sufficient wet and air-dried strength to maintain their shape after forming (The Brick Industry Association, 2006).

Hendry and Khalaf (2001) reported that the best material for brick making is clay containing about 30% sand, as it reduces the shrinkage occurring during the burning of soft clay. Vitruvius (1960) suggested that bricks should be made of white and chalky or of red clay or coarse grained gravelly clays as these materials are smooth and durable. Guggenheim (2011) refers to clay as a naturally occurring material composed primarily of fine grained minerals, which is generally plastic at appropriate water contents and will harden when fired or dried.

The behavior of clay is affected by the particle size, for example, if the clay has been carried long distances by water, the particles are smaller and smoother so that the resulting clay is usually more plastic (Petersham, 2010). Clay occurs in three principal forms namely surface clays, shale clays and fire clays. The Brick Industry Association (2006) describes the three types of clays as follows: Surface clays may be the up thrusts of older deposits or of more recent sedimentary formations.

Surface clays are normally found near the surface of the earth, hence the name surface clays. Shales are clays that have been subjected to high pressures until they have nearly hardened into slate. Fire clays are usually mined at deeper levels than other clays and have refractory qualities. According to Batchelder *et al.* (1985), clay for brick making must satisfy the following requirements: The deposit must be easily available, which means there must be access to the deposit so that the clay can be excavated using the facilities at hand. At the same time, the clay deposit should be located within a reasonable distance of the people who are going to buy or use the bricks. The clay must be suitably plastic when mixed with water, and such mixing must be easily done using the facilities available.

The plastic clay must be able to hold its shape when moulded into a brick and must not warp, distort or crack during the drying process. The dried brick must be strong enough to withstand whatever handling is required during the production process. For example, bricks at the ground level under the weight of the stack of bricks above them in the kiln must be able to withstand the weight and pressure of the bricks in the settings above. The clay should be free from harmful impurities such as limestone, large stones and soluble salts. Limestone can cause the brick to burst around the limestone particles after it has been fired. Stones can cause cracking in the bricks. Soluble salts can cause harmful and unsightly deposits on the bricks after they are fired. The clay should have the qualities of forming into an adequately durable brick as a result of the firing process, and not distorting or warping during firing.

## **2.3 Selection of Materials for Making Burnt Clay Bricks**

Raw materials used for brick manufacturing play an important role on the quality of the final brick product. Consequently, this section covers some of the important issues that need to be considered when selecting raw materials for brick making. These issues include particle size in brick making soils, clay minerals and chemical composition of brick making soil.

### **2.3.1 Textural properties of brick making soils**

The size of clay particles present in brick making clays have a decisive quality influence depending on the selected firing technology (Mueller *et al.*, 2008). This is therefore very important in selecting raw materials for brick making. Particle sizes also affect the cohesiveness, forming characteristics and drying properties of clay. In practice, a raw material for brick making should contain a clay fraction (about 10 to 50%) together with some silt and some sand (International Labour Office, 1984).

Depending on relative proportions of various elements in the raw material, the material might be described, for example, as a silty clay or, if containing some clay and similar proportions of silt and sand, as a loam. Table 2.1 gives the description of particle sizes according to the International Labour Office (1984).

**Table 2.1:** Definition of particle sizes in brick making

Fraction		Size range
Sand	Coarse	2 - 0,6
	Medium	0,6 - 0,2
	Fine	0,2 - 0,06
Silt	Coarse	0,06 - 0,02
	Medium	0,02 - 0,006
	Fine	0,006 - 0,002
Clay		<0,002

### 2.3.2 Clay minerals

Clay minerals play a significant role in the forming properties of brick making soils, hence they also influence the quality of the final brick. Clay minerals are often found in shells, which is the most common type of sedimentary rock. There are many types of known clay minerals. Some of the most common types of clay minerals related for brick making are described in this section.

#### ***Kaolin***

Kaolin is commonly referred to as China clay. Its principal constituent is kaolinite. Kaolinite is the purest form of clay and consists of hydrated alumina-silicates (Mueller *et al.*, 2008). It has a white, powdery appearance and is usually fine grained. Kaolinite is named after a locality in China called Kaolin. The structural formula for kaolinite is  $Al_4Si_4O(OH)$  and the theoretical chemical composition is  $SiO_2$ , 46.54%;  $Al_2O_3$ , 39.50%; and  $H_2O$ , 13.96% (Murray, 2007). The chemical formula of Kaolinite is  $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$ . According to Mueller *et al.*, (2008) normal brick making soil does not contain any appreciable amount of kaolinite. Contrarily, the International Labour Office (1984) shows that the kaolin group minerals present no particular problems in brick manufacturing.

### ***Illites and the hydrous micas***

Illite is one of the most common forms of clay available in soil. Its crystal structure consists of Mg (magnesium) and K (potassium). Illites usually have low melting points (1050°C to 1150°C) because of their high K<sub>2</sub>O content (Mueller *at al.*, 2008). Mueller *at al.*, (2008) strongly recommended firing close to these limiting values since at this temperature the stable phases are formed in the brick body. Illites often contain iron also in the lattice, which is released at about 900°C firing temperature in the form of red hematite. The red colouring of the brick persists as long as no CaO is present. The International Labour Office (1984) states that the hydrous micas and illites are also frequently found in brick making materials and also adds that chlorites, which are related to hydrous micas, are also found in various clay materials.

### ***Montmorillonite***

The montmorillonite group, which often occurs in the drier tropics, has two silica layers for every one gibbsite (International Labour Office, 1984). In Montmorillonite the aluminium ion is partially substituted by Sodium and Magnesium. The resultant crystal structure has a capacity to absorb high water content and expand (Mueller *at al.*, 2008). This has important consequences in brick making since montmorillonite-bearing clays have a considerably higher drying shrinkage (Mueller *at al.*, 2008 and International Labour Office, 1984).

According to the International Labour Office (1984) montmorillonites would be best moulded from the driest possible mix, and then dried very slowly to avoid cracking. In addition, the ILO states that montmorillonites have high specific area that gives great plasticity, stickiness and strength. Due to their high plastic nature, in very small amounts, preferably not exceeding 3%, they can increase the plasticity of non-plastic materials thereby increasing the compressive strength of the fired bricks. Montmorillonites after drying, rapidly reabsorb moisture from the atmosphere, causing renewed swelling of the green products and accelerated drying in the kiln usually with high breakage, therefore, montmorillonite clays are not suitable for brick making (Mueller *at al.*, 2008).

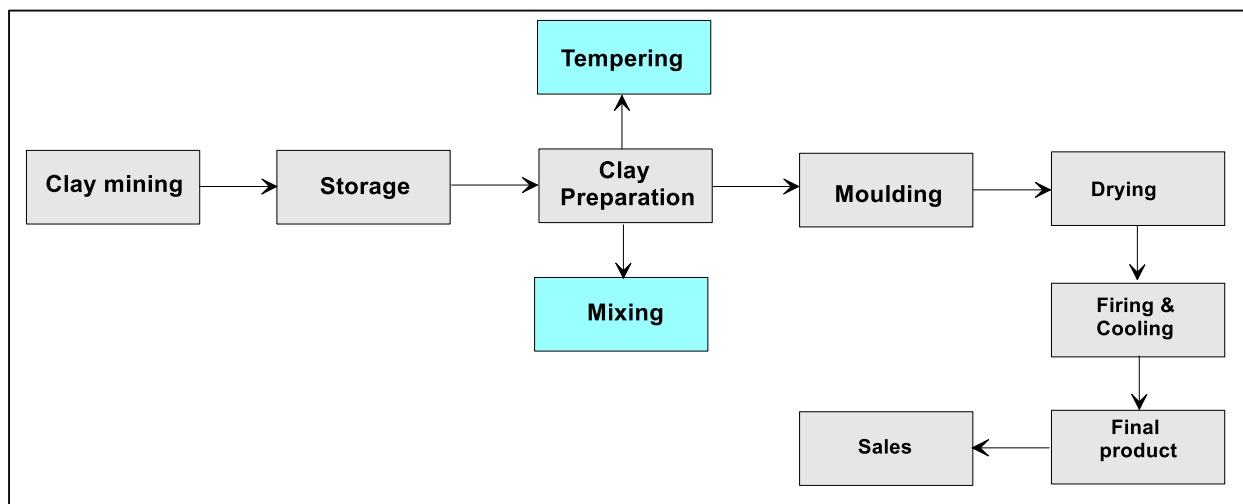
### **2.3.3 Chemical composition of brick making soil**

The main constituents of brick making clays are silica and alumina with small amounts of iron, calcium, sodium and other elements (Pacheco-Torgal *et al.*, 2015). The contents of alumina and iron in brick making clays play a decisive role in determining the brick quality as alumina

determines the plasticity in the soil which is an important component for high strength bricks and the higher percentage of alumina silicates in the soil results in stronger bricks (Mueller *et al.*, 2008). However, Mueller *et al.*, (2008) recommends a quantity of not greater than 30% as a practical working limit as higher alumina content in the clay will result in higher firing shrinkage.

## 2.4 Clay Brick Manufacturing Process

The general phases of the clay brick manufacture process involve clay mining, storage, clay preparation, moulding, drying, firing and cooling. A diagrammatic representation of the manufacturing process used in brick making is shown in Figure 2.1.



**Figure 2.1:** Diagrammatic representation of the clay brick manufacturing process

### 2.4.1 Clay mining

The work of extraction begins after the assessment of the quality of the raw material for brick making is done. Following Beamish and Donovan (1993) and Mueller *et al.* (2008), the first step in this stage is to cut the grass and do a general cleaning, removing all surface vegetation, and stones from the area. The second step is to excavate only the selected soil. Heavy earth-moving equipment such as bulldozers, scrapers and mechanical shovels are used to extract the clay (Clay Brick Technical Guide, 2007). Informal small-scale brick manufacturers use picks, hoes and shovels to extract the clay and buckets and wheelbarrows are used for transport. Once the clay is extracted, it is transported to an open storage area.

## 2.4.2 Clay preparation

Clay preparation follows after the raw material has been extracted. In small-scale clay brick making, clay is prepared manually in small brick yards. Clay for brick manufacturing needs to be prepared to ensure a high quality end product. According to the Building Advisory Service and Information Network (1999), neglecting a proper preparation of the clay raw material results in cracks during firing, visible defects of the fired brick and therefore in low quality of the end product. Clay for brick manufacturing is prepared by tempering and mixing. In the tempering process, clay is further crushed and mixed with water (Fernandes *et al.*, 2009). This is necessary for the easy mixing and workability.

Cermalab (2014) claims that in the informal small-scale clay brick manufacturing operations no further size reduction is done after extraction. This has a significant effect on the quality of the final brick unit as further crushing helps remove unwanted particles such as stones, plastics and wood. Mixing involves the addition of water to produce a homogenous material, the quantity added depends on the production material being used (Mortar Industry Association, 2013). The addition of water should be controlled in a way that does not affect moulding and drying. Excessive moisture may affect the size and shape of the finished brick. Mixing is usually carried by hand, and if done in an ineffective manner, this will affect the quality of the final product.

## 2.4.3 Moulding of bricks

This is the process by which the prepared soil is placed in mould to form specified shapes of bricks (Mueller *et al.*, 2008). This is shown in Figure 2.2. For shaping, the clay feed must be consistent in content, grading, plasticity and water. The shaping method depends on the type of raw material and the type of the brick required. Small-scale clay brick manufacturers use traditional hand moulding methods since these are simple and affordable.

### ***Hand moulding***

In hand moulding, bricks are moulded manually by hand. Hand moulding can be done in two different ways and they are slop moulding method and sand moulding method. According to (Cermalab, 2014), slop moulding is the traditional method of brick manufacturing usually used by all the informal small-scale clay brick manufacturers in South Africa. In slop moulding, the mould is wetted and placed on the ground and mixed with a very wet clay mixture. The brick is formed in a rectangular mould which has no top or bottom.

This method often produces poor quality bricks due to the excessive water used both in the mixing of clay and wetting the mould (Beamish and Donovan, 1993). The clay mixture becomes so wet and soft that the newly formed brick begins to deform under its own weight. The excess water can also cause the brick to crack and break during drying. According to Beamish and Donovan (1993), sand moulding uses a drier stiffer clay mixture and the clay is formed into a wedge shape and its sides are covered with a releasing agent which prevents the clay from sticking to the sides of the mould. The releasing agent is commonly sand. The wedge, covered with a releasing agent, is thrown into a simple hinged bottom moulds which sits on a table. A bow cutter is used to remove the excess clay and smooth the top of the brick. The newly formed brick slides easily out of the mould onto the table top.



**Figure 2.2:** Placing the clay in a mould to form bricks (Mueller *et al.*, 2008)

#### **2.4.4 Drying of bricks**

During the preparation stage, water is added to make the clay soft and easier to shape into bricks. Before the bricks can be fired, they must be dried properly. Drying in brick making commonly refers to the process of thermally removing moisture to yield a solid product (Mueller *et al.*, 2008). The moisture content has to be reduced to 8% of volume for the clamp kiln (Clay Brick Technical Guide, 2007). Thermally removing the moisture can be attained by either mechanical heating (dryer) or atmospheric drying (exposure to sun rays).

Although, mechanical drying methods reduce the drying cycle, informal small-scale units rely on the sun for drying operation. The importance of drying is explained by Vitruvius (1960) who suggested that bricks should be made in spring or autumn to allow uniform drying.

Vitruvius (1960) also stated that bricks made in summer are defective, because the fierce heat of the sun bakes their inside surfaces and make them dry while inside they are not, and so the shrinking which follows as they dry, causes the cracks in the parts which were dried before, and these cracks make the bricks weak. Figure 2.3 shows clay bricks layed on the ground for drying.



**Figure 2.3:** Clay bricks arranged on the ground to allow drying (Cermalab, 2014).

### 2.4.5 Firing

Firing of the bricks is the last stage in brick making process. Firing hardens the brick in order to acquire additional resistance. During firing, bricks go through a number of property changes. According to Mortar Industry Association (2013), firing enhances the colour and develops durability of the bricks. Historically, bricks were dried in stacks about seven courses high. Nowadays, bricks are dried either in a drier or in a kiln (Mortar Industry Association, 2013). Bricks are fired at temperatures between 1000 °C and 1200 °C depending on the type of clay (Clay Brick Technical Guide, 2007).

There are two broad categories of kiln and they are intermittent and continuous/semi continuous kilns. Intermittent kilns include clamp kilns, scotch or up-drought kiln and down-drought kiln and continuous kilns include the Hoffman-type Traverse Arch kiln (TVA). Figure 2.4 show fire boxes around the clamp.



**Figure 2.4:** Fire Boxes around the sides of the clamp (Cermalab, 2014).

## **2.5 Standards for Burnt Clay Masonry Units**

One of the objectives of this study is to determine the properties of clay bricks and compare them with the required burnt bricks standards. The standards are developed in order to protect the end-users by ensuring product consistency and uniformity. This section provides the required standards for burnt clay bricks for the Republic of South Africa. It classifies burnt clay bricks according to the South African National standards, provides the required dimensions and tolerances and the recommended burnt bricks compressive strength.

### **2.5.1 Classification of burnt bricks**

Table 2.2 provides the classification of burnt clay bricks according to the South African National Standards for burnt clay masonry units (SANS 227:2007).

**Table 2.2:** Classification of burnt bricks [SANS 227 (2007)].

Brick unit	Description
Face Brick Extra (FBE)	These are clay bricks that are produced or selected for their durability and high degree of uniformity of size, shape and colour.
Face Brick Standard (FBS)	Clay bricks selected or produced for their durability and uniformity in size and shape
Face Brick Aesthetic (FBA)	Clay bricks selected or produced for their durability and aesthetic effect deriving from non-uniformity of size, shape and colour.
Non-Facing Plastered (NFP)	Clay bricks suitable for general building work that is to be plastered.
Non-Facing Extra (NFX)	Clay bricks suitable for use, plastered or unplastered, for general building work below damp-proof course or under damp conditions or below ground level where durability rather than aesthetics is the criterion selection.
Engineering units (E)	These include any masonry unit produced for structural or load-bearing purposes in face or non-face work, where the manufacture supplies clay bricks to an agreed compressive strength.
Clay Pavers (PA)	Clay pavers that are selected or produced for their durability and for high degree of uniformity in size and shape, and that have dimensions such that the ratio of work size length to work size width is approximately 1:1, 2:1 or 3:1.
Clay Pavers (PB)	These are clay pavers that are selected or produced for their durability and uniformity on size and shape.

### 2.5.2 Overall dimensions and tolerances

The imperial brick is the most commonly used brick size. It is 222 mm long x 106 mm wide x 73 mm high with a mass between 3 and 3.5 kg, depending on the materials used, the degree of vitrification and the perforations provided (SABS, 2007). The required tolerances on work size are shown in Table 2.3.

**Table 2.3:** Tolerances on work size by SABS 227 (2007)

Class unit	Tolerances (mm)		
	Length	Width	Height
	<b>Individual units</b>		
FBX	±5	±3	±3
FBS	±7	±4	±4
	<b>Average 32 units</b>		
FBX	±2,5	±1,5	±15
FBS	±3,5	±2	±2
NFP, NFX	±3,5	±2	±2

### 2.5.3 Compressive strength of bricks

According to SABS 227 (2007), bricks vary in compressive strength due to the differing qualities of the raw materials and the method of firing. The compressive strengths can range from 3.5 for NFP to greater than 50 MPa for face brick extra and engineering products. Table 2.4 shows the required compressive strengths of burnt clay masonry units by SANS 227(2007).

**Table 2.4:** Required compressive strengths of burnt clay masonry units by SANS 227(2007)

Required compressive strengths of burnt bricks (SAN 227:2007)		
Description	Average (MPa)	Individual (MPa)
Single-storey construction:		
On-site manufacture	4.0	3.2
Off-site manufacture	5.0	4.0
Double-storey construction	10.0	8.0
On-site manufacture is where units do not require to be transported more than 25 m to the place where they will be built into walls.		

## 2.6 Properties of Burnt Clay Bricks

The quality of burnt clay bricks rely essentially on its properties which are influenced by the characteristics of the raw materials. This section therefore aims at reviewing the properties of burnt clay bricks and their influence on the quality of burnt clay bricks. The properties discussed in this section include physical, mechanical and chemical properties.

### 2.6.1 Physical properties

Physical properties are the properties that define the behaviour of the materials in response to the physical forces. These properties are important in brick manufacturing as they influence the quality performance of the bricks. This section reviews the physical properties of burnt clay bricks such as porosity, initial rate of absorption, colour and durability.

#### **Porosity**

Porosity ( $n$ ) is described as the ratio of the volume of the pore spaces ( $V_p$ ) and the total volume ( $V_t$ ),  $n=V_p/V_t$  (Day, 2012 and Verruijt, 2001). The pores can be expressed by the void ratio  $e$ , defined as the ratio of the volume of pores to the total volume of the solids (Verruijt, 2001). Again, Day (2012) and Verruijt (2001) defined the total volume as the sum of the volume of the pores and the volume of the solids,  $V_t= V_p+V_s$ . Porosity is an important parameter concerning

clay bricks due to its influence on the properties such as chemical reactivity, mechanical strength, durability and the general quality of the brick (Fernandes *et al.*, 2009). Furthermore, Fernandes *et al.* (2009) indicated that porosity of a brick is influenced by a series of mineralogical, textural and physical changes that occur during the firing stage of brick manufacturing. Cultrone *et al.* (2004) observed that if the firing temperature increases, the proportion of large pores (3–15  $\mu\text{m}$ ) increases and the connectivity between pores is reduced, whereas the amount of small pores diminishes.

Hughes and Bargh (1982) reported that at low temperatures, bricks expand more, absorb more water and are less strong and more likely to deteriorate than bricks fired at high temperatures. In a study by Nieminen and Romu (2015) porosity properties were measured using a mercury porosimeter and it was concluded that when only clay is used, small pores are developed and when materials such as sand are added to the clay the pore sizes can be increased and in a well fired brick the area of pore walls is clearly smaller than in an under-fired brick.

### ***Apparent density***

Apparent density is described as the ratio between the dry brick weight and the volume of the clay brick, measuring the proportion of matter (clay) found in the volume (Fernandes *et al.*, 2009). Density of clay bricks depend on specific gravity of the clay, method of manufacture and degree of burning. In a study by Karaman *et al.*, (2006) it was reported that density of bricks decrease with decreasing strength and heat conductivity and increasing water absorption. It was also reported that density was improved by firing at high temperatures and that when density values obtained ranged from 1.61  $\text{g}/\text{cm}^3$  at 700 $^{\circ}\text{C}$  to 1.77 $\text{g}/\text{cm}^3$  at 1110 $^{\circ}\text{C}$ .

### ***Water absorption***

Water absorption determines the capacity of the fluid to be stored and circulate within the brick, favouring deterioration and reduction of mechanical strength (Fernandes *et al.*, 2009). The Brick Industry Association (2006) indicated that absorption depend largely on the properties of raw materials, however, absorption can also be controlled by manufacturing and firing methods. According to Mortar Industry Association (2013), low water absorption of less than 7% by mass, usually indicates high resistance to damage by freezing, although in some types of brick much high absorption may also be frost resistant.

In a study by Koroth (1997) three types of water absorption tests were carried out and these included submersion in cold water, capillary absorption in cold water and boiling water

absorption and it was reported that the bricks showed an initial period of high rate of absorption followed by a slow rate in both submersion and capillary absorptions. Furthermore, it was noted that the rate of absorption was faster for bricks with high porosity. A similar conclusion was given by Karamen *et al.*, (2006) for clay bricks that were highly porous.

### ***Initial Rate of Absorption (IRA)***

According to Hendry and Khalaf (2001), IRA gives an indication of the amount of water that a brick will absorb when it is laid on the mortar bed. IRA is a measure of bricks suction and can be used as a factor of mortars that will bond strongly with brick units (Bricks and Pavers Technical Manual, 2005). The optimum value of IRA is considered to be between 0.5 and 1.5 kg/m<sup>2</sup>/min (Hendry and Khalaf, 2001; Bricks and Pavers Technical Manual, 2005).

### ***Colour of fired clay bricks***

The Brick Industry Association (2006) indicated that the colour of fired clay bricks is influenced by its chemical composition, the firing temperature and method of firing. It also reported that iron oxide has the greatest effect on colour. In support of this, International Labour Office (2013) states that red soil may be high in iron while very dark colours or nusty smell in the damp soil, may indicate the presence of organic matter.

### ***Durability of fired clay bricks***

Hendry and Khalaf (2001) describe durability as the ability of a material or construction to remain unserviceable for an acceptable period (e.g. for decades) without excessive or unexpected maintenance. Salt attack is the most common durability problem affecting bricks (Bricks and Pavers Technical Manual, 2005). Other factors affecting durability of burnt bricks include frost action and biological agencies (Hendry and Khalaf, 2001).

