

University of Venda  
School of Environmental Sciences



**Department of Hydrology and Water Resources**

Impact of rainfall events on suspended sediment load and water quality and links to sediment management in Dzindi River Catchment.

**Nemapate Muthuhadini**

**Student no.11583189**

Supervisor: Prof J.O. Odiyo

Co-supervisor: Ms R. Makungo

**A dissertation submitted to the Department of Hydrology and Water Resources in fulfilment of Masters of Earth Sciences degree in Hydrology and Water Resources.**

NOVEMBER 2016

## Declaration

I, Muthuhadini Nemapate (student number 11583189) declare that this research is my original work and has not been submitted for any degree at any other university or institution. The dissertation does not contain other persons' writing unless specifically acknowledged and referenced accordingly.

Signature.....

Date.....

## **Acknowledgements**

I would firstly like to thank the Almighty God who guided me through this journey. I would also like to thank Prof J.O Odiyo and Miss Makungo R. for their patience and encouragement towards this research. I would like to thank my father Dr. M.A Nemapate for his support and motivational words on how important this research is. I would like to thank the Nethononda, Siliga and Mammburu families for the love and support they showed through hard times, may the good almighty God bless them. I would like to thank Mr. T.R. Nkuna for his assistance in field work. I would also like to thank my two sisters Vhonani and Shumani Nemapate for the faith they had in me. I would also like to thank NRF for funding my study and SAWS for providing data.

## **DEDICATION**

This research is dedicated to my son Rilinde Nethononda.

.

## ABSTRACT

This research was aimed at determining the impact of rainfall events on suspended sediment concentration (SSC) and water quality and links to sediment management in Dzindi River Catchment, Limpopo Province. Rainfall events of different magnitudes and duration erode different sediment volumes resulting in significant variation in sediment loads of receiving water bodies. This affects the water quality of such water bodies. Water samples for water quality and suspended sediment measurements were collected after each rainfall event for periods of six and five months, respectively, in two consecutive rainy seasons. The periods were from October 2012 to March 2013 and December 2013 to April 2014. The samples were collected from selected cross-sections at four sites along Dzindi River. Physical water quality parameters or water quality indicators (pH, Electrical conductivity (EC) and turbidity) were measured with multi 340i/set multimeter and Orion Aqua Fast II turbidity meter, as they are the indicators of the overall status of the water quality. Suspended sediment concentration (SSC) for each sample was measured using evaporation method. SSC at each cross section was computed using the mean discharge-weighted formula. Field survey was undertaken to identify land use activities that promote erosion and hence sedimentation. The relationship between SSC and rainfall magnitude was determined using sediment rating curves. Water quality and sedimentation status at each cross-section together with the information from the GIS map aided in identifying and recommending the best sediment management strategies for different sites in the study area. pH values for October 2012 to March 2013 and December 2013 to April 2014 were both higher in the downstream site of the river catchment, which is Manamani site. Lowest pH was found in the upstream and mid-stream sites, which were Dzindi water treatment works (DWTW) and Tshisaulu, respectively. Tshisaulu had highest EC value and Lwandani had lowest value, respectively, for the period of October 2012 to March 2013. DWTW had the highest EC value and Tshisaulu had the lowest EC value, respectively, for the period of December 2013 to April 2014. Manamani had high turbidity value and Lwandani had low turbidity value for October 2012 to March 2013. Turbidity for DWTW for the period of December 2013 to April 2014 was the highest and Tshisaulu had the lowest turbidity value. Sediment rating curves for DWTW, Tshisaulu and Manamani, respectively, had coefficient of determination ( $R^2$ ) values of 0.185, 0.53 and 0.99, respectively. Different sediment management strategies, including slope and bank protection and minimum and mulch tillage, were recommended based on topography and land use activities and these strategies can prevent soil erosion and minimize transport of sediments into the river.

## TABLE OF CONTENT

<b>Declaration</b> .....	<b>i</b>
<b>Acknowledgements</b> .....	<b>ii</b>
<b>DEDICATION</b> .....	<b>iii</b>
<b>ABSTRACT</b> .....	<b>iv</b>
<b>ABBREVIATIONS</b> .....	<b>vii</b>
<b>List of Tables</b> .....	<b>viii</b>
<b>List of Figures</b> .....	<b>ix</b>
<b>CHAPTER 1: INTRODUCTION</b> .....	<b>1</b>
1.1 Background.....	1
1.2 Statement of problem.....	1
1.3 Justification of the study .....	4
1.4 Objectives of the study.....	5
1.4.1 <i>The main objective</i> .....	5
1.4.2 <i>Specific objectives</i> .....	5
1.4.3 <i>Research questions</i> .....	5
1.5 Characteristics of the study area .....	6
1.5.1 <i>Location</i> .....	6
1.5.2 <i>Climate</i> .....	7
1.5.3 <i>Geology</i> .....	7
1.5.4 <i>Topography</i> .....	7
1.5.5 <i>Vegetation</i> .....	8
1.5.6 <i>Pedology</i> .....	9
1.5.7 <i>Land use</i> .....	9
<b>CHAPTER 2: LITERATURE REVIEW</b> .....	<b>10</b>
2.1 Preamble .....	10
2.2 Impacts of sedimentation in river catchments .....	10
2.3 Influence of rainfall magnitude and duration on suspended sediment volume .....	12
2.4 Sediment management strategies.....	13
2.5 Sampling methods for suspended sediments discharge measurements .....	17
2.5.1 <i>Depth integrated sampling methods</i> .....	18
2.5.2 <i>Point sampling methods</i> .....	20
2.6 Surrogate technologies for suspended sediment measurements .....	21
2.7 Samplers used to collect sediment samples .....	25
2.7.1 <i>Depth integrated sampler</i> .....	25
2.7.2 <i>Point integrated sampler</i> .....	25
2.7.3 <i>Grab /Dip /Bottle sampling</i> .....	26
2.7.4 <i>Pump sampling</i> .....	27
2.8 Laboratory measurements of SSC .....	28
2.9 Sediment rating curves.....	29
<b>CHAPTER 3: METHODOLOGY</b> .....	<b>31</b>
3.1 Preamble .....	31

3.2 Data acquisition .....	31
3.2.1 Suspended sediments measurements.....	31
3.2.2 Water quality analysis.....	32
3.3 Data analysis .....	33
3.3.1 Field surveys .....	33
3.3.2 Suspended sediment concentration (SSC) computation and suspended sediments rating curves .....	33
3.3.4 Selection and recommendation of sediment management strategies.....	33
<b>CHAPTER 4: RESULTS AND DISSCUSSION .....</b>	<b>34</b>
4.1 Preamble .....	34
4.2 Potential sources of sediments and water pollution.....	34
4.4 Results of physical water quality indicators .....	44
4.4.1. pH 44	
4.4.2 Electrical conductivity (EC) .....	48
4.4.3 Turbidity.....	51
4.5 Effect of the magnitude of each rainfall event on SSCs .....	55
4.6 Sediment rating curves.....	60
<b>CHAPTER 5: CONCLUSION AND RECOMMENDATIONS.....</b>	<b>63</b>
5.1 Conclusions.....	63
5.2 Recommendations.....	65
<b>APPENDICES .....</b>	<b>77</b>

## **ABBREVIATIONS**

**EC:** ELECTRICAL CONDUCTIVITY

**SSC:** SUSPENDED SEDIMENT CONCENTRATION

**DWTW:** DZINDI WATER TREATMENT WORKS

<b>List of Tables</b>	<b>page</b>
Table 4.1: Sediment rating curves	59
Table 4.2: Coefficient of determination ( $R^2$ ) and evaluation criteria	61

<b>List of Figures</b>	<b>Page</b>
Figure 1.1: River showing brownish colour (22/10/2013)	2
Figure 1.2: Return flows from irrigation in Dzindi River Catchment	3
Figure 1.3: Villagers washing clothes in the neighborhood of the Dzindi River Catchment	3
Figure 1.4: Map of the study area map	6
Figure 1.5: Contour lines map of Dzindi River Quaternary catchment	8
Figure 1.6: Land use map in Dzindi River Catchment	9
Figure 2.1: Illustration of grab sampling method	26
Figure 3.1: Example of partitioned cross section	32
Figure 4.1: Potential source of sediments and water pollution at Lwandani	36
Figure 4.2: Potential source of sediments and water pollution at Tshisaulu	37
Figure 4.3: Potential source of sediments and water pollution at DWTW	38
Figure 4.4: Potential source of sediments and water pollution at Manamani	39
Figure 4.5: SSC in Dzindi River Catchment for the period October 2012 to April 2013	40
Figure 4.6: Bridge to Lwandani site damaged by flood	41
Figure 4.7: SSC in Dzindi River Catchment for the period of December 2013 to March 2014	42
Figure 4.8: Mean SSC in Dzindi River Catchment for the period October 2012 to April 2013	43
Figure 4.9: Mean SSC in Dzindi River Catchment for the period of December 2013 to March 2014.	43
Figure 4.10: pH values of Dzindi River Catchment for period of October 2012 to April 2013	44
Figure 4.11: pH values of Dzindi River Catchment for December 2013 to March 2014	45

Figure 4.12: Mean pH values of Dzindi River Catchment for the period of October 2012to April 2013	47
Figure 4.14: EC values in Dzindi River Catchment for the period of October 2012-April 2013	47
Figure 4.15: EC values in Dzindi River Catchment for the period of December 2013-March 2014	49
Figure 4.16: Mean EC values for Dzindi River Catchment for the period October 2012-April 2013.	51
Figure 4.17: Mean EC values for Dzindi River Catchment for the period of December 2013-March 2014	51
Figure 4.18: Turbidity values for Dzindi River Catchment for period of October 2012-April 2013	52
Figure 4.19: Turbidity values for Dzindi River Catchment for period of December 2013-March 2014	53
Figure 4.20: Mean for turbidity in Dzindi River Catchment period of November 2012-March 2013	54
Figure 4.21: Mean turbidity in Dzindi River Catchment for the period of December 2013-March 2014	54
Figure 4.22: Rainfall and SSCs for Manamani for the period of November 2012-March 2013	55
Figure 4.23: Rainfall and SSCs for DWTW for the period of November 2012-March 2013	56
Figure 4.24: Rainfall and SSCs for Tshisaulu for the period of November 2012-March 2013	56
Figure 4.25: Rainfall and SSCs for Tshisaulu for the period of December 2013- March 2014	57
Figure 4.26: Rainfall and SSCs for DWTW for the period of December 2013- March 2014	58
Figure 4.27: Rainfall and SSCs for Manamani for period of December 2013- March 2014	58

Figure 4.28: Figure 4.28: Dzindi River Catchment at Tshisaulu site during (a) dry and (b) rainy season 59

Figure 4.29: Sediment rating curves 60

## CHAPTER 1: INTRODUCTION

### 1.1 Background

Rainfall is the direct driving force for sediment production and transportation in rivers (Zhu *et al.*, 2006). Suspended sediments affect the water environment and water quality considerably (Xiaoqing, 2003). The effect has dual characteristics. From one aspect, sediment is a chief pollutant which comes from a non-point source, causing physical, chemical and biological pollution on the water body. It seriously affects the water quality and the aquatic ecological environment.

Sedimentation is the tendency of particles in suspension to settle out of the fluid in which they are entrained, and come to rest against a barrier. This is due to their motion through the fluid in response to the forces such as gravity, centrifugal acceleration or electromagnetism acting on them (Wikipedia, 2012). Land use practices are assumed to have important impacts on both the availability and quality of water resources. Land use activities such as agricultural, woodland, highway road banks construction sites and mining operation can result in sedimentation (Wikipedia, 2012). Sediment in rivers and lakes is also a concern because many contaminants can attach (adsorb) and move with the sediment particles (Roberts *et al.*, 1996). These impacts are on the quantity and quality of water in rivers and lakes. Rainfall events can cause great impact on sedimentation through runoff, where lots of sediments are transported into the rivers or any other water sources. These have great effects on rivers and change their water quality.

### 1.2 Statement of problem

Rivers in Venda region of Limpopo Province, South Africa, experience sedimentation associated with rainfall events. Dzindi River is an example of rivers that experience such problems. During the rainy season river water changes to brownish colour due to the eroded sediments that are carried by runoff into the river (Figure 1.1).



**Figure 1.1: River showing brownish colour (22/10/2013)**

Villages in Dzindi River Catchment use the river for washing clothes, feeding livestock and for agricultural purposes (irrigation). Sedimentation in this river is very high due to sediment inflow which is caused mostly by agriculture, riparian activities and poorly planned rural settlements. These sediments contain different types of contaminants, such as phosphorus (a nutrient which can cause excessive plant growth in rivers and lakes). The upper section of the river is affected by sediments from the brick yards in Tshisaulu and agricultural activities. Sediments especially from agricultural activities are likely to reduce the quality of water in Dzindi River and affect the aquatic ecosystem. Examples of land use activities that contribute to sedimentation and water pollution are shown in Figures 1.2 and 1.3.

In areas around Dzindi River people also commonly abstract water directly from the river and use it for domestic purposes without treatment. This is likely to result in health impact with associated negative socio- economic implications. The high concentration of suspended sediment in water provides the most appropriate condition for survival and multiplicity of water borne disease causing pathogens. Thus, high level of sedimentation increases water borne diseases. The suspended sediment is ultimately deposited in the bottom of the river (river bed) and reduces the capacity of the river to store water. This results in reduction in water storage capacity and impacts on the amount of water available for different uses. It also increases the flooding of the banks of

the river during high rainfall events and this has the potential to destroy infrastructure and cause harm to inhabitants and agricultural activities in the riparian zone.



**Figure 1.2: Return flows from irrigation in Dzindi River Catchment. (12/10/2012)**



**Figure 1.3: Villagers washing clothes in the neighborhood of the Dzindi River Catchment (12/10/2012)**

Rainfall events have a major impact on erosion and sediment yield as they are a key driver in the production and delivery of sediments in river catchments. The volume of sediment produced during each rainfall event depends on the rainfall magnitude and the duration of the event. Thus,

rainfall events of different magnitudes and duration erode different volumes of sediment. This results in significant variations in the load of sediment that is transported to rivers. Variations in volumes of sediment in the river cause variations in the quality of the receiving water bodies. This therefore makes the investigation of the impact of different rainfall events on suspended sediment concentration (SSC) and water quality an important study.

### **1.3 Justification of the study**

The current study is focused on determining the influence of the magnitude of each rainfall event on sediment concentration and water quality. This provides information on the extent to which rainfall magnitude and duration impact on volume of sediment generated and water quality, and their variations. Such information is useful when determining the sedimentation and water quality status of the study area. The study also maps the potential sources of sediments and contaminants that can pollute the river during rainfall periods. This is crucial in developing sediment management measures/strategies for the study area. The study further proposes suitable strategies that aid in the minimization of erosion and hence sediment yields in the study area. This makes this study of strategic importance as managing the impacts of sedimentation in the Dzindi River Quaternary Catchment will assist in the management of scarce water resources. The study will indicate the effect of land use activities in the neighbourhood of each site on SSC and potential pollution. The relationship between suspended sediments concentration and rainfall event magnitudes be determined. This type of study has not yet been conducted in Dzindi River Quaternary Catchment.

There are a few studies that have been done elsewhere focusing on investigating sedimentation and its impact on water resources and aquatic system, for example, Heikkilä (1991) studied the influence of land use on sedimentation of river delta in the Kyriinjoki drainage basin. The study found that the increase of organic matter and heavy metal content in sediment. McClanahan and Oburab (1995) studied the sedimentation effects on shallow coral communities of Kenya, Changes in land-use practices in the Sabaki River catchment basin and the study found that the coral reef cover increased significantly over time. Elliot and Flaxman (1967) studied sedimentation and its effect on water quality in New Mexico that was caused by human activities. The study revealed

that sediments limited the water used for domestic purpose, recreation, growth propagation of fish and other aquatic lives and agricultural water supply. Grobler *et al.* (1987) reviewed sediment/water quality interaction in the Vaal River system and the implications for water quality management. It was found out that Vaal River carried large sediment load. This creates the need for a study that investigates the impacts of rainfall events on SSC and water quality.

## **1.4 Objectives of the study**

### **1.4.1 The main objective**

To determine SSCs associated with individual rainfall events and land use activities and their impacts on water quality; and implications on sediment management in Dzindi River Quaternary Catchment.

### **1.4.2 Specific objectives**

- To identify and map the potential sources of sediments and water pollution in the study area
- To investigate the impact of land use activities on SSCs and physical water quality in each site.
- To measure physical water quality indicators (pH, Electrical conductivity and turbidity) after each rainfall event in order to indicate the potential water quality status.
- To determine the effect of the magnitude of each rainfall event on SSCs from different sites and compare the results.
- To recommend suitable sediment management strategies for the study area

### **1.4.3 Research questions**

- What are the potential sources of sediment and water pollution in Dzindi River?
- What is the volume of SSC in Dzindi River Quaternary Catchment?
- How do rainfall events impact on SSCs and water quality of Dzindi River?
- What are the best sediment management strategies for Dzindi River Quaternary Catchment?

## 1.5 Characteristics of the study area

### 1.5.1 Location

Dzindi River Catchment ( $23^{\circ} 01' 00''$  and  $22^{\circ} 58' 9''$  S and  $30^{\circ} 26' 8''$  and  $30^{\circ} 21' 8''$  E) is located in the Limpopo Province of South Africa about 6 km Southwest of the town of Thohoyandou, in the Thulamela Local Municipality of the Vhembe District Municipality. It is found within quaternary catchment A91E of the Luvuvhu River Catchment (Figure 1.4). The selected sampling points are Lwandani, DWTW, Tshisaulu and Manamani, these sites were selected because they are located where there are a lot of land use activities that contribute to sedimentation and water pollution.

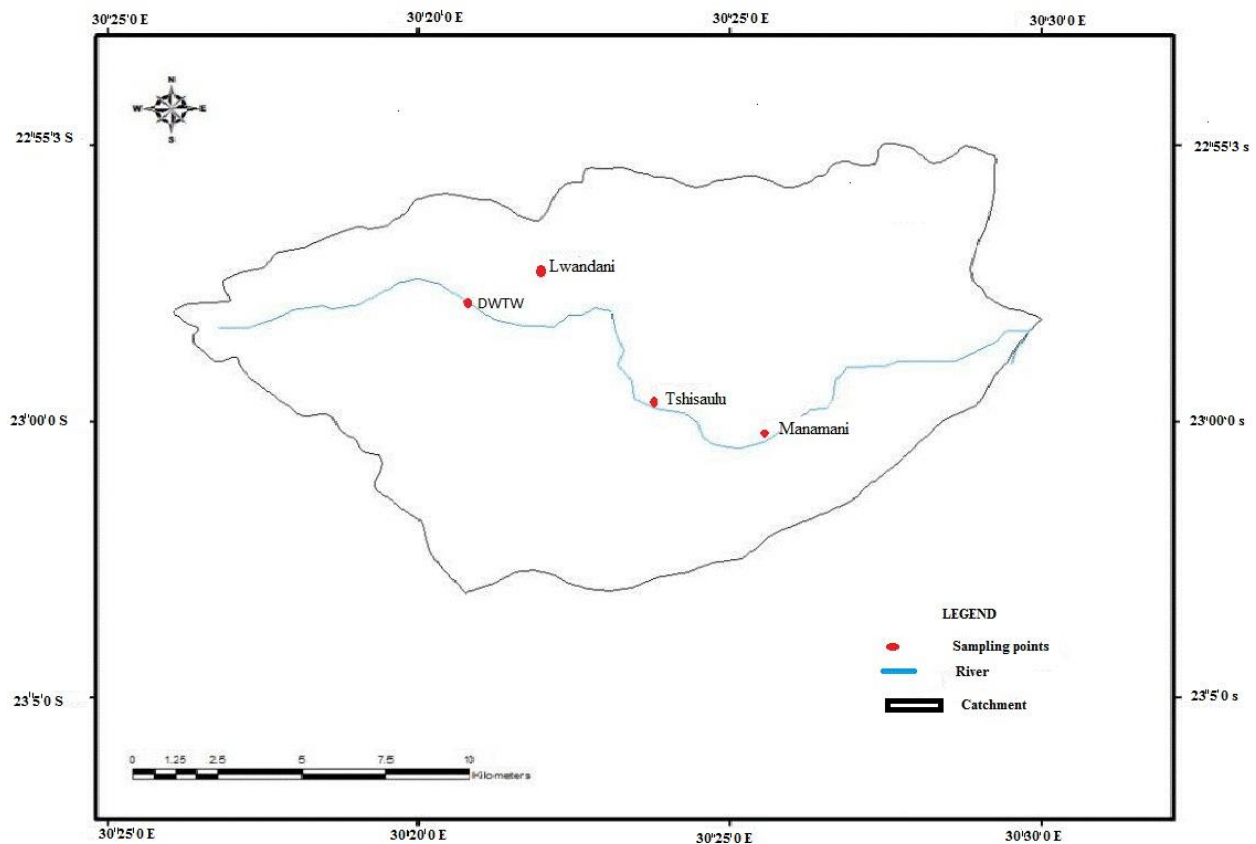


Figure 1.4: Map of the study area map

### **1.5.2 Climate**

The climate at Dzindi River Quaternary Catchment can be described as semi-arid and subtropical with a mean annual rainfall of about 700 mm and no frost (Van Averbek, 2007). Most of the rain falls during summer, from October to March. Cloudy conditions during that period limit evaporative demand. As a result, potential evapotranspiration tends to peak during early and late winter instead of summer.

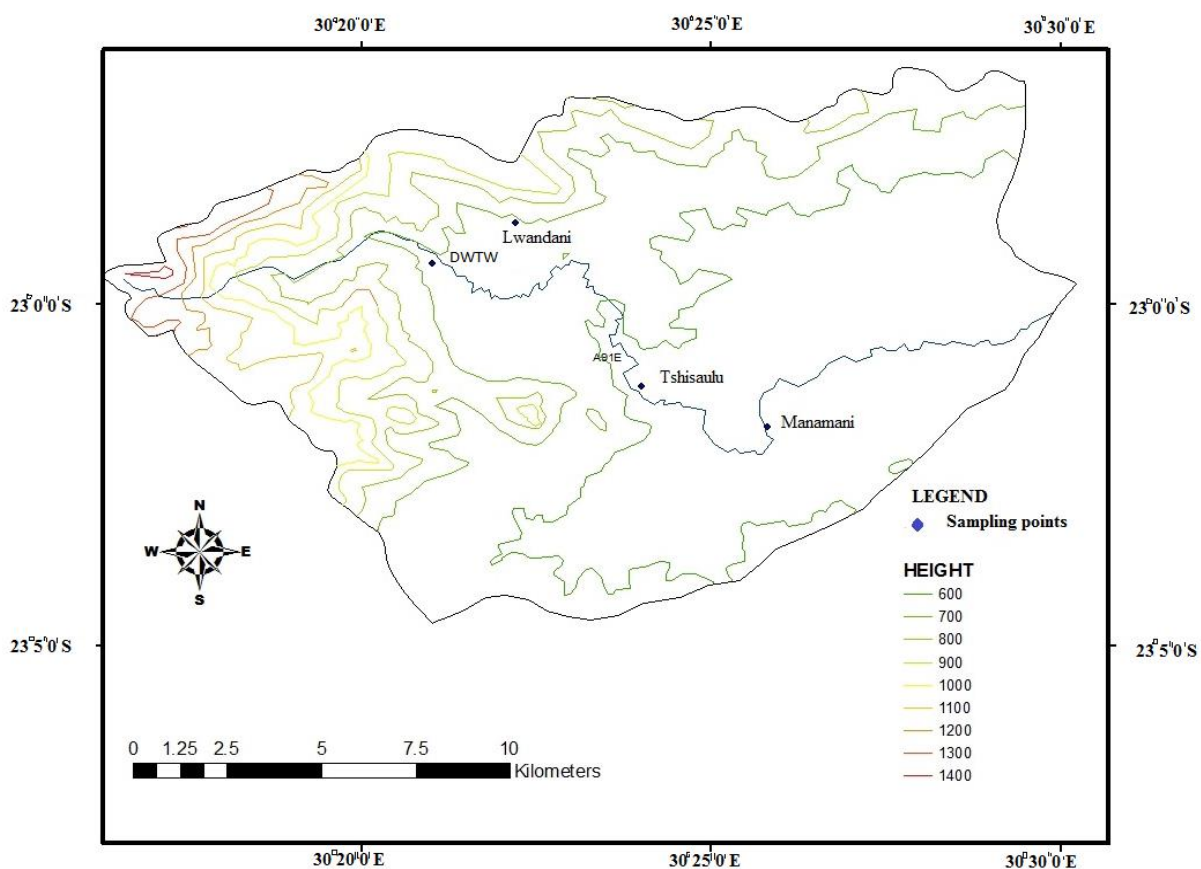
### **1.5.3 Geology**

Litho-stratigraphically, Dzindi River Quaternary Catchment is situated on the Goudplaats Gneiss unit, which is the oldest unit in the area and the base of the Swazian (Brandl, 1987). Dzindi River Quaternary Catchment is situated near the north-western edge of this unit (Department of Mineral and Energy Affairs, 1985). The rocks in this unit consist of light and dark grey biotite gneiss and migmatite. Mineralogically, the rocks in this unit consist primarily of oligoclase, quartz, biotite and hornblende (Brandl, 1987). Dzindi River flows through rocks of the Sibasa Formation, which forms part of the Soutpansberg Group. These rocks occur west of Dzindi River Catchment (Department of Mineral and Energy Affairs, 1985). The Sibasa Formation is a volcanic succession with sparse intercalations of quartzite, shale and tuff. Its thickness is estimated to be around 2000 m. The lavas are blackish or greenish black in colour and consist of altered pyroxene and plagioclase with minor amounts of olivine and opaque minerals. The groundmass is often intensely epidotised and chloritised (Brandl, 1987).

### **1.5.4 Topography**

Dzindi River Quaternary Catchment is situated about 550 m above sea level and forms part of a gentle to moderately undulating plateau found south of the Soutpansberg mountains, where the relief is considerably steeper than on this plateau. Most of the command area of Dzindi is located on hill sides and has been terraced.

Figure 1.5 shows the contour lines map around the study area showing the range of topography from the highest to lowest height above sea level (1400 to 600 m).



