University of Venda
Creating Future Leaders

A COMPARATIVE STUDY OF SEDIMENT CHARACTERISTICS OF SAND RIVER AND NZHELELE RIVER IN LIMPOPO PROVINCE, SOUTH AFRICA

By
Ramadolela Zwanga
Student no: 11575200

A Dissertation Submitted in Fulfillment of the Requirements of the Degree of Master of Environmental Sciences in Geography.

In the

Department of Geography and Geo-Information Sciences,

At the

University of Venda,

Supervisor: Prof BDO Odhiambo
Co-supervisor: Mr. E Kori

July 2023

DEDICATION

To the Almighty God for making, it possible for me to complete this degree.

To my mother, Mrs. Ramadolela Esther, who never cease to encourage and inspired me.

To my beloved family members for their supports.

To my Co-Supervisor, Mr. Edmore Kori, without whom this work would not have been completed.

DECLARATION

I, Zwanga Ramadolela, declare that by submitting this dissertation electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the owner of the copyright thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signed (Student): Date: 25 July 2023

ACKNOWLEDGEMENTS

I would like to thank the Almighty God for his incomparable grace that enabled me to successfully complete this dissertation.

A word of thanks to my supervisor, Prof B.D.O. Odhiambo, for introducing the topic project to me and suggesting that I do it on my own.

I am indebted to my co-supervisor, Mr. Edmore Kori, who always navigated me in the right direction when needed while allowing the research to be my own work. I acknowledge that I have not only been enlightened and converted into a better researcher, but also received priceless contribution and insight from the best supervisors in the universe. Your financial support towards my data collection and field trip is greatly appreciated.

A word of thanks to NRF for funding my studies at the University of Venda.

I received great help from many people on different occasions; amongst them is Mr. Mulisa from the School of Environmental Science MEG lab and Ms. Edith from the School of Agriculture Sediment Science lab. I am grateful for your assistance.

Finally, I would like to acknowledge my mother, Mrs. Ramadolela Esther, the life-long contributor to my being, you have been my pillar of strength and I am grateful for your moral support throughout my days of studying.

ABSTRACT

To describe a sediment and possibly learn more about its creation and depositional processes, grain size statistics might be used. In order to understand the hydrodynamic conditions, mode of transit, and deposition of detrital sediments, grain size analysis is a dynamic sedimentological tool. Fluvial scientists are particularly interested in understanding the relationships between river systems that have been subjected to a variety of forcing factors, such as climate, tectonics, and sea level variations. This study examined the textural, particle size, and mineralogical characteristics of the sediments from the Sand River and the Nzhelele River. At the mouth of each chosen river, a collection of recently deposition sediments was collected to get a representative sample of the watershed. With particular attention paid to Sand River and Nzhelele River. The study's objectives included identifying the grain size distribution pattern of the sediments from Sand River and Nzhelele River and evaluating the mineralogical makeup of the coarse fraction of the sediments from Sand River and Nzhelele River in order to achieve the study's overall goal. In accordance with the "sand suite" methodology, sediments were collected. Using an Excel spreadsheet, the dry and wet sieve methods of grain size analysis were carried out and tabulated, and Gradistat was used to determine Folk and Ward's parameters.

The sediments were analysed using a sieve with a 14 Phi-scale (Φ) interval and interpreted using an Excel spreadsheet. The Folk and Ward statistical parameters (mean, standard deviation, skewness, and kurtosis) were calculated using the Gradistat statistics tool. A key factor in the mechanics of sediment travel is a sediment particle's form, which can provide insight on some of the particle's past movement. The Hydrometer method was used to analyze the particle size of sediments to estimate their percentage sand, silt, and clay content. Once the distribution of sand, silt, and clay had been determined, the sediment was classified according to its textural triangle. Using an X-Ray Diffraction (XRD) spectrometer, the mineralogical composition of sand, fine powder, and coarse fraction samples was analyzed semi-quantitatively. This analytical technique revealed the crystallinity and concentration of mineral phases in the samples.

The unimodal grain size distribution, which is indicative of a moderate energy environment at Sand River, shows that medium sand to fine sand predominates. The monomodal particle size distribution in Nzhelele River, which is a sign of a high energy environment, shows that very coarse to medium sand predominates there. The majority of the alluvial deposits were sandy, and they were rich in actinolite, quartz, albite, orthoclase, muscovite, and kaolinite. The dominating minerals were leftovers from the minerals in the original parent material and were present in both the sand and silt fractions. They are therefore referred to as fundamental minerals. Quartz ($SiO2$), a mineral with high weather resistance, comes in first. Albite, Orthoclase, Muscovite, Kaolinite, and Actinolite are other minerals that are frequently found, but in smaller proportions. The mineral makeup of the investigated deposits showed that the minerals at Nzhelele River were Quartz (49.3%), Albite (29.8%), Orthoclase (18.1%), Muscovite (2.1%), and Kaolinite (0.6%), whereas the minerals at Sand River were Quartz (38.9%), Albite (38.2%), Orthoclase (20.1%), Muscovite (2.5%), Kaolinite (Nil), and Actinolite (0.4%). The two river sediment samples under study had a lot of quartz, according to the chemical composition data.

The distance traveled depends on the size of the sediments in rivers; the smaller the size, the longer the journey. The majority of river sediments range from gravel to sand. As sediments typically become coarser with an increase in the energy of the transporting medium, this suggests that the sediments were transported under high energy conditions (Folk, 1974). Due to their longer distance of travel, finer sediments in Sand River were present in greater amounts, but coarser sediments were present in greater amounts in Nzhelele River due to their shorter travel distance. According to the current study, sediments' various textural traits can provide crucial hints for comprehending both their depositional settings and the mechanisms underlying movement.

Based primarily on the information supplied by the grain size distribution curves, mineral composition, log-cumulative curves, and grain size distribution histograms, the current Sand River and Nzhelele River samples have been interpreted. According to the grain size distribution, the Nzhelele River sediments are primarily coarse-grained, poorly sorted, leptokurtic, and platykurtic in character, while the sediments from the Sand River are primarily fine-grained, moderately sorted, mesokurtic, and nearly symmetrical. The sediments' fine-sand makeup indicates that fairly low-energy conditions predominate in the research area. The sediments' well-sorted to moderately-sorted character points to an abrupt winnowing and back and forth migration by the depositing processes. A riverine input and mixing of similar modal fractions may be indicated by the dominance of the nearly symmetrical category. The sediments' unimodal distribution demonstrates the stable depositional process that underwent the deposition of the Sand River and Nzhelele River sediments.

Key words: *Grain size, Sedimentation, Sediment load, and Sediment transport*.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

Appendix A: Grain Size Parameters

Appendix B: Grain Size Distribution Histograms

Appendix C: Distribution (phi) Curves

Appendix D: Cumulative (phi) Curves

Appendix E: Distribution (microns) Curves

Appendix F: Cumulative (microns) Curves

CHAPTER 1
RESEARCH PROBLEM AND ITS SETTING

1.1 Introduction

Sediments are solid particles generated by the disintegration process of organic and inorganic materials (Bortone, 2006). These particles are found in various shapes and sizes, and can be transported by water, wind, glaciers, and other natural causes (Montgomery et al., 2000). According to Ulrich and Philip (2007), sediments are an integral and dynamic part of aquatic systems and play a major role in the hydrological, geomorphological, and ecological functioning of river basins. River basins is an areas of land that drains all streams and rainfall towards the same terminus, generally a river or the sea, sometimes an inland water body. River basins are also called catchments in British English, while watershed, which in American English designates smaller basins of a few thousand square kilometers, refers to the line dividing two river basins (Francois, 2017).

Daming et al., (2016) state that sediment parameters include particle size, shape, mineral composition, and orientation. Grain size distribution is one of the most important properties of sediment particles because the sizes of grains in a specific deposit reveal hydrodynamic energy as well as the transportation and depositional processes. Grain size analysis is a useful tool used by geoscientists on siliciclastic sedimentary rocks in order to obtain a detailed understanding of the hydrodynamic condition and paleoenvironmental features as well as reconstruct ancient sedimentary transport histories and sediment provenance (Srivastava et al. 2012). Grain size distribution is one of the most significant properties of sediment particles because sizes of particles or grains in a particular deposit reveal their hydrodynamic energy and transportation processes (Blot and Pye, 2001). Consequently, grain size analysis reveals some essential evidence of transportation and depositional conditions (Baiyegunhi and Gwavava, 2017).

Folk (1974) and Folk & Ward (1957) depicted some of the statistical parameters used to explain particle size distributions. Mean grain size, sorting, skewness and kurtosis are examples of statistical parameters. These parameters can be presented in the form of histograms, cumulative frequency curves and bivariate scatter plots. The mean grain size, sorting and skewness of sediments are determined by their grain size distribution, erosion processes and transportation history (Folk, 1966). Grain size parameters of clastic rocks also give detailed information on the sediment mode of transportation, sorting and depositional conditions prior to final induration (Goswami and Ghosh, 2011). Several researchers (Goswami and Ghosh, 2011., Srivastava et al. 2012) have documented that indeed each sedimentary environment are thought to have adversely different particle size features that separate them from sediments deposited in other environments. The particles size distributions directly depend on the transporting medium, duration of transportation, depositional conditions and nature of the environmental setting; and therefore, it has momentous value as an environmental indicator (Stanley-Wood and Lines, 1992). Daming et al. (2016) state that sediment parameters include particle size, shape, mineral composition, and orientation. According to Daming et al. (2016), the particle size indicates the fluid medium and flow velocity, and the particle mineral composition indicates the sediment source and transport distance, whilst the particle orientation indicates the flow direction and the orientation of stress state at deposition. Further, the particle shape indicates fluid medium, movement distance, and movement intensity. It is vital to note that sediment morphology has an influence on the transportation, settlement, and adsorption process of the sediment (Daming et al., 2016). Furthermore, Daming et al*.* (2016) affirm that the longer the sediment movement distance, the greater the number of inter-particle and particle-bed collisions. This result in any sharp corners becoming smoother, and sediment particles becoming more rounded (Daming et al., 2016).

Grain size characteristics of river sediments have attracted the attention of numerous geologists and engineers over the years (Garde & Raju, 2000; Surian, 2002). Wang and Andutta (2013) report that the dynamics of sediment transport rely upon water circulation, salinity, biological interaction, and sediment type. Many numerical models include such processes and are based on empirical experiments, often performed in laboratories. The experiments provide estimates of the bed load transport according to particle size, bottom stress, and a threshold stress for initial bed movement (Wolanski et al., 2012). It is, therefore, essential to understand the principles of sediment transport for application to the solution of engineering and environmental problems associated with natural events and human activities (Ghani et al., 2003). Hence, the relevancy of this study which sought to investigate sediments grain size distribution of Sand and Nzhelele Rivers.

1.2 Background

Sediment transport is commonly thought of as an ensemble of particles that undergo periods of motion and periods of rest (Furbish *et al.,* 2012). Probability distributions can be used to describe the stochastic nature of the sediment transport episodes, which together can be used to define the nature and virtual velocity of transport (Haschenburger, & Church, 2001; Bradley and Tucker, 2010; Furbish et al., 2012). In the same vein, Furbish et al. *(*2012) and Rosenberry et al. *(*2012) advise that the concept is found in studies of bed load transport and saltating particles in wind (Valance et al., 2015). However, an understanding of the episodes of suspended sediment transport is surprisingly lacking (Parsons et al., 2015). The probability distribution of suspended sediment transport distances is uncertain, so it can only be hypothesised. The climate in a region has a great influence on flood generating factors as it controls the seasonality of rainfall and evaporation. It may also affect the fluvial processes in terms of geomorphological conditions such as sediment type and erosion processes (Marchi et al., 2010).

Several field and flume studies indicate that grain size distribution in sediments of a riverbed is similar to the river's bedload. Sediment transport during flooding in ephemeral streams is highly influenced by the riverbank stability. Previous studies indicate that with poor stability, even low to moderate flow volumes entail instability and mobility of the riverbed (Tooth, 2000). In addition, Ashraf et al. (2016) reports that erosion rates are more dependent on mean high flows than mean annual flows (Ashraf et al., 2016). Since streams are open systems, an alluvial channel can adjust to altered environmental conditions. Adjustment processes that can affect entire fluvial systems include channel degradation and aggradation, lateral channel migration, channel widening or narrowing, channel avulsion and changes in the quantity and character of the sediment load. These processes differ from short-term, event-related localised processes such as scour and fill, which can be limited in magnitude and in temporal and spatial scale.

1.3 Problem Statement

One of a sediment's most fundamental physical characteristics is its particle size distribution, which, among other things, determines the texture of the sediment and has a significant impact on a number of other physical and chemical characteristics. Given that both rivers are used for sand mining, knowledge of the sediment characteristics of Sand River and Nzhelele River will be essential for sand miners. Sand miners might not be aware of the Nzhelele River's mineral makeup or the distribution of sediments, which could lead to issues if they harvest the sand and utilize it for various uses without first determining whether it will be durable enough. It is frequently expressed as a percentage of the sediment's total mass that a certain size fraction occupies. The problem of elevated sediment concentration in rivers and sediment deposition in reservoirs is currently producing marked effects on land and water resources in Southern Africa (Msadala, 2009). Natural flow regimes have been considerably altered as a result of sand mining, with considerable effects on sediment transport. A typical management issue occurs when changes to sediment quality and quantity have a detrimental influence on natural populations, raise the risk of flooding, and shorten the useful life of infrastructure. We require a detailed understanding of sediment sources, pathways, and transport dynamics as well as drivers that underpin regional and temporal variability in deposited sediment transit in rivers in order to address these difficulties and design sustainable management methods.

Sediment deposition creates habitats for aquatic life. While too much sediment can be detrimental, too little sediment can also diminish ecosystem quality (Czuba et al., 2011). Some aquatic habitats are even grain-size specific. Many spawning habitats require a specific sediment size (e.g., gravel) and too fine of sediment can end up smothering eggs and other benthic creatures (EPA, 2012). Too much sediment deposition can also bury habitats and even physically alter a waterway (EPA, 2012). Excessive levels of suspended load tend to have negative impacts on aquatic life. Suspended sediment can prevent light from reaching submerged vegetation and clog fish gills (EPA, 2012). If a body of water is continually exposed to high levels of sediment transport, it may encourage more sensitive species to leave the area, while silt-tolerant organisms move in (Czuba et al., 2011). On the other hand, too little sediment transport can lead to nutrient depletion in floodplains and marshes, diminishing the habitat and vegetative growth (EPA, 2012).

The most evident and immediate issue with rivers is the total amount of discharged material. Stage-discharge-sediment transport correlations are a topic that is brought up by the fact that sediments increase the roughness and frictional resistance of natural streams. Another crucial issue is the resilience of beds and banks to erosion and deposition, especially for man-made canals and rivers. The sediment load of the contributing natural streams affects the useful life of reservoirs. The amount and frequency of maintaining navigable waterways in estuaries are based on the rates of sediment deposition, particularly fine sediment deposition, by the river or rivers discharging into that particular estuary.Rivers also carry sediments from erosive processes or upstream. The qualities and flow of the river could be impacted by sediments. This knowledge gap can be attributed to uncertainty in the travel velocities and exchange rates of different grain sizes throughout a river system as well as a lack of trustworthy field data to calibrate models (Papanicolaou et al., 2008). It is crucial to investigate any linkages that might exist between geomorphic processes and material characteristics that could serve as a stand-in for these processes.

1.4 Motivation

The particle size distribution of sediments must be known in order to assess their suitability for usage in geotechnical structures, sediment design, or the mixing of concrete, among other applications. It is possible to examine the sediment properties of the Sand River and Nzhelele River and analyze the ongoing weathering and erosional processes in the two rivers. Given that sand is being mined from both rivers, understanding the characteristics of the grains' sizes and the minerals present in the sediments will be crucial in determining whether the sand from the Nzhelele River or the Sand River is strong enough to be used in construction. The engineering qualities of soil are influenced by grain size distribution. Analysis of grain size offers the grain size distribution, and it is required in classifying soil.

Weirs' ability to alter sediment movement in rivers can result in the river bed deepening downstream of weirs, which has detrimental effects on the environment and ground water level nearby. Sediment transport is important for several types of research in addition to its effects on hydraulics. To comprehend the processes that sculpt the terrain and give rise to particular kinds of rock formation, geologists examine the specifics of sediment transport. Solids material can be transported by fluid in several engineering applications, which can be very advantageous. Fluvial sedimentologists need to understand the physics of particle movement for a number of reasons, including: (1) to comprehend the large variations in grainsize and other textural parameters in fluvial deposits; (2) to understand bedform generation and flow regime concepts; and (3) to provide an explanation for the density sorting of clastic grains, which is crucial in petrological studies, particularly those involving economic placer deposits.

From a scholarly perspective, thorough scientific characterization of sediments and mineral composition of sediments will not only add to the body of knowledge regarding grain size distribution but will also produce a reliable report that potential businesses, industrialists, and governments can use as a basis for decision-making. From an economic perspective, this will encourage the establishment of enterprises or businesses that gather sand from rivers (sand mining), manufacture construction materials like bricks and tiles, and create jobs for graduates and unskilled workers alike.

The information from grainsize distribution curves can be used to design filters for earth dams and to assess if sediments are suitable for building roads and other structures. There are numerous environmental, geotechnical, and geological issues that sediment transfer can help with. Therefore, it is crucial for coastal engineering to measure or quantify sediment characteristics (Grant et al., 2013). In rivers, sediment movement is crucial for creating habitat for fish and other organisms. Therefore, it is frequently recommended to managers of highly regulated rivers—often sediment-starved as a result of dams—to initiate brief floods in order to replenish the bed material and rebuild bars. For civil and hydraulic engineers, it's crucial to have a solid understanding of the mechanisms governing sediment properties and sediment transport in constructed environments.

Additionally, this research will contribute to our understanding of the various processes that occur in a fine sandy fluvial system, enabling geomorphologists, hydrologists, fluvial geologists, and civil engineers to create long-term plans that will improve how the Sand River and Nzhelele River are used and managed for millions of people. An improved understanding of the transport dynamics of fluvial sediments is based on knowledge of their grain size properties. Additionally, in the case of sediments with a mechanical origin, a systematic analysis of grain size, sphericity, and roundness aids in determining the direction of the paleocurrent (Rabindra, 2013).

1.5 Hypothesis

- In order to determine the grain size distribution of sediments, sieve analysis of sediments and the hydrometer method are crucial.

1.6 Aim and Research Objectives

1.6.1 Aim

The study aims to characterise sediments of Sand River and Nzhelele River.

1.6.2 Specific Objectives

The specific objectives of this research are to.

- Determine the grain size distribution pattern of sediments from Sand River and Nzhelele River;
- Determine the mineralogical composition of coarse-grained sediments from the Sand River and Nzhelele River.

1.7 Description of the Study Area

1.7.1 Location

Sand River (Figure 1-1) and Nzhelele River (Figure 1-2) catchment were selected to evaluate sediment characteristics in Limpopo Province, South Africa. Sand River is located between latitudes 22°18'50"S and 23°13'60"S and longitude 30°7'41"E and 27°43'0"E whereas Nzhelele River is located between latitudes 22°53’15.8’’ S and 22°54’5’’ S and longitudes 30°11’10.2’’ E and 30°11’23.5’’ E in the Limpopo Province of South Africa. Nzhelele River is a major watercourse in Limpopo Province, South Africa. The river's catchment area comprises 2,436 square kilometers. This river collects much of the drainage of the northern slopes of the extensive rock formation of the Soutpansberg. Leaving the mountainous area, it meanders in a northeastward direction across the Lowveld, a wide plain that contains considerable biodiversity, including numerous large mammals such as giraffes, white rhinos and blue wildebeests. It joins the right bank of the Limpopo River 33 km east of Musina.

The Sand River has its source south of Mokopane and flows northwards across central Limpopo Province until it cuts across the Soutpansberg through a deep gorge, the Waterpoort. Then it meanders northwards across the Lowveld until it joins the right bank of the Limpopo at approximately 7 kilometers (4 mi) east of Musina. Although considered a perennial stream, it is often dry in winter. The Sand River has its source south of Mokopane and flows northwards across central Limpopo Province. The river flows by the western edge of the city of Polokwane.

1.7.2 Climate

The average temperature in Limpopo is 20^{0}C, with the average maximum monthly temperature being 30^{0}C during January and the average minimum monthly temperature being 4^{0}C during July. The climate over Nzhelele River and Sand River is temperate, semi-arid in the south to extremely arid in the north. Mean annual rainfall ranges from 300mm to 700mm with potential evaporation well in excess of the rainfall. Rainfall is seasonal with most rainfall occurring in the summer with thunderstorms. Runoff is low due to the sandy soil occurring over most of Nzhelele and Sand River, however, loam and clays are also found in both rivers. Nzhelele River is characterised by a warm wet season which is associated with high temperatures up to 40°C usually between October and March (with peak precipitation in January and February) and cold dry season (April-September)

(FAOUN, 2004). The Sand River, although considered a perennial stream it is often dry in the winter. Sand River is characterised by hot semi-arid (steppe) climate.

1.7.3 Geology

Nzhelele River is predominantly white or light coloured, brown-weathering, laminated quartzitic sandstone with interbedded shale and sandy shale above reddish argillite, which is above basaltic lavas with interbedded tuff, ignimbrite, sandstone, shale and chert. The Sand River is characterised by a unique shelf-type supracrustal sequence-the Beit Bridge Complex- which is made up of quartzo-felspathic gneiss, quartzite, marble, and mafic and ultramafic gneiss, which all possibly overlay the Sand River Gneiss (Cheney et al., 1990).

1.8 Definition of Key Terms

Grain-size – It is the diameter of individual grains of sediment, or the lithified particles in clastic sediments.

Sedimentation - It is the tendency for particles in suspension to settle out of the fluid in which they are entrained and come to rest against a barrier.

Sediment transport – It is the movement of organic and inorganic particles by water.

Suspended load – It is the amount of sediment carried downstream within the water column by the water flow.

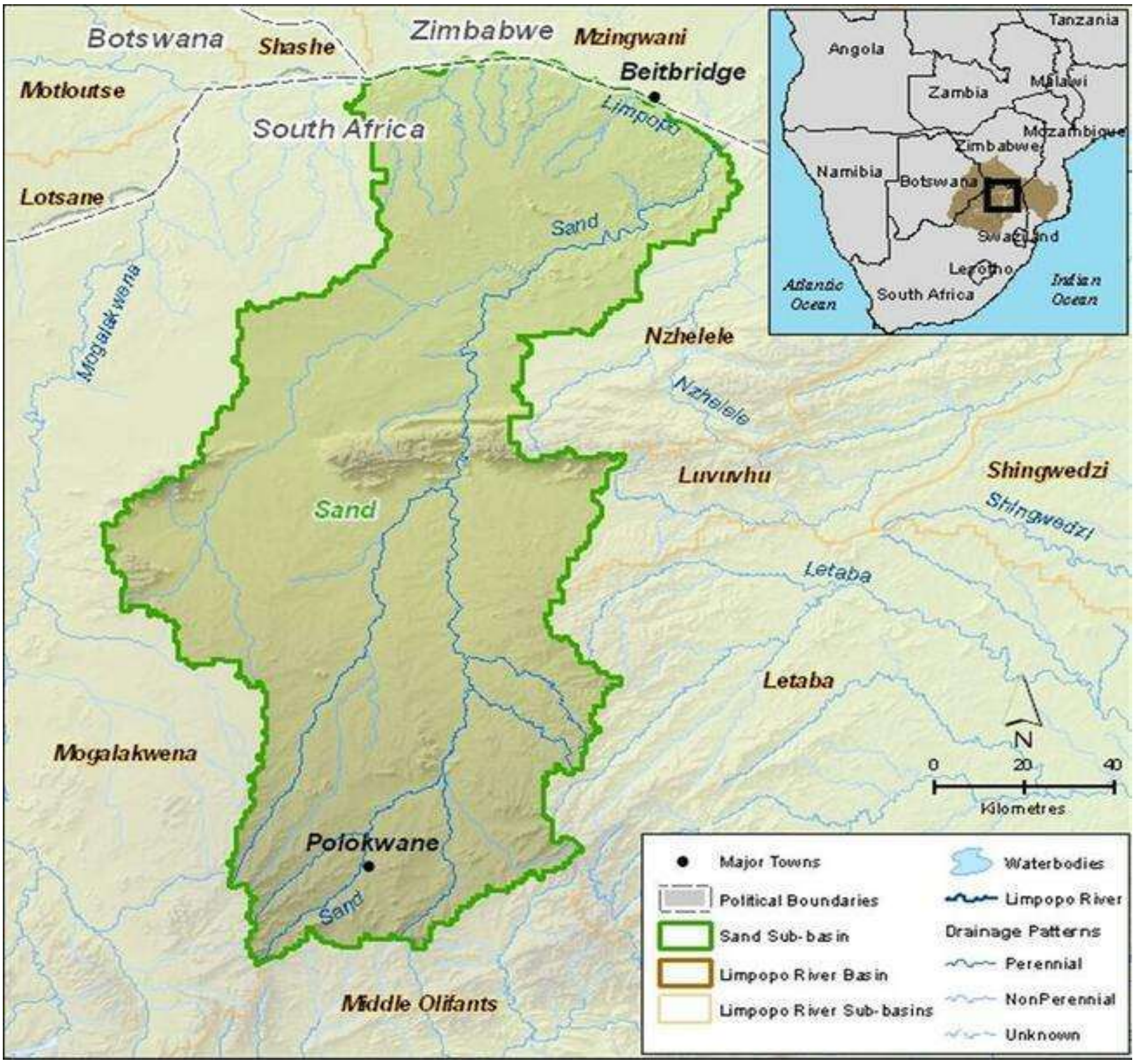


Figure 0-1: Sand River Study Area Map

Source: (Dacosta and Mathada, 2017)

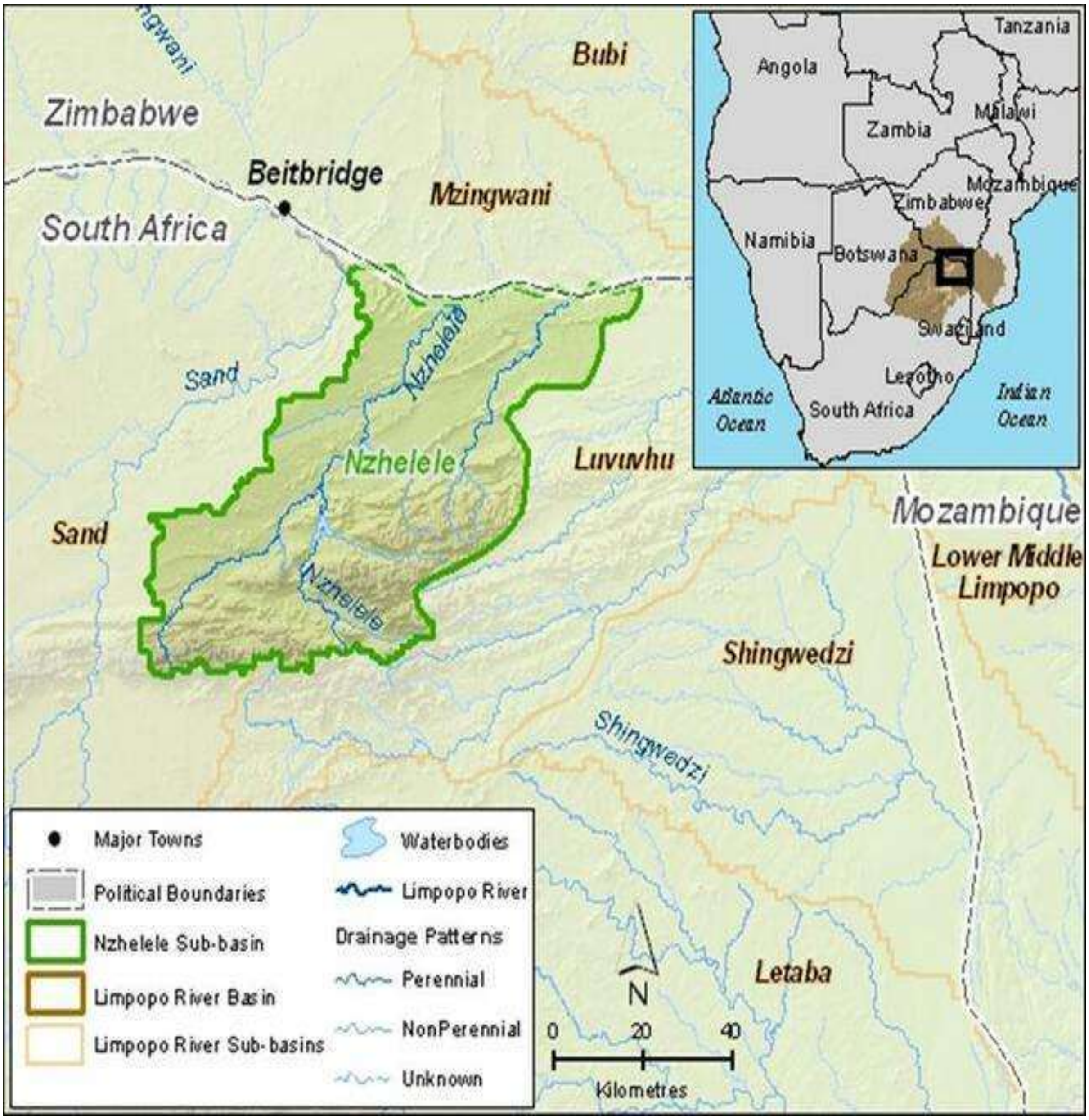


Figure 0-2: Nzhelele River Study Area

Source: (Dacosta and Mathada, 2017)

1.9 Chapter Summary

The issue under examination and the rationale for selecting the study topic are introduced in Chapter 1 of this dissertation. The research background and overviews of sediment behavior with various grain sizes and sediment transport are briefly presented in this chapter. There are suggested research aims and questions. As stated in the issue description, one of the most fundamental physical characteristics of a sediment that defines, for instance, the sediment texture, and significantly influences many other physical and chemical sediment properties is particle size distribution. Understanding how sediment transport can be used to address a variety of environmental, geotechnical, and geological issues is crucial, and measuring or quantifying sediment properties is crucial for coastal engineering. This study's overarching goal is to identify the sediment characteristics of Sand River and Nzhelele River.

1.10 Outline of the Dissertation

The dissertation is organized into seven chapters in which each section has distinct information.

Chapter one succinctly discusses the background on sediment characteristics and mineralogical composition of the sediments with the purpose of analysing the grain size distribution.

Chapter two provides literature review where current level of knowledge in relation to the general overview of sediment characteristics or grain size distribution and sediment transport are elaborately discussed.

Chapter three describes the procedural steps, tools and equipment used to analyse grain size characteristics, sample collections and research methodology.

Chapter four presents the interpretation and discussion of the experimental results obtained from dry and wet sieve analysis, hydrometer analysis and traces of mineral composition of sediments using X-ray diffraction.

Chapter five presents the conclusion and recommendation remarks of the study and the summary of the study.

CHAPTER 2
LITERATURE REVIEW

2.1. Introduction

Rivers are dynamic by nature; they adjust their characteristics in response to any change in the environment. These environmental changes may occur naturally, as in the case of climatic variation or changes in vegetative cover, or may be a result of human activities (Wampler, 2012). Human factors influence channel changes, both directly by engineering projects including channelization, dredging, snag removals, dam construction and bridge construction, and indirectly through altering floodplain land-use such that erosion is more likely to occur during flood events more likely to occur during flood events (Ab. Ghani et al., 2010). Civil and environmental engineers frequently face sediment transport issues such as local scouring, sedimentation in reservoirs, and erosion after floods or dam breaching flow as well as long tern aggradation or degradation of riverbed (Dewals et al. 2010b). Such sediment related problems are of huge importance in most projects of river engineering, calling for structures to be designed considering sediment transport issues from the very early stages of project development. Sediment transport has been studied from a physical point of view for almost two hundred years but is not yet fully understood (Frey and Church 2009). Some studies have pointed to the matches between climate and the record afforded by fluvial sediments and others to complicated behaviour of river systems in processing climatic events, while investigations based on numerical and physical modeling have suggested that fluvial sediment transport processes can destroy environmental signals (Macklin & Lewin, 2008).

2.2. Sediment Transport Capacity and Sediment Load

The transporting capacity is determined by the characteristics of the river channel and other factors. Every sediment particle that passes a given stream cross-section should satisfy the two conditions below (Julien, 1998):

- It should be eroded somewhere in the catchment above the cross section
- It should be transported by the flow from the place of erosion to the cross section.

It was concluded by Julien, 1998 that the above conditions the rate of sediment transport depends on the transport capacity of the stream and availability of sediment. Julien (1998) further says that the amount of transported material in the stream would therefore depend on two groups of variables:

(a) Characteristics and quantity of material made available for transport (characteristic variables): catchment topography, geology, rainfall intensity, magnitude and duration, weathering, vegetation, surface erosion, sediment supply from tributaries, mineralogy, sediment type and land use.

(b) Sediment transport capacity (defining variables): channel geometry, width, depth, shape, wetted perimeter, slope, vegetation, roughness, velocity distribution, turbulence, and uniformity of discharge.

The sediment transported by the river has varying sizes in terms of diameter. In regions where the sediment transported in the river is relatively coarse consisting of sand, gravel, or coarser particles, it is possible to hydraulically determine the sediment yield (Basson, 2008). Sediment yield is the quantity of sediment that has been mobilised from a known catchment area size which is passing through a river channel's reference point in each time interval. Sediment quantitative analysis is sometimes expressed as the total sediment load in a stream. The sediment transport capacity is considered as a function of hydraulic conditions and the shape of the stream cross section.

Many attempts have been made to try to relate the quantity of material made available for transport, transport capacity and sediment sizes. Figure 2-1 below gives the general sediment transport capacity and supply relationship. From Figure 2-1, it is evident that for finer sized sediment, the transport capacity of the stream is much higher than the sediment supplied (up to some limiting grain size). The wash load's availability is limited; therefore, it is not possible to do a direct quantitative analysis of the sediment yield for a flow discharge on a particular river. The criterion for the determination of sediment yield for finer sediment is typically less than 0.06 mm, which generally use regression analysis.

2.3. Factors that Influence Sediment Transport

Sediment transport is not constant. In fact, it is constantly subject to change. In addition to the changes in sediment load due to geology, geomorphology and organic elements, sediment transport can be altered by other external factors. The alteration to sediment transport might come from changes in water flow, water level, weather events and human influence.

2.3.1. Water Flow

Water flow, also called water discharge is the single most important element of sediment transport. The flow of water is responsible for picking up, moving and depositing sediment in a waterway (Missouri, 2009). Without flow, sediment might remain suspended or settle out – but it will not move downstream. Flow is required to initiate the transport process (McNally, & Mehta, 2004). There are two basic ways to calculate flow. Water discharge can be simplified as an area (a cross-section of the waterway) multiplied by velocity, or as the volume of water moved over time (The University of Arizona, 2009). Whether sediment will be eroded, transported, or deposited is depended on the particle size and the flow rate of the water.

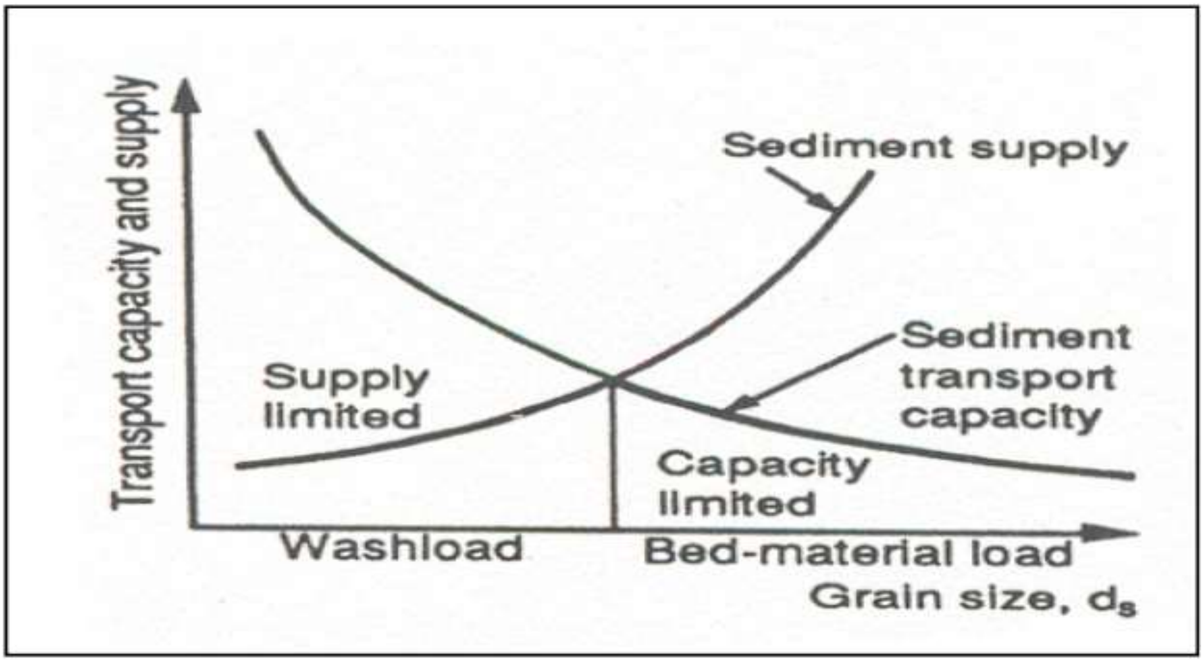


Figure 0-1: Sediment Transport Capacity and Supply Relationship

(Julien, 1998)

2.3.2. Weather Events and Water Level

Sediment transport relies on water flow to move a load downstream. Water flow is a variable affected not only by the local terrain (e.g., slope), but by water level which, in turn, is influenced by precipitation (or lack thereof). Most changes in water level are due to weather events such as rainfall (Missouri, 2009). Precipitation causes water levels to initially rise, and then return to previous levels (base flow) over the course of hours or days.

Rainfall, weather slight or heavy rain can affect water flow and sediment transport. The extent to which a weather event will influence sediment transport is dependent on the amount of sediment available. Snowmelt in a glaciated area will result in a high sediment load due to glacial silt (Czuba et al., 2011). Heavy rainfall over an area of loose sediment and minimal vegetation will create runoff, carrying loose particles into the waterway. Similarly, flooding will also pick-up sediment from the local area. In fact, most of the waterway’s sediment load occurs during flood events (Czuba et al., 2011).

Figure 0-2: Rainstorms can cause Water Level and Sediments Transport Rates to Rise

(Photo Credit: Jason Hollinger licensed CC Attribution-ShareAlike 2.0 Generic).

Increased water level creates additional volume in a channel and increases the hydraulic radius (cross-sectional area of a waterway). The increased hydraulic radius increases the discharge rate, regardless of whether flow is uniform or non-uniform (Wilcock et al., 2009). Increased flow increases the stress on the bed, making it more likely for water flow to initiate sediment transport. The higher velocity also increases erosion rates as flow overcomes the shear stress of sediment. Seasonal effects are also responsible for changes in water level and flow. Most seasonal changes are due to precipitation levels and events such as snowmelt (Missouri, 2009). During low precipitation and low flow periods, sediment transport falls. During the peak of snowmelt, the sediment load can increase by a factor of 15 or more. Climate change can also play a role in sediment transport, as it affects both the timing and magnitude of floods and other weather events (Czuba et al., 2011).

2.3.3. Human Influence

Anthropogenic factors, such as dams and altered land use affects both the sediment load and sediment transport rate (Czuba et al., 2011). Dams affect the water flow through complete detention or restricted channels (Missouri, 2009). According to Zaimes and Emanuel (2006), the restricted flow can cause the channel downstream of the dam to become “sediment-starved”, while the sediment load behind the dam builds up. These scholars further explain that a sediment-starved river will not be able to provide habitats for benthic organisms or spawning fish (Zaimes & Emanuel, 2006). The highly silted reservoir behind the dam may face issues of too much sediment, including changes in aquatic life and the potential for algal blooms. On the other side of the spectrum, when a dam release occurs, the flow rate downstream can drastically increase. If the release is controlled, it can refresh the bed material, building bars and other habitat areas. An uncontrolled release or dam removal can result in flooding, carrying the released sediment further downstream than is needed (Czuba et al., 2011).