A study conducted by Korothe (1997) shows that frost action is produced when the temperature falls below freezing and the water in the pores of the material starts freezing. The expansion of the ice in the pores results in pressure development inside the material. When the developed pressure exceeds brick strength, it results in frost damage. Biological agencies that may affect clay bricks durability include algae, lichens, mosses, fungi, bacteria as well as higher plants. Hendry and Khalaf (2001) show that these organisms can penetrate the pores of the brick material, causing damage by generating organic acids which may have a negative effect on the durability of the clay brick.

## 2.6.2 Mechanical properties of clay bricks

Mechanical properties of materials are the properties that describe the behaviour of the materials under external load. These properties enable the material to withstand mechanical forces and load. Mechanical properties of materials include plasticity, modulus of elasticity, tensile strength, hardness and compressive strength. Hendry and Khalif (2001) stated that the most important mechanical property of burnt bricks is the compressive strength as it serves as a general index to the characteristics of the unit. Similarly, Pacheco-Torgal and Lourenco (2015) stated that compressive strength is the most important mechanical property of clay bricks as it is an indication of brick quality. Compressive strength measures the resistance to crushing and it is used by engineers to assess brickwork strength.

According to Clay Brick Association of Canada (2012), compressive strength was considered an important indicator of durability as it is a measure of the fired bond strength in the bricks. However, the association adds that compressive strength is no longer considered critical indicator of durability, but it is used to determine the load-bearing capacity of the masonry. Clay bricks have a vast range of compressive strengths ranging from 10 N/mm<sup>2</sup> for soft mud brick to more than 100 N/mm<sup>2</sup> for an engineering brick (Mortar Industry Association, 2013).

Fernandes *et al.* (2009) and the Brick Industry Association (2006) stated that compressive strength is strongly influenced by the properties of the raw materials and by the manufacture process. It is noted that for a given clay and production method, higher compressive strength is associated with high firing temperature (Clay Brick Technical Guide, 2007). Fernandes *et al.* (2009) reported that experimental results indicate that masonry compressive strength is mostly influenced by strength of the brick unit.

## 2.6.3 Chemical composition of clay bricks

The chemical composition of clay bricks rely essentially on the composition of the soil used to manufacture the bricks. Clay bricks are most commonly composed of chemical oxides such as silica (SiO<sub>2</sub>), alumina (Al<sub>2</sub>O<sub>3</sub>), iron (Fe<sub>2</sub>O<sub>3</sub>), potassium oxide (K<sub>2</sub>O), titanium dioxide (TiO<sub>2</sub>) as well as sodium (Na<sub>2</sub>O), calcium (CaO) and magnesium oxide (MgO) with silica and alumina constituting the base elements of clay and usually found in the following proportions: about 50% SiO<sub>2</sub> and 15-20% Al<sub>2</sub>O<sub>3</sub> (Fernandes *at al.*, 2009). Chemical composition of the material plays a significant role in determining the quality of the bricks.

According to Mueller *et al.* (2008), alumina determines the plasticity of the soil which is an important component for high strength bricks. High percentage of hydrated alumina silicates (not greater than 30%) in the soil results in stronger bricks. The higher the alumina content in a soil, the higher will be the firing shrinkage. The presence of iron oxide in brick making soil influences the colour of the bricks while alkali oxides are of decisive significance for the vitrification behavior of clay. Furthermore, Mueller *et al.* (2008) show that higher alkali oxide of >3% (MgO, K<sub>2</sub>O, Na<sub>2</sub>O) contents results in low temperature vitrification and increases the firing shrinkage.

## **2.7 Overview of Product Quality Management**

This section provides an overview of basic concepts of quality and product quality management. It also addresses the effects of costs of quality and poor quality. The purpose of this section is to provide an understanding of the importance of considering product quality management.

### **2.7.1 Quality of product**

Small-scale manufacturing enterprises are associated with either lack of management involvement or management team that is responsible for developing efficient production processes and ensuring quality of products. As a result, they are often associated with inefficient production techniques, low productivity rate and inadequate product quality. This study focuses on developing product quality management guidelines for the informal small-scale clay brick manufacturing enterprises in Didi. These guidelines will assist small-scale manufacturing enterprises in ensuring production of quality products.

The term quality is defined in a wide variety of ways. UNIDO (2006) described quality of a product as its ability to fulfill the customer's needs and expectations. Buntak *et al.* (2012) define product quality as the product's conformity to the requirements of the customer, which in the long run results in the sustainability of the product for use. According to Schuurman (1998), quality refers to the totality of features or characteristics of a product that bear on its ability to satisfy stated or implied needs. ISO 9000 refers to quality as the degree to which a set of inherent characteristics fulfils requirement. Garvin and Klein (1990) compared the three of America's leading quality management experts' definitions of quality. Deming defines quality as "zero defects" or "reduced variation" and according to Juran quality means fitness for use while Crosby defines quality as conformance to requirements.

Garvin (1984) identified five approaches to defining quality and they are the transcendent approach of philosophy, the product-based approach of economics, the user-based approach of economics, marketing and operations management, the manufacturing based approach and the value-based approach. The transcendent approach states that quality is both absolute and universally recognizable, and that it is a mark of uncompromising standards and high achievement.

According to the product-based approach, differences in quality reflect differences in quantity of some ingredient or attribute possessed by the product. The user-based approach defines quality as the degree to which a specific product satisfies consumer's wants. According to the manufacture-based approach, quality means conformance to requirements and the value-based approach defines quality in terms of costs and prices. Value-based approach views a quality product as one that provides performance at acceptable price and conformance at acceptable cost.

Garvin (1984) also identified the eight dimensions of quality namely, performance, features, durability, reliability, conformance, serviceability, aesthetics, and perceived quality. Performance refers to the primary operating characteristics of a product. It combines both the product and user-based approaches. Features are the secondary characteristics that supplement the product's basic functioning. Both Features and performance involve objective and measurable attributes: their translation into quality is affected by individual preferences. Reliability is a dimension of quality that reflects the probability of a product's failing within a specified period of time. It is commonly measured using the mean time to first failure (MTFF), the mean time between failure (MTBF), and the failure rate per unit time.

Conformance refers to the degree to which a product's design and operating characteristics match pre-established standards. Both reliability and conformance are closely related to the manufacturing-based approach to quality. Durability is a dimension of quality that measures product's life. It has both economic and technical dimensions. Durability can be defined as the amount of use one gets from a product before it physically deteriorates. Serviceability can be defined as the speed, courtesy, and competence of repair. Aesthetics and perceived quality are the two final dimensions of quality. They are the most subjective and are both closely related to the user-based approach. They are based on personal judgment, for example, how the product looks and feels.

## 2.7.2 Product quality management

Product quality management is defined as a formalised system that documents the structure, responsibilities and procedures required to achieve and deliver a quality product. Product quality management is the management of the important processes in production such that the desired quality of the product is achieved for as long as necessary and at optimal cost. Furthermore, Olusanya and Adegbola (2014) describe quality management as a method of ensuring that all the activities necessary to design, develop and deliver a product are conducted effectively and efficiently with respect to its performance. Quality management uses quality control and quality assurance of processes and products to achieve more consistent quality. According to Nanda (2005), quality management comprises all activities that are required to plan for product quality, and all activities that are required to satisfy quality objectives. Specifically, quality management comprises of quality planning, quality control, quality assurance and quality improvement.

### ***Quality planning***

Quality planning refers to activities that are performed to establish quality objectives. According to the project management institute (PMI) project management body of knowledge (PMBOK), quality planning is a part of quality management that involves identifying regulatory quality standards that are relevant to the product and how to satisfy them. Quality planning outlines the rules that define the quality needs of a product, the required standards and how it will be confirmed that the planned requirements are provided in the final product. The aim of quality planning is to ensure that the quality objectives are planned and met in all circumstances

### ***Quality Control***

Quality control is defined as the operational techniques and activities that are used to fulfill requirements for quality. It is the process of checking whether the product conforms and is fit for use and if it is not responding appropriately (American Society for Quality, 2005). Quality control comprises activities executed to fulfill requirements for quality. This includes activities to monitor a process to ensure its output is of required quality, and activities to correct discrepancies when they occur. Quality control activities are regarded as reactive because their primary purpose is to detect and eliminate defects already in a product (Nanda, 2005). According to Popa (2011), quality control involves reviewing the quality of all factors during the production process. Quality control may be applied at different stages of the production process to help increase the level of predictability, define possible failure in the products and prevent changes.

## **Quality Assurance**

According to WMO (2013), quality assurance is the totality of the activities required for ensuring that products are of the quality required for their intended use. In addition, Huemann (2004) refers to quality assurance as the evaluation of processes to ensure that the product quality standards are met. Quality assurance consists of all the planned and systematic activities implemented with the quality system and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality. Quality assurance activities primarily seek to prevent defects in a product and are therefore generally regarded as proactive.

## **Quality Improvement**

According to ISO: 9000, quality improvement refers to the actions taken throughout the organization to increase the effectiveness of activities and processes to provide added benefits to both the organization and its customers. It focuses on activities that are responsive to customers' needs and improving product's quality. Therefore, quality improvement can be described as a systematic approach to the production processes that looks to remove waste, loss, and rework, frustration in order to make the processes of work more effective, efficient, and appropriate. According to popa (2011), quality improvement is a part of quality management that seeks to obtain better characteristics of the products and processes to meet superior quality of the products.

### **2.7.3 Adoption of quality management**

Studies show that the adoption of quality management to improve quality and meet customer's requirements has been increasing (Mahmood *et al.*, 2006; Kanji and Wong, 1998). However, the concept and importance of quality management in informal small-scale brick making enterprises is still not well understood. Hence the development and adoption of product quality management is particularly difficult. A study by Mahmood *et al.* (2006) shows the major determinant of a successful quality management is management commitment.

Many small and medium scale enterprises (SMEs) suffer lack of management support; hence quality management is rarely introduced in SMEs. Wanjau *et al.* (2013) indicated that the rate of quality management adoption in SMEs is very low and that many are not aware of the importance and benefits of quality management. Previous studies by Motoso and Benedict (2015) and Hoonaker *et al.* (2010) identified quite a number of benefits associated with the

development and implementation of quality management. These benefits include improved employee involvement, improved communication, increased productivity, improved product quality and reduced rework, more repeat customers, improved competitive advantage, improved production processes and reduced costs of poor quality.

#### **2.7.4 Cost of poor quality**

Despite the importance of product quality management and its benefits, small-scale enterprises are slow in adopting product quality management to ensure efficient quality products. Quality is very vital in manufacturing as it directly and indirectly affects productivity and cost of quality. Poor quality leads to more defects which in turn result in increased cost of poor quality. Every time work is redone, the cost of quality increases. The American Society for quality control defines quality cost as a measure of costs specifically associated with the achievement or non-achievement of product quality as defined by all product requirements established by the company, its contracts and society.

According to Beecroft (2003), cost of quality can be defined as the sum of the costs incurred to ensure and evaluate that the quality requirements are being met, and any other cost incurred as a result of poor quality being produced. Beecroft (2003) also defines poor quality as non-measure added activities, waste, error and failure to meet customer needs. The cost of poor quality refers to all costs caused by quality deficiencies in processes and products that are non-value creating costs (Holmqvist, 2004). The elements of cost of poor quality include scrap, rework and deviations, margin slippage, warranty costs and lack of supplier performance.

Shrouty and Tiwari (2017) identified the four categories of the cost of poor quality namely; appraisal costs, prevention costs, internal error costs and external error costs. Appraisal costs are costs associated with determining conformance with quality standards. Measurement systems include inspection, checking, auditing, surveying, inquiries. Prevention costs are costs associated with quality planning and preventing errors from reaching final customer. It is the least expensive type of quality cost, and it is therefore highly recommended. Prevention costs include all activities required for avoiding poor quality which take place in the pre-production stage of products. Prevention costs can be seen to be proactive costs related to building quality into the product as they occur in order to minimize appraisal costs and failure costs. Prevention costs focuses on reducing preventable scrap costs. Internal error costs are costs associated with rework due to poor quality.

External error costs are costs associated with impact of poor quality product on customer such as loss of goodwill, returned sales and warranty obligations. The costs involved in defective products, reworking of product, customer complaints, returned sales and down degrade are higher than costs involved in making products and ensuring quality. It is therefore important for manufacturing enterprises to ensure production of quality products to avoid unnecessary preventable costs of poor quality. Adoption of product quality management techniques is crucial in order to achieve the desired uniform quality of the final brick products and prevent the costs of poor quality. Production of quality products also helps avoid selecting the products with the desired quality and discarding and re-working those with defects.

## CHAPTER THREE

### RESEARCH METHODOLOGY

This chapter describes the methods and procedures that were adopted in order to achieve the objectives of this study. Multiple research approaches were adopted to carry out this study. These approaches covered preliminary work which was subdivided into desktop and reconnaissance study, field work which comprised of soil sampling, collection of samples of both burnt and unburned bricks and analysis of brick production. The methods also included laboratory tests which involved sieve analysis, determination of Atterberg limits, chemical and mineralogical analysis. The last approach involved development of product quality management guidelines for the informal small-scale clay brick manufacturing enterprises. The methods and techniques of data acquisition are presented in Table 3.1.

**Table 3.1:** Methods and techniques of data acquisition

Type	Method	Technique
1.Preliminary work	i. Desktop study	Recording of notes from various sources such as books, journals, articles, electronics reports etc.
	ii. Reconnaissance study	Visiting the study sites and conducting observational analysis.
2. Field work	i. Soil sampling	Random sampling methodology
	ii. Collection of clay bricks	Samples of burnt were collected from three selected sites in the study area.
3.Laboratory work	i. Sieve analysis	Performing sieve tests using the different sieve sets
	ii. Atterberg limits	Conducting Atterberg limits tests
	iii. Chemical analysis and mineralogical analysis	Use of XRF and XRD respectively
	iv. Bricks testing	Testing the compressive strength of the bricks and water absorption of the bricks.
4. Analysis of brick production	Direct observation of the production process and survey method by questionnaires	Analysis was carried out using statistical package for social scientists(SPSS)
5. Development of PQM guidelines	Reviewing the findings then formulating recommendations	The guidelines were developed through reviewing the conclusions and then formulating recommendations relating to the findings

### **3.1 Preliminary Work**

Preliminary work was undertaken before the actual field work. This involved desktop study and reconnaissance survey. Desktop study was undertaken in order to review existing published information relating to the study. The main sources of information that were used for desktop study include various sources such as books, journals, articles, electronic reports, and other existing literature. Desktop study was done by recording notes from different sources that are related to the study.

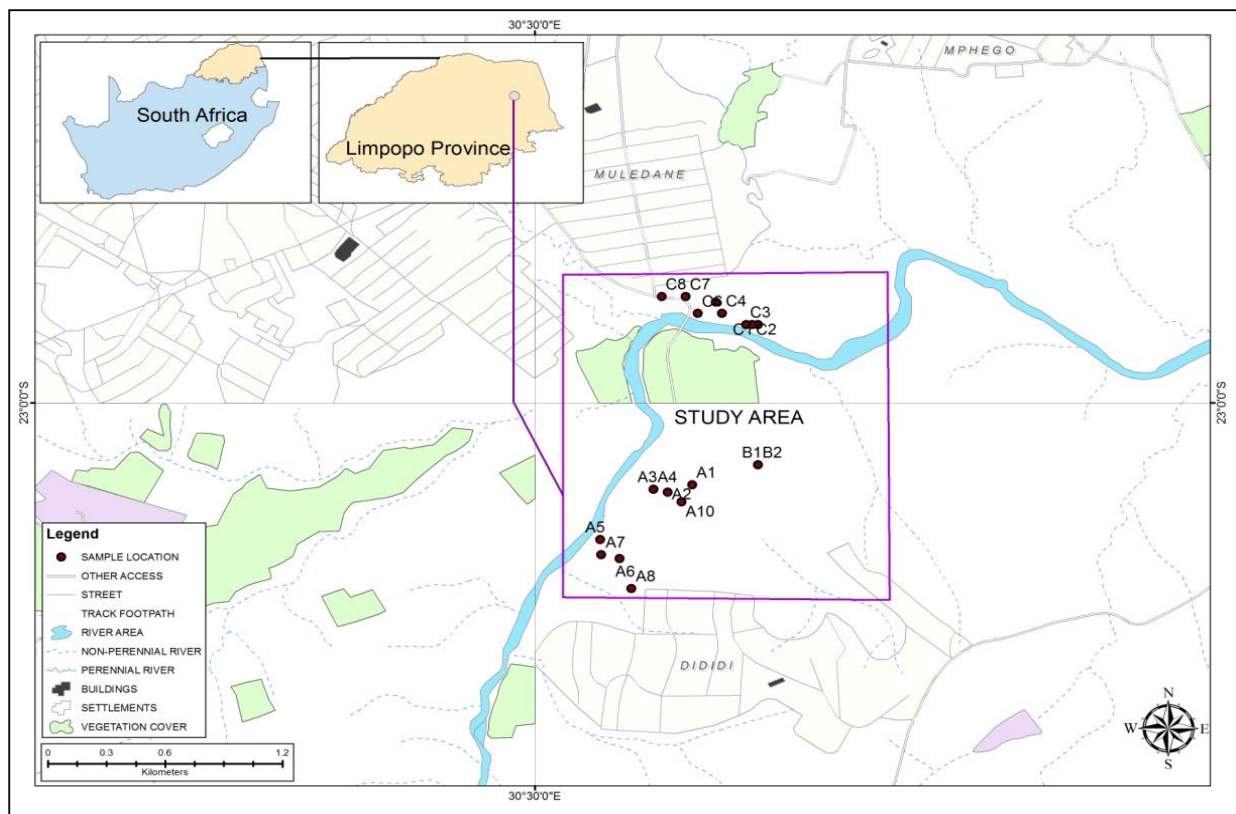
Reconnaissance was undertaken by visiting the study area in order to identify the locations of the study and sampling areas. This also provided first-hand information about the different study sites. Site investigation also helped in ensuring good planning for the actual field work. Reconnaissance involved identification of different features such as the vegetation and soil types as well as onsite observation of the production process used to manufacture the bricks in the area.

### **3.2 Fieldwork**

This section provides the methods and procedures that were used for field data collection. The methods for field data collection included soil sampling, collection of bricks, and analysis of clay brick production.

#### **3.2.1 Soil sampling**

Soil sampling was conducted in order to obtain clay raw materials to be analyzed for geotechnical, geochemical and mineralogical characteristics. Raw material characterization is important in identifying suitability of the raw material for burnt brick manufacturing. A total of twenty soil samples were collected from different brick manufacturing enterprises in three different locations in the study area. The samples were collected at depth greater than 2m using random sampling methodology. Testing the raw materials from entire area is not feasible as this would be too much time consuming, therefore, the unbiased random soil sampling was used in order to obtain an unbiased representative soil sample from each of the selected brick making enterprise in the study area. Geographic coordinates of each sampling area were recorded in order to identify areas where each individual sample was taken. The samples were marked for identification. The coordinates of the sampling points are presented in Appendix A. Figure 3.1 shows the distribution of the sampling points around the study area.



**Figure 3.1:** A map showing the extent of the study area and sampling points

### 3.2.2 Collection of samples of clay bricks

A total of 27 burnt brick specimens were collected from selected areas in the field. 12 of the collected brick specimens were taken to SGS Metrolab in Polokwane in order to conduct compressive strength test and 15 were used to measure the brick dimensions and test the water absorption of the bricks. These were then compared with the South African National Standards for burnt clay masonry units. The bricks were randomly selected from different brick manufacturers in the area. Factors such as colour, shape, appearance, and texture of the bricks were considered when selecting the bricks.

### 3.2.3 Analysis of clay brick production

The brick manufacturing process technology is one of the major factors affecting the quality of burnt clay bricks. Consequently, an assessment of production process used for the manufacture of clay bricks in Dididi was conducted. The study employed a survey method by questionnaires to obtain information on brick production processes from the brick manufacturers. The questionnaires capture information such as production methods, fuels used, the type and

method for selecting raw materials used. About 20 questionnaires were distributed to randomly selected brick manufacturers and the response rate was 100%. Different brick manufacturers use different manufacturing methods and techniques, hence the study employed questionnaire survey method in order to obtain first-hand information on the production process techniques used by different brick manufacturers in Dididi.

Statistical analysis using statistical package for social sciences (SPSS) was used to calculate the descriptive statistics. SPSS was used in analyzing the questionnaire data due to that it shortens the timeframes of the analysis and provides a more thorough and rigorous coding and interpretation and provides enhanced data management. The results were used to assess the factors affecting the brick production process and the quality of the end brick product. The questionnaires are presented in Appendix E.

### **3.3 Laboratory Tests**

This section describes the laboratory techniques and procedures that were employed for laboratory soil tests. It addresses the equipment and procedures for performing sieve analysis, Atterberg limits tests, chemical and mineralogical analysis. The methods and formulae for the analysis of the properties of the soil are presented in Table 3.3. Atterberg limits tests consist of two tests namely plastic limit, (PL) and liquid limit, (LL). The tests determine the consistency of clay and are used to characterize the fine-grained fractions of soils.

**Table 3.3:** Method and formulae for the analysis of the geo-engineering, chemical and mineralogical properties of the soil.

Method	Properties	Formula
Oven-drying method	Moisture content (W)	$w = \frac{w_2 - w_3}{w_3 - w_1} \times 100$ Where, $w_1$ =Mass of container (gm), $w_2$ = Mass of wet sample and container (gm), $w_3$ =Mass of dry sample and container (gm)
Sieve analysis	Particle size distribution	The total % passed for each sieve were calculated and the results were shown in a graph
Casagrande apparatus	Liquid Limit (LL)	The points obtained from each determination were plotted on a semi log graph representing water content on the arithmetical and the number of drops on the log scale
Rolling thread method	Plastic Limit (PL)	$PL = \frac{w_2 - w_3}{w_3 - w_1} \times 100$ Where, $w_1$ = Mass of container (gm), $w_2$ = Mass of thread of sample and container (gm), $w_3$ = Mass of dry thread of sample and container (gm)
	Plasticity Index(PI)	$PI = LL - PL$ Where, $LL$ = Liquid limit (%), $PL$ = Plastic limit (%).
X-Ray Fluorescence (XRF)	Chemical Composition	Chemical characteristics of the soil were analysed using XRF method
XRD	Mineral Composition	The mineralogy of the soil was determined using XRD
ASTM	Brick Strength	The compressive strength of the brick was tested using ASTM techniques

### 3.3.1 Sieve analysis

Sieve analysis tests were undertaken at the University of Venda Mining and Environmental Geology laboratory. Sieving is defined as the separation of fine material from coarse material by means of mesh or perforated vessel (Principles and Procedures Manual, 2005). Sieve analysis is the distribution of size particles expressed as a percent of the total dry weight. Knowing the particle size distribution of the soil was important for this study as it has a decisive influence on its moulding properties which plays an important role in deciding good quality clay for brick making. Analysis of the distribution of size particles in a soil sample was achieved by shaking approximately 500g of the soil sample through a set of sieves of progressively smaller openings with a pan at the bottom. The first step in sieve analysis was to thoroughly dry the soil to a constant weight in an oven at a temperature of 110°C for at least six hours. This was followed by reducing soil samples with large particle sizes to about 500g. The samples were then separated into various sieve sizes using the mechanical shaker operated for a 15 minutes trial period.