**Figure 1.5: Contour lines map of Dzindi River Quaternary catchment**

### 1.5.5 Vegetation

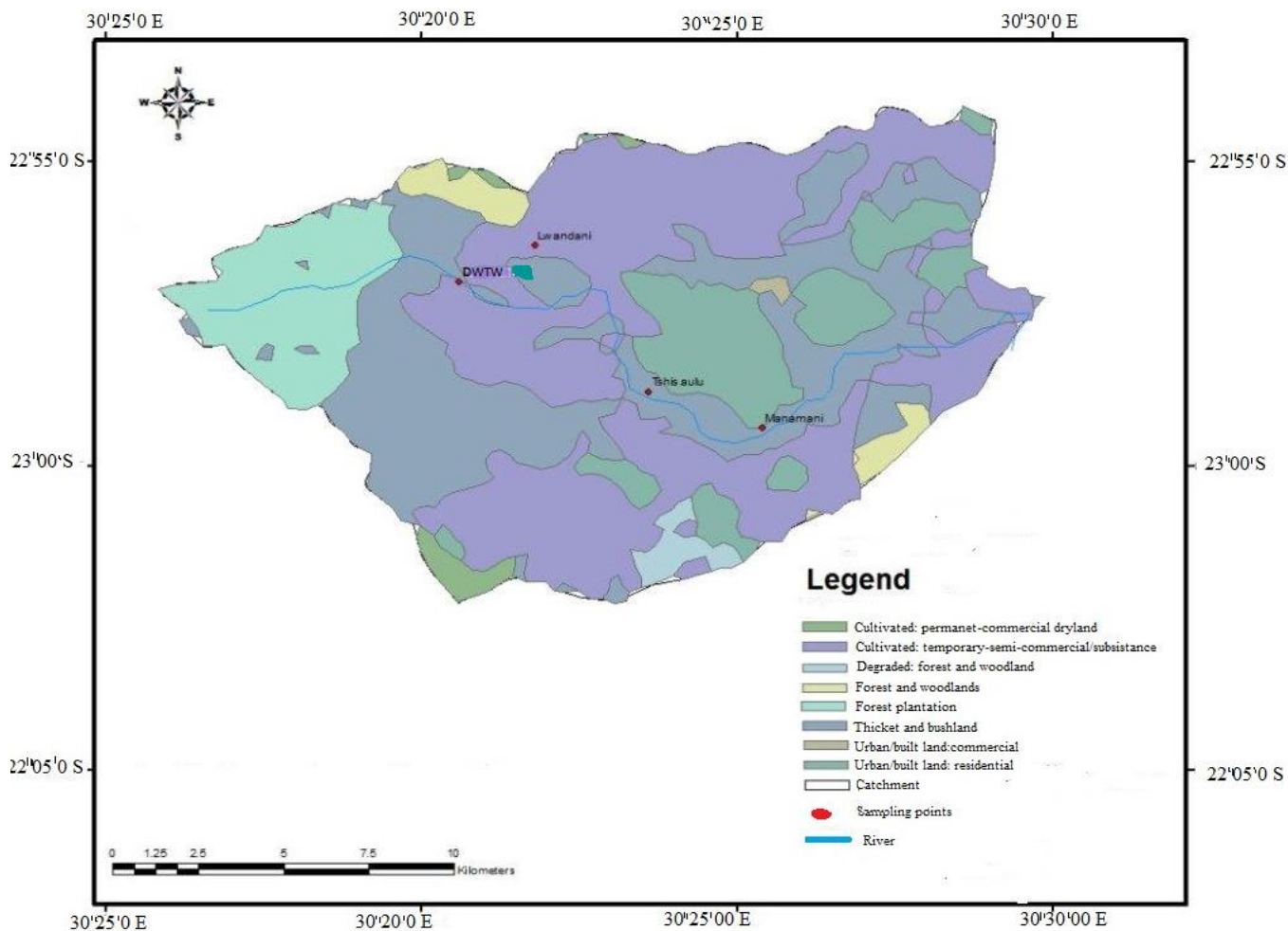
Dzindi River Catchment forms part of the vegetation unit called the North-eastern Mountain Sourveld (Acocks, 1988). Locally this unit is found along the southern edge of the Soutpansberg mountain range. It is a strongly sour, Themeda-dominated veld, which is less dense than southerly sourveld types, but the tufts may be larger. Dominant species are *Themeda triandra*, *Loudetia simplex* and *Rendlia altera*. Typically rows of *Cyathea dregei* occur along streams in the grassveld.

### 1.5.6 Pedology

There are four main soil types in the area in Dzindi River Quaternary Catchment. These are reddish brown clays, grey sands, grey clays and alluvium Reddish brown clays, which have a rooting depth of at least four feet (1220 mm) (Murray, 1951).

### 1.5.7 Land use

Figure 1.5 shows the land uses around Dzindi River Quaternary Catchment, which include agriculture and rural settlements. There are land use activities such as poor settlement, planting of crops, brick making and irrigation of trees.



**Figure 1.6: Land use map in Dzindi River Catchment:**

## **CHAPTER 2: LITERATURE REVIEW**

### **2.1 Preamble**

This chapter reviews previous studies on the impacts of sedimentation in river basins or catchments; sedimentation management strategies and influence of rainfall magnitude and duration on sedimentation volume. Methods used to measure and analyse sedimentation volume and develop sediment rating curves have been reviewed.

### **2.2 Impacts of sedimentation in river catchments**

Most rivers and streams around the world are affected by sedimentation. Sediments can be washed from the land into rivers and streams during periods of heavy rainfall. Activities that disturb soil and expose it to rainfall will allow sediment to be transported and deposited to nearby rivers. Many human activities like road construction, stream disturbance, land clearing and industrial processes have a lot of potential to increase sediment level (NRE, 2001). The increased levels of sediment can reduce the quality of water and habitat in freshwater ecosystems. Heikkilä (1991) studied the influence of land use on sedimentation of river delta in the Kyriinjoki drainage basin. The aim of the study was to determine the effects of human activities in the drainage basin on sedimentation rates and sediment quality in the delta of the River Kyriinjoki. Sediment samples were analyzed for organic content and heavy metals (iron, manganese, lead, cadmium, copper and zinc). The study found that the increase of organic matter and heavy metal content in the sediment over recent decades was evidently due to the increased intensity of agriculture, forestry and peat harvesting in the drainage basin.

Suspended sediments can alter taste, odour, temperature and abrasiveness of water (Oschwald, 1972) and reduce levels of dissolved oxygen particularly in deeper, thermally stratified lakes (Appleby and Scarratt 1989; Cramer, 1974). Increases in sediment inputs have also been noted to decrease pH at the substrate-water interface of streams (Lemly, 1982). A decrease in water clarity is another obvious change resulting from an increase of suspended solids.

McClanahan and Oburab (1996) studied the sedimentation effects on shallow coral communities of Kenya. Changes in land-use practices in the Sabaki River catchment basin were found to increase soil erosion and river-sediment discharge into coastal waters around Malindi, Kenya. Turbidity was found to have much impact in coral communities. The study found that the coral reef cover increased significantly over time. Lastly there was no evidence for decreased diversity and ecological health of sediment influenced reefs.

Elliot and Flaxman (1967) studied sedimentation and its effect on water quality in New Mexico that was caused by human activities. The study revealed that sediments limited the water used for domestic purpose, recreation, growth propagation of fish and other aquatic lives and agricultural water supply.

Waters (1995) studied effects of sedimentation on biodiversity in rivers and streams of the Southeastern United States wherein impacts on aquatic ecosystems resulted from excessive sedimentation and turbidity. Sediments that were filled with interstices of gravel and cobble stream bottoms greatly decreased the spawning areas for many fish species and the habitat for macro invertebrates, which served as food for many fish species (National Technical Advisory Committee, 1968).

Deforestation may increase erosion. In Malaysia, streams from logged areas carry 8 to 17 times more sediment load than before logging (Falkenmark and Chapman, 1989). The actual soil loss, however, depends largely on the use to which the land is put after the trees have been cleared. Surface erosion from well-kept grassland, moderately grazed forests and soil-conserving agriculture are low to moderate (Bruijnzeel, 1990). Road construction may be a major cause of erosion during timber harvesting operations. In the USA, forest roads are estimated to account for 90 percent of the erosion caused by logging activities (Brooks *et al.*, 1991). Grobler *et al.* (1987) reviewed sediment/water quality interaction in the Vaal River system and the implications for water quality management. It was found out that Vaal River carried large sediment loads. The major impact was found to be turbidity which was accompanied by the increased salinity in the lower Vaal River. The study also discussed the implications for management of water quality in the Vaal River system wherein high priority was placed on maintaining and improving water quality in the Vaal River system

### **2.3 Influence of rainfall magnitude and duration on suspended sediment volume**

Flood magnitude and duration are important for understanding the impacts of floods on erosion, sedimentation and river morphology (Wolman and Miller, 1960). A single extreme rainfall event can produce more sediment than a number of small to moderate rainfall events during the year (Van Zyl and Lorentz, 2003). Short duration flood with a high discharge produces more damage than small, less intense floods. Floods of long duration transport more sediments than a flood of the same magnitude but for short duration and when these two factors combine, they result in major erosion, sedimentation and morphologic change in the channel system (Wolman and Miller, 1960). Conversely, if only magnitude or duration is maximized, a flood may result in relatively modest impacts on the river system.

Wolman and Miller (1960) used a unique approach to investigate the effectiveness of streams in transporting sediment and whether events of high magnitude and low frequency, or events with a moderate magnitude but high frequency, are more responsible for the majority of sediment transport in rivers. Their research concluded that a stream tends to transport most of its suspended sediment load over a range of discharges, with the most effective discharge being of moderate magnitude and having a fairly frequent rate of occurrence, usually once to twice per year.

Van Zyl and Lorentz (2003) selected the highest two daily rainfall amounts out of the 21 and 14 years of available records for Kokstad and Mtunzini stations, respectively, to analyze the effect of large storm events on predicted sediment yield. The option of the Water Erosion Prediction Projects (WEPP) model to run in a single storm mode was invoked to predict the contribution of extreme rainfall events to sediment yield in relation to average predicted annual sediment yield. The information that was required by the WEPP model to run in a single storm mode was the storm amount, duration, maximum intensity and percentage of storm duration to peak. The selected extreme events comprised several showers of high and low rainfall intensities during the day which could not be dealt with in the single storm mode of the WEPP model. One of the major advantages of the WEPP model is that single storm events could be simulated in addition to the continuous simulation mode.

Mwamba and Torres (2002) studied the effects of rainfall on marsh sediment redistribution in north inlet, South Carolina and the study was based on the terrestrial landscapes showing that raindrop impacts on sheet flow entrain and transport sediment. Sprinkler irrigation experiments were

conducted during low tide to examine the sediment transport processes and sediment fluxes resulting from low tide rainstorms. Its findings were that sediment transport was influenced by raindrop impact and transferred by sheet flow.

Rodríguez-Blanco *et al.* (2008) studied the suspended sediment-discharge hysteresis during rainfall events in a small headwater catchment in the NW Spain. Hysteresis types of the discharge-suspended sediments concentration relationships of four single rainfall events were produced at different times of the year and the relationships between the hysteretic loops and the associated source areas were identified. Significant variations in the concentration and sediment load were found between events. Relationship between discharge and suspended sediment concentrations during all events was characterized by positive hysteresis meaning there was suspended concentration in the stream. The results were that the suspended sediment was higher at a given discharge on the rising limb of the hydrograph than at the same discharge on the falling limb.

Schulz (2000) studied rainfall-induced sediment and pesticide input from orchards into the Lourens River, Western Cape, South Africa. In this study, the importance of a single heavy rainfall event occurring within the spraying season was investigated with regard to pesticide and sediment input. Standard sampling procedure during the rainfall event included measurement of discharge and total suspended solids (TSS) as well as collecting of water and suspended sediments for pesticide analysis at all sites. The study found that runoff events lead to increase in TSS levels exceeding the target water quality range.

## **2.4 Sediment management strategies**

Sediment management refers to the optimum use of various sediment resources (littoral, estuarine, and riverine) in an environmentally effective and economically feasible manner (Syde *et al.*, 2010). SedNet (2006) explained that sediment management can also be useful to secure human activities and environmental objectives, and should be subjected to different legal requirements so that sedimentation management plans should be developed. Sediment management plan probably aims to provide a tool and an opportunity to proactively identify and minimize conflicting uses for sediment such that more sediment can be made available by proper management (Syde *et al.*, 2010).

The issues faced by sediment managers are complex; the problems involve a large number of variables, the systems involved are dynamic, and the uncertainties associated with them are large and often dominate the decision-making process (Apitz, 2008). To balance all these, sediment management plans (SMP) should be developed. Broad Authority (2007) developed a sediment management strategy that provides an overview of the challenges in managing the Broads Waterways to be able to target resources effectively. The strategy was achieved by compiling a comprehensive assessment of the sediment within the rivers and broads (using information from a hydrographic survey, a desk based study of sediment inputs, sediment quality data and information from stakeholder consultations on user requirements) to enable the Broad Authority to take a proactive, rather than a reactive approach to the sediment management.

Syde *et al.* (2010) reviewed new approaches to sediment management on the Inner Continental Shelf Offshore Coastal Louisiana including the Louisiana Sediment Management Plan (LASMP). The LASMP was expected to provide an inventory of potential sediment/sand resources, along with sediment needs, in order to develop regional strategies for better planning. This plan was expected to evaluate the competing needs for sediment while facilitating cooperation among stakeholders. The overarching goal of this plan was expected to enhance abilities to make informed, cooperative management decisions for an effective restoration and protection strategy. Sediment data management was a crucial element of this plan.

According to Apitz and Power (2002) sediment management strategies can be categorized into five broad groups which are selected based upon an evaluation of site specific risks and goals:

- No action. This category is only appropriately applied if it is determined that sediment poses no risk.
- Monitored natural recovery. This is based on the assumption that while sediment poses some risks, it is low enough that natural processes can reduce the risks over time in a safe manner.
- In situ containment. In this process, sediment contaminants are in some manner isolated from target organisms, though the sediments are left in place. It does not require landfill.
- In situ treatment
- Dredging or excavation. In this process, physical and mechanical methods are applied and these processes may require landfill.

### **2.4.1 Sediment management strategies in river catchments**

There are a number of sediment management strategies which can be applied within the reservoir and river catchment. However, the current study will only review sediment management strategies within the river catchment. Strategies that are used to prevent sedimentation in river catchments include soil erosion control/conservation, slope, bank protection and settling basins.

- **Soil erosion control/ conservation**

Soil erosion control/conservation is a complex engineering method to promote sustainable development of agricultural production and social economies. It concerns a number of aspects such as environment, scientific techniques, economies, societies, policies and regulations (Xiaoqing, 2003). Soil conservation methods are used to prevent the soil from getting eroded and preventing it from losing its fertility (Soil Conservation Strategies, 2012). Soil conservation is capable of greatly reducing runoff, soil-loss rates and sediment yields from small basins which are highly impacted by agriculture and/or erosion (Erskine and Saynor, 1996).

The soil erosion control/conservation methods can be divided into several categories which include rotation, tillage, and minimum and mulch tillage. All these techniques assist in reducing runoff that can transport sediments in water.

- **Rotations**

Rotation assists in erosion control by ensuring that soils are not exposed to the same risks each season (soil conservation strategy, 2012). Differing crop plant covers, growing period and rooting densities, especially when periods of grass cover are incorporated, help to reduce erosion and increase the binding organic matter content of soils (soil conservation strategy, 2012).

- **Minimum and mulch Tillage**

Tillage helps to increase infiltration and reduce runoff and soil loss, at least for a short time, (soil conservation strategy, 2012). However, excessive tillage destroys the natural structure of soils and exposes organic matter to oxidation. Thus, a balance must be made between sufficient tillage to achieve a good growing environment for crops and too much tillage which can lead to soil crust development and enhanced runoff (soil conservation strategy, 2012). Ploughing depths should be

varied to reduce the risk of a hard plough pan forming beneath the soil surface (soil conservation strategy, 2012). Minimum tillage can give better erosion control. Mulch tillage involves covering the soil surface with suitable residues and can reduce runoff and soil losses considerably.

UNESCO (2011) studied that Tillage Yellow River Basin in china has the most significant impact on soil structure, by breaking up the soil and leaving it vulnerable to wind and water erosion. there has been significant progress in banning tillage on almost 5% of all farmland in the Loess Plateau. This 5% accounts for the farmland designated as unsuitable for tillage, because its slope is greater than 250 and it is often converted into forest or improved pastures for livestock. Terracing of farmland and the building of horizontal ditches to trap sediment are other ways in which agricultural soil loss is being reduced in China.

- **Slope and bank protection**

Slope and bank protection measures minimize soil erosion and reduce sediment loads to streams and reservoirs. These include traditional (structural) methods which use steels, woods, rocks or other aggregate, concrete, or a combination of these materials to protect the stream bank and bioengineering methods which use grasses, trees or other living plants to restore natural stream bank protection (USDA, 1992). Vegetative buffers are intended to intercept overland soil run-off before it enters a water body as well as stabilize stream banks and shorelines to prevent erosion. The effectiveness of vegetated buffers depends on their width as well as the types of vegetation, soils, slopes and surrounding activities (USDA, 1992). Soil bioengineering, in the context of upland slope protection and erosion reduction, combines mechanical, biological, and ecological concepts to arrest and prevent slope failures and erosion (USDA, 1992).

Lewis *et al.* (2001) illustrated the application of bioengineering methods in 3 sites (Lost Creek, Raymond and Chelan) in Washington. The study concluded that when technically feasible, soil bioengineering alternatives can be adopted to produce equal or better economic and environmental results than the traditional geotechnical solutions alone. Li and Eddleman (2002) discussed their applications, costs and strength matrices. The study concluded that the biotechnical methods can offer ecologically focused alternatives to traditional practice.

- **Sediment/Settling basins**

Sediment basins consist of settling ponds with a structure for controlled overflow release and are designed to store a pre-determined quantity of runoff, allowing the runoff to be gradually released after most sediment has settled down (UNEP, 1994). Settling basins are often constructed in catchments to limit gully erosion (International Sediment Initiative, 2011). Settling basins operate on the principle of forcing sediment to deposit through a significant reduction in velocity (Raju and Kothiyari, 2004). Ranga *et al.* (1999) studied sediment removal efficiency of settling basins. Experiments were carried out on sediment removal efficiency of settling basins. (UNESCO, 2011) reported that Yellow River basin engineering in China measurements for sediment control have been widely used and include the construction of structures to trap sediment on slopes, and within rivers.

The disadvantage of sediment basins is that they are expensive to build and require regular maintenance and cleaning and they do not remove the bulk of fine silts and clays unless used in conjunction with other erosion and sediment control practices (UNEP, 1994). Another problem with settling basins is finding a place for continuous, long-term disposal of incoming sediments which accumulate indefinitely (Oehy, 2003).

## **2.5 Sampling methods for suspended sediments discharge measurements**

Suspended sediment discharge over an entire cross-section is usually measured by dividing the cross-section into a number of sections. Sediment discharge passing through each section is obtained by taking measurements along the vertical within the portion of the section it represents. It has been shown by field data that the vertical distribution of sediment concentration for various size groups is quite different (Xiaoqing, 2003).

There are four most common sampling methods for suspended sediments discharge measurements in streams which are the depth integrated, point integrated, grab and the pump sampling. Depth integrated and the point integrated sampling methods are used to measure vertical distribution of suspended sediments.

### 2.5.1 Depth integrated sampling methods

These are methods used to measure suspended sediments by taking samples in a cross section. These include transverse distribution of concentration, equal width increment (EWI), equal discharge increment (EDI), multipoint and multi vertical and simplified methods.

- **Transverse distribution of concentration method**

In this method the number of verticals required for sediment discharge measurements depends on the size distribution and concentration distribution of the sediment, as well as on the desired accuracy of data acquisition (Xiaoqing, 2003). Verticals should be spaced closely in zones with large transverse variations in sediment concentration and in the main currents. In measuring sediment discharge, it is usual to measure the velocity simultaneously with the sediment concentration.

- **Equal discharge increment (EDI)**

In this method, verticals are arranged according to the distribution of water discharge across the section (Xiaoqing, 2003). Each sampling vertical represents approximately an equal portion of discharge. The transit rate for each vertical may not be equal, but the sample volume for each vertical should be kept approximately equal.

This method requires that a complete flow measurement be carried out across the cross-section of the river (Ongly, 1996), before samples for suspended sediments measurements are collected. Using the results, the cross-section is divided into five (more on large or complex rivers) increments (i.e. vertical sections) having equal discharge. The number ( $n$ ) of increments is based on experience. Depth integrated suspended sediment sampling is carried out at one vertical within each of the equal-discharge-increments, usually at a location most closely representing the centroid of flow for that increment. The mean discharge-weighted SSC is obtained by taking the average of the concentration values ( $C$ ) obtained for each interval ( $i$ ) using the equation:

$$SSC = \frac{\sum_{i=1} C_i}{n} \quad 2.1$$

The discharge-weighted suspended sediment load (SSL), in tones per day, for the river cross-section is obtained by multiplying the concentration,  $SSC$ , in ppm (mg/L) by the discharge,  $Q$ , in  $m^3/s$  of each equal-discharge- increment,  $i$ , and summing for all increments (Equation 2.2)

$$SSL = \sum (C_i Q_i) 0.0864 \quad 2.2$$

The disadvantages of this method include that it is very time-consuming, and the flow of the river must be known. The advantages include that it gives accurate results and cross sectional variation in concentration can be determined if samples are analyzed individually (Garcia, 1959).

- **Equal width increment method (EWI)**

This method is used without making flow measurements and is usually used in small to medium rivers and especially rivers that are shallow enough for wading (Ongly, 1996). The Guide to Hydrological Practices (WMO, 1994) suggested that the whole width be divided into six to ten equal segments for taking depth integrated samples. The equal width increment (EWI) is also referred to as equally spaced verticals method (Xiaoqing, 2003). At the deepest point, the operator takes a depth-integrated sample, noting the transit rate of the sampler (i.e. the uniform speed, at which the sampler is lowered, and then raised to the surface). Using that same transit rate, a suspended sediment sample is then taken at each of the intervals. Because each vertical will have a different depth and velocity, the sample volume will vary with each vertical sampled.

Lietz *et al.* (2005) studied the two types of water samples in Florida that were collected at the C-51 Canal during each sampling event: point samples (at the turbidity probe) and cross-sectional samples (at the bridge). Water samples at the probe were collected using a Van Dorn sampler which consists of a chamber that can be remotely closed to contain a sample at the desired depth. Depth and width-integrated samples also were collected using the (EWI) method at the stream cross section upstream of structure S-155 at the U.S. Highway 1 Bridge. By this method, the stream cross section was divided into equal intervals, and a sampling vertical was established in the center of each interval meaning that the three to five intervals in the cross section were usually sufficient to collect a representative water sample.

All samples are composited into a single container which is then agitated and sub-sampled, usually two or three times, and analyzed for SSC. The average of these analyses is the mean cross-sectional SSC. In this method, the results are corrected for differences in discharge at each section by virtue of using the same transit rate (and the same nozzle diameter) at all sections i.e. a shallow section with less discharge will produce a proportionally smaller suspended sediment sample than a deep section having greater discharge (Xiaoqing, 2003).

The mean discharge-weighted SSC in a cross section using EWI method is calculated from mean concentration from individual sample. The mean discharge weighted suspended sediments is calculated as follows (Garcia, 1959)].

$$C_{xs} = \frac{\sum_{j=1}^J Vol_j C_j}{\sum_{j=1}^J Vol_j} \quad 2.3$$

Where  $C_{xs}$  is the mean discharge weighted SSC in cross section, J is total number of sampling bottles used in the EWI measurements,  $C_j$  is the concentration in sample bottle j, and  $Vol_j$  is the total volume of water collected in sample j.

Advantages of this method include that the flow of the river must not be known to take measurements (Garcia, 1959). This method is easy to learn and use due to the straight forward spacing of vertical segments based on streams width as compared to the cross sectional distribution of discharge and less total time is required on site. The disadvantage is that it is not as accurate as the EDI.

### 2.5.2 Point sampling methods

- **Multi-point and multi-vertical methods**

These methods are used to determine as accurately as possible the sediment concentration, size distribution and sediment discharge along a vertical and across the entire section of a stream (Xiaoqing, 2003). They also provide the basis for simplified measuring methods. In multi- point

and multi-vertical methods, the basis for selection of the number of verticals to be sampled is mainly intuition. Generally, two to five depth-integrated samples are collected in the cross section usually, only three verticals (Guy and Norman, 1970).

Edwards and Glysson (1999) used this method to collect single vertical and multi-vertical, suspended-sediment samples at upper Yuba River gauging stations following standard USGS procedures. Single vertical samples were collected 1 to 7 days per week, depending on hydrologic conditions, with increased frequency of sampling during periods of higher stream flow. The samples were analyzed to determine SSC. Multi-vertical cross-section samples, collected approximately monthly, were used to determine a coefficient to account for discrepancies between the mean suspended-sediment concentration of the single vertical samples and that of the entire cross section in a study by Curtis *et al.* (2006).

- **Simplified method**

During a flood, adequate sampling using conventional methods may not be carried out due to rapid changes in both discharge and sediment concentration (Xiaoqing, 2003). Hence, there is a need to develop a sampling method of greater ease and simplicity of operation to take samples to define the temporal variation of concentration during the entire flood (Xiaoqing, 2003). Simplified method also is referred to as the index-sampling method and in the USA it is called the Box method. In small streams, structures already in existence or build can be utilized to take sediment measurements by installing index sampling apparatuses or *in situ* instruments and these devices can be used to monitor the variations in sediment concentration during flash floods (Xiaoqing, 2003). Its disadvantage is that the simplified method is only used during floods.