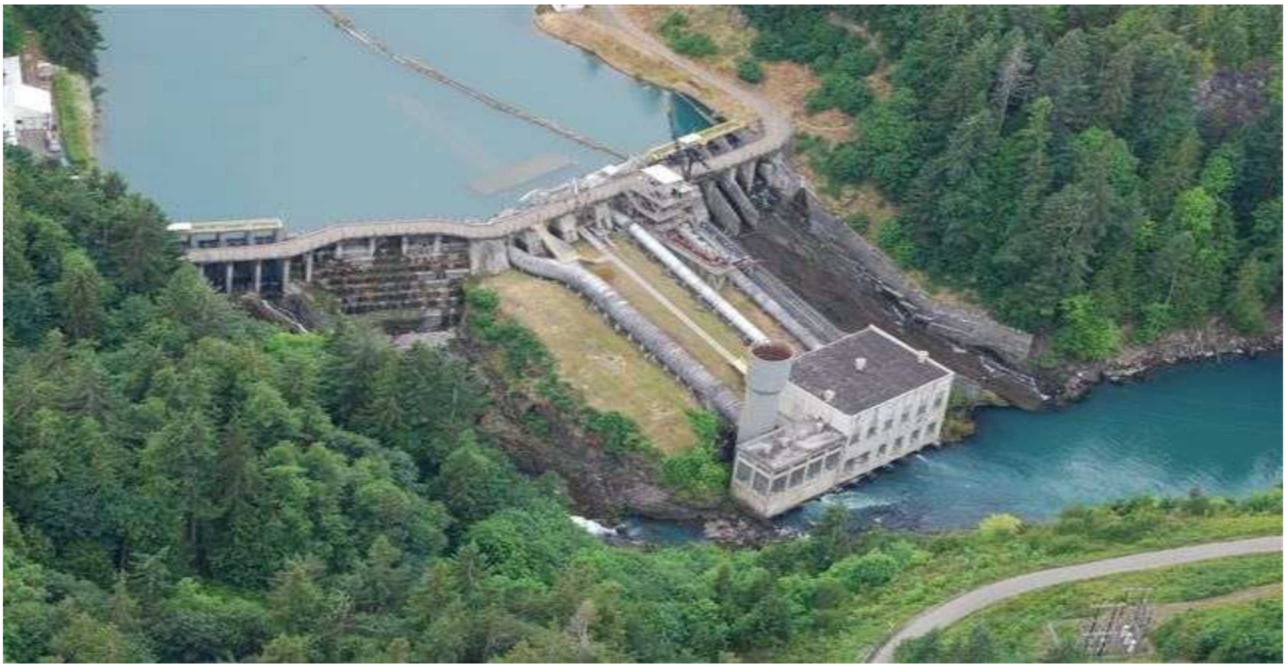


Figure 0-3: The Elwha Dam in the United States

Source: NPS, 2021.

The Elwha Dam project above Figure 2-3 removed two major dams to improve natural sediment transport levels along the river, as well as opening the waterway to salmon migration and spawning. Human land use, such as urban areas, agricultural farms and construction sites affect the sediment load, but not the transport rate (Czuba et al., 2011). These effects are indirect, as they require heavy rainfall or flooding to carry their sediment into the waterway. However, anthropogenic land use is one of the leading contributors to excessive sedimentation due to erosion and runoff (Washington State Department of Ecology, 1991). This increase occurs because “disturbed sites” (logging, mining, and construction and farm sites) often expose or loosen top sediment by removing native vegetation (Murphy, 2007). This loose sediment is then easily carried into a nearby river or stream by rainfall and runoff.

2.4. Erosion and Sediment Transport by Overland Flow

Erosion is defined as the wearing a way of land surface by detachment and movement of sediment and rock fragments through the action of ‘moving water’ and other geological agents (ICOLD, 1998). The emphasis on the action ‘moving water’ indicates the intrinsic ability of run-off to detach sediment. Sediment detachment by runoff contributes significantly to the sediment production process. Overland flow is characterized by sediment entrainment, transport, and deposition. According to Pidwirny (2008), entrainment is the process of particle lifting by the agent of erosion and there is a thin line between entrainment and detachment so much so that it is somehow hard to distinguish between entrainment and detachment. The latter is mostly influenced by fluid drag.

In the EUROSEM User Manual, sediment detachment by flow and deposition is expressed in terms of settling velocity and transport capacity (Morgan et al., 1998), The rate of sediment detachment due to overland flow on hill slopes of a catchment can also be determined from various empirical relationships that have been developed which aim to relate the rate of sediment detachment to other dependent variables, such as the shear stress, erodible sediment thickness, vegetation cover, rock cover, canopy cover and other factors.

Once the particle is detached, it is prone to be transported by any transporting medium mostly water or wind. Detachment and entrainment can occur in cyclic sequences depending on the prevailing flow conditions. Pidwirny (2008) states that an entrained particle tends to move on as long as the velocity of the medium is high enough to transport the particle horizontally. Pidwirny (2008) further gives four different ways in which transport can occur in the transporting medium:

- Suspension is where the particles are carried by the medium without touching the surface of their origin. This can occur in air, water, and ice.
- Saltation is where the particle moves from the surface to the medium in quick continuous repeated cycles. The action of returning to the surface usually has enough force to cause the entrainment of new particles. This process is only active in air and water.
- Traction is the movement of particles by rolling, sliding, and shuffling along the eroded surface.
- Solution is a transport mechanism that occurs only in aqueous environment and it mainly involves the eroded material being dissolved and carried along in water as individual ions. Particle weight, size, shape, surface configuration, and medium type are the main factors that determine which of these processes operate (Pidwirny, 2008).

2.5. Sediment Deposition

Once the particles have been detached and/or entrained, they continue to be transported in each transporting media. Some of these particles become deposited while in transit. The interaction between flow velocity and particle erosion, transport, and deposition is illustrated by Pidwirny (2008) using Figure 2-4. Pidwirny (2008) states that the curved line marked "erosion velocity" describes the velocity required to entrain particles from the surface and further explains that the entrainment of silt and clay needs greater velocities than larger sand particles because silt and clay can form cohesive bounds between particles. Therefore, greater flow velocities are required to break the bonds and move these particles.

From Figure 2-4 below, the line labeled "settling velocity" shows at what velocity certain sized particles fall out of transport and are deposited (Pidwirny, 2008). The illustration shows the interaction between flow velocity, erosion, transport, settling velocity and deposition of particles of varying sizes in the form of clay, silt, or sand. The yellow band describes the relationship between “erosion velocity” and “settling velocity” for larger sized particles. The curves indicate that greater flow velocities are required to entrain larger sized particles from the stream’s bed and banks and to make them fall out of transport and be deposited. The “erosion velocity” is slightly lower than the “settling velocity” for similar larger sized particles.

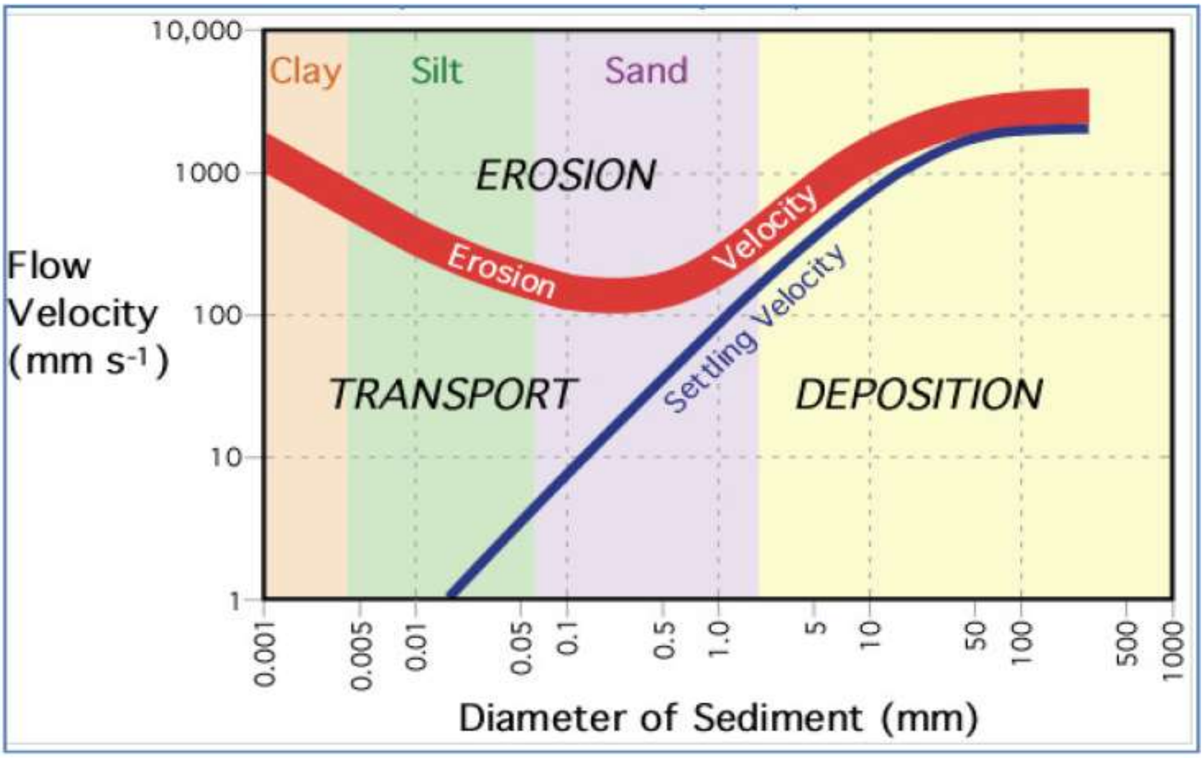


Figure 0-4: Glacier Lake Vermont: Hjulstrom Curve

(Source: Hjulstrom, 1935)

The complexity of the interaction is one of the reasons why a quantitative analysis of the sediments supplied to a stream from a watershed is usually difficult to perform as pointed out by Julien (1998). In other words, while it is possible to quantify sediment transport capacity, sediment supply to streams or dams is affected by parameters such as deposition and entrainment, which cannot be accurately deciphered within the typically vast watershed areas encountered in practice. Julien (1998) states that physical processes involved in the spatial and temporal variations of all the parameters describing upland erosion from local rainstorms and bank erosion processes exacerbate the complexity of quantifying sediment supply.

2.6. Temporal and Spatial Variability in Sediment Yields

Sediment yield varies both in time and space. Knowledge of the extent of the temporal and spatial variability in sediment yields is significant in the context of resource allocation for sediment control measures. According to a study by Guyot et al. (1994) on sediment transport in the Rio Grande (the Andean River of the Bolivian Amazon drainage basin), most transport occurs during the three months of the year in which the river has high water flows. The period contributed up to 90% of the annual load.

The determining factors for an increase or decrease in sediment yield with time depend on the site-specific conditions. In some circumstances, annual variability in sediment yield can just reflect the variability in precipitation and runoff. Batalla et al. (1994) report about an investigation of the temporal variability of the suspended sediment load in a Mediterranean sandy gravel-bed river where marked temporal variability was caused by seasonal effects.

A cumulative plot of the observed sediment load can indicate the temporal variability in sediment yield by inspecting the slope changes in the graph of the cumulative water discharge against cumulative sediment discharge. The same factors that have been reported to be responsible for the temporal variability of sediment yield can influence the spatial variability in sediment yield if there is possibility of spatial variability in the controlling variables within a catchment area. The temporal variation can be seasonally, annually, and even inter-annually. It, therefore, emphasises the need for longer term sampling records for a detailed understanding of the temporal variation in sediment yield and in order to draw realistic conclusions from observations. Guyot et al. (1994) report that the spatial variability is very strong in the Rio Grande to the extent that one sub-catchment would have almost fifty times the sediment yield observed in the other region.

Theoretically, it is possible to discover that in a catchment; only 20% of the total catchment is contributing to over 80% of all sediment. Olive et al. (1994) report that most sediments in the Murrumbidge River, New South Wales in Australia were generated from a localised area from one of the tributaries and was only transported for a short distance through the main Murrumbidge River before being deposited in the reservoir. This means that the longest water course is not necessarily the major sediment source.

2.7. Dynamics of River Mouth Deposits

The area in front of the mouth of deltaic distributary channels and rivers is location where sediments accumulate and new land forms. At these locations sediment deposition can occur by growth of natural levees and channel elongation or by deposition and vertical aggradation of mouth bars (Costanza et al., 2008). In general, land naturally builds and erodes in relation to switching depocenters of rivers debouching in the ocean or sea level oscillation over long timescales, and storms and river floods over shorter timescales. In recent decades several river mouth landforms have been deteriorating because of sediment starvation triggered by the damming of large rivers, which reduces the flux of sediments to the ocean (Syvitski et al., 2005). In a period in which sea level rise is enhancing coastal erosion and flooding (Nicholls and Mimura, 1998), it is more important than ever to understand the physics of river mouth sediment deposits and how new land is built. In fact, deposition of sediments at river mouths not only can mitigate coastal erosion but it can also promote land expansion thus restoring anthropogenically modified coastlines (Paola et al., 2011; Nittrouer et al., 2012a; Edmonds, 2012, Kim et al., 2009b; Kim, 2012).

Wright (1977) provides an excellent review of research results on sediment transport and deposition at river mouths. He suggests that effluent behavior and depositional patterns are affected by outflow inertia, bedfriction, and buoyancy. Distinct deposits spring from the dominance of one of these forces. Inertial conditions reflect an unbounded jet debouching into a deep (relative to the river channel) basin that results in lunate bars or a classic “Gilbert-type” delta. In friction-dominated flows river mouth hydrodynamics are characterized by bed friction, rapid spreading, and rapid levee divergence around a central mouth bar. In contrast, channels with straight parallel banks, low width-to-depth ratios and infrequent bifurcations were attributed to river mouth settings characterized by buoyant or hypopycnal outflows. Moreover, Wright (1977) highlights the role of tides and waves in sediment dispersal and accumulation patterns. However, while capturing the main dynamics of sediment dispersal at river mouths and related deposits, the results reported in Wright (1977) are mostly qualitative in nature.

2.8. The Effects of Sediment Cohesion and Vegetation

In the most general sense, both sediment cohesion and vegetation influence river mouth deposits by stabilizing the sediment surface. Cohesion stabilizes the sediment due to intermolecular forces among particles that make them harder to erode once they are deposited and aged (e.g., Black et al., 2002). In the case of vegetation, stabilization arises from belowground roots that can withstand higher tensile stresses and increase material strength (van Eerdt, 1985; Hey and Thorne, 1986; Huang and Nanson, 1997) and from dense aboveground biomass that diminishes turbulent kinetic energy in the flow (e.g., Nepf, 1999), thereby increasing deposition and reducing sediment erosion (Fagherazzi et al., 2012). Enhanced accretion triggered by vegetation can lead to the emergence of mouth bars that thus becomes deltaic islands. This process can be accelerated by production of belowground organic material (roots and rhizomes) (Mudd et al., 2010).

The enhanced stabilization from sediment cohesion and vegetation also changes the hydraulic geometry of the river mouth thereby altering the hydrodynamics of the turbulent jet (equations (6) and (7)). For example, all else being equal, stabilization of river mouth levees from either sediment cohesion or vegetation reduces bank erosion and creates narrower and deeper channels (Camporeale et al., 2013, and references therein). The width-to-depth ratio of a river is a key parameter for river morphodynamics (e.g., Zolezzi et al., 2012). Recent numerical and physical modeling (Hoyal and Sheets, 2009; Edmonds and Slingerland, 2010; Caldwell and Edmonds, 2014) has confirmed that sediment cohesion influences river mouth dynamics because it affects the aspect ratio of the river mouth (i.e., the ratio of width to depth) leading to different turbulent jet characteristics and different depositional morphologies.

2.9. Behaviour of sediments with different grain sizes

Basically, distinguished by grain sizes, sediment can be classified into gravel, sand, silt, and clay. Normally, sediment with grain size less than 62 μm (silt+clay) is defined as cohesive sediment and sediment with grain size larger than 62 μm is defined as non-cohesive sediment (Winterwerp and Van Kesteren, 2004). There is a fundamental difference in sedimentary behaviour between sand and clay materials (van Rijn, 1993). The reasons of different behaviour with different particle sizes are mainly their physical characteristics (e.g., inertial force), diffusion mechanism, flocculation etc. For larger particles (sand and gravel), sediments behave in a non-cohesive manner, for example, sediment particles consolidate instantaneously, the surface erodes particle by particle, and the bed load transport is the main type, etc. For smaller particles (clay), the sediments behave in a cohesive manner, for example, they consolidate relatively slowly, the surface erodes in aggregates (Righetti and Lucarelli, 2007), flocculation is a common phenomenon, and the suspended load transport is the main type.

2.10. Mineral Composition

The dominant minerals in both sand and silt fractions are residue of minerals in the original parent material; hence, they are known as primary minerals. Foremost is the weathering-resistant mineral quartz (SiO_2). Other minerals often present, though in smaller amounts are mica, feldspar, zircon, hematite, and limonite. If the sediment is not strongly leached, the sand and silt fraction may also contain fragments of calcite and dolomite (Daniel, 2008).

The clay fraction differs fundamentally from the sand and silt fractions, not only in grain size but generally in mineralogy as well. It typically contains a class of minerals that are products of chemical weathering and re-precipitation, known as secondary minerals or clay minerals. They consist largely of aluminosilicates and hydrated oxides. The most prevalent of the clay minerals are amorphous, e.g., allophane and imogolite. The crystal structured aluminosilicates are of three main types: (a) minerals with 1:1 alternating sheet of alumina and silica, such as in kaolinite and halloysite: (b) minerals with 2:1 alternating layer of silica and alumina, such as illite, vermiculite and smectite; and (c) minerals with 2:2 layers such as chlorite (Daniel, 2008).

2.11. Chapter Summary

Chapter two reviewed theoretically and general concepts of sediment transport and grain size characteristics as reported in existing literature. Erosion and sediment yield relationships were also reviewed. Erosion and sedimentation transport by overland flow showed that sediment detachment by run-off contributes significantly to sediment production process. The chapter also provided background aspects on factors influencing sediment transportation, including mineral composition of sediments deposited. Some of the particles become deposited while in transit and the sediments that are transported by the river have varied in sizes in terms of diameter. Sediment transport is not constant; in fact, it is constantly subjected to change. Significantly, this chapter exhibit that water flow is the single most important element of sediment transport and most changes in water level are due to weather events such as rainfall.

CHAPTER 3
RESEARCH METHODOLOGY

3.1. Introduction

This chapter describes specific steps and procedures that were followed to achieve the objectives of this research. The research was systematically approached by locating the sand deposits during reconnaissance and field surveys. In the field, sediments were collected, labeled, and taken to the laboratory for various analyses. Several analytical; methods were used to characterise the samples in terms of physical and mineralogical properties as shown in Figure 3-1. Experimental results that were obtained from the characterisation of sediments were evaluated using different empirical charts, tables, curves, and diagrams.

3.2. Research Design

Experimental research design was used in this study. Experimental research design is the process of carrying out research in an objective and controlled fashion so that precision is maximized and specific conclusions can be drawn regarding a hypothesis statement. The type of experimental research design that has been adopted in this research is true experimental design which relies on statistical analysis to prove a hypothesis, making it the most accurate form of research. Sediment samples were collected from Sand River and Nzhelele River at the mouth of both rivers to get a representative sample of the river. This study used scheduled study area visits to collect data on sediment characteristics of Sand River and Nzhelele River. The data collected included sediments samples that were carried out during different seasons namely winter (August) and autumn (April). The samples were air-dried and sieved to separate the >1 mm from <1 mm fraction in the laboratory. The particle size distributions of >1 mm fraction was determined by the sieving method and calculated by weight percentage. All samples were dried at 110 °C, sieved (2.0 mm) except for texture analysis ground using an agate mortar. The shape of sedimentary particles is an important physical attribute that may provide information about the sedimentary history of a deposit or the hydrodynamic behaviour of particles in a transporting medium. Particle shape, however, is a complex function of lithology, particle size, the mode and duration of transport, the energy of the transporting medium, the nature and extent of post-depositional weathering, and the history of sediment transport and deposition (https://serc.carleton.edu/files/NAGTWorkshops/sedimentary/activities/particle_shape.pdf).

3.3. Data Sources

The data used in this study contain field surveyed data such as sediments that were collected in both rivers. Sediments were collected using sampling bags for both Sand River and Nzhelele River respectively, to gain a more complete picture of the sediments' characteristics in the study area. Credibility of the research findings was increased by drawing from evidence taken from a variety of data sources, for example, to just name a few common sources of data; evidence was gathered from observation, written documents, personal papers, and photographs. Each type of source of data yielded different evidence that in turn provides different insight regarding sediment characteristics of Sand River and Nzhelele River.

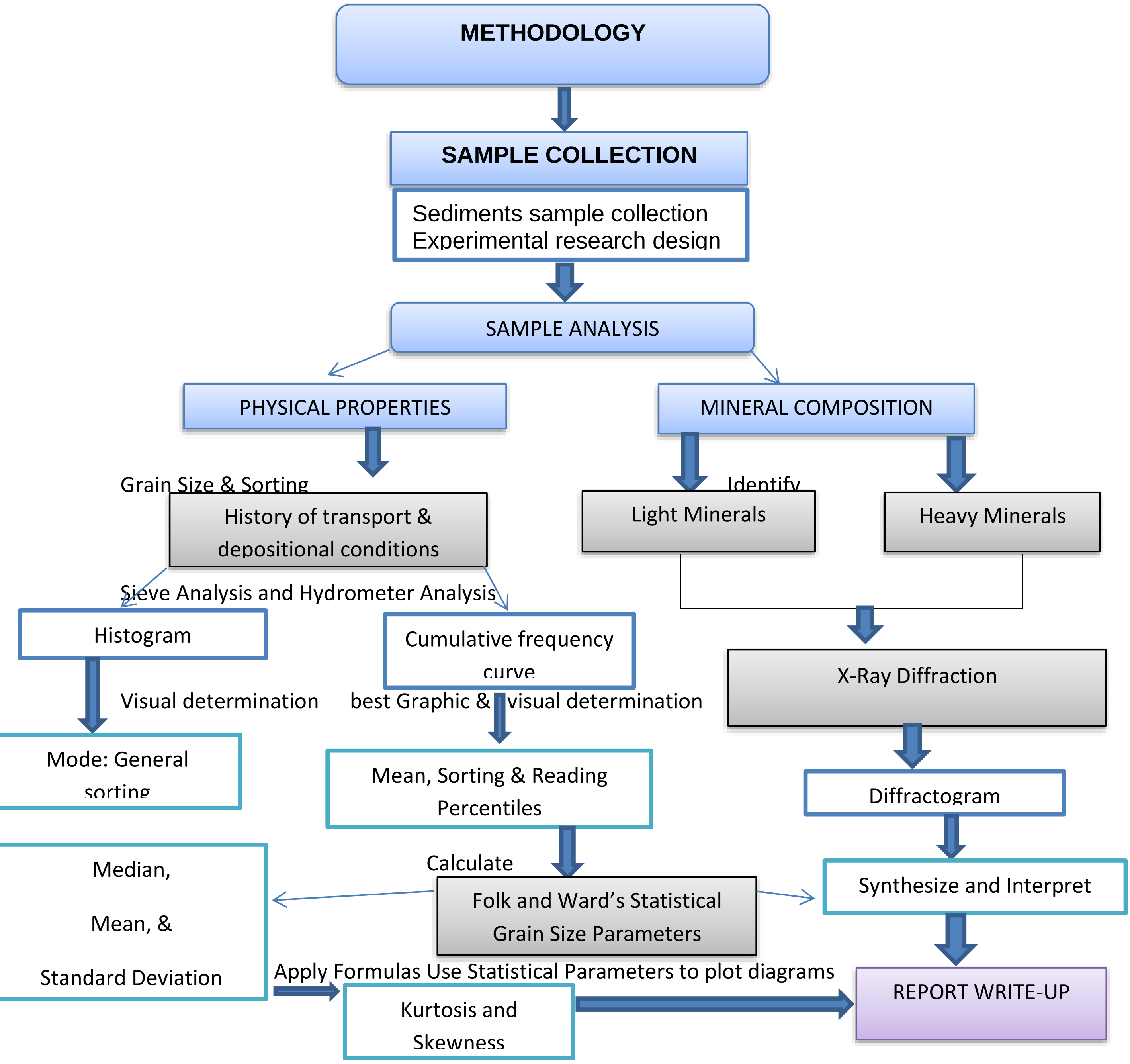


Figure 0-1: Flowchart of the Research Methodology

3.4. Data Collection Techniques

The samples were collected by a means of scheduling a visit in the study area where the researcher used a spade to collect the sediments during low flow season from Sand River and Nzhelele River in Limpopo province, South Africa. The sediments on top were removed to remove the organics and the sediments underneath were collected. The sediments were sampled in the middle of the river because there is a confluence from Limpopo River, so, the researcher wanted to sample 2 meters away from the influence of Limpopo River. The sediments were collected by a spade and transferred into a sampling bag; the sediments were stored in two sampling bags per river and the quantity of the samples overall used for dry sieving was 5703.98 g for Nzhelele River and 6879.54 g for Sand River, and the quantity for wet sieving was 5516.13 g for Nzhelele River and 5824.29 g for Sand River which were then taken to the lab for analysis.

Figure 0-2: Collecting River Sediments at Sand River

3.4.1. Sampling Method

Sediment samples was collected from the mouth of the river as a representative sample for the entire catchment. The river mouth is where much of the gravel, sand, silt and clay-called alluvium-is deposited. The river slows down at the mouth, so it doesn't have the energy to carry all the silt, sand and clay anymore, hence the researcher is able to get a representative sample of the entire river catchment. At the mouth of the river, sediments are often deposited due to the slowing of the current, reducing the carrying capacity of the water (Charles, 2014). Two samples were collected at the mouth of the river of each river to get "representative" data for the bed-load sediments of that river.

3.5. Data Analysis and Interpretation

Microsoft excel 2010 was used to generate smooth line plots showing grain size distribution curves. The data from the site survey was then transformed and analysed using Microsoft Excel, where the total number of grain sizes were obtained and then the percent in each size class calculated, and finally the cumulative percent for each size class was determined. The cumulative percent was calculated by adding all the percentage size class by moving down the matrix. The value was plotted to calculate percentage for size class, D50 and mean diameter. Statistical parameters were analysed using gradiatat software to determine the mean, median and mode, skewness, kurtosis of the sediments. Data was interpreted by using graphs, tables, and pie graphs to show the sediment characteristics of both rivers, average value of grain size and mineralogical composition of sediments. Particle Size distribution Curve was used to show the textural characteristics of the sediments of the Sand River and Nzhelele River. Scatter plots with smooth lines and markers were used to show the relationship between medium of sand and very fine sand versus mean grain size of sediments. Sediment classification was done by plotting the percentage of sand, silt and clay in a triangular diagram proposed by folk (1966).

3.5.1. X-Ray Diffraction for Mineralogical Characteristics

The mineral composition of fine powders of the gravel fraction and sediment samples were semi-quantitatively determined using X-Ray Diffraction (XRD) spectrometer. This analytical technique revealed the crystallinity and concentration of clay mineral phases present in the samples. The gravel fraction from sieving analysis that was used to depict the mineral composition of Sand River and Nzhelele River was medium sand, coarse sand and fine gravel.

The mineralogical composition of bulk sediments was measured by X-ray powder diffraction (XRD) at the Laboratory, XRD Analytical & Consulting cc. For each sample, a 200 mg split of the sand fraction obtained by wet sieving was dried and ground to ≤ 200 mesh in an agate mortar. After splitting and milling, the material was scanned preparing for XRD analysis using a backloading preparation method (Zhang et al. 2003). Diffractograms were obtained using a Malvern Panalytical Aeris diffractometer with PIXcel detector and fixed silts with Fe filtered Co-Kα radiation. The phases were identified using X'Pert HighScore plus software (Malvern Panalytical). The relative phase amounts (weight %) was estimated using the Rietveld method (Deschamps and Flippen-Anderson, 2002).

3.5.2. Grain Size Analysis (Sediment Characterisation) Through Sieving

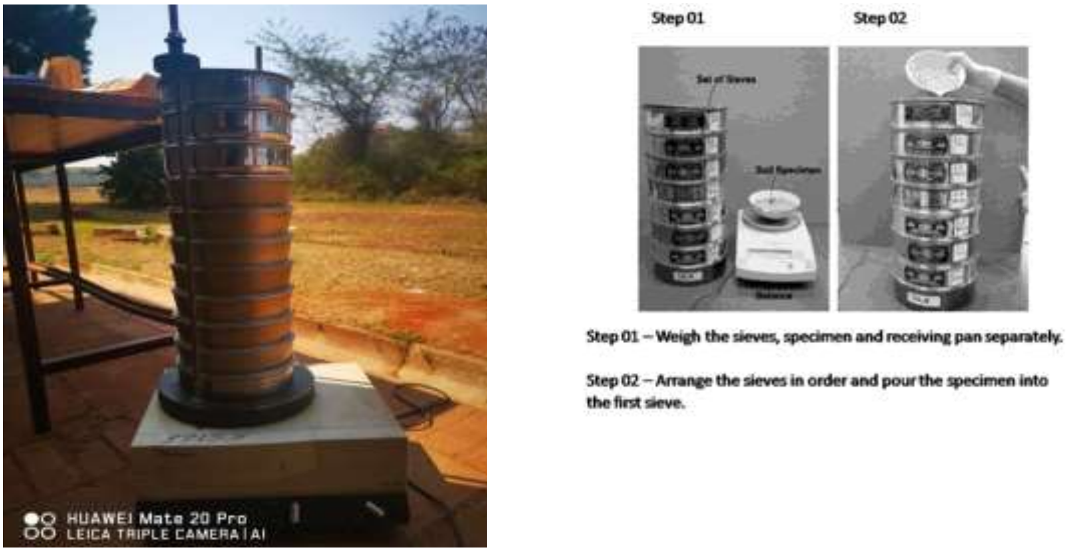
The distribution of particle sizes within a sediment sample helps to classify the sediment and better understand the physical properties of the river sediments. Particle sizes larger than 75µm sized fractions were obtained by No 200 sieve while less than 75µm sized fractions were determined by sedimentation process using hydrometer test. The stack of sieves set up that were used during textural characterisation of sand sediments is shown in Figure 3-3 and that of the hydrometer test is shown in Figure 3-8. The whole sample was not used for dry sieving only, so, the samples were typically split using a riffle sample splitter. The split wet sample was placed in a pre-weighed envelope, weighed, and recorded the weight of the samples. Dry sieving maintains large soil aggregates sizes (> 2 mm) but is usually limited to the size fraction > 250µm. In contrast wet sieving can separate soil aggregates from various size classes and in particular smaller sizes (<250µm) and it can be used to remove fines of sediments that may be difficult to sieve, prior to drying and testing a sample normally. The envelope was scribed with a unique number and, therefore, would require no additional labels, which would alter the weight of the envelope. Gross wet-sample weight minus the weight of the envelope gives the net wet-sample weight. Deposited sediment samples were dried in an electric oven at 110 °C for 48hrs because dry sieving required a completely dry sample even if moisture is 1%, adhesion forces can exceed the weight of grains smaller than 1mm, preventing them from passing through the smaller sieve. This temperature only drove off unbound water and did not affect the grain size.

About 100 g of the sample were used for the dry sieve analysis at 1/4 Φ intervals by ASTM (American Society for Testing and Materials) sieve mesh of different numbers (ASMT D 422). For the deposited sediment samples, about 20 g of the dried samples was to be re-suspended for several hours in distilled water. The deposited sediment was segregated into 200, 63, and 20µm Teflon nylon sieves to separate the sediments. The sieved fractions were collected in clean porcelain bowls and dried at 110 °C for 48hrs. The dried sediment fraction was again weighted to determine the grain size distribution of sediment fractions N200, 200−63, 63−20, and 20µm by weight percentage.

Weight percentage of each size fraction was calculated using the Phi-scale (Φ) to grade and classify these sediments. The cumulative frequency plots were made on a log-probability paper, and Φ values at 5th, 16th, 25th, 50th, 75th, 84th, and 95th percentiles were obtained from the plot. Statistical parameters of sand silt and clay were calculated using the method of Folk & Ward (1957).

3.5.2.1. The Sieve Analysis

This method is one of the simple and ancient methods of analysis of particle size distribution in which sieves of different sizes were arranged in descending order. The weighted sample was poured on the top-most sieve and vibrated for about 30 minutes. Total weight of the sediment in each sieve was noted to find the particle size distribution. A set of sieves of required sizes were stacked together, decreasing in aperture size downward from 20.00 mm, 10.00 mm, 5.00 mm, 4 mm, 3.15 mm, 2 mm, 1 mm, 500µm, 250µm, 125µm and 63µm, respectively. The sieves were weighed then samples were divided into two, using the sample splitter to be used for wet and dry sieving. The sediments were sieved for 30 minutes at amplitude 50. After sieving, the sediments were weighed in the sieves to determine their mass minus the sieve’s mass.



Step 01 – Weigh the sieves, specimen and receiving pan separately.

Step 02 – Arrange the sieves in order and pour the specimen into the first sieve.

Figure 0-3: Sieving Analysis for Grain Size

The collected sediments from Nzhelele River and Sand River were first air-dried until constant mass was achieved, and the weighed sediment samples were shaken through a stack of sieves with openings of decreasing size from top to bottom using a mechanical shaker. The mass of sediment retained and passing each sieve was weighed and recorded after the sediment was shaken on a mechanical shaker. According to Wentworth particle size classes, the grain size was calculated as percentage in four classes which are gravel, sand, silt and mud. Gravel (4, 5, 10 and 20 mm), very coarse sand (1-2 mm), coarse sand (500µm), medium sand (250µm), fine sand (125µm), very fine sand (63µm), coarse silt (16~63µm), fine and very fine silt (4~16µm), and clay (<4µm) (Wentworth, 1992; Blott and Pye, 2012).

The coefficient of curvature (C_c) is the parameter estimated using the gradation curve through sieve analysis. This parameter is used to classify the sediment as well graded or poorly graded and is given by the equation 3.1.

$$C_c = D_{30}^2 / D_{10}D_{60}$$ **Equation 1**

Here D_{30} is grain diameter below which there are 30% of particles present in the sample, D_{60} is grain size diameter below which 60% of particles exist, and D_{10} is grain size diameter below which 10% of the particles exist. The diameter taken from gradation curve for which the 10% particles are finer is known as effective size. When the value of C_c is less than 3 and greater than 1 for both sand and gravel, it is said to be well graded.

Calculate the mass retained percentage on each sieve. This is determined by multiplying mass retained in g by 100%, then dividing by the total mass shown by equation 3.2.

$$\text{Mass retained \%} = \text{mass retained (g)} \times 100/\text{total mass retained (g)}$$ **Equation 2**

= 21 x 100/3507.06

= 0.6%

This is performed for each sieve size and the end figures entered on the “Mass Retained” column of the worksheet, respectively.

Calculate the percentage retained on each sieve. This is determined by the following formula.

Cumulative % retained = Cumulative mass retained /weight of dry samples X 100

Equation 3

= 21/3525.66X100

= 0.59%

This is performed for each sieve and entered on the “Cumulative % Retained” column of the worksheet, respectively.

Calculate the percentage passing each sieve. To determine this figure, subtract the percentage retained on each sieve from 100.

% finer = 100 – cumulative % retained **Equation 4**

= 100 – 0.59

= 99.41%

This is performed for each sieve and entered in the percentage finer column of the worksheet, respectively.

3.5.3. Grain Size Analysis and Statistic Parameters

Grain-size parameters (mean grain size, standard deviation, skewness, and kurtosis) are the fundamental and readily studied features of clastic sediments and deposits of all depositional environments. In the river sediments, these parameters are dependent on sediment grain size distribution of its source and processes of winnowing, selective deposition of grain size during transport, and total deposition of sediment in transport (McLaren, 1981).

The different shapes of the relative frequency distribution curve can be interpreted as how well sorted the sample is. A narrow size range or narrow Gaussian-shaped curve implies a well-sorted sample, whereas a larger size range or ample Gaussian-shaped curve implies a poorly sorted sample (i.e., a wide range of particle sizes). Particle size distributions are based upon statistics, and the description of the statistical parameters usually depends on how the data is to be used. These calculated statistical parameters may give insight into various aspects of the environmental, depositional, and transport conditions the sediment grains endured, linking them to sedimentary systems. Three common parameters are the mean, the median, and the mode (Table 4-1 and Table 4-2). The mean is the average size of the entire sample, as seen in Table 4-1 and Table 4-2. The median is the diameter where 50% of the particles are below or above that threshold. It is by far the easiest measure to determine but the least useful as it does not reflect the extremes of the curve (Folk, 1980). The mode on the other hand, is the particle size with the highest frequency, as seen in Table 4-1 and Table 4-2, but it is not a good proxy of the overall sediment mixture (Folk, 1980). The only instance where all these three parameters coincide is when the frequency distribution curve is a perfectly Symmetrical Gaussian curve.

Other important statistical parameters obtained from the analysis of the distribution of particles which can help elucidate how uniform, symmetric, or well-sorted the sediment sample are the standard deviation, skewness, and kurtosis (Folk, 1980). The standard deviation is an accurate measure of the scatter of grain size values from the mean, corresponding then to a measure of spread or sorting of the sample. In combination with the mean, the standard deviation is the most useful and widely applied value in granulometric statistics. The skewness is used to establish the normality or symmetry of the distribution and a distribution is symmetric if it looks the same to the left and right of the center point. The closer the skewness value is to zero, the more symmetrical (i.e., normal or uni-modal) the distribution is. Asymmetrical and multi-modal sediment mixtures exhibit high values of skewness to maximums of +1.00 and -1.00. The positive and negative sign of the skewness value indicates whether the asymmetrical tail extends to the left or right of the curve (Folk, 1980).

The kurtosis is also a quantitative measure to describe the degree of Gaussian normality of the grain size distribution, but in terms of how acute or flat the curve is. This is a sorting relation between the end members of the curve and its centre (Folk, 1980). If the central portion of the curve is peaked, otherwise better sorted than its tails, the distribution curve is said to be leptokurtic with values > 1.00. The opposite a flat-peaked curve with a large spread of grain size in the centre, is called platykurtic, with values < 1.00. Normal probability curves have a kurtosis of 1.0 (Folk, 1980). Both kurtosis and skewness values are ratios of dispersion; thus, they are dimensionless and do not have units.

3.5.4. Sediment Particle Size Analysis by the Bouyoucos or Hydrometer Method Principle

The particle size analysis of a sediment estimated the percentage sand, silt and clay contents of the sediment and was reported as percentage by weight of oven-dry sediment. The analyses were performed on air-dry sediment. Based on the proportions of different particle sizes, a sediment textural category was assigned to the sample and the first stage was dispersion of the sediment into individual particles. These are sand (2.00 - 0.05 mm), silt (0.05 - 0.002 mm) and clay (< 0.002 mm) fractions. Individual sediment particles were often bound into aggregates hence the requirement for dispersion. The hydrometer method of silt and clay measurement relies in the effects of particle size on the differential settling velocities within a water column (John et al. 2001). The settling velocity is also a function of liquid temperature, viscosity, and specific gravity of the falling particle. Theoretically, the particles were assumed to be spherical and to have a specific gravity of 2.65. If all other factors were constant, then the settling velocity is proportional to the square of the radius of the particle (Stokes law). In practice, temperature correction of the liquid was done using (Table 3-1). Since the hydrometer has been calibrated at 680F (20 ^{0}C), either correction factors were applied, or the determination conducted in a temperature-controlled room kept at the correct temperature Greater temperatures result in reduced viscosity due to liquid expansion and a more rapid descent of falling particles (Gee and Bauder, 1986).

3.5.4.1. Reagents

1. Calgon (sodium Hexametaphosphate) solution 10%, 100 g of Calgon was dissolved in 1 litre of distilled water. According to Okalebo et al. (2002) this solution must not be kept over one month, when too old it loses its dispersing efficiency.

Figure 0-4: Beakers with Sediment for Hydrometer Analysis

2. Amyl Alcohol

3. Deionized Water, ASTM Type I grade.

3.5.4.2. Apparatus

1. Hydrometer with Bouyoucos scale in gram per litre

Figure 0-5: Hydrometer Reading

2. Sediment dispersing stirrer. A high-speed electric stirrer with a cup receptacle.

3. Reciprocating shaker.

Figure 0-6: Sediment Slurry Preparation Using a Reciprocating Shaker

Figure 0-7: Sedimentation Cylinders and Beakers during Hydrometer Analysis

Calculations: To calculate sand in percentages (%): after 40 seconds, the sand had settled and the hydrometer reading reflected the grams of silt + clay in 1 litre of the suspension. To calculate the amount sand present in 1 litre of the suspension, this value was subtracted from the original sample weight.

Sample Calculation: If the hydrometer reading after 40 seconds corrected for temperature is 18.0 g per litre, then silt + clay weigh 18.0 g in the 1 litre sediment suspension. Therefore, the sand weighs 50.0 - 18.0 = 32.0 g in the 1 litre suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (32 g) by the total (50 g) and multiplying by 100 as follows:

Sand % = (Sand/50.0) x 100 **Equation 5**

(32.0 / 50.0) x 100 = 64%

Clay: After 2 hours, the silt had settled. The hydrometer reading now reflected the clay content of the original suspension. For example, if hydrometer reading after temperature correction is 4.7 g/litre, then the percentage of clay in sediment is:

Clay % = (4.7 / 50) x 100 = 9.4% **Equation 6**

Silt: The silt content is calculated by subtracting the sum of the clay and sand contents from 100% or:

Silt % = 100 - (9.4% clay + 64% sand) = 26.6% **Equation 7**

The assumption made here is that the organic matter is negligible. However, in cases where sediment was found to be high, the sediment was treated with hydrogen peroxide until the frothing reaction subsides. An alternatively, determined the organic matter content and subtracted it from 100 before assigning it in the formulae.

Sediment texture: Once the sand, silt and clay distribution are measured, the sediment may be assigned to a texture class based on the sediment textural triangle (Shepard triangle) (Figure 3-9). Within the textural triangle are various sediment textural classes which depend on the relative proportions of sediment particle size classes. Users simply obtained the appropriate texture based on the particle size distribution. In the example above (64% sand, 27% silt and 9% clay), the corresponding sediment texture is a sandy loam.