At the end of the shaking period, the weights retained on each sieve were weighed and the total percent passing was calculated. The total percent passing through a sieve were presented in a semi log graph called particle size distribution curve. Cumulative grams retained on each sieve were determined using equation 3.1.

$$\text{cumulative \% retained} = \frac{\text{cumulative mass retained}}{\text{Total mass}} \times 100 \quad (3.1)$$

The uniformity coefficient ( $C_u$ ) and the coefficient of gradation ( $C_c$ ) were determined from the particle size distribution curve. Uniformity coefficient ( $C_u$ ) and coefficient of gradation were calculated using equation 3.2 and 3.3.

$$C_u = \frac{D_{60}}{D_{10}} \quad (3.2)$$

$$C_c = \frac{D_{30}^2}{(D_{60})(D_{10})} \quad (3.3)$$

Where  $D_{10}$ ,  $D_{30}$  and  $D_{60}$  are the diameters corresponding to the percent finer than 10, 30 and 60 respectively.

### 3.3.2 Atterberg Limit tests

Fine grained soil is classified using Atterberg limits; therefore, determination of Atterberg Limits in brick making soils is important. Atterberg Limits refer to the water contents corresponding to the transition from one state to another (Murthy, 2007). Atterberg limits tests consist of three tests namely, plastic limit, shrinkage limit and liquid limit. State of New York Department of Transportation (2015) describe liquid limit as the water content, expressed as a percentage of the weight of the oven-dried soil, at the boundary between the liquid and plastic state of consistency. Plastic limit is the transition from the plastic state to the semi-solid state (Murthy, 2007).

### ***Liquid limit test procedure***

Before starting this test, approximately 20 g of material were removed and placed on the glass plate to be used for the plastic limit test. The test started with weighing the empty can. A portion of the prepared sample was weighed in a bowl then the mixture was spread into the liquid limit device bowl and split in 2 using the groove. The crank was then turned to raise and drop the cup twice per second until the two sides of the grooved samples come in contact at the bottom of the groove and then the number of blows was recorded. The liquid limit cup was cleaned after each trial test. The moisture content was determined by placing the sample in a can and weighing it. Then the soil from the liquid limit device was removed and remixed then the test was repeated to obtain the second liquid limit sample for a duplicate result. 5 trials were performed for each soil sample. The samples were oven dried at 110 °C to a constant weight for at least six hours and weighed after cooling.

### ***Plastic Limit Test Procedure***

The 20 g portion of soil from the prepared sample that was removed before the Liquid Limit test was used to determine the plastic limit of the raw materials. The water content of the soil was reduced to a consistency at which it could be rolled without sticking to the hands by spreading and mixing it continuously by hand on the glass plate and some of the moistened soil was taken for testing. The mass of the empty can was determined before starting the analysis. The test started by taking the soil and then rolling it between the palms on the glass plate to form a thread of a uniform diameter. The thread was then broken into pieces, and the portions of the crumbled thread were gathered together and rolled back into a ball. The ball was rolled out until the thread crumbles and could not be rolled back into a ball. The crumbled soil was gathered and placed in a can and weighed, then was oven dried at 110 °C to a constant weight and weighed again after cooling. A total of 5 trials were performed for each soil sample and the plastic limit was computed using equation (3.4). Based on the results of plastic limit (PL) and liquid limit (LL), the plasticity index (PI) was computed using equation 3.5.

$$PL = \frac{wt_{H_2O}}{wt_{oven}} - \text{dry soil} \quad (3.4)$$

$$PI = LL - PL \quad (3.5)$$

### 3.3.3 Chemical and mineralogical analyses

This section describes the methods used for chemical and mineralogical analyses of the materials used to manufacture clay bricks. It explains in details the methods and procedures that were followed to determine the chemical and mineralogical composition of the soil used to manufacture the bricks.

#### ***Determination of chemical composition of the soil samples***

Chemical analysis was conducted in order to determine the chemical composition of the raw material. The analysis was carried out using the X-ray Fluorescence method which was used to determine the major and trace element composition of the raw material used for brick making in Dididi. The chemical composition analysis involved drying, milling, pressing and analyzing. The materials were first oven-dried at 110<sup>o</sup>C for at least six hours in the laboratory. After drying, the samples were allowed to cool after which they were taken for milling.

Before the milling commenced, the milling dishes were cleaned using quartz in order to prevent the samples from sticking to the dish. Cleaning was done after each sample was milled to prevent contamination. Milling was done using a mill grinding machine which stops automatically after grinding for a pre-set time of 2 minutes. After milling, the samples were put in a sample bag and were labeled then they were ready for pressing. The soil sample was added into the pellet cup and boric acid was added as a binding reagent. The pellet cup was then centrally placed in an automatic hydraulic operated press and was pressed at 30 tons load for 30 seconds hold time.

Once pressing was complete, the pressed pellet was carefully removed from the pressing die and was transferred into the X-ray analyser sample holder ready for analysis. The pressed pellet was loaded in the sample port of the X-Ray Fluorescent analyser which was connected to a computer system and the assembly left for about six to twelve minutes after which the values of elements concentration were displayed on the monitor. This was saved directly on the system and then presented as the result of the analysis.

#### ***Determination of mineralogical composition of the soil samples***

Mineralogical analysis of the soil was conducted in order to determine the mineral composition of the soil used for brick manufacturing. The mineralogical composition of the raw materials was carried out using X-ray diffraction method.

Prior to the mineralogical analysis, the materials were first oven dried for at least six hours at 110°C. After drying, the materials were allowed to cool at room temperature and then they were taken for milling. After milling the samples were packed in labeled plastic bags. They were then dispatched to the University of Pretoria for X-ray diffraction analysis.

The samples were prepared according to the standardized Panalytical back loading system, which provides nearly random distribution of the particles. The samples were analyzed using a PANalytical X'Pert Pro powder diffractometer in  $\theta$ - $\theta$  configuration with an X'Celerator detector and variable divergence- and fixed receiving slits with Fe filtered Co-K $\alpha$  radiation ( $\lambda=1.789\text{\AA}$ ). The phases were identified using X'Pert Highscore plus software. The relative phase amounts (%) were estimated using the Rietveld method (Autoquan Program).

### **3.3.4 Compressive strength test**

Brick testing was conducted in order to determine the strength and quality of the bricks. A total of 12 burnt bricks (4 from each site) were taken to Polokwane SGS Metrolab to be examined for compressive strength. External dimensions of each sampled brick were taken and the brick was marked for identification. Then the bricks were weighed and recorded in grams. The brick strength was tested by determining the compressive strength of the brick against vertical load. The brick was subjected to a compressive force until failure and the failure load over gross area was recorded as strength.

### **3.3.5 Water absorption test**

The water absorption test of the bricks was carried out in order to determine the durability and suitability of the bricks for construction purposes. This was carried out by soaking the bricks in water for a period of 24 hours. A total of 15 burnt bricks (5 for each selected site) were used to carry out the test. The bricks were first weighed dry and this was recorded as weight 1 ( $W_1$ ), then they were soaked in cold water for 24 hours and were weighed again after soaking, the weight after soaking was recorded as weight 2 ( $W_2$ ). The percentage of the water absorbed was then calculated. The water absorbed by the brick was indicated by the difference in weight 2 and weight 1. The water absorption value for each site was indicated by the average values of the brick replicates for each site.

### **3.4 Development of Product Quality Management Guidelines**

Product quality management guidelines were developed after both fieldwork and laboratory works have been completed. The guidelines were developed to ensure improvement of performance and quality of the produced clay bricks. The guidelines development procedure involved scope which covered identification of the need for the guidelines and objectives of the guidelines, and guideline development which focused on formulating recommended guidelines in relation to the findings of the study.

#### ***Identification the need for the guidelines***

The interest for the development of the product quality management guidelines for the informal brick manufacturing enterprises in Dididi was triggered by the issues associated with the manufacturing operations in the area. These issues were identified at the field and some of them include the fact that clay brick manufacturers at Dididi are not registered, hence they are not known by the Clay Brick Association of South Africa, as thus they do not have any one to oversee their problems. Their manufacturing operations are not inefficient and as a result they produce poor quality bricks.

#### ***Objectives of the guidelines***

The objectives of the guidelines were outlined in order to define the overall aims of the guidelines to the informal small-scale bricks manufacturing enterprises in Dididi.

#### ***Guideline development***

The guideline development process involved reviewing the shortcomings associated with small-scale brick manufacturing enterprises in Dididi and then providing recommendations for overcoming the shortcomings and improving the production operations.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

This chapter focuses on the presentation and discussion of the data collected using the methods presented in Chapter 3. It presents both qualitative and quantitative data from fieldwork and laboratory analysis. The data is presented in chronological sequence with the research objectives. The results obtained from the laboratory analysis of raw materials used to make bricks and brick testing are presented in the form of graphs and tables.

#### 4.1 Characteristics of the Brick Manufacturing Materials

The first specific objective of this study was to characterize the raw materials used in clay bricks manufacturing. This is crucial in quantifying the efficiency of the materials used for brick making. Various laboratory analyses including sieve analysis, Atterberg limit tests, chemical and mineralogical analysis were conducted in order to achieve this objective.

##### 4.1.1 Textural properties of the soil

The sieve analysis technique was performed in all collected samples in order to establish the grain size distribution of the soil used to manufacture burnt bricks in the informal brick making enterprises in Dididi. The plot of the grain size distribution curves of the samples from the three selected sites in the study area is shown in Figure 4.1. The results obtained from sieve analysis indicate that the materials used to manufacture burnt bricks from the three selected sites in Dididi village have similar characteristics in terms of particle size distribution.

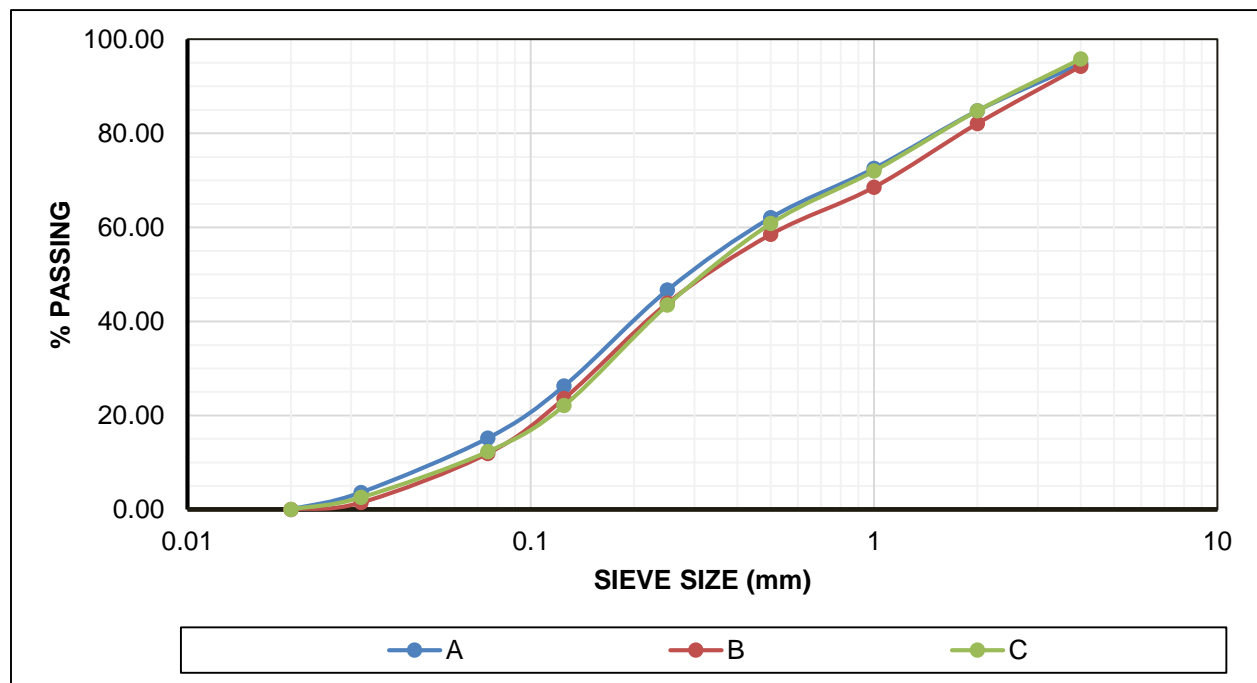
Based on the summary of the grain size distribution curve shown in Table 4.1, the materials for making of clay bricks in Dididi area indicated to be dominantly composed of sand sized particles with minor amounts of silt and clay particles. According to Hendry and Khalaf (2001), the best material for making clay bricks should contain about 30% sand as it reduces shrinkage that mostly occur during the firing of soft clay. Moreover Mueller et al. (2008) indicated that soil for brick making must contain about 10-50% clay fraction and 30% sand particles. According to the International Labour Office, the ideal grain size distribution in the soil in order to achieve good quality bricks should have about 20-40% sand, 25-45% silt and 20-35% clay sized particles.

As reported by Fernandes *et al.* (2009) early brick makers often used clay mixture of about 30% sand and 70% of plastic clay. In this case, the particle size distribution shows that the raw materials used to manufacture burnt bricks in Dididi contain an abundance of sand particles ranging from 77 to 79%, silt ranging from 17 to 18% and clay ranging from 4 to 5%. According to Cole (1959), soil that have such high amount of sand make poor bricks whereas good brick making soils are high in silt. The amount of clay fractions found in the soil used for brick making in Dididi is relatively lower than the recommended while the sand percentage is extremely high. Based on the particle size distribution of the samples, the soil used for manufacturing clay bricks in Dididi do not contain enough clay particles to be considered a good clay raw materials for manufacturing of good quality burnt bricks.

**Table 4.1:** Particle size distribution of the raw materials obtained from sieve analysis.

Site	D <sub>10</sub>	D <sub>30</sub>	D <sub>60</sub>	C <sub>u</sub>	C <sub>c</sub>	Sample composition			Classification USCS
						Clay %	Silt %	Sand %	
A	0.05	0.13	0.5	10	14.4	5	18	77	SW
B	0.07	0.125	0.5	8.6	8.3	4	18	79	SW
C	0.07	0.125	0.5	7.1	10	4	17	79	SW

**Note:** SW indicates well graded sands, gravelly sands with little or no fines



**Figure 4.1:** Grain size distribution curve of the soil used to manufacture fired bricks in Dididi

#### 4.1.2 Atterberg limit tests results

The Atterberg limits are important parameters in clay brick manufacturing as they indicate how the soil will behave under certain conditions. The soil mixture for brick making must have enough plasticity to facilitate the molding process. The plots of the liquid limits of the soil from the three studied sites are shown in Figure 4.2. The results show the highest liquid limit value of 30.58% obtained from Site C while the lowest liquid limit of 25.62% was obtained from Site B. Site C also had the highest plastic limit value of 27.22% while the lowest plastic limit value of 15.22% was obtained from site A. The highest plasticity index of 14.25% was obtained from Site A while the lowest (3.36%) was obtained from Site C. These results reflect that the plasticity of the soil used to manufacture clay bricks in Dididi ranges from slightly plastic to medium plastic.

According to Mueller et al. (2008), the expected liquid limit values for brick making soil ranges from 25% to 38% while the expected plasticity index values range from 7 to 16%. Johari *et al.* (2010) reported that the liquid limit value of 47.70%, plastic limit of 25.56% and a plasticity index of 24.14% are required in making of high quality clay bricks. Taking a closer look at the liquid limit and plasticity index values presented in the summary of the Atterberg limit test results in Table 4.2, it is clear that the soil used for manufacturing fired bricks at Dididi possess a wide range of plasticity depending on the location in which the soil was collected.

Soil collected from Site A and Site B were found with plasticity values falling within the values recommended by Mueller et al. (2008). Soil from Site C was characterized by less plasticity than that of Site A and B, therefore, it can be concluded that soil from Site C does not have adequate plasticity required for moulding the bricks into good quality shaped bricks.

**Table 4.2:** Atterberg Limit Results.

Site	Liquid limit (%)	Plastic limit (%)	Plasticity index (%)	Plasticity
A	29.46	15.22	14.25	Medium plastic
B	25.62	17.13	8.49	Low plasticity
C	30.58	27.22	3.36	Slightly plastic

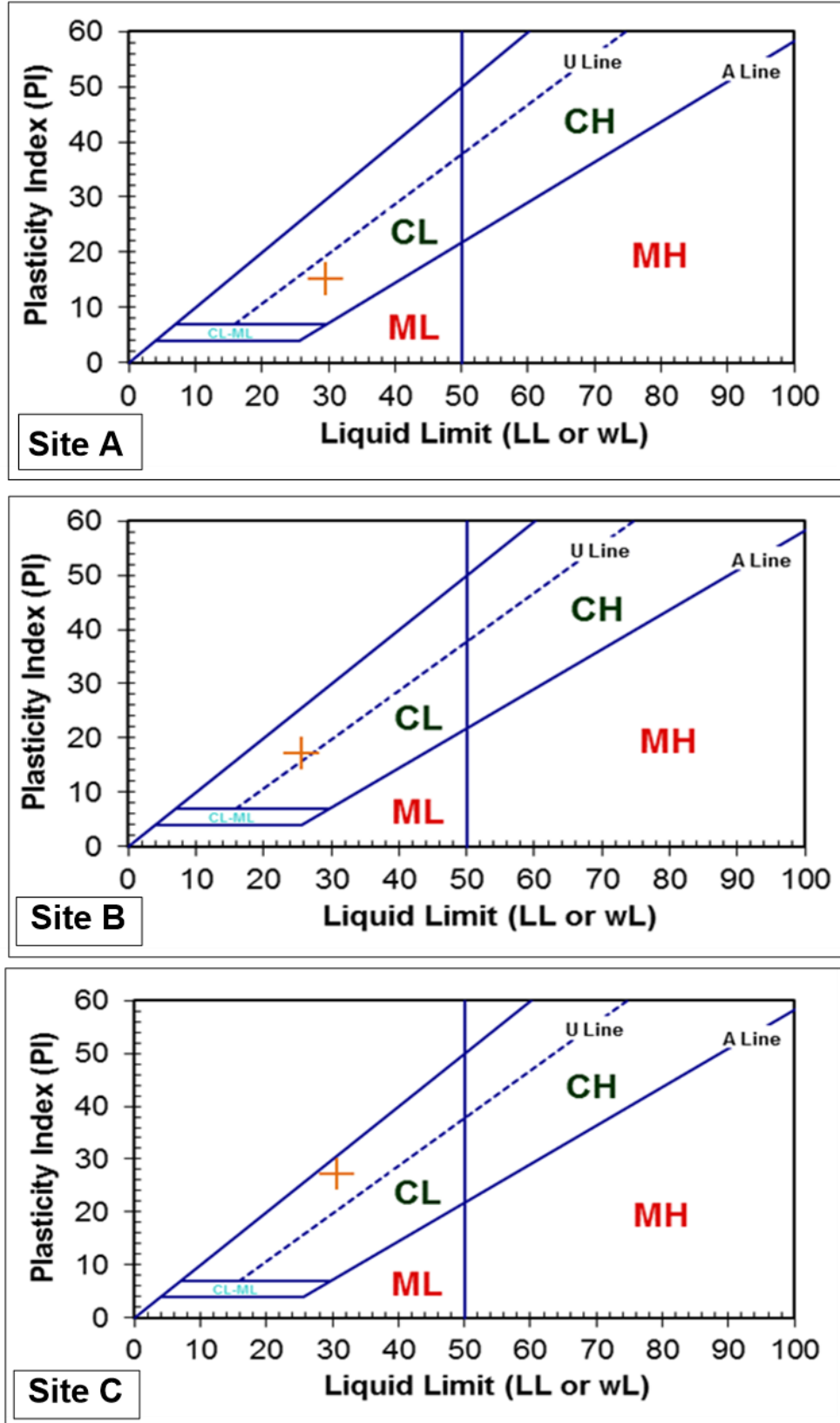


Figure 4.2: The flow curves of the liquid limit of the soil samples from Dididi

### 4.1.3 Chemical properties of the soil used to manufacture clay bricks

Chemical analysis was carried out to determine the chemical composition of the soil used to manufacture burnt bricks in the study area. Table 4.3 shows the results of the major element composition while Table 4.4 presents the trace element composition of the soil. The results showed almost similar chemical characteristics in all the samples. The chemical analysis reflects silica as the main constituent of the materials followed by alumina and iron oxide. The amount of silica was found ranging from 52.44 to 54.2% while alumina and iron oxide ranged from 13.89 to 14.45% and 5.79 to 6.17% respectively. The high content of silica could be from the quartz in the sand particles. The fluxing oxides such as  $\text{TiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{MnO}$ ,  $\text{MgO}$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and  $\text{P}_2\text{O}_5$  were present in relatively low quantities.

Fernandes *et al.* (2009) reported the main constituents of clay bricks with proportions of silica ranging from 53 to 61% and alumina varying from 22 to 32%. According to Punmia *et al.* (2003), normal clay for making bricks should contain not less than 60%  $\text{SiO}_2$ , not less than 15%  $\text{Al}_2\text{O}_3$ , not less than 3%  $\text{Fe}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{MgO}$  and not less than 4%  $\text{K}_2\text{O}$ . According to Alteyework (2013), a good clay material for brick making contains  $\text{SiO}_2$  ranging from 50 to 60%,  $\text{Al}_2\text{O}_3$  ranging from 20 to 30%,  $\text{CaO}$  10%, less than 7%  $\text{Fe}_2\text{O}_3$  and 10% alkalis. In addition, Mueller *et al.* (2008), reported the chemical analysis results of a good soil for making clay bricks as follows;  $\text{SiO}_2$  (61.8%),  $\text{Fe}_2\text{O}_3$  (>3%) and  $\text{Al}_2\text{O}_3$  (23%).