## **2.6 Surrogate technologies for suspended sediment measurements**

There is considerable difficulty and expense in sediment measurement. Some of the expense is due to the fact that streams carry more than 50% of their total sediment transport during flood events (Nelson and Benedict, 1950). Since these large flows often occur at night and are hard to predict,

it is difficult to obtain sediment samples unless some type of automated measurement system is used. Even under good conditions, the time and labour inherent in sediment sampling add to its expense. In addition, traditional forms of sediment measurement where sediment samples are taken in the field and analyzed in a laboratory may accumulate errors in sampling and computation as large as 20% (McHenry *et al.*, 1967)

- **Optical method**

Optical backscatter sensors (OBS) are used to predict SSC in rivers if particle size and sediment colour remain fairly constant (Schoellhamer and Wright, 2003). Optical method offers two possibilities, which are scattering and transmission. Transmission systems were developed for determining total suspended matter or turbidity in marine environment. They show minimum disturbance to flow but require frequent calibration using the sediment present in the area. Diatoms, algae, and organic detritus cause turbidity in the water column, as they cannot be distinguished from suspended sediment (Schoellhamer and Wright, 2003). The sensors are very sensitive to biological fouling. Optical backscatter sensors response to varying concentrations of homogeneous sediments is nearly linear. Its design is simple, compact and capable of measuring much higher particles concentration (IAEA, 2005).

Optical backscatter sensor was calibrated successfully to measure discharge-weighted, cross-sectional averaged suspended-sediment concentration, using the equal discharge, and width-increment methods and an isokinetic sampler in the Sacramento River at Freeport in California in a study by Schoellhamer and Wright (2003). Correction for sensor drift was applied to the 3-year time series. However, the calibration of an optical backscatter sensor used in the Colorado River at Cisco, Utah, USA, was affected by particle-size variability (Schoellhamer and Wright, 2003). Haimann *et al.* (2011) used optical turbidity sensors within the Danube River to record the SSC continuously at one point of the river. The study found that the data was dependent on grain size and had to be calibrated with water samples taken close to the sensor. Curtis *et al.* (2006) used OBS to assess event-based suspended sediment transport in the upper Yuba River watershed, California. Streamflow and suspended-sediment concentration (SSC) samples were collected at four gauging stations. Event-based suspended-sediment loads were calculated using seasonal SSC rating curves and compared with loads calculated using calibrated OBS output.

The disadvantage of the OBS is that they need maintenance and cleaning regularly (Curtis *et al.*, 2006). The advantage is that OBS data can provide a more accurate estimate of suspended-sediment transport (Curtis *et al.*, 2006).

- **Nuclear methods**

Nuclear method includes the use of probes (scattering and transmission principles) and artificial radioactive tracers. Nuclear techniques have played a major role in recent years notably in the use of radiation probes for measuring very high densities of suspended sediment. The nuclear tracers generally used are gamma emitters. The choice of tracers depends on the duration of the experiment and nature of the sediment. Tracers are not used for the determination of the suspended sediment concentration but for measuring dynamics of the sediment in flow (IAEA, 2005).

Xhi *et al.* (1981) developed field application of three types of nuclear sediment concentration gauges successfully for use on the Yellow River. The three gauges differ mainly in the construction of the probes. They have been developed to meet the particular requirements of the sediment regime of the Yellow River. Emphasis was placed on increasing the rate of impulse-counting, reducing statistical errors and improving the sensitivity of the devices while using low energy sources. Preliminary results from the use of these gauges on the Yellow River were encouraging and support the extension of their use on this river.

The advantages of this method are that it is reliable and do not need much man power (IAEA, 2005). Nuclear method measurements can be carried out without interruption and practically without disturbance to the fluid, thus giving more reliable data than can normally be obtained by other sampling techniques (Giulio, 1981).

The disadvantage is that license and, much training are needed and maintenance is required for using this method (IAEA, 2005).

- **Acoustic methods**

In acoustic method, single frequency sensors permit quantitative estimation of suspended sediment concentration from acoustic backscatter intensity. In the early 1980's, the method provided only qualitative results, but the first quantitative data was obtained 10 years later. The method is non-

intrusive and overcomes the problem of biological fouling. Improvement of the acoustic method has also been encouraged (Van Rijn, 1993; Van Rijn and Schaafsma, 1986). Peter and Daniel (2002) examined the capability of acoustics to measure SSC and particle size profiles. This was done using a series of illustrations from laboratory calibration.

The disadvantage of this method is that it cannot differentiate between changes in concentration and changes in particle size distribution and the translation of acoustic backscatter data into sediment concentration and size is a difficult problem (Hanes *et al.*, 1988).

The advantage of this method is that acoustic sensors are more sensitive to large particles than optical methods (Thorne *et al.*, 1995). Suspended-sediment measurement offers the ability to non-intrusively measure sediment parameters through a vertical range on the order of several meters (Thorne *et al.*, 1995). Acoustic measurement provides a large advantage over pump and bottle sampling because it allows the researcher to observe the behavior of turbulent processes acting on the sediment.

- **Laser diffraction method**

The laser instrumentation has been developed to provide an alternative method for measuring suspended sediment in lakes. A well-known, commercially available laser sensor is the Laser *in situ* Scattering and Transmissometer (LISST). It measures the scattering of a laser beam by particles in a volume of water. Sensors are small and suitable for field development with real-time data return capabilities (International Association of Hydrological Sciences (CESTM), 1981). In laser diffraction, a laser beam is directed into the sample volume where particles in suspension will scatter, absorb, and reflect the beam. Scattered laser light is received by a multi-element photo detector consisting of a series of ring shaped detectors of progressive diameters that allow measurement of the scattering angle of the beam (Daniel *et al.*, 2000).

The advantage of this method is that the instrument is powerful for low concentration determination (CESTM, 1981). The disadvantage of this method is that it is quite expensive and susceptible to biological fouling and they are quite complicated devices that may require specialized training for operation and data interpretation (Daniel *et al.*, 2000).

## **2.7 Samplers used to collect sediment samples**

### **2.7.1 Depth integrated sampler**

Depth integrating samplers are used to sample the water column in a vertical section by lowering the apparatus to the desired level, usually as close to the bed as possible, then raising the sampler back to the surface at the same rate. This technique is dependent on the speed of the sampler as it moves through the water column (Daniel *et al.*, 2000). Depth integration is usually performed with depth integrating samplers. Water and sediment mixture can then be sampled continuously while the sampler is moving at a constant transit rate along the vertical (Xiaoqing, 2003).

USGS (2005) stated that depth integrating samplers are designed to collect water samples from a stream vertically and they were the first method developed as the manual sampling methods that were used in the mid-1800s, in the Mississippi River.

When the depth integration method is employed, the transit rate of the sampler for all the verticals should be kept the same (that is, established at the deepest and fastest vertical in the cross-section) (WMO, 1994). In round trip depth integration, the descending and ascending transit rates should also be kept the same. The same nozzle is used at all verticals. The sample bottle should not be allowed to fill completely. The common advantage about these sampler methods are that they are reliable and used manually and the common disadvantage is that they are high time consuming and cumbersome (meaning they are difficult to carry or use and even slow).

### **2.7.2 Point integrated sampler**

Point integrated samplers are used to collect point integrating samples. Point integrated sample is a sample of the water sediment mixture collected isokinetically from a single point in a cross section. Point integrated samplers can sample sections of water depth by electronically opening a valve at the appropriate time. Point integrated samplers may also be used in the same manner as depth integrated samplers when necessary (Interagency Committee on Water Resources, 1963). Multi points and multi vertical are some of the methods used in point integrated sampling (Xiaoqing, 2003). Multi point samples may be used to define distribution of sediment in vertical (Garcia, 1959).

Point integrated samplers are more versatile than the simpler depth integrated samplers. They can be used to collect suspended sediment samples representing the mean sediment concentration at any point from the surface of a stream to within several centimeters of the bed as well as to integrate over a range in depth. These samplers were designed for depth integrated sampling of streams too deep as well as to integrate over a range depth (Garcia, 1959). Point samplers are mostly used in multi-point vertical and simplified sampling methods.

### 2.7.3 Grab /Dip /Bottle sampling

Grab sampling involves extracting water sample by dipping a bottle into the river as shown in Figure 2.1. The sample is then to be analyzed in the laboratory to determine its suspended sediment concentration. Sampling time and location (river and position in cross section) are of great importance to be recorded. However, if the velocity at the mouth of the jar differs from the local stream velocity, then the amount of sand-sized suspended sediment entering the jar may not be representative of that in the stream that is the subject of measurement (Daniel *et al.*, 2000). Performing isokinetic sampling in which the velocity in the jar is equal to the local velocity in the stream can rectify this error (Daniel *et al.*, 2000). Rooseboom and Annandale (1981) mentioned that the simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream, preferably at a point where it will be well mixed, such as downstream from a weir or rock bar. The sediment contained in a measured volume of water is filtered, dried and weighed. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge.



Figure 2.1 Illustration of grab sampling method (Daniel *et al.*, 2000)

During the ARCS Program, Ponar and van Veen grab samples were used to collect surface sediments. The 0.05-m<sup>2</sup> Ponar grab sampler was designed to penetrate the sediment by weight alone and to sample about the same amount of sediment with each cast and a sediment penetration depth of 10-20 cm was desired and Ponar grab sampler was designed for use in lakes, reservoirs, rivers, and estuaries with soft or hard sediments (US Environmental Protection Agency, 1994). It is equipped with No. 30 mesh brass screens on the open ends of its jaws to minimize loss of material. The van Veen grab sampler (Kahl Scientific Instrument Corporation, El Cajon, California) samples a surface area of 1 ft<sup>2</sup> (0.1 m<sup>2</sup>) and has a capacity of 5 gal (20 L). The Ponar grab sampler was easier to handle than the van Veen grab sampler, but collected smaller samples. The van Veen grab sampler proved to be much more efficient for collecting large volumes of sediment, although it requires a power winch to operate safely. The van Veen grab sampler penetrates to a greater depth than the Ponar grab sampler (US Environmental Protection Agency, 1994).

The advantages of bottle sampling method are that it is a reliable, well documented, and widely used technique and bottle samplers are generally considered the standard against which other types of samplers are calibrated (FAO, 1982). The disadvantage is that the bottling method as compared to other techniques has poor temporal resolution. Unlike automated methods such as pump sampling, personnel must be on hand to take samples. This often involves working late at night in storm conditions, which adds to the expense of taking the samples (Daniel *et al.*, 2000).

#### **2.7.4 Pump sampling**

In pump sampling a vacuum is applied to a line submerged in the channel, and a fluid/sediment sample is taken and stored until retrieved for laboratory analysis. The line's intake nozzle is usually pointed upstream. To avoid sample biasing, the intake velocity must be matched to the local stream velocity. The sediment concentration and size distribution are determined in a laboratory using standard techniques (Daniel *et al.*, 2000).

Pump sampling have been used by many countries such as Indonesia, Italy, the United Kingdom and the United States, amongst others (CESTM, 1981). The advantages of this methods include that automatic pump samplers can be programmed to take samples at predetermined intervals, or when coupled with appropriate sensors, at predetermined flows or depths. Pump samplers are often automated, which eliminates the need for personnel to be present in order to take samples (Daniel

*et al.*, 2000). The disadvantage of this sampling method is that sampling frequency is limited by the time taken to fill each bottle and the number of bottles in the sampler (CESTM, 1981).

## 2.8 Laboratory measurements of SSC

There are three common methods used to measure suspended sediment concentration samples in the laboratory (Xiaoqing, 2003). These include evaporation, filtration and displacement methods for analysis. The method for analysis should be chosen on the basis of the quantity and the composition of sediment in the sample and the desired accuracy (Xiaoqing, 2003).

- **Evaporation method**

In the evaporation method, the wet sediment sample, after the supernatant liquid is decanted from the vessel, is transferred to an evaporation dish and dried in an oven at a temperature slightly below the boiling point until the visible moisture is evaporated (Xiaoqing, 2003). The oven temperature is then raised to 105°C for two hours. If the dissolved solids exceed 2 percent of the sample weight, their concentration should be determined separately in the original water (Xiaoqing, 2003). The content of dissolved solids should be subtracted from the dried sediment weight in computing the sediment concentration. The dry weight of the evaporation dish is usually precisely determined beforehand. In routine operations, it should be checked to avoid any possible error.

- **Filtration method**

Filtration is used to determine concentration that is low (Edwards and Glysson, 1999). The quality of the filter material influences the accuracy of this method to a great extent. Experiments should be carried out to test the filter material before it is finally selected. The first experiment is to determine the amount of sediment that may be leaking through the filter material. If the leak exceeds 2 percent of the total sampled sediment, better quality filter material should be used (Edwards and Glysson, 1999). The second experiment is to determine the content of soluble matter in the filter material. By comparing the dry weight of the filter material before and after immersion in water, the weight loss can be determined and used to correct the dry weight of the sediment obtained by filtering. In the United States, it is considered that the filter pore size (filter ratings) and filter diameter are critical in the filtration method (Edwards and Glysson, 1999). Filters with

retention ratings of 1.5 micron and a filter diameter exceeding 24 mm are commonly used in the sediment laboratory (Edwards and Glysson, 1999).

- **Displacement method**

The displacement method involves determining the difference in weight between a sample of sediment-laden water and an equal volume of clear water (Xiaoqing, 2003). This method can only be applied to samples with a relatively high sediment concentration. The dry weight of sediment is computed by the following equation:

$$W_s = k(W_{ws} + W_w) \quad 2.4$$

Where

$$k = \frac{\rho_s}{\rho_s - \rho} \quad 2.5$$

where  $W_s$  is the sediment weight to be determined in g,  $W_{ws}$  is the weight of the specific gravity flask plus the weight of sediment water mixture in g,  $W_w$  is the weight of the specific gravity flask plus the clear water weight with volume and temperature equal to that of the sediment-water mixture (during weighing the water temperature should be constant),  $\rho_s$  is the density of sediment particles, and  $\rho$  is the density of water.

## 2.9 Sediment rating curves

Sediment rating curves are mainly applied to obtain the value of sediment concentration for a given discharge, along with the flow duration curve at a given location (McCutcheon *et al.*, 1993). The sediment rating curve can also be used to estimate the amount of sediment transport over a period of time, say a year. Reichel (1998) mentioned the other important use of sediment rating curve is in estimation of the impact of land use changes and watershed management on sediment yield.

Swamee and Tyagi (2000) reported that if a plot between discharge and sediment concentration has large scatter in points, one reason behind this scatter is that soil erosion rates in a watershed are not the same during different seasons of the year. If the scatter is large, it might be necessary to develop separate rating curves for different seasons or according to streamflow generation mechanisms, such as rainfall, snowmelt, amongst others. The data pertaining to rising and falling limbs of the hydrograph may also be separated to improve the relationship (Swamee and Tyagi, 2000). Advantages of a sediment rating curve is that once a transport relationship has been developed, it can be applied to past streamflow data to reconstruct long-term sediment records. Its limitation is that it is not reliable due to errors (Walling, 1974).

Tfwala and Wang (2016) estimated sediment discharge using sediment rating curves in Shiwen River in Taiwan. Data was manually collected on an hourly basis during 8 typhoon events, which occurred between the period of 2012 and 2014. Observation of cross section area (for computing discharge) and SSC were made. Filtration methods, evaporation and weighing of remaining sediments were employed.

Post and Jakeman, (1993) studied the relationship between rainfall and suspended sediments loads for different sites in Murry River, Australia. Sediment rating curves were developed wherein  $R^2$  values were 0.72, 0.40, 0.90 and 0.13 and the rainfall values ranged from 11.6 to 72.1mm. The study noted that rainfall less than 20 mm can deposit considerable volume of sediments into the river, but because of high volume of water in the river the impact of this sediment is not always seen.

## **CHAPTER 3: METHODOLOGY**

### **3.1 Preamble**

This chapter covers the methods used for sampling and analysis of suspended sediments and water quality samples. It also includes acquisition of data on magnitude and duration of specific rainfall events and their analysis.

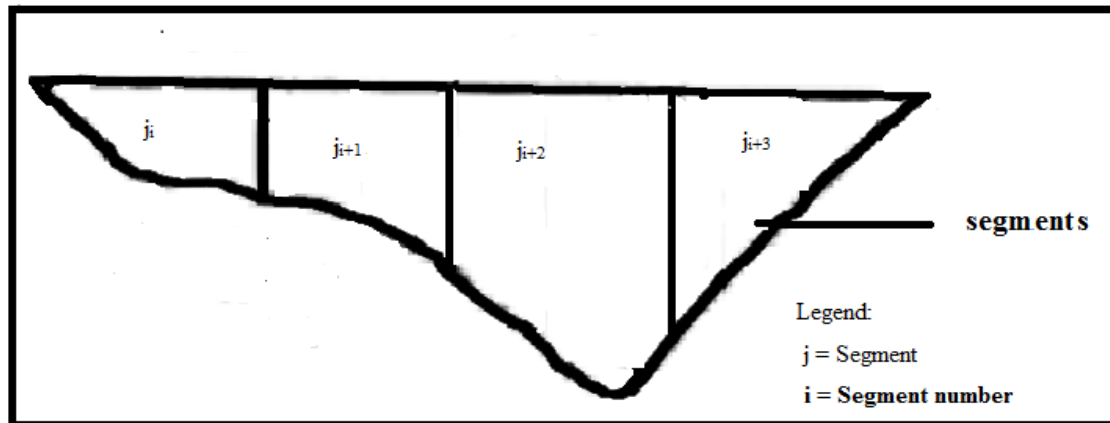
### **3.2 Data acquisition**

Data sets that were acquired include land use, rainfall magnitude and duration. Land use maps were acquired from the Department of Land Affairs. Rainfall magnitude and duration were acquired from Vuwani weather station, which is owned by the South African Weather Services.

#### **3.2.1 Suspended sediments measurements**

Water sampling for suspended sediments measurements were done along cross sections at four sites along the Dzindi River following the grab sampling method. Grab sampling method was used for sampling because it is reliable, well documented and widely used technique and it is generally considered the standard against which other types of samplers are calibrated. In addition, the current study was focused on generating relative values measurements that allow comparisons from one site to another and with time for each discharge event. Thus, the grab sampling method was appropriate for this study.

Each cross-section was partitioned into a number of equal segments following the EWI method. Three and four water samples were collected at each site along the cross section of the river depending on the width of the river. Three equal segments water samples collected in Lwandani, Tshisaulu and Manamani and four segment water samples were collected in DWTW site. An example of how the partitioning was done is shown in Figure 3.1. Water sampling was done after selected rainfall events from October 2012 to April 2013 and December 2013 to March 2014.



**Figure 3.1: Example of partitioned cross section**

Suspended sediments concentrations (SSCs) were determined using evaporation method since most of the sediments were dissolved in water. This method consists of allowing the sediment to settle to the bottom of the sample bottle, decanting the supernatant liquid, washing the sediment into an evaporating dish with distilled water, drying it in an oven, cooling it in a desiccator and weighing the dried sample.

### 3.2.2 Water quality analysis

Sampling for water quality analysis was done along the sites where sampling for suspended sediment analysis were done. Three samples were collected in Lwandani, Tshisaulu and Manamani and four water samples were collected at DWTW after each rainfall event from October 2012 to March 2013 and December 2013 to March 2014. The physical water quality parameters (pH, EC and turbidity) were measured. These parameters were selected because they are indicators of the overall status of the water quality. pH is one of the most common water quality indicator that shows acidity or alkalinity. It also shows potential presence of certain chemical parameters of specific ranges. Turbidity is considered as a good indicator of the microbial quality of water. EC estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. The physical quality indicators showed the potential water quality status and guided the need for recommendation for further detailed quality analysis where possible. EC and pH were measured with Multi 340i /set multimeter, while the turbidity was measured using Orion Aqua fast II turbidity meter.

### **3.3 Data analysis**

#### **3.3.1 Field surveys**

Field surveys were undertaken to identify land use activities that promote erosion and hence increase sedimentation. The hotspots/priority areas were mapped in relation to land use activities in a GIS map. In the current study hotspots/priority areas are considered as areas that are prone to erosion. Examples include steep slopes where cultivation is practiced.

#### **3.3.2 Suspended sediment concentration (SSC) computation and suspended sediments rating curves**

SSC in each cross section was computed using Equation 2.3 based on data that was obtained from suspended sediments analysis at each segment of the cross section. Measurements and analysis of SSC for specific rainfall events were done. Graphs of SSCs and daily rainfall were plotted to determine the effect rainfall magnitude on SSCs. SSCs and daily rainfall events from December 2013 to March 2014 of each site were plotted to derive the suspended sediment rating curves for the study sites.

#### **3.3.4 Selection and recommendation of sediment management strategies**

Data on physical water quality parameters analysis and SSC were used in determining the water quality and sedimentation status at each cross-section. This together with the information from the GIS map aided in identifying and recommending the best sediment management strategies for different sites in the study area. Thus, different strategies were recommended based on the land use activities, sedimentation and water quality status of different sites. Topography (slope) was also taken into consideration when selecting the strategies as it influences erosion and hence sedimentation.

## **CHAPTER 4: RESULTS AND DISSCUSION**

### **4.1 Preamble**

The results on potential sources of sediments and water pollution, SSC in Dzindi River Catchment, physical water quality indicators, and effects of rainfall magnitude are discussed and presented in this chapter.

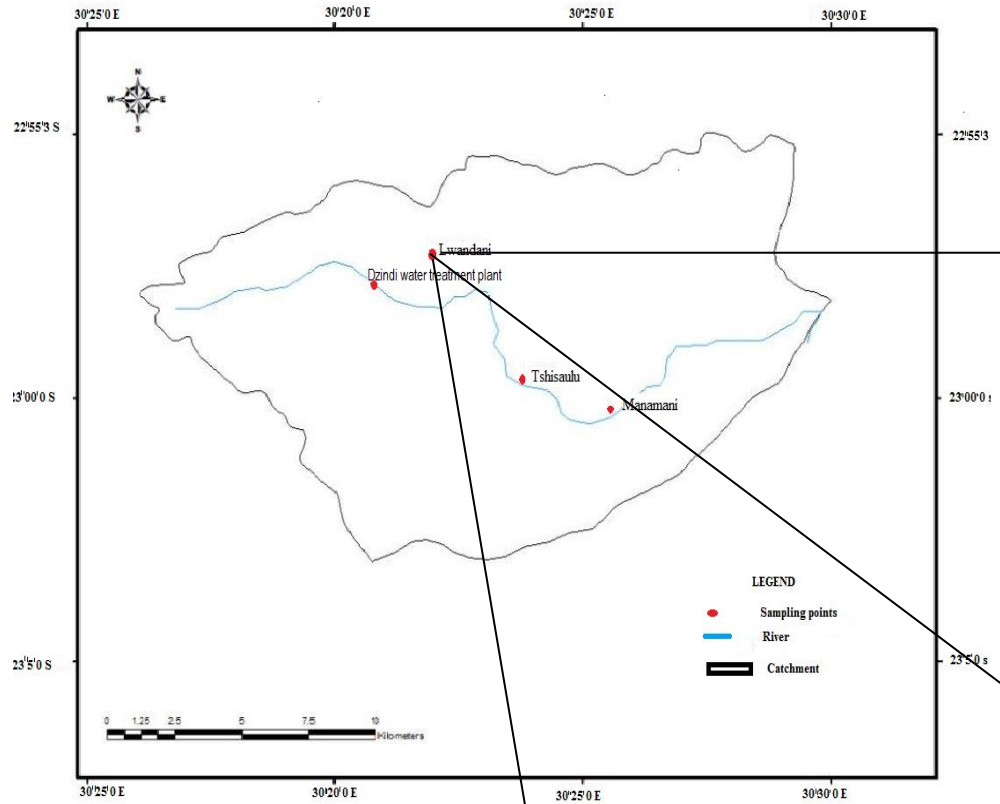
### **4.2 Potential sources of sediments and water pollution**

Agricultural activities such as clearing of land for cultivation purposes and planting crops are practiced around Lwandani site (Figure 4.1). Crops, orchards and livestock watering are common around Lwandani (Figure 4.1). Community members also wash clothes in the river thereby contributing to water pollution. There are also return flows from the crop farming which contribute to pollution and high sedimentation (Figure 4.1).

Agricultural practices (such as planting crops), brick making, livestock watering are activities around Tshisaulu site which contribute to water pollution. Sand harvesting is also common at this site (Figure 4.2). Soil harvesting is practiced at a distance of about 5 m from the river and this also contributes to water pollution and sedimentation in DWTW site. There is livestock littering around DWTW site which contributes to pollution of river water (Figure 4.3). Agricultural activities such as planting crops, livestock watering and poor settlement planning contribute to sedimentation and water pollution around Manamani site (Figure 4.4). These impact on water quality of the river. Wright (2006) reported that agricultural activities in Lesotho Highlands River and poor methods of agriculture resulted in soil erosion and increase in sediments in surrounding rivers.

Sand harvesting, brick laying and agricultural activities loosen the soil making it prone to soil erosion particularly during the rainfall season. These also contribute to water pollution because rainfall can erode pollutants together with the sediments. Livestock can defecate along the river bank affecting water quality. The results of the field survey show that agricultural activities, sand harvesting, bricks laying, and washing of clothes in the river are the main potential sources of sedimentation and water pollution in the study area. Thus, all the study sites are hot spots/priority

areas which require urgent management strategies for minimizing or preventing sedimentation and water pollution.