Figure 0-8: Sedimentation Cylinders and Control Cylinder during Hydrometer Reading

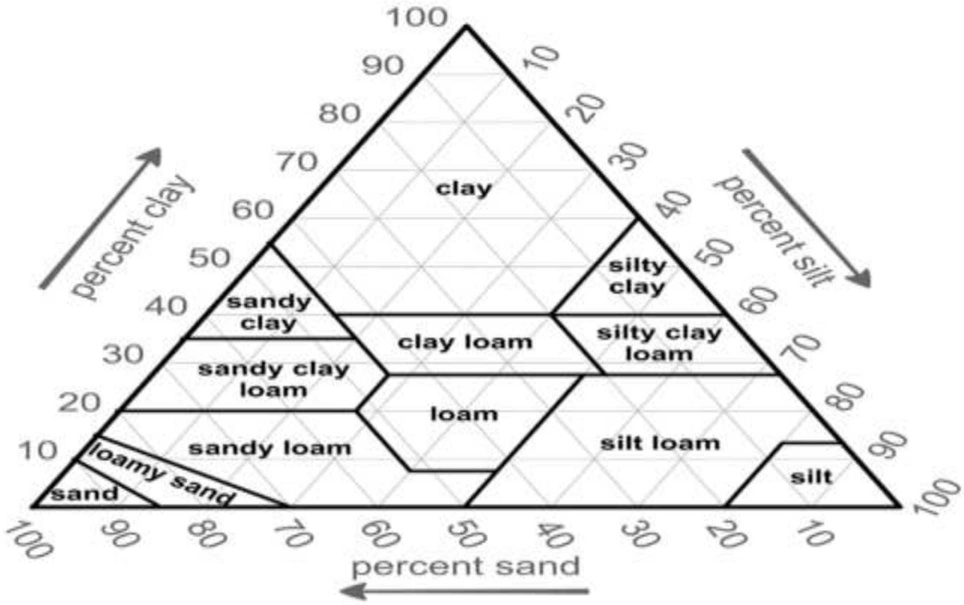


Figure 0-9: Sediment Textural Trilinear plot

Sediments may be assigned to textural classes based on particle size distribution using the sediment textural triangle.

3.6. Chapter Summary

The approach used to accomplish the goals was described in Chapter 3. This chapter examined the study goals and the various analysis techniques that were used to meet them. The grain sizes were described by sieving (dry and wet sieving). The distribution of grain size was also determined using hydrometer analysis. Gradistat was used to determine the mean, median, mode, skewness, and kurtosis of the grain size parameters after the sediments had been sieved. The mineral composition of the sediments was revealed by mineralogical investigation using XRD.

CHAPTER 4
RESULTS AND DISCUSSION

4.1. Sediment Characteristics of Sand River and Nzhelele River

Sediments play a vital role in fundamental cycling of riverine species in the aquatic environment. As noted in Chapter Two, they are responsible for transporting a significant proportion of many nutrients and contaminants. Sediments also facilitate their uptake, storage, release, and transfer between environmental compartments. Most sediment in surface water derives from surface erosion and comprises of a mineral component, arising from the erosion of bedrock, and an organic component arising during sediment-forming process (including biological and microbiological production as well as decomposition).

4.1.1. Textural Properties of Sediments

After dry sieving Sand River is characterised by the predominance of fine sand, coarse sand, and medium sand whilst Nzhelele River is characterised by the pre-dominance of gravel, coarse sand, and medium sand respectively. After wet sieving, the dominant grain sizes in Sand River were fine sand, very coarse sand, coarse sand, and medium sand, whereas Nzhelele River was characterised by coarse gravel, very coarse sand, coarse sand, and medium sand. Additionally, Nzhelele River was characterised by a higher content of coarse sand and gravel than Sand River, which is characterised by a high content of medium sand and very fine sand. In alignment with this finding, McLaren (1981) finds that grain size characteristics of sediments are controlled more by the nature of the source area than by the transportation process or depositional environment. Within the scope of the scope of this study, Nzhelele River is characterised by a gravel-sand composition and the Sand River by a medium to very fine sand composition, respectively. There is a strong association between the occurrence of gravels and the occurrence of very coarse sand. Thus, fine sand and very fine sand are the main fraction of grain size at Sand River.

4.1.2. Granulometric Distribution of Sediments

Considering the variety of granulometric distributions in modern sediments of Sand River and Nzhelele River. We can distinguish between different types of sediment corresponding to different particle sizes classes which reflect the energy level of each deposition environment and the process of sediment transport process. Knowledge of the dimensional gradient of particles that make up the suspended load is required to understand the source, transport, and, in some cases, the environmental impact of sediment. The mean grain size distribution indicates that the coarsest sediments are found in the Nzhelele River and finer sediments are found in the Sand River. In nature, sediments do not consist of only one kind of particle, but rather a combination of various particle sizes, hence it is reasonable to consider grain size as a continuous variable (Lopez, 2017). Only perfectly monodispersed samples have particles of the same size, for example, highly sorted sand thanks to hydrodynamic processes. Most naturally occurring samples contain a range, or distribution, of various particle sizes and forms.

Table 4-1 illustrate the calculations for the sieve assays conducted for the Nzhelele and Sand Rivers. It shows the mass of sediment retained after sieving, and the other values for the percentage of mass retained, the cumulated percentage retained, and the finer percentage were calculated respectively.

The curve (Figure 4-1) covers variety of particulate sizes ranging from gravel to fine. This graph (Figure 4-1) represents sediments, which contain nearly all particles of different sizes, which is why this curve is said to represent a well-classified sediment. Well means good and grading means particle distribution. This is a good particle distribution which indicates that all particles of different sizes are present in the sediment.

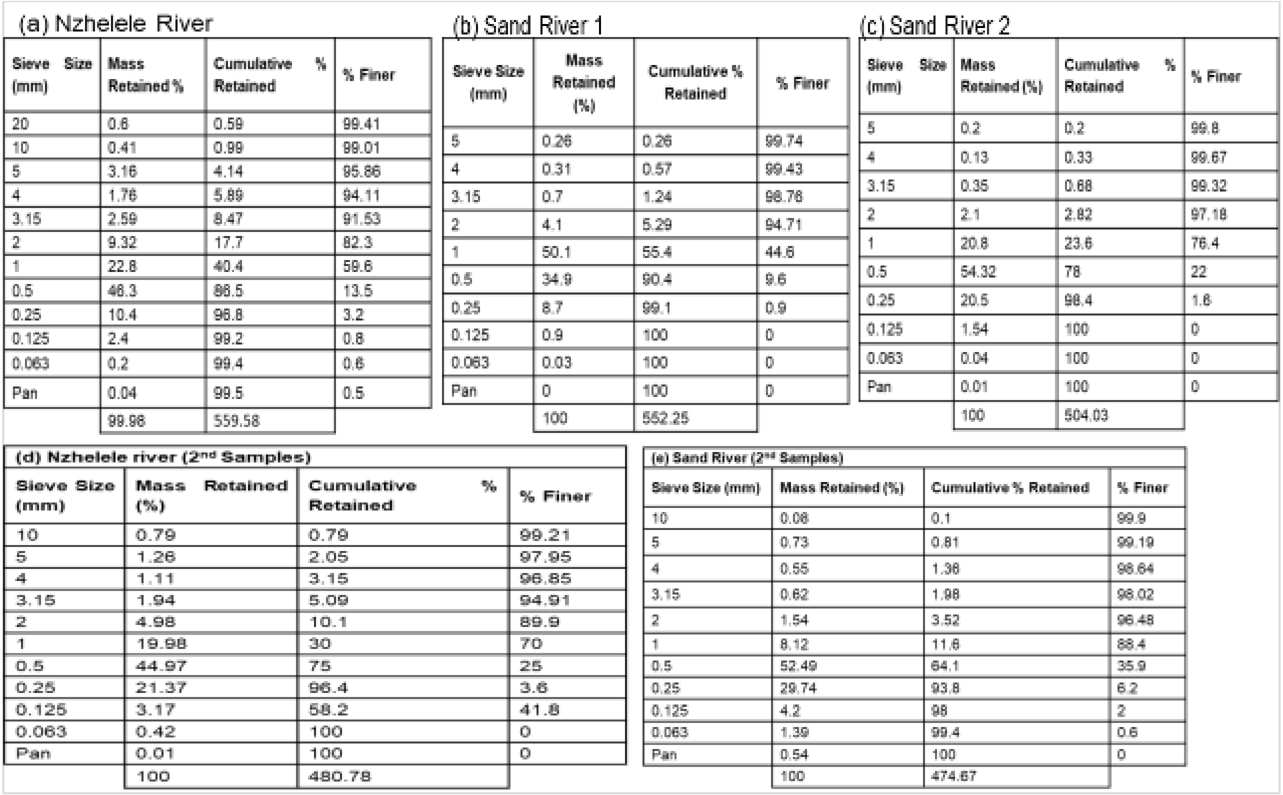
4.1.3. Dry Sieving of Sediments from the Sand River and Nzhelele River

The results are shown in Figure 4-1 where the sieve size is presented in relation to the finer percent. This is an overall graph of the sieve analysis, which is used to characterise the size of the sediment and its representative content in the sample collected. The results of the sieve analysis were recorded and compiled in excel. The following table shows the sieve analysis data sheet for both Sand River and Nzhelele River (Table 4-1) after sediment has been sieves. After plotting the particle size distribution curve, the uniformity coefficient and coefficient of curvature were computed for the curves.

The table below (Table 4-1) illustrates the calculations of the sieve assays conducted for the Nzhelele River and the Sand River following the dry sieve assay. It shows the mass of sediment retained after sieving, and the remaining values for the percentage of mass retained, the cumulative percentage retained and the finer percentage were calculated, respectively. The predominant grain size at (b) Sand River 1 after dry sieving is at sieves 1 mm very coarse sand, 0.5 mm coarse sand and 0.25 mm medium sand while for (a) Nzhelele River the dominant grain size were also found at sieve 1 mm very coarse sand, 0.5 mm coarse sand and 0.25 mm which is medium sand respectively. The predominant sediments for Nzhelele River were found at sieve size 0.5 mm (1623.32 g) followed by 1 mm (800.74 g) and 0.25 mm (364.97 g) while for Sand River they were found at sieve 1 mm (1703.77 g) followed by 0.5 mm (1187.72 g) and 0.25 mm (295.14) respectively.

The predominant grain size at (c) Sand River 2 after dry sieve analysis ranged from 1 mm to 0.25 mm which was finer than that from Nzhelele River. The predominant grain size at Sand River 2 after dry sieving is 0.5 mm coarse sand, 1 mm of very coarse sand and 0.25 mm medium sand.

Table 4-1: Dry Sieve Analysis Data Sheet



(a) Nzhelele River

Sieve Size (mm)	Mass Retained %	Cumulative % Retained	% Finer
20	0.6	0.59	99.41
10	0.41	0.99	99.01
5	3.16	4.14	95.86
4	1.76	5.89	94.11
3.15	2.59	8.47	91.53
2	9.32	17.7	82.3
1	22.8	40.4	59.6
0.5	46.3	86.5	13.5
0.25	10.4	96.8	3.2
0.125	2.4	99.2	0.8
0.063	0.2	99.4	0.6
Pan	0.04	99.5	0.5
	99.98	559.58	

(b) Sand River 1

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
5	0.26	0.26	99.74
4	0.31	0.57	99.43
3.15	0.7	1.24	98.76
2	4.1	5.29	94.71
1	50.1	55.4	44.6
0.5	34.9	90.4	9.6
0.25	8.7	99.1	0.9
0.125	0.9	100	0
0.063	0.03	100	0
Pan	0	100	0
	100	552.25	

(c) Sand River 2

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
5	0.2	0.2	99.8
4	0.13	0.33	99.67
3.15	0.35	0.68	99.32
2	2.1	2.82	97.18
1	20.8	23.6	76.4
0.5	54.32	78	22
0.25	20.5	98.4	1.6
0.125	1.54	100	0
0.063	0.04	100	0
Pan	0.01	100	0
	100	504.03	

(d) Nzhelele river (2nd Samples)

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
10	0.79	0.79	99.21
5	1.26	2.05	97.95
4	1.11	3.15	96.85
3.15	1.94	5.09	94.91
2	4.98	10.1	89.9
1	19.98	30	70
0.5	44.97	75	25
0.25	21.37	96.4	3.6
0.125	3.17	58.2	41.8
0.063	0.42	100	0
Pan	0.01	100	0
	100	480.78	

(e) Sand River (2nd Samples)

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
10	0.08	0.1	99.9
5	0.73	0.81	99.19
4	0.55	1.36	98.64
3.15	0.62	1.98	98.02
2	1.54	3.52	96.48
1	8.12	11.6	88.4
0.5	52.49	64.1	35.9
0.25	29.74	93.8	6.2
0.125	4.2	98	2
0.063	1.39	99.4	0.6
Pan	0.54	100	0
	100	474.67	

The table above (Table 4-1) provides the calculations for the sieve assays performed for (d) the Nzhelele River and (e) the Sand River. The dominant grain size at (d) Nzhelele River after dry sieving is sand at sieves 0.5 mm coarse sand, 0.25 mm medium sand and 1 mm very coarse sand, which were coarser than sediments of (e) Sand River. Whereas at Sand River, after dry sieving its sediments with sieves, it resulted in 0.5 mm coarse sand, 0.25 mm medium sand and 1 mm very coarse sand, which were finer than sediments from Nzhelele River. It is critical to note that this sediment was collected after the rainy season in the two rivers.

The results of the grain size distribution results were presented in a semi-logarithmic chart called the grain size distribution curve (Figure 4-1). In this graph, the particle diameters were plotted on a logarithmic scale and the corresponding percentage finer was further plotted on an arithmetical scale. The main advantage of using semilogarithmic graph is that it can highlight features in the data that would not be readily visible if both variables had been plotted linearly. The curve (Figure 4-1) was plotted between obtained percentage finer than D and the diameter of the particle d. this curve is obtained from the percentage finer results of both coarse- and fine-grained portions of the sediments, which results from sieving analysis. The predominant grain size was found between sieve size 1 mm and 0.25 mm sieve size which is finer than that from the Nzhelele River. In the graph, the various particle sizes D_{10}, D_{30}, and D_{60} are shown as illustrated in Figure 4-1 below.

The results of the particle size distribution analysis of the sand samples collected from Nzhelele River and Sand River were presented in semi-logarithm curve known as particle size distribution curves (see Figure 4-1). All samples showed a consistent distribution of sand size fractions (3.15 to 0.5 mm) with compositional values ranging from 91.53% to 13.5%. Sediments collected from the Nzhelele River has a relatively high coarse grain content in comparison to the Sand River. The Figure below (Figure 4-1) represents a monomodal particle size distribution, and it contains particles of different size, hence it is a polydisperse curve at (a) Nzhelele River while at (b) Sand River depicts a bimodal particle size distribution, and it contains particles of different sizes hence it is a polydisperse curve. The grain sizes in the sediments at Nzhelele River are poorly graded and Sand River graph represents a sediment which doesn't contain some of the particles of different sizes that is why this curve is said to be representing a poorly graded sediment .

The following curve (Figure 4-2) covers different particle sizes ranging from coarse to fine. This is a good particle distribution which says, some of the particles of different sizes are found in the sediment. The coefficient of uniformity was 0.85 for (a) Nzhelele River and 0.78 for (b) Sand River which meant the sediments were poorly sorted and coefficient of curvature was 1 for Nzhelele River and 1.03 at Sand River and the sediments were well graded for both rivers.

The curve below (Figure 4-1 (c)) includes various particle sizes ranging from coarse sand to fine. This graph represents a sediment, which does not contain certain particles of different sizes, which is why this curve represents a poorly graded sediment. This is a misdistribution of particles that indicates that certain particles of different sizes are missing from the sediment. The poorly graded sediments represent either a deficiency or an excess of some particle sizes or most particles of the same size. The Figure above depicts a bimodal particle size distribution, and contains particles of various sizes resulting in a polydispersed curve. The coefficient of uniformity was 0.83 and the coefficient of curvature was 0.99, indicating that the sediments were poorly sorted.

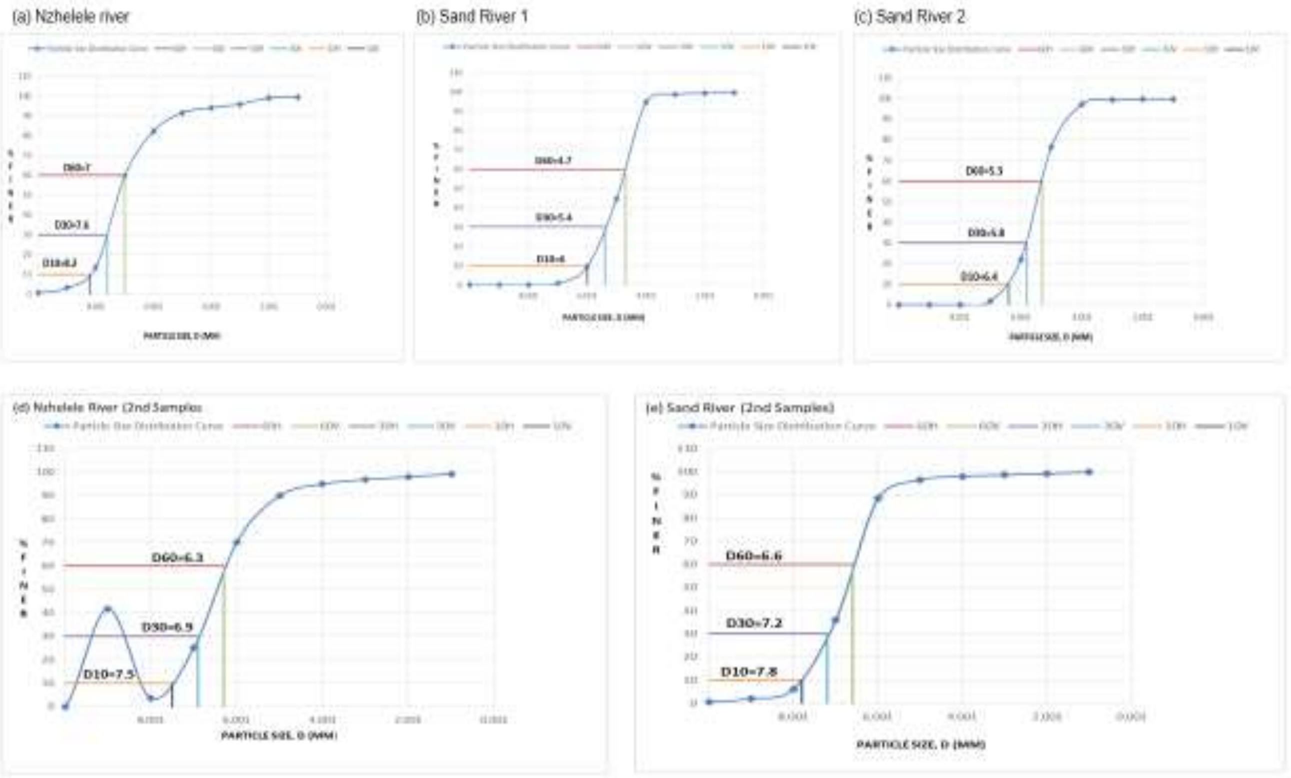


Figure 4-1: Grain Size distribution Curve (Dry Sieving)

The curves above covers various particle sizes ranging from coarse to fine. This clearly indicates that this sediment does not have a good representation of all particle sizes. Hence, this curve is said to be representing a poorly graded sediment. This poorly graded sediments either has a deficiency or an excess of some particle sizes or most particles of the same size. The Figure above depicts a multimodal particle size distribution, and contains particles of various sizes resulting in a polydispersed curve for (d) the Nzhelele River and for (e) the Sand River it resulted a bimodal particle size distribution, and it contains particles of different size, hence it is a polydispersed curve. The coefficient of uniformity was 0.84 for (d) Nzhelele River sediments while it was 0.85 for (e) Sand River sediments which depicts a poorly graded curve. The coefficient of curvature was 1 for (d) the Nzhelele River and 1.01 for (e) the Sand River, which depicted a well graded curve. Poorly graded sediment either has a deficiency or an excess of certain particle sizes or most of the particles of the same size.

.

4.1.4. Wet Sieving of Sediments from the Sand River and Nzhelele River

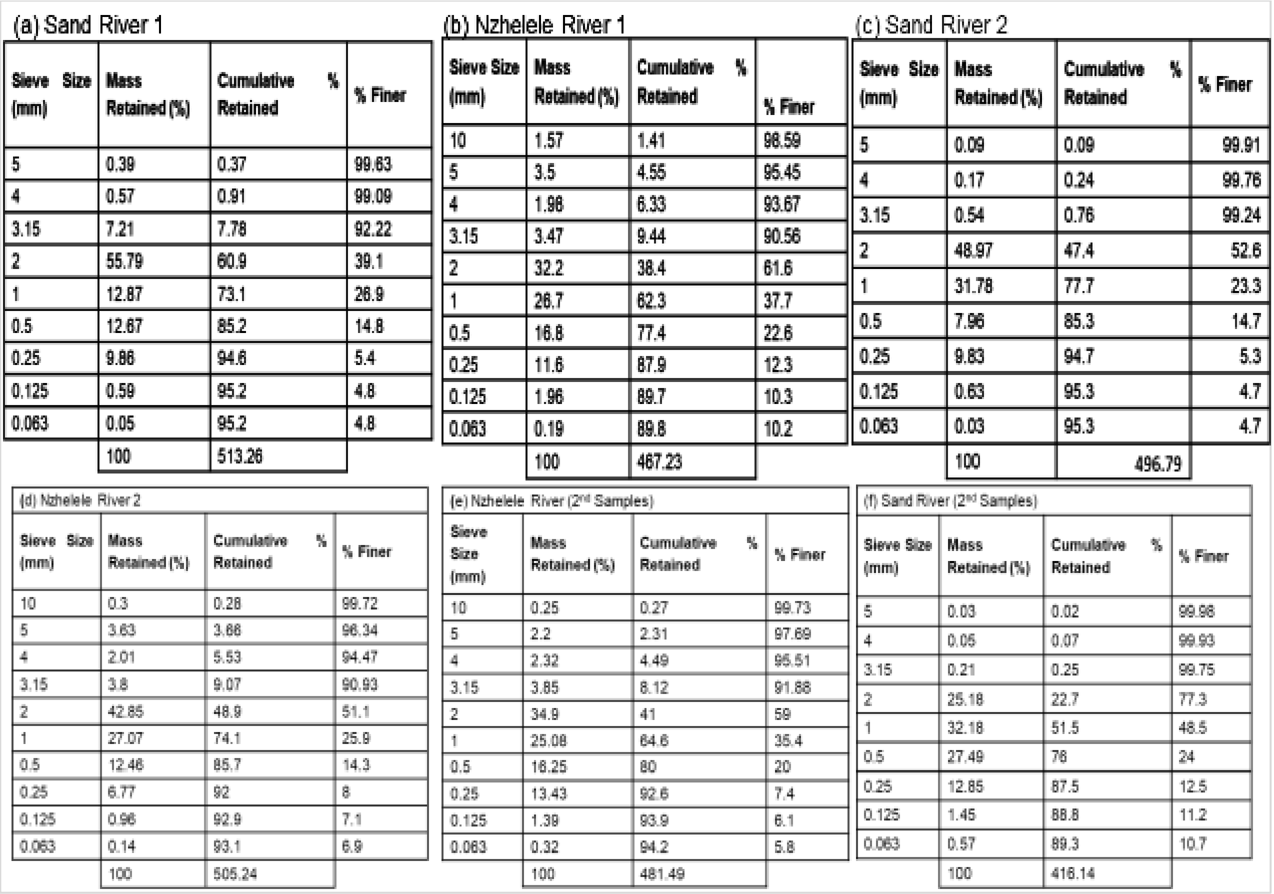
Table 4-2 below shows the sieve analysis data sheet for both Sand River and Nzhelele River after sieving the sediments. The uniformity coefficient (c_u) expresses the variety of particle sizes of sediment and is defined as the ratio of D_{60} to D_{10}. The value of D_{60} is the grain diameter at 60% of sediment sediments is finer and 40% of sediment sediments are coarser, while D_{30} is the size at which 30% is finer by weight and remaining 70% sediments are coarser than D_{30} size and D_{10} is called effective particle size and the grain size diameter at which 10% of the sediments are finer and 90% of the sediments are coarser. Hence, D_{10}, D_{30}, and D_{60} are used to determine the measure of gradation. Therefore, C_u is estimated as $C_u = D_{60} / D_{10}$. When C_u is greater than 4, the sediment is classified as well graded; whereas when C_u is less than 4 the sediment is classified as poorly graded/uniformly graded. The coefficient of curvature (C_c) is the parameter estimated using the gradation curve through sieve analysis. This parameter is used to classify the sediment as well graded or poorly graded and is given by the equation $C_c = (D_{30})^2 / D_{10} X D_{60}$.

Here D_{30} is grain diameter below which there are 30% of particles present in the sample, D_{60} is grain size diameter below which 60% of particles exist, and D_{10} is grain size diameter below which 10% of the particles exist. The diameter taken from particle size distribution curve for which the 10% particles are finer is known as effective size. When the value of C_c is less than 3 and greater than 1 for both sand and gravel, it is said to be well graded. The calculations are performed for each sieve and entered in the percentage finer column of the worksheet respectively.

The Table below (Table 4-2) depicts sieve analysis test calculations performed for Sand River and Nzhelele River after wet sieving. It shows the mass of sediments retained after sieving, and the other values for mass retained percentage, cumulative percentage retained and percentage finer where calculated, respectively. The dominant grain size at (a) Sand River 1 after wet sieve analysis is between sieve size 2 mm (fine gravel) and 0.25 mm (medium sand) which is coarser than sediments from Nzhelele River while The dominant grain size at (b) Nzhelele River 1 after wet sieve analysis was between sieve size 2 mm (fine gravel) and 1 mm (very coarse sand) which were finer than that from Sand River.

The Table below (Table 4-2) depicts sieve analysis test calculations performed for (c) Sand River 2 and (d) Nzhelele River 2. The dominant grain size at (c) Sand River 2 after wet sieve analysis was between sieve size 2 mm (fine gravel), 1 mm (very coarse sand) and 0.25 mm (medium sand) which were finer than that from Nzhelele River 2 while the dominant grain size at (d) Nzhelele River 2 after wet sieving is gravel at sieve 2 mm (fine gravel) and sand at sieves 1 mm (very coarse sand) and 0.5 mm coarse sand.

Table 4-2: Wet Sieve Analysis Data Sheet



(a) Sand River 1

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
5	0.39	0.37	99.63
4	0.57	0.91	99.09
3.15	7.21	7.78	92.22
2	55.79	60.9	39.1
1	12.87	73.1	26.9
0.5	12.67	85.2	14.8
0.25	9.86	94.6	5.4
0.125	0.59	95.2	4.8
0.063	0.05	95.2	4.8
	100	513.26	

(b) Nzhelele River 1

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
10	1.57	1.41	98.59
5	3.5	4.55	95.45
4	1.98	6.33	93.67
3.15	3.47	9.44	90.56
2	32.2	38.4	61.6
1	26.7	62.3	37.7
0.5	16.8	77.4	22.6
0.25	11.6	87.9	12.3
0.125	1.96	89.7	10.3
0.063	0.19	89.8	10.2
	100	467.23	

(c) Sand River 2

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
5	0.09	0.09	99.91
4	0.17	0.24	99.76
3.15	0.54	0.76	99.24
2	48.97	47.4	52.6
1	31.78	77.7	23.3
0.5	7.96	85.3	14.7
0.25	9.83	94.7	5.3
0.125	0.63	95.3	4.7
0.063	0.03	95.3	4.7
	100	496.79	

(d) Nzhelele River 2

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
10	0.3	0.28	99.72
5	3.63	3.66	96.34
4	2.01	5.53	94.47
3.15	3.8	9.07	90.93
2	42.85	48.9	51.1
1	27.07	74.1	25.9
0.5	12.46	85.7	14.3
0.25	6.77	92	8
0.125	0.96	92.9	7.1
0.063	0.14	93.1	6.9
	100	505.24	

(e) Nzhelele River (2nd Samples)

Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
10	0.25	0.27	99.73
5	2.2	2.31	97.69
4	2.32	4.49	95.51
3.15	3.85	8.12	91.88
2	34.9	41	59
1	25.08	64.6	35.4
0.5	16.25	80	20
0.25	13.43	92.6	7.4
0.125	1.39	93.9	6.1
0.063	0.32	94.2	5.8
	100	481.49	

(f) Sand River (2nd Samples)

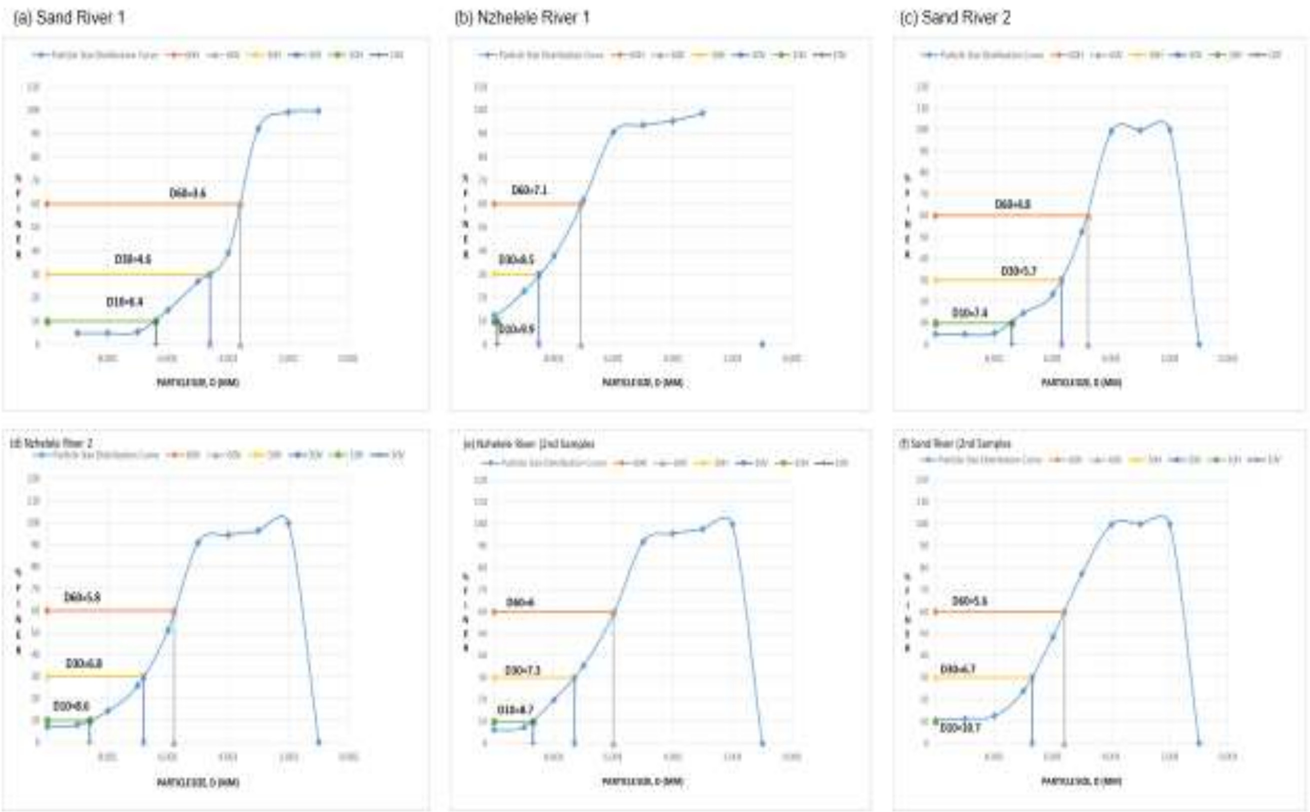
Sieve Size (mm)	Mass Retained (%)	Cumulative % Retained	% Finer
5	0.03	0.02	99.98
4	0.05	0.07	99.93
3.15	0.21	0.25	99.75
2	25.18	22.7	77.3
1	32.18	51.5	48.5
0.5	27.49	76	24
0.25	12.85	87.5	12.5
0.125	1.45	88.8	11.2
0.063	0.57	89.3	10.7
	100	416.14	

The dominant grain size (Table 4-2 above) at (e) Nzhelele River after wet sieving were gravel at sieve 2 mm (fine gravel) and sand at sieve 1 mm (very coarse sand), 0.5 mm (coarse sand) and 0.25 mm (medium sand) while the at (f) Sand River after wet sieving is gravel at sieve 2 mm (fine gravel) and sand at sieve 1 mm (very coarse sand), 0.5 mm (coarse sand) and 0.25 mm (medium sand) respectively.

Particle size distribution curve with different particle size D_{10}, D_{30}, and D_{60} are represented as shown in Figure 4-2 below. The curve below (Figure 4-2) covers various particle sizes ranging from coarse to fine. This clearly shows that this sediment has a good representation of all particle sizes. Hence, this curve is said to be representing a well graded sediment. The Figure below represents a bimodal particle size distribution, and it contains particles of different size and it is representing a polydisperse curve at (a) Sand River 1 while (b) Nzhelele River 1 represents a monomodal particle size distribution, and it contains particles of different size hence it is a polydisperse curve. The coefficient of uniformity was 0.56 at (a) Sand River 1 and 0.71 at (b) Nzhelele River 1 which depicted a poorly graded curve, whereas the coefficient of curvature was 0.92 at Sand River 1 and 1.03 at Nzhelele River 1 respectively which depicts a particle size that is well graded for Nzhelele River 1 and a poorly graded particle size for Sand River 1.

The curve below covers various particle sizes ranging from coarse to fine. This clearly indicates that this sediment has a good representation of all particle sizes. Hence, this curve is said to be representing a well graded sediment. The coefficient of uniformity was 0.65 at (c) Sand River 2 and 0.6 at (d) Nzhelele River 2 and coefficient of curvature was 0.91 for (c) Sand River 2 and 0.92 for (d) Nzhelele River 2 respectively, which shows that the sediments are poorly graded. The particle size distribution curve below represents a monomodal particle size distribution, and it contains particles of different size hence it is a polydisperse curve for (c) Sand River 2 while for (d) Nzhelele River the curve depicts a monomodal particle size distribution, and it contains particles of different size hence it is a polydisperse curve respectively. This clearly shows that the soil does not have a good representation of all particles size. Hence this curves (c and d) is said to be representing a poorly graded soil. A poorly graded soil either has a deficiency or an excess of certain particles sizes or has most of the particles of the same size.

The curve below (Figure 4-2) is said to be representing poorly-well graded sediments at (e) Nzhelele River while (f) Sand River curve represents poorly graded sediment. Poorly graded sediments either has a deficiency or an excess of certain particle sizes or most of the particles of the same size. The coefficient of uniformity was 0.69 (poorly graded) at Nzhelele River and 0.52 (poorly graded) at Sand River and the coefficient of curvature was 1 (well graded) at Nzhelele River while at Sand River it was 0.74 (poorly graded) respectively. The Figure (e and f) below represents a monomodal particle size distribution, and it contains particles of different size hence it is a polydisperse curve for Nzhelele River whereas Sand River represents a monomodal particle size distribution, and it contains particles of different size hence it is a polydisperse curve respectively.


(a) Sand River 1

(b) Nzhelele River 1

(c) Sand River 2

(d) Nzhelele River 2

(e) Nzhelele River (2nd Samples)

(f) Sand River (2nd Samples)

Figure 4-2: Particle Size Distribution Curve (Wet Sieving)

4.2. Establishing Core Statistical Parameters

After sieving the samples, a granulometric analysis of each sample was carried out with the GRADISTAT software and MS Excel software. In addition to determining particle size distributions determined, the individual statistical parameters (mean value, sorting, skewness, and kurtosis) were also calculated. For each element, the values are expressed as arithmetical mean, geometric mean, median, minimum and maximum concentration, variance, standard deviation, skewness and kurtosis. Summary of the statistical parameters is given in Appendix A.

Grain-size parameters (mean grain size, standard deviation, skewness, and kurtosis) are the basic and easily studied characteristics of clastic sediments and deposits from all depositional media. In the river sediments, these parameters are dependent on sediment grain size distribution of its source and processes of winnowing, selective deposition of grain size during transport, and total deposition of sediment in transport (McLaren, 1981).

Three limits are useful when computing standard deviations within a single sample: 1 standard deviation (±σ) from the mean implies that 68% of the grain size values fall within this limit; 2 standard deviations (±2σ) correspond to 95% of the particles; and 3 standard deviations (±3σ) to 99% (Folk, 1980). Highly asymmetric distribution curves (Appendix C) at low particle size values show a negative value and are a diagnostic of environments with higher concentrations of silt and clay. The inverse is the case for environments where the concentrations of coarser materials are higher and where the curves are asymmetrical depending on the size of the grains, hence positive values.

4.2.1. Graphic Mean Grain-size

A well-known phenomenon of a fluvial system is an exponential decrease in grain size with the distance downstream if there are no lateral inputs of sediment from tributaries and hillsides. Hydraulic sorting and abrasion processes are considered to explain the downstream decline in grain size (Musselman and Tarbox, 2013). When sorting hydraulically, finer sediments are transported more quickly and further than coarse sediments. The size of individual sediments decreases as the abrasion process progresses. Over the past two decades, observations of modern and ancient rivers and canal studies have significantly improved man’s understanding of the downstream variation of grain size in a river system. A further exponential decrease in mean grain size in alluvial channels is widely accepted by riverine geomorphologists and sedimentologists. The downstream decline in sediment gravel content is a results of a downstream decrease in stream power (Surian, 2002).

After dry sieving, the Sand River sediment's mean grain size ranges from -0.025 to 0.827ϕ, or "gravel to slightly gravel sand." Following wet sieving, the mean sediment grain size (from gravel to gravel sand) ranges from -0.721 to -0.175ϕ, respectively. The Nzhelele River sediments have a mean grain size of 0.003 and 0.387ϕ (gravelly sand) after dry sieving, however the mean grain size varies between -0.467 and -0.437ϕ (sandy gravel) after wet sieving. This range suggests that the Sand River sediments are finer than the Nzhelele River sediments.

The grain size characteristics following dry sieving of (a) Sand River 1 and (b) Nzhelele River sediments using the folk and ward method are shown in the Table in (Appendix A). The physical descriptions (such as "very coarse sand" and "moderately sorted") are listed in the table in Appendix A. A physical description of the textural category to which the sample belongs as well as the name of the sediment (such as "fine gravel or coarse sand") after Folk (1954) are also provided in the statistical table. The grain size distribution graph from the table, which was modified from Udden (1914) and Wentworth (1922), is given below. The table also includes the percentage of grains that fall into each size fraction.

After dry sieving, the findings of the statistical parameters for (a) Sand River 1 and (b) Nzhelele River are provided in Appendix A. While the mean grain size of the Nzhelele River sediments indicates that gravel to coarse sand sediments predominate, the mean grain size of the Sand River sediments indicates that coarse to fine sand predominates. For the Sand River, the mean values range from 0.006ϕ to -0.025ϕ (very coarse sand), and for the Nzhelele River, they are 0.030ϕ to 0.003ϕ (coarse sand). While the variation of phi values reveals the various energy conditions, the majority values of sediments at Sand River 1 reveal coarse sand, which denotes higher energy conditions. The majority of Nzhelele River sediment measurements show coarse sand, which denotes moderate energy conditions and the variation of phi values shows different energy conditions.

The Sand River 2 sediments' mean grain size indicates that coarse to fine sand predominates (Appendix A). The mean readings (coarse sand) vary from 0.478ϕ to 0.472ϕ. The source supply, transportation, and energy characteristics of the deposition environment all affect these parameters (Folk, 1966). The mean grain size of (b) Sand River sediments points to the predominance of coarse to fine sand and the mean value is (coarse sand) (Appendix A). The graphic mean for (a) Nzhelele River sediments points to the predominance of gravel to coarse sand and the mean value is (coarse sand) 0.379ϕ to 0.387ϕ whereas Sand River points to the predominance of coarse to fine sand and the mean value is (coarse sand) 0.795ϕ to 0.827ϕ (Appendix A).

According to the mean grain size after wet sieving, gravel predominates over coarse sand in the sediments from Sand River 1 (a), while gravel predominates over coarse sand in the sediments from Nzhelele River 1 (b) (Appendix A). While the mean value is -0.452ϕ to -0.467ϕ (very coarse sand), the mean value from Sand River 1 sediments is -0.722ϕ to -0.721ϕ (very coarse sand).

The average grain size of the sediments from Sand River 2 (a) indicates that coarse to fine sand predominates, whereas the sediments from Nzhelele River 2 (b) indicate that gravel predominates over coarse sand. The mean values for Sand River 1 and Nzhelele River, respectively, range from -0.619ϕ to -0.713ϕ (very coarse sand) and -0.727ϕ to -0.751ϕ (very coarse sand), respectively.

The Nzhelele River sediments' mean grain size (a) indicates that gravel and coarse sand predominate, whereas the Sand River sediments' mean grain size (b) indicates that extremely coarse and coarse sand predominate. The very coarse sand mean value from Nzhelele River sediments ranges from -0.443ϕ to -0.437ϕ, whereas the very coarse sand mean value from Sand River ranges from -0.114ϕ to -0.175ϕ. Most values show coarse sand, which denotes moderate energy conditions for sediments from the Sand River and the Nzhelele River. While the difference in phi values between the Sand and Nzhelele rivers demonstrates the different energy conditions.