Based on the chemical analysis results obtained in this study, the amounts of silica and iron oxide conform to the findings of Alteyework (2013) and Fernandes *et al.* (2009). However, the values obtained for alumina are relatively lower than the recommended values of Alteyework (2013) and Fernandes *et al.* (2009) as well as the findings of Punmia *et al.* (2003) and Mueller *et al.* (2008). Alumina gives the plasticity needed for moulding the bricks into the required shape; therefore, inadequate quantity of alumina in the soil lowers the plasticity of the soil, resulting in production of bricks with poor bond.

Excess amount of silica in the soil for brick making destroys the cohesion property and renders the bricks brittle. Iron oxides influence the colour of the bricks. Although the fluxing oxides were present in a relatively low proportion, their presence in the raw materials used to manufacture clay bricks have a great influence on the final properties of the bricks. The fluxing elements in the brick making soil are necessary to enable the silica to melt and bind the particles during firing. However, they may also cause insufficient sintering and bloating during the firing stage.

Excessive amounts of fluxing elements such as sodium oxides ( $\text{Na}_2\text{O}$ ) and potassium oxide ( $\text{P}_2\text{O}_5$ ) in the soil used for brick manufacturing may cause the bricks to crack and warp. The presence of  $\text{CaO}$  in the soil may change the interior colour of the brick.

**Table 4.3:** Major element composition of the clay bricks making material from Dididi

Site	Composition (%)									
	$\text{SiO}_2$	$\text{TiO}_2$	$\text{Al}_2\text{O}_3$	$\text{Fe}_2\text{O}_3$	$\text{MnO}$	$\text{MgO}$	$\text{CaO}$	$\text{Na}_2\text{O}$	$\text{K}_2\text{O}$	$\text{P}_2\text{O}_5$
A	54.12	1.24	14.20	5.80	0.11	1.70	1.54	0.85	2.68	0.16
B	54.52	1.34	13.89	5.79	0.92	1.91	1.61	0.67	2.71	0.18
C	52.44	1.33	14.45	6.17	0.80	1.71	1.44	0.71	2.59	0.15

### **Trace Element Composition**

The determined trace element compositions of the materials are presented in Table 4.4. The results revealed that the soil used to manufacture clay bricks in Dididi contain abundance of the following trace elements; Site A was found with 981.97 ppm (Ba), 318.4 ppm of (Zr), 391.50ppm of (Sr), 226.39 ppm (Ni) and 151.50 ppm (Cr). Site B was composed of 1051.55 ppm of (Ba), 334.70 ppm (Zr), 394.65ppm (Sr), and 244.10 ppm Ni and 165.60 ppm Cr. Site C was found was composed of 1047.41ppm Ba, 300.84 ppm (Zr), and 347.98 ppm (Sr), 232.36 ppm (Ni) and 169.86 ppm (Cr).

**Table 4.4:** Trace element composition

Site	Composition (ppm)										
	Cu	Ga	Ni	Rb	Zn	Zr	Co	Cr	V	Sr	Ba
A	68.21	17.03	226.39	87.31	69.99	318.45	14.80	151.50	263.91	391.50	981.97
B	67.50	16.40	244.10	93.45	68.90	334.70	14.75	165.60	286.70	394.65	1051.55
C	69.04	15.54	232.36	79.04	65.93	300.84	15.01	169.86	282.64	347.98	1047.41

#### **4.1.4 Mineralogical composition of the soil used to manufacture clay bricks**

Mineralogical composition of the soil used for brick manufacturing has the greatest influence in the forming properties of the soil. Table 4.5 shows the results obtained from the XRD analysis of the raw materials used to make bricks in the three selected sites in Dididi. The results revealed

that the soil comprised two different species of the mineral group amphibole. The results shown in Table 4.5 reflect quartz as the dominant mineral in all the samples.

The concentration of quartz was found to be in accordance with the chemical analysis which revealed the predominance of silica in the samples. Other non-clay minerals detected include plagioclase, microcline, hornblende, and anthophyllite. No muscovite was detected except in sample A10 in Site A. Site C contained the highest concentration of quartz (36.99%) followed by Site A with 36.25% of quartz; then Site B with 34.16% of quartz. The main clay minerals detected were chlorite and talc. However, these minerals were present in low proportions. The highest value of chlorite (8.50%) was obtained in Site C while Site A and B had similar values of 7.90% chlorite. Site C also had the highest value of talc (7.05%) whereas the lowest (6.90%) was obtained in Site B.

High proportion of quartz decreases the plasticity of the soil (Fgaier *et al.*, 2016). Moreover, Cole (1959) showed that high proportion of quartz together with metal oxides in brick making soil increases vitrification temperature and reduces drying and firing shrinkage. Although the raw materials used to manufacture clay bricks in Dididi are dominantly composed of non-clay materials and mainly quartz, brick manufacturers do not use any additives to improve the quality of the materials. This might contribute to poor quality of the final bricks. The presence of clay minerals in the soil used for brick manufacturing play a significant role in facilitating the forming properties of the soil.

The only clay minerals detected in the soil used to manufacture clay bricks in Dididi are chlorite and talc. According to Cole (1959), chloritic clays make poor quality bricks as they produce lightweight aggregates when fired rapidly under reducing conditions. Although talc can increase vitrification of the material, it can also be used as a flux and can be used to reduce expansion of bricks provided it is present in low quantities. The feldspar minerals in the raw materials can also act as flux and lower vitrification temperature.

**Table 4.5:** Mineralogical composition of the raw materials.

	Sample	Mineral composition (%)							
		Anthophyllite	Chlorite	Hornblende	Microcline	Muscovite	Plagioclase	Quartz	Talc
Site A	A1	1.38	6.12	5.98	11.21	-	29.66	39.12	6.54
	A2	-	8.42	3.96	15.01	-	22.78	43.03	6.8
	A3	-	7.42	6.46	9.34	-	33.57	38.53	4.68
	A4	2.99	7.76	6.1	13.31	-	28.26	33.03	8.55
	A5	1.57	10.59	4.61	11.67	-	29.42	35.81	6.32
	A6	3.72	5.26	7.22	10.85	-	29.45	35.12	8.37
	A7	-	9.69	4.66	12.43	-	28.91	37.63	6.68
	A8	-	5.87	2.37	13.79	-	35.08	37.58	5.3
	A9	-	11.81	4.58	12.62	-	34.42	29.27	7.3
	A10	3.88	6.01	4.97	10.09	5.5	28.43	33.46	7.66
	<b>Average</b>	<b>2.71</b>	<b>7.90</b>	<b>5.09</b>	<b>12.03</b>	<b>5.50</b>	<b>30.00</b>	<b>36.26</b>	<b>6.82</b>
Site B	DID-11	-	8.82	5.76	13.36	-	29.06	37.5	5.5
	DID-12	2.26	5.81	4.96	12.76	-	35.11	30.81	8.29
	<b>Average</b>	<b>2.26</b>	<b>7.90</b>	<b>5.36</b>	<b>13.06</b>		<b>32.09</b>	<b>34.16</b>	<b>6.90</b>
Site C	DID-13	1.46	5.98	7.06	12.09	-	31.57	35.33	6.51
	DID-14	-	7.36	6.12	12.02	-	33.54	37.18	3.78
	DID-15	-	11.3	4.98	13.78	-	25.46	36.15	8.34
	DID-16	-	13.2	6.35	10.97	-	21.6	37.96	9.91
	DID-17	0.92	1.11	4.93	15.39	-	29.79	42.24	5.62
	DID-18	-	13.02	6.58	11.92	-	25.36	34.89	8.24
	DID-19	0.79	7.23	4.99	13.58	-	29.29	37.17	6.94
	DID-20	1.25	8.8	5.41	10.51	-	31.94	35.01	7.07
	<b>Average</b>	<b>1.11</b>	<b>8.50</b>	<b>5.80</b>	<b>12.53</b>		<b>28.57</b>	<b>36.99</b>	<b>7.05</b>

## 4.2 Assessment of the Technical Problems of Clay Brick Production

One of the objectives of this work was to identify and assess the technical problems of clay brick production. This objective is imperative in identifying the technical factors affecting the quality efficiency of the final bricks. Laboratory analyses of the final bricks were conducted to determine the technical inefficiencies associated with the production process. These analyses include the compressive strength tests, water absorption test, and measurement of the brick dimensions. The following sections highlight the results obtained from laboratory analyses of the final bricks properties.

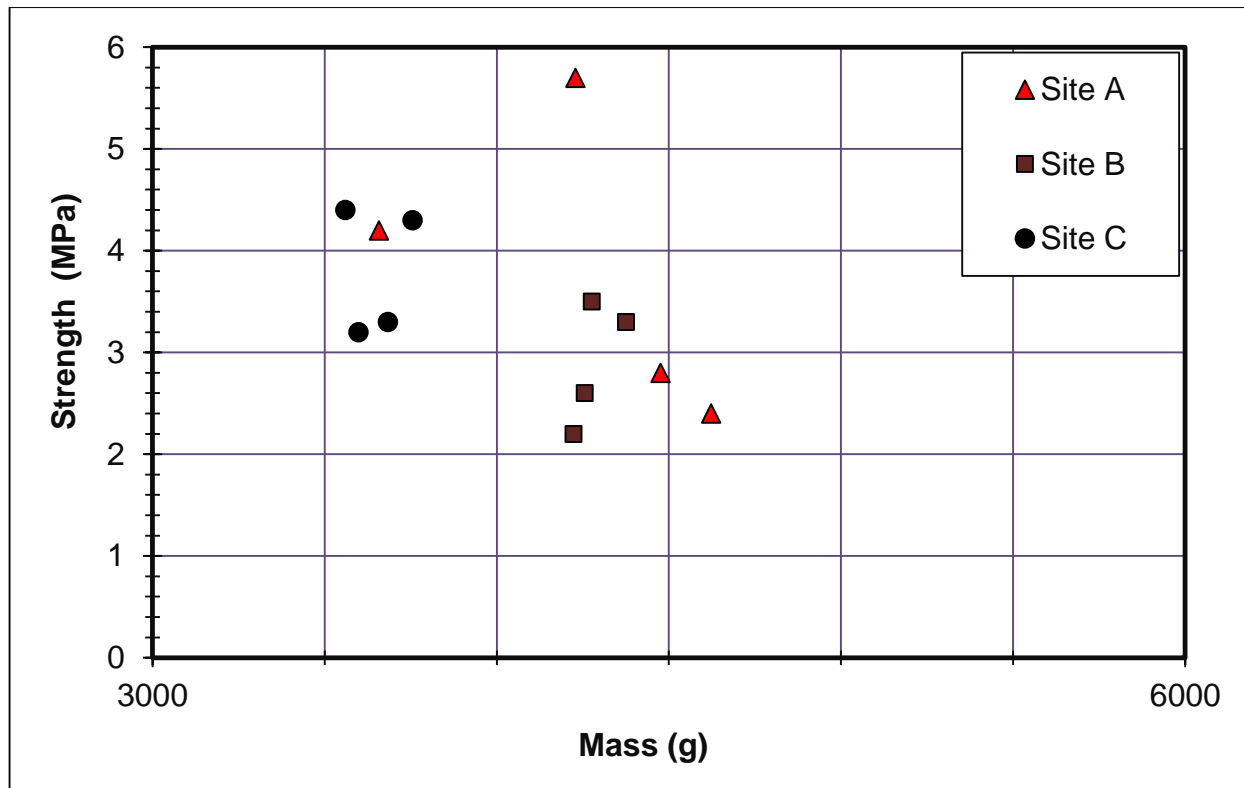
### 4.2.1 The compressive strength of bricks produced in the study area

The compressive strength of the bricks plays an imperative role in determining the quality of the bricks. Compressive strength of the bricks indicates durability and load-bearing capacity of the bricks. Table 4.6 presents the summary of the results of the compressive strength of the examined bricks with the required burnt bricks standards. Figure 4.3 shows the comparative strength of the bricks. The bricks produced in Site A and Site C tested stronger than those from Site B, with similar average compressive strength values of 3.8 MPa each while Site B had an average compressive strength of 2.9 MPa. The plot of the comparative strength of the bricks shows that the bricks from Site A had a wide range of compressive strength values while bricks in Site B and Site C had almost similar compressive strength values.

The standards stipulate the average compressive strength values of 4.0 MPa for on-site manufacture, 5.0 MPa for off-site manufacture and 10 MPa for double-storey constructions. Based on the average compressive strength values obtained in this study, the bricks manufactured by informal brick makers in Dididi do not meet the required average compressive strength for burnt clay bricks. Hence their use is not fully recommended. However, the South African National Standards also stipulates the individual compressive strength values of 3.2 MPa for on-site manufacture and 4.0 MPa for off-site manufacture.

Based on the stipulated individual compressive strengths, sample A5, B2, B3, C1, C4 fall within the requirements for on-site manufacture whereas sample A3, A4, C2, C3 adequately meet the requirements for off-sight manufacture. Considering the fact that the bricks manufactured by informal brick manufacturing enterprises in Dididi are used for building purposes by the nearby communities, it should be noted that the bricks falling within the limits for on-site manufacture do

not qualify to make good quality houses as they are transported to distances exceeding 25 m from the manufacturing site.



**Figure 4.3:** Comparison of the comparative strength of the bricks and their masses

**Table 4.6:** The comparison of the compressive strength of the tested bricks with standards

	Brick Making		
	Site A	Site B	Site C
Mass (g)	4245.5	4282.25	3649
Average strength (MPa)	3.8	2.9	3.8
<b>Required compressive strengths of burnt bricks (SAN 227:2007)</b>			
Description	<b>Average</b>		<b>Individual</b>
Single-storey construction:			
On-site manufacture	4.0		3.2
Off-site manufacture	5.0		4.0
Double-storey construction	10.0		8.0
On-site manufacture is where units do not do not require to be transported more than 25 m to the place where they will be built into walls.			

## 4.2.2 Water absorption property of the bricks

Table 4.7 presents the results of water absorption tests carried out on the bricks collected from the three selected brick manufacturing sites in Dididi. Fifteen burnt bricks (five from each site) were tested for water absorption property. The results revealed the average water absorption values of 13.5, 15.0 and 16.1% for Site A, B and C respectively. Samples from Site B and C were noted to be too absorbent than brick samples from Site A. The results imply that bricks in Site B and C do not comply with the requirements of SANS 227:2007 of less than 14% accepted water absorption value. Although bricks from Site B and C had higher values of water absorption, they did not dissolve in water whereas some of the samples from Site A dissolved in water. For examples, sample A4 dissolved completely in water within the period of 24 hours. This could be as a result of either over-heating during the firing process or under-firing of these bricks. In view of this some of these bricks can be considered dangerous to use in any building as they can be significantly affected by changes in weather conditions. For example, when it rains or freezes, the bricks could absorb water resulting in cracks in the buildings which may compromise safety of the occupants of the building.

**Table 4.7:** The water absorption of the bricks from Dididi area

Sample number	Initial weight of dry bricks W1 (kg)	Final weight of bricks W2 (kg)	Water absorption $\frac{w2 - w1}{w1} \times 100$	Average % water absorption
Site A				
A1	2.619	2.993	14.3	13.5
A2	2.562	2.905	13.4	
A3	2.526	2.854	13.0	
A4	2.516	-	-	
A5	2.713	3.074	13.3	
Site B				
B1	3.762	4.332	15.2	15.0
B2	3.993	4.551	14.0	
B3	3.479	3.988	14.6	
B4	3.432	3.963	15.5	
B5	3.964	4.580	15.5	
Site C				
C1	3.140	3.643	16.1	16.1
C2	3.040	3.567	17.3	
C3	3.335	3.911	17.3	
C4	3.098	3.644	17.6	
C5	2.896	3.406	17.6	

●**Note:** - indicate the brick dissolved in water.

### 4.2.3 Brick dimensions

The dimensions of the measured brick samples are presented in Table 4.8. The sizes of the bricks were measured with a tape measure in the laboratory. According to the South African Bureau of Standards the most common brick size is 222 mm long, 106 mm wide and 73 mm high. According to SANS 227:2007, an acceptable burnt brick size should not be more than 300 mm long, not more than 130 mm high and not more than 120 mm. Brick dimension measurements were carried out using 15 bricks (5 bricks from each site). The dimensions of the bricks from the study area fall within the size limits prescribed in the standards.

However, it should be noted that brick samples from each site were moulded using the same brick mould, therefore they were expected to have similar dimensions. Although the measured bricks dimensions fall within the size limits of SANS 227:2007, bricks obtained from the same site were found with varying sizes. Some of the brick samples also had chipped corners and damaged edges. The variations in brick dimensions can be as a result of inadequate mixing, inappropriate moulding, damaged moulds and handling, under drying or under-firing as well as over burning of the bricks, causing cracks in the bricks.

**Table 4.8:** Measured dimensions of the bricks

Location	Sample	Width (mm)	High (mm)	Length (mm)
Site A	A1	210	105	75
	A2	210	107	68
	A3	210	100	60
	A4	209	102	60
	A5	205	102	70
Site B	B1	222	122	83
	B2	225	124	77
	B3	224	122	75
	B4	216	120	82
	B5	220	123	80
Site C	C1	207	120	77
	C2	202	120	70
	C3	200	120	80
	C4	202	122	70
	C5	207	117	60

#### 4.2.4 Process efficiency analysis

Efficiency is defined as the extent to which input is well used for an intended output. In a nutshell, efficiency means doing things well and successfully without wasting resources. The efficiency of the brick production process was determined from the results obtained from the assessment of the technical problems associated with brick production. A scoring criteria was developed to measure the quality efficiency of the bricks. In the criteria, the symbol ✓ was used to indicate that the bricks meet the quality standards while the symbol ✗ was used to indicate that bricks do not meet the required standards. Table 4.9 shows the bricks quality efficiency scores. The scores were given based on the results of the analysis of the characteristics of the materials used and assessment of the technical problems of bricks production.

**Table 4.9:** process efficiency results

Description	Site A	Site B	Site C
Material suitability	✗	✗	✗
Compressive strength	✗	✗	✗
Water absorption	✓	✗	✗
Bricks dimensions	✓	✓	✓
Shape	✓	✓	✓
Appearance	✗	✗	✗

**Note:** ✓ indicate that it meets the requirement ✗ means does not meet the requirement

#### 4.3 Analysis of Clay Brick Production Process

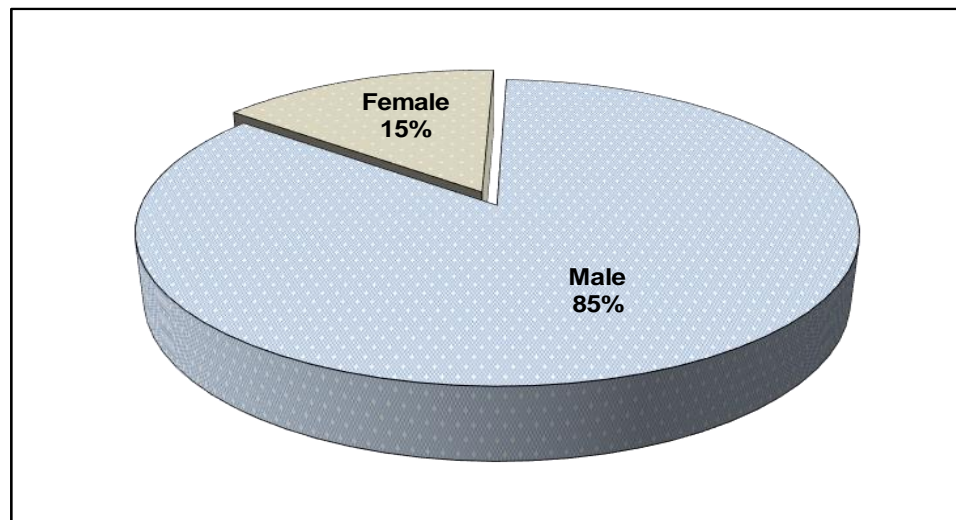
The third specific objective of this research was to analyze the process of clay brick production and determine areas where product quality improvement is warranted. The study adopted a survey method which involved the administration of questionnaires and processing the findings. The questionnaires were used to obtain information on the manufacturing process technique used to produce the bricks in order to identify the factors leading to the brick quality inefficiency. The responses were analysed using statistical package for the social sciences (SPSS). Questionnaires were distributed randomly to about 20 different brick manufacturing enterprises in Dididi and the response rate was 100%. The following sections present the results of the analysis.

### 4.3.1 Demographic analysis

The study analysed the demographic background of the respondents in order to get a better understanding of the implications of human factors on the quality of the bricks. The demographics analysis of the respondents included their gender, age, educational background, experience and motivation for their involvement in clay brick making enterprise.

#### ***Gender***

The study questionnaire survey covered demographic analysis of the respondents in order to analyse the human factors affecting the brick production process. Figure 4.4 shows the gender of the respondents. According to the results of the questionnaire analysis, the informal brick manufacturing enterprises in Dididi is dominated by males. Out of the 100% response rate, 85% of the respondents were males while female respondents were only 15%. This can be seen as a result of the nature of the processes involved in brick manufacturing which involve hard labour. This is contrary to the study by Khan and More (2015) that indicated that females make half of the workers in the brick industry in Karad, China.



**Figure 4.4:** Gender of the respondents

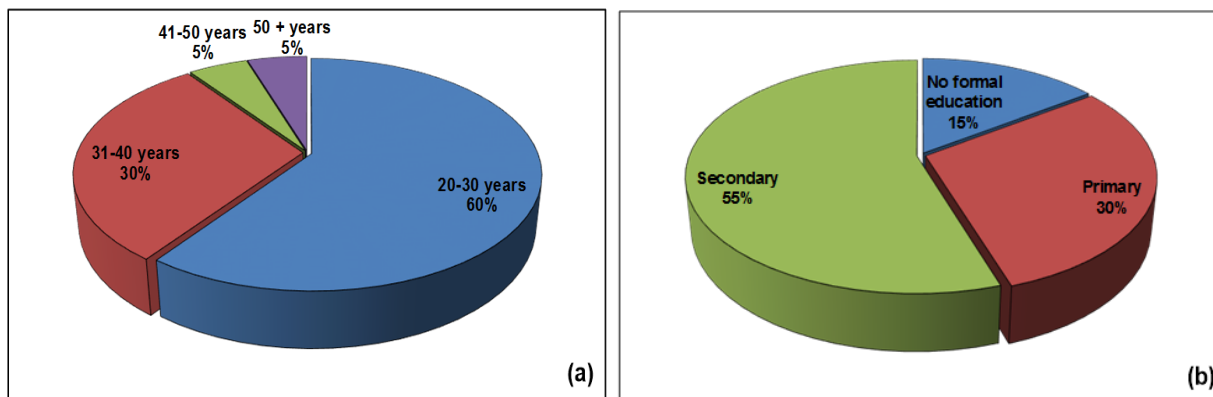
#### ***Age and additional background***

Figure 4.5a presents the age of the respondents. The age of the respondents can be used to determine the ability of the respondents to perform the labour intensive work involved in the brick manufacturing process. The results show that the majority of the respondents were

between 20 to 30 years and the lowest percentage age group was respondents between 41 to 50 and over 50 years. This gives an indication that most of the brick manufacturers are young males and therefore are still energetic and able to perform the hard work associated with brick making operation in the area.