Return flows from agriculture

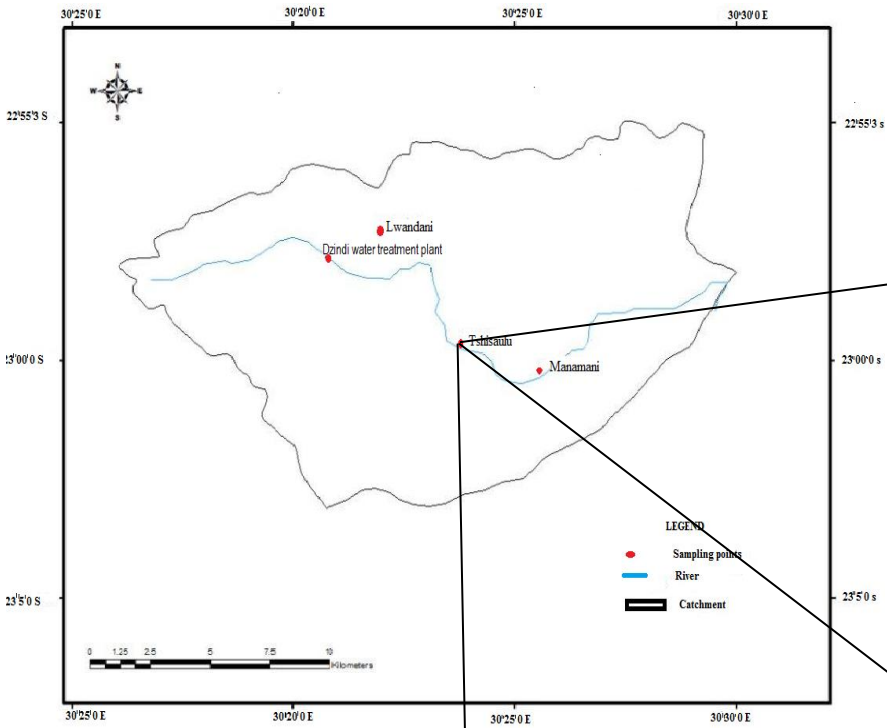


Clearing of forest



Washing clothes in the river

Figure 4.1: Potential sources of sediments and water pollution at Lwandani



Cultivation

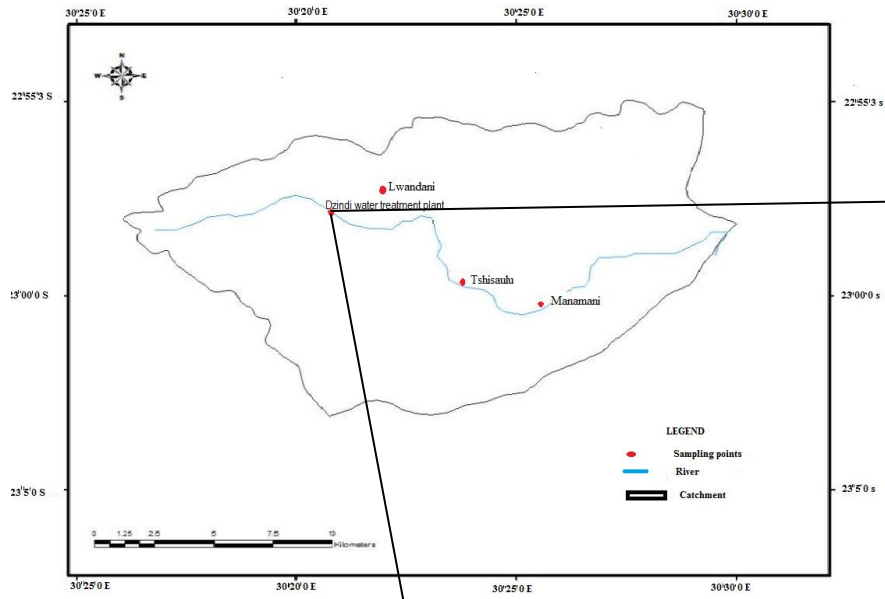


Brick making



Cultivation of land

Figure 4.2: Potential sources of sediments and water pollution at Tshisaulu.

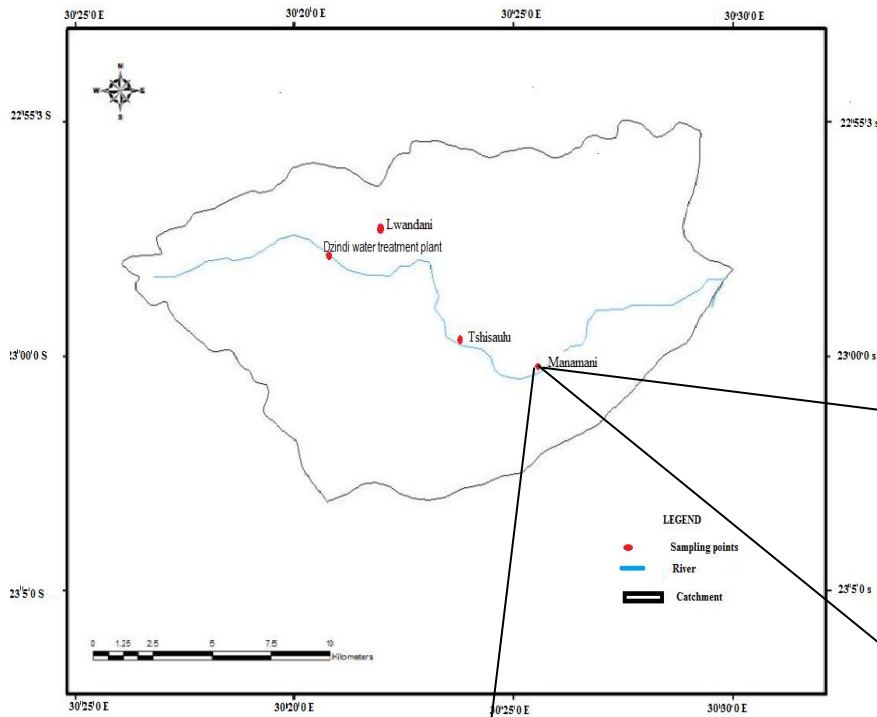


Livestock litter



Soil harvesting

Figure 4.3: Potential sources of sediments and water pollution at DWTW



Washing clothes in the river



Poor settlement



Growing of crops

Figure 4.4: Potential sources of sediments and water pollution at

### 4.3 Suspended Sediment Concentrations in Dzindi River Catchment

SSCs for the period October 2012 to April 2013 ranged from 1.0 to 8.0, 2.1 to 12.1, 0.4 to 6.8 and 0.6 to 11.4 g at Lwandani, DWTW, Tshisaulu and Manamani, respectively (Figure 4.5). Figure 4.5 was plotted using data presented in Appendix A1. DWTW and Lwandani are the upstream sampling points, and Tshisaulu and Manamani are the downstream sampling points. The SSC results for Lwandani site are up to 2013/01/15 since the bridge to Lwandani was destroyed by the flood of 16/01/2013 (Figure 4.6). The highest SSC value of 12.1 g was found in DWTW. The high SSC in this site are likely to be from loosened soil due to soil harvesting. The lowest SSC of 1.0 g was found in Tshisaulu site.

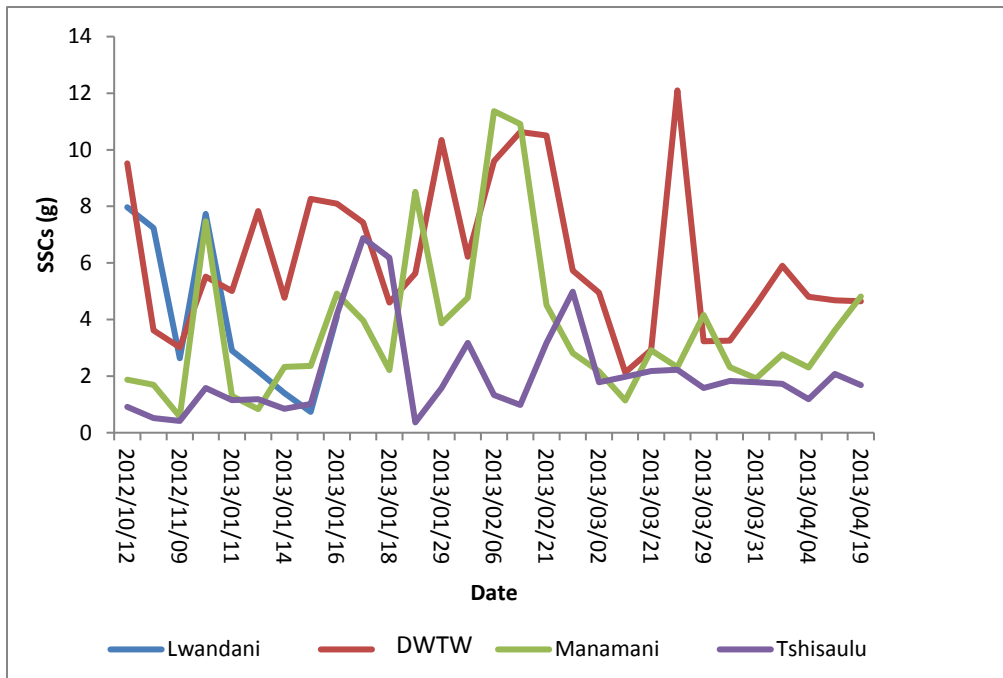


Figure 4.5: SSC in Dzindi River Catchment for the period October 2012 to April 2013



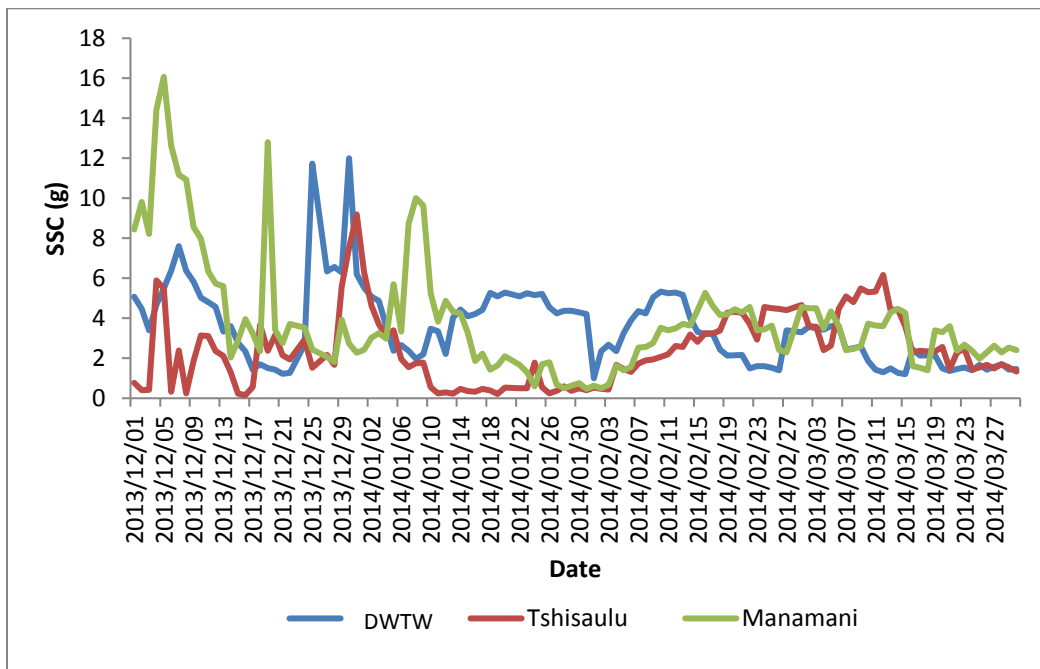
**Figure 4.6: Bridge to Lwandani site damaged by flood (16/01/2013)**

Neal *et al.* (1998) reported SSC of less than 202 g in Bubwith River. Sediment concentrations in excess of these totals have been sampled during storm condition in the latter study. These SSCs are higher than those obtained in the current study. Neal *et al.* (1998) indicated that one of the main reasons for these level of SSCs may be the combination of rainfall totals, greater infiltration and shallower slopes. Leeks (1992) reported that SSCs and loads in rivers in small catchment in upland Wales increased for moderate to high stream flows in two years after trees felling. These studies show that land use activities, particularly those that loosen the soil contribute to increase in SSCs in rivers. Grenfell and Ellery (2009) studied sediment transport dynamics in Mfolozi River in Kwazulu Natal, it was indicated that during early wet season sediment concentration was higher and it was lower during late wet season. This was similarly observed in the current study area.

Suspended sediment concentration ranged from 1.4 to 12, 0.4 to 16.1 and 0.15 to 9.19 g at DWTW, Manamani and Tshisaulu, respectively, from December 2013 to March 2014 (Figure 4.7). Figure 4.7 was plotted using data presented in Appendix A2. The highest SSC of 16.1g was found at Manamani site and the lowest SSC of 0.15 was found at Tshisaulu site. Figure 4.7 generally shows high SSC at the beginning of the sampling period (2013/12/02 to 2014/01/11) for all the sampling points. This may have been due to reduced top soil that was eroded at the beginning of the rainfall season. Figure 4.7 also generally shows low SSCs towards the end of the sampling period (2014/01/16 to 2014/03/29). This may have been due to reduced top soil by soil erosion during the

beginning of the sampling period, leaving less soil available for erosion at the end of the sampling period.

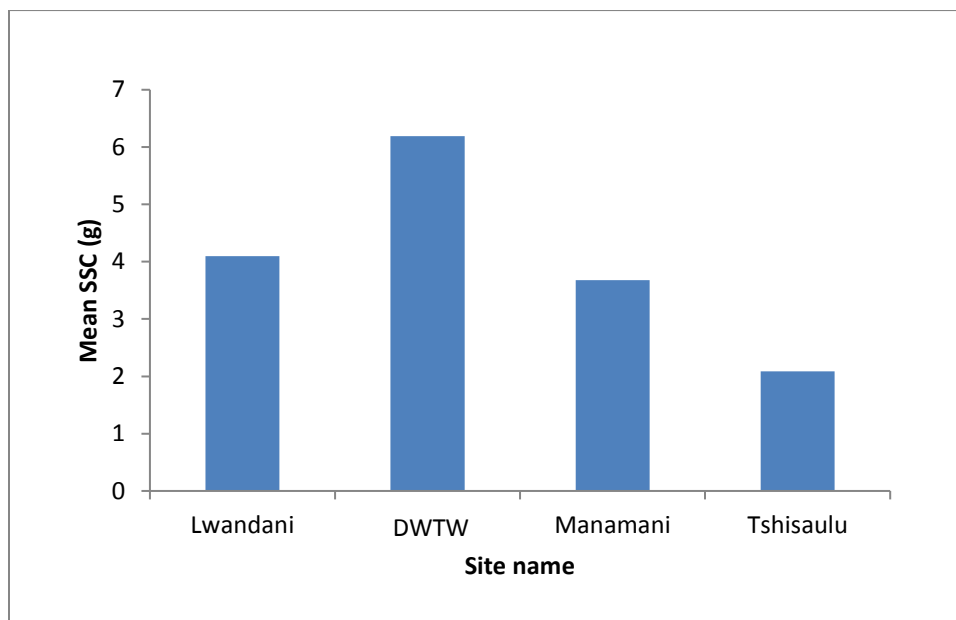
Woodward and Foster (1997) found that the combined influence of steep slope, soft lithology and often poor land management practices created a highly erodible landscape in the Colorado green rivers. This contributed to high sedimentation in addition to intensive seasonal rainfall that generated high rates of soil loss resulting to extensive gully cutting and even bad land formation. In the current study area, poor land management practices and possibly slopes of the Soutpansberg mountain in the upstream areas resulted to high levels of SSCs during the rainfall season. The study area is within the Soutpansberg area characterized by steep slopes and poorly drained soils which are prone to erosion (Mostert, 2006). This also contributes to increased SSCs during the rainfall season in the study area.



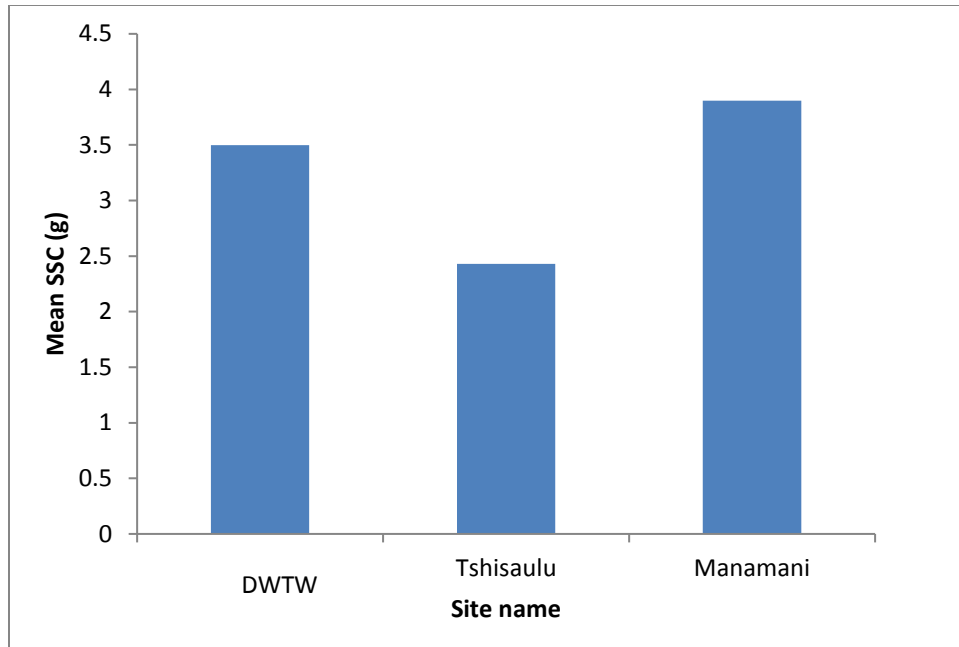
**Figure 4.7: SSC in Dzindi River Catchment for the period of December 2013 to March 2014**

During the period October 2012 to April 2013 the mean SSCs were 4.0, 6.1, 3.6 and 2.0 g for Lwandani, DWTW, Manamani and Tshisaulu sites, respectively (Figure 4.8). The highest mean SSC of 6.1 g was found in DWTW and the lowest mean SSC of 2.0 g was found in Tshisaulu site

(Figure 4.8). As explained earlier in this section, high SSC in DWTW likely to be from loosened soil due to soil harvesting. During the period December 2013 to March 2014 mean SSCs were 3.49, 3.8 and 2.4 g for DWTW, Manamani and Tshisaulu sites, respectively (Figure 4.9). The highest mean SSCs of 3.8 g was found in Manamani and the lowest mean SSCs of 2.4 g was found in Tshisaulu site (Figure 4.9). Figure 4.9 was plotted using data presented in Appendix A2. Manamani has highest concentration of SSC because it is located downstream of DWTW and Tshisaulu sites whose SSC are transported to Manamani during rainfall. In a study by Welch *et al.* (2011), high SSC were observed at stations downstream of the confluence of the upper Mississippi and Ohio Rivers.



**Figure 4.8: Mean SSC in Dzindi River Catchment for the period October 2012 to April 2013.**

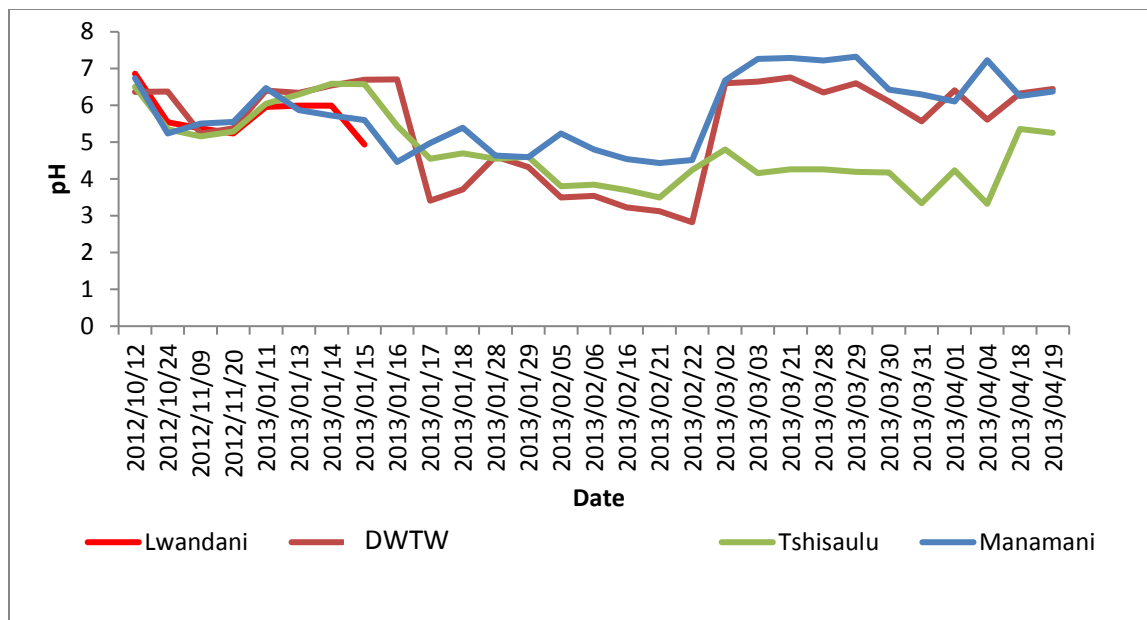


**Figure 4.9: Mean SSC in Dzindi River Catchment for the period of December 2013 to March 2014**

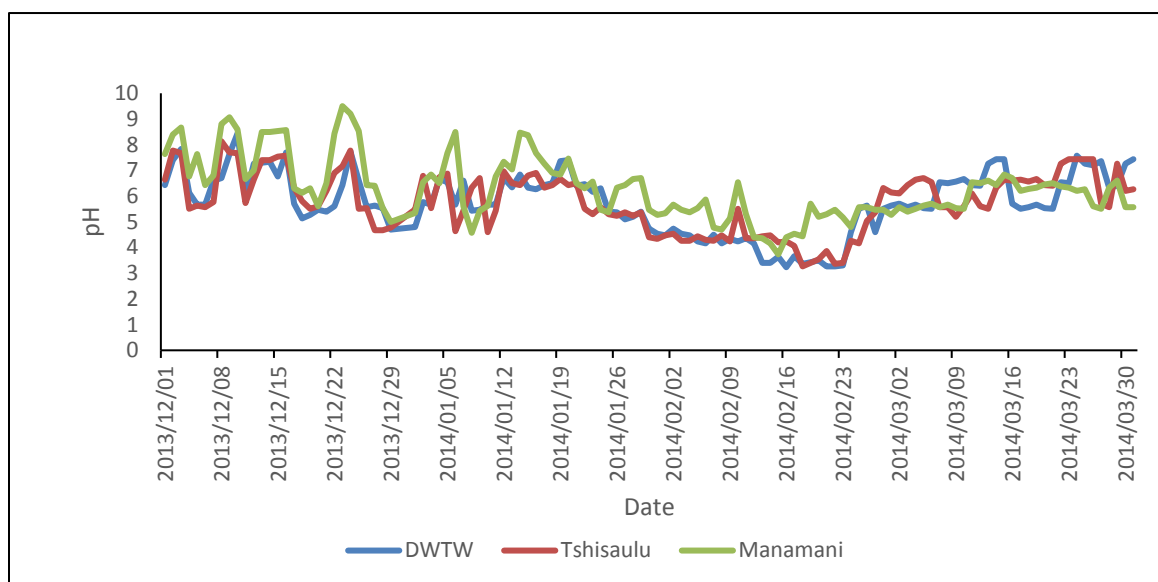
#### **4.4 Results of physical water quality indicators**

##### **4.4.1. pH**

pH values for the period of October 2012 – April 2013 ranged from 4.9 to 6.8, 2.83 to 6.76, 4.4 to 7.3, and 3.3 to 6.59 at Lwandani, DWTW, Manamani and Tshisaulu, respectively (Figure 4.10). Figure 4.10 was plotted using data presented in Appendix B1. Highest pH value of 7.3 was found at Manamani site, and the lowest pH value of 2.83 was found in DWTW. pH values for the period of December 2013- March 2014 ranged from 3.23 to 8.43, 3.73 to 9.50 and 3.27 to 8.13 at DWTW, Manamani and Tshisaulu, respectively, for the period 2013/12/01 to 2014/03/30 (Figure 4.11). Figure 4.11 was plotted using data presented in Appendix B2. Highest pH value of 9.50 was found at Manamani site, and the lowest pH value of 3.23 was found in DWTW.



**Figure 4.10: pH values of Dzindi River Catchment for period of October 2012 – April 2013**



**Figure 4.11: pH values of Dzindi River Catchment for December 2013-March 2014**

pH values for DWTW and Manamani were mostly within the range of 6-9 in the period of December 2013-March 2014. There were a few occasions when the pH values were below 4 for the dates of 14/02/2014 to 24/02/2014 for DWTW, Tshisaulu, and Manamani, (Figure 4.11). pH values in surface water typically ranges between 4 and 11 (DWAF, 1996b). Within the period of 2012/10/12 to 2013/04/19, and 2013/12/01 to 2014/03/03 pH values were mostly within this range

and thus water was suitable for sustenance of aquatic ecosystems. Toxic effects of acid pH on fish increase as the concentration of calcium chloride and sodium decrease.

There was only one pH value which was above 9 which occurred on 2013/12/22 for Manamani site. Metal ions (except manganese) are unlikely to dissolve readily in the pH range of 6-9 unless complexing ions or agents are present and slight metal solubility may occur at the extremes. Aluminium solubility begins to increase at pH 6, and amphoteric oxides may begin to dissolve at a pH of greater than 8.5 (DWAF, 1996a). Thus, there is potential existence of aluminum and amphoteric oxides in the river at pH of 6-9.

Water with pH ranges of 4-6 or lower has toxic effects associated with dissolved metals. Water also tastes slightly sour. Water with pH values that ranges from 4-6 or lower contain certain dissolved metals such as lead, copper, zinc and cadmium (slightly acidic) (DWAF, 1996a). This shows there is potential existence of metals such as lead, copper, zinc and cadmium and hence increase of health effects if water is used for domestic purpose and aquatic ecosystem during this period.

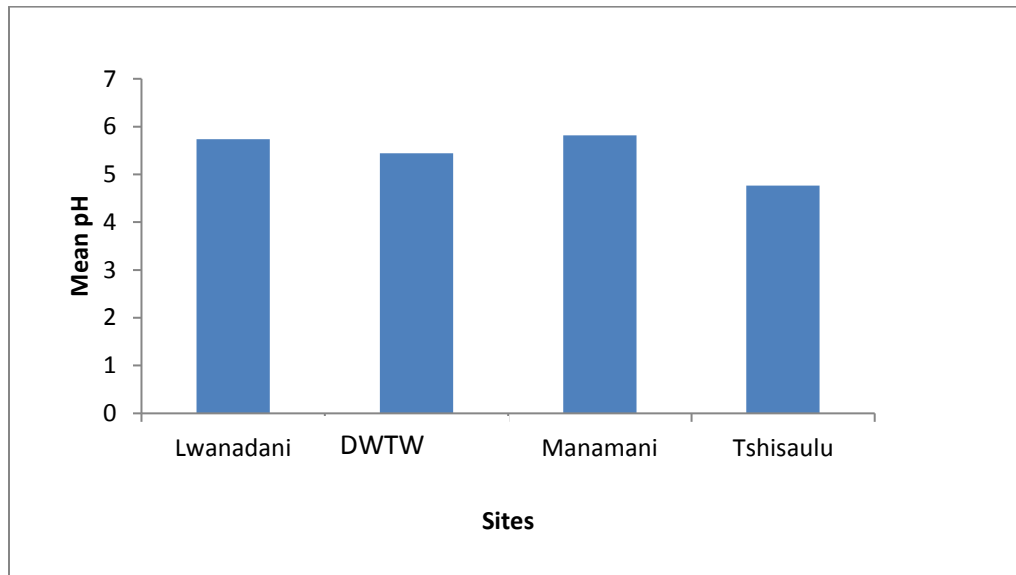
DWTW and Tshisaulu sites (Figure 4.10) had pH values  $<4$  during the period of 2013/01/17 to 2013/02/22. DWTW and Tshisaulu (Figure 4.11) had pH values  $<4$  during the period of 2014/02/11 to 2014/02/23. According to water quality guidelines for domestic water use (DWAF 1996), pH  $< 4$  has severe danger of health effects due to dissolved toxic metal ions, and water tastes sour. Manamani had pH value of 9 (Figure 4.11) which fell within the range of 9-11 on 2013/12/11. According to water quality guidelines for domestic water use (DWAF, 1996a), there is a possibility of toxic effects associated with deprotonated species (for example, ammonium deprotonating to form ammonia) increasing sharply within this range. Water tastes bitter at a pH of greater than 9.