4.2.2. Graphic Standard Deviation

The range of sizes of the available sediments, the pace of the deposition agent, and the amount of time available for sorting are all factors that affect standard deviation, a poorly understood measurement (Baiyegunhi et al., 2017). Sorting (Standard Deviation): This is a function of the size distribution of the source rock, the degree of weathering, the distance traveled, and the energy variation of the depositing medium (Folk and Ward, 1957). The variance in sorting that was observed is attributable to variations in depositing current velocity and water turbulence. Four main elements influence the standard deviation of river sediments: (i) the source sediment's grain size distribution;

(ii) the preferential fluvial entrainment of particles for saltation; (iii) the gravitational effects of downslope sediment transportation; and (iv) the water flow characteristics (Baiyegunhi et al., 2017). Each control has a different meaning and impact over time and space. Sediments from the Sand River that have been dry sieved range in sorting from 0.792ϕ to 0.827ϕ (moderately sorted). After wet sieving, the value of sorting (from poorly to moderately sorted) ranges between 1.042ϕ and 1.051ϕ. After dry sieving, the suspended load sediments from the Nzhelele River were sorted into 1.114ϕ and 1.077ϕ (poorly sorted). Following wet sieving, the value of sorting sediments ranges from 1.224ϕ to 1.182ϕ (poorly sorted), respectively.

The standard deviation values for (a) Sand River 1 range from 0.763ϕ to 0.792ϕ, and for (b) Nzhelele River, which is badly sorted as indicated in Appendix A, the standard deviation value is 1.116ϕ to 1.114ϕ. River sediments from Sand River 1 are moderately sorted, indicating that moderate to strong energy conditions have a predominance in the basin. In contrast, sediments from Nzhelele River are poorly sorted, indicating that medium to adequate energy conditions have a predominance in the basin and that the sediments were typically deposited quickly. The results for Sand River 2 have a standard deviation that ranges from 0.764ϕ to 0.829ϕ (moderately sorted).

Sediments are poorly sorted for (a) Nzhelele River, and the graphic standard deviation value is 1.028ϕ to 1.077ϕ. This reflects the influence of medium to adequate energy conditions in the basin, which implies the sediments are typically deposited swiftly. For (b) Sand River, the standard deviation ranges from 1.008ϕ to 0.864ϕ, and the sediments are fairly sorted, which points to the influence of moderate to strong energy conditions in the basin (Appendix A). For (a) Sand River 1, the standard deviation ranges from 1.029ϕ to 1.042ϕ, which is poorly sorted. For (b) Nzhelele River 1, the standard deviation ranges from 1.169ϕ to 1.224ϕ, which is similarly poorly sorted. For (a) Sand River 2, the standard deviation value ranges from 0.933ϕ to 0.918ϕ, which is moderately sorted while for (b) Nzhelele River 2, the standard deviation value ranges from 1.032ϕ to 1.019ϕ which is poorly sorted.

The (a) Nzhelele River's standard deviation ranged from 1.168ϕ to 1.182ϕ, which indicates poor sorting, and the (b) Sand River's standard deviation ranged from 1.019ϕ to 1.051ϕ, again indicating poor sorting. Sediments that are poorly sorted show the influence of basin energy conditions that range from adequate to sufficient, indicating that the sediments were often deposited swiftly.

Sediments that are poorly sorted show the influence of basin energy conditions that range from adequate to sufficient, indicating that the sediments were often deposited swiftly. The influence of moderate to strong energy conditions can be seen in the basin, according to relatively well-sorted sediments. According to Balyegunhi et al. (2017), this may be caused by incomplete winnowing actions, addition, or input of previously sorted sediments in the marine environment.

4.2.3. Graphic Skewness

The symmetry of the core portion of the distribution is ascertained using skewness. It displays the symmetry or asymmetries of the sediment frequency distribution. For the sediments from the Sand River and Nzhelele River, a wide range of skewness and kurtosis values were obtained. After dry screening, the skewness of the sediment from Sand River sediments ranges between 0.214ϕ and 0.089ϕ (fine to symmetrical skewed). Skewness for sediments that have been wet sieved ranges from 0.621ϕ to 0.150ϕ (very fine and fine skewed, respectively). After dry screening, the sediments from the Nzhelele River are coarsely skewed and have a skewness of -0.246ϕ and -0.127ϕ. Sediments that have been wet sieved have skewness that is, respectively, between 0.268ϕ and 0.354ϕ (fine to extremely fine skewed).

For (a) Sand River, the values of skewness vary from 0.627ϕ to 0.214ϕ (fine skewed), whereas for (b) Nzhelele River, the values of skewness range from -0.442 to -0.246 (coarse skewed) (see Appendix A). The positive skewed distribution of the sediments at Sand River 1 indicates that the finer fraction is prevalent in the depositional environment and deposited under high energy conditions together with selective deposition and winnowing. The sediments are fine skewed in nature. The channel character of the sediments at Nzhelele River indicates the absence of harsh conditions. For Sand River 2, the skewness values vary from 0.012ϕ to -0.019ϕ. The symmetrical pattern of the sediments suggests that no extreme conditions existed. Skewness values at (a) the Nzhelele River range from -0.396ϕ to -0.127ϕ, which is coarse skewed while the value of Skewness at (b) Sand River are 0.910 ϕ to 0.089 ϕ.

The sediments from (a) Sand River 1 had a skewness value of 1.201ϕ to 0.621ϕ, which is very finely skewed, whereas the sediments from (b) Nzhelele River 1 had a skewness value of 0.477ϕ to 0.268ϕ, which is finely skewed. While Nzhelele River 2 ranges from 0.795ϕ to 0.417ϕ, Sand River 2's value of skewness ranges from 1.317ϕ to 0.547ϕ, both rivers are extremely finely skewed. The relatively fine skewed structure of the sediments suggests that no harsh conditions existed. The (a) Nzhelele River had a value of 0.574ϕ to 0.354ϕ, which is very finely skewed, whereas the (b) Sand River had a value of 0.610ϕ to 0.150ϕ, which is finely skewed.

While the symmetrical nature of the sediments indicates the presence of extreme conditions, the course nature of the Nzhelele River sediments indicates the absence of such conditions. Nzhelele River sediments are finely skewed in nature, showing the absence of extreme conditions, in contrast to Sand River sediments, which are very finely skewed in nature. According to Folk (1974), the presence of small coarse grain is what causes the negative Skewness on sediments from the Nzhelele River, although it is important to note that the values are close to zero. Since all of the river's eroded material was deposited at once, the sediments of the Nzhelele River are negatively skewed.

4.2.4. Graphic Kurtosis

Peakness is quantified by kurtosis. Adigan (1961) asserts that it also serves the purpose of internal distribution or sorting. After dry screening the sediments from the Sand River, the kurtosis values range from 0.907 to 1.139ϕ, showing a mesokurtic to leptokurtic distribution. Kurtosis values range from 1.048 to 0.823ϕ after wet sieving Sand River sediments, showing a mesokurtic, leptokurtic, and platykurtic distribution. After dry screening, the kurtosis values for the Nzhelele River sediments are 1.131 and 1.180ϕ, respectively, showing a leptokurtic distribution. Kurtosis values range from 0.991 to 0.879ϕ after wet sieving Nzhelele River Sediments, indicating a mesokurtic, leptokurtic, and platykurtic distribution.

The (a) Sand River 1 kurtosis graph runs from 3.937ϕ to 0.907ϕ, making it mesokurtic in nature, while the (b) Nzhelele River kurtosis graph extends from 4.343ϕ to 1.132ϕ, making it leptokurtic (see Appendix A). They are leptokurtic at Sand River 2 because the kurtosis graph spans from 3.906ϕ to 1.215ϕ (Appendix A).
The kurtosis graph (a) for the Nzhelele River ranged from 3.865ϕ to 1.180ϕ, and (b) for the Sand River ranged from 11.26ϕ to 1.139ϕ, both of which are leptokurtic. The kurtosis graph for the Sand River in (a) has a value of 3.280ϕ to 1.048ϕ and is mesokurtic, whereas the kurtosis graph for the Nzhelele River has a value of 2.868ϕ to 0.991ϕ and is also mesokurtic.

Leptokurtic values for the kurtosis graph for (a) Sand River 2 are 3.876ϕ to 1.150ϕ and for (b) Nzhelele River 2 are 3.820ϕ to 1.173ϕ, both of which are leptokurtic. Kurtosis graph readings for the (a) Nzhelele River are 2.755ϕ to 0.879ϕ, which is platykurtic, and for the (b) Sand River are 2.904ϕ to 0.823ϕ, which is also platykurtic.

The continual addition of finer or coarser materials after winnowing action and preservation of their original characteristics throughout deposition are referred to as the mesokurtic nature of the sediments at Sand River 1 (Avramidis, 2012). The constant addition of finer or coarser materials following winnowing action and conservation of their original characteristics throughout deposition are referred to as the leptokurtic nature of the sediments of Nzhelele River and Sand River (Avramidis, 2012). The samples have a strong platykurtic distribution and a positive excess kurtosis value, both of which imply that the sands were deposited in a fluvial or tidal environment, indicating that they are river-derived. According to Freidman (1961), high or low levels of kurtosis indicate that some of the sediments were sorted in a high-energy environment. The platykurtic distribution would, therefore, have thinner tails than a normal distribution, leading to less extreme positive or negative events.

4.2.5. Cumulative curves

The sediment grain-size distribution can be linked to sediment transportation, which often takes place during significant flood discharges. These sediments <3ϕ were deposited at low flow stages and are often conveyed wholly in suspension without any bed-load phase. The cumulative curves of bedload and suspended load sediments provide a large portion of the explanation for the discrepancies in their transport behaviors. These curves reveal the process and hydraulic parameters under which these river sediments are re-transported, as sediments can be transported by river water in a variety of ways. It is without a doubt true that the primary grain-size properties of sediments deposited in a riverbed can be linked to bed-load transit during deposition, which typically takes place within a very small range of high flows in flood discharges. It is popular among sedimentologists and hydrologists that (in the case of unidirectional flow) bedload, saltation, and suspension are the three transportation mechanisms of sediments (Perlman, 2004).

Appendix B displays the cumulative grain-size curves from the sediments of the Sand River and Nzhelele River. From gravel to fines, the curves cover a broad range of particle sizes. This demonstrates that this sediment graph displays a sediment that almost entirely consists of particles of various sizes. Because of this, it is claimed that these curves show well-graded silt. The curve can be used to distinguish between sediments with coarse and fine grains. A sediment is said to as coarse-grained if it contains more than 50% of particles larger than 0.075 mm. The phrase "fine grained sediment" is used when more than 50% of the sediment material comprises particles smaller than 0.075 mm. As can be seen in Appendix B, the sediments at Sand River are fine-grained because, according to the cumulative curves, 50% of the material is fine, but the sediments at Nzhelele River are coarse-grained because, according to the cumulative curves, more than 50% of the material is coarse.

4.3. Grain Size Distribution Histogram (Dry Sieving)

The analysis of different grain size parameters shows the prevalence of unimodal distribution from both Sand River and Nzhelele River sediments. The histograms (Appendix B) shows the grain size distribution at (a) Sand River 1 and (b) Nzhelele River after dry sieving. The distribution was at the highest between particle diameters 0.0 and -1.0 ϕ for Sand River 1 while for Nzhelele River the distribution is at the highest between particle diameters 1.0 and 00 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand and the distribution is left skewed for Sand River sediments and the grain size distribution for river sand from Nzhelele River are right skewed. This sediments from Sand River are described as unimodal, moderately sorted while sediments from Nzhelele River are unimodal and poorly sorted.

The histogram (Appendix B) shows the grain size distribution at (c) Sand River 2 after dry sieving. The distribution was at the highest between particle diameters 1.0 and 00 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand and the sand is described as unimodal, moderately sorted. The histogram shows a typical symmetric distribution which means the left- and right-hand side of the distribution are roughly equally balanced around the mean.

The histogram on Appendix B shows the grain size distribution at (d) Nzhelele River and (e) Sand River after dry sieving. The distribution for Nzhelele River is at the highest between particle diameters 1.0 and 00 ϕ while the distribution for Sand River was at the highest between particle diameters 1.0 and 00 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand. Nzhelele River sediments are described as unimodal and poorly sorted while the sediments from Sand River are described as unimodal and moderately sorted respectively. The histogram for both Nzhelele River and Sand River illustrates a right skewed distribution, and this shows that the finer fraction is abundant in the depositional environment.

The histogram (Appendix B) shows the grain size distribution at (a) Sand River 1 and (b) Nzhelele River 1 after wet sieving. Sand River 1 distribution is at the highest between particle diameters -1.0 and -2.0 ϕ while grain size distribution for Nzhelele River 1 is at the highest between particle diameters -1.0 and -2.0 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand and the distribution is left skewed for both Sand River 1 and Nzhelele River 1 respectively, which indicates the abundance of fines with a tail in the direction of the coarse sediments. Sediments from Sand River 1 and Nzhelele River 1 after wet sieving are described as unimodal and poorly sorted.

The histogram (Appendix B) shows the grain size distribution at (c) Sand River 2 and (d) Nzhelele River 2 after wet sieving. Sand River 2 distribution is at the highest between particle diameters -1.0 and -2.0 ϕ while Nzhelele River distribution is at the highest between particle diameters -1.0 and -2.0 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand and the Sand River 2 and Nzhelele River 2 distribution is left skewed, which indicates the abundance of fines with a tail in the direction of the coarse sediments. This sediments from Sand River 2 is described as unimodal, moderately sorted while Nzhelele river 2 sediments are also unimodal but poorly sorted.

The histogram (Appendix B) shows the grain size distribution at (a) Nzhelele River and (b) Sand River after wet sieving. Nzhelele River distribution was at the highest between particle diameters -1.0 and -2.0 ϕ while Sand River distribution was at the highest between particle diameters -1.0 and

-2.0 ϕ. Sediments from different depositional environments give different grain size distribution plots. This shows the grain size distribution for river sand and the distribution is left skewed for both rivers, which indicates the abundance of fines with a tail in the direction of the coarse sediments. Both Nzhelele River and Sand River histograms exhibits unimodal, poorly sorted trends.

4.3.1. Sediment Texture Triangle

The trilinear plot (triangle) in appendix E shows that most of the sediments at Nzhelele River are gravelly sand-sandy gravel whereas at Sand River they are sandy gravel-slightly gravelly sand. The sediment texture triangle is used to convert particle size distribution into a recognised texture class based on the relative amounts of sand, silt, and clay as a percentage. Sediment texture analysis is done by determining the percentage of sand, silt, and clay in each sediment. These findings are plugged into a texture analysis triangle (as appendix 9) to determine sediment classification. Sediment texture and structure are considered master variables meaning that texture and structure directly impact many other sediment properties. Here, sediment texture was determined quantitatively using the hydrometer method and estimated using the sediment texture triangle. Nearly any type of land management will be influenced by sediment texture.

4.4. Hydrometer Method Results

Hydrometer test results show the percentage composition of sand, silt and clay, and the results show that the study areas were dominated by sand sized sediments.

Hydrometer test results (Tables 4-23- 4-26) show the percentage composition of sand, silt, and clay. The results show that the study area is dominated by sand-sized sediments. The overall percentage composition of grain size distribution exhibits the study area as sand-dominated (a sandy River). The distribution of a high percentage of sand-sized sediments across all samples is due to the prevailing high energy environment.

The sand content varies from 97.6% to 97.8% for Sand River 1 and 97.6% to 97.8% for Nzhelele River 1, whereas for Sand River 2 it is 97.6% to 97.4% and at Nzhelele River 2 it was 97.6% respectively. The silt content varies from 0% to 0.2% for Sand River 1 and 0% for Nzhelele River 1, whereas for Sand River 2 it is 0.2% to 0.4% and at Nzhelele River 2 it was 0% to 0.2% respectively. The clay content is lowest at Sand River and highest at Nzhelele River. The overall percentage composition of the grain size distribution depicted that the studied area was sand dominated. The distribution of a high percentage of sand sized sediments across Nzhelele River is due to the predominant high energy environment.

4.4.1. Hydrometer Calculations

Sand River 1

Rep 1

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g p/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep3

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

Sand River 2

Rep 1

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.3 g/liter, then silt + clay weigh 1.3 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.3 g) = 48.7 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.7 g) by the total (50 g) and multiplying by 100, which is 97.4%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.4%.

Rep 3

If the hydrometer reading after 40 seconds corrected for temperature is 1.3 g/liter, then silt + clay weigh 1.3 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.3 g) = 48.7 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.7 g) by the total (50 g) and multiplying by 100 which gave us 97.4%.

After 2 hours, the silt has settled. The hydrometer reading now reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100% which is equivalent to 0.4%.

Nzhelele River 1

Rep 1

If the hydrometer reading, it is 1.2g per lire after being corrected for 40 seconds, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 g – (1.2 g), which equals 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100 which gave us 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.2 g/liter, and then the percentage of clay in sediment is 2.4%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100% which is equivalent to 0%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g per liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.2 g/liter, and then the percentage of clay in sediment is 2.4%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100% which is equivalent to 0%.

Rep 3

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g p/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

Nzhelele River 2

Rep 1

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g g/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying it by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The sand percentage is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.2 g/liter, and the percentage of clay in sediment is 2.4%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

Rep 3

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 – (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.2 g/liter, and the percentage of clay in sediment is 2.4%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

4.4.2. Sediment Texture Distribution

Once the sand, silt, and clay distribution are measured, the sediment may be assigned to a texture class based on the sediment textural triangle (Trilinear Plot, see Figure 3-9). Within the textural triangle, there are various sediment textures which depend on the relative proportions of sediment particles. Users simply obtain the appropriate texture based on the particle size distribution. The diagram below (Table 4-4) presents the results of a classification obtained for the granulometric fractions of the fine fraction of the sediments from the river. According to the diagram, the fine sediments from the river were mainly formed of sand with fractions of granules greater than 97.8%, also, these particles (silt and clay) represent, on average, 0.2% and 2.2% of the fraction from both rivers respectively.

Table 4-3: Classification of Sediment Texture of Sand River and Nzhelele River

Rivers	Sediment Texture
Sand River 1	Sand
Sand River 2	Sand
Nzhelele River 1	Sand
Nzhelele river 2	Sand

The corresponding sediment texture is sand from both Sand River and Nzhelele River respectively.

4.4.3. Hydrometer Analysis Second Samples

Hydrometer Calculations

Sand River

Rep 1

If the hydrometer reading after 40 seconds corrected for temperature is 1.2 g p/liter, then silt + clay weigh 1.2 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1.2 g) = 48.8 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.8 g) by the total (50 g) and multiplying by 100, which is 97.6%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g p/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading now reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

Rep3

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1 g/liter, and then the percentage of clay in sediment is 2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Nzhelele River

Rep 1

If the hydrometer reading after 40 seconds corrected for temperature is 1 g/liter, then silt + clay weigh 1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1 g) = 49 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (49 g) by the total (50 g) and multiplying by 100, which is 98%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0.2%.

Rep 2

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g p/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1.1 g/liter, and then the percentage of clay in sediment is 2.2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100%, which is equivalent to 0%.

Rep 3

If the hydrometer reading after 40 seconds corrected for temperature is 1.1 g/liter, then silt + clay weigh 1.1 g in the 1-liter sediment suspension. Therefore, the sand weighs 50.0 - (1.1 g) = 48.9 g in the 1-liter suspension (of the original 50.0 g of air-dry sediment sample). The percentage sand is calculated by dividing the sand content (48.9 g) by the total (50 g) and multiplying by 100, which is 97.8%.

After 2 hours, the silt is settled. The hydrometer reading then reflects the clay content of the original suspension. The hydrometer reading after temperature correction is 1 g/liter, and then the percentage of clay in sediment is 2%.

The silt content is calculated by subtracting the sum of the clay and sand contents from 100% which is equivalent to 0.2%.

4.4.4. Sediment Texture

Once the sand, silt, and clay distribution are measured, the sediment was assigned to a texture class based on the sediment textural triangle (Trilinear Plot, see Figure 3-9). Within the textural triangle, there are various sediment textures, which depend on the relative proportions of sediment particles. Users simply obtain the appropriate texture based on the particle size distribution.

Table 4-5: Classification of Sediment Texture of Sand River and Nzhelele River 2nd Samples

Rivers	Sediment Texture
Sand River	Sand
Nzhelele River	Sand

The corresponding sediment texture is sand from both Sand River and Nzhelele River respectively.

4.5. Mineralogy of Sediments

To aid understanding, mineral analysis was visualized using pie charts and diffractograms. As illustrated in Figures 4-3 and 4-4, all the sediments were presented as percentages to show the relative makeup of each mineral type. Sediment analysis also includes the analysis of mineral content. According to the Mohs hardness scale, quartz has a hardness of 7, feldspar has a hardness of 6–6.5, and mica–muscovite has a hardness of 2.5–3 (Awal et al., 2019). Minerals with harder compositions than hydropower have a larger potential for erosion. The peaks in the diffractograms (Figures 4-5 and 4-6) show where the crystal lattice has diffracted the x-ray beam.

The outcomes of the selected sediment samples' of the semi-quantitative mineralogical examination are shown in Table 4-6. Rietveld study of the initial powder XRD patterns was used to do quantitative study on the sand samples fraction (Table 4-6). Kaolinite is undermined at Nzhelele River, whereas Actinolite is undermined at Sand River. Quartz is also overstated at Nzhelele River and Sand River, according to a comparison with the quantification produced using the Rietveld analysis method.

The most prevalent mineral is quartz (49.3 and 38.9%), which is followed by a variety of feldspar group minerals (Albite (29.8 and 38.3%) and Orthoclase (18.1 and 20.1%), mica group minerals (Muscovite (2.1 and 2.5%), clay minerals (Kaolinite, 0.6%), and hornblende group (amphibole silicate minerals) in the form of Actinolite (0.4%).

The sand samples of the powder contain about 49.3 weight percent (Nzhelele River) and 38.9 weight percent (Sand River) of silicon dioxide, the majority of which is present as quartz; 29.8 weight percent (Nzhelele River) and 38.2 weight percent (Sand River) of albite, a plagioclase feldspar mineral; 18.1 weight percent (Nzhelele River) and 20.1 weight percent (Sand River) of orthoclase as feldspar Minerals; 2.1 weight percent (Nzhelele River) and 2.5 weight percent (Sand River) of muscovite as Mica; 0.6 weight percent of clay mineral particles as kaolinite at Nzhelele River and 0.4 weight percent of actinolite as amphibole silicate minerals at Sand River.

Table 4-6: Quantitative Analysis of the Mineral Phase from Rietveld Method (XRD)

Mineral phase	**Weight Percent (Rietveld)**	
	Nzhelele River	**Sand River**
Quartz	49.3	38.9
Albite	29.8	38.2
Orthoclase	18.1	20.1
Muscovite	2.1	2.5
Kaolinite	0.6	Nil
Actinolite	0.0	0.4

The ratio of quartz to feldspar, which is a frequent indicator of mineralogical maturity, is shown in Table 4-6 above. Sand River's high feldspar content points to mineralogical immaturity. Only the sediments at the Nzhelele River can be submature because of the larger ratio of Quartz to feldspar (stable to unstable minerals) that lower feldspar concentrations produce (Samuel and Akinade, 2017).

Table 4-6 provides a summary of the quantitative analysis of the mineral phase using the Rietveld method and XRD data for the sand sample. The most prevalent lithogenic elements in the sand samples according to the mineralogical analyses (Table 4-6) are quartz and feldspar (Albite and Orthoclase). According to Chima et al. (2018), several of the samples had extremely broken quartz grains and occasionally even feldspar, with quartz exhibiting undulatory extinction.

Quartz was generally the major lithogenic mineral component in the samples (Table 4-6), reaching the highest composition of 49.3% by volume. The quartz content in most of the sand samples analysed was more than 30% by volume. The highest quartz content in the samples was generally at Nzhelele River wherein the quartz content in the samples was between 30 and 40% by volume.

Pie chart was also used to enhance understanding of the mineral analysis. All the sediment minerals were presented in percentage to realize the relative composition of each mineral type as shown in Figure 4-3 and 4-4 below.

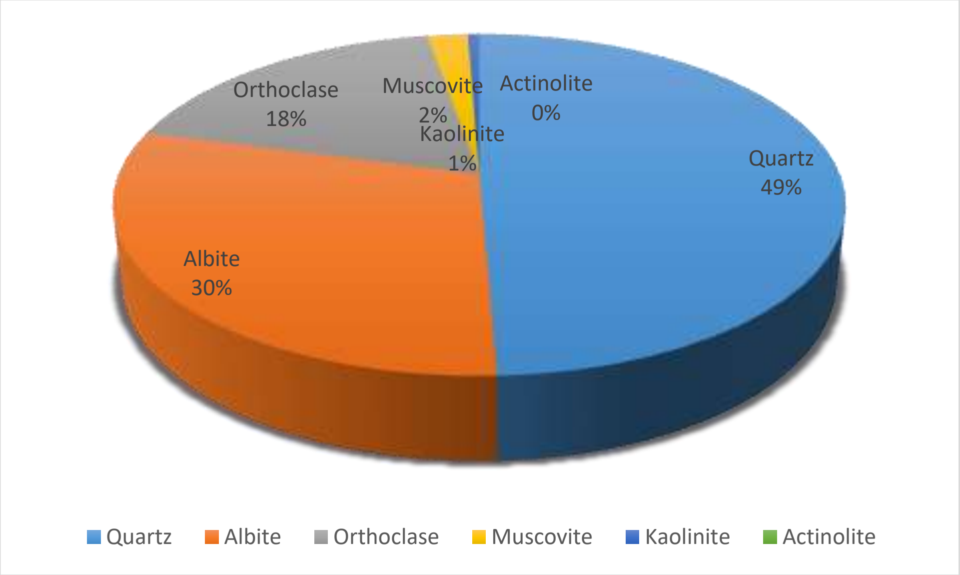


Figure 4-3: Nzhelele River Mineral Composition

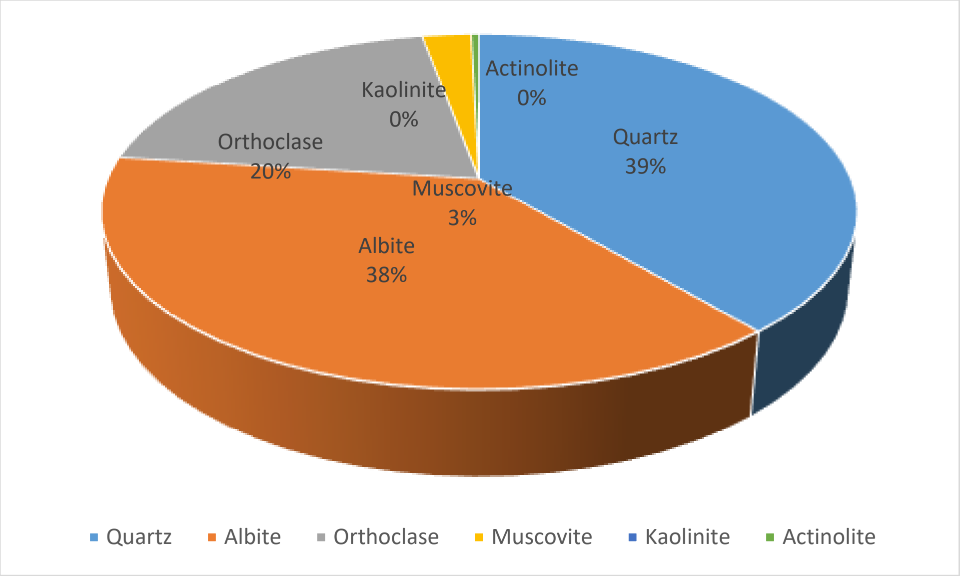


Figure 4-4: Sand River Mineral Composition

According to the results of the mineralogical investigation (Figures 4-3 and 4-4), quartz is the most prevalent mineral. Its concentration varies depending on the distribution of different grain sizes in the sediments, with an average content of 49% at the Nzhelele River and 39% at the Sand River. Orthoclase is scarce; its content ranges from 18% for the Nzhelele River to 20% for the Sand River, showing the sediments' highly developed composition. Albite, the second mineral that is more prevalent in sediments after quartz, exhibits average contents of 30% for Nzhelele River and 30% for Sand River. Other minerals include kaolinite with a 1% content for Nzhelele River Sediments and muscovite with very low amounts (2%) for Nzhelele River and (3%) for Sand River.

Based on the crystalline structural characteristics of the minerals or phases present in a sample, X-ray diffraction (XRD) is used to identify them. As shown in figure 4-5 and 4-6 below, the output is an X-ray diffractogram, which is a plot of angles versus X-ray intensity acquired from the sample. The Cu kα radiation interacting with the sediment's atoms causes constructive interference in the areas of angular space shown in the diffractogram in the figures below. The pattern is measured on the x-axis in units of 2θ, and the diffracted beam's relative intensity is shown on the y-axis.

Red lines indicating the relative intensities of each peak are overlaid on the diffractogram. The coherent scattering's d-spacing identifies the places. According to the XRD study, the principal mineral contents at the Nzhelele River and Sand River deposits are quartz, albite, and orthoclase, while muscovite, kaolinite, and actinolite are minor components.

The second lithogenic mineral found in the examined sand samples was albite. Feldspar's (albite) volumetric composition ranged between 20 and 30%. Albite content in the Nzhelele River was 29.8%, whereas it was 38.2% in the Sand River. Similar to the quartz distribution, Sand River (Figure

4-5 and 4-6) had the highest concentration of feldspar (albite) in the samples, with albite content ranging from 20 to 30% by volume for the two samples.

Most of the examined sand samples had feldspar (orthoclase) contents that ranged from 10 to 20% by volume. Up to 18.1% percent feldspar by volume was found in the Nzhelele River, and 20.1% was found in the Sand River. The mineral that was discovered in small concentration in the sand sample fractions was actinolite, according to the results of the X-ray diffraction examination. No other clay mineral was discovered in the samples than kaolinite. Additionally, the lithogenic sand-dominated sediments showed a general variation in both the quartz and albite content by volume, with higher quartz and albite content in the sediments at Sand River.

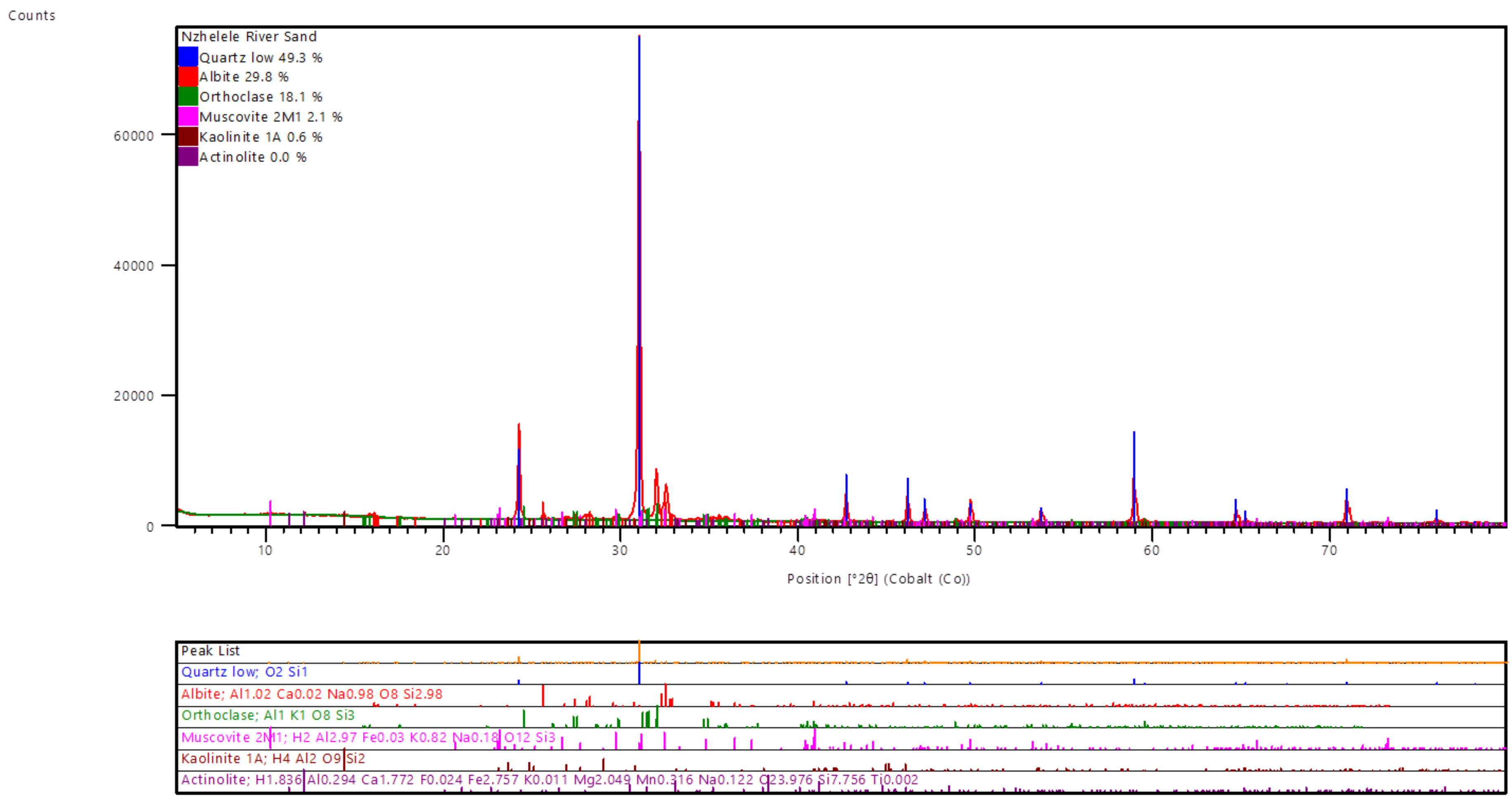


Figure 4-5: Minerals Detection for Nzhelele River Sample

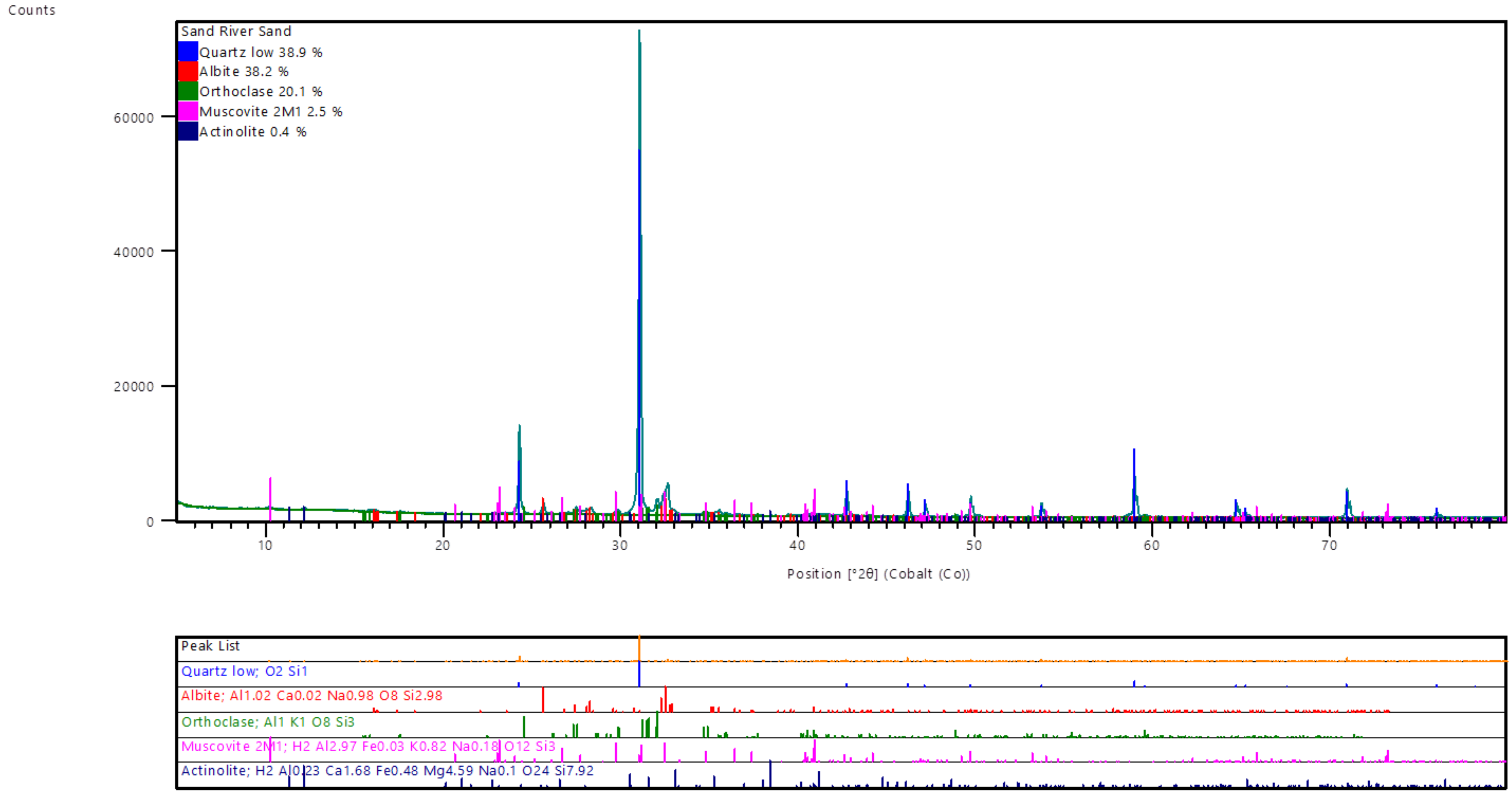


Figure 4-6: Minerals Detection for Sand River Samples

Figure 4-5 and 4-6 above illustrates the XRD spectrum of the sand samples. It can be visualised that XRD analysis enables the identification of several minerals present in the samples. For instance, blue peaks are observed with varying peak positions and intensities, indicating a variety of atomic positions, the size and shape of the quartz unit cell. There is a higher content of quartz detected at Nzhelele River compared to the content of quartz which is 38.9% at Sand River. Quartz is the most important sun-forming mineral because it is resistant to both physical and chemical weathering. Sand that is enriched in Quartz is likely old (mature) and has travelled far from the source area, sometimes thousands of kilometers.

Figure 4-5 and 4-6 plots the intensity vs wavelength of Nzhelele River and Sand River X-rays. While Sand River X-rays have a higher intensity at lower wavelength, Nzhelele River X-rays have a higher magnitude of intensity overall. Nzhelele River X-rays occur at distinct wavelengths while Sand River X-Rays occur almost anywhere and at significantly lower intensities, thereby forming background compared to Nzhelele River. X-ray powder diffractogram peak positions occur where the X-ray beam has been diffracted by the crystal lattice. The unique set of d-spacings derived from this patter can be used to fingerprint the minerals. Preferred orientation is a condition in which the distribution of crystal orientation is non-random, a real problem with powder samples. It is noted that due to preferred orientation several blue peaks are completely missing, and intensity of other blue peaks is very misleading at Nzhelele River. Preferred orientation can substantially alter the appearance of the powder pattern. It is a serious problem in experimental powder diffraction.

It needs to be recognised that the presence of clay minerals in a sediment aggregate has a great influence on the engineering properties of the sediment. When moisture is present, the engineering behaviour of a sediment changes greatly as the percentage of clay mineral content increases. For all practical purposes, when the clay content is about 50% or more, the sand and silt particles float in a clay matrix, and the clay minerals primarily dictate the engineering properties of the sediment.

4.6. Discussion

4.6.1 Particle size Distribution

Numerous studies have shown that many sediments' grain size distributions are close to lognormal. Because many natural sediments contain a wide range of particle sizes, it is practical to use a grade scale or a set of class intervals that are always related to one another. The scale that Krumbein (1934) proposed is the one that sedimentologists use the most frequently. The amount of material available for sedimentation and the natural processes of sedimentation mainly determine the deviations from lognormality among samples, although sampling techniques can also have an impact (Friedman, 1962).

The graph of the sieve analysis demonstrates that the percentage finer curves for the samples taken from the Nzhelele River and Sand River were different. The particle size distribution curve at Nzhelele River and Sand River exhibits a strong gradient between 0.1 mm and 0.2 mm, and a mild gradient between 0.2 mm and 1 mm. According to this data, 80% of the sediment was between 0.1 and 0.2 mm in size, and the remaining 20% was greater than 0.2 mm. The gathered samples were evaluated for both mineralogical composition and grain size in addition to size. A sample weight, weight, and % retained per sieve were the results of the laboratory experiment. Because of the coarse-grained nature of sediments, erosion has a substantial impact. Sand makes up the majority of the sediment, and the Nzhelele River has a high concentration of sand with a sand component of more than 50%. There were also some mixed gravel deposits. The Nzhelele River exhibits the strongest hydrodynamic changes, as evidenced by the fact that the sediment grain sizes were coarser than those of the Sand River.

The categorization and naming of the sediments in the research region were determined using the Shepard Triangle classification method in accordance with the findings of the grain size analysis. There were several different types of sediments in the study area, including clay, very coarse sand, coarse sand, medium sand, and fine sand at Nzhelele River and fine gravel, very fine gravel, very coarse sand, coarse sand, medium sand, fine sand, and very fine sand at Sand River. Of these, gravel, coarse sand, and sand were the most prevalent.

The average grain size (D60) for each stage of the dredging and placement cycle was calculated using the grain size information gathered during the dredging and placement processes. By using the Folk and Ward (1957) equation, the cumulative curves (Appendices B and D) were used to compute the statistical parameters for grain size. The link between particle size (mm) and percentage finer is depicted in Figures 4-1 and 4-2. The majority of the samples that were obtained fall into the category of sediments that are poorly sorted to moderately sorted and range from gravel to coarse sand. According to Angusamy and Rajamanickam (2006), textural characteristics of sediments including mean, sorting, skewness, and kurtosis are frequently utilized to recreate the depositional environment of sediments. These characteristics are displayed in the Table in Appendix A.