The educational background of the respondents was analyzed. This is because educational background plays an important role in determining the knowledge and skills of an individual. For one to be able to understand the nature and suitability of materials for brick making as well as methods and equipment that can lead to production of high quality bricks, a certain level of education and skills is required. According to the findings of the study, none of the respondents had tertiary education. The results of the educational level of the respondents are shown in Figure 4.5b.

The results showed that 55% of the respondents were literate with a secondary level of education while 30% of the respondents had only primary level of education and 15% of the had no formal education. These results give an indication that the brick manufacturing enterprises in Dididi is comprised of semi-skilled and unskilled individuals. This corresponds with the findings of Cermaleb (2014) who indicated that informal clay brick makers are unskilled and as a results, quality and productivity rate are affected. Based on the educational background of the respondents, it can be concluded that the level of understanding of the important factors that affect the quality of the products is generally low.

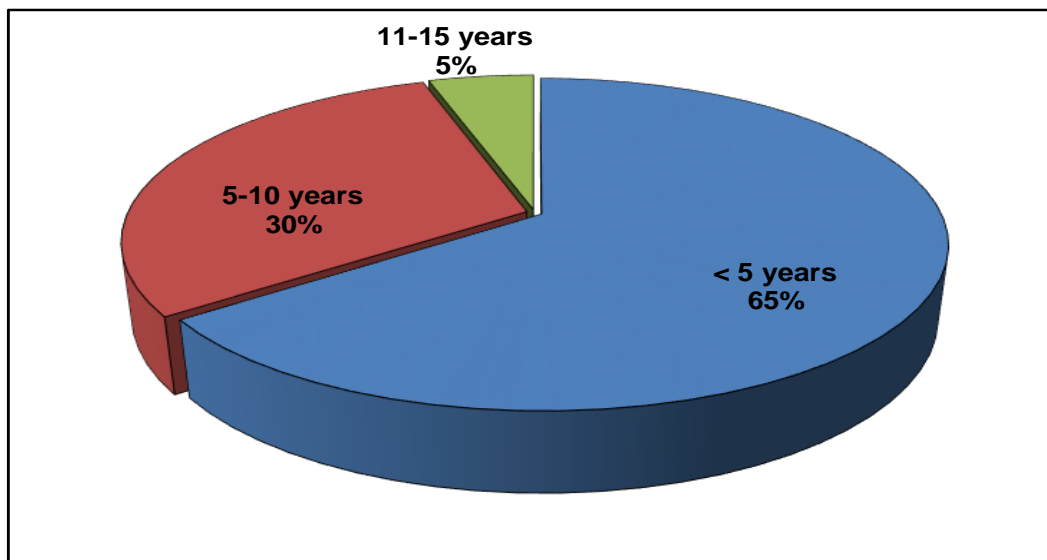


**Figure 4.5:** Age and educational background of the respondents

### ***Brick making experience***

The experience of an individual also plays a key role on the final quality of the bricks. Figure 4.6 shows the percentages of the level of experience of the respondents in brick manufacturing. The study revealed that the majority (65%) of the respondents have less than 5 years of experience in burnt brick making while 30% had about 5 to 10 years of experience and only 5% had more than 10 years of experience. The experience determines the ability of an individual to understand the factors influencing quality of the bricks produced.

Based on the responses, those with adequate experience were only few compared to those without enough experience. This in turn has a potential of affecting the quality of the final bricks produced. A brick produced by someone with many years of experience in brick manufacturing and that produced by someone with only a few years of experience will differ in terms of quality.

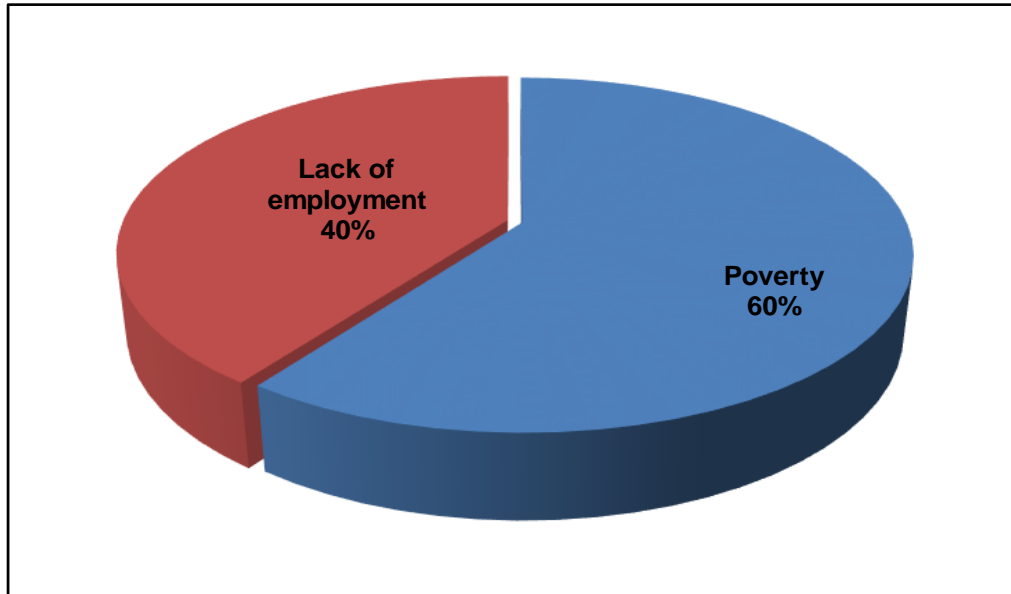


**Figure 4.6:** Experience of the respondents in brick making

### ***Motivation for brick making enterprise***

The study analyzed what motivated the brick manufacturers to enter into the brick manufacturing business. The results of this analysis are presented in Figure 4.7. The results indicate that poverty and lack of employment as the main reasons for the respondents' involvement in brick manufacturing enterprises. According to the statistical analysis, 60% of the respondents entered the brick manufacturing enterprise due to poverty while 40% entered as a result of lack of employment.

These results show that none of the respondents entered the brick making business as something they are passionate about, but only as something that can help them sustain themselves and their families. This gives an indication that the brick manufacturing enterprises in Dididi play an important role in reducing poverty in the area. This is in line with the study by Cermalab (2014) that indicated that the informal clay brick manufacturing contributes in creating employment to local communities, thereby reducing poverty in the rural areas.



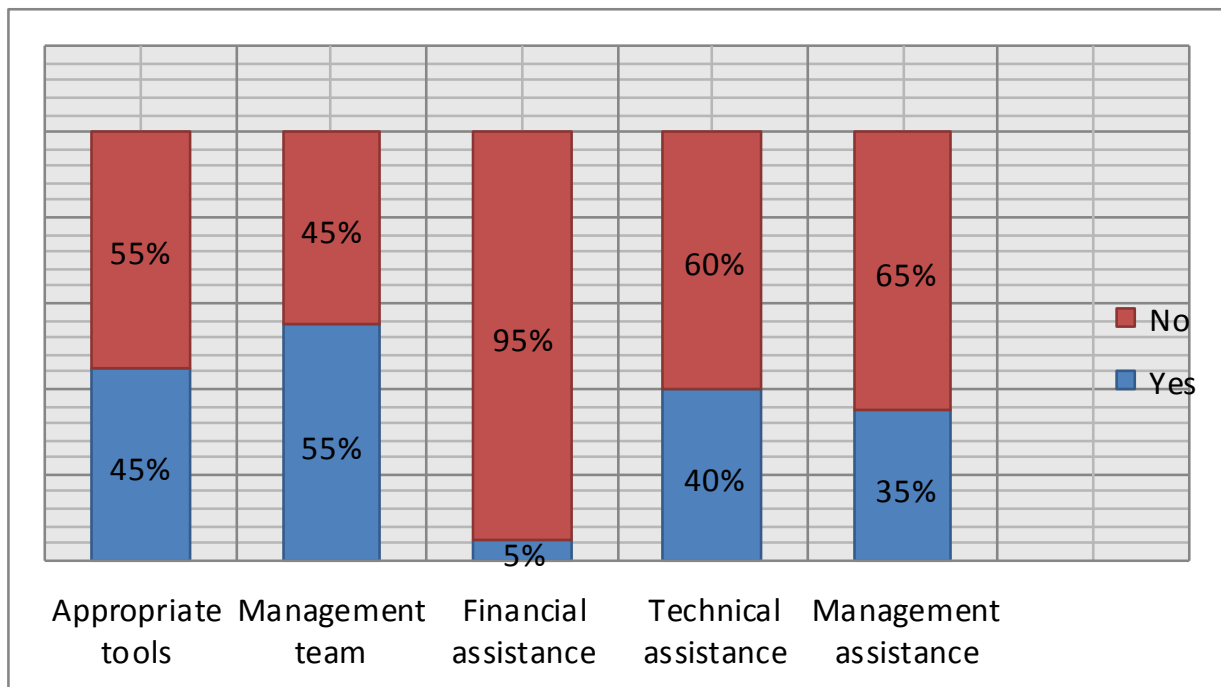
**Figure 4.7:** Motivation of the respondents for entering the brick manufacturing enterprise

### 4.3.2 Resources for brick manufacturing

The study also used the questionnaires to analyse the resources used to manufacture burnt bricks in Dididi. Figure 4.8 and Table 4.10 show the results of the statistical analysis of the responses with regard to the resources. The tools used to manufacture the bricks have the greatest influence on the final quality of the bricks. According to the statistical analysis, the majority of the respondents indicated that they do not have appropriate tools for manufacturing quality bricks. Thus they used locally made metal moulds to make bricks and fired them using firewood (see Table 4.10). This was seen to be affecting the quality and the rate of productivity of bricks.

The study also tried to find out if the brick manufacturers have any form of support in terms of financial, technical and management assistance.

In this case the results revealed that about 95% of the respondents do not have any financial support while 60% showed to be not having technical support. Although 55% of the respondents indicated that they have a management team, 65% indicated that they lack management assistance. This confirms the idea that informal small-scale industries are mainly associated with lack of technical assistance, lack of financial assistance and poor management involvement and commitment. Different authors indicated that it is impossible to manage product quality if top management is not committed (Mahmood, 2006 and Singh, 2013).



**Figure 4.8:** Resource availability

**Table 4.10:** Moulds and fuel used

Type of moulds	Frequency	Percentage
Wooden	-	-
Metal	20	100
<b>Type of fuel</b>		
Firewood	20	
Coal	-	100
Charcoal	-	-
Total	20	100

### 4.3.3 Analysis of production and soil testing methods

The brick production process technology used to manufacture the bricks has the greatest influence of the final quality of the bricks. Therefore, the study also analysed the production process and methods used to manufacture the burnt bricks as well as the methods used for testing the materials suitability and bricks quality. The analysis of the production process is important in determining the implications of the production method on the quality of the bricks. This section discusses the methods used to manufacture the bricks in the small-scale brick making business in Dididi. It covers the methods used for determining suitability of the raw materials for brick making, size reduction methods and material preparation methods, moulding, drying and firing techniques. It also analyses production rate and the method used to test the quality of the final bricks produced.

#### ***Manufacturing methods***

Table 4.11 presents the descriptive statistical results of the analysis of the production process and technology used in bricks manufacturing in the small-scale brick manufacturing enterprises in Dididi. The production process technology plays a significant role on the quality of the final bricks. Fernandes *et al.* (2009) emphasized the importance of analyzing the manufacturing technology, therefore; the study also analysed the technology used for brick manufacturing in the study area. From the operations observed and the statistical results, the method used for brick manufacturing in Dididi is traditional and too manual and labour intensive. As indicated by Fernandes *et al.* (2009), the quality of the soil relies essentially on its characteristics, which in turn influences the quality of the bricks. Consequently, the study also analysed the method used to select suitable raw materials for the manufacturing of clay bricks.

Based on the responses, selection of the raw material was based on the knowledge of the brick manufacturer. None of the brick manufacturers conducted scientific tests to determine the suitability of the raw material for brick manufacturing. This means that the brick manufacturers used the soil without knowing whether it is suitable for brick manufacturing or not in terms of the chemical and mineralogical constituents. Moreover, as indicated in the demographic analysis, majority of the brick manufacturers have little experience in brick manufacturing, therefore, selecting the materials based on indigenous knowledge is not effective. This confirms a report by Mueller *et al.* (2008) that indicated that brick manufacturers use soil without taking into consideration its characteristics thus resulting in production of poor quality bricks.

The study shows that 100% of the respondents use manual crushing to reduce large lumps in the raw material. This process is too labour intensive and time consuming, resulting in reduced production rate. In addition, manual crushing can leave some of the lumps not properly reduced, therefore affecting the quality of the mixture and that of the brick produced. The results also show that the preparation method used was mixing. This was done through mixing the raw materials for brick making with water to form a mixture. As shown in Table 4.11, informal brick manufacturing enterprises in Dididi used hand moulding method to manufacture the bricks. The bricks were traditionally sun dried and were fired traditionally in stacks.

The final properties of the brick play a fundamental role in determining the quality of the bricks. Therefore the study also analysed the method used to determine the quality of the fired bricks in the study area. The results revealed that none of the respondents used any practical or scientific testing method to assess the quality of the final product. All the respondents indicated that they used observation to make judgement of the quality of the bricks produced. This means that the bricks are sold without knowing going through any scientific test of their strength and water absorption properties.

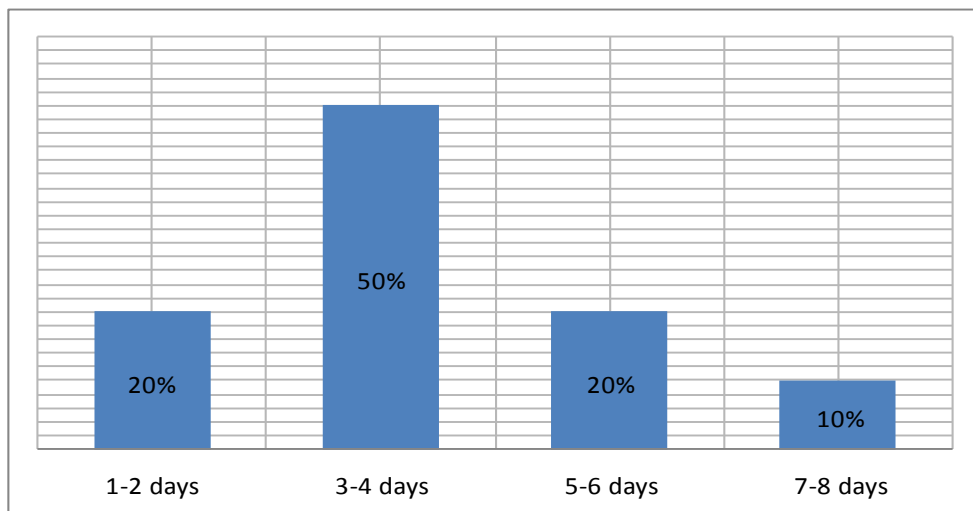
**Table 4.11:** Methods used to manufacture burnt bricks in Dididi

<b>Manufacturing method</b>	<b>Frequency</b>	<b>Percentage</b>
Traditional	20	100
Mechanical	-	-
<b>Method of testing suitability of material</b>		
Field tests	-	-
Laboratory tests	-	-
Indigenous knowledge	20	100
<b>Size reduction method</b>		
No size reduction	-	-
Sieving	-	-
Milling	-	-
Manual crushing	20	100
<b>Preparation method</b>		
Tempering	-	-
Mixing	20	100
<b>Moulding method</b>		
Mechanical	-	-
Hand moulding	20	100
<b>Drying method</b>		
Mechanical drying	-	-
Traditional drying	20	100
<b>Firing method</b>		
Traditional (Stacks)	20	100
Mechanical ovens	-	-
<b>Brick quality testing method</b>		
Observation	20	100
Touch	-	-
Laboratory	-	-
Other	-	-
Total	20	100

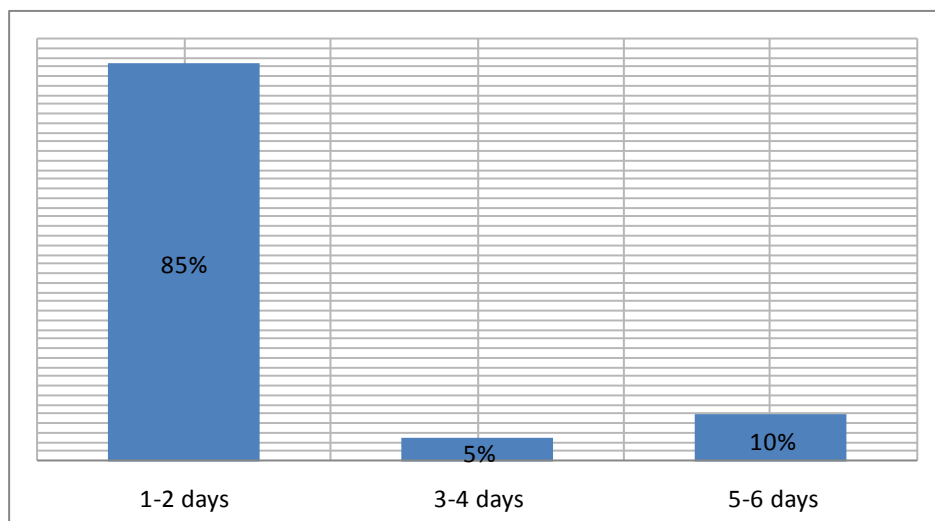
### ***Drying and firing period***

The drying period also has a major impact on the quality of the final bricks. For a brick to be strong and of good quality, it needs to be fully dried both in the inside and outside to prevent cracking during firing. Drying also influences the water absorption property of the bricks. When a brick is under dried it can be too absorbent, thus making it weak. According to the majority of the respondents (50%), bricks drying in the study area lasted for about 3 to 4 days while the lowest number of the respondents (10%) indicated that drying took at least 7 to 8 days.

The differences in the responses of the drying period could be due to the differences in weather conditions and seasons. Figure 4.9a shows the results for the responses regarding the drying period of the bricks. The firing process and period also has the greatest influence on the final quality of the bricks. The firing process influences the properties such as water absorption, compressive strength, and general durability of the bricks. The bricks in Dididi are fired traditionally in stacks using firewood. The majority of the respondents (85%) indicated that firing of the bricks generally take about 1 to 2 days while 5% indicated that it take about 3 to 4 days. These results are shown in Figure 4.9b.



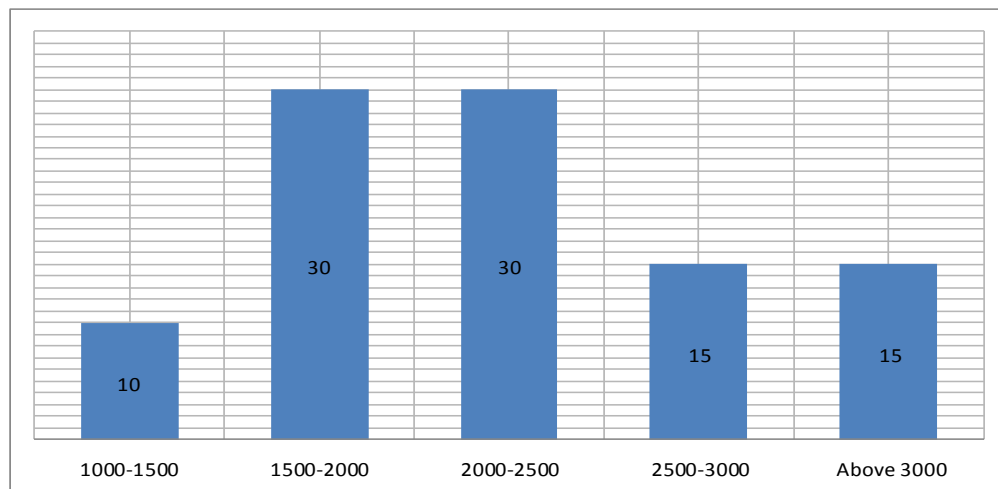
**Figure 4.9a:** Drying period



**Figure 4.9b:** Firing period.

### ***Production rate***

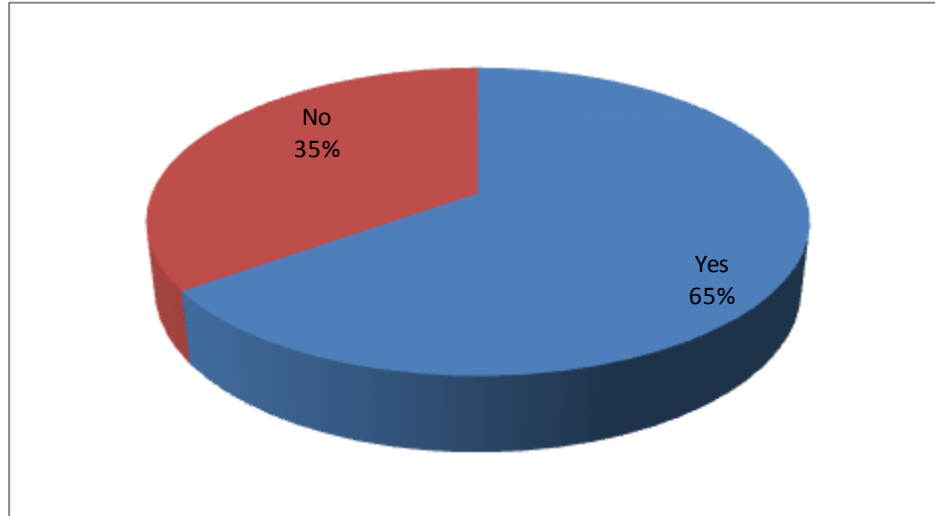
In order to get an idea of the effectiveness and efficiency of the production process technology used, the study analysed the number of bricks produced per day. The results are presented in Figure 4.10. According to the responses, the highest number of bricks (over 3000) was being produced by 15% of the respondents while the lowest number of bricks produced per day was between 1000 and 1500 bricks which were made by 10% of the respondents. This implies that the number of bricks made in one day depend largely on the capability of the manufacturer since the method is particularly manual.