Figures 4.10 and 4.11 show a general decrease in pH from mid-January to early March which is followed by an increase in pH at all sites. This shows that pH decreases during the peak of the rainfall season (February) as more soil is eroded into the river bringing more pollutants. Decrease

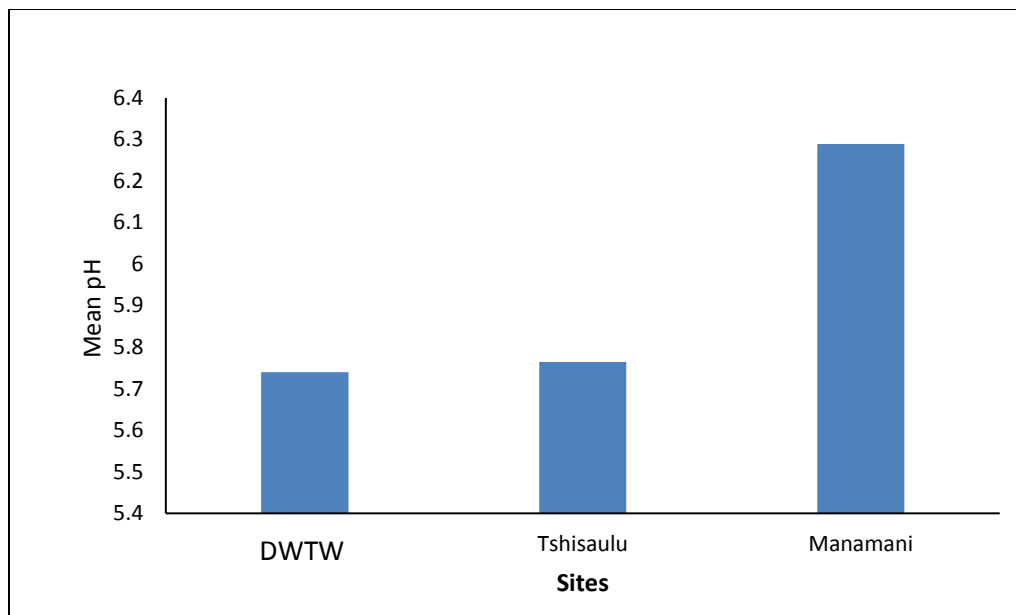
in pH is associated with presence of metals such as lead, copper, zinc and cadmium. Thus, the water at all these sites is not suitable for domestic use during rainy season.

Mean pH values were 5.7, 5.4, 5.8 and 4.7 for Lwandani, DWTW, Manamani and Tshisaulu sites, respectively, from October 2012 to April 2013 (Figure 4.12). The highest mean pH value was found in Manamani and the lowest mean pH value was found in Tshisaulu site. The mean of pH values for Lwandani, DWTW, Manamani and Tshisaulu fall within the range of 4-6 where toxic effects associated with dissolved metals, including lead, copper, zinc and cadmium are likely to occur and water taste is also likely to be slightly sour. This shows water at all the sites was not suitable for domestic use and aquatic species during this period.

Mean pH values were 5.74, 6.39 and 5.76, for DWTW, Manamani and Tshisaulu sites, respectively, for period of December 2013 to March 2014 (Figure 4.13). The highest mean pH value of water was found in Manamani and the lowest mean pH value was found in DWTW. These pH values fall within the range of 4-6 and has similar effects as described in the previous paragraph.



**Figure 4.12: Mean pH values of Dzindi River Catchment for the period of October 2012-April 2013**



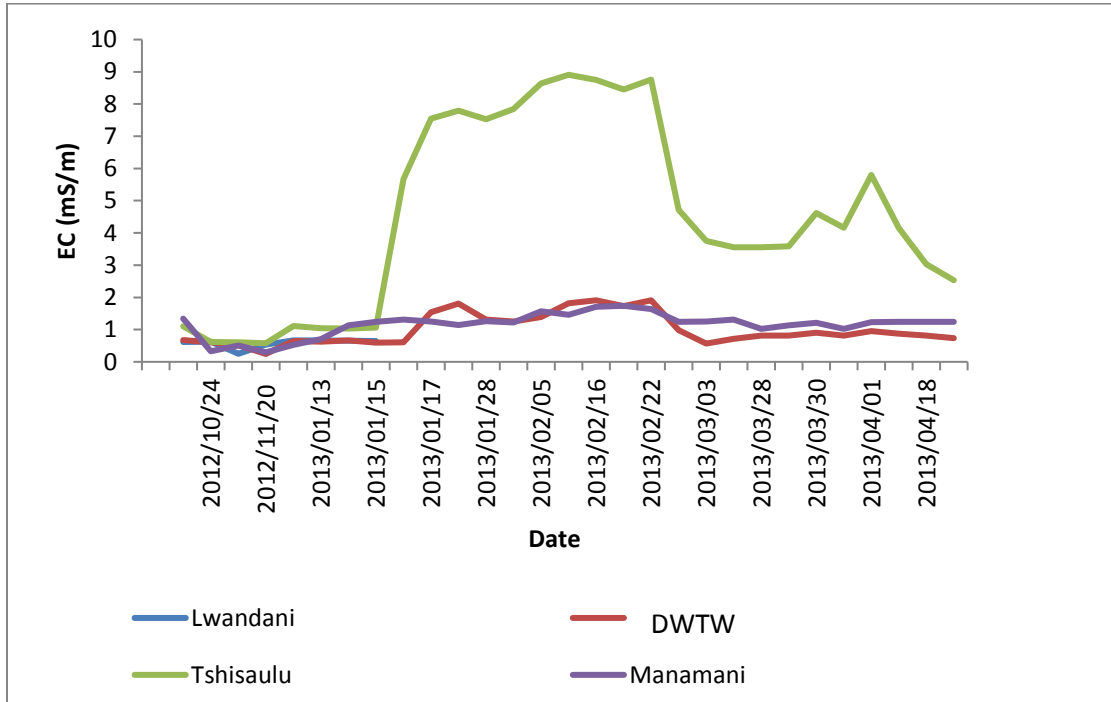
**Figure 4.13: Mean pH values of Dzindi River Catchment for the period of December 2013-March 2014**

#### 4.4.2 Electrical conductivity (EC)

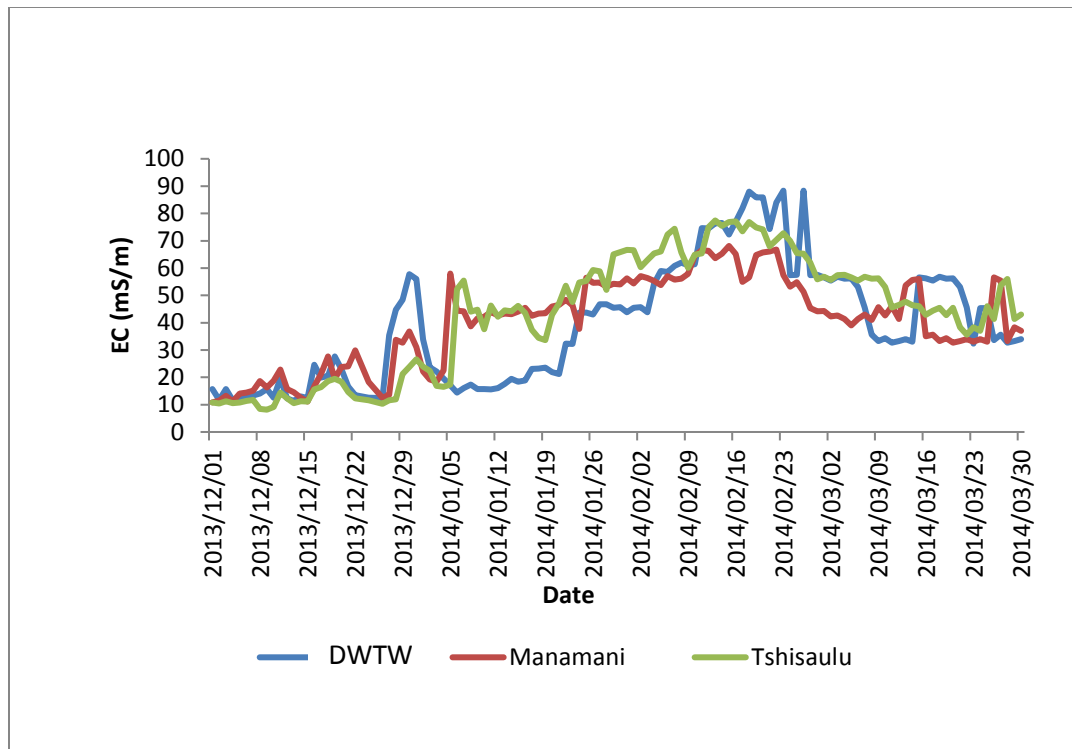
EC values ranged from 0.25 to 0.66, 0.25 to 1.91, 0.3 to 1.7 and 0.61 to 8.91 mS/m at Lwandani, DWTW, Manamani and Tshisaulu, respectively, for October 2012 to April 2013 (Figure 4.14). Figure 4.14 was plotted using data presented in Appendix D1. Highest EC value of 8.91 was found in Tshisaulu. This was due to land use activities practiced around which include brick making (see Figure 4.2) and the lowest EC values ranging from 0.2 were found in Lwandani and DWTW for the period of October 2012 to April 2013. EC values for all sites were mostly within the range from 0–70 mS/m. There are no health effects associated with the EC values less than 70 mS/m (DWAF, 1996a).

EC values ranged from 11.34 to 88.3, 10.8 to 68.10 and 8.17 to 77.43 mS/m at DWTW, Manamani and Tshisaulu, respectively, for December 2013 to March 2014 (Figure 4.15). Figure 4.15 was plotted using data presented in Appendix D2. Highest EC value of 88.3 mS/m was found in DWTW and the lowest in Tshisaulu for the value of 8.17 mS/m. DWTW, Manamani and Tshisaulu had EC values within the range of 70-150 mS/m (Figure 4.15). According to DWAF (1996a), water within this EC range has no health effects for both domestic use and aquatic ecosystems. Figures 4.14 and 4.15 show a general decrease or a slow change in EC at the beginning of the

sampling period (October- part of January), which increases from mid-January to end of February followed by a decrease or slow change towards the end of the sampling period.

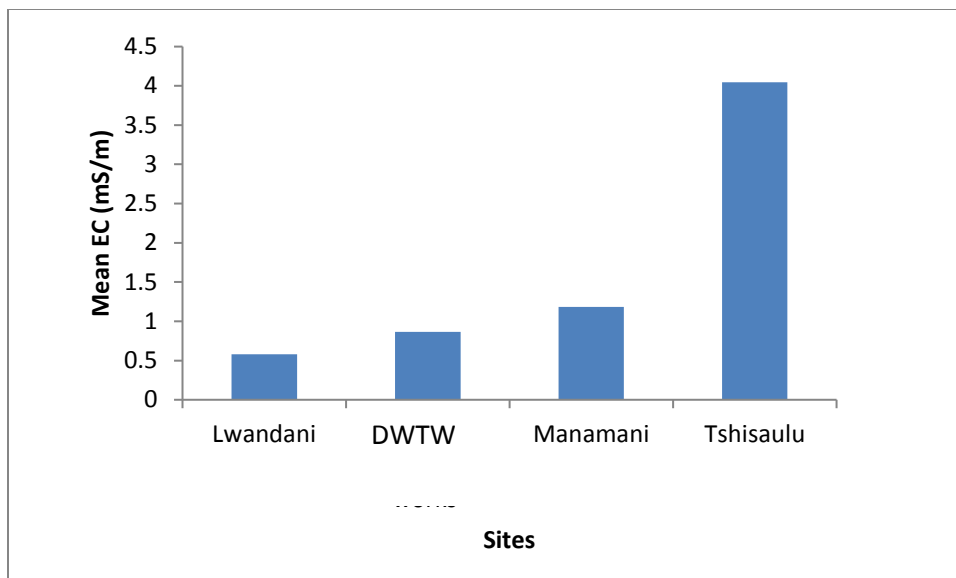


**Figure 4.14: EC values in Dzindi River Catchment for the period of October 2012-April 2013**

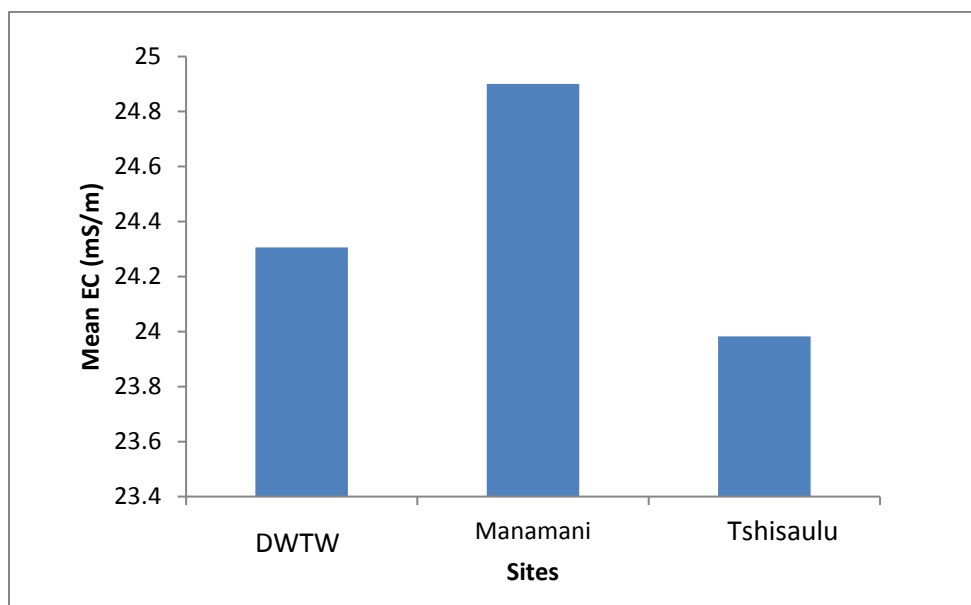


**Figure 4.15: EC values in Dzindi River Catchment for the period of December 2013-March 2014**

Mean EC values were 0.58, 0.89, 1.18 and 4.04 mS/m for Lwandani, DWTW, Manamani and Tshisaulu sites, respectively, for October 2012 to April 2013 (Figure 4.16). Figure 4.16 was plotted using data presented in Appendix D1. The highest mean EC was found in Tshisaulu due to land use activities practiced around Tshisaulu (brick making) (see Figure 4.2) and the lowest mean EC was found in Lwandani site. Mean EC values were 24.3, 24.9 and 23.9 mS/m for DWTW, Manamani, Tshisaulu, sites, respectively, for December 2013 to March 2014 (Figure 4.17). The highest mean EC value of 24.9 mS/m was found in Manamani due to land use activities practiced such as ploughing of crops and poor settlement and the lowest mean EC value of 23.9 mS/m was found in Tshisaulu site.



**Figure 4.16: Mean EC values for Dzindi River Catchment for the period October 2012-April 2013.**



**Figure 4.17: Mean EC values for Dzindi River Catchment for the period of December 2013-March 2014**

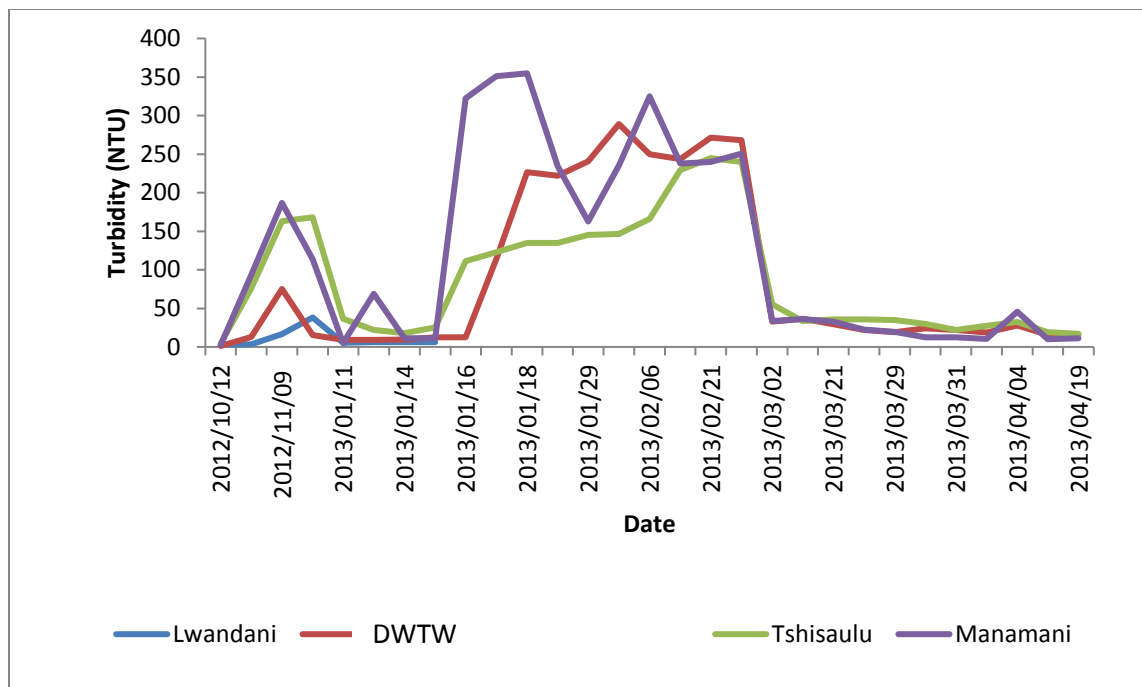
#### 4.4.3 Turbidity

Turbidity values ranged from 2.9 to 38.1, 9.08 to 289, 2.5 to 354.8 and 4.41 to 244.8 NTU for Lwandani, DWTW, Manamani and Tshisaulu, respectively, for October 2012 to April 2013. (Figure 4.18). Figure 4.18 was plotted using data presented in Appendix C1. Turbidity values for

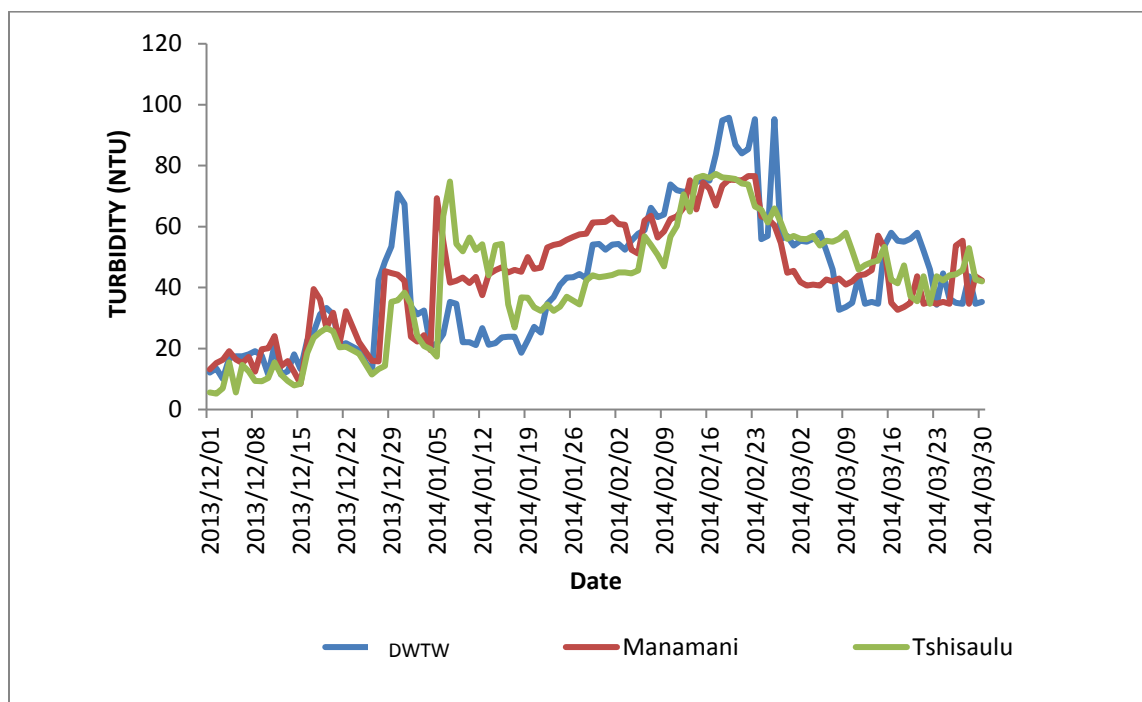
all sites were mostly greater than 10 NTU (Figures 4.18 and 4.19). Water with turbidity values greater than 10 NTU is associated with severe aesthetic effects (appearance, taste and odour) according to DWAF (1996). Such water carries an associated risk of disease due to infectious disease agents and chemicals adsorbed onto particulate matter and a chance of disease transmission at epidemic level exists (DWAF, 1996).

Turbidity values ranged from 10 to 95.7, 8.44 to 76.6, and 5.22 to 77.3 NTU for DWTW, Manamani and Tshisaulu, respectively, for December 2013 to March 2014 (Figure 4.19). Figure 4.19 was plotted using data presented in Appendix C2. Highest turbidity value of 95.7 NTU was at DWTW and the lowest value of 5.22 NTU was found at Tshisaulu. Turbidity was high in all the sites most of the time. Turbidity is visible and water may be objectionable to users (DWAF, 1996a). There is some chance of transmission of disease by micro-organisms associated with particulate matter, particularly for agents with low infective dose such as viruses and protozoan parasites (DWAF, 1996b). This shows high potential for the presence of disease causing organisms at all sites and hence high, negative health effects if water is used for domestic use.

USGS (2004) reported turbidity at Northern Santiam River near Detroit Station which exceeded 5000 NTU after 6 hours of rainfall event and then it decreased to 560 NTU after 4 hours. This shows that during the first period of rainfall, sediments that are eroded to the river can have high turbidity which can change the colour of the water and this can decrease later after the top soil has been eroded. This was also observed in the current study. It is important to note that turbidity variations (Figures 4.18 and 4.19) followed almost similar trend as that observed in EC, showing that EC is similarly affected by variations in rainfall in the study area.

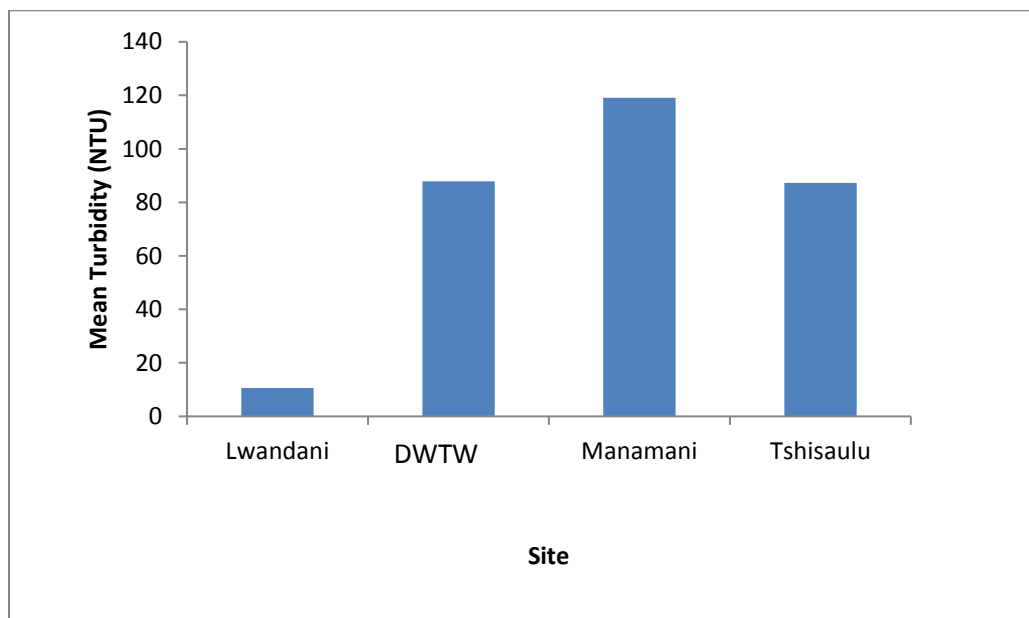


**Figure 4.18: Turbidity values for Dzindi River Catchment for period of October 2012-April 2013**

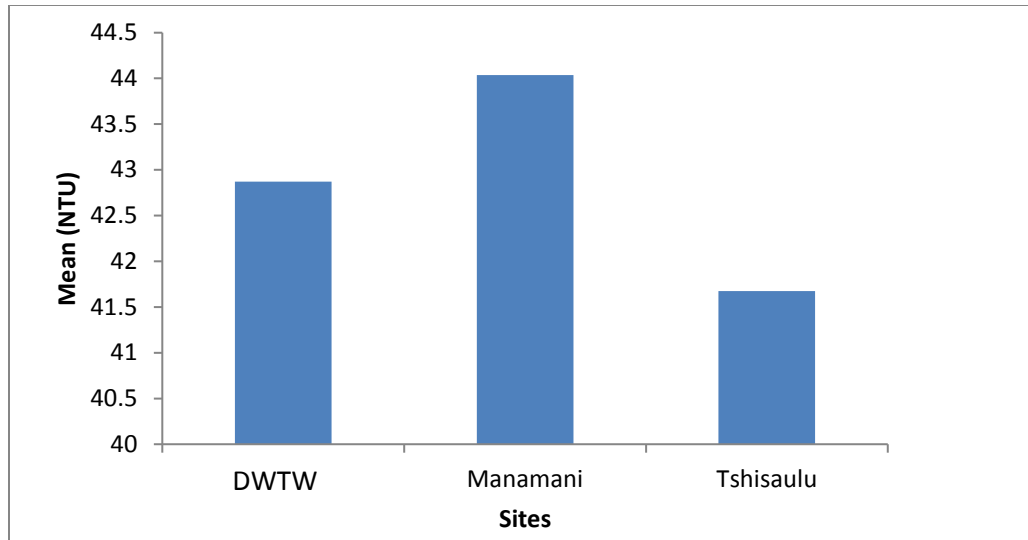


**Figure 4.19: Turbidity values for Dzindi River Catchment for period of December 2013-March 2014**

Mean turbidity values were 10.6, 87.8, 119.0 and 87.3 NTU for Lwandani, DWTW, Manamani and Tshisaulu sites, respectively, for October 2012 to March 2013 (Figure 4.20). The highest mean turbidity value of 119.0 NTU was found in Manamani and the lowest mean turbidity value of 10.6 NTU was found in Lwandani site. Mean turbidity values were 42.8, 44.0 and 41.6 NTU for DWTW, Manamani, and Tshisaulu, respectively, for December 2013 to March 2014 (Figure 4.21). The highest mean turbidity value of 44.0 NTU was found in Manamani and the lowest mean turbidity value of 41.6 NTU was found in Tshisaulu site. These turbidity values are associated with severe aesthetic effects (appearance, taste and odour) and such water carries an associated risk of disease due to infectious disease agents and chemicals adsorbed onto particulate matter as explained earlier.