More over two-thirds of the river sand is improperly sorted, according to the data in Appendix A. Poor sorting suggests that there hasn't been much grain selection during transport or deposition. A lack of steady energy in either direction, turbulent conditions, or highly fluctuating energy may all contribute to this. The amount of finer particles in Sand River is higher because they traveled a greater distance, but the amount of coarser sediments in Nzhelele River is higher because they traveled a less distance in the watershed. The amount of sand present and its size provide clear clues as to the mode of transit and deposition. While fine sands are transported as Aeolian sands and deposited by suspension, coarse sands are transported as bed loads and deposited through sortation.

4.6.2 Textural parameters

Any grain size distribution curve can be used to calculate a number of textural parameters. The median, mean (Mz), standard deviations (σ1), skewness (SK1), and kurtosis (KG) are the four statistical parameters employed in this research to represent the textural characteristics of the Nzhelele River and Sand River sediments (Appendix A).

4.6.2.1 Mean Grain Size (Mz)

The average size of the river samples as a whole is represented by the mean, which is affected by deposition (Folk, 1966; Udder, 1914). The computed mean values for the Sand River samples range between 0.827Ø and 0.427Ø (coarse sand), with an average value of -0.025Ø (extremely coarse sand) after dry screening. The mean grain size of the Sand River and Nzhelele River samples is shown in Appendix A. In contrast, the Nzhelele River's computed mean values after dry sieving range from 0.387Ø (coarse sand) to 0.003Ø (coarse sand), with a mean value of 0.379Ø (coarse sand) on average. After wet sieving, the computed mean values for the samples from the Sand River vary from -0.721Ø to -0.713Ø (extremely coarse sand), with an average value of -0.175Ø (very coarse sand). In contrast, the Nzhelele River's computed mean values after wet screening range from -0.751Ø (extremely coarse sand) to -0.467Ø (very coarse sand), with an average value of -0.437Ø (very coarse sand). These average values demonstrate that very coarse sand predominates after wet sifting for both the Sand and Nzhelele Rivers and that coarse sand predominates after dry sieving for both rivers. Local variances, ranging from medium- to fine-grained sands, can still be seen in each river. The observed fluctuations in mean grain size are typically caused by instability in the energy conditions during sediment deposition. The fine-grained structure of the material may have revealed the basin's somewhat low energy level at the time of deposition. The sporadic development of medium-grained sand, on the other hand, might be caused by a lack of inputs and an abrupt rise in energy conditions (Frirdman, 1967).

4.6.2.2 Standard Deviations (σ1)

After dry sieving, the Sand River study samples' standard deviation values range from 0.864∅ to 0.829∅ (moderately sorted), with an average value of 0.792∅ (moderately sorted) (Table in Appendix A), while the Nzhelele River standard deviation (Appendix A) ranges from 1.114∅ (poorly sorted) to 1.077∅ (poorly sorted) after dry sieving. After wet sieving, the standard deviation values for the studied samples at Sand River range from 1.051∅ to 1.042∅ (poorly sorted), with an average value of 0.918 (moderately sorted). In contrast, the standard deviation along the study area (Table in Appendix A) ranges from 1.224∅ (poorly sorted) to 1.182∅ (poorly sorted), with an average value of 1.019∅ (poorly sorted) for Nzhelele River. While sediments from the Nzhelele River are poorly sorted, sediments from the Sand River showed moderately to poorly sorted sediments. The majority of the sediments at Sand River were moderately sorted, indicating that they had been transported extensively and had traveled a great distance; in contrast, the sediments at Nzhelele River were poorly sorted, indicating that they had not been transported much. In addition to revealing the energy, velocity, and/or duration of deposition, the degree of sorting may also reveal the mode of conveyance (river, debris, flow, etc.) that was responsible for depositing the sediment. Reworking the material after deposition, for as by winnowing, can also have an impact on sediment sorting. Poorly sorted rocks have low porosity and low permeability, especially when fine-grained, while well-sorted rocks are frequently both porous and permeable. In general, frequent back-and-forth movement or winnowing action by the depositing agent as well as increased incursion of previously sorted sediments in the depositional environment could be the cause of the prevalence of fairly well-sorted sediments (Ramanathan et al. 2009).

4.6.2.3 Graphic Skewness (SK1)

While the Nzhelele River samples' calculated graphic skewness values range from -0.246 (coarse skewed) to -0.127 (coarse skewed), indicating coarse skewed sediments after dry sieving, the Sand River samples' values range from 0.214 (fine skewed) to 0.019 (symmetrical skewed) (Table in Appendix A). The calculated graphic skewness values range from 0.621 (very fine skewed) to 0.150 (fine skewed), indicating very fine skewed to fine skewed sediments in the Sand River samples, whereas they range from 0.417 (very fine skewed) to -0.268 (fine skewed) in the Nzhelele River samples.

The presence of both finer and coarser fractions is demonstrated by the estimated skewness values' range between negative and positive values. The onset of the deposition of fine materials and the removal of coarser components are typically signaled by the existence of near-symmetrical and finely skewed sediments. While the finely skewed sediments indicate much winnowing or longer transportation of the sediments, the near-symmetrical sediments indicate moderate energy conditions in the depositional environment (Duane, 1964). Grain size parameters According to the table in Appendix A, from very finely skewed to finely skewed, over 90% of the river samples from Sand River are skewed. Thus showing that the fine sediment fraction is dominant. However, they are coarsely to finely skewed at the Nzhelele River, demonstrating the predominance of the coarse fraction in the sediments. Indicated by positive numbers is skewness toward smaller grain sizes, while negative values show skewness toward larger grain sizes. Positive skewness results from the efficient unidirectional flow of the transportation agent, whereas negative skewness is brought on by the winnowing operation that eliminates the fine-grained tail of the distribution. Positively skewed curves show deposition, whereas negatively skewed curves suggest erosion or non-depositional locations. A combination of positive and negative skewness indicates an area in a state of flux. This is consistent with Cameron's (1977) claim that the inclusion of finer material causes positive skewness. The studied samples had a tendency to have larger grains, which is a sign that they are marine biogenic sediments. The middle regions of sand samples are better sorted at the tails because they are leptokurtic to mesokurtic in nature. This firmly implies a fluvial or tidal environment, establishing the sands' river-deposited origin.

4.6.2.4 Kurtosis (KG)

A more "peaky" distribution is indicated by a high kurtosis value, which is frequently coupled by a low standard deviation. This is because, by definition, a peakier sample has a higher percentage of the material occupying fewer size classes, which must be closer to the mean size class. The average KG value for the Sand River samples under study ranges from 0.823 (platykurtic) to 1.215 (leptokurtic), falling within the leptokurtic to platykurtic group (Table in Appendix A). The kurtosis along the Nzhelele river is also leptokurtic to platykurtic, ranging from 1.180 (leptokurtic) to 1.173 (leptokurtic), with an average value of 0.897 (platykurtic). A third of the samples had leptokurtic distribution curves, whereas around a quarter have mesokurtic curves, according to the kurtosis scale.

The examined samples' mesokurtic to leptokurtic composition indicates the continuous addition of smaller fractions or materials following the depositing agent's winnowing action and the preservation of their initial or original characteristics during deposition. According to Duane (1964), the predominance of mesokurtic character indicates that the better sorted sediments were laid down by a one-directional flow of current, allowing the sediments to settle in the lower energy environment. The leptokurtic nature of the samples under study also implies variations in the energy circumstances during deposition. The differences in the flow properties of the transportation and depositional medium are the cause of the variations in kurtosis levels. The presence of spherical grains and fine sand-size particles with mesokurtic to platykurtic characteristics indicates the maturity of the sands, which may be the result of the accumulation of fine sand-size materials in the predominately low-energy environment.

4.6.3 Histograms of Grain Size Distribution

All of the examined samples are unimodal in nature, with peaks primarily at 1.0∅ and 0.0∅ (Appendix B), others with a peak at -1.0∅ and -2.0∅, one with a peak at 00∅ and -1.0∅, and the remainder exhibiting a poorly sorted to moderately sorted distribution (Appendix A). This is revealed by the grain size cumulative frequency curves for the analyzed samples. The sediments under study are unimodal, which suggests a regular or constant depositional process during which the sediments were settled. Additionally, the unimodality properties and the occurrence of the majority of peaks at 1.0∅ point to a possible high-energy condition that was roughly uniform in nature during the deposition of the sediments. The cumulative curves' generally wide and gently sloping shape denotes the depositing media's low kinetic energy and velocity domain. Given that the energy of the medium and the sediments' particle sizes are the two fundamental determinants of sediment size, the range of grain sizes (0.5∅ up to 4.0∅) often denotes fine to medium sediments. The sediments' fine-to-medium texture can be linked to the medium's slightly lower energy level and less velocity variance. Likely abundant in the depositional environment is a finer fraction, as shown by the presence of a finely skewed distribution in four of the studied rivers. It can be assumed that widespread uplift or subsidence covering both the source area and depositional area has place since there is no rapid change in grain sizes.

4.6.4 Mineralogy of Sediments

Tables 4–6 give the findings of the semi-quantitative mineralogical examination of the chosen sediment samples (fraction 63 m). The most common mineral is quartz (49.3 and 38.9%), which is followed by various feldspar minerals (Albite (29.8 and 38.3%) and Orthoclase (18.1 and 20.1%), mica minerals (Muscovite, 2.1 and 2.5%), clay minerals (Kaolinite, 0.6%), and less common minerals from the hornblende group (amphibole silicate minerals), such as Actinolite (0.4%). The most prevalent mineral was discovered to be quartz, which made up roughly 49.3% of the sediment in the Nzhelele River sample and 38.9% of the sediment in the Sand River sample. The Nzhelele River's albite concentration was 29.8%, which was lower than the Sand River's level of 38.2%. While orthoclase was 20.1% at Sand River and 18.1% at Nzhelele River, respectively. Kaolinite and actinolite have rather uniform compositions, with average variations of 0.6% and 0.4%, as shown in Tables 4-6. The most common mineral is quartz (49.3 and 38.9%), which is followed by various feldspar minerals (Albite (29.8 and 38.3%) and Orthoclase (18.1 and 20.1%), mica minerals (Muscovite, 2.1 and 2.5%), clay minerals (Kaolinite, 0.6%), and less common minerals from the hornblende group (amphibole silicate minerals), such as Actinolite (0.4%). The most prevalent mineral was discovered to be quartz, which made up roughly 49.3% of the sediment in the Nzhelele River sample and 38.9% of the sediment in the Sand River sample. The Nzhelele River's albite concentration was 29.8%, which was lower than the Sand River's level of 38.2%. While orthoclase was 20.1% at Sand River and 18.1% at Nzhelele River, respectively. Kaolinite and actinolite have rather uniform compositions, with average variations of 0.6% and 0.4%, respectively.

Quartz is the last mineral to crystallize at a lower temperature, according to Bowen's Reaction Series. Additionally, compared to other minerals, quartz has a lower tendency to weather and is the most stable sediment and rock mineral on the earth's surface (Bowen, 2012). These factors lead scientists to conclude that quartz is the most prevalent mineral in river silt. In this situation, quartz is abundant in the majority of river sediments.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Overview of the Study

According to the current study, sediments' various textural traits can provide crucial hints for comprehending both their depositional settings and the mechanisms underlying movement. Based primarily on the information supplied by the grain size distribution curves, mineral composition, log-cumulative curves, and grain size distribution histograms, the current Sand River and Nzhelele River samples have been interpreted. According to the grain size distribution, the Nzhelele River sediments are primarily coarse-grained, weakly sorted, leptokurtic, and platykurtic in character, while the sediments from the Sand River are primarily fine-grained, moderately sorted, mesokurtic, and nearly symmetrical. The sediments' fine-sand makeup indicates that fairly low-energy conditions predominate in the research area. The sediments' well-sorted to moderately-sorted character points to an abrupt winnowing and back and forth migration by the depositing processes. A riverine input and mixing of similar modal fractions may be indicated by the dominance of the nearly symmetrical category. The sediments' unimodal distribution demonstrates the stable depositional process that underwent the deposition of the Sand River and Nzhelele River sediments.

The study's primary goal was successfully met. The demand for sand and gravel, which have long been utilized as aggregates in the construction of buildings and roads, is still growing today. Locally, instream sand mining or sand extraction is done in the Sand River and Nzhelele River.

However, the mineralogical properties of the sand and gravel being extracted are not taken into account by this method of instream sand mining. Sand miners should consider the mineral composition of the sand they extract since it will enable them to determine whether the sand will be strong enough and able to endure harsh weather conditions when utilized for construction. This study was conducted in this context to analyze the properties of the sediment particle size distribution and to ascertain the mineralogical makeup of the sediments in the river basin. Locating the mouths of both rivers during reconnaissance and field surveys was a systematic approach to the investigation.

5.2. Conclusion

Gravel and sand were mixed intricately in the deposits of the Sand and Nzhelele rivers. The main goal of this study was to characterize the sediments of Sand River and Nzhelele River in order to understand the interaction between the rivers' sediments, water flow, and sediment transport. It was discovered that the two rivers' respective grain-size characteristics are gravel, coarse sand, medium sand, fine sand, and very fine sand. Quartz, Albite, Orthoclase, Muscovite, Kaolinite, and Actinolite made up the mineral composition of the Sand River, whereas Quartz, Albite, Orthoclase, Muscovite, and Actinolite made up the Nzhelele River.

The majority of the lithogenic sand-sized sediments, particularly the Quartz, are of angular to sub-angular shape, suggesting that the sediments are texturally immature, meaning that the sediments have not been transported for a long distance before deposition at Sand River. This was revealed by the mineralogical analysis of the sand sediments. Another indication of the sediments' immaturity is the presence of hornblende in them. The majority of the Quartz in the sediments fragmented and occasionally displayed undulatory extinction, indicating that the sediments are made up of a source rock that has undergone extensive metamorphism.

The unimodal grain size distribution, which is indicative of a moderate energy environment at Sand River, shows that medium sand to fine sand predominates. Grain size statistics show that samples are often reasonably well sorted, nearly symmetrically skewed, and mostly have a mesokurtic to leptokurtic distribution. The examined sediments comprised fine gravel and coarse sand, as seen by the particle size distribution charts. The coefficient of curvature (Cc) and sorting values, which were discovered to be below 3 and above 1, respectively, are inconsistent with this. Sediment that is poorly graded and poorly sorted is defined as having a Cc value of less than 3 and a uniformity of coefficient (CU) of less than 2 or 3.

5.3 Recommendations

- Although the study's goals and objectives have been addressed, the researcher advises the use of SWAT model hydrological modeling to measure the effects of land management practices in the study area.
- In order to distinguish between the differences in chemical properties of the sediments from various sediment sources, the researcher also suggests sediment provenance using sediment fingerprint techniques.

6. REFERENCES

Allen, J.D., 2004. Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems. Annual review of ecological and evolutionary systematics 35: 257–284.

Ashmore, P., and Church, M. 2001. The impact of climate change on rivers and river processes in Canada. Geological Survey of Canada: Bulletin 555.

Awal, R., Sapkota, P., Chitrakar, S., Thapa, B.S., and Neopane, B. 2019. A general review on methods of sediment sampling and mineral content analysis. J. Phys: Conf. Se 1266 012005.

Baiyegunhi, C., Liu, K., Gwavava, O. 2017. Grain size statistics and depositional pattern of the Ecca Group sandstones, Karoo Supergroup in the Eastern Cape Province, South Africa. Open Geosci. 9:554‐76.

Bates, B.C., Kundzewicz, Z.W., and Palutiko, J.P. (eds) 2008. Climate change and water. Technical paper of the intergovernmental on climate change. IPCC secretariat: Geneva: pp 210.

Baxter, C.V., and Hauer, F.R. 2000. Geomorphology, hyporheic exchange, and selection of spawning habitat by bull trout (Salvelinus confluentus). *Canadian Journal of Fisheries and Aquatic Sciences,* 57: 1470–1481.

Beusen, A.H.W., Dekkers, A.L.M., Bouwman, A.F., Ludwig, W., and Harrison, J. 2005. Estimation of global river transport of sediments and associated particulate C, N and P. Glob: Biogeochem. 19(4).

Bui, E.N., Mazullo, J., Wilding, LP. 1990. Using quartz size and shape analysis to distinguish between aeolian and fluvial deposits in the Dllot Bosso of Niger (West Africa). Earth Surf Process Landf. 14:157‐66.

Bogaart, P.W., Van Balen, R.T., Kasse, C., and Vandenberghe, J. 2003. Process-based modeling of fluvial system response to rapid climate change: model formulation and generic applications. Quatenary Science Reviews, 22(20):2077–2095.

Bortone, G. 2006. Sediment and Dredged Material Treatment. Amsterdam, the Netherlands: Elsevier Science & Technology.

Black, K.S., Tolhurst, T.J., Paterson, D.M., and Hagerthey, S.E. 2002. Working with natural cohesive sediments, J. Hydraul. Eng., 128, 2–8.

Blott, S.J., Pye, K. 2001. Radistat: A grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surf Process Landf. 26:1237‑48.

Bradley, D.N., and Tucker, G.E. 2012. Measuring gravel transport and dispersion in a mountain river using passive radio tracers. Earth Surface Processes and Landforms. 37(10): 1034-1045.

Caldwell, R.L., and Edmonds, D.A. 2014. The effects of sediment properties on deltaic processes and morphologies: A numerical modeling study, J. Geophys. Res. Earth Surf, 119, 961–982.

Camporeale, C., Perucca, E., Ridolfi, L., and Gurnell, A.M. 2013. Modeling the interactions between river morphodynamics and riparian vegetation, Rev. Geophys., 51, 379–414, doi:10.1002/rog.20014.

Costanza, R., Pérez-Maqueo, O., Martinez, M.L., Sutton, P., Anderson, S.J., and Mulder, K. 2008. The value of coastal wetlands for hurricane protection, AMBIO: A J. Human Environ., 37(4), 241–248.

Chima, P., Baiyegunhi, C., Liu, K., and Gwavava, O. 2018. Petrography, modal composition and tetonic provenance of some selected sand stones from the Molteno, Elliot and Clarens formations, Karoo supergroup, in the Eastern Cape prounce, South Africa. GeoSci, 2008; 10:821-833.

Chowdhury, S. 2009. Bangladesh – Climate Change and Sustainable Development. Washington DC: World Bank, 166.

Csiki, S.J.C., and Rhoads, B.L. 2014. Influence of four run-of-river dams on channel morphology and sediment characteristics in Illinois, USA. Geomorphology, 206: 215‑229.

Czuba, J.A., Magirl, C.S., Czuba, C.R., Grossman, E.E., Curran, C.A., Gendaszek, A.S., and Dinicola, R.S. 2011. August. Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data Sediment Load from Major Rivers into Puget Sound and its Adjacent Waters. USGS, Fact Sheet 3083. Tacoma, WA: U S Geological Survey.

Dai, A. 2013. Increasing drought under global warming in observations and models. National Climate Change. 3(1)52–58.

Dagada, K. 2013. The investigation of long-term changes in evaporation and links to climate changes and land use along Luvuvhu River Catchment, Honours dissertation submitted to the Department of Hydrology and Water Resources at the University of Venda, pp 80.

Daming, L.I., Yangyang, L.I., Zhichao, W., Xiao, W., and Yanging, L.I. 2016. Quantitative, SEM-based shape analysis of sediments particles in the Yellow River. *International Journal of Sediment Research*, 31(4).

Dankers, R., and Feyen, L. 2013. A first look at changes in flood hazard.

De Wit, M., and Stankiewicz, J. 2006. Changes in surface water supply across Africa with predicted climate change. Science, 311(5769):1917–1921.

Dewals, B.J., Rulot, F., Erpicum, S., Archambeau, P., and Pirotton, M. 2010b. "Long-term sediment management for sustainable hydropower." Comprehensive Renewable Energy. Volume 6 - Hydro Power, A. Sayigh, ed., Elsevier, Oxford.

Doney, S.C. 2010. The growing human footprint on coastal and open-ocean biogeochemistry. *Science*, 2010(328): 1512–1516.

Deschamps, J.R., and Flippen-Anderson, J.L. 2002. Crystallography. Encyclopedia of Physical Science and Technology. (pp. 121-153).

Duane D.B. 1964. Significance of skewness in recent sediments, western Pamlico Sound, North Carolina. J Sediment Petrol. 1964; 34(4):864–74.

Duarte, C.M., Borja, A., Carstensen, J., Elliott, M., Krause-Jensen, D., and Marba, N. 2015. Paradigms in the recovery of estuarine and coastal ecosystems. Estuaries Coasts, 38(4): 1202–1212.

Edmonds, D.A. 2012. Restoration sedimentology, Nat. Geosci., 5, 758–759, doi: 10.1038/ngeo1620.

Edmonds, D.A., and Slingerland, R.L. 2010. Significant effect of sediment cohesion on delta morphology, Nat. Geosci., 3(2), 105–109.

Edwards, A.C. 2001 Grain size and sorting in modern beach sands. J Coast Res. 17:38‑52.

EPA. 2012. March. What are Suspended and Bedded Sediments (SABS)? In Water: WARSSS. Retrieved from http://water.epa.gov/scitech/datait/tools/warsss/sabs.cfm.

Fagherazzi, S., Kirwan, M.L., Mudd, S.M., Guntenspergen, G.R., Temmerman, S., D'Alpaos, A., Koppel, J., Rybczyk, J.M., Reyes, E., and Craft, C. 2012. Numerical models of salt marsh evolution:

Ecological, geomorphic, and climatic factors, Rev. Geophys., 50, RG1002, doi: 10.1029/2011RG000359.

Food and Agricultural organization of United Nations. 2004. Drought impact mitigation and prevention in the Limpopo River Basin. [Internet]. Natural Resources Management and Environment Department.

Furbish, D.J., Haff, P.K., Roseberry, J.C., and Schmeeckle, M.W. 2012. A probabilistic description of the bed load sediment flux: 1. Theory. *Journal of Geophysical Research, Earth Surface*, 117(F3): 2003–2012.

Flannigan, M.D., Stocks, B.J., and Wotton, B.M. 2000. Climate change and forest fires. The Science of the Total Environment, 262(3): 221–230.

Florsheim, J.L., Pellerin, B.A., Oh, N.H., Ohara, N., and Bachand, P.A.M. 2011. From deposition to erosion: Spatial and temporal variability of sediment sources, storage, and transport in a small agricultural watershed. Geomorphology, 132(3-4): 272–286.

Francois, M. 2017. River basin development-international encyclopedia of geography, people, the earth, environment and technology.

Frey, P., and Church, M. 2009. "How River Beds Move." Science, 325(5947), 1509-1510.

Gao, H., Bohn, T., Podest, E., McDonald, K., and Lettenmaier, D. 2011. On the causes of the shrinking of Lake Chad. Environ *Research Letters,* 6(03): 034021.

Gee, G.W., and Bauder, J.W. 1986. Particle size analysis. P383-411. In a Klute (ed) Methods of soil analysia part 1, 2nd ed., zArron Monogr. G. ASA-SSSA, Madison, W.L.

Gourgue, O., Comblen, R., Lambrechts, J., Kärnä, T., Legat, V., and Deleersnijder, E. 2009. "A flux-limiting wetting-drying method for finite-element shallow-water models, with application to the Scheldt Estuary." Advances in Water Resources, 32(12), 1726-1739.

Goswami, B., Ghosh, D. 2011. Understanding the transportational and depositional setting of Panchet Formation, Purulia and Bankura districts of West Bengal, India - Evidence from grain size analysis. Front Earth Sci. 5(2):138‑49.

Ghani, A.B A., Zakaria, N.A., Ali, R., Abu, N.A., Hasan, Z., Chang, C.K., and Ahamad, M.S.S. (2010). A Temporal Change Study of the Muda River System over 22 Years. *International Journal of River Basin Management*, IAHR & INBO. Vol. 8, No. 1, 25-37. ISSN: 1571-5124.

Grant, J., Walker, T.R., Hill, P.S., and Lintern, D.G. 2013. BEAST-a portable device for quantification of erosion in intact sediment cores. Methods in oceanography, 5: 39-55.

Hey, R.D., and Thorne, C.R. 1986. Stable channels with mobile gravel beds, J. Hydraul. Eng., 112(8), 671–689.

Hickey, B.M., Kudela, R.M., Nash, J.D., Bruland, K.W., Peterson, W.T., MacCready, P., Lessard, E.J., Jay, D.A., Banas, N.S. & Baptista, A.M., *et al*. 2010. River Influences on Shelf Ecosystems: Introduction and synthesis. *Journal of Geophysical Research*: Oceans 115 (C2).

Hirabayashi, Y., Mahendran, R., Koirala S., Konoshima L., Yamazaki, D., Watanabe, S., Kim, H., and Kanae, S. 2013. Global flood risk under climate change. National Climate Change, 3:816–821.

Hoyal, D. C. J. D., and Sheets, B.A. 2009. Morphodynamic evolution of experimental cohesive deltas, J. Geophys. Res., 114, F02009, doi: 10.1029/2007JF000882.

Huang, H.Q., and Nanson, G.C. 1997. Vegetation and channel variation: A case study of four small streams in southeastern Australia, Geomorphology, 18, 237–249.

Hjulstrom, F. 1935. Studies of the morphological activity of rivers as illustrtated by ther River Fyris, Bulletin. Geological Institute Upsalsa, 25, 221-527

Jeffrey R. Deschamps, and Judith L. Flippen-Anderson 2002. Encyclopedia of Physical Science and Technology (Third Edition).

Jones, J.B., and Mulholland, P.J. (eds). 2000. Streams and Ground Waters. Academic Press: San Diego.

Kim, W. 2012. Geomorphology: Flood-built land, Nat. Geosci., 5(8), 521–522.

Kim, W., Dai, A., Muto, T., and Parker, G. 2009a. Delta progradation driven by an advancing sediment source: Coupled theory and experiment describing the evolution of elongated deltas, Water Resour. Res., 45, W06428, doi: 10.1029/2008WR007382.

Kim, W., Mohrig, D., Twilley, R., Paola, C., and Parker, G. 2009b. is it feasible to build new land in the Mississippi River delta? Eos Trans. AGU, 90(42), 373–374, doi: 10.1029/2009EO420001.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Doll, P., Kabat, P., Jimenez, B., Miller, K.A., Oki, T., Sen, Z., and Shiklomanov, I.A. 2007. Freshwater resources and their management. In: Parry, M., Canziani, O., Palutikof, J., van der Linden, P. & Hanson, C. (eds). Climate Change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press, 173–210.

Knight, J., and Harrison, S. 2013. The impacts of climate change on terrestrial Earth surface systems. National Climate Change, 3(1):24–29.

Kjellesvig, H.M. 2002. Dam Safety–The Passage of Floods that Exceed the Design Flood. Dr.ing.thesis:84. Norwegian University of Science and Technology, Trondheim.

Lamb, M., and Fonstad, M. 2010. Rapid formation of a modern bedrock canyon by a single flood event. National Geoscience, 3:477–481.
Liu. Z., Colin. C., Li. X., Zhao. Y., Tuo. S., Chen. Z., et al. 2010. Clay mineral distribution in surface sediments of the northeastern South China Sea and surrounding fluvial drainage basins: source and transport. *Marine Geology,* 277(1-4), 48–60.

Lopez, G.I. 2017. Grain Size Analysis. In: Gilbert, A.S. (eds) Encyclopedia of Geoarchaelogy. Encyclopedia of Earth Science Series. Springer, Dordrecht.

Martin. Y., and Church. M. 2004. Numerical modelling of landscape evolution: geomorphological perspectives. Progress in Physical Geography, 28(3), 317-339.

McNally, W.H., and Mehta, A.J. 2004. Sediment Transport and Deposition in Estuaries (Sample Chapter). In Encyclopedia of Life Support Systesm (EOLSS): Coastal Zones and Estuaries.

Milner, A.M., Robertson, A.L., McDermott, M.J., Klaar, M.J., and Brown, L.E. 2013. Major flood disturbance alters river ecosystem evolution. *National Climate Change*, 3:137–141.

Minshall, G.W., Thomas, S.A., Newbold, J.D., Monaghan, M.T., and Cushing, C.E. 2000. Physical factors influencing fine organic particle transport and deposition in streams. *Journal of the North American Benthological Society*, 19(1): 1–16.

Missouri, D.N.R. 2009. Chapter 3: Stream Discharge. In Introductory Level Volunteer Water Quality Monitoring Training Notebook.

Montgomery. D.R., Zabowski. D., Ugolini. F.C., Hallberg. R.O., and Spaltenstein. H. 2000. Sediments, watershed processes, and marine sediments. International Geophysics, 72: 159‐194.

Mudd, S.M., Howell, S.M., and Morris, J.T. 2010, Impact of dynamic feedbacks between sedimentation, sea-level rise, and biomass production on near-surface marsh stratigraphy and carbon accumulation, Estuarine Coastal Shelf Sci., 82(3), 377–389.

Murphy, S. 2007. General Information on Solids. In City of Boulder: USGS Water Quality Monitoring. Retrieved from http://bcn.boulder.co.us/basin/data/NEW/info/TSS.html.

Musselman, Z.A., and Tarbox, A.M. 2013. Downstream Trends in Grain Size, Angularity, and Sorting of Channel-Bed and Bank Deposits in a Coastal Sand-Bed River: the Pascagoula River System, Mississippi, USA. Southeastern Geographer, 53(2), 177-197

Nearing, M.A. 2001. Potential changes in rainfall erosivity in the US with climate change during the 21st century. *Journal of Sediment and Water Conservation*, 56(3): 229–232.

Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nicholas, M.H., Nunes, J.P., Renschler, C.S., Souchere, K., and Van Oost, K. 2005. Modeling response of sediment erosion and runoff to changes in precipitation and cover. *Catena*, 61(2-3): 131–154.

Nepf, H.M. 1999. Drag, turbulence, and diffusion in flow through emergent vegetation, Water Resour. Res., 35(2), 479–489.

Nicholls, R.J., and Mimura, N. 1998. Regional issues raised by sea-level rise and their policy implications, Clim. Res., 11(1), 5–18.

Nittrouer, J.A., Best, J.L., Brantley, C., Cash, R.W., Czapiga, M., Kumar, P., and Parker, G. 2012a. Mitigating land loss in coastal Louisiana by controlled diversion of Mississippi River sand, Nat. Geosci., 5, 534–537, doi: 10.1038/ngeo1525.

Nittrouer, J.A., Shaw, J., Lamb, M.P., and Mohrig, D. 2012b. Spatial and temporal trends for water-flow velocity and bed-material sediment transport in the lower Mississippi River, Geol. Soc. Am. Bull., 124(3–4), 400–414.

Odiyo J.O., and Makungo R. 2012. Fluoride concentrations in groundwater and impact on human health in Siloam Village, Limpopo Province, South Africa. Water SA, 38, 731–736.

Packman, A.I., Brooks, N.H., and Morgan, J.J. 2000. A physicochemical model for colloid exchange between a stream and a sand streambed with bed forms. Water Resources Research, 36(8): 2351–2361.

Packman, A.I., Brooks, N.H., and Morgan, J.J. 2000. Kaolinite exchange between a stream and streambed: laboratory experiments and evaluation of a colloid transport model. Water Resources Research 36(8): 2363–2372.

Packman, A.I., and Brooks, N.H. 2001. Hyporheic exchange of solutes and colloids with moving bed forms. Water Resources Research, 37(10): 2591–2605.

Packman, A.I., and MacKay, J.S. 2003. Interplay of stream–subsurface exchange, clay particle deposition, and stream bed evolution. Water Resources Research, 39(4).

Paola, C., Twilley, R.R., Edmonds, D.A., Kim, W., Mohrig, D., Parker, G., Viparelli, E., and Voller, V.R. 2011. Natural processes in delta restoration: Application to the Mississippi Delta, Annu. Rev. Mar. Sci., 3, 67–91, doi: 10.1146/annurev-marine-120709-142856.

Papanicolaou, A.N., Elhakeem, M., Krallis, G., Prakash, S., and Edinger, J. 2008. Sediment transport modeling review—current and future developments. *Journal of Hydraulic Engineering*, 134(1): 1-14.

Parsons, A.J., Cooper, J., and Wainwright, J. 2015. What is suspended sediment? Earth Surface Processes Landforms, 40(10): 1417–1420.

Pidwirny, M. 2008. Physical Geography Website. Accessed at http://physicalgeography.net. Accessed on 5 March 2019.

Phillips, J.D. 2003. Sources of nonlinearity and complexity in geomorphic systems. Progress in Physical Geography, 27:1–23.

Phillips, J.D., 2009. Changes, perturbations, and responses in geomorphic systems. Progress in Physical Geography, 33:17–30.

Ramanathan, A.L., Rajkumar, K., Majumdar, J., Singh, G., Behera, P.N., Santra, S.C, et al. 2009. Textural characteristics of the surface sediments of a tropical mangrove Sundarban ecosystem. India Indian Journ Mar Sci. 2009; 38(4):397–403.

Rabindra, H. 2013. Granulometric analysis of Ib River Sediments near Sundargarh, Odisha.

Ren, J., and Packman, A.I. 2002. Effects of particle size and background water composition on stream–subsurface exchange of colloids. *Journal of Civil and Environmental Engineering*, 128(7): 624–634.

Righetti, M., and Lucarelli, C. 2007. May the Shields theory be extended to cohesive and adhesive benthic sediments? Journal of Geophysical Research 112: doi: 10. 1029/2006JC003669. Issn: 0148-0227.

Roseberry, J. C., Schmeeckle, M. W., and Furbish, D. J. 2012. A probabilistic description of the bed load sediment flux: 2. Particle activity and motions. Journal of Geophysical Research: Earth Surface, 117(F3).

Samuel, O.O., and Akinade, S.O. 2017. Depositional environments signatures, maturity and source weathering of Niger Delta sediments from an oil well in Southeastern Delta State, Nigeria. J. Soil Sci 2017, 6(3) 259-274.

Surian, N. 2002. Downstream Variation in Grain Size along the Alpine River: Analysis of controls and processes. Geomorphology. 43(1-2):137-149.

Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankersf, R., Eisnerg, S., Feketeh, B.M., Colón-Gonzálezi, F.J., et al, 2013. Multimodel assessment of water scarcity under climate change. Proceedings of the National Academy of Science.

Shrestha, P. 2010. Climate change impact on river dynamics of the Bagmati Basin, Kathmandu, Nepal. Report Submitted to National Adaptation Program of Action (NAPA) to Climate Change Project, Government of Nepal.

Srivastava, A.K., Ingle, PS., Lunge, H.S., and Khare, N. 2012. Grain-size characteristics of deposits derived from different glaciogenic environments of the Schirmacher Oasis, East Antarctica. Geologos. 18(4):251‐66.

Stanley-Wood, N., Lines, R.W. 1992. Particle size analysis. Cambridge: Royal Society of Chemistry, Special Publication; p. 101‐3.

Syvitski, J.P., Vörösmarty, C.J., Kettner, A.J., and Green, P. 2005. Impact of humans on the flux of terrestrial sediment to the global coastal ocean. *Science*, 308(5720): 376-380, doi:10.1126/science.1109454.

The University of Arizona. 2009. HWR203 Arizona Water Issues (PowerPoint). In SAHRA. Retrieved from http://web.sahra.arizona.edu/education2/azwater/docs/lesson9/Hwr203FlowCalcs_ho.pdf.

Trenberth, K.E. 2012. Framing the Way to Relate Climate Extremes to Climate Change. Climate Change, 115(2):283-290.

UNEP, 2008. Africa: Atlas of our Changing Environment. Division of Early Warning and Assessment (DEWA). United Nations Environmental Program, Nairobi, Kenya.

Valance, A., Rasmussen, K. R., El Moctar, A. O., and Dupont, P. 2015. The physics of Aeolian sand transport. *Comptes Rendus Physique*, 16(1): 105-117.

Van Eerdt, M. M. 1985. The influence of vegetation on erosion and accretion in salt marshes of the Oosterschelde, The Netherlands, Vegetatio, 62(1–3), 367–373.

Van De Wiel, M.J., Coulthard, T.J., Macklin, M.G., and Lewin, J. 2011. Modelling the response of river systems to environmental change: progress, problems, and prospects for palaeo-environmental reconstructions. Earth Science Review, 104(1-3):167–185.

Van Rijn, L.C. 1993. Principles of Sediment Transport in Rivers, Estuaries and Coastal Seas, Part 2.

Vörösmarty, C.J., Green, P., Salisbury, J., and Lammers, B.B. 2000. Global water resources: vulnerability from climate change and population growth. *Science*, 289(5477):284–288.

Wampler, P.J. 2012. Rivers and streams- Water and sediments in motion. Nature Education Knowledge 3(10):18

Wolanski, E., Andutta, F. P., and Delhez, E. 2012. Estuarine hydrology. *In*: *Encyclopedia of Lakes and Reservoirs.* Lars Bengtsson, Reginald Herschy, Rhodes Fairbridge (eds.), Springer, in press.

Wilcock, P., Pitlick, J., and Cui, Y. 2009. Sediment Transport Primer: Estimating Bed-Material Transport in Gravel-bed Rivers. General Technical Report. Fort Collins, CO. U S Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Winterwerp, C.J., and Van Kesteren, G.M.W. 2004. Introduction to the Physics of Cohesive Sediment Dynamics in the Marine Environment. Elsevier, Amsterdam.

Wright, L. D. 1977. Sediment transport and deposition at river mouths: A synthesis, Geol. Soc. Am. Bull., 88(6), 857–868.

Yang, D., Kanae, S., Oki, T., and Musiake, K. 2003. Global potential sediment erosion with reference to land use and climate changes. Hydrological Processes, 17(14):2913–2928.

Zaimes, G., and Emanuel, R. 2006. Stream processes Part I - Basic. Arizona Watershed Stewardship Guide.

Zolezzi, G., Luchi, R., and Tubino, M. 2012. Modeling morphodynamic processes in meandering rivers with spatial width variations, Rev. Geophys., 50, RG4005, doi: 10.1029/2012RG000392.

Zhang, G., Germaine, J.T., Martin, T.R., and Whittle, A. 2003. A simple sampling-mounting method for random powder x-ray diffraction, 51(2):218-225

http://www.dnaindia.com/india/1437236/report-is-river-indus-changing-its-course-after-pak-floods. (Accessed on July 25, 2021).

7. APPENDICES

Sieve Analysis Procedure

After selection of the parameters, the actual sieving process started. The following steps were carried out in a chronological order:

1. Putting together a sieve stack with collecting pan.
2. Selecting sieving aids, if required: for mesh sizes < 500µm the use of cubes, chains or brushes is recommended to facilitate passage of the sample
3. Determining the empty weight of sieves and collecting pan: This was done through software-based or manually by using a balance. Suitable programs such as Easy Sieve make weighing and evaluation much easier.
4. Placing the sieve stack with increasing mesh size on the collecting pan
5. Weighing the sample and putting it on the top sieve (biggest mesh size); clamp sieve stack on the machine
6. Setting the amplitude / speed and sieving time on the sieve shaker
7. Started the sieve shaker
8. When the sieving time has expired, the researcher weighed each sieve and the collecting pan with the fraction on it
9. Determined the mass and percentage of each fraction
10. Evaluation

Hydrometer Analysis Procedure:

1. Weighed out 50 g of air-dry < 2 mm sediment (100 g in case of very sandy sediment) into a 400 ml beaker.
2. Saturated the sediment with distilled water and added 10 ml of 10% Calgon solution. The mixture was set aside for 10 minutes.
3. Transferred the suspension to the dispersing cup and distilled water was poured up to the mark in the cup as shown in figure 3-6.
4. Mixed the suspension for 2 minutes with an electric high-speed stirrer. The suspension was shaken with reciprocating shaker.
5. Transferred the suspension into a graduated cylinder and rinsed the remaining sediment into the cylinder with distilled water. Inserted the hydrometer into the suspension and added water to 1130 ml, and then removed the hydrometer.
6. Covered the cylinder with a tight-fitting rubber bung and mix the suspension by inverting the cylinder carefully ten (10) times. Note the time.
7. Quickly added 2 - 3 drops of amyl alcohol to the sediment suspension to remove froth and after 20 seconds place the hydrometer gently into the column.

8. At 40 seconds, the researcher took a hydrometer reading and measured the temperature of the suspension.

9. Repeated step 6 (mixing of the sediment suspension 10 times) and allowed the cylinder to stand undisturbed for 2 hours. After two hours, the researcher took both hydrometer and temperature readings.

10. Made the necessary temperature corrections (Table 3-1). Temperature affected the hydrometer readings. Since the hydrometer has been calibrated at 68^{0}F (20^{0}C), either correction factors were applied, or the determination conducted in a temperature-controlled room kept at the correct temperature.

Temperature Correction for Hydrometer Readings of Sediment Texture

Temperature (°C)	15	16	17	18	19	20	21	22	23	24	25
Hydrometer Correction (g per litre)	-2.0	-1.5	-1.0	-1.0	+0.5	Nil	+0.5	+1.0	+1.0	+1.5	+2.0

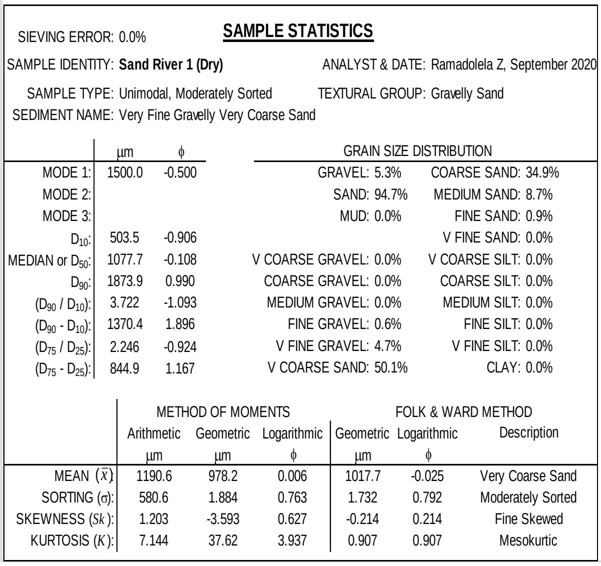
Procedural notes:

1. Cylinders for particle size analysis are calibrated depending upon the volume of the hydrometer in use. At NARC Muguga, the calibration is 1130 ml, indicating the final volume of the sediment suspension with the hydrometer inserted.