**Figure 4.10:** Number of bricks made per day

### ***Complains about the quality of the bricks***

Figure 4.11 shows the results of the number of respondents who have received complaints from customers regarding the quality of the bricks. According to the descriptive statistics, the majority of the respondents (65%) have received complaints from customers. This gives an indication that the majority of the customers are not satisfied with the quality of the bricks produced by informal brick manufacturers in Dididi. This can result in the manufacturers losing customers. Although the brick makers are receiving a lot of complaints from customers, they have not done anything to improve the quality of the bricks. This was seen to be resulting from the lack of adequate knowledge and funds for improving the methods used to manufacture the bricks.



**Figure 4.11:** Number of respondents who have received complaints from customers

#### ***Bricks manufacturers' awareness of SANS 227:2007 for burnt clay masonry units***

The survey also assessed the brick manufacturer's awareness of the standards for burnt clay masonry and product quality management. The results are presented in Table 4.12. Based on the results of the descriptive statistics, 100% of the respondents were not aware of the required standard for burnt bricks. The results also show that none of the respondents are aware of product quality management. This was found to be in accordance with the study by Wanjau et al. (2013) that showed that many small and medium scale enterprises are not aware of product quality management programs; hence the rate of adoption of quality is low.

**Table 4.12:** Respondents' awareness of SANS 227:2007 for burnt brick

<b>Are you aware of SANS for burnt clay bricks</b>	<b>Frequency</b>	<b>Percentage %</b>
Yes	-	-
No	20	100
Total	20	100
<b>Are you aware of product quality management</b>		
Yes	-	-
No	20	100
Total	100	100

## 4.4 Field Analysis of the Brick Making Process

From the operations observed during the study, five major stages were used to manufacture clay bricks in Dididi and this included extraction of the raw materials, preparation, shaping, drying and firing. These stages are discussed in the following sections.

### 4.4.1 Extraction of the raw materials

It was observed in the field that raw clay materials for brick manufacturing is being excavated manually using picks and shovels. The raw materials were extracted without any scientific tests of the soil to identify the characteristics and suitability of the materials for brick manufacturing purposes. As indicated in the responses, the brick manufacturers in the study area used indigenous knowledge to determine the suitability of raw material for brick making purposes. However, most of the interviewed brick manufacturers (65%) had less than 5 years of experience in the brick manufacturing enterprise thus increasing possibilities of them using unsuitable material in making bricks of poor quality. Prior to extraction of raw material, the area was being cleared off vegetations to expose the targeted layers of clay soil. Figure 4.12 shows operations of extraction of raw material used to make bricks in the study area.



**Figure 4.12:** The operations of extraction of raw material for bricks manufacturing

#### 4.4.2 The preparation of raw materials for brick making and moulding of bricks

Material preparation started right after there were enough raw materials for production of the targeted amount of bricks. Preparation was done near the extraction area. The materials were being prepared by mixing the raw materials with the right amount of water for a desired mixture for bricks making. Figure 4.13 shows how the brick makers prepare the raw materials in one of the sites in the study area. From the observations as well as the responses obtained from the brick makers, large lumps in the materials were being reduced manually by adding water into the soil and breaking and crushing the materials using shovels. Such a traditional and manual mixing process might leave some of the material not properly reduced to right sizes and this can in turn affect the quality of the final products.

Moulding was done manually using traditional hand moulding tools. As observed in the field, the mould was being wetted and placed on the ground and get filled with the wet soil mixture. The mould was then lifted and the brick was left on the ground to dry. The wet bricks were covered with dry raw materials to control the moisture content as the bricks dry. This assured that there is constant drying and that prevents breaking of the bricks from overheating by the sun. Figure 4.14 shows the process of moulding of bricks in one of the sites in the study area.



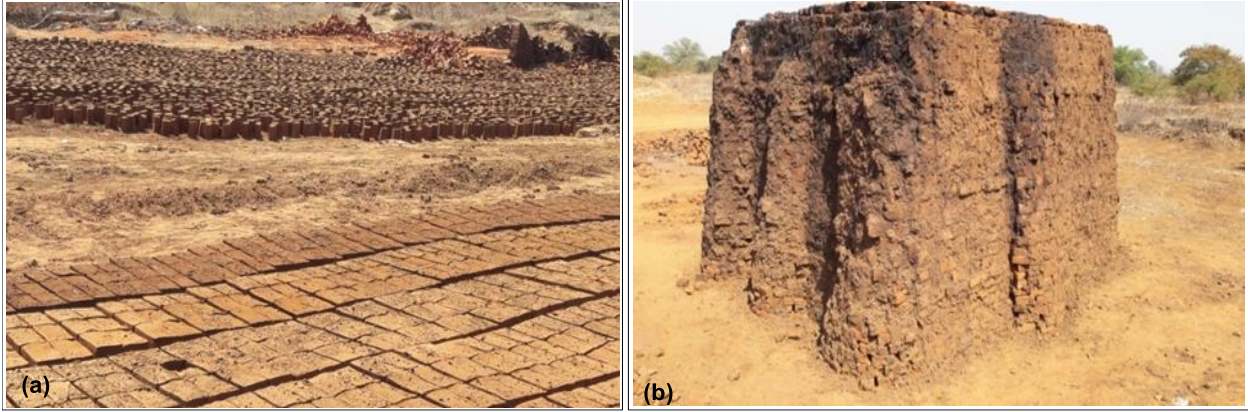
**Figure 4.13:** Mixing of soil used for brick making done using legs and shovels in Dididi



**Figure 4.14:** Material preparation and brick moulding in one of the selected areas in Dididi

#### **4.4.3 Drying and firing of bricks**

The bricks were sun dried for about 3 to 4 days as indicated by the majority of the respondents in the questionnaire survey. However, it was observed in the field that the drying period depended mainly on the season and weather conditions. During sunny days, drying only took 2 to 3 days while in cloudy days it went beyond this number of days. An image of drying is shown in Figure 4.15a. On completion of drying, the bricks were being packed in stacks as shown in Figure 4.15b and were fired using firewood and this process took about 1 to 2 days. The firing temperature is generally not known as there was no temperature sensor used in all the brick firing set ups. This resulted in under firing of some of the bricks while others were over fired. This was observed to be one of the factors that seriously affected the quality of bricks produced in the study area.



**Figure 4.15a and Figure 4.15b:** Images showing drying and firing of bricks

## CHAPTER FIVE

### PRODUCT QUALITY MANAGEMENT GUIDELINES

The main objective of this study was to develop product quality management guidelines for informal small-scale clay brick manufacturing enterprises in Dididi. The results of the survey conducted on the brick manufacturers demonstrated that the majority of the informal brick manufacturers in the study area lacked adequate management skills and are not aware of the prescribed standards for burnt clay bricks. The guidelines presented in this chapter were developed in order to bridge this gap. Therefore, this chapter discusses the recommended guidelines developed towards achieving improved production process for ensuring product quality in the informal small-scale clay brick manufacturing enterprises. The guidelines development procedure involved identifying the need for the specific guidelines, objectives of the guidelines, and then formulating guidelines for improving product quality.

#### 5.1 The Need for the Guidelines

Informal brick manufacturing enterprises in South Africa are not monitored. As a result, most of them are not aware of the required standards for burnt bricks hence the quality of their bricks do not fully comply with the requirements of some of the standards. In the study area, majority of the brick manufacturing enterprises indicated that customers complain about the poor quality of their bricks. Because of the absence of guidelines for ensuring quality in the small-scale brick making, the brick makers at Dididi are still with no idea of what could be done to improve the quality of their products. There is also poor management involvement in the brick making enterprises. Therefore there is a need for developing product quality management guidelines for informal small-scale brick manufacturers in the study area.

#### 5.2 Objectives of the Guidelines

The primary objective of developing product quality management (PQM) guidelines for informal small-scale clay brick manufacturing enterprises in Dididi was to provide guidance for improving the quality of the produced burnt bricks. These guidelines are developed to assist in improving the production processes in order to promote the production of high quality bricks. The guidelines are aimed at improving the involvement and participation of management in the brick making business. This is expected to help in reducing the number of products with defects and

reworking of such products. This will go a long way in promoting safety as the guideline will help in reducing public safety concerns arising from building houses using bricks of unreliable quality. Production of good quality bricks can also help the brick manufacturers to gain recognition from both large private and public construction sectors. The guidelines are to provide guidance on the factors that need to be considered in order to achieve good quality bricks.

### **5.3 Guidelines for Ensuring Product Quality**

This section provides the guidelines developed towards improving product quality in the informal small-scale brick manufacturing enterprises. The guidelines include establishment of quality management team and training activities, analysis of suitability of raw materials prior to selection and preparation of materials for brick making. It also provides guidelines for moulding, drying and firing of bricks. The section is concluded by highlighting the importance of measuring product quality and formalization of the brick manufacturing enterprises.

#### **5.3.1 Establishment of quality management team and training activities**

The results of the survey demonstrated that most of the informal brick manufacturers in Didi do not have any management team. Literature shows that a successful quality management is determined by management commitment (Mahmood *et al.*, 2006). Therefore, brick manufacturers need to establish a quality management team to ensure that all the activities necessary to ensure quality of the products are performed effectively and efficiently. The management team should be responsible for assuring compliance with the requirements stipulated for good quality bricks. The quality management team should also be responsible for establishing quality policies and objectives. In order to improve the managerial skills of the team, there should be continuous training of the management team on different aspects of quality bricks production. The team together with brick manufacturers needs training about the concepts and importance of product quality management.

#### **5.3.2 Analysis of suitability of raw materials prior to selection**

One of the important factors influencing the quality of burnt brick is the quality of the soil used for making bricks. The questionnaire survey results on method used for determining the suitability of the soil for making of bricks in the study area showed that informal brick manufacturers select their material based on indigenous knowledge.

Although indigenous knowledge plays a vital role in identifying and selecting materials for brick making, it needs to be supported by scientific testing of the raw materials. In order to understand the characteristics of the raw materials, it is important that proper assessments of factors such as plasticity, chemical and mineralogical composition of the raw materials are conducted prior to extraction of the material. This helps prevent manufacturing of bricks using soil that is not suitable for brick making, thereby saving resources and time as well as preventing the dangers that may be caused by building houses using bricks of unreliable quality.

### **5.3.3 Preparation of the materials for brick making**

Clay preparation is one of the most crucial stages in clay bricks manufacturing. Neglecting this stage may result in poor quality of the end brick products. Therefore, clay for brick manufacturing must be prepared thoroughly to achieve a good mixture that will produce good quality bricks. Before mixing the clay, the material must be reduced to right sizes in order to ensure that all the lumps are properly crushed. About 100% of the interviewed brick manufacturers indicated that they reduce large lumps in the soil manually using shovels and hoes. This may still leave some coarse materials in the soil, thus resulting to poor mixture and subsequently poor quality of the bricks produced.

Mechanized size reduction methods such as mechanical grinding may be introduced to ensure that all the larger materials are separated from the finer materials. Mechanical grinding techniques consist of primary and secondary crushers. The most commonly used primary crushers include rolls or hammer mills. These crushers reduce the particle size down to about 3 to 5mm. Secondary crushers make use of pan mills. Mechanical crushers ensure that the material is well mixed and gives good uniformity, consistency and density resulting in uniformity in terms of the size and shape of the bricks. Internal fuel such as coal dust may be added to the materials during mixing to prevent bricks from cracking during firing.

### **5.3.4 Guidance for moulding of bricks**

Brick moulding is a crucial stage in the brick manufacturing process as it also influences the quality of the final product. Therefore, it is important that good quality moulds with equal sizes are used to produce well shaped bricks with standard sizes. Moulding does not only determine the shape of the bricks but also determine the size and appearance of the bricks. To ensure good quality bricks, mechanical extrusion methods may be introduced to replace hand moulding

methods. In mechanical extrusion, the clay mixture is forced through a die into a clay column which is then sliced by wires into brick shaped pieces. Mechanical extrusion requires smaller water content for moulding the bricks resulting in production of denser bricks which are stronger. The lower moisture content also results in lower shrinkages. Mechanical extrusion produces bricks that are consistent in terms of quality and less cracking resulting in lower waste.

### **5.3.5 Guidelines for drying of bricks**

Drying of clay bricks is an important stage in brick manufacturing. Underestimating the importance of drying can result in poor quality of the bricks. The process of brick making in Dididi continues throughout the year. Depending on the season and weather conditions, the bricks can be subjected to differential drying. Differential drying may affect the strength of the bricks as this may result in bricks cracking. Sometimes during rainy seasons the bricks get destroyed before they can even be fired. Therefore, an adequately sized drying shed needs be constructed to ensure uninterrupted supply of dried clay bricks even in the rainy seasons.

Mechanical drying methods may be used to replace the traditional sun drying methods which is the common practice in the study area in order to avoid cracking of bricks during drying as a result of fast drying during sunny seasons. The two most common mechanical drying methods are tunnel and chamber driers. In the tunnel driers, the bricks are produced and then off-set on flat rail trolleys or kiln cars that are pushed through a tunnel. Chamber driers are large rooms where bricks are packed onto pallets. Hot air under controlled conditions is fed into the chamber. Mechanical drying methods allows better control of drying temperature, air speed and humidity for optimum drying, resulting in greater bricks uniformity and quality. Mechanical driers takes about 2 to 3 days which is much quicker than traditional sun drying.

### **5.3.6 Guidelines for firing of bricks**

Firing of the kiln is the most important stage in the brick manufacturing process (Schilderman, 2008), (Beamish and Donavan, 1993). These authors show that it is important to know the number of bricks that will be fired, the fuel that will be used, the dimensions of the kiln and the wind direction. Knowing the direction of wind helps ensure that the length of the field kiln is laid out in the same direction as the wind will prevent the wind from blowing down into the tunnels and reducing the heat during firing. From the observations of firing in the field, most of the bricks were lost during the firing stage. This may have been due to overheating since there was no

control of the heat once the fire started as there were no temperature sensor. To improve and control the effects of firing on the quality of the bricks, heat treatment is required in order to produce good quality bricks. Temperature sensors for sensing and regulating the temperatures in stacks must be employed.

### **5.3.7 Product quality measurement**

The findings of the study showed that the informal brick manufacturers do not conduct any scientific or practical tests to determine the quality of the bricks they produce and sell to customers. As a result, they have on many occasions sold bricks of poor quality and received complaints from customers. Therefore, it is important to measure the quality of the bricks through conducting brick tests such as compressive strength, water absorption, porosity and density of the bricks after firing. This will avoid selling of poor quality bricks that might lead to lack of confidence and trust of customers to the products. It is also important to compare the final bricks with the required SANS for burnt clay bricks in order to ensure continuous improvement of quality.

### **5.3.8 Formalization of the brick manufacturing enterprises**

Brick manufacturers in Dididi are not registered hence they are not known. Therefore, there is a need for them to regularize their operations. Informality of the operations is associated with a number of negative issues including non-uniformity of bricks quality, under-fired and over-fired final bricks, and high wastage of bricks resulting from poor firing techniques. All these negative issues may cause customer dissatisfaction. Other negative aspects associated with informal brick making enterprises include lack of knowledge and skills in different areas such as management, sales, marketing, production costs and techniques and lack of funds to improve production processes.

It is therefore important for informal brick making enterprises in Dididi to formalize their businesses. Once they are registered, they can gain access to technical and market information related to brick industry such as information on new production methods and different ways of marketing their products. Therefore improving their operation techniques resulting in improved quality. They can also seek accreditation of their products from the SABS. This will also help them to get recognition from the clay brick manufacturing association of South Africa as well as both private and public building construction sectors.

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the main findings of this research. It begins with providing a summary of the work done in terms of highlighting the problem and the focus of the research. It also discusses the approach used to achieve the objectives of the study. Lastly, it provides the conclusions and recommendations for further research and development based on the major findings of the study.

#### 6.1 Summary of the Study

Although the South African National Standards for burnt clay masonry units provides specifications for burnt clay bricks, informal small-scale brick manufacturers are still not regulated, as a result, they do not adhere to the demanding requirements of the standards. As such, the bricks produced by informal small-scale clay brick manufacturers in Dididi lack uniformity in terms of quality; consequently, with time the buildings constructed with these bricks develop cracks thereby compromising safety of the residents. The concept of product quality management in the study area is not well understood; hence the importance of adopting quality management to improve production process and to ensure quality of the products remains unknown to the informal brick makers in Dididi.

The main purpose of this study was to develop product quality management guidelines for informal small-scale brick manufacturing enterprises in the area. The specific objectives of this research were to characterize the raw materials for clay bricks, identify and assess the technical problems associated with clay brick production, to analyse the process of clay brick production and identify areas that require product quality improvement then come up with product quality management guidelines for the informal small-scale brick making enterprises. The characterization of raw materials was achieved through carrying out several laboratory tests such as textural analysis, mechanical analysis, chemical and mineralogical analysis. Brick testing was also conducted to assess the technical problems of currently produced bricks. The tests included compressive strength and water absorption tests as well as determining the compliance of the brick produced to standards in terms of their dimensions. Questionnaire survey was used to analyse the clay brick production process.

The analysis of the particle size distribution of the materials used for brick manufacturing in Dididi revealed that the material was dominantly characterized by sandy sized particles with significantly low amounts of clay and silt. Based on the Unified Soil Classification System (USCS), the soil from the three selected brick making sites in Dididi was classified as well graded sands (SW). Such soils are known to be dominantly composed of sand sized particles with little or no fines. Literature shows that soils with high amounts of sand make poor bricks compared to soils with high quantity of silt (Cole, 1959).

The plasticity of the soil from the three selected sites was found to be varying from slightly plastic to medium plasticity. The plasticity of the materials can be related to its textural properties. The reduced plasticity can be attributed to large particles in the soil. Soil for brick making must contain enough plasticity to facilitate moulding, but not too plastic as it can lead to severe shrinkage and cracking during drying and firing. According to Mueller et al. (2008), soil for burnt bricks making is expected to have a plasticity index ranging from 7 to 16%. Soil from Site A and B had the plasticity index values of 14.25 and 8.49% respectively while soil from Site C had the lowest plasticity index of 3.36%. Therefore, soil from Site A and B can be used for making bricks provided that brick bats to test suitability for brick making are made prior to making the bricks. Soil from Site C did not well suit the bricks making use.

The findings of chemical and mineralogical analysis were also linked to each other. For example, the major chemical component of the soil was found to be silica while mineralogical analysis confirmed that the soil used to manufacture fired bricks in the area contains abundance of non-clay minerals in the soil with quartz being the main constituents. Other major chemical elements revealed were alumina and iron while the minerals were plagioclase, microcline and hornblende. The clay minerals which were found present in relatively small quantities were chlorite and talc.

The results of the compressive strengths indicated that Site A and C bricks had similar compressive strength characteristics while Site B had the lowest average compressive strength value. The bricks strength did not meet the required average compressive strength. The average water absorption of the bricks was 13.5, 15.0 and 16.1% for Sites A, B and C respectively. Although the bricks in Site A and B were too absorbent, they did not dissolve in water while some from Site A dissolved in water.

From the descriptive analysis of the production techniques, the major factors affecting the efficiency of the production of quality products were identified and classified as human and technical factors. Human factors influencing the production process were mostly the experience of the brick makers, their educational background and management support while technical factors included the suitability of the materials, appropriateness of equipment used and the methods used to manufacture the bricks. From the observations of the operations, the brick production process was found to be too manual and labour intensive from soil extraction with picks, shovels and hoes, clearing the space for making the bricks, mixing soil and water using shovels to transporting the soil mixture to the moulding area with wheel barrows. Then hand moulding the bricks followed by stacking and unstacking the bricks after firing. Hence majority of the brick manufacturers were males.

Although the majority of the brick makers were literate, the knowledge to identify suitable materials was lacking and the level of understanding of the importance of selecting appropriate raw materials and ensuring product quality was insufficient. Therefore educational programs are recommended. Material selection was not based on any scientific tests to determine their suitability, selection was based solely on the knowledge and experience of the manufacturer and some brick manufacturers did not have adequate experience, hence they end up using the soil depending on the availability. Furthermore, although some of the brick manufacturers were experienced, some practical testing of the raw materials prior to making bricks is recommended to ensure that the material is suitable. The study also revealed that the majority of the informal brick manufacturers in Dididi were mostly challenged by financial constraints and lack of technical and management support. None of the brick manufacturers was aware of SANS for brick making and the understanding of product quality management was very poor.

## **6.2 Conclusions**

Based on the combined results of the characterization of the raw materials used for brick manufacturing in the study area, it can be concluded that the soil from the selected sites is not well suited for brick manufacturing. The large grain size particles together with the low plasticity of the soil make the mixing and molding process difficult. Chemical analysis demonstrated that the material had elevated concentrations of silica with small amounts of alumina and iron oxide. The inadequate amount of alumina in the soil contributes to the reduced plasticity of the soil, thereby making the moulding property of the soil poor. Excess amount of silica reduces the cohesion property of the soil thus making shaping difficult.

In addition, too much silica in the soil used for brick making make the bricks too hard during firing; however, such bricks turn to break easily. The XRD analysis of the soil revealed the dominance of non-clay minerals in the soil, with quartz being the major constituent. Clay minerals play a significant role in the forming property of the bricks. Therefore the study concludes that the absence of clay minerals in the soil contribute to its poor moulding property. The study also concludes that the elevated amount of quartz also has also contributed to the decreased amount plasticity of the soil. The XRD analysis also detected chlorite in the soil. The presence of chlorite in brick making soils makes the quality of the bricks poor as chloritic clays can result in lightweight aggregates.

In terms of the bricks compressive strength, the bricks produced at Dididi did not meet the acceptable average compressive strength stipulated by SANS. They also did not meet the required water absorption for fired bricks. Although bricks from Site A met the required water absorption standards, some of them dissolved in water, thus making them completely not appropriate for use. The bricks from all three selected sites met the recommended bricks dimensions although their sizes were not uniform.

Based on the analysis of the brick manufacturing process, the study concludes that the process of brick production contributes to the poor quality of the final products. The study revealed that the technical inefficiencies were mostly influenced by human and mechanical factors as well as the material inappropriateness. The major challenge affecting the production process is lack of adequate equipment for manufacturing of quality bricks. One of the major determinants of product quality in the informal brick making at Dididi is the ability of the brick manufacturer.

The production process is manual; therefore the whole process depends on the ability of the manufacturer. The selection of the raw materials for brick manufacturing was based on indigenous knowledge and experience and most of the brick manufacturers lacked the prerequisite experience for making quality bricks. This results in selection of inadequate materials which in turn affect the quality of the final bricks. The study also revealed that the informal brick manufacturers in Dididi area also have no management support and some of the brick makers do not have a management team. The study also shows that the brick manufacturers are not aware of the required standards for burnt clay bricks; hence the non-compliance with the required bricks quality standards. This together with the lack of quality management guideline has resulted in poor product quality management in the sector.