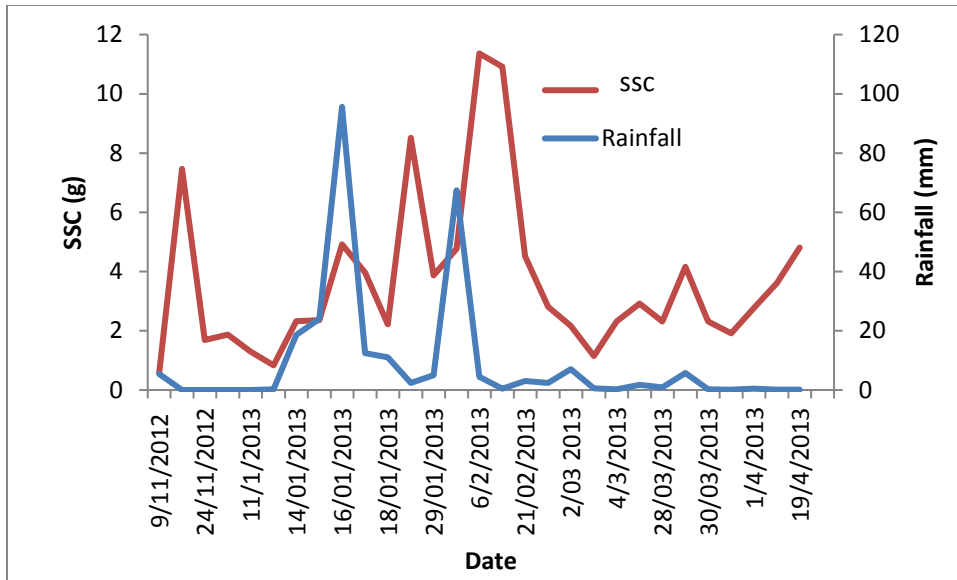
**Figure 4.20: Mean turbidity in Dzindi River Catchment period of November 2012-March 2013**



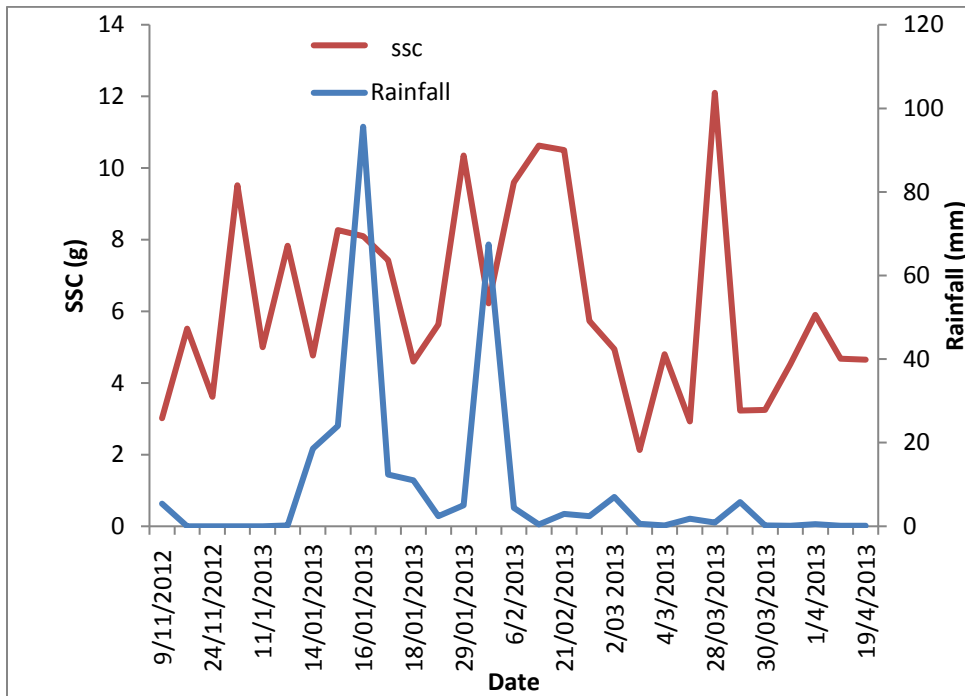
**Figure 4.21: Mean turbidity in Dzindi River Catchment for the period of December 2013-March 2014**

#### **4.5 Effect of the magnitude of each rainfall event on SSCs**

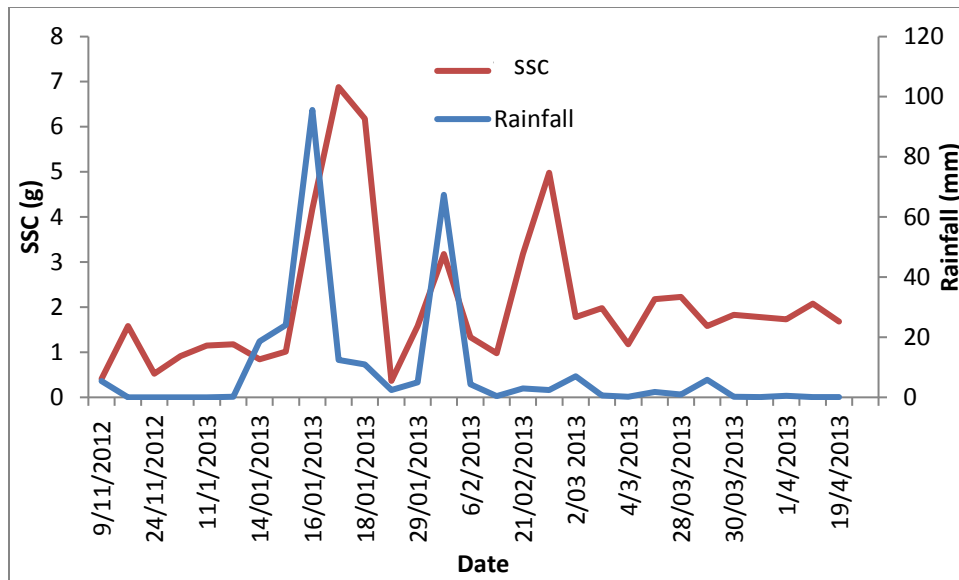
Figures 4.22 to 4.24 show the graphical correlation of SSC and rainfall at Manamani, DWTW and Tshisaulu, respectively. The rainfall data was collected from Vuwani weather station. Generally, SSCs were relatively higher after the peak rainfall events for rainy seasons (November 2012-March 2013). The study thus, indicates that peak rainfall events are responsible for more erosion compared to smaller (minor) peak rainfall events. A study by Nu -Fang *et al.* (2013) confirmed that large-magnitude rainfall events contributed to soil erosion in Wangjiaqiao watershed in China. The analysis of the findings of the latter study indicated that extreme erosion was characterized by high maximum flood-suspended sediment concentrations, high runoff, and high flood peak discharge. The findings of this study also show that at the end of the rainy season towards the end of March, the SSC recedes to lower levels. Nearing and Commons (2013) also reported that SSC was relatively high at the beginning of the event and gradually decreased as rainfall event decreases towards the end of rainy seasons in Walnut Gulch, southeastern Arizona, USA.



**Figure 4.22: Rainfall and SSCs for Manamami for the period of November 2012-March 2013**

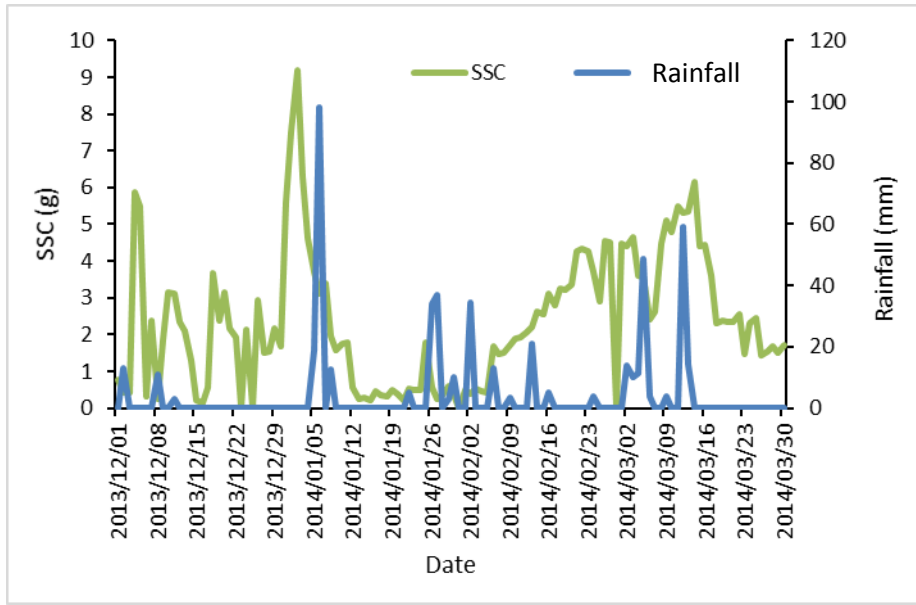


**Figure 4.23: Rainfall and SSCs for DWTW for the period of November 2012-March 2013**

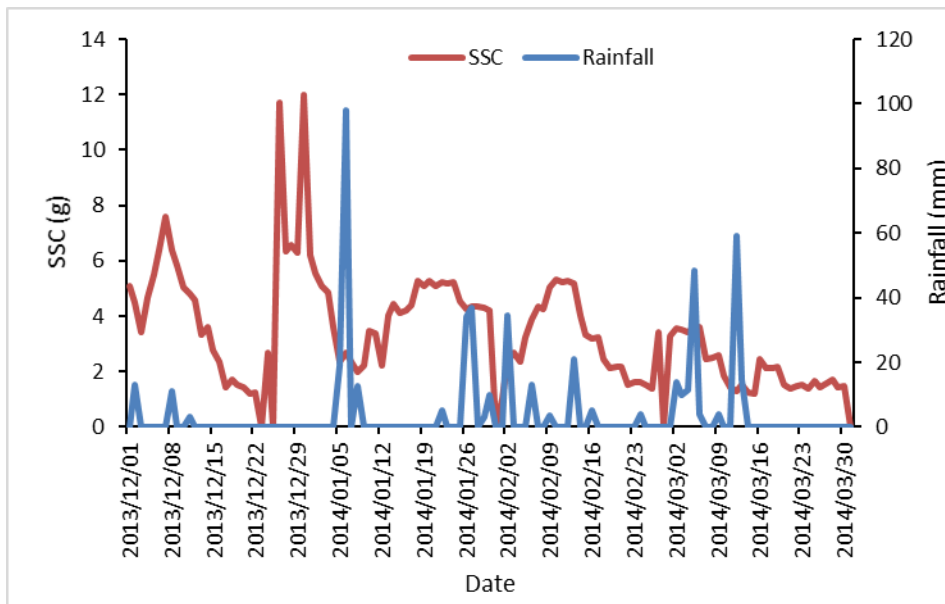


**Figure 4.24: Rainfall and SSCs for Tshisaulu for the period of November 2012-March 2013**

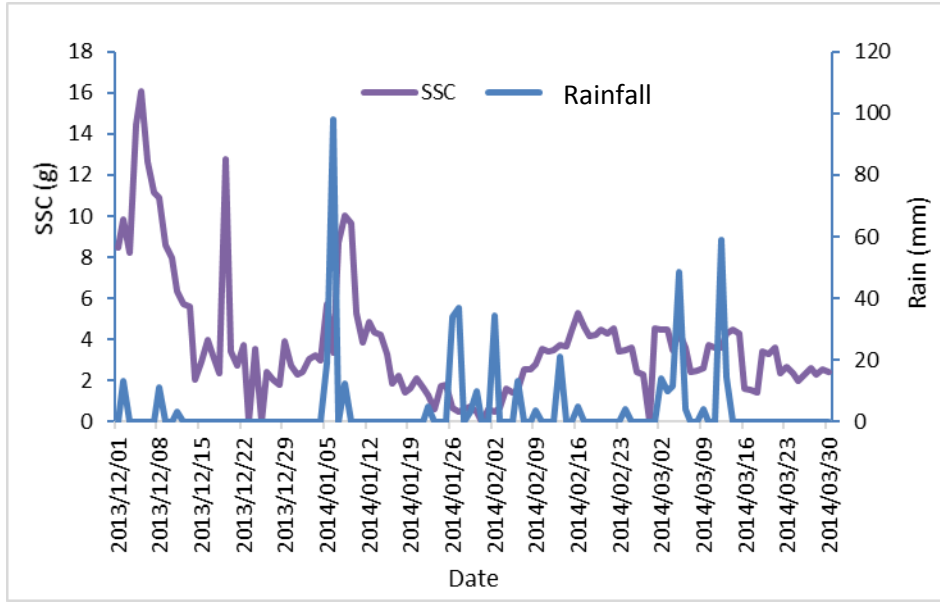
Even though the results of correlation between SSC and rainfall for the rainy seasons of December 2013 to March 2014 (Figures 4.25 to 4.27) was dependent on peak rainfall events to some extent with some lag, this was not very prominent as in the cases shown in Figure 4.22 to 4.24. Thus, this rainy season seems to bring out the complex interplay of factors including the state of the soil surface such as loose soil that are easily eroded by small rainfall events and the fact that small events can erode more than large events that come later depending on how easy it is to erode the soil. For example, later major rainfall events eroded less sediments than smaller earlier events. The smaller earlier events corresponded to the period when the riparian zone had been ploughed and soil loosened and hence easy to detach and erode. On the contrary, the later major events occurred when loose soil had been eroded and transported into the river and planted crop had established themselves making it difficult to erode. Boardmans (2013) reported that small scale rainfall can promote fine sediments losses than large scale rainfall.



**Figure 4.25: Rainfall and SSCs for Tshisaulu for the period of December 2013- March 2014**

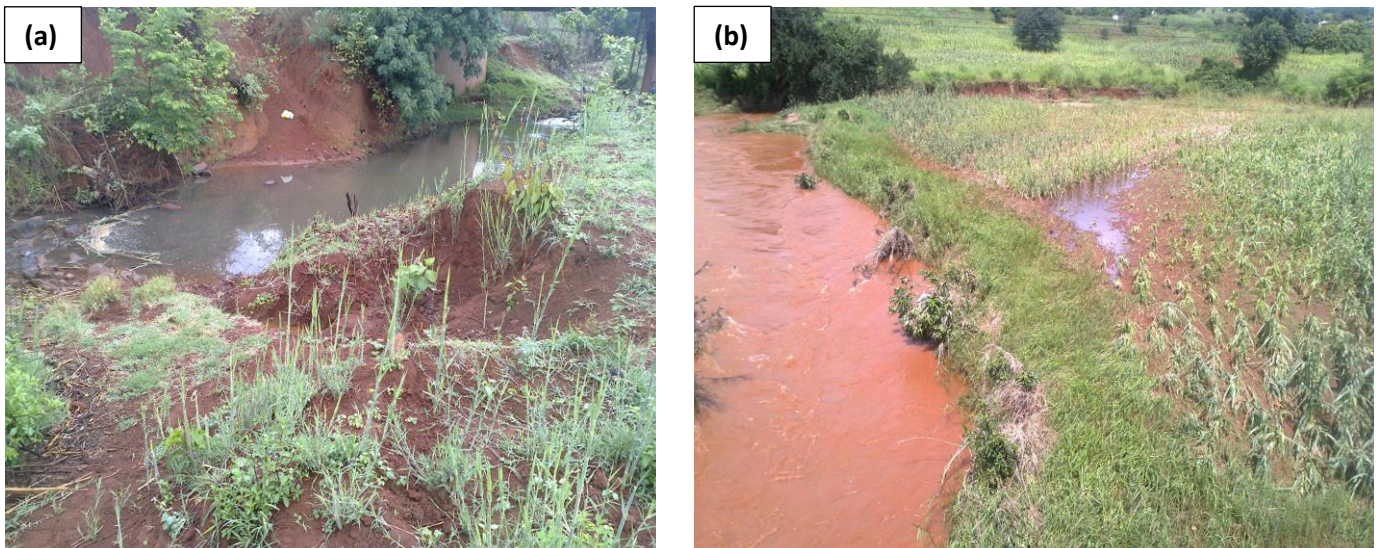


**Figure 4.26: Rainfall and SSCs for DWTW for the period of December 2013- March 2014**



**Figure 4.27: Rainfall and SSCs for Manamani for the period of December 2013- March 2014**

Figure 4.28 shows state of Tshisaulu site during the dry and rainy season. Cultivation closer to the river bank (Figure 4.28a) loosens the soil and hence enhances detachment and transportation of sediments during rainfall. This supports the observed increased SSC in the rainy season.



**Figure 4.28: Dzindi River Catchment at Tshisaulu site during (a) dry and (b) rainy season**

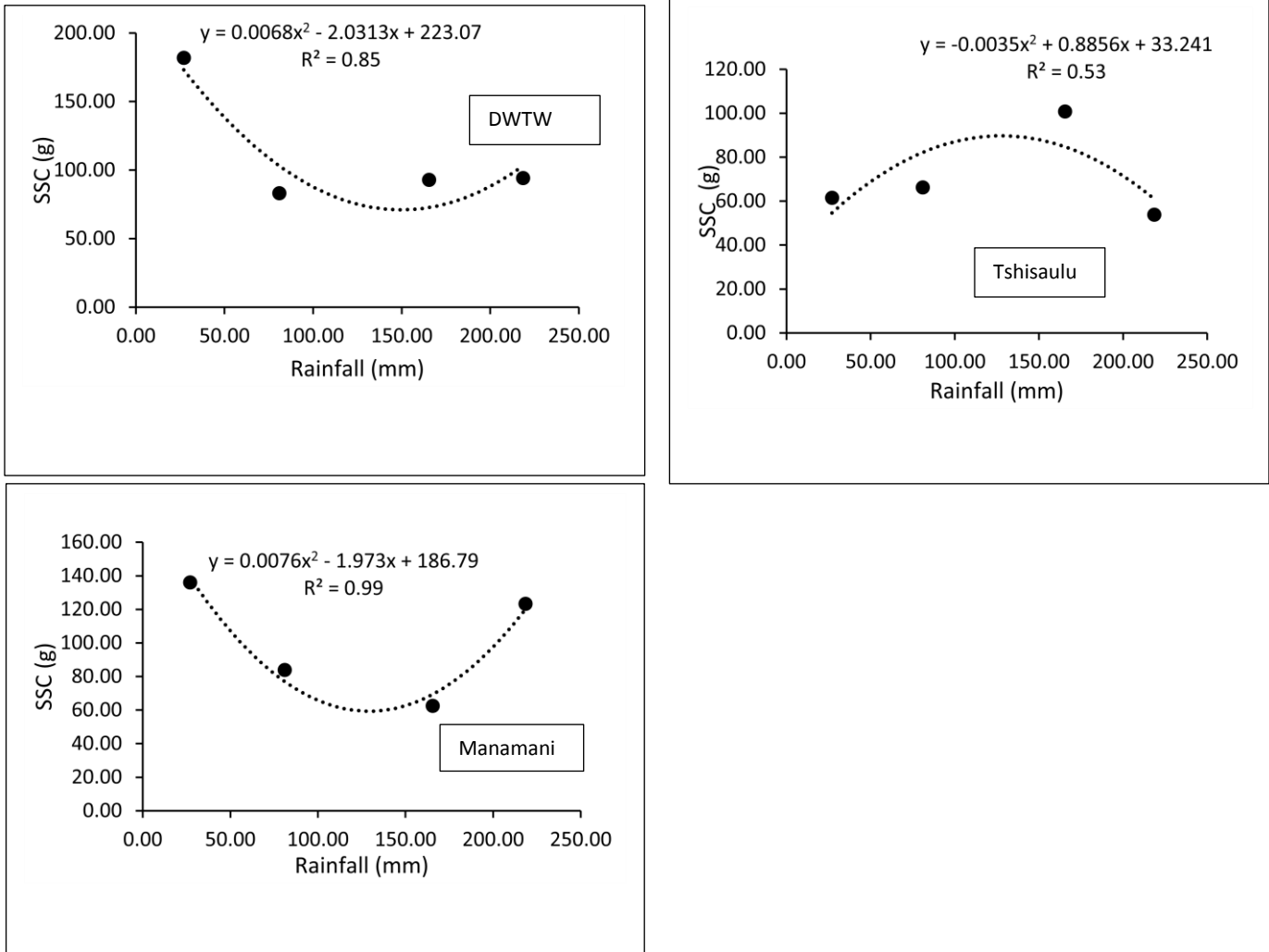
## 4.6 Sediment rating curves

Monthly rainfall and SSCs which were used to plot sediment rating curves are presented in Table 4.1. Maximum SSCs for DWTW and Manamani occurred in December 2013. The results in Table 4.1 show decrease in SSCs in January to March 2014 as compared to those of December 2013. This confirms that rainfall events which occur later are likely to erode less volume of suspended sediment since the top soil has been eroded by earlier rainfall events, as explained in section 4.4. Manamani SSCs were relatively higher throughout the rainfall period possibly because the site is located in the downstream area which accumulates sediments.

Table 4.1: Monthly rainfall and SSCs

Month	Rainfall	DWTW	Tshisaulu	Manamani
December 2013	27.00	136.10	61.59	181.88
January 2014	218.50	123.33	53.83	94.25
February 2014	81.00	83.91	66.29	83.18
March 2014	165.50	62.51	100.79	92.85

Figure 4.29 shows sediment rating curves for DWTW, Tshisaulu and Manamani. The sediment rating curves show second order polynomial relationship between rainfall and SSCs. Coefficient of determination ( $R^2$ ) values for DWTW, Tshisaulu and Manamani were 0.85, 0.53 and 0.99, respectively (Table 4.29).  $R^2$  value for DWTW fell in the range of 0.75-0.85 which indicates very good polynomial relationship between rainfall and SSCs, according to Yan *et al.* (2014).  $R^2$  value for Tshisaulu fell in the range of 0.5-0.65 which indicates satisfactory polynomial relationship between rainfall and SSCs and the  $R^2$  value of Manamani is greater than 0.85 which indicates excellent polynomial relationship between rainfall and SSCs (Table 4.2). This shows that the derived polynomial equation can be used for estimating SSCs. It is important to note that these estimations can only be done within the period of measurements since limited data was used in deriving the rating curves in this study.  $R^2$  values obtained in sediment rating curves developed for different sites in Murry River, Australia in a study by Post and Jakeman (1993) were 0.72, 0.40, 0.90 and 0.13. Some of these values are comparable to those obtained in the current study. Tfwala and Wang (2016) obtained sediment rating curves with  $R^2= 0.621$  which is also within the range of values obtained in the current study.



**Figure 4.29: Sediment rating curves**

Table 4.2: Coefficient of determination ( $R^2$ ) and evaluation criteria

$R^2$ value	Evaluation criteria
> 0.85	Excellent
0.75-0.85	Very good
0.5-0.65	Satisfactory

#### 4.7 Sediment management strategies

The study generally showed high SSCs at the beginning of the sampling periods (2013/12/02 to 2014/01/11) and low SSCs towards the end of rainy period (2014/01/16 to 2014/03/29) for all sampling points. Lwandani, DWTW, Tshisaulu and Manamani have different sediment problems. Lwandani practices different agricultural activities where the return flows into the river carry

suspended sediments which result in changing colour of the river and DWTW practices a lot of soil harvesting wherein during rainfall a lot of sediments are eroded into the river. These are the upstream sites with high slope topography. Sediment management strategy that can be used is slope and bank protection at these upstream sites. Lower slope sites which are Tshisaulu and Manamani, practice crop farming, brick making and poor settlement and the sediment management strategy which can be used is minimum and mulch tillage.

## CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusions

This study focused on determining the influence of the magnitude of each rainfall event on sediment concentration and water quality. Agricultural activities such as clearing of land for cultivation purposes and planting crops, sand/soil harvesting, brick making, livestock watering and washing clothes in the river that are practiced around Lwandani, DWTW, Tshisaulu and Manamani sites were identified as potential sources of sediments and water pollution.