2. Many laboratories have developed their own temperature conversion tables depending on the exact procedure and working conditions.

Appendix A: Grain Size Parameters

(a) Sand River 1



SIEVING ERROR: 0.0%

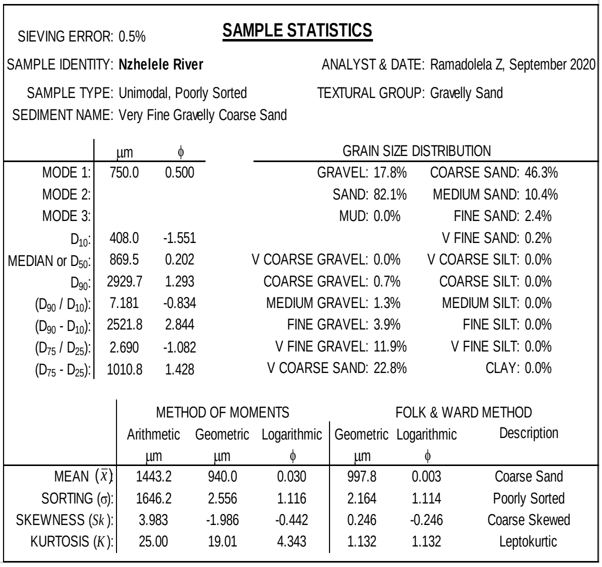
SAMPLE STATISTICS

SAMPLE IDENTITY: **Sand River 1 (Dry)**
ANALYST & DATE: Ramadolela Z, September 2020
SAMPLE TYPE: Unimodal, Moderately Sorted
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	1500.0	-0.500	GRAVEL:	5.3%	COARSE SAND:	34.9%
MODE 2:			SAND:	94.7%	MEDIUM SAND:	8.7%
MODE 3:			MUD:	0.0%	FINE SAND:	0.9%
D_{10}:	503.5	-0.906			V FINE SAND:	0.0%
MEDIAN or D_{50}:	1077.7	-0.108	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	1873.9	0.990	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	3.722	-1.093	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	1370.4	1.896	FINE GRAVEL:	0.6%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.246	-0.924	V FINE GRAVEL:	4.7%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	844.9	1.167	V COARSE SAND:	50.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN $(\bar{x})$:	1190.6	978.2	0.006	1017.7	-0.025	Very Coarse Sand
SORTING (σ):	580.6	1.884	0.763	1.732	0.792	Moderately Sorted
SKEWNESS (Sk):	1.203	-3.593	0.627	-0.214	0.214	Fine Skewed
KURTOSIS (K):	7.144	37.62	3.937	0.907	0.907	Mesokurtic

(b) Nzhelele River



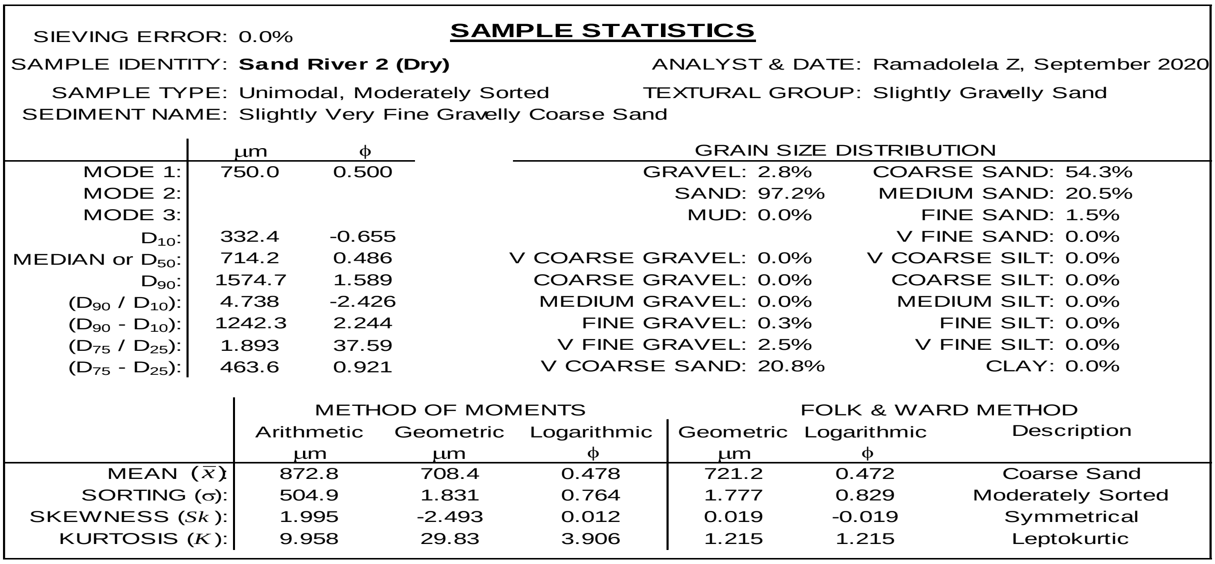
SIEVING ERROR: 0.5%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Nzhelele River**
ANALYST & DATE: Ramadolela Z, September 2020
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	750.0	0.500	GRAVEL:	17.8%	COARSE SAND:	46.3%
MODE 2:			SAND:	82.1%	MEDIUM SAND:	10.4%
MODE 3:			MUD:	0.0%	FINE SAND:	2.4%
D_{10}:	408.0	-1.551			V FINE SAND:	0.2%
MEDIAN or D_{50}:	869.5	0.202	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	2929.7	1.293	COARSE GRAVEL:	0.7%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	7.181	-0.834	MEDIUM GRAVEL:	1.3%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2521.8	2.844	FINE GRAVEL:	3.9%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.690	-1.082	V FINE GRAVEL:	11.9%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1010.8	1.428	V COARSE SAND:	22.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN $(\bar{x})$:	1443.2	940.0	0.030	997.8	0.003	Coarse Sand
SORTING (σ):	1646.2	2.556	1.116	2.164	1.114	Poorly Sorted
SKEWNESS (Sk):	3.983	-1.986	-0.442	0.246	-0.246	Coarse Skewed
KURTOSIS (K):	25.00	19.01	4.343	1.132	1.132	Leptokurtic



SIEVING ERROR: 0.0%

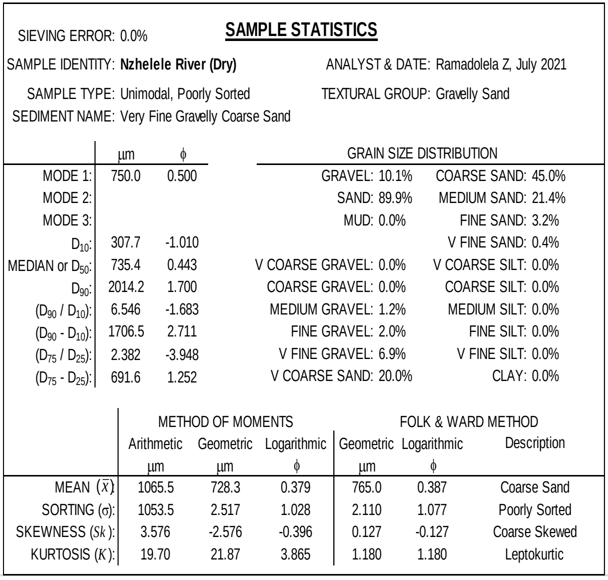
SAMPLE STATISTICS

SAMPLE IDENTITY: **Sand River 2 (Dry)**
ANALYST & DATE: Ramadolela Z, September 2020
SAMPLE TYPE: Unimodal, Moderately Sorted
TEXTURAL GROUP: Slightly Gravelly Sand
SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	750.0	0.500	GRAVEL:	2.8%	COARSE SAND:	54.3%
MODE 2:			SAND:	97.2%	MEDIUM SAND:	20.5%
MODE 3:			MUD:	0.0%	FINE SAND:	1.5%
D_{10}:	332.4	-0.655			V FINE SAND:	0.0%
MEDIAN or D_{50}:	714.2	0.486	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	1574.7	1.589	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	4.738	-2.426	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	1242.3	2.244	FINE GRAVEL:	0.3%	FINE SILT:	0.0%
(D_{75} / D_{25}):	1.893	37.59	V FINE GRAVEL:	2.5%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	463.6	0.921	V COARSE SAND:	20.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN $(\bar{x})$:	872.8	708.4	0.478	721.2	0.472	Coarse Sand
SORTING (σ):	504.9	1.831	0.764	1.777	0.829	Moderately Sorted
SKEWNESS (Sk):	1.995	-2.493	0.012	0.019	-0.019	Symmetrical
KURTOSIS (K):	9.958	29.83	3.906	1.215	1.215	Leptokurtic

(a) Nzhelele River



SIEVING ERROR: 0.0%

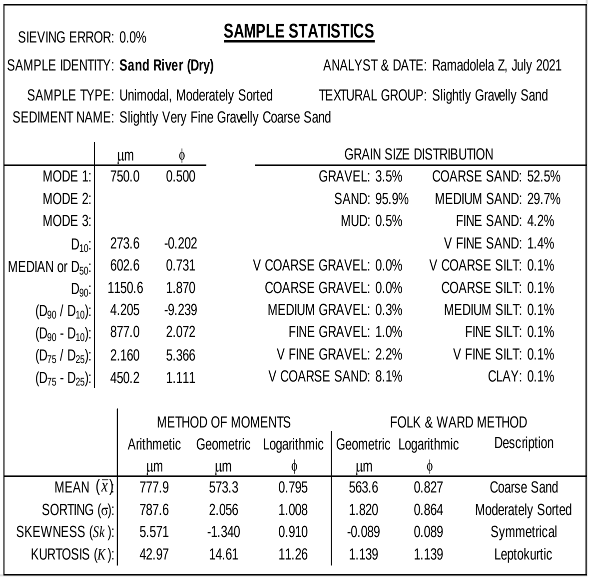
SAMPLE STATISTICS

SAMPLE IDENTITY: **Nzhelele River (Dry)**
ANALYST & DATE: Ramadolela Z, July 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	750.0	0.500	GRAVEL:	10.1%	COARSE SAND:	45.0%
MODE 2:			SAND:	89.9%	MEDIUM SAND:	21.4%
MODE 3:			MUD:	0.0%	FINE SAND:	3.2%
D_{10}:	307.7	-1.010			V FINE SAND:	0.4%
MEDIAN or D_{50}:	735.4	0.443	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	2014.2	1.700	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	6.546	-1.683	MEDIUM GRAVEL:	1.2%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	1706.5	2.711	FINE GRAVEL:	2.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.382	-3.948	V FINE GRAVEL:	6.9%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	691.6	1.252	V COARSE SAND:	20.0%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN $(\bar{x})$:	1065.5	728.3	0.379	765.0	0.387	Coarse Sand
SORTING (σ):	1053.5	2.517	1.028	2.110	1.077	Poorly Sorted
SKEWNESS (Sk):	3.576	-2.576	-0.396	0.127	-0.127	Coarse Skewed
KURTOSIS (K):	19.70	21.87	3.865	1.180	1.180	Leptokurtic

(b) Sand River



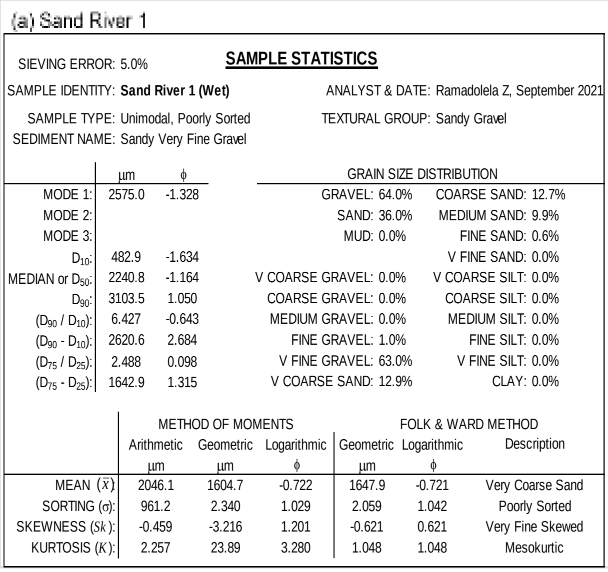
SIEVING ERROR: 0.0%

SAMPLE STATISTICS

SAMPLE IDENTITY: **Sand River (Dry)**
ANALYST & DATE: Ramadolela Z, July 2021
SAMPLE TYPE: Unimodal, Moderately Sorted
TEXTURAL GROUP: Slightly Gravelly Sand
SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	750.0	0.500	GRAVEL:	3.5%	COARSE SAND:	52.5%
MODE 2:			SAND:	95.9%	MEDIUM SAND:	29.7%
MODE 3:			MUD:	0.5%	FINE SAND:	4.2%
D_{10}:	273.6	-0.202			V FINE SAND:	1.4%
MEDIAN or D_{50}:	602.6	0.731	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.1%
D_{90}:	1150.6	1.870	COARSE GRAVEL:	0.0%	COARSE SILT:	0.1%
(D_{90} / D_{10}):	4.205	-9.239	MEDIUM GRAVEL:	0.3%	MEDIUM SILT:	0.1%
$(D_{90} - D_{10})$:	877.0	2.072	FINE GRAVEL:	1.0%	FINE SILT:	0.1%
(D_{75} / D_{25}):	2.160	5.366	V FINE GRAVEL:	2.2%	V FINE SILT:	0.1%
$(D_{75} - D_{25})$:	450.2	1.111	V COARSE SAND:	8.1%	CLAY:	0.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN $(\bar{x})$:	777.9	573.3	0.795	563.6	0.827	Coarse Sand
SORTING (σ):	787.6	2.056	1.008	1.820	0.864	Moderately Sorted
SKEWNESS (Sk):	5.571	-1.340	0.910	-0.089	0.089	Symmetrical
KURTOSIS (K):	42.97	14.61	11.26	1.139	1.139	Leptokurtic



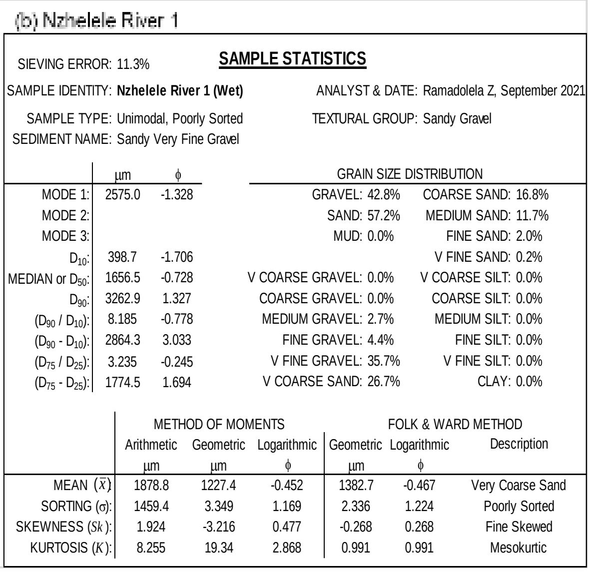
(a) Sand River 1

SAMPLE STATISTICS

SIEVING ERROR: 5.0%
SAMPLE IDENTITY: **Sand River 1 (Wet)**
ANALYST & DATE: Ramadolela Z, September 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	64.0%	COARSE SAND:	12.7%
MODE 2:			SAND:	36.0%	MEDIUM SAND:	9.9%
MODE 3:			MUD:	0.0%	FINE SAND:	0.6%
D_{10}:	482.9	-1.634			V FINE SAND:	0.0%
MEDIAN or D_{50}:	2240.8	-1.164	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	3103.5	1.050	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	6.427	-0.643	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2620.6	2.684	FINE GRAVEL:	1.0%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.488	0.098	V FINE GRAVEL:	63.0%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1642.9	1.315	V COARSE SAND:	12.9%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	2046.1	1604.7	-0.722	1647.9	-0.721	Very Coarse Sand
SORTING (σ):	961.2	2.340	1.029	2.059	1.042	Poorly Sorted
SKEWNESS (Sk):	-0.459	-3.216	1.201	-0.621	0.621	Very Fine Skewed
KURTOSIS (K):	2.257	23.89	3.280	1.048	1.048	Mesokurtic



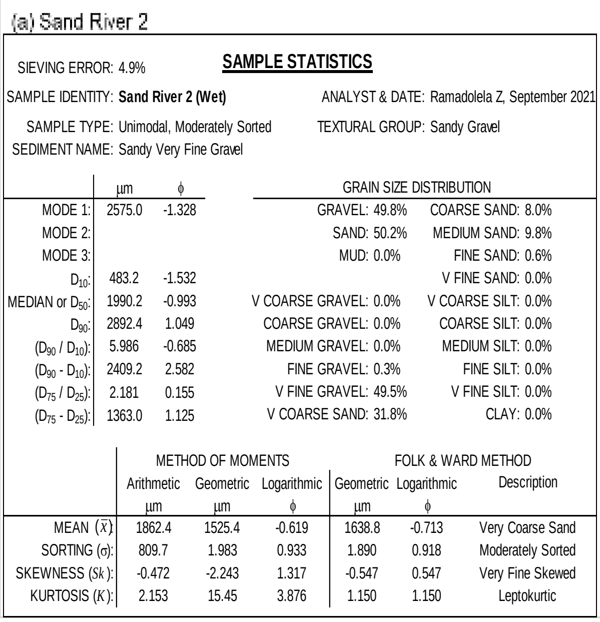
(b) Nzhelele River 1

SAMPLE STATISTICS

SIEVING ERROR: 11.3%
SAMPLE IDENTITY: **Nzhelele River 1 (Wet)**
ANALYST & DATE: Ramadolela Z, September 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	42.8%	COARSE SAND:	16.8%
MODE 2:			SAND:	57.2%	MEDIUM SAND:	11.7%
MODE 3:			MUD:	0.0%	FINE SAND:	2.0%
D_{10}:	398.7	-1.706			V FINE SAND:	0.2%
MEDIAN or D_{50}:	1656.5	-0.728	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	3262.9	1.327	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	8.185	-0.778	MEDIUM GRAVEL:	2.7%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2864.3	3.033	FINE GRAVEL:	4.4%	FINE SILT:	0.0%
(D_{75} / D_{25}):	3.235	-0.245	V FINE GRAVEL:	35.7%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1774.5	1.694	V COARSE SAND:	26.7%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	1878.8	1227.4	-0.452	1382.7	-0.467	Very Coarse Sand
SORTING (σ):	1459.4	3.349	1.169	2.336	1.224	Poorly Sorted
SKEWNESS (Sk):	1.924	-3.216	0.477	-0.268	0.268	Fine Skewed
KURTOSIS (K):	8.255	19.34	2.868	0.991	0.991	Mesokurtic



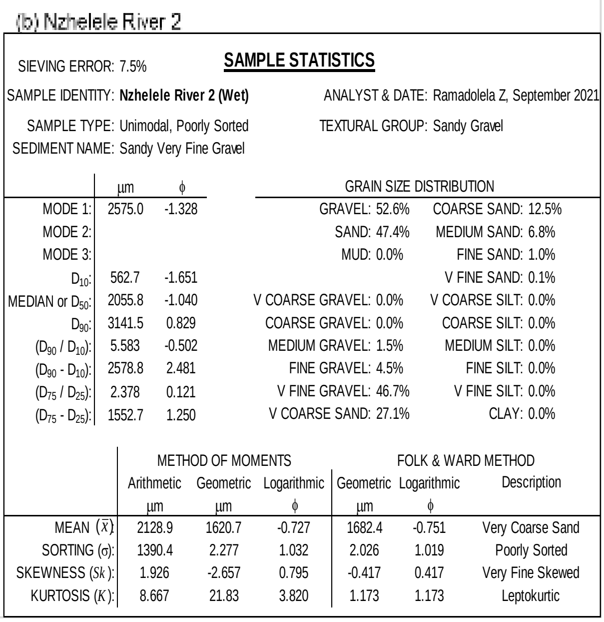
(a) Sand River 2

SAMPLE STATISTICS

SIEVING ERROR: 4.9%
SAMPLE IDENTITY: **Sand River 2 (Wet)**
ANALYST & DATE: Ramadolela Z, September 2021
SAMPLE TYPE: Unimodal, Moderately Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	49.8%	COARSE SAND:	8.0%
MODE 2:			SAND:	50.2%	MEDIUM SAND:	9.8%
MODE 3:			MUD:	0.0%	FINE SAND:	0.6%
D_{10}:	483.2	-1.532			V FINE SAND:	0.0%
MEDIAN or D_{50}:	1990.2	-0.993	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	2892.4	1.049	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	5.986	-0.685	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2409.2	2.582	FINE GRAVEL:	0.3%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.181	0.155	V FINE GRAVEL:	49.5%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1363.0	1.125	V COARSE SAND:	31.8%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	1862.4	1525.4	-0.619	1638.8	-0.713	Very Coarse Sand
SORTING (σ):	809.7	1.983	0.933	1.890	0.918	Moderately Sorted
SKEWNESS (Sk):	-0.472	-2.243	1.317	-0.547	0.547	Very Fine Skewed
KURTOSIS (K):	2.153	15.45	3.876	1.150	1.150	Leptokurtic



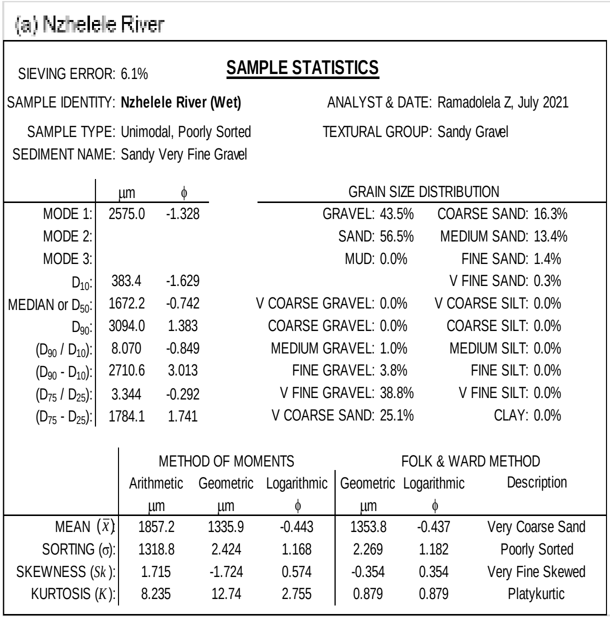
(b) Nzhelele River 2

SAMPLE STATISTICS

SIEVING ERROR: 7.5%
SAMPLE IDENTITY: **Nzhelele River 2 (Wet)**
ANALYST & DATE: Ramadolela Z, September 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	52.6%	COARSE SAND:	12.5%
MODE 2:			SAND:	47.4%	MEDIUM SAND:	6.8%
MODE 3:			MUD:	0.0%	FINE SAND:	1.0%
D_{10}:	562.7	-1.651			V FINE SAND:	0.1%
MEDIAN or D_{50}:	2055.8	-1.040	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	3141.5	0.829	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	5.583	-0.502	MEDIUM GRAVEL:	1.5%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2578.8	2.481	FINE GRAVEL:	4.5%	FINE SILT:	0.0%
(D_{75} / D_{25}):	2.378	0.121	V FINE GRAVEL:	46.7%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1552.7	1.250	V COARSE SAND:	27.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	2128.9	1620.7	-0.727	1682.4	-0.751	Very Coarse Sand
SORTING (σ):	1390.4	2.277	1.032	2.026	1.019	Poorly Sorted
SKEWNESS (Sk):	1.926	-2.657	0.795	-0.417	0.417	Very Fine Skewed
KURTOSIS (K):	8.667	21.83	3.820	1.173	1.173	Leptokurtic



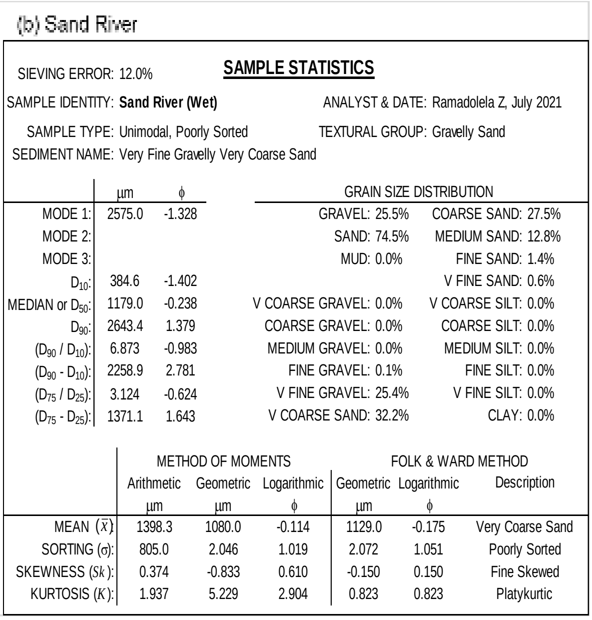
(a) Nzhelele River

SAMPLE STATISTICS

SIEVING ERROR: 6.1%
SAMPLE IDENTITY: **Nzhelele River (Wet)**
ANALYST & DATE: Ramadolela Z, July 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	43.5%	COARSE SAND:	16.3%
MODE 2:			SAND:	56.5%	MEDIUM SAND:	13.4%
MODE 3:			MUD:	0.0%	FINE SAND:	1.4%
D_{10}:	383.4	-1.629			V FINE SAND:	0.3%
MEDIAN or D_{50}:	1672.2	-0.742	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	3094.0	1.383	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	8.070	-0.849	MEDIUM GRAVEL:	1.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2710.6	3.013	FINE GRAVEL:	3.8%	FINE SILT:	0.0%
(D_{75} / D_{25}):	3.344	-0.292	V FINE GRAVEL:	38.8%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1784.1	1.741	V COARSE SAND:	25.1%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	1857.2	1335.9	-0.443	1353.8	-0.437	Very Coarse Sand
SORTING (σ):	1318.8	2.424	1.168	2.269	1.182	Poorly Sorted
SKEWNESS (Sk):	1.715	-1.724	0.574	-0.354	0.354	Very Fine Skewed
KURTOSIS (K):	8.235	12.74	2.755	0.879	0.879	Platykurtic



(b) Sand River

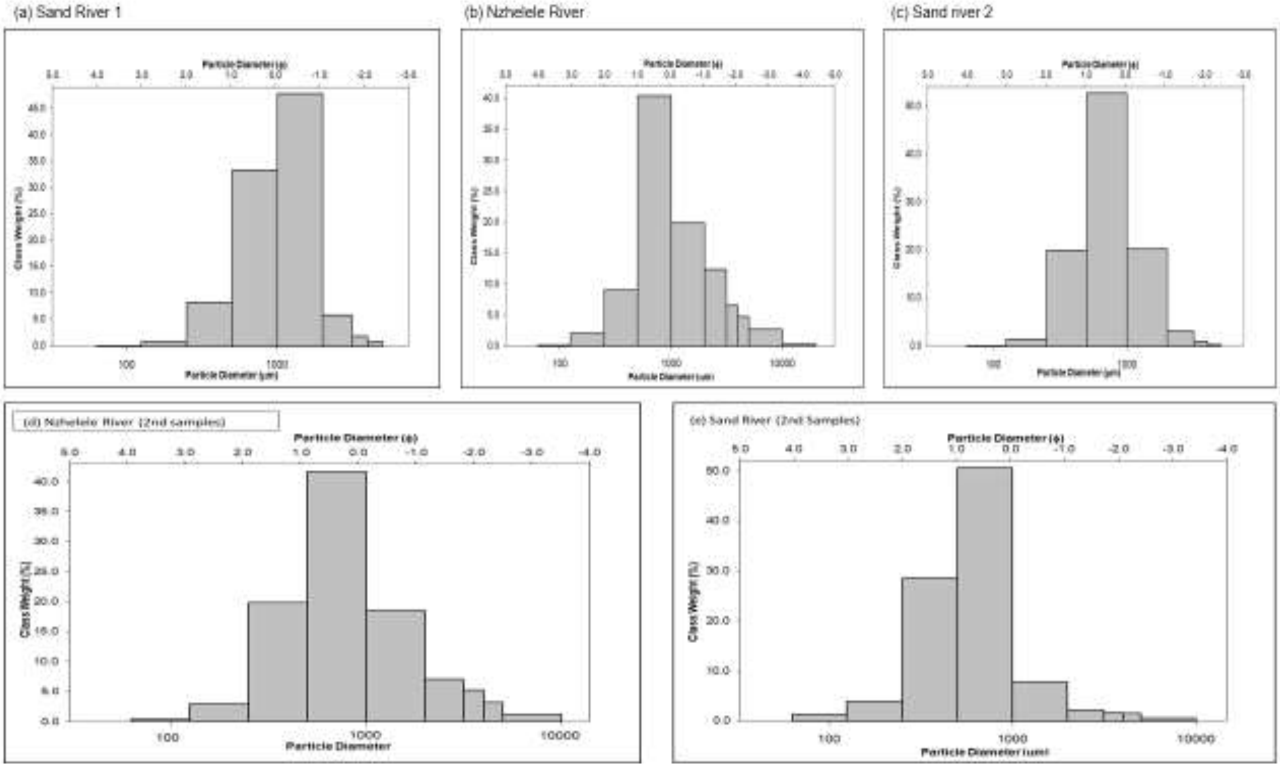
SAMPLE STATISTICS

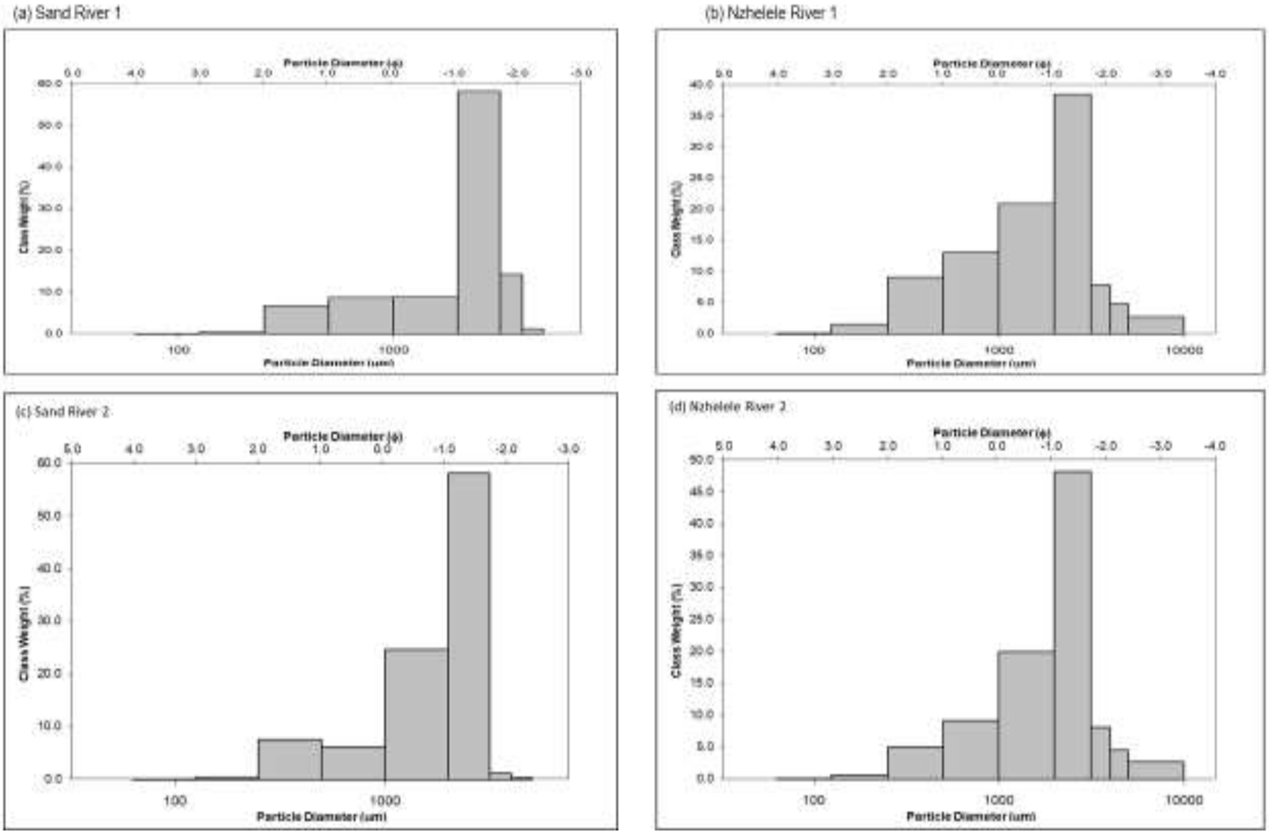
SIEVING ERROR: 12.0%
SAMPLE IDENTITY: **Sand River (Wet)**
ANALYST & DATE: Ramadolela Z, July 2021
SAMPLE TYPE: Unimodal, Poorly Sorted
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

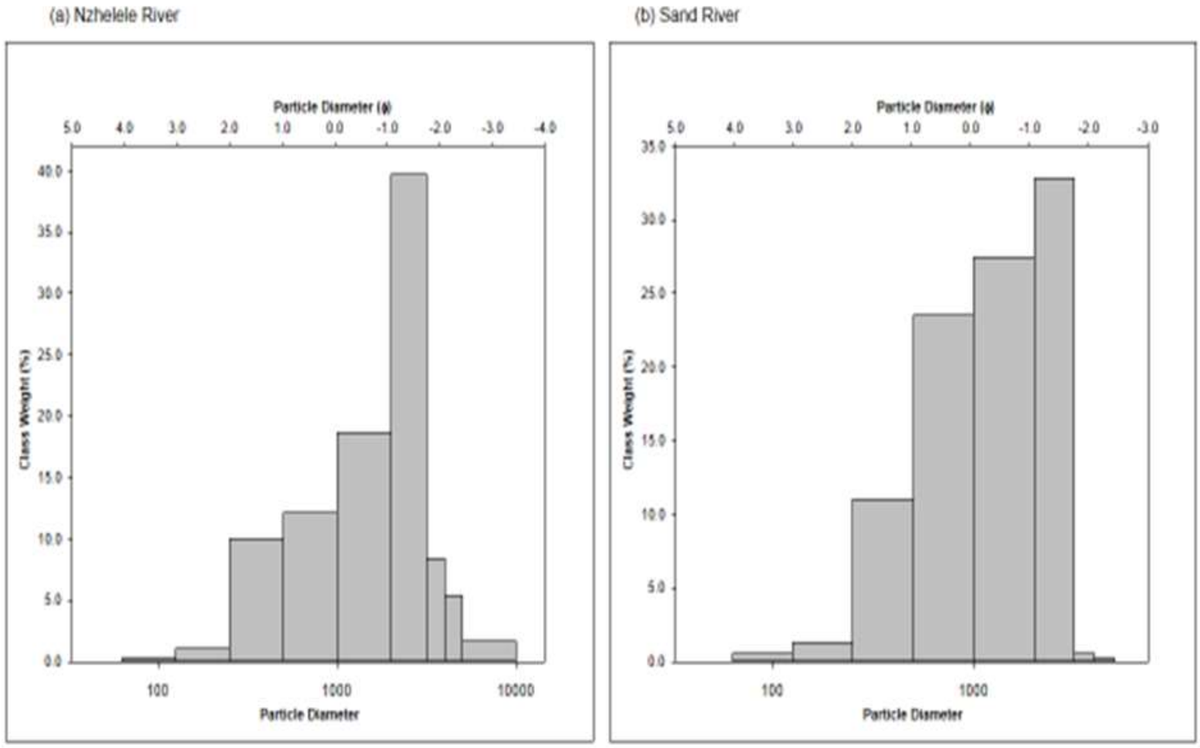
	μm	ϕ	GRAIN SIZE DISTRIBUTION			
MODE 1:	2575.0	-1.328	GRAVEL:	25.5%	COARSE SAND:	27.5%
MODE 2:			SAND:	74.5%	MEDIUM SAND:	12.8%
MODE 3:			MUD:	0.0%	FINE SAND:	1.4%
D_{10}:	384.6	-1.402			V FINE SAND:	0.6%
MEDIAN or D_{50}:	1179.0	-0.238	V COARSE GRAVEL:	0.0%	V COARSE SILT:	0.0%
D_{90}:	2643.4	1.379	COARSE GRAVEL:	0.0%	COARSE SILT:	0.0%
(D_{90} / D_{10}):	6.873	-0.983	MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	0.0%
$(D_{90} - D_{10})$:	2258.9	2.781	FINE GRAVEL:	0.1%	FINE SILT:	0.0%
(D_{75} / D_{25}):	3.124	-0.624	V FINE GRAVEL:	25.4%	V FINE SILT:	0.0%
$(D_{75} - D_{25})$:	1371.1	1.643	V COARSE SAND:	32.2%	CLAY:	0.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic	Geometric	Logarithmic	Geometric	Logarithmic	Description
	μm	μm	ϕ	μm	ϕ	
MEAN $(\bar{x})$:	1398.3	1080.0	-0.114	1129.0	-0.175	Very Coarse Sand
SORTING (σ):	805.0	2.046	1.019	2.072	1.051	Poorly Sorted
SKEWNESS (Sk):	0.374	-0.833	0.610	-0.150	0.150	Fine Skewed
KURTOSIS (K):	1.937	5.229	2.904	0.823	0.823	Platykurtic

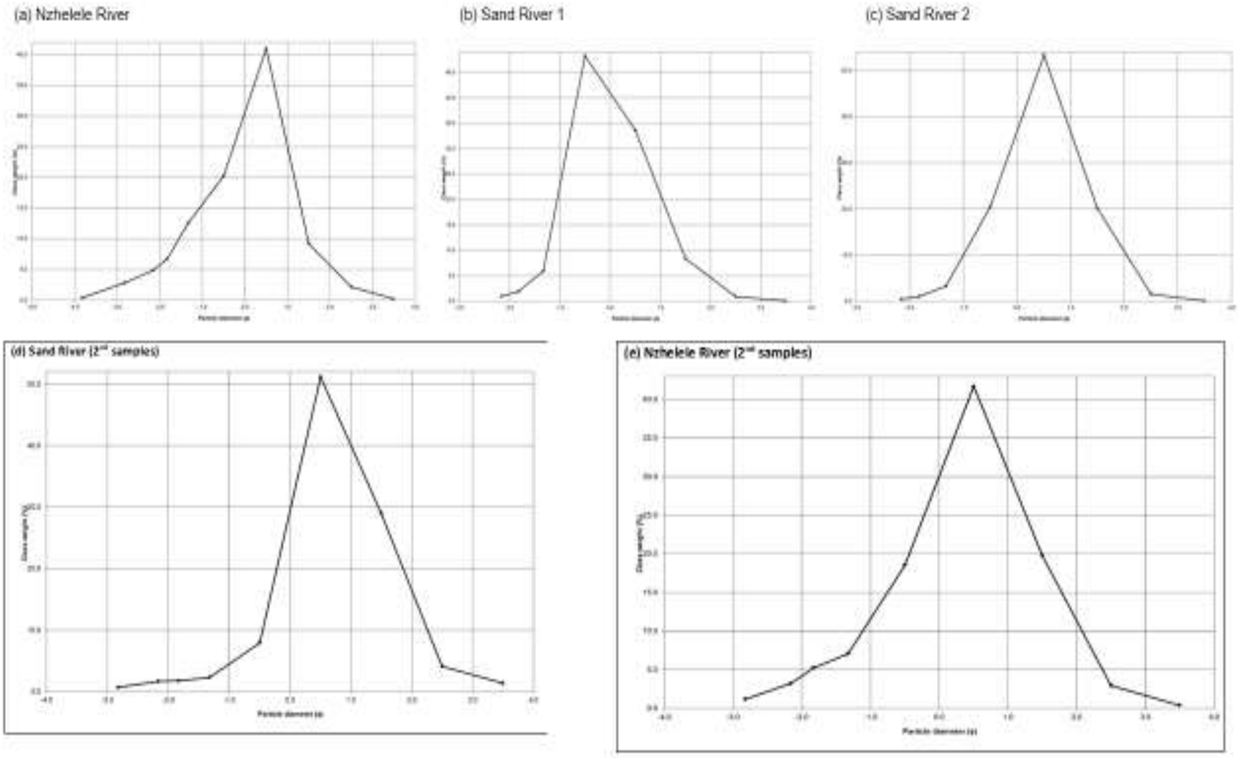
Appendix B: Grain Size Distribution Histograms


(a) Sand River 1
(b) Nzhelele River
(c) Sand river 2
(d) Nzhelele River (2nd samples)
(e) Sand River (2nd Samples)
Particle Diameter (φ)
Class Weight (%)
Particle Diameter (um)
Particle Diameter
100
1000
10000


(a) Sand River 1
(b) Nzhelele River 1
(c) Sand River 2
(d) Nzhelele River 2
Particle Diameter (φ)
Class Weight (%)
Particle Diameter (um)
100
1000
10000