### 6.3 Recommendations

Based on the findings and conclusions of the study, the following recommendations were made:

- In addition to indigenous knowledge, scientific determination of the suitability of the material for brick making should be performed prior to the use of material. The soil can be sent to the laboratories for testing in order to assist with the analysis.
- To increase the workability of the soil locally available, plastic clays can be sourced and added to the soil. This will help in binding the coarse particles during firing and increase the compressive strength of the bricks.
- Additive materials such as internal fuel (coal dust) and anti-shrinkage materials should be added in the mixture to avoid cracking during drying and firing.
- The bricks production process should be improved through incorporation of selective mechanized methods.
- Considering the strength and water absorption properties of the fired bricks manufactured by informal small-scale bricks manufacturers in Dididi, their use for construction purposes should be limited to minor constructions such as stop-nonsense and landscaping.
- An establishment of the product quality management team and learning programs to improve their managerial skills is also recommended.
- It is recommended that awareness training to equip brick manufacturers with the knowledge and skills needed to improve production processes and quality of the bricks as well as learning programs about product quality management be facilitated.
- Further studies on improving quality of the material and development of production process techniques that will improve the production rate of the brick making enterprises while ensuring that quality products are achieved is strongly recommended.

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## APPENDICES

### Appendix A: Sampling Points

Location	Sample number	Latitude	Longitude
Site A	A1	-23.004	30.50724
	A2	-23.0044	30.50611
	A3	-23.0043	30.50546
	A4	-23.0043	30.50546
	A5	-23.0068	30.50301
	A6	-23.0077	30.50389
	A7	-23.0075	30.50306
	A8	-23.0092	30.50444
	A9	-23.0889	30.50361
	A10	-23.0049	30.50674
Site B	B1	-23.00306	30.51028
	B2	-23.00306	30.51028
Site C	C1	-22.9961	30.51028
	C2	-22.9961	30.51
	C3	-22.9961	30.50972
	C4	-22.9956	30.50861
	C5	-22.995	30.50833
	C6	-22.9956	30.5075
	C7	-22.9947	30.50694
	C8	-22.9947	30.50583

### Appendix B: Sieve Analysis Results

#### B1: Sieve analysis results for Site

Sieve No	Mass of empty sieve (g)	Mass of sieve + soil retained (g)	Sample wt	Cumulative wt	% Retained	Mass passing	Total % passed
4mm	388.81	414.76	25.95	25.95	5.19	0.95	94.81
2 mm	326.63	376.64	50.01	75.96	10.01	0.85	84.80
1mm	295.71	356.93	61.22	137.18	12.25	0.73	72.55
500 µm	293.72	346.21	52.49	189.67	10.5	0.62	62.05
250 µm	243.06	320.06	77.00	266.67	15.41	0.47	46.64
125 µm	236.57	338.49	101.92	368.59	20.39	0.26	26.25
75 µm	265.59	320.88	55.29	423.88	11.06	0.15	15.18
32 µm	257.99	315.82	57.83	481.71	11.57	0.04	3.61
Pan	527.61	545.67	18.06	499.77	3.61	0.00	0.00
		Total weight	499.77				

### B2: Sieve analysis results for Site B

Sieve No	Mass of empty sieve (g)	Mass of sieve + soil retained (g)	Sample wt	Cumulative wt	% Retained	Mass passing	Total % passed
4mm	388.79	417.46	28.67	28.67	5.74	0.94	94.26
2 mm	326.34	387.11	60.78	89.44	12.17	0.82	82.09
1mm	296.03	363.66	67.64	157.08	13.55	0.69	68.54
500 µm	293.99	344.15	50.16	207.24	10.05	0.58	58.50
250 µm	243.42	316.46	73.04	280.27	14.63	0.44	43.87
125 µm	236.73	338.07	101.34	381.61	20.30	0.24	23.58
75 µm	265.47	323.62	58.16	439.77	11.65	0.12	11.93
32 µm	258.01	310.32	52.31	492.08	10.48	0.01	1.45
Pan	529.62	536.87	7.26	499.33	1.45	0.00	0.00
		Total weight	499.33				

### B3: Sieve analysis results for Site C

Sieve No	Mass of empty sieve (g)	Mass of sieve + soil retained (g)	Sample wt	Cumulative wt	% Retained	Mass passing	Total % passed
4mm	388.78	409.59	20.82	20.82	4.17	0.96	95.83
2 mm	326.59	381.65	55.06	75.88	11.04	0.85	84.79
1mm	294.97	358.77	63.81	139.69	12.79	0.72	72.00
500 µm	292.49	348.38	55.89	195.57	11.20	0.61	60.80
250 µm	241.80	328.17	86.38	281.95	17.31	0.43	43.49
125 µm	238.09	344.94	106.86	388.81	21.42	0.22	22.07
75 µm	264.55	313.28	48.74	437.55	9.77	0.12	12.30
32 µm	257.81	306.52	48.71	486.25	9.76	0.03	2.54
Pan	529.62	542.29	12.67	498.92	2.54	0.00	0.00
		Total weight	498.92				

## APPENDIX C: ATTERBERG LIMIT TESTS RESULTS

### C1: Liquid limit results for site A

Test No.	1	2	3	4	5
Mass of can, W1 (g)	18.04	18.04	17.87	17.95	18.02
Mass of can + moist soil W2 (g)	23.45	23.74	25.08	24.63	25.16
Mass of can + dry soil W3 (g)	22.1	22.37	23.41	23.21	23.72
W2-W3	1.35	1.37	1.67	1.42	1.44
W3-W1	4.06	4.33	5.54	5.26	5.7
W%	33.25	31.64	30.14	27.00	25.26
Number of blows	3	4	6	19	32

### C2: Liquid limit results for site B

Test No.	1	2	3	4	5
Mass of can, W1 (g)	18.02	18.05	18.05	18.01	18.09
Mass of can + moist soil W2 (g)	22.51	22.31	24.08	24.43	24.3
Mass of can + dry soil W3 (g)	21.56	21.43	22.85	23.14	23.08
W2-W3	0.95	0.88	1.23	1.29	1.22
W3-W1	3.54	3.38	4.8	5.13	4.99
W%	26.84	26.04	25.62	25.15	24.45
Number of blows	6	9	14	19	28

### C3: Liquid limit results for site C

Test No.	1	2	3	4	5
Mass of can, W1 (g)	18.06	18.03	18.02	18.93	17.91
Mass of can + moist soil W2 (g)	21.17	22.84	22.88	22.66	22.41
Mass of can + dry soil W3 (g)	20.37	21.71	21.78	21.83	21.38
W2-W3	0.8	1.13	1.1	0.83	1.03
W3-W1	2.31	3.68	3.76	2.9	3.47
W%	34.63	30.71	29.26	28.62	29.68
Number of blows	5	10	17	26	37

### C4: Plastic limit results for site A

Test No	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Mass of can, W1 (g)	19.04	18.04	18.01	17.98	18.01
Mass of can + moist soil W2 (g)	20.06	19.26	19.25	19.76	19.26
Mass of can + dry soil W3 (g)	19.92	19.1	19.09	19.52	19.1
W2-W3	0.14	0.16	0.16	0.24	0.16
W3-W1	0.88	1.06	1.08	1.54	1.09
W%	15.91	5.09	14.81	15.58	14.68

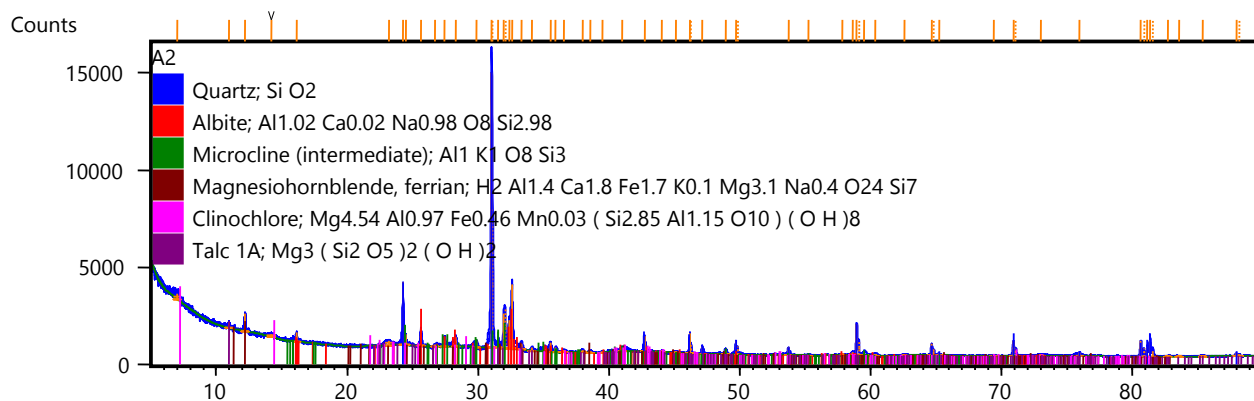
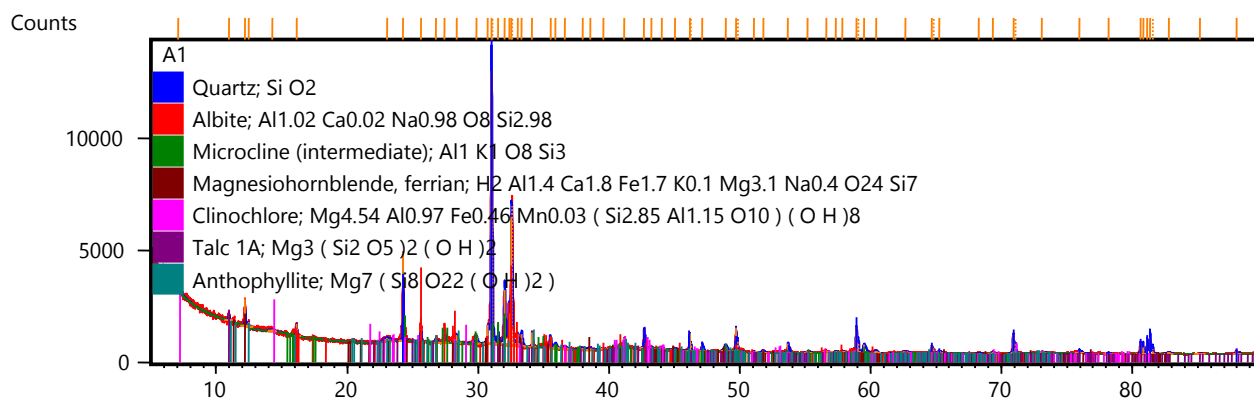
### C5: Plastic limit results for site B

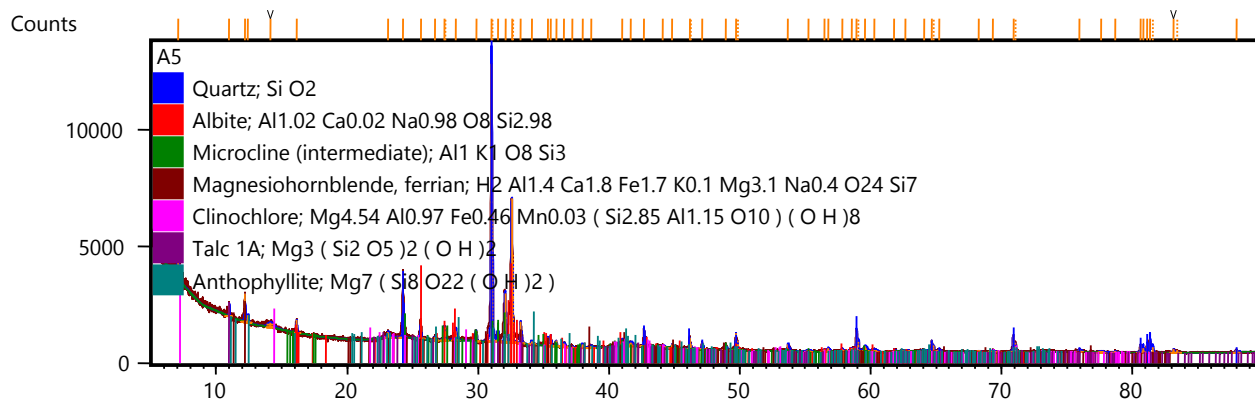
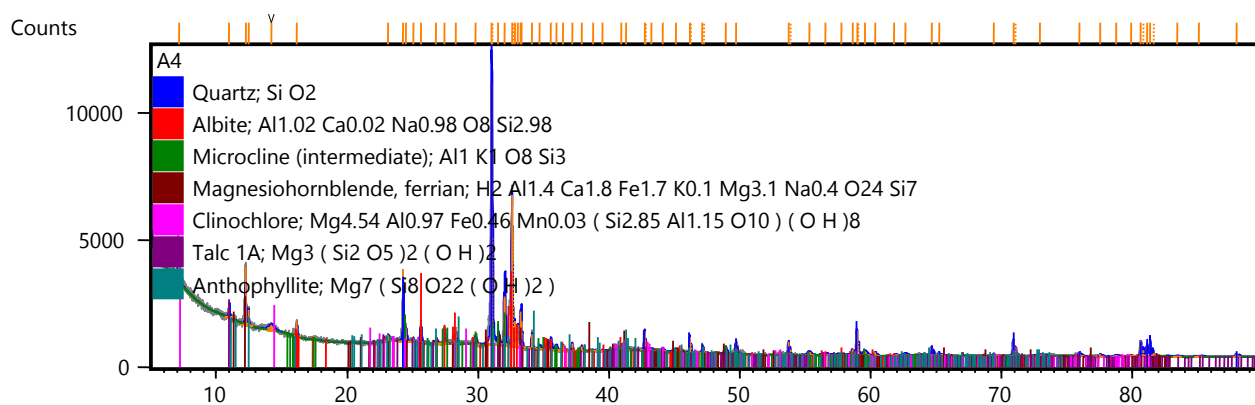
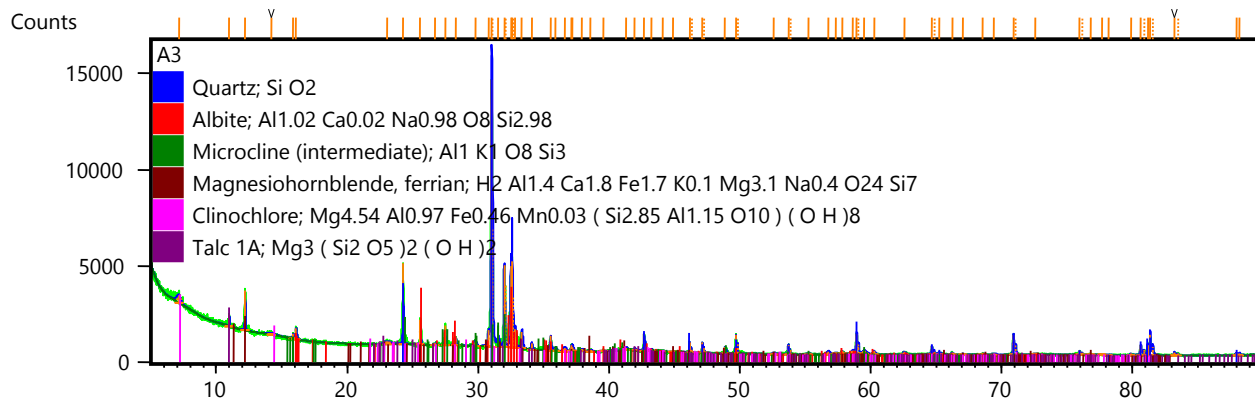
Test No.	1	2	3	4	5
Mass of can, W1 (g)	18.05	19.06	17.89	17.97	18.01
Mass of can + moist soil W2 (g)	21.54	21.74	19.51	22.58	23.9
Mass of can + dry soil W3 (g)	21.04	21.34	19.3	21.91	22.94
W2-W3	0.5	0.4	0.21	0.67	0.96
W3-W1	2.99	2.28	1.41	3.94	4.93
W%	16.72	17.54	14.89	17.01	19.47

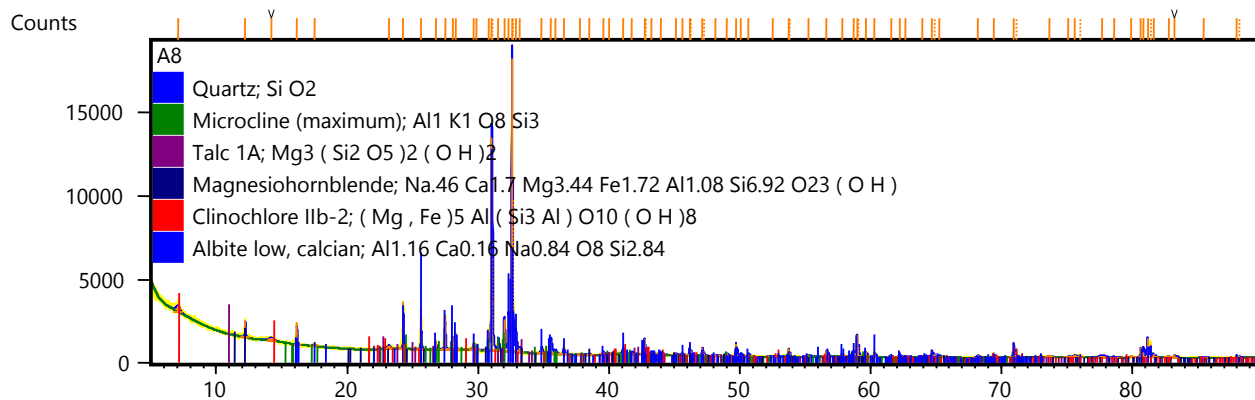
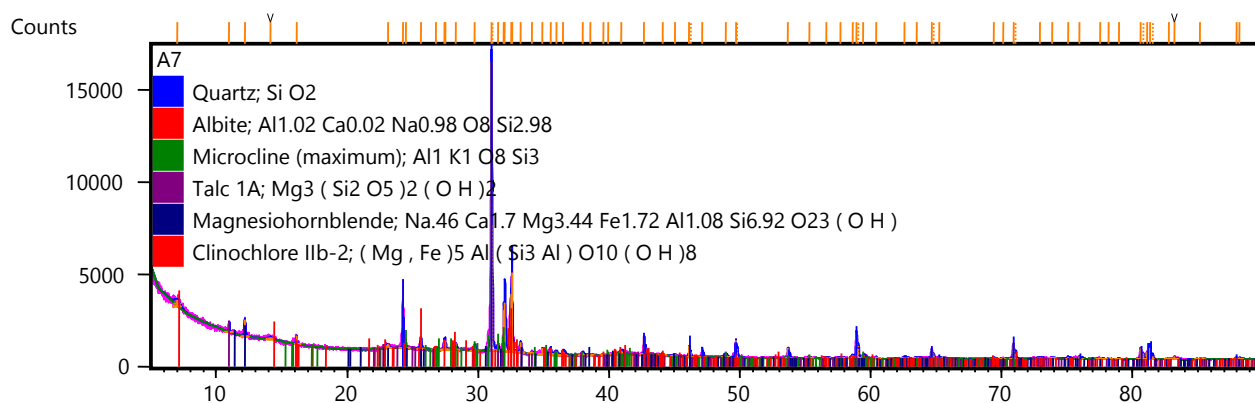
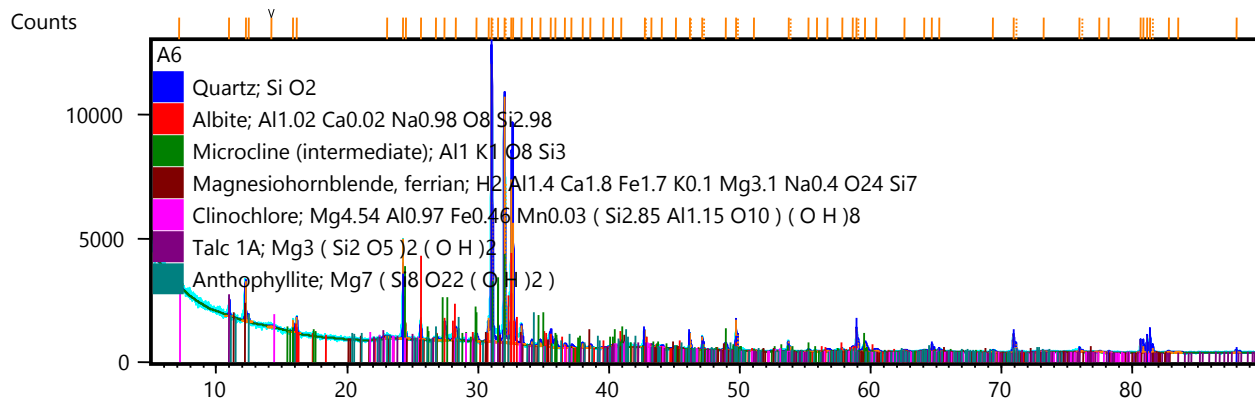
### C6: Plastic limit results for site C