Concentration of suspended sediments for all sites for the period October 2012 to April 2013 ranged from 1.0 to 12.1g at Lwandani, DWTW, Tshisaulu and Manamani. SSCs for all sites ranged from 0.15 to 16.1g for the period December 2013 to March 2014. The results of the study generally showed high SSCs at the beginning of the sampling periods and low SSCs towards the end of sampling period for all sampling points. This was attributed to the fact that most of the top soil is eroded at the beginning of the rainfall season leaving less soil available for erosion towards the end of rainfall season. Mean SSCs ranged from 2.0 to 6.1 g and 2.4 to 3.8 g, during the period October 2012 to April 2013 and December 2013 to March 2014, respectively.

pH values for all sites for the period of October 2012 to April 2013 ranged from 2.83 to 7.3. The highest pH value was found in Manamani and the lowest pH value was found in DWTW. And For the period of December 2013 to March 2014 the highest pH value was 9.50 which was found at Manamani site, and the lowest pH value of 3.23 was found in DWTW. The results of the study show that the pH for the sampling period of October 2012 to April 2013 and December 2013 to March 2014 were higher at the beginning and also towards the end of the rainy season. This was caused by more SSCs during the first rainy days and last rainy days which deposited into the river with more contaminants as compared to that of mid rainy days. Mean pH for the periods of October 2012 to April 2013 and December 2013 to March 2014 ranged from 4.7 to 5.8 and 5.74 to 6.39, respectively.

EC values for all the sites for the period of October 2012 to April 2013 ranged from 0.25 to 8.91 mS/m. The highest EC value was found in Tshisaulu and the lowest was found in Lwandani site. EC values for period of December 2013 to March 2014 ranged from 8.17 to 88.3 mS/m. Highest was found on DWTW and the lowest was in Tshisaulu. Highest EC values were mostly found in sites where there are a lot of human activities. Mean EC values for the periods of October 2012 to April 2013 and December 2013 to March 2014 ranged from 0.58 to 4.04 and 23.9 to 24.3 mS/m. Turbidity values for all the sites for the period of October 2012 to April 2013 ranged from 2.5 to 354.8 NTU and for the period of December 2013 to March 2014 ranged from 5.2 to 95.7 NTU. Mean turbidity values from October 2012 to April 2013 ranged from 10.6 to 119.0 NTU and for the period of December 2013 to March 2014 values range from 41.6 to 44.0 NTU.

The results of the physical water quality indicators showed that the mean of pH values for Lwandani, DWTW, Manamani and Tshisaulu mostly fell within the range of 4-6 where toxic effects associated with dissolved metals, including lead, copper, Zinc and cadmium are likely to occur and water taste is also likely to be slightly sour. Turbidity was high in all sites most of the time indicating high potential for the presents of diseases causing organism hence high, negative health effects if water is used for domestic use. EC values for all sites were mostly within the range from 0-70mS/m and it had no health effects. This showed that water quality at all sites was not suitable for domestic use due to turbidity and pH values which did not comply with water quality guidelines

The results on effects of magnitude of rainfall events on SSCs for the periods of October 2012 to April 2013 and December 2013 to March 2014 showed that SSCs were generally higher at the beginning of rainy season than at the end of the rainy season and this was attributed to more SSCs concentration eroded and transported to the river due to varying ease of erosion. Sediment management strategies that can be used are slope and bank protection and minimum and mulch tillage, wherein both these strategies can prevent soil from eroding and being transported by runoff as sediments into the river and for soil not to lose its fertility in all the sites.

## 5.2 Recommendations

Physical water quality indicators showed potential presence of microbial and chemical parameters at harmful levels in the study. This should be confirmed from detailed microbial and chemical analysis so that appropriate remedial measures can be undertaken. SSCs monitoring should be continued to aid in identifying concentration levels which are harmful to aquatic species. This will also aid in improving the sedimentation rating curves developed in the current study. Best management strategies recommended in this study should be implemented as they can aid in minimizing sedimentation problem into the river catchments.

## References

- Acocks, J.P.H. (1988). Veld types of South Africa. 3<sup>rd</sup> Ed, Botanical Research Institute, Pretoria. pp. 1-146.
- Appleby, J.P. and Scarratt D.J. (1989). Physical effects of suspended solids on marine and estuarine fish and shellfish with special reference to ocean dumping: A literature review. Canadian Technical Report of Fisheries and Aquatic Sciences. pp .16-81.
- Apitz, S.E. and Power, E.A. (2002). Risk assessment to sediment management-An international perspective, *Journal Soils and Sediments*, vol. 2(2), pp. 61-66.
- Apitz, S.E. (2008). Adaptive management principles and sediment management, *Journal of Soils and Sediments*, vol. 8, pp. 359-362.
- Boardman, J., (2013), Soil erosion in Britain: Updating the record, Published by MDPI AG, Basel, Switzerland. vol 3, pp 418-442
- Brandl, G. (1987). Geological Survey, Department of Mineral and Energy Affairs, Silverton, Pretoria, pp. 43-67.
- Broad Authority (2007) sediments management strategies <http://www.broads-authority.gov.uk/looking-after/managing-land-and-water>. 23<sup>th</sup> October 2013.
- Brooks, K.N., Folliott, P.F., Gregersen, H.M. and Thames, J.L, (1991). Hydrology and the management of watersheds. Ames, Iowa: Iowa State University Press, pp. 10-24.
- Bruijnzeel, L.A. (1990). Hydrology of moist tropical forests and effects of conversion: A state-of-knowledge review. Paris: UNESCO International Hydrological Programmed. Amsterdam, Netherlands, pp. 20-150.

Castelle, A.J., Johnson, A.W. and. Conolly, C. (1994). Wetland and stream buffer size requirements: A review, *Journal of Environmental Quality*, vol. 23(5), pp 878-882.

China Erosion and Sediment Transport Measurement (CESTM) 1981. Technologies for suspended sediment measurements, Proceedings of the Florence Symposium. IAHS Publ. no. 133, pp 1-8.

Curtis J.A., Flint, L.E, Alpers, C.N., and Wright, S.A. (2006). Evaluating sediment sources, erosion and transport processes in the upper Yuber River Watershed, California, Proceedings of the 8<sup>th</sup> Federal Interagency Sedimentation Conference, USA, pp. 450- 456

Cramer, O.P. (1974). Environmental effects of forest residues management in the Pacific northwest. General Technical Report PNW-24, Pacific Northwest Forest and Range Experiment Station, Portland, pp. 22.

Daniel G.W., Sean J.B., Brian D.B., and Roger A.K. (2000) studies in suspended in suspended sediments and turbulence in open channel flow research, Channel & Watershed Processes Research Unit and National sedimentation laboratory Oxford, Mississippi, Report no.18, pp. 15 – 133.

Department of Mineral and Energy Affairs. (1985). 1:250 000 Geological Series: 2330 Tzaneen. Silverton: Geological Survey.

Department of Water Affairs and Forestry (DWAF), (1996a). South african water quality guidelines (second edition). Vol 1, Aquatic ecosystem, pp. 156.

Department of Water Affairs and Forestry (DWAF), (1996b). South african water quality guidelines (second edition). Vol 2, Domestic Use, pp. 129.

Durgunoglu, A. and Singh, K.P. (1993) the economics of using sediment-entrapment reduction measures in Lake and Reservoir design, WRC Research Report No. 216, University of Illinois at Urbana-Champaign.

Edwards, T.K. and Glysson, D.G. (1999). Field methods for measurement of fluvial sediment, U.S. Geological survey open-file report 86-531, pp. 61-64.

Elliot, M.F. and Flaxman, M.D. (1967) Sediment and its effect on water quality. pp 4.

Erskine, W.D. and Saynor, M.J. (1996) Success of soil conservation works in reducing soil erosion rates and sediment yields in central eastern Australia, Erosion and Sediment Yield. University of New South Wales, Sydney, Australia, pp. 523-529

Falkenmark, M. and Chapman, T. (1989). Comparative Hydrology. An ecological approach to land and water resources, Paris, France, UNESCO, pp 10-42.

Garcia, M.H. (1959) Sedimentation engineering process, measurements, modeling and practice (ASCE) American Society of Civil Engineering, Manuals and reports on engineering practice vol. 110, pp. 133.

Giulio S.T. (1981). Nuclear techniques for measuring sediment transport in natural streams — examples from instrumented basins, erosion and sediment transport measurement (Proceedings of the Florence Symposium), University of Napoli, Italy, pp. 1-20.

Grenfell S.E. and Ellery W.M. (2009). Hydrology, sediment transport dynamics and geomorphology of variable flow river Mfolozi River, Kwazulu Natal South Africa. University of Kwazulu Natal, vol 35, pp. 271-281.

Grobler, D.C, Toerien D.F. and Rossouw J.N. (1987). A review of sediment/water quality interaction with particular reference to the Vaal River system National Institute for Water Research, *Water SA*, vol. 13, pp. 1-10.

Guy, H.P., and Norman, V.W., (1970). Field methods for measurement of fluvial sediment: U.S. Geol. Survey Techniques of Water Resources, pp. 59.

Haimann, M., Lalk, P., Liedermann, M., Schabus, C., and Habersack, H. (2011) suspended sediment monitoring at the Danube Diver using optic and acoustic devices. International Conference on the Status and Future of the World's Large Rivers. Pp. 120-134.

Hanes, D. M., Vincent, C. E., Huntley, D. A., and Clarke, T. L. (1988). Acoustic measurements of suspended sand concentrations in the C2S2 experiment at Stanhope Lane, Prince Edward Island, *Journal of Marine Geology*, vol. 81, pp 185-196.

Heikkila R. (1991) The influence of land use on the sedimentation of the river delta in the kyronjoki drainage basin vol. 214: pp 143 -147

International Atomic Energy Agency (IAEA) (2005) Fluvial sediment transport: analytical techniques for measuring sediment load pp 7- 35.

International Sediment Initiative (ISI), (2011) Sediment issues and sediment management in large river basins, Interim Case Study Synthesis Report, Technical Documents in Hydrology.

Inter-agency Committee on Water Resources. (1963). A study of methods used in measurement and analysis of sediment loads in streams- field practice and equipment used in sampling suspended sediment Report No. 14. St. Anthony Falls Hydraulic Laboratory.

Lemly, A.D. (1982). Modification of benthic insect communities in polluted streams: Combined effects of sedimentation and nutrient enrichment. *Hydrobiologia*, vol 87, pp. 229-245.

Lewis, V. (1999). The management of freshwater fisheries. National Trust, Cirencester, pp 50-78.

Lewis, L., Hagen, S. and Salisbury, D. (2001). Soil bioengineering for upland slope stabilization, Research Project WA-RD 491.1 Soil Bioengineering for Slopes, Washington, pp. 55- 85.

Li, M. and Eddleman, K.E. (2002). Biotechnical engineering as an alternative to traditional engineering methods, A biotechnical streambank stabilization design approach, *Landscape and Urban Planning*, vol. 60, pp. 225-242.

Lietz A.C., and Debiak E.A. (2005). Development of rating curve estimators for suspended-sediment concentration and transport in the C-51 canal based on surrogate technology, palm beach county, florida, pp 1-18.

McClanahan, T.R. and Obura, D. (1995). Status of Kenyan coral reefs, *Coastal, Management*, vol. 23, pp. 57-76.

McHenry, J.R., Coleman, N. L., Willis, A.C., Sansom, O.W., and Carrol, B.R. (1967). Effect of concentration gradients on the performance of a nuclear sediment concentration gage, *Water Resources Research*, vol. 6 (2), pp. 538-548.

McCutcheon, S.C., Martin, J.L, and Barnwell, T.O. (1993). Water Quality. In Handbook of Hydrology, Edited by D.R. Maidment. McGraw-Hill Inc., New York, pp. 30-37.

Meyer, J.L and Dr. Freeman J.B. Institute of Ecology, University of Georgia, Athen (2005) Effects of Sedimentation on Biodiversity in Rivers and Streams of the Southeastern United States, pp. 12-34.

Morgan, R.P.C. (1995). Modeling soil erosion. Morgan R (edition.). Soil erosion and conservation. 2<sup>nd</sup> Ed, Longman Group Limited, London. Pp 250-316.

Mostert, T.H.C., (2006). Vegetation ecology of the southpansberg and blouberg areas in the Limpopo province. Department of Botany Faculty of Natural and Agricultural Sciences University of Pretoria, pp 11.

Murray, G. (1951). The soil survey of the Dzindi Irrigation River Irrigation Project: Report No 295. Sibasa: Division of Chemical Services of the Department of Agriculture, pp. 45-97.

Mwamba, M.J. and Torres, R. (2002). Rainfall effects on marsh sediment redistribution, North Inlet, South Carolina, Department of Geological Sciences, University of South Carolina, USA, *Marine Geology* vol 189, pp 267–287.

National Technical Advisory Committee (NTAC), (1968). *Water Quality Criteria*. Federal Water Pollution Control Administration, Washington DC, Federal water pollution control administration, pp 105 -138.

National Resources and Environment (NRE). (2001). Fresh ecosystem biodiversity management issues sedimentation of rivers and streams, pp. 1-4.

National Trust, (2002). Manual of Building – Best practice, Relevant sections include practice notes for major projects (Vol. 1 Section 10-1), preparation of a project brief (Vol. 1 Section 10-6) and general requirements for building work (Vol. 1 Section 3)

Neal, C., Smith, C.J. and Hill, S. (1998) Forestry impact on upland water quality, Institute of Hydrology, Report no. 119, pp. 45-50.

Nearing, M. A. and Commons, M. (2013) Suspended sediment transport at the instantaneous and event time scales in semiarid watersheds of south eastern Arizona, USA Peng Gao. Publisher: water resources research, vol. 49, pp. 6857–6870.

Nelson, M.E. and Benedict, P.C. (1950). Measurement and analysis of suspended loads in streams, Transactions of the American Society of Civil Engineers, Paper no. 2450, pp 891-918.

Nu-fang, F., Zhi-hua, S., Ben jiang, Y. and Ling W. The Characteristics of Extreme Erosion Events in a Small Mountainous Watershed, pp. 115-130.

Oehy, C. (2003) Effects of obstacles and jets on reservoir sedimentation due to turbidity currents, Laboratoire de Constructions Hydrauliques, Communacation 15, EDcloe Polytechnique, Fédérale de Lausanne, pp. 34-347.

Ongly, E. (1996) Water quality monitoring - practical guide to the design and implementation of freshwater quality studies and monitoring programmes. pp 6.

Oschwald, W.R. (1972). Sediment-water interactions. *Journal of Environmental Quality*, vol1. pp 360-366.

Pao, S.C., Xin, Z.Y.R. and Melodie, G. (2008). Extreme Rainfall Events in the Hawaiian Islands. *Journal of applied meteorology and climatology* vol 48. pp.502

Peter, D.T. and Daniel, M.H. (2002). A review of acoustic measurement of small-scale Sediment processes. *Confidential shelf research* 22, pp 603- 632.

Post, D.A. and Jakeman, A.J. (1993) Impact of rainfall on turbidity and suspended sediments load at five sites on the Murray River between Albury and Swan hill and possible relationship to catchment attributes, report for NWS environmental protection authority. pp 194 -199.

Ranga, R.K.G. and Kothyari, U.C. (2004) Sediment management in hydroelectric projects, Proceedings of the Ninth International Symposium on River Sedimentation, Yichang, China. Pp 34-56.

Ranga, R. K. G., Kothyari, U. C. Somya, .S. and Manish, S. (1999) *Journal of Irrigation and Drainage Engineering*. pp 13-42.

Reichel, G. (1998). Suspended sediment monitoring: Use of Acoustic Doppler Current Profiler. In *Encyclopedia of Hydrology and Water Resources*, pp 67-69.

Roberts, R.G., Spooner, N.A., Jones, R., Cane, S., Olley, J.M., Murray, A.S., and Head, M.J., (1996). Preliminary luminescence dates for Archaeological sediments on the Nullabor Plain, South Australia, *Australian Archaeometry* vol. 42, pp 7-16.

Rodriguez - Blanco, M.L., Taboada-Castro, M.M., Taboada-Castro, M.T., Oropeza Mota, J.L. (2008). Suspended sediments-discharge hysteresis during rainfall events in a small headwater Catchment. [tucson.ars.ag.gov/.../Rodriquez%20Blanco%20ML-Suspended%20se](http://tucson.ars.ag.gov/.../Rodriquez%20Blanco%20ML-Suspended%20se), pp. 205 – 217.

Rooseboom A. and Annandale G. W (1981). Techniques applied in determining sediment loads in South African Rivers, Department of Civil Engineering, University of Pretoria, South Africa, Erosion and Sediment Transport Measurement (Proceedings of the Florence Symposium, June 1981). IAHS Publ. no. 133, pp. 220-229.

Schulz, R. (2000) Rainfall-induced sediment and pesticide input from orchards into the lourens river, Western Cape, South Africa: importance of a single event. Vol 3, pp. 35-40.

Schoellhamer D.H and Scott A.W (2003), Continuous measurement of suspended-sediment discharge In rivers by use of optical backscatterance sensors erosion and sediment transport measurement in rivers: Technological and methodological advances. IAHS Publ. pp 283.

Schoellhamer D.H. and Wright S.A. (2003), Continuous measurement of suspended-sediment discharge in rivers by use of optical backscatterance sensors. pp 18- 34.

SedNet, (2006). Report on the round table discussion sediment management – an essential element of river basin management plans venice [www.sednet.org/.../061122](http://www.sednet.org/.../061122) Report SedNet Round Table Discussion.

Syed, M.K., Charles, W.F., Harry, H.R and Richards, C.R. (2010), New Approaches to Sediment Management on the Inner Continental Shelf Offshore Coastal Louisiana. *Journal of Coastal Research*, vol. 26 (4), pp. 591 – 604.

Soil Conservation Strategies (2012) <http://www.greenstone.org/greenstone3/nzdL>, 5<sup>th</sup> February 2013.

Soil Conservation Method, (2012) <http://refrance.com/motif/Science/soil-conservation-method>, 20<sup>th</sup> September 2013.

Swamee, P. K. and Tyagi, A. (2000). Describing water quality with aggregate index, *Journal of Environmental Engineering*, vol. 126, pp 451-455.

Tfwala, S.S and Wang, Y. (2016). Estimating sediment discharge using sediment rating curves and artificial neural networks in the Shiwen River. Taiwan, vol. 8, pp. 58.

Thorne, P.D., Waters, K R., and Brudner, T.J. (1995). Acoustic measurements of scattering by objects of irregular shape, *Journal of Acoustic Society of America*, vol 97(1) pp. 242-251.

United Nations Environment Programme (UNEP) (1994) Guidelines for sediment control practices in the insular Caribbean, CEP Technical Report No. 32. pp 1-58.

UNESCO (2011) Sediment issues and sediment management in large river basins, Interim Case Study Synthesis Report, pp. 45-50.

U.S. Department of Agriculture (USDA) (1992). Soil bioengineering for upland slope protection and erosion reduction, In: Tuttle, R. W. (Ed.), *Engineering Field Handbook*, United States Department of Agriculture – National Resources Conservation Services, pp. 33-52.

US Environmental Protection Agency. (1994). ARCS Assessment Guidance Document. EPA 905-B94-002. Chicago, Ill.: Great Lakes National Program Office, Assessment Guidance Document Chapter 3, pp 115- 209.

U.S. Department of Agriculture (USDA) (2006) How to control streambank erosion. Department of Agriculture. pp 2-48.

United States Geological Survey (USGS) (2005). Manual Sampling method for sedimentation for mid80s <http://water.usgs.gov/lookup/get?> 16/03/ 2013.

Van Rijn, L.C. and Schaafsma, A.S. (1986). Evaluation of measuring instruments for suspended sediment. International Conference on Measuring Techniques of Hydraulics Phenomena in Offshore, Coastal & Inland Waters. London, England, pp 401-423.

Van Rijn, L.C. (1993) Principles of sediment transport of rivers, estuaries and coastal seas, Aqual publications, Amsterdam, Nertherlands, pp 235.

Van Averbeke, W. (2007). Best management practices for small-scale subsistence farming on selected irrigation schemes and surrounding areas through participatory adaptive research in Limpopo Province: Draft Final Report of WRC Project K5/1464//4. Pretoria, South Africa, pp. 423.

Van Zyl, A. and Lorentz, S. (2003) Report to the Water Research Commission. Pretoria South Africa. Report no 1061 and 1086/1/04, pp. 10-96.

Walling D. E. (1974) Limitations of the rating curve technique for estimating suspended sediment loads, with particular reference to British rivers, vol. 13, pp. 34-49.

Waters, T.F. (1995) Sediment in streams: sources, biological effects and control. American Fisheries Society, Bethesda, Md. pp 251.

Welch H.L, Coupe R.H, and Aulebach B.T (2011) Transport of SS, nutrients and pesticide in lower Mississippi Atclafalaye River flood, pp. 45-78.

Wolman, M.G. and Miller, J.P. (1960) Magnitude and frequency of forces in geomorphic processes, Journal of Geology, vol. 68, pp. 54-74.

Woodward, J. and Foster, I. (1997) Erosion and suspended sediment transfer in river catchments, Environmental Controls, Processes and Problems, pp. 353-376.

Wikipedia (2012) Scientific phenomenon of sedimentation, <http://www.wikipedia.com>, 13<sup>th</sup> January 2013.

World Meteorological Organization (WMO) (1994) Manual on sediment management and measurement hydrology, WMO Report No47, pp. 121-132.

Wright S.A (2006) Impact of agricultural activities in Lesotho Highlands River. Pp12-32.

Xiaoqing, Y. (2003) Manual on sediment management and measurement, Operational Hydrology Report No. 47, World Meteorological Organization, Geneva, Switzerland. PP 132-145

Xhi, L., Yuren, L., Leling, S., Xianglin X., Yujing, Y. and Lingqi, K. (1981). The development of nuclear sediment concentration gauges for use on the Yellow River. Institute of Hydraulic Research, Yellow River Conservancy Commission, Zhengzhou. pp 56-89.

Yan, C.A, Zhang W., and Zhang, Z. (2014) Hydrological modeling of Jiaoyi Watershed (china), using HSPF model, The scientific world journal, pp 9.

Zhu Y-M, Lu, X.X, Zhou, Y. (2006) Suspended sediment flux modeling with artificial neural network: An example of the Long chuanjiang River in the Upper Yangtze Catchment, China. Science Direct for geomorphology. pp 111-125.

## APPENDICES

### Appendix A: SSCs OF DZINDI RIVER CATCHMENT FOR OCTOBER 2012 TO APRIL 2013

Appendix A1: SSCs OF DZINDI RIVER CATCHMENT FOR OCTOBER 2012 TO APRIL 2013

DATE	LWANDANI	DWTW	MANAMANI	TSHISAULU
2012/10/12	7.97	9.52	1.87	0.91
2012/10/24	7.24	3.62	0.84	0.52
2012/11/09	2.64	3.02	2.33	0.41
2012/11/20	7.74	5.52	2.36	1.58
2013/01/11	2.90	5.00	4.92	1.15
2013/01/13	2.17	7.83	3.97	1.18
2013/01/14	1.40	4.77	2.22	0.85
2013/01/15	0.74	8.27	8.52	1.01
2013/01/16		8.10	3.87	4.18
2013/01/17		7.43	4.77	6.88
2013/01/18		4.60	11.37	6.18
<b>2013/01/28</b>		5.63	10.92	0.37
<b>2013/01/29</b>		10.35	4.52	1.58
<b>2013/02/05</b>		6.22	2.82	3.18
<b>2013/02/06</b>		9.60	2.17	1.33
<b>2013/02/16</b>		10.63	1.15	0.98
<b>2013/02/21</b>		10.50	2.31	3.18
<b>2013/02/22</b>		5.73	2.92	4.98
2013/03/02		4.95	2.32	1.78
2013/03/03		2.13	4.17	1.98
2013/03/04		4.80	2.32	1.18
2013/03/21		2.93	1.92	2.18
2013/03/28		12.10	2.77	2.23
2013/03/29		3.23	3.62	1.58
2013/03/30		3.25	4.82	1.83
2013/03/31		4.53	1.92	1.78
2013/04/04		5.90	2.77	1.73
2013/05/18		4.68	3.62	2.08
2013/05/19		4.65	4.82	1.68
<b>Mean</b>	<b>4.0</b>	<b>6.1</b>	<b>3.6</b>	<b>2.0</b>

Appendix A2: SSCs FOR THE PERIOD OF DECMBER 2013 TO MARCH 2014

DATE	DWTW	MANAMANI	TSHISAULU	DATE	DWTW	MANAMANI	TSHISAULU
2013/12/01	5.07	0.77	8.44	2014/01/06	2.67	3.11	3.33
2013/12/02	4.47	0.41	9.82	2014/01/07	2.37	3.40	8.73
2013/12/03	3.40	0.41	8.22	2014/01/08	1.97	1.96	10.00
2013/12/04	4.68	5.89	14.43	2014/01/09	2.20	1.56	9.63
2013/12/05	5.50	5.49	16.07	2014/01/10	3.47	1.75	5.26
2013/12/06	6.37	0.33	12.63	2014/01/11	3.36	1.78	3.83
2013/12/07	7.60	2.39	11.17	2014/01/12	2.22	0.55	4.87
2013/12/08	6.37	0.25	10.93	2014/01/13	4.04	0.25	4.33
2013/12/09	5.83	1.86	8.57	2014/01/14	4.44	0.29	4.25
2013/12/10	5.03	3.14	7.97	2014/01/15	4.10	0.23	3.27
2013/12/11	4.80	3.10	6.33	2014/01/16	4.21	0.47	1.87
2013/12/12	4.57	2.36	5.73	2014/01/17	4.42	0.35	2.23
2013/12/13	3.33	2.11	5.60	2014/01/18	5.27	0.32	1.43
2013/12/14	3.60	1.30	2.04	2014/01/19	5.10	0.48	1.63
2013/12/15	2.77	0.22	2.90	2014/01/20	5.29	0.39	2.10
2013/12/16	2.33	0.16	3.96	2014/01/21	5.10	0.22	1.67
2013/12/17	1.43	0.57	3.24	2014/01/22	5.25	0.53	1.30
2013/12/18	1.70	3.66	2.36	2014/01/23	5.16	0.50	0.60
2013/12/19	1.51	2.37	12.81	2014/01/24	5.22	0.50	1.70
2013/12/20	1.42	3.15	3.42	2014/01/25	4.55	1.77	1.80
2013/12/21	1.22	2.16	2.75	2014/01/26	4.25	0.55	0.67
2013/12/22	1.27	1.94	3.71	2014/01/27	4.37	0.24	0.50
2013/12/23	0.00	0.00	0.00	2014/01/28	4.37	0.36	0.63
2013/12/24	2.70	2.15	3.52	2014/01/29	4.29	0.60	0.76
2013/12/25	0.00	0.00	0.00	2014/01/30	4.22	0.36	0.47
2013/12/26	11.73	2.93	2.44	2014/01/31	0.00	0.00	0.00
2013/12/27	6.33	1.52	2.07	2014/02/01	1.00	0.50	0.63
2013/12/28	6.57	1.53	1.82	2014/02/02	2.36	0.40	0.50
2013/12/29	6.30	2.16	3.92	2014/02/03	2.67	0.53	0.67
2013/12/30	12.00	1.67	2.73	2014/02/04	2.36	0.46	1.63
2013/12/31	6.20	5.59	2.28	2014/02/05	3.25	0.43	1.40
2014/01/01	5.53	7.52	2.43	2014/02/06	3.90	1.67	1.56
2014/01/02	5.07	9.19	3.03	2014/02/07	4.36	1.46	2.53
2014/01/03	4.87	6.30	3.26	2014/02/08	4.24	1.52	2.56
2014/01/04	3.60	4.62	2.99	2014/02/09	5.04	1.73	2.76
2014/01/05	2.37	3.70	5.70	2014/02/10	5.33	1.90	3.53