Appendix C: Distribution (phi) curves



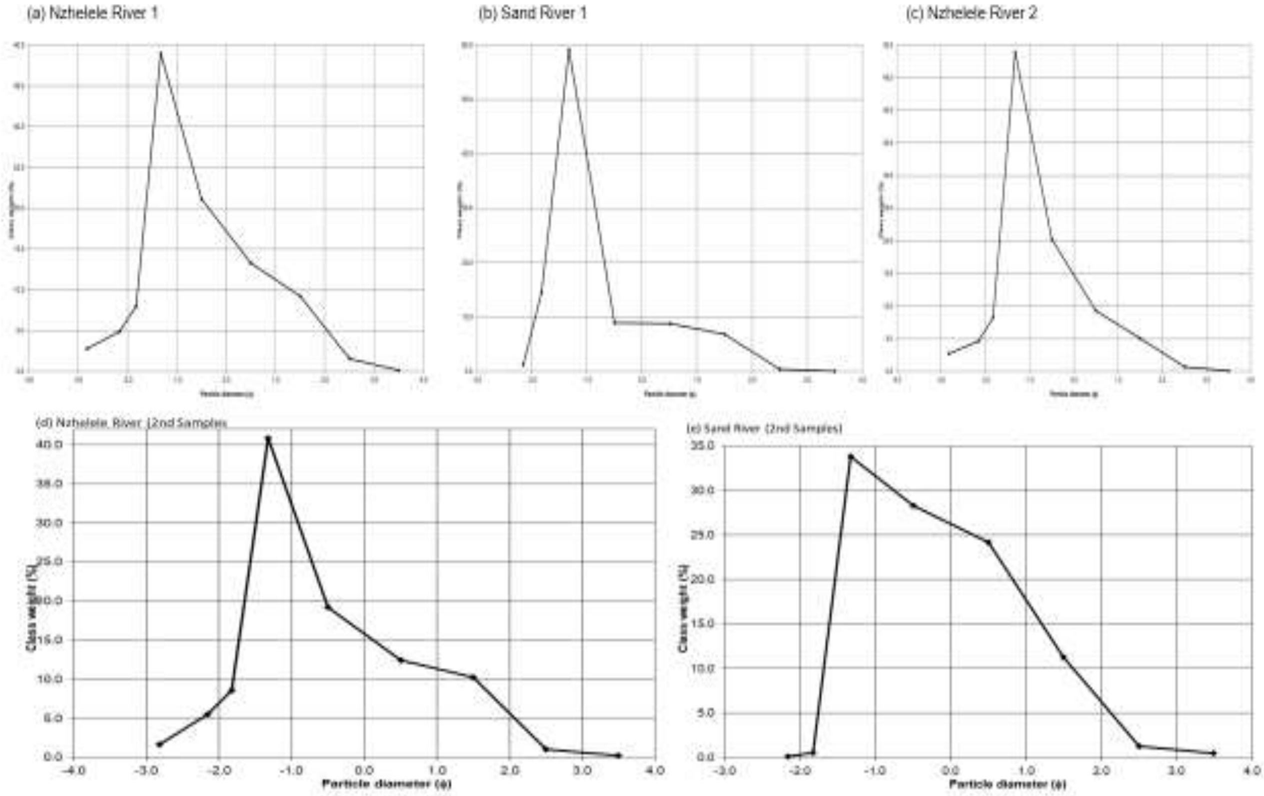
(a) Nzhelele River

(b) Sand River 1

(c) Sand River 2

(d) Sand River (2nd samples)

(e) Nzhelele River (2nd samples)



(a) Nzhelele River 1

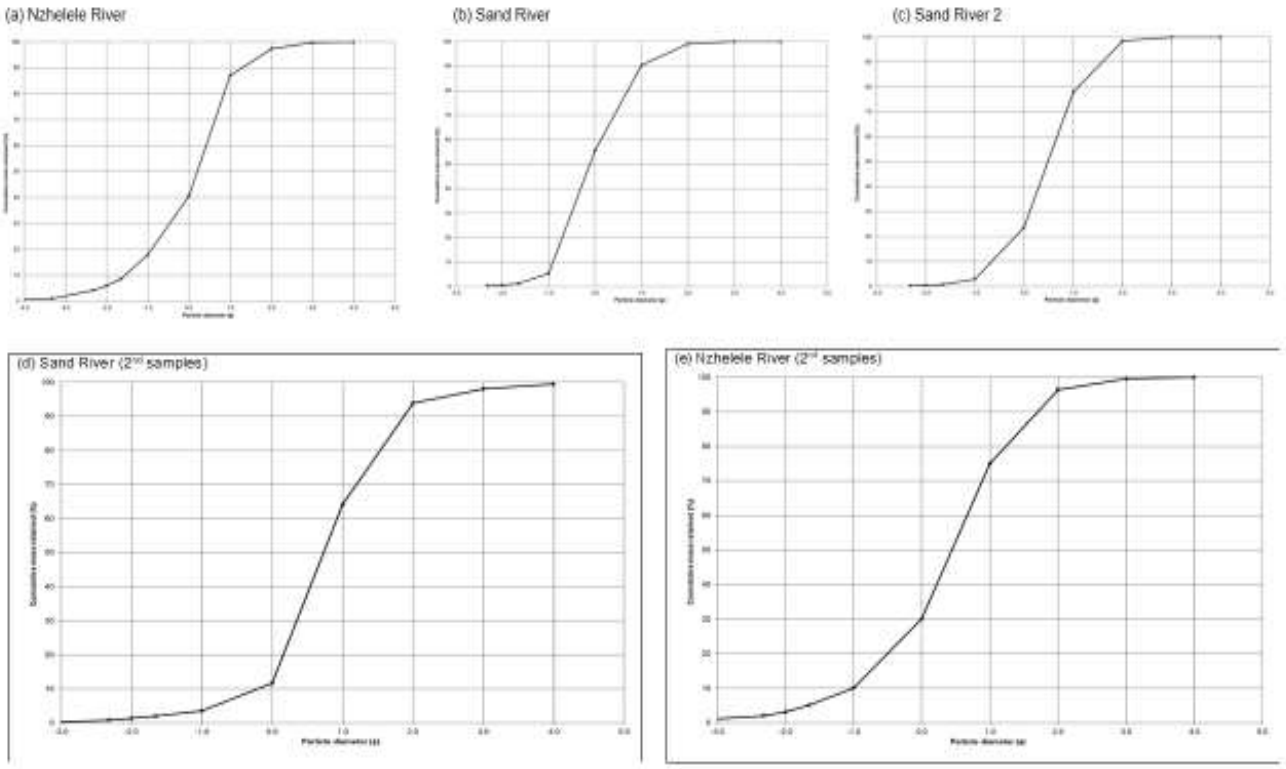
(b) Sand River 1

(c) Nzhelele River 2

(d) Nzhelele River (2nd Samples)

(e) Sand River (2nd Samples)

Appendix D: Cumulative (phi) Curves



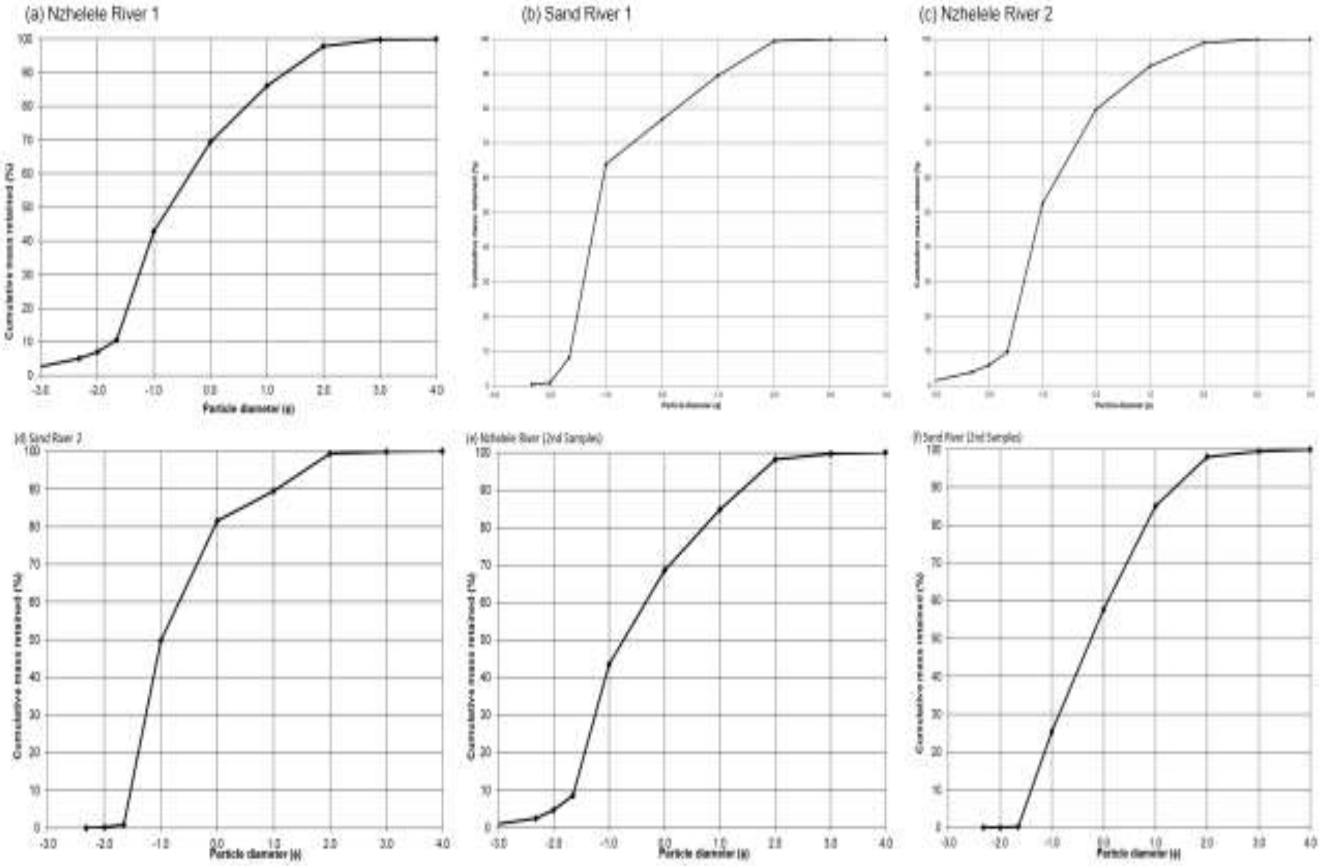
(a) Nzhelele River

(b) Sand River

(c) Sand River 2

(d) Sand River (2nd samples)

(e) Nzhelele River (2nd samples)



(a) Nzhelele River 1

(b) Sand River 1

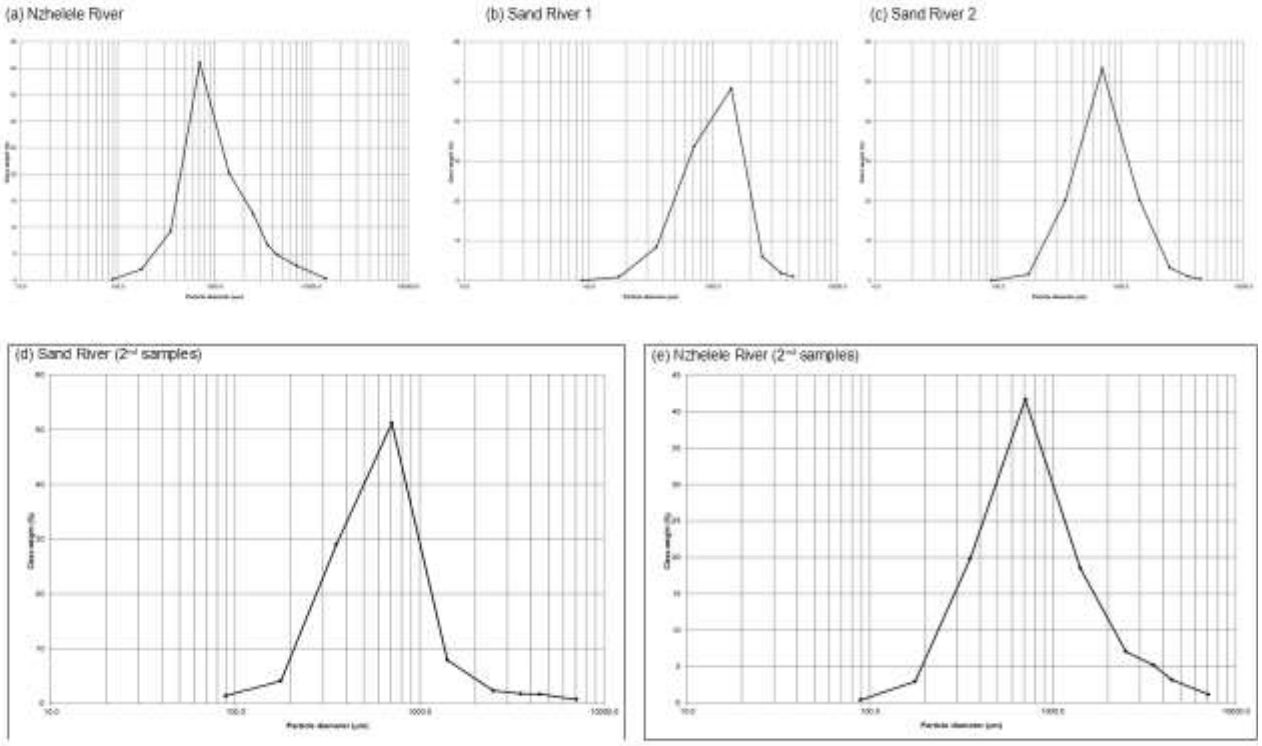
(c) Nzhelele River 2

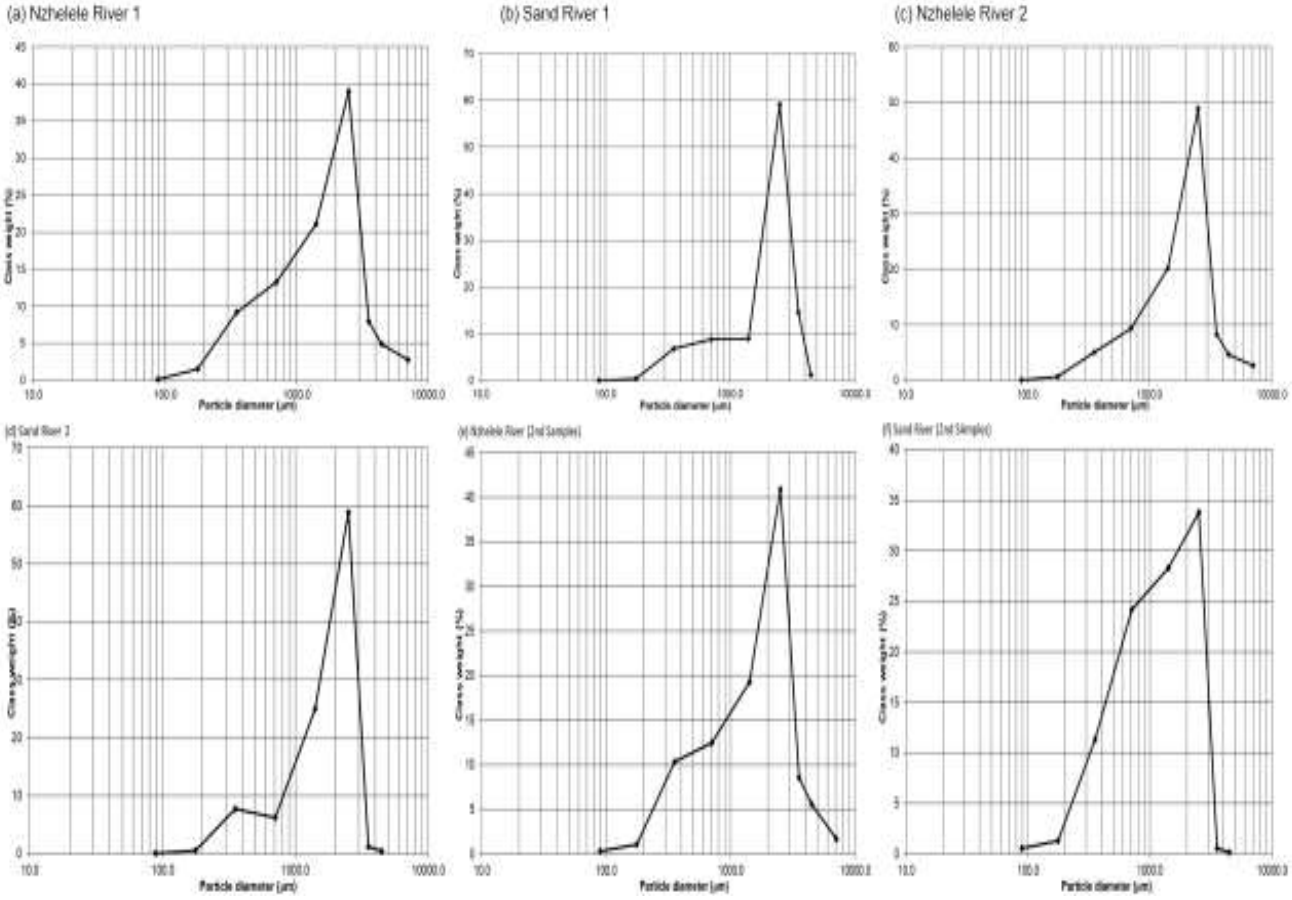
(d) Sand River 2

(e) Nzhelele River (2nd Samples)

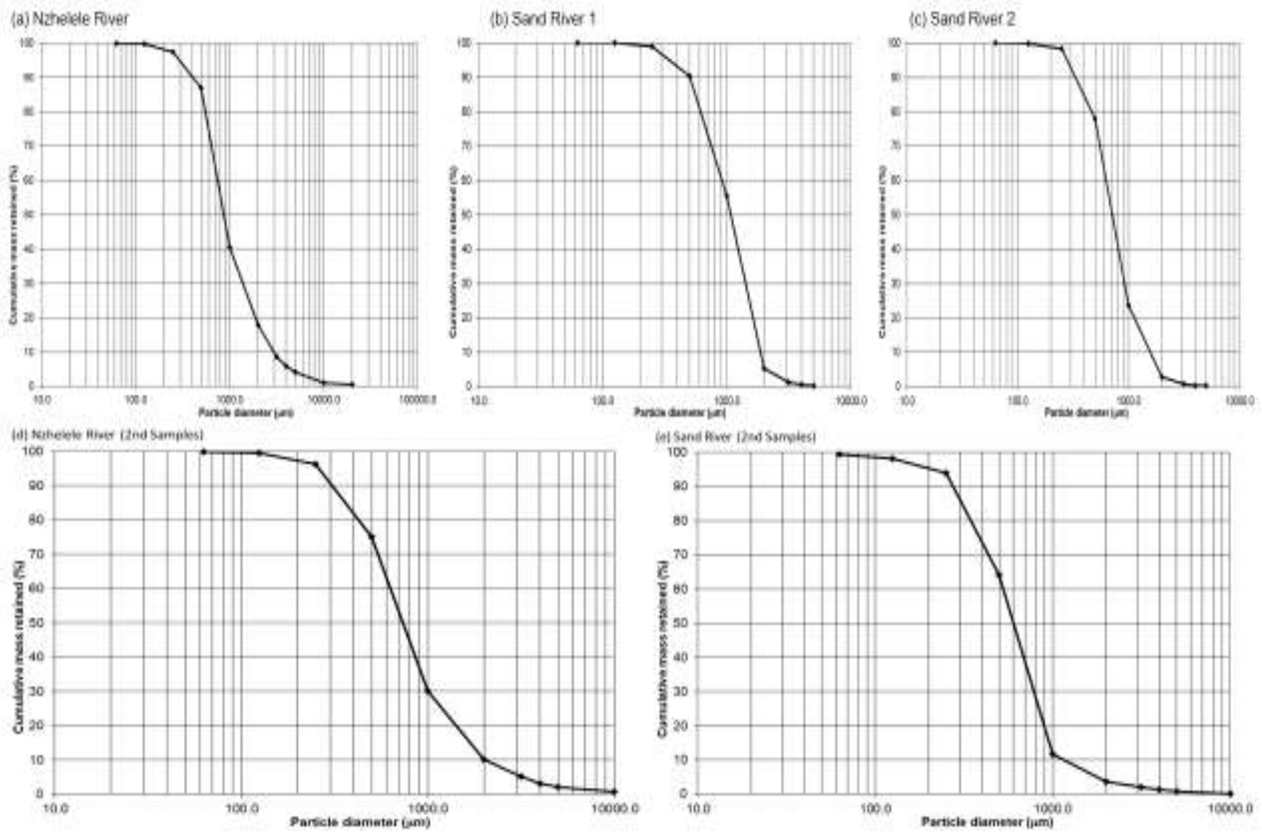
(f) Sand River (2nd Samples)

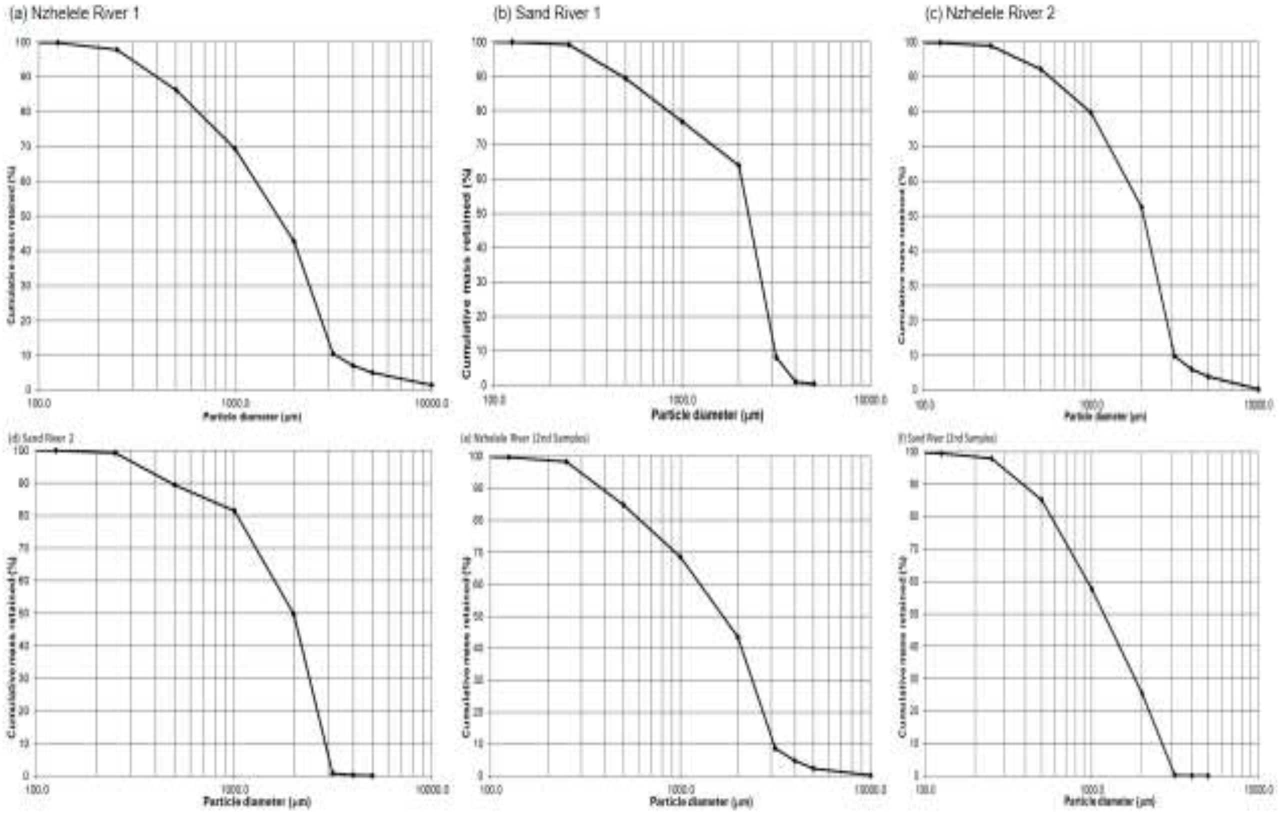
Appendix E: Distribution (Microns) Curves


(a) Nzhelele River
(b) Sand River 1
(c) Sand River 2
(d) Sand River (2nd samples)
(e) Nzhelele River (2nd samples)
Class weight (%)
Particle diameter (µm)
10.0
100.0
1000.0
10000.0


(a) Nzhelele River 1
(b) Sand River 1
(c) Nzhelele River 2
(d) Sand River 2
(e) Nzhelele River (2nd Samples)
(f) Sand River (2nd Samples)
Class weight (%)
Particle diameter (µm)
10.0
100.0
1000.0
10000.0

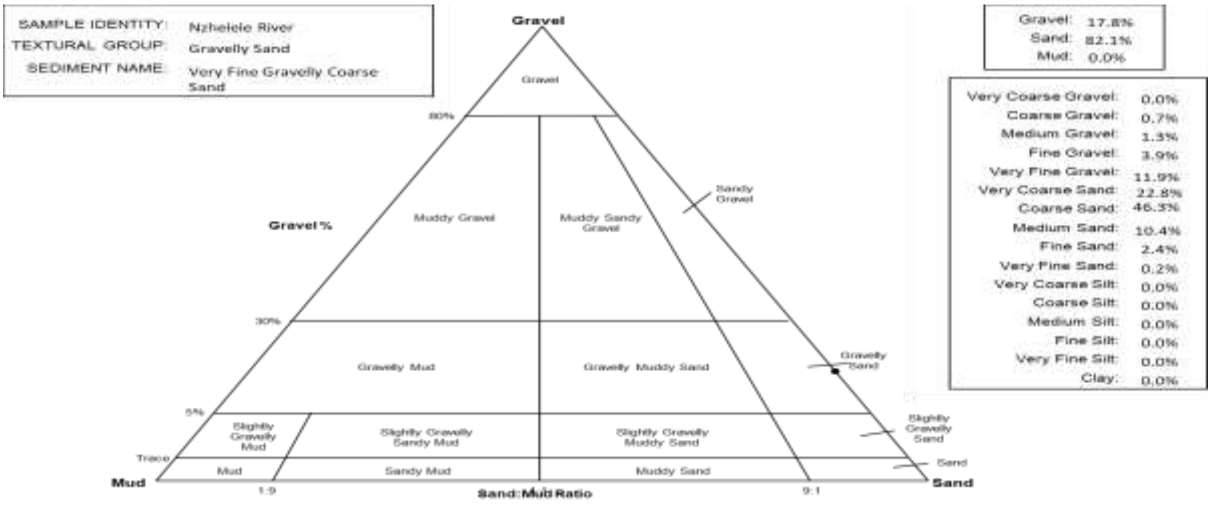
Appendix F: Cumulative (Microns) Curves





Appendix G: Gravel, Sand and Mud Diagrams

Gravel, Sand, & Mud Trilinear Plot for Nzhelele River after dry sieving

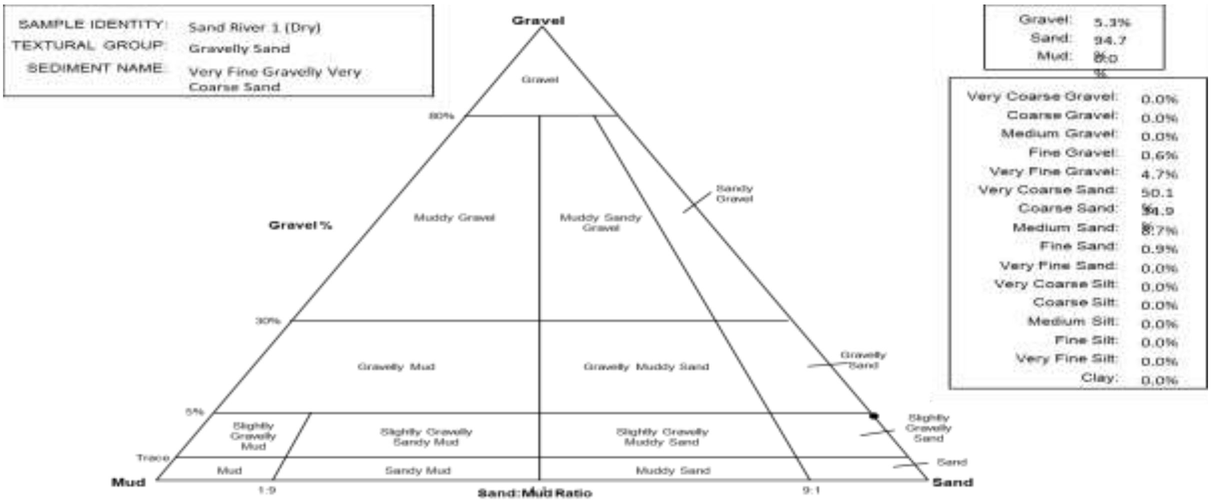


SAMPLE IDENTITY: Nzhelele River
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

Gravel: 17.8%
Sand: 82.1%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.7%
Medium Gravel:	1.3%
Fine Gravel:	3.9%
Very Fine Gravel:	11.9%
Very Coarse Sand:	22.8%
Coarse Sand:	46.3%
Medium Sand:	10.4%
Fine Sand:	2.4%
Very Fine Sand:	0.2%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Sand River 1 after dry sieving

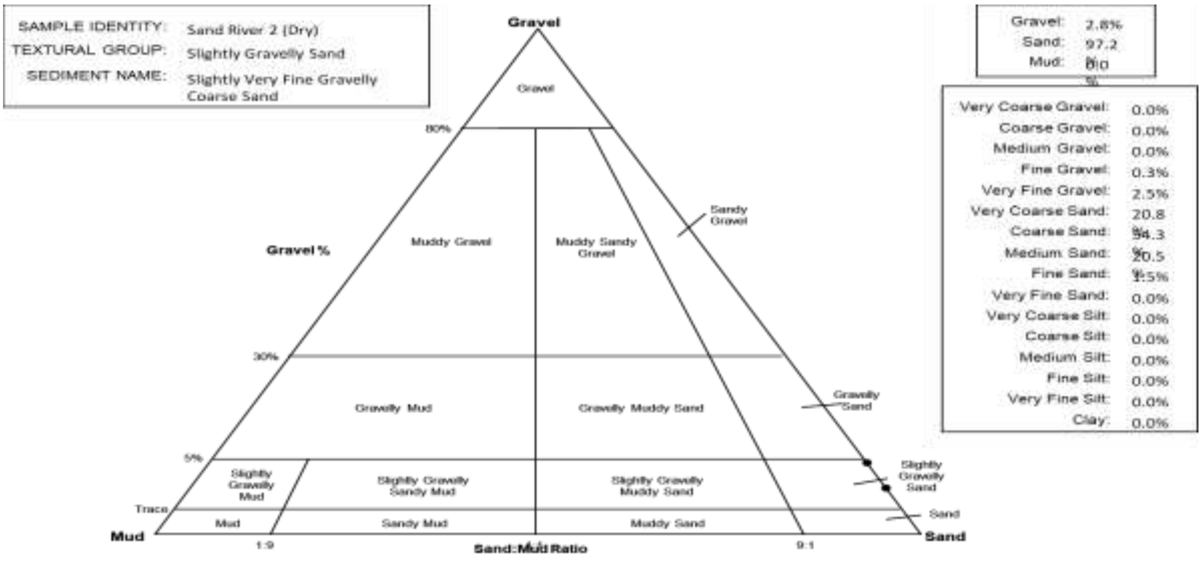


SAMPLE IDENTITY: Sand River 1 (Dry)
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

Gravel: 5.3%
Sand: 94.7%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.6%
Very Fine Gravel:	4.7%
Very Coarse Sand:	50.1%
Coarse Sand:	34.9%
Medium Sand:	8.7%
Fine Sand:	0.9%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Sand River 2 after dry sieving

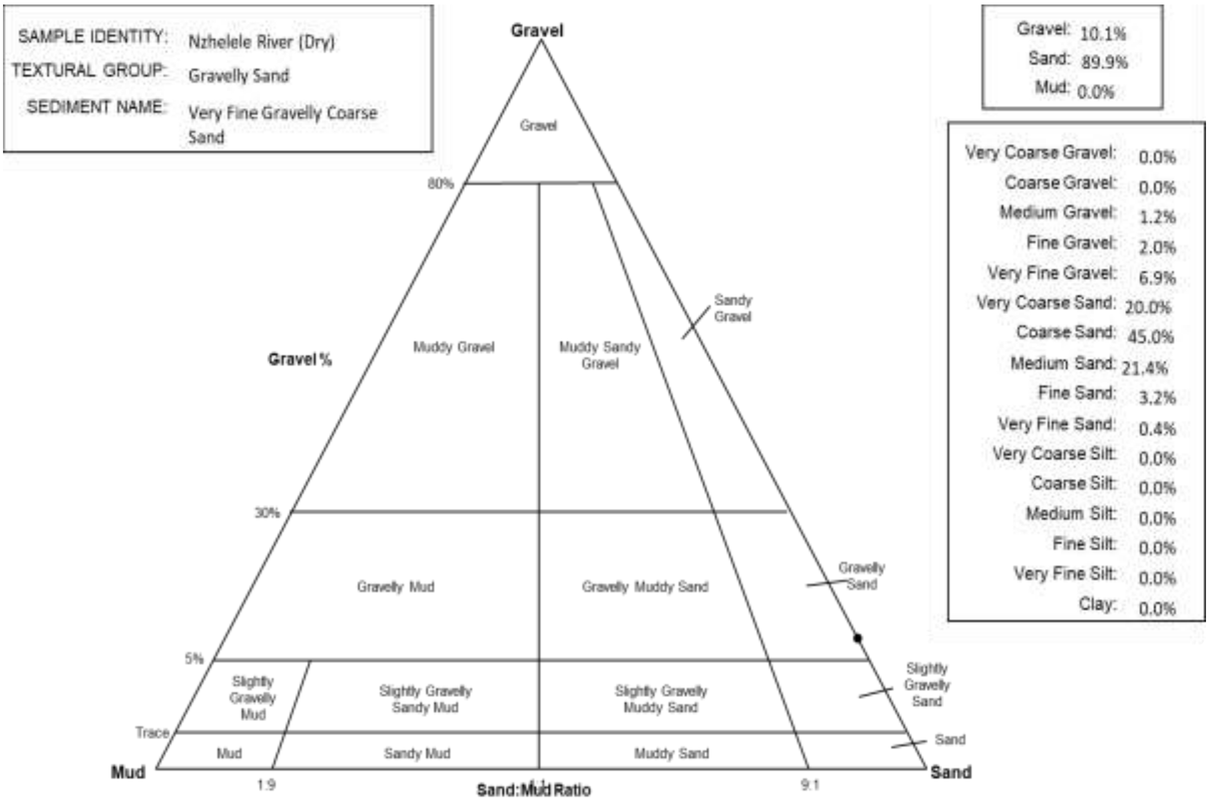


SAMPLE IDENTITY: Sand River 2 (Dry)
TEXTURAL GROUP: Slightly Gravelly Sand
SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

Gravel: 2.8%
Sand: 97.2%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.3%
Very Fine Gravel:	2.5%
Very Coarse Sand:	20.8%
Coarse Sand:	54.3%
Medium Sand:	20.5%
Fine Sand:	1.5%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Nzhelele River after dry sieving (2nd samples)

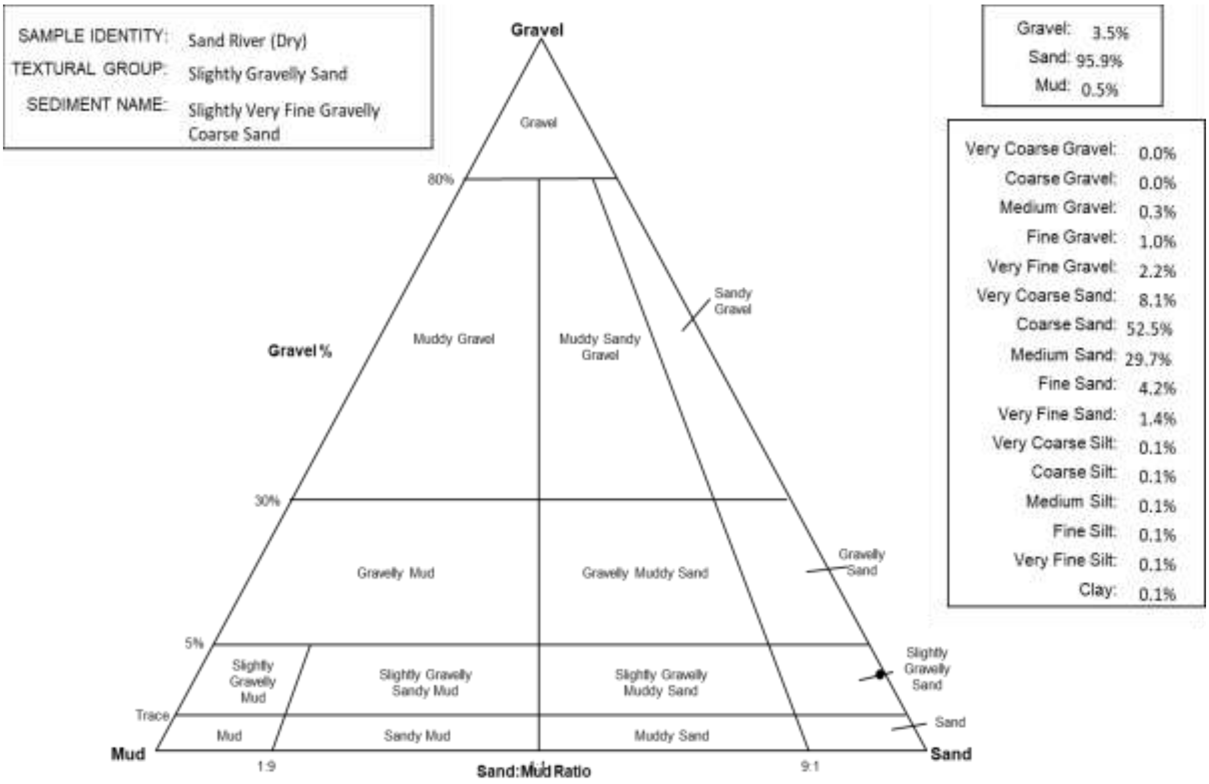


SAMPLE IDENTITY: Nzhelele River (Dry)
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Coarse Sand

Gravel: 10.1%
Sand: 89.9%
Mud: 0.0%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 1.2%
Fine Gravel: 2.0%
Very Fine Gravel: 6.9%
Very Coarse Sand: 20.0%
Coarse Sand: 45.0%
Medium Sand: 21.4%
Fine Sand: 3.2%
Very Fine Sand: 0.4%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%

Gravel, Sand & Mud Trilinear Plot for Sand River after dry sieving (2nd samples)



SAMPLE IDENTITY: Sand River (Dry)
TEXTURAL GROUP: Slightly Gravelly Sand
SEDIMENT NAME: Slightly Very Fine Gravelly Coarse Sand

Gravel: 3.5%
Sand: 95.9%
Mud: 0.5%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.3%
Fine Gravel: 1.0%
Very Fine Gravel: 2.2%
Very Coarse Sand: 8.1%
Coarse Sand: 52.5%
Medium Sand: 29.7%
Fine Sand: 4.2%
Very Fine Sand: 1.4%
Very Coarse Silt: 0.1%
Coarse Silt: 0.1%
Medium Silt: 0.1%
Fine Silt: 0.1%
Very Fine Silt: 0.1%
Clay: 0.1%

PLE IDENTITY: Nzhelele River 1 (Wet)
EXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

Gravel: 42.8%
Sand: 57.2%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	2.7%
Fine Gravel:	4.4%
Very Fine Gravel:	35.7%
Very Coarse Sand:	26.7%
Coarse Sand:	16.8%
Medium Sand:	11.7%
Fine Sand:	2.0%
Very Fine Sand:	0.2%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Nzhelele River 1 after wet sieving

PLE IDENTITY: Nzhelele River 2 (Wet)
EXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

Gravel: 52.6%
Sand: 47.4%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	1.5%
Fine Gravel:	4.5%
Very Fine Gravel:	46.7%
Very Coarse Sand:	27.1%
Coarse Sand:	12.5%
Medium Sand:	6.8%
Fine Sand:	1.0%
Very Fine Sand:	0.1%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

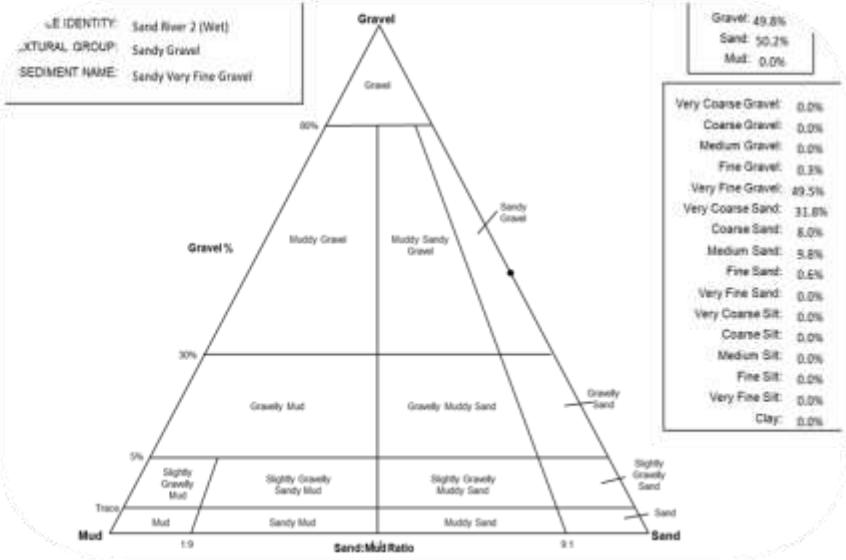
Gravel, Sand & Mud Trilinear Plot for Nzhelele river 2 after wet sieving

