

MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY
NDATA SCHOOL OF CLIMATE AND EARTH SCIENCE
DEPARTMENT OF EARTH SCIENCES

IMPACTS OF SAND MINING ON RIVER MORPHOLOGY

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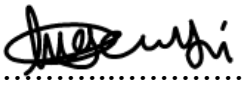
DISSERTATION SUBMITTED TO NDATA SCHOOL OF CLIMATE AND EARTH SCIENCES OF MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF SCIENCE DEGREE IN EARTH SCIENCES (GEOLOGY)

SUPERVISOR: MR. D. MBEYA

DATE: 29th April, 2025

DECLARATION

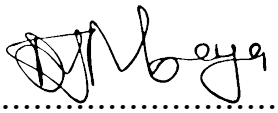
I Kingsley Chidyamayani declare that this research project represents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

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ABSTRACT

Current global rate of sand mining in river channels is unsustainable, and in Malawi the activity going on unregulated. This study established the morphological effects of sand mining in Luchenza by addressing the following objectives: To determine the: extent of sand mining; morphological factors influencing abundance of sand; effects of sand mining on the morphology of Luchenza River. Systematic sampling was used on this section to select the areas to collect data. Data on channel depth, width, vegetation cover, erosion status, sand volume status, channel slope angles, and bank position were obtained through physical measurements in the field. ArcMap GIS was used to map the spatial extent of sand mining along Luchenza river. The binary logistic regression analysis was employed to show factors influencing abundance of sand in Luchenza river channel. The study established that river channel width (P=6.47e-05), depth (P=7.00e-07), slope angles (P=3.36e-06) and bank position (P=2.2e-16) were significant in influencing sand abundance in the river channel as indicated by the respective marginal effects and p-values. Additionally, sand mining had modified the river channel morphology through causing increase in depth (P=7.19e-02), width (P=9.95e-03) and slope angles (P=9.37e-03) at the active mining sites, compared with the control sites as shown by the respective p-values. Field data analysis was combined with google earth imagery data for 2013, 2016 and 2024 using ArcGIS 10.8 software to see changes in river morphology, formation and extent of point bar and channel bar, as well as changes in the area of river water bodies and non-water river bodies. The results showed that the changes in morphology and physical dynamics conditions of the Luchenza River showed their own pattern. If sediment deposits forming point bars or channel bars were reduced, the area of river water bodies tended to increase. Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form the point bar and channel bar tends to decrease.

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CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The rapid rise in urbanization and the construction of large-scale infrastructure projects are increasing global demand for construction materials. Sand mining is a phenomenon that is evident in many places across the world, mainly associated with the construction industry (Rinaldi *et al.*, 2005). The construction industry prefers sand from the river channels, floodplain and shores of the lake and oceans, simply because it is clean and its grains are angular, a factor that enhances the strength of the concrete (Kondolf, 1997). Sand from the desert terrain is least preferred because its grains are rounded and for that reason does not bind well with cement (Lu *et al.,* 2007). According to Peduzzi (2014), between 47 and 59 billion tonnes of solid materials are mined globally in a year at the current period. Of this, sand accounts for the largest share ranging between 68 and 85%. This value was arrived at by looking into the cement production across the world, and subsequently computing the quantities of sand recommended for a given amount of cement in the certified ratio in which they are mixed to make concrete. United Nations Environmental Program (UNEP