Appendix A2: Continued

Date	DWTW	MANAMANI	TSHISAULU	DATE	DWTW	MANAMANI	TSHISAULU
2014/02/11	5.25	1.94	3.40	2014/03/21	1.37	2.33	3.60
2014/02/12	5.29	2.06	3.50	2014/03/22	1.47	2.57	2.37
2014/02/14	4.01	2.61	3.64	2014/03/23	1.53	1.47	2.67
2014/02/15	3.31	2.56	4.40	2014/03/24	1.40	2.30	2.37
2014/02/16	3.21	3.10	5.27	2014/03/25	1.67	2.47	1.97
2014/02/17	3.24	2.80	4.63	2014/03/26	1.43	1.43	2.30
2014/02/18	2.43	3.25	4.16	2014/03/27	1.57	1.53	2.63
2014/02/19	2.14	3.23	4.20	2014/03/28	1.70	1.67	2.30
2014/02/20	2.15	3.37	4.46	2014/03/29	1.43	1.50	2.53
2014/02/21	2.16	4.28	4.30	2014/03/30	1.47	1.70	2.40
2014/02/22	1.50	4.32	4.56	2014/03/31	0.00	0.00	0.00
2014/02/23	1.60	4.27	3.40	<b>Mean</b>	<b>3.49</b>	<b>2.4</b>	<b>3.8</b>
2014/02/24	1.60	3.72	3.45				
2014/02/25	1.53	2.92	3.63				
2014/02/26	1.40	4.56	2.40				
2014/02/27	3.40	4.50	2.30				
2014/02/28	0.00	0.00	0.00				
2014/03/01	3.30	4.46	4.57				
2014/03/02	3.57	4.40	4.50				
2014/03/03	3.50	4.67	4.50				
2014/03/04	3.43	3.60	3.50				
2014/03/05	3.60	3.57	4.34				
2014/03/06	3.60	2.40	3.60				
2014/03/07	2.43	2.63	2.40				
2014/03/08	2.50	4.47	2.47				
2014/03/09	2.60	5.10	2.60				
2014/03/10	1.87	4.80	3.73				
2014/03/11	1.43	5.50	3.63				
2014/03/12	1.30	5.30	3.60				
2014/03/13	1.50	5.33	4.30				
2014/03/14	1.27	6.17	4.47				
2014/03/15	1.20	4.40	4.27				
2014/03/16	2.44	4.43	1.60				
2014/03/17	2.14	3.60	1.53				
2014/03/18	2.15	2.30	1.40				
2014/03/19	2.16	2.37	3.40				
2014/03/20	1.50	2.33	3.30				

APPENDIX B: MEASURED pH VALUES

Appendix B1: pH for the period of October 2012 to April 2013

Date	Lwandani	DWTW	Tshisaulu	Manamani
2012/10/12	6.86	6.37	6.51	6.7
2012/10/24	5.55	6.38	5.35	5.2
2012/11/09	5.38	5.24	5.16	5.5
2012/11/20	5.23	5.37	5.29	5.6
2013/01/11	5.96	6.40	6.05	6.5
2013/01/13	5.99	6.34	6.30	5.9
2013/01/14	6.00	6.54	6.59	5.7
2013/01/15	4.94	6.70	6.58	5.6
2013/01/16		6.71	5.45	4.5
2013/01/17		3.42	4.55	5.0
2013/01/18		3.72	4.70	5.4
2013/01/28		4.62	4.55	4.6
2013/01/29		4.32	4.60	4.6
2013/02/05		3.50	3.80	5.2
2013/02/06		3.54	3.85	4.8
2013/02/16		3.23	3.70	4.5
2013/02/21		3.12	3.50	4.4
2013/02/22		2.83	4.25	4.5
2013/03/02		6.60	4.80	6.7
2013/03/03		6.65	4.16	7.3
2013/03/21		6.76	4.27	7.3
2013/03/28		6.35	4.27	7.2
2013/03/29		6.60	4.19	7.3
2013/03/30		6.11	4.18	6.4
2013/03/31		5.57	3.34	6.3
2013/04/01		6.41	4.24	6.1
2013/04/04		5.62	3.33	7.2
2013/04/18		6.33	5.36	6.3
2013/04/19		6.45	5.26	6.4
<b>Mean</b>	<b>5.7</b>	<b>5.4</b>	<b>4.7</b>	<b>5.8</b>

Appendix B2: pH of December 2013 to March 2014

Date	DWTW	TSHISAULU	MANAMANI	DATE	DWTW	TSHISAULU	MANAMANI
12/1/2013	6.43	6.63	7.63	1/2/2014	5.67	5.53	6.83
12/2/2013	7.40	7.77	8.40	1/3/2014	6.67	6.73	6.50
12/3/2013	7.83	7.67	8.67	1/4/2014	6.53	6.87	7.67
12/4/2013	6.13	5.50	6.77	1/5/2014	5.67	4.63	8.50
12/5/2013	5.67	5.63	7.63	1/6/2014	6.60	5.43	5.60
12/6/2013	5.67	5.57	6.43	1/7/2014	5.43	6.33	4.57
12/7/2013	6.60	5.77	6.80	1/8/2014	5.47	6.70	5.43
12/8/2013	6.70	8.13	8.80	1/9/2014	5.67	4.60	5.62
12/9/2013	7.63	7.70	9.07	1/10/2014	5.67	5.43	6.77
12/10/2013	8.43	7.67	8.59	1/11/2014	6.70	6.97	7.33
12/11/2013	5.97	5.73	6.67	1/12/2014	6.34	6.50	7.03
12/12/2013	7.27	6.63	7.00	1/13/2014	6.83	6.43	8.47
12/13/2013	7.33	7.40	8.50	1/14/2014	6.33	6.80	8.37
12/14/2013	6.77	7.53	8.53	1/15/2014	6.27	6.90	7.67
12/15/2013	7.70	7.57	8.57	1/16/2014	6.43	6.33	7.27
12/16/2013	5.70	6.33	6.30	1/17/2014	6.50	6.43	6.90
12/17/2013	5.13	5.80	6.13	1/18/2014	7.37	6.67	6.83
12/18/2013	5.27	5.50	6.30	1/19/2014	7.40	6.43	7.47
12/19/2013	5.47	5.60	5.60	1/20/2014	6.40	6.50	6.50
12/20/2013	5.40	6.20	6.50	1/21/2014	6.47	5.50	6.30
12/21/2013	5.60	6.90	8.43	1/22/2014	6.17	5.30	6.57
12/22/2013	6.43	7.17	9.50	1/23/2014	6.30	5.57	5.47
12/24/2013	7.73	7.77	9.20	1/24/2014	5.40	5.30	5.37
12/26/2013	6.60	5.50	8.53	1/25/2014	5.37	5.23	6.33
12/27/2013	5.57	5.53	6.43	1/26/2014	5.10	5.37	6.43
12/28/2013	5.63	4.67	6.40	1/27/2014	5.20	5.23	6.67
12/29/2013	5.53	4.67	5.53	1/28/2014	5.40	5.37	6.70
12/30/2013	4.70	4.77	5.00	1/29/2014	4.73	4.40	5.47
12/31/2013	4.80	5.48	5.34	1/30/2014	4.53	4.33	5.27
1/1/2014	5.77	6.79	6.53	1/31/2014	4.47	4.47	5.33

Appendix B2: Continued

DATE	DWTW	TSHISAULU	MANAMANI	DATE	DWTW	TSHISAULU	MANAMANI
2/1/2014	4.73	4.53	5.67	3/4/2014	5.53	6.70	5.63
2/2/2014	4.53	4.27	5.47	3/5/2014	5.50	6.53	5.70
2/3/2014	4.47	4.27	5.37	3/6/2014	6.53	5.57	5.57
2/4/2014	4.24	4.43	5.53	3/11/2014	6.40	5.60	6.50
2/5/2014	4.17	4.30	5.87	3/12/2014	7.27	5.50	6.60
2/6/2014	4.50	4.27	4.77	3/13/2014	7.43	6.33	6.43
2/7/2014	4.17	4.47	4.70	3/14/2014	7.43	6.63	6.83
2/8/2014	4.33	4.23	5.13	3/15/2014	5.70	6.60	6.70
2/9/2014	4.23	5.50	6.53	3/16/2014	5.50	6.63	6.20
2/10/2014	4.37	4.37	5.30	3/17/2014	5.57	6.57	6.27
2/11/2014	4.17	4.37	4.40	3/18/2014	5.67	6.67	6.33
2/12/2014	3.41	4.43	4.37	3/19/2014	5.53	6.43	6.45
2/13/2014	3.40	4.47	4.17	3/20/2014	5.50	6.40	6.51
2/14/2014	3.63	4.20	3.73	3/21/2014	6.53	7.27	6.38
2/15/2014	3.23	4.23	4.40	3/22/2014	6.50	7.43	6.33
2/16/2014	3.67	4.07	4.53	3/23/2014	7.57	7.43	6.20
2/17/2014	3.37	3.27	4.43	3/24/2014	7.27	7.43	6.27
2/18/2014	3.43	3.40	5.70	3/25/2014	7.20	7.43	5.60
2/19/2014	3.50	3.53	5.20	3/26/2014	7.37	5.70	5.50
2/20/2014	3.27	3.87	5.30	3/27/2014	6.33	5.57	6.33
2/21/2014	3.27	3.37	5.47	3/28/2014	6.40	7.27	6.60
2/22/2014	3.30	3.40	5.17	3/29/2014	7.27	6.20	5.57
2/23/2014	4.60	4.27	4.80	3/30/2014	7.43	6.27	5.57
2/24/2014	5.50	4.17	5.57	<b>Mean</b>	<b>5.74</b>	<b>5.76</b>	<b>6.39</b>
2/25/2014	5.63	5.03	5.57				
2/26/2014	4.60	5.37	5.47				
2/27/2014	5.50	6.32	5.47				
2/28/2014	5.63	6.14	5.27				
3/1/2014	5.70	6.11	5.57				
3/2/2014	5.57	6.43	5.40				
3/3/2014	5.67	6.63	5.50				

## Appendix C: MEASURED TURBIDITY VALUES

### Appendix C1: TURBIDITY October 2012 to April 2013

Date	LWANDANI	DWTW	TSHISAULU	MANAMANI
10/12/2012	2.97	1.25	4.41	2.5
10/24/2012	3.47	12.80	76.00	93.3
11/9/2012	16.54	74.99	163.11	186.7
11/20/2012	38.17	15.16	168.00	113.9
1/11/2013	5.37	9.08	36.44	4.8
1/13/2013	6.21	9.29	22.14	68.7
1/14/2013	6.10	9.57	17.95	11.3
1/15/2013	6.32	12.46	10.11	11.3
1/16/2013		12.39	111.20	322.3
1/17/2013		114.25	122.82	351.2
1/18/2013		226.60	134.93	354.8
1/28/2013		222.10	134.70	234.1
1/29/2013		240.85	145.05	162.8
2/5/2013		289.05	146.55	235.2
2/6/2013		249.90	165.86	324.8
2/16/2013		243.50	229.35	237.7
2/21/2013		271.25	244.84	240.0
2/22/2013		267.90	240.00	250.8
3/2/2013		32.90	55.35	33.7
3/3/2013		36.71	33.70	35.9
3/21/2013		29.40	35.55	32.8
3/28/2013		22.00	35.55	22.5
3/29/2013		19.15	34.72	19.5
3/30/2013		24.00	30.00	12.5
3/31/2013		22.20	22.17	12.3
4/1/2013		18.76	27.51	10.2
4/4/2013		27.65	32.21	45.7
4/18/2013		15.70	19.09	10.0
4/19/2013		16.23	17.14	11.2
<b>Mean</b>	<b>10.6</b>	<b>87.8</b>	<b>87.3</b>	<b>119.0</b>

Appendix C2: Turbidity for the period of December 2013 to March 2014

Date	DWTW	Manamani	Tshisaulu	Date	DWTW	Manamani	Tshisaulu
12/1/2013	12.13	13.20	5.63	1/9/2014	22.10	43.33	51.87
12/2/2013	13.44	15.22	5.22	1/10/2014	22.10	41.47	56.40
12/3/2013	10.07	16.27	6.93	1/11/2014	21.13	43.53	52.33
12/4/2013	16.77	19.10	15.43	1/12/2014	26.73	37.53	54.27
12/5/2013	17.50	16.40	5.63	1/13/2014	21.30	44.33	44.07
12/6/2013	17.50	15.27	14.67	1/14/2014	21.77	45.67	53.93
12/7/2013	18.13	17.23	12.57	1/15/2014	23.70	46.70	54.30
12/8/2013	19.13	12.47	9.39	1/16/2014	23.87	45.00	34.50
12/9/2013	17.63	19.77	9.29	1/17/2014	23.87	45.77	26.90
12/10/2013	11.44	20.07	10.33	1/18/2014	18.63	45.20	36.77
12/11/2013	21.33	24.03	15.50	1/19/2014	22.73	50.07	36.67
12/12/2013	11.53	14.20	11.53	1/20/2014	27.13	46.17	33.53
12/13/2013	12.53	15.93	9.37	1/21/2014	25.20	46.53	32.40
12/14/2013	18.07	12.33	7.97	1/22/2014	34.70	53.13	34.50
12/15/2013	13.27	8.44	8.44	1/23/2014	36.84	54.03	32.40
12/16/2013	22.70	21.87	18.47	1/24/2014	40.83	54.47	33.77
12/17/2013	25.37	39.53	23.53	1/25/2014	43.30	55.67	37.03
12/18/2013	31.20	36.20	25.37	1/26/2014	43.40	56.63	35.70
12/19/2013	33.33	26.70	26.70	1/27/2014	44.40	57.43	34.43
12/20/2013	31.23	31.77	25.67	1/28/2014	42.93	57.67	42.33
12/21/2013	20.93	21.70	20.37	1/29/2014	54.10	61.33	44.00
12/22/2013	21.80	32.27	20.60	1/30/2014	54.33	61.43	43.43
12/24/2013	19.50	22.07	18.30	1/31/2014	52.43	61.57	43.77
12/26/2013	11.81	15.97	11.43	2/1/2014	54.10	63.00	44.10
12/27/2013	42.47	15.80	13.27	2/2/2014	54.33	60.87	45.00
12/28/2013	48.53	45.43	14.27	2/3/2014	52.43	60.67	44.97
12/29/2013	53.47	44.80	35.37	2/4/2014	55.36	52.43	44.63
12/30/2013	70.93	44.20	35.87	2/5/2014	57.67	51.17	45.63
12/31/2013	67.40	42.23	38.40	2/6/2014	58.80	61.97	56.87
1/1/2014	33.80	23.83	34.60	2/7/2014	66.13	63.57	53.97
1/2/2014	31.23	22.27	24.03	2/8/2014	63.17	56.47	50.77
1/3/2014	32.50	24.40	20.83	2/9/2014	64.00	58.47	47.00
1/4/2014	20.87	19.51	19.77	2/10/2014	73.83	62.53	56.73
1/5/2014	21.57	69.30	17.37	2/11/2014	71.97	63.33	60.20
1/6/2014	24.70	55.27	63.47	2/12/2014	71.40	66.23	70.60
1/7/2014	35.30	41.60	74.77	2/13/2014	71.70	75.27	64.93
1/8/2014	34.67	42.20	54.36	2/14/2014	74.67	65.67	75.97

Appendix C2: Continued

Date	DWTW	Manamani	Tshisaulu	Date	DWTW	Manamani	Tshisaulu
2/15/2014	75.33	74.43	76.70	3/24/2014	44.67	35.33	42.33
2/16/2014	75.07	72.47	75.90	3/25/2014	36.33	34.67	44.00
2/17/2014	83.67	66.90	77.30	3/26/2014	35.00	53.80	44.33
2/18/2014	94.90	73.47	76.20	3/27/2014	34.67	55.37	45.67
2/19/2014	95.73	75.43	76.00	3/28/2014	43.67	34.67	53.00
2/20/2014	86.87	75.37	75.60	3/29/2014	34.67	43.67	42.67
2/21/2014	84.00	75.13	74.17	3/30/2014	35.33	42.33	42.00
2/22/2014	85.43	76.60	73.90	<b>Mean</b>	<b>42.8</b>	<b>44.0</b>	<b>41.6</b>
2/23/2014	95.27	76.57	66.63				
2/24/2014	55.87	63.33	65.53				
2/25/2014	56.90	62.67	61.33				
2/26/2014	95.27	60.40	66.00				
2/27/2014	55.87	54.67	61.33				
2/28/2014	56.90	44.90	55.97				
3/1/2014	53.80	45.53	56.90				
3/2/2014	55.37	41.83	55.97				
3/3/2014	55.07	40.67	55.87				
3/4/2014	56.03	41.00	56.90				
3/5/2014	58.00	40.67	53.80				
3/6/2014	52.07	42.67	55.37				
3/7/2014	45.93	42.00	55.07				
3/8/2014	32.67	43.00	56.03				
3/9/2014	33.67	41.00	58.00				
3/10/2014	35.00	42.00	52.07				
3/11/2014	43.67	44.00	45.93				
3/12/2014	34.67	44.33	47.40				
3/13/2014	35.33	45.67	48.37				
3/14/2014	34.67	57.00	48.87				
3/15/2014	53.80	53.00	53.37				
3/16/2014	58.00	35.00	42.57				
3/17/2014	55.37	32.67	41.40				
3/18/2014	55.07	33.67	47.30				
3/19/2014	56.03	35.00	37.17				
3/20/2014	58.00	43.67	35.53				
3/21/2014	52.07	34.67	43.67				
3/22/2014	45.93	35.33	34.67				
3/23/2014	34.33	34.67	43.67				

## APPEDIX D: MEASURED EC VALUES

Appendix D1: EC (mS/m) for the period of October 2012 to April 2013

Date	LWANDANI	DWTW	TSHISAULU	MANAMANI
10/12/2012	0.62	0.67	1.10	1.3
10/24/2012	0.62	0.61	0.62	0.3
11/9/2012	0.25	0.52	0.61	0.5
11/20/2012	0.54	0.25	0.58	0.3
1/11/2013	0.66	0.65	1.11	0.5
1/13/2013	0.66	0.62	1.04	0.7
1/14/2013	0.66	0.67	1.03	1.1
1/15/2013	0.64	0.60	1.06	1.2
1/16/2013		0.61	5.67	1.3
1/17/2013		1.54	7.54	1.3
1/18/2013		1.81	7.80	1.1
1/28/2013		1.32	7.53	1.3
1/29/2013		1.25	7.84	1.2
2/5/2013		1.39	8.64	1.6
2/6/2013		1.82	8.91	1.5
2/16/2013		1.91	8.75	1.7
2/21/2013		1.73	8.45	1.7
2/22/2013		1.91	8.76	1.6
3/2/2013		0.98	4.72	1.2
3/3/2013		0.57	3.75	1.3
3/21/2013		0.72	3.55	1.3
3/28/2013		0.81	3.55	1.0
3/29/2013		0.81	3.59	1.1
3/30/2013		0.91	4.62	1.2
3/31/2013		0.81	4.16	1.0
4/1/2013		0.96	5.80	1.2
4/4/2013		0.87	4.15	1.2
4/18/2013		0.82	3.03	1.2
4/19/2013		0.74	2.54	1.2
<b>Mean</b>	<b>0.58</b>	<b>0.89</b>	<b>4.04</b>	<b>1.18</b>

**Appendix D2: EC for the period of December 2013 to March 2014**

Date	DWTW	Manamani	Tshisaulu	Date	DWTW	Manamani	Tshisaulu
12/1/2013	15.73	10.83	10.80	1/10/2014	15.70	42.23	37.67
12/2/2013	11.70	11.47	10.47	1/11/2014	15.63	43.90	46.23
12/3/2013	15.67	13.27	11.27	1/12/2014	16.00	42.70	42.17
12/4/2013	11.58	11.17	10.53	1/13/2014	17.63	43.33	44.47
12/5/2013	12.80	14.10	10.80	1/14/2014	19.47	43.07	44.20
12/6/2013	12.80	14.40	11.40	1/15/2014	18.43	44.00	46.13
12/7/2013	13.31	15.13	11.67	1/16/2014	18.87	45.43	43.60
12/8/2013	14.10	18.60	8.40	1/17/2014	23.03	42.53	37.40
12/9/2013	15.67	16.33	8.17	1/18/2014	23.23	43.30	34.47
12/10/2013	12.53	18.77	9.10	1/19/2014	23.60	43.50	33.63
12/11/2013	19.53	22.90	14.37	1/20/2014	21.91	45.90	42.87
12/12/2013	12.33	15.70	12.33	1/21/2014	21.20	46.57	47.07
12/13/2013	11.34	14.53	10.53	1/22/2014	32.34	48.40	53.53
12/14/2013	12.97	12.60	11.20	1/23/2014	32.20	46.40	47.57
12/15/2013	12.47	11.13	11.13	1/24/2014	43.67	37.77	54.67
12/16/2013	24.57	16.77	15.53	1/25/2014	43.70	56.43	55.33
12/17/2013	19.87	21.20	16.47	1/26/2014	42.97	54.63	59.23
12/18/2013	20.57	27.63	18.63	1/27/2014	46.80	54.73	58.77
12/19/2013	27.63	19.50	19.50	1/28/2014	46.77	53.17	52.07
12/20/2013	22.93	23.73	18.40	1/29/2014	45.47	54.23	65.00
12/21/2013	16.60	24.07	14.70	1/30/2014	45.73	54.03	65.87
12/22/2013	13.47	29.83	12.27	1/31/2014	43.80	56.20	66.67
12/24/2013	12.50	18.27	11.60	2/1/2014	45.47	54.33	66.53
12/26/2013	12.43	12.60	10.37	2/2/2014	45.73	57.00	60.30
12/27/2013	35.40	13.63	11.57	2/3/2014	43.80	56.30	62.97
12/28/2013	44.80	33.73	12.00	2/4/2014	54.33	55.33	65.43
12/29/2013	48.37	32.67	21.27	2/5/2014	58.93	53.77	66.13
12/30/2013	57.80	36.83	23.80	2/6/2014	58.53	57.07	72.27
12/31/2013	55.97	31.00	26.63	2/7/2014	60.80	55.77	74.43
1/1/2014	33.90	22.13	23.90	2/8/2014	61.97	56.10	65.77
1/2/2014	23.63	19.17	22.43	2/9/2014	61.00	57.87	60.10
1/3/2014	22.10	18.43	16.93	2/10/2014	61.37	64.60	64.93
1/4/2014	19.53	22.53	16.57	2/11/2014	74.67	66.60	65.33
1/5/2014	17.07	57.94	17.30	2/12/2014	74.47	66.33	75.03
1/6/2014	14.40	44.40	52.27	2/13/2014	76.37	63.67	77.43
1/7/2014	16.10	44.17	55.47	2/14/2014	76.50	65.23	75.47
1/8/2014	17.40	38.70	44.00	2/15/2014	72.30	68.10	76.80
1/9/2014	15.70	41.60	44.70	2/16/2014	76.93	65.17	77.10

Appendix D2: Continued

Date	DWTW	Manamani	Tshisaulu	Date	DWTW	Manamani	Tshisaulu
2/17/2014	81.87	55.00	73.40	3/25/2014	45.33	33.00	46.00
2/18/2014	88.03	56.53	76.83	3/26/2014	33.67	56.53	41.33
2/19/2014	85.90	64.73	74.83	3/27/2014	35.67	55.47	53.67
2/20/2014	85.90	65.73	74.13	3/28/2014	32.67	33.33	56.00
2/21/2014	74.33	66.03	67.90	3/29/2014	33.33	38.33	41.33
2/22/2014	84.00	66.73	70.33	3/30/2014	34.00	37.00	43.00
2/23/2014	88.33	57.43	72.70	<b>Mean</b>	<b>24.3</b>	<b>24.9</b>	<b>23.9</b>
2/24/2014	57.37	53.23	69.97				
2/25/2014	57.57	54.80	65.47				
2/26/2014	88.33	51.27	65.20				
2/27/2014	57.37	45.30	62.00				
2/28/2014	57.57	44.17	55.90				
3/1/2014	56.53	44.27	56.87				
3/2/2014	55.47	42.33	55.60				
3/3/2014	56.83	42.67	57.37				
3/4/2014	56.17	41.33	57.57				
3/5/2014	56.23	39.00	56.53				
3/6/2014	53.03	41.33	55.47				
3/7/2014	45.63	43.00	56.83				
3/8/2014	35.67	41.00	56.17				
3/9/2014	33.33	45.67	56.23				
3/10/2014	34.33	42.67	53.03				
3/11/2014	32.67	46.00	45.63				
3/12/2014	33.33	41.33	46.53				
3/13/2014	34.00	53.67	47.67				
3/14/2014	33.00	55.67	46.37				
3/15/2014	56.53	56.00	46.00				
3/16/2014	56.23	35.00	42.87				
3/17/2014	55.47	35.67	44.37				
3/18/2014	56.83	33.33	45.43				
3/19/2014	56.17	34.33	42.73				
3/20/2014	56.23	32.67	45.47				
3/21/2014	53.03	33.33	38.33				
3/22/2014	45.63	34.00	35.67				
3/23/2014	32.33	33.00	38.33				
3/24/2014	45.33	34.00	37.00				

....END....