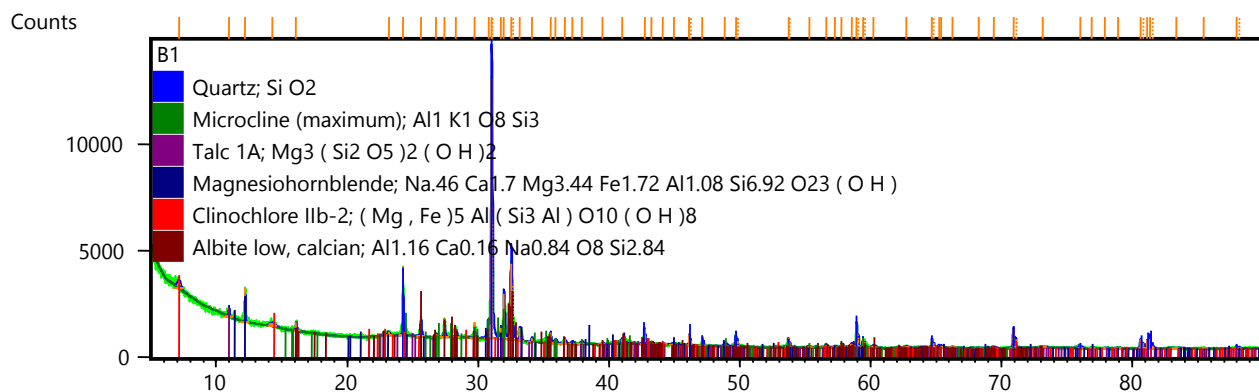
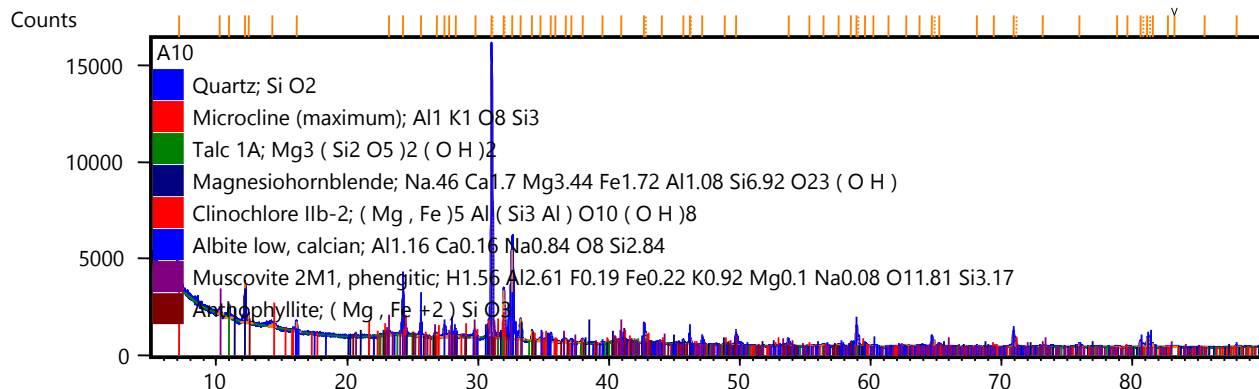
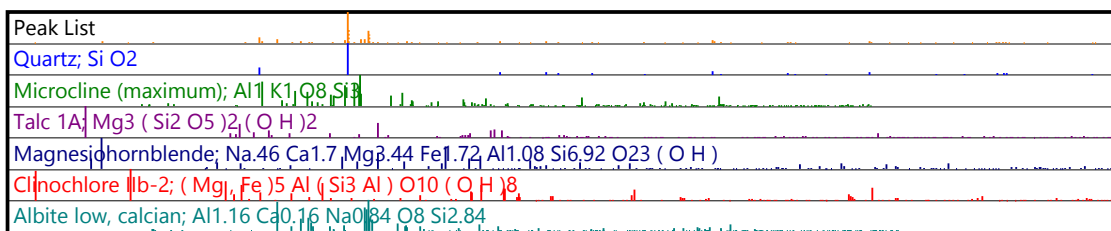
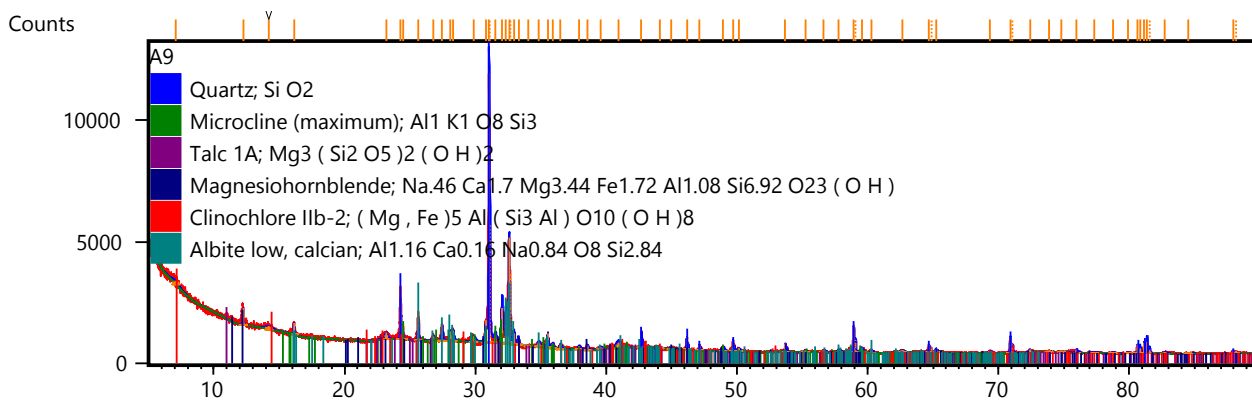
Test No.	1	2	3	4	5
Mass of can, W1 (g)	17.91	18.03	17.87	18.07	18.01
Mass of can + moist soil W2 (g)	20.88	20.49	21.04	24.83	22.73
Mass of can + dry soil W3 (g)	20.37	20.17	20.63	22.09	22.03
W2-W3	0.51	0.32	0.41	2.74	0.7
W3-W1	2.46	2.14	2.76	4.02	4.02
W%	20.73	14.95	14.86	68.16	17.41

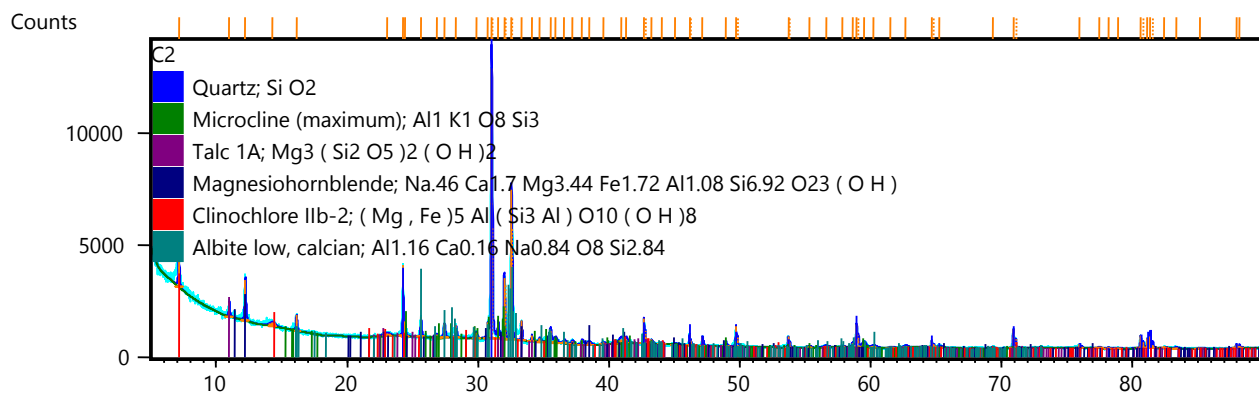
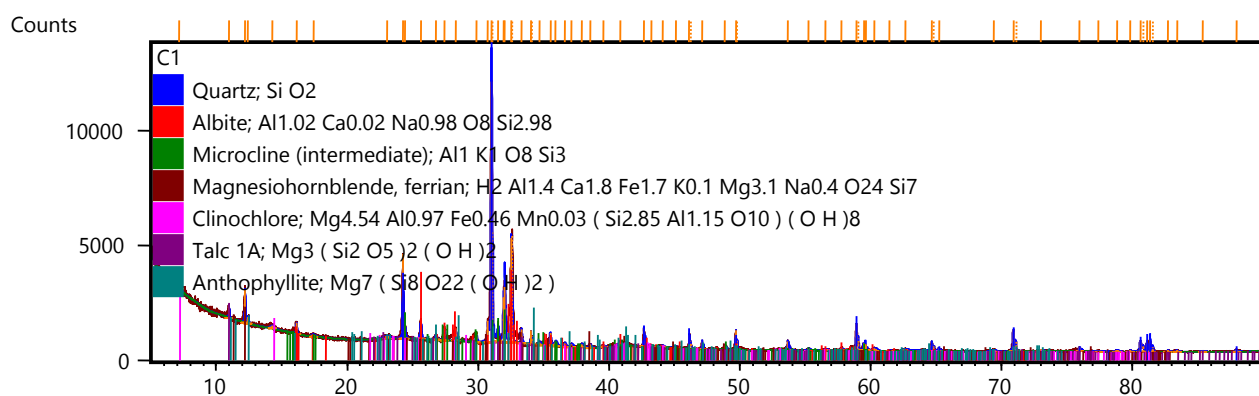
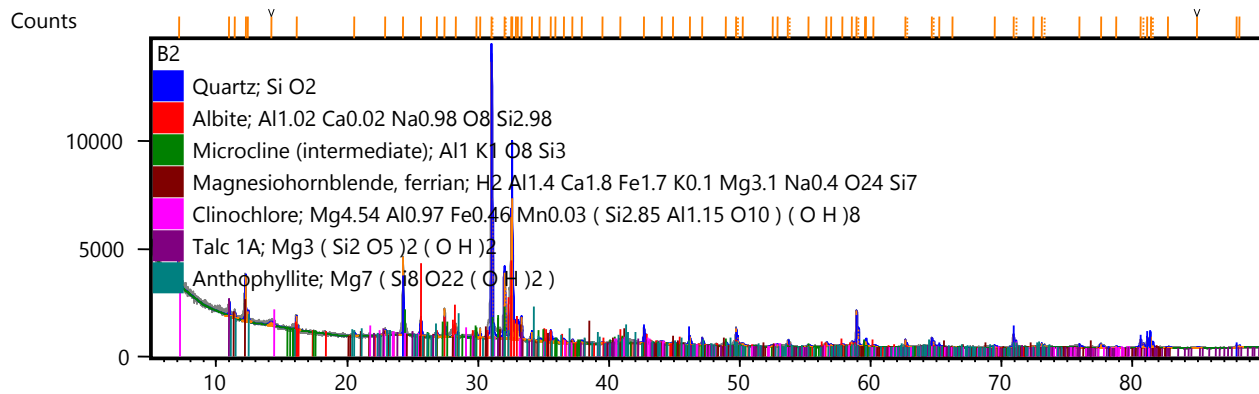
## APPENDIX D: QUANTITATIVE RESULTS OF MINERALOGICAL ANALYSIS

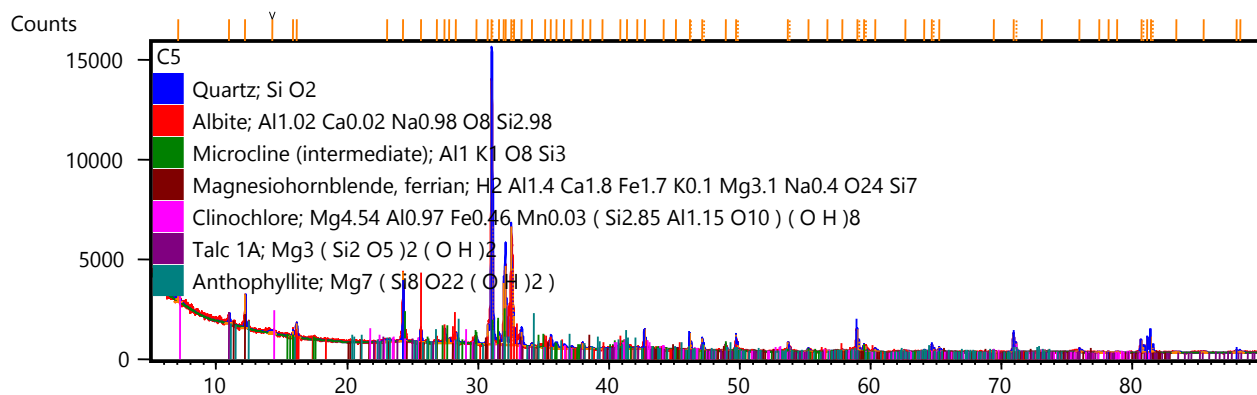
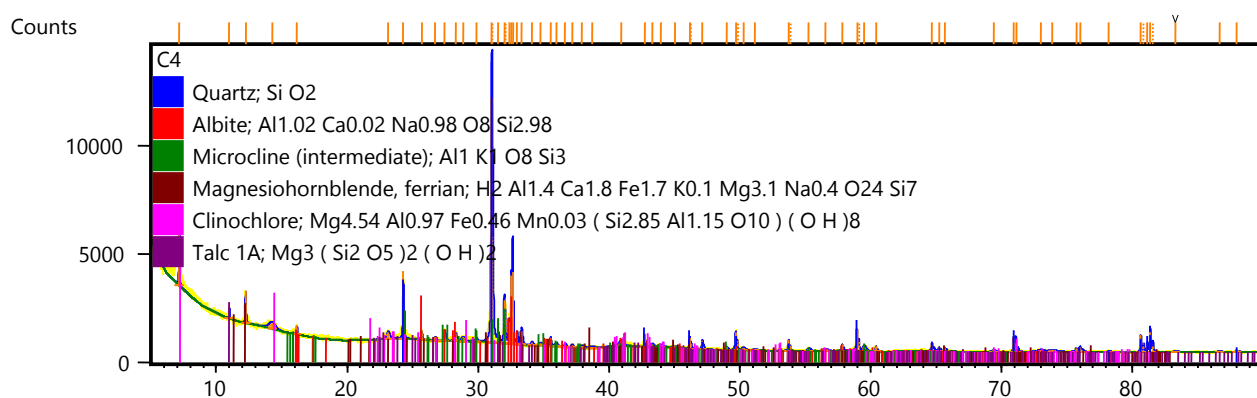
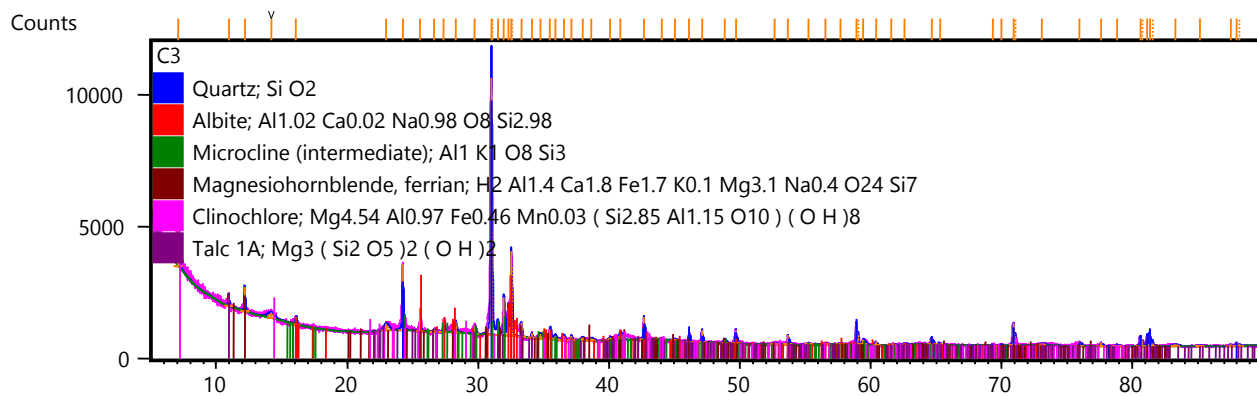


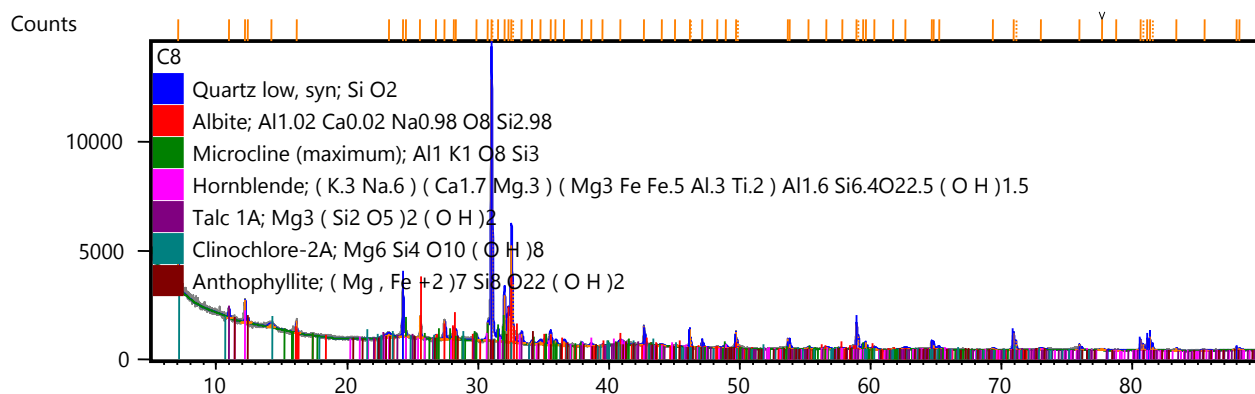
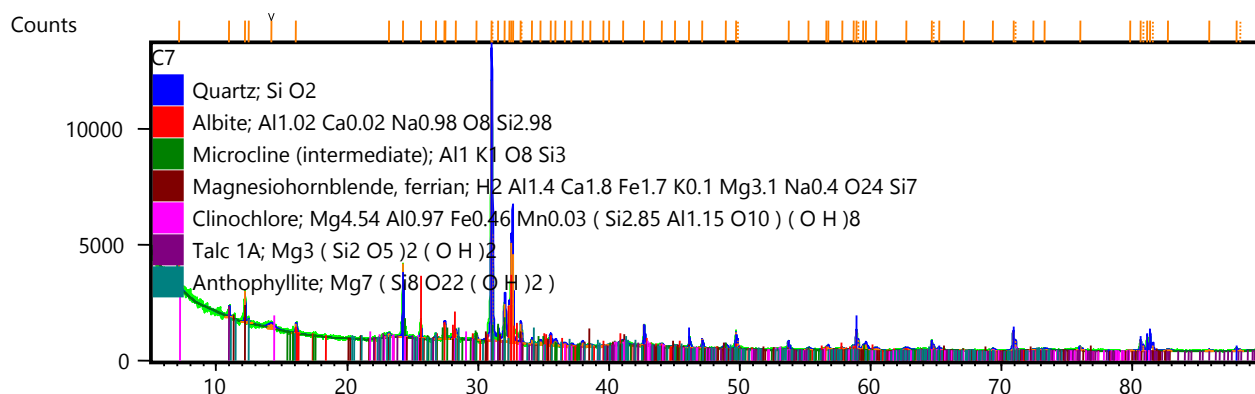
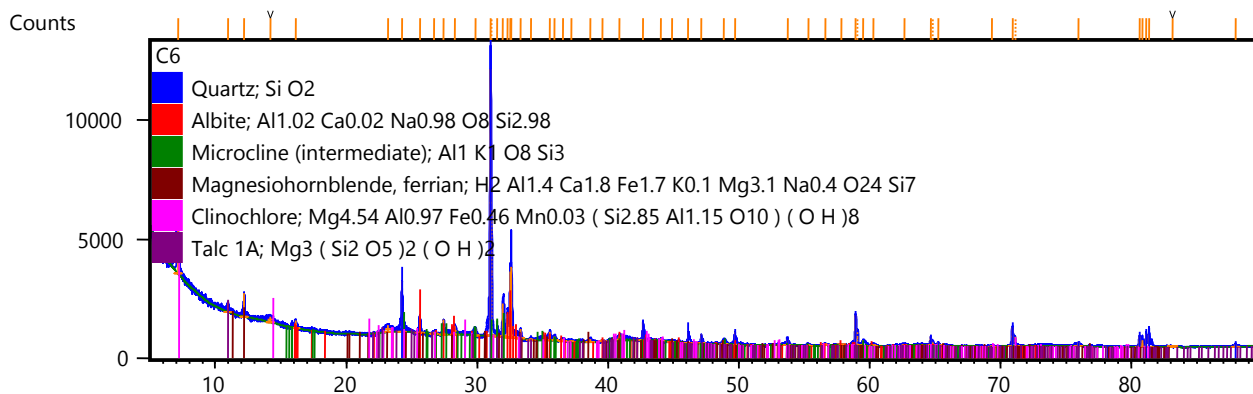












## APPENDIX E: QUESTIONNAIRE SURVEY

The following survey questionnaire was distributed to the informal small-scale clay brick manufacturing enterprises in Dididi Village. It consists of questions regarding the brick manufacturing process technology as well as implications on the final clay bricks quality.

**Consent Declaration:** I, Khensani Eullen Matsiketa, hereby declare that the information provided will be treated with high confidentiality and will only be used specifically for the purpose of this study. The respondents' identity and privacy will be safeguard and will not be exposed to any form of harm.

**Survey aim:** To understand the production process technology used to manufacture clay bricks at Dididi village, in order to explore factors affecting the quality of the clay bricks produced in the area.

### Section A: Demographic Information

#### 1. Gender

Male	
Female	

#### 2. Age

20-30	
31-40	
41-50	
Over	

#### 3. What is your highest educational qualification?

No formal education	
Primary	
Secondary	
Tertiary	

**4. How many years have you been in small-scale clay brick manufacturing enterprise?**

Less than 5	
5-10 years	
11-15	
16-20	
21-25	
Above 25	

**5. What motivated you to enter the small-scale brick manufacturing enterprise?**

Poverty	
Lack of employment	
Profession	
Other	

If the answer is other, please specify.....

**Section B: Resource Availability**

**6. Are the following resources available at the manufacturing site?**

Resources	Yes	No
Appropriate tools		
Management team		

**7. Do you have any of the following assistance?**

Assistance type	Yes	No
Financial assistance		
Technical assistance		
Management assistance		

**8. What kind of moulds do you use for shaping the bricks?**

Wooden moulds	
Metal moulds	

**9. Which type of fuel do you use for the firing of clay bricks?**

Firewood	
Coal	
Charcoal	
Other	

If the answer is other, please specify.....

**Section C: Brick Manufacturing Process**

**10. Which method do you use to manufacture your clay bricks?**

Traditional methods	
Modern(Mechanical) methods	

**11. How do you test if the raw materials are suitable for brick making?**

Field tests	
Laboratory tests	
Visual tests	
All of the above	

**12. Which method do you use for size reduction of the raw materials?**

No size reduction	
Traditional reduction method	
Mechanical size reduction	

**13. Which method do you use for preparation of the clay for brick making?**

Tempering	
Mixing	
Other	

If the answer is other, please specify .....

**14. Which method do you use for moulding/forming the bricks?**

Slop moulding	
Sand moulding	
Mechanical moulding	

**15. Which method do you use for drying your bricks?**

Mechanical drying methods	
Traditional (Sun) drying methods	

**16. What is your brick drying period?**

1-2 days	
3-4 days	
5-6 days	
7-8 days	
Above 8 days	

**17. Indicate the method you use for firing the bricks?**

Traditional (In stacks)	
In Kilns	
Mechanical oven	

**18. What is your brick firing period**

1-2 days	
3-4 days	
5-6 days	
7-8 days	
Above 8 days	

**19. How many bricks do you make per day?**

Less than 500	
500-1000	
1000-1500	
1500-2000	
2000-2500	
2500-3000	
Above 3000	

**Section D: Bricks Quality**

**20. How do you determine the quality of your bricks?**

Observation	
Touch	
Laboratory tests	
All of the above	

**21. Have you ever received complaints from the customers regarding the quality of your bricks?**

Yes	
No	

**22. Are you aware of the South African National Standard (SANS) for burnt clay masonry units?**

Yes	
No	

**23. Are you aware of product quality management?**

Yes	
No	