LE IDENTITY: Sand River 1 (Wet)
XTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

Gravel: 64.0%
Sand: 36.0%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	1.0%
Very Fine Gravel:	63.0%
Very Coarse Sand:	12.9%
Coarse Sand:	12.7%
Medium Sand:	9.9%
Fine Sand:	0.6%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Sand River 1 after wet sieving



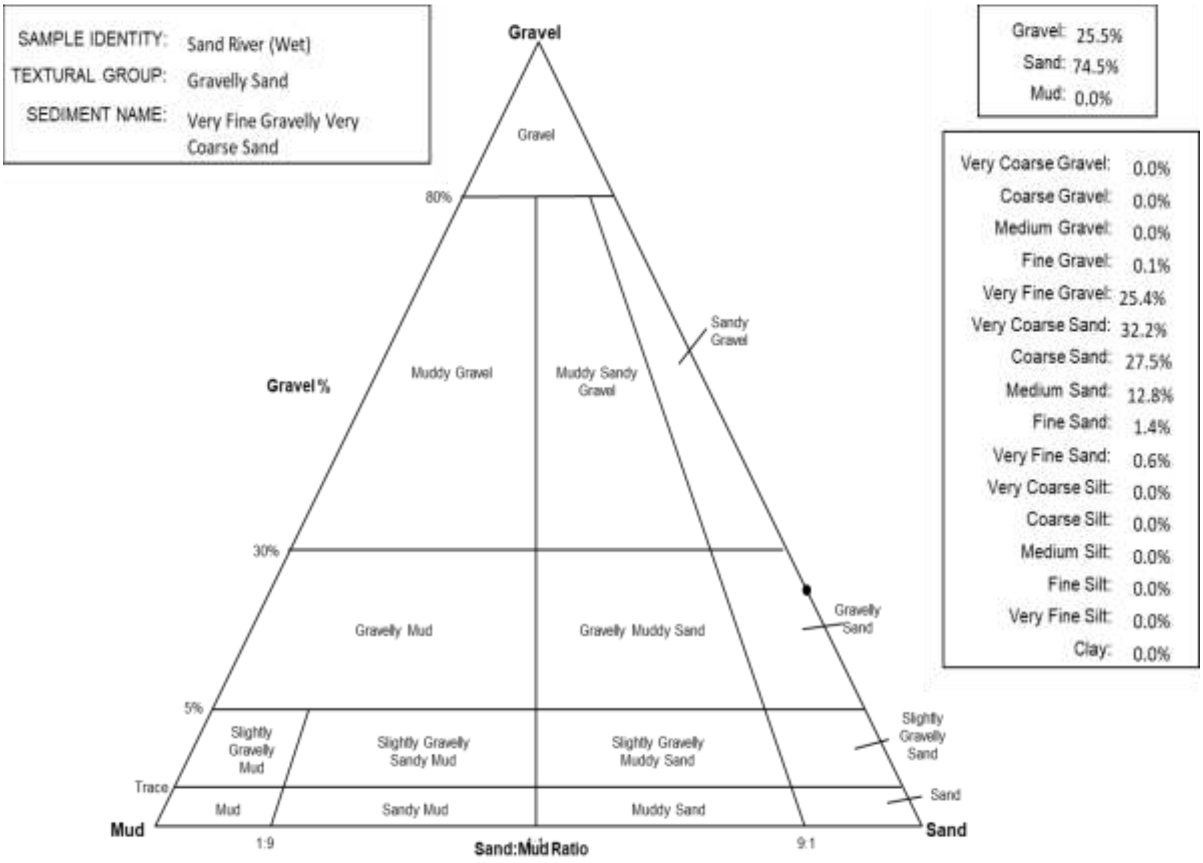
E IDENTITY: Sand River 2 (Wet)
XTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

Gravel: 49.8%
Sand: 50.2%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.3%
Very Fine Gravel:	49.5%
Very Coarse Sand:	31.8%
Coarse Sand:	8.0%
Medium Sand:	9.8%
Fine Sand:	0.6%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Sand River 2 after wet sieving

Gravel, Sand & Mud Trilinear Plot for Sand River after wet sieving (2nd samples)

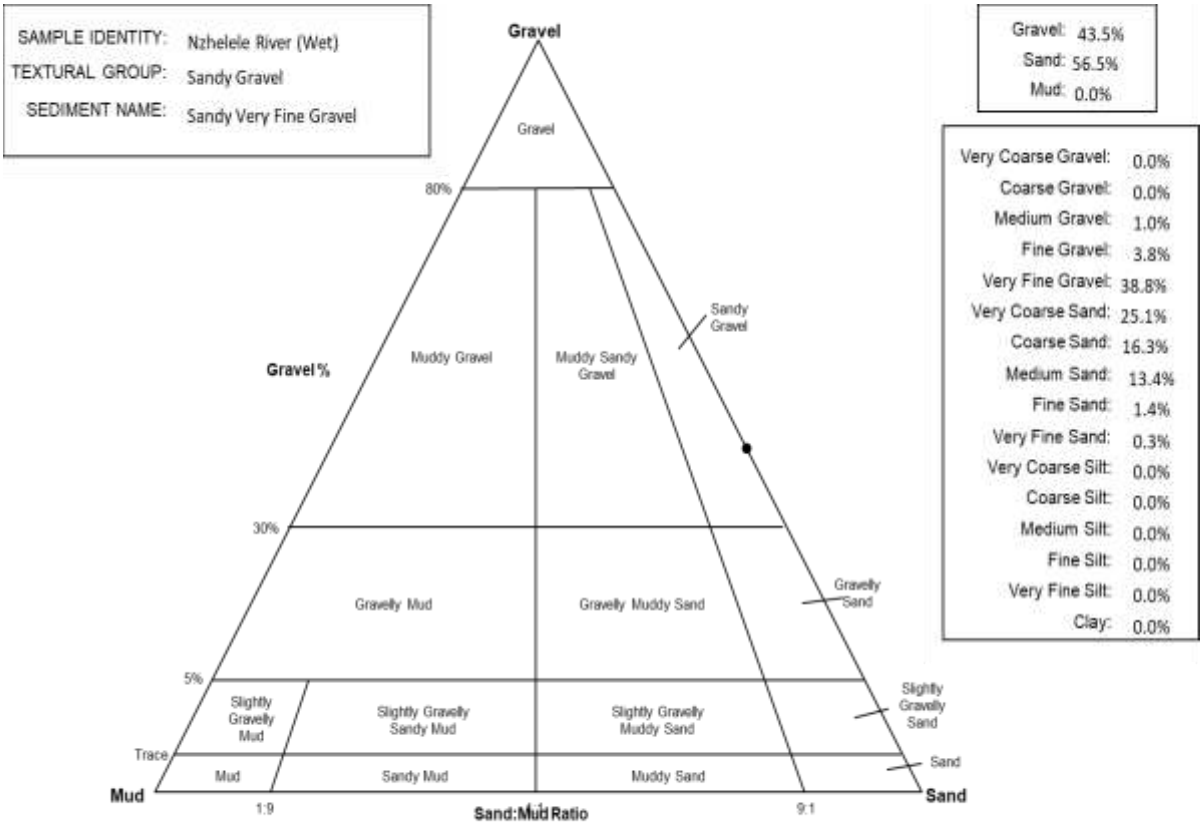


SAMPLE IDENTITY: Sand River (Wet)
TEXTURAL GROUP: Gravelly Sand
SEDIMENT NAME: Very Fine Gravelly Very Coarse Sand

Gravel: 25.5%
Sand: 74.5%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.1%
Very Fine Gravel:	25.4%
Very Coarse Sand:	32.2%
Coarse Sand:	27.5%
Medium Sand:	12.8%
Fine Sand:	1.4%
Very Fine Sand:	0.6%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Gravel, Sand & Mud Trilinear Plot for Nzhelele River after wet sieving (2nd samples)



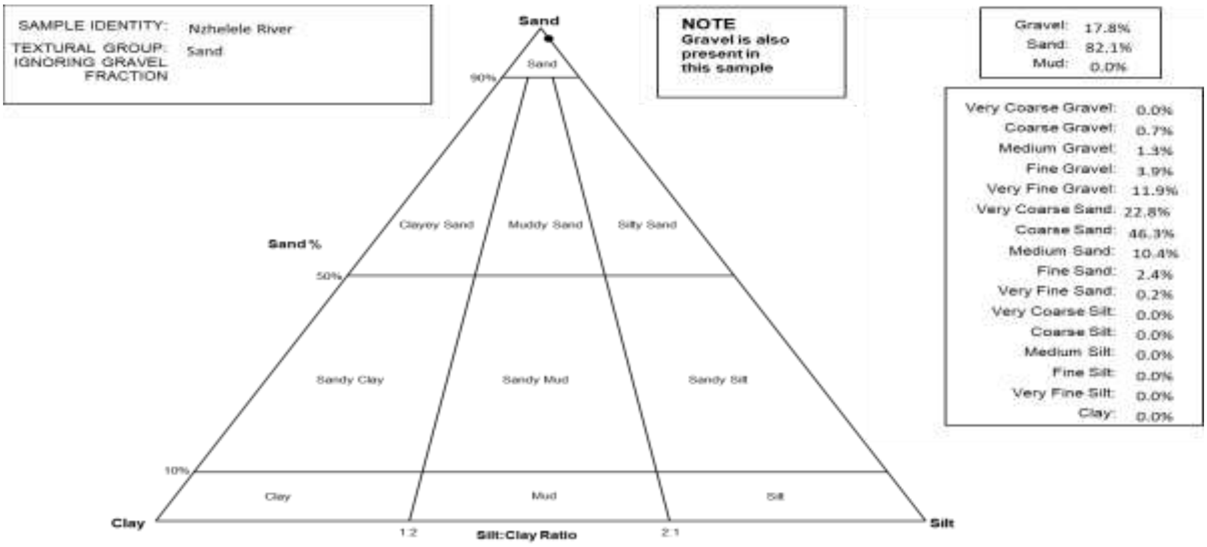
SAMPLE IDENTITY: Nzhelele River (Wet)
TEXTURAL GROUP: Sandy Gravel
SEDIMENT NAME: Sandy Very Fine Gravel

Gravel: 43.5%
Sand: 56.5%
Mud: 0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	1.0%
Fine Gravel:	3.8%
Very Fine Gravel:	38.8%
Very Coarse Sand:	25.1%
Coarse Sand:	16.3%
Medium Sand:	13.4%
Fine Sand:	1.4%
Very Fine Sand:	0.3%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Appendix H: Sand, Silt and Clay Diagrams

Sand, Silt & Clay Trilinear Plot for Nzhelele River after dry sieving



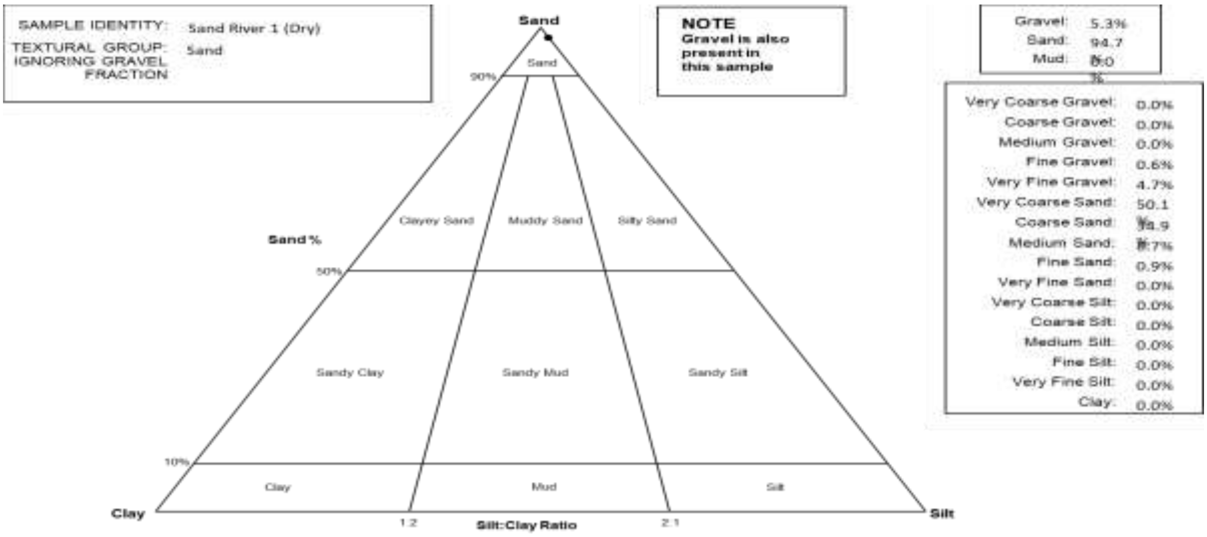
SAMPLE IDENTITY: Nzhelele River
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	17.8%
Sand:	82.1%
Mud:	0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.7%
Medium Gravel:	1.3%
Fine Gravel:	3.9%
Very Fine Gravel:	11.9%
Very Coarse Sand:	22.8%
Coarse Sand:	46.3%
Medium Sand:	10.4%
Fine Sand:	2.4%
Very Fine Sand:	0.2%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Sand, Silt & Clay Trilinear Plot for Sand River 1 after dry sieving



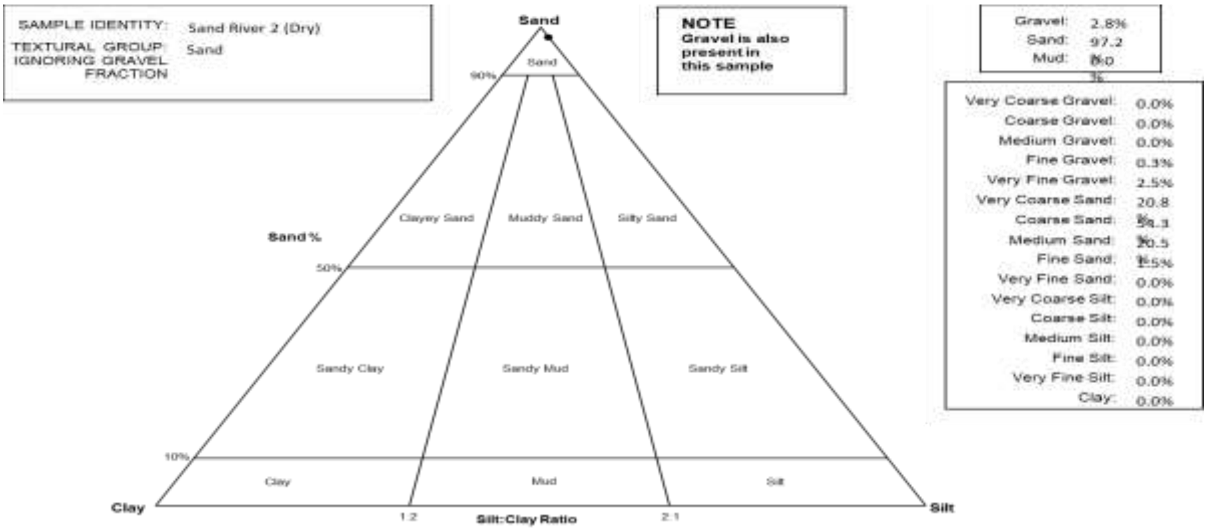
SAMPLE IDENTITY: Sand River 1 (Dry)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	5.3%
Sand:	94.7 %
Mud:	0.0 %

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.6%
Very Fine Gravel:	4.7%
Very Coarse Sand:	50.1 %
Coarse Sand:	38.9 %
Medium Sand:	4.7%
Fine Sand:	0.9%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Sand, Silt & Clay Trilinear Plot for Sand River 2 after dry sieving



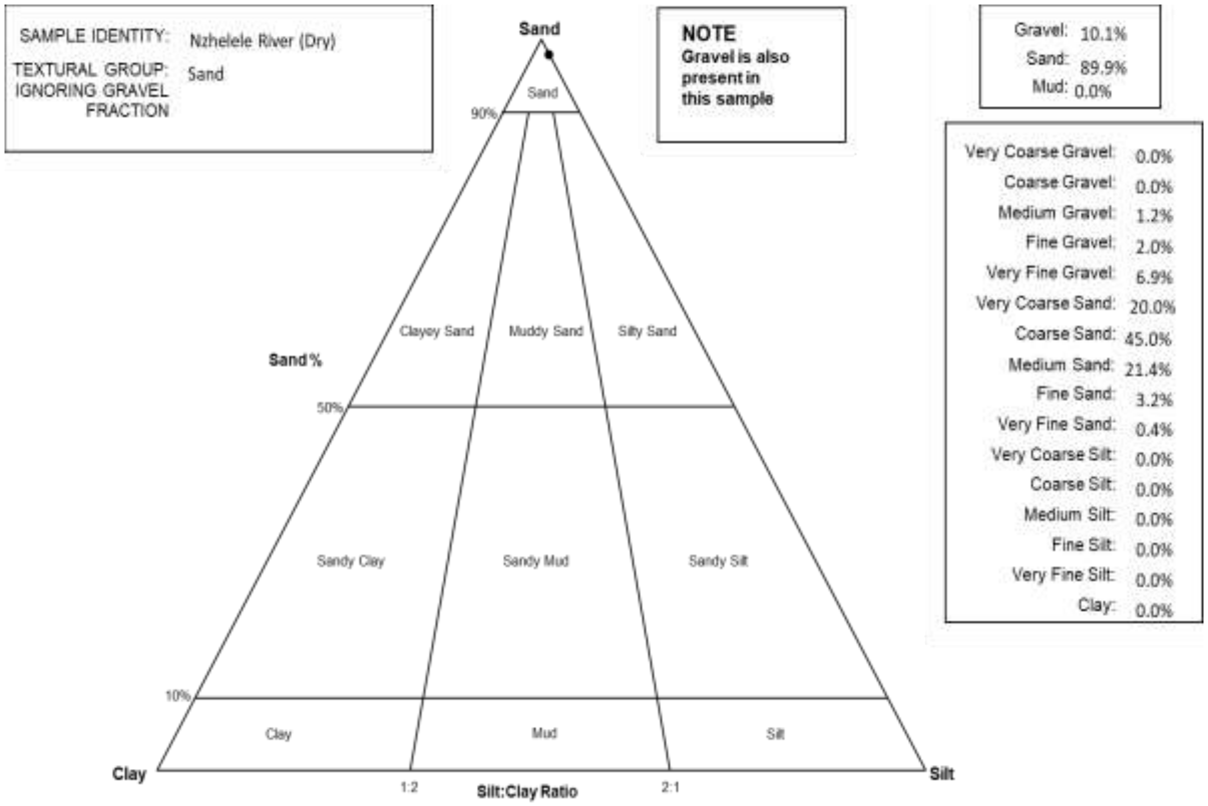
SAMPLE IDENTITY: Sand River 2 (Dry)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	2.8%
Sand:	97.2 %
Mud:	0.0 %

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.3%
Very Fine Gravel:	2.5%
Very Coarse Sand:	20.8 %
Coarse Sand:	54.3 %
Medium Sand:	20.5 %
Fine Sand:	1.5%
Very Fine Sand:	0.0%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Sand, Silt & Clay Trilinear Plot for Nzhelele River after dry sieving (2^{nd} samples)



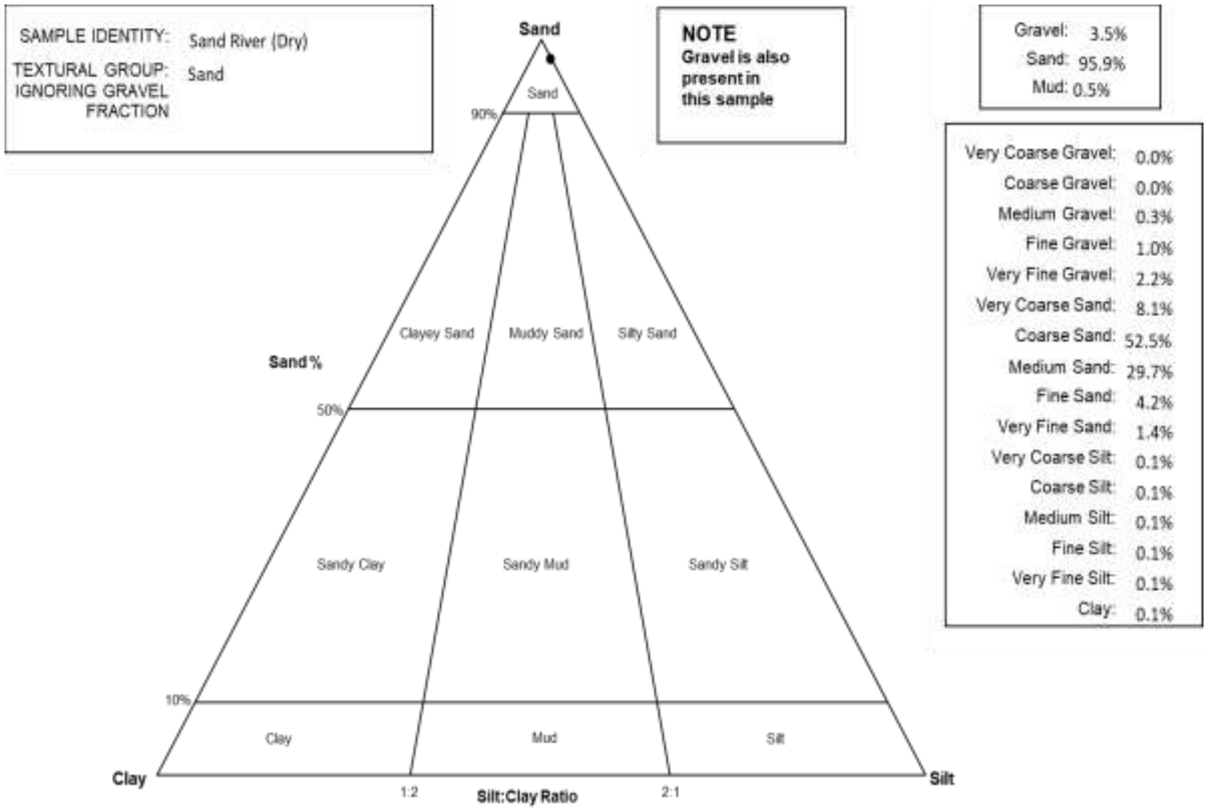
SAMPLE IDENTITY: Nzhelele River (Dry)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	10.1%
Sand:	89.9%
Mud:	0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	1.2%
Fine Gravel:	2.0%
Very Fine Gravel:	6.9%
Very Coarse Sand:	20.0%
Coarse Sand:	45.0%
Medium Sand:	21.4%
Fine Sand:	3.2%
Very Fine Sand:	0.4%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Sand, Silt & Mud Trilinear Plot for Sand River after dry sieving (2^{nd} samples)

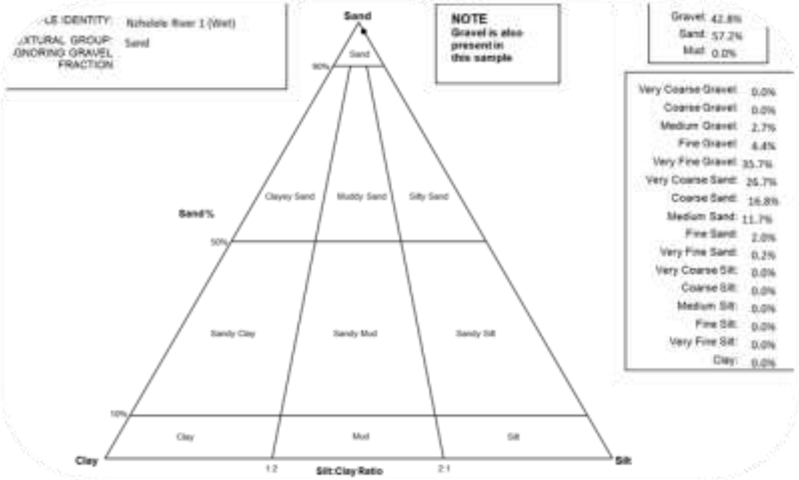


SAMPLE IDENTITY: Sand River (Dry)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	3.5%
Sand:	95.9%
Mud:	0.5%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.3%
Fine Gravel:	1.0%
Very Fine Gravel:	2.2%
Very Coarse Sand:	8.1%
Coarse Sand:	52.5%
Medium Sand:	29.7%
Fine Sand:	4.2%
Very Fine Sand:	1.4%
Very Coarse Silt:	0.1%
Coarse Silt:	0.1%
Medium Silt:	0.1%
Fine Silt:	0.1%
Very Fine Silt:	0.1%
Clay:	0.1%



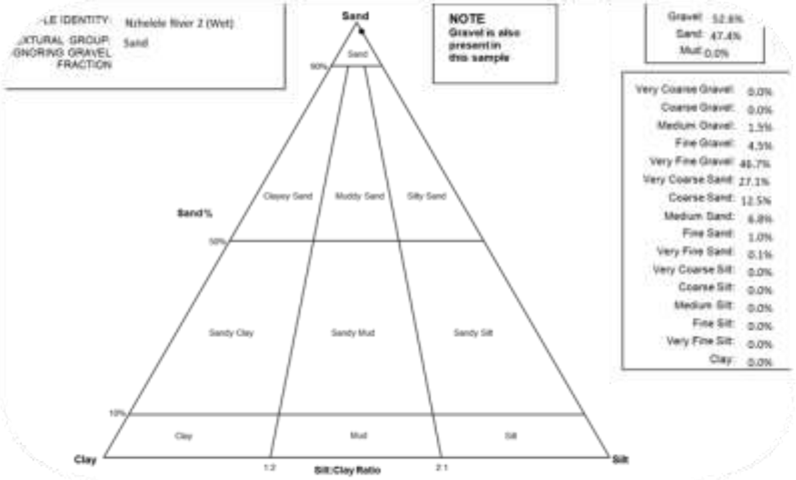
LE IDENTITY: Nzhelele River 1 (Wet)
XTURAL GROUP: Sand
GNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel: 42.8%
Sand: 57.2%
Mud: 0.0%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 2.7%
Fine Gravel: 4.4%
Very Fine Gravel: 35.7%
Very Coarse Sand: 26.7%
Coarse Sand: 16.8%
Medium Sand: 11.7%
Fine Sand: 2.0%
Very Fine Sand: 0.2%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%

Sand, Silt & Clay Trilinear Plot for Nzhelele River 1 after wet sieving



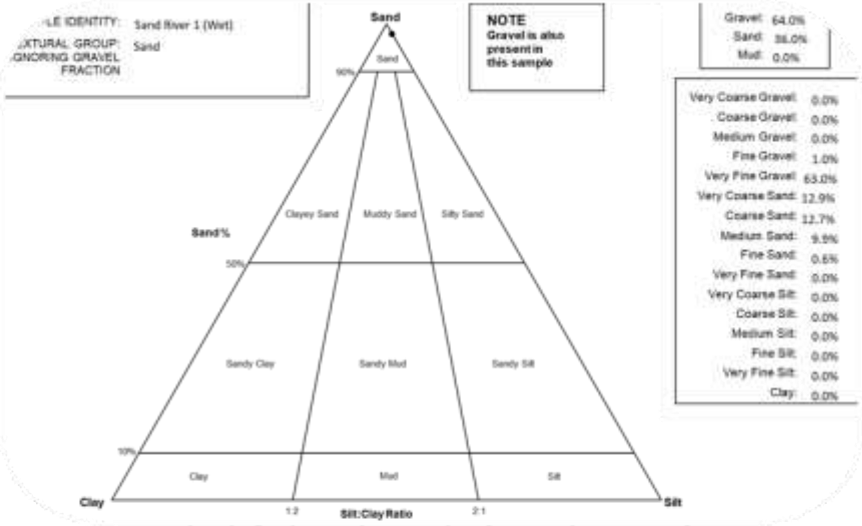
LE IDENTITY: Nzhelele River 2 (Wet)
XTURAL GROUP: Sand
GNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel: 52.6%
Sand: 47.4%
Mud: 0.0%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 1.5%
Fine Gravel: 4.5%
Very Fine Gravel: 46.7%
Very Coarse Sand: 27.1%
Coarse Sand: 12.5%
Medium Sand: 6.8%
Fine Sand: 1.0%
Very Fine Sand: 0.1%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%

Sand, Silt, & Clay Trilinear Plot for Nzhelele River 2 after wet sieving



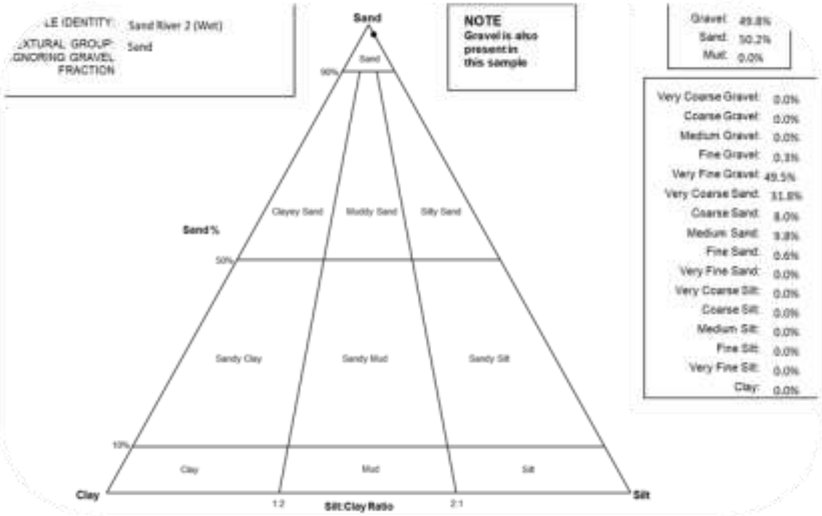
LE IDENTITY: Sand River 1 (Wet)
XTURAL GROUP: Sand
GNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel: 64.0%
Sand: 36.0%
Mud: 0.0%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 1.0%
Very Fine Gravel: 63.0%
Very Coarse Sand: 12.9%
Coarse Sand: 12.7%
Medium Sand: 9.9%
Fine Sand: 0.6%
Very Fine Sand: 0.0%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%

Sand, Silt & Clay Trilinear Plot for Sand River 1 after wet sieving



LE IDENTITY: Sand River 2 (Wet)
XTURAL GROUP: Sand
GNORING GRAVEL FRACTION

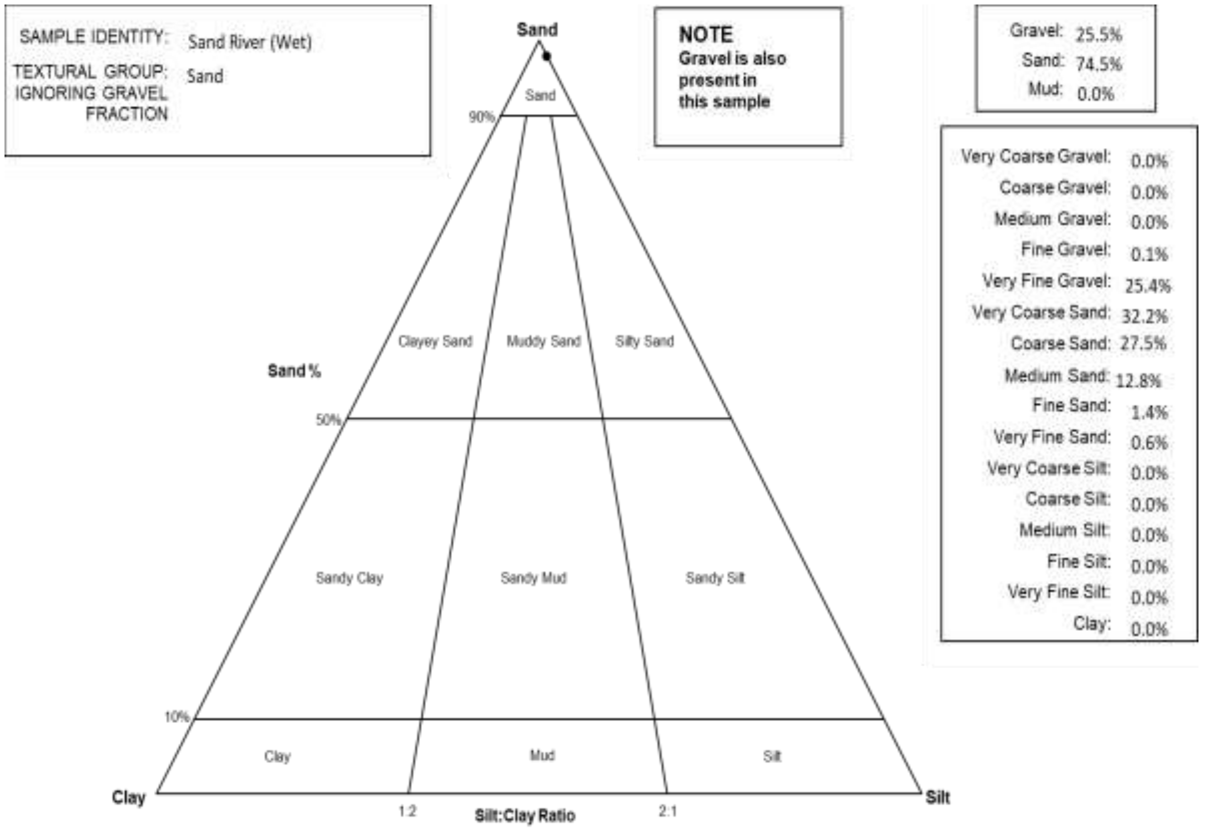
NOTE
Gravel is also present in this sample

Gravel: 49.8%
Sand: 50.2%
Mud: 0.0%

Very Coarse Gravel: 0.0%
Coarse Gravel: 0.0%
Medium Gravel: 0.0%
Fine Gravel: 0.3%
Very Fine Gravel: 49.5%
Very Coarse Sand: 31.8%
Coarse Sand: 8.0%
Medium Sand: 9.8%
Fine Sand: 0.6%
Very Fine Sand: 0.0%
Very Coarse Silt: 0.0%
Coarse Silt: 0.0%
Medium Silt: 0.0%
Fine Silt: 0.0%
Very Fine Silt: 0.0%
Clay: 0.0%

Sand, Silt & Clay Trilinear Plot for Sand River 2 after wet sieving

Sand, Silt & Clay Trilinear Plot for Sand River after wet sieving (2nd samples)

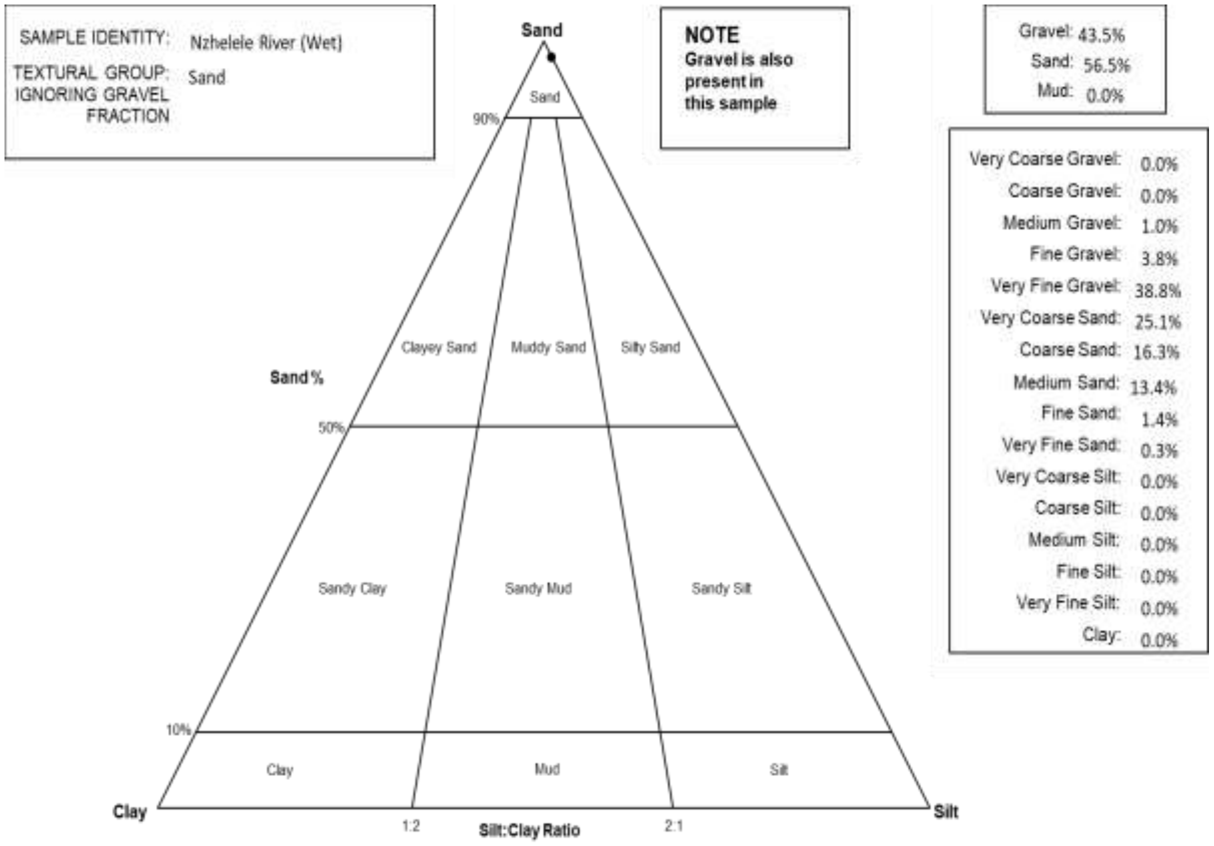

SAMPLE IDENTITY: Sand River (Wet)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	25.5%
Sand:	74.5%
Mud:	0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	0.0%
Fine Gravel:	0.1%
Very Fine Gravel:	25.4%
Very Coarse Sand:	32.2%
Coarse Sand:	27.5%
Medium Sand:	12.8%
Fine Sand:	1.4%
Very Fine Sand:	0.6%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

Sand, Silt & Clay Trilinear Plot for Nzhelele River after wet sieving (2nd Samples)


SAMPLE IDENTITY: Nzhelele River (Wet)
TEXTURAL GROUP: Sand
IGNORING GRAVEL FRACTION

NOTE
Gravel is also present in this sample

Gravel:	43.5%
Sand:	56.5%
Mud:	0.0%

Very Coarse Gravel:	0.0%
Coarse Gravel:	0.0%
Medium Gravel:	1.0%
Fine Gravel:	3.8%
Very Fine Gravel:	38.8%
Very Coarse Sand:	25.1%
Coarse Sand:	16.3%
Medium Sand:	13.4%
Fine Sand:	1.4%
Very Fine Sand:	0.3%
Very Coarse Silt:	0.0%
Coarse Silt:	0.0%
Medium Silt:	0.0%
Fine Silt:	0.0%
Very Fine Silt:	0.0%
Clay:	0.0%

APPENDIX I: HYDROMETER DATA

Hydrometer Readings of Sand River and Nzhelele Rivers Replicated

Rivers	Replications	Hydrometer Readings	
		After 40 seconds	After 2 hours
Sand River 1	Rep 1	1.2	1.1
	Rep 2	1.2	1.1
	Rep 3	1.1	1.1
Sand River 2	Rep 1	1.2	1.1
	Rep 2	1.3	1.1
	Rep 3	1.3	1.1
Nzhelele River 1	Rep 1	1.2	1.3
	Rep 2	1.1	1.2
	Rep 3	1.1	1.1
Nzhelele River 2	Rep 1	1.2	1.1
	Rep 2	1.2	1.2
	Rep 3	1.2	1.2

Classifications of Sediments for Sand River and Nzhelele River

Rivers	Sediment Type	Replication		
		Rep 1	Rep 2	Rep 3
Sand River 1	Sand	97.6%	97.6%	97.8%
	Clay	2.2%	2.2%	2.2%
	Silt	0.2%	0.2%	0%
Sand River 2	Sand	97.6%	97.4%	97.4%
	Clay	2.2%	2.2%	2.2%
	Silt	0.2%	0.4%	0.4%
Nzhelele River 1	Sand	97.6%	97.6%	97.8%
	Clay	2.4%	2.4%	2.2%
	Silt	0%	0%	0%
Nzhelele River 2	Sand	97.6%	97.6%	97.6%
	Clay	2.2%	2.4%	2.4%
	Silt	0.2%	0%	0%

Hydrometer Readings of Sand River and Nzhelele River Replicated 2nd Samples

Rivers	**Replications**	**Hydrometer Readings**	
		After 40 seconds	**After 2 hours**
Sand River	Rep 1	1.2	1.1
	Rep 2	1.1	1.1
	Rep 3	1.1	1
Nzhelele River	Rep 1	1	1.1
	Rep 2	1.1	1.1
	Rep 3	1.1	1

Classifications of Sediments for Sand River and Nzhelele River

Rivers	Sediment Type	Replication		
		Rep 1	Rep 2	Rep 3
Sand River	Sand	97.6%	97.8%	97.8%
	Clay	2.2%	2.2%	2%
	Silt	0.2%	0%	0.2%
Nzhelele River	Sand	98%	97.8%	97.8%
	Clay	2.2%	2.2%	2%
	Silt	-0.2%	0%	0.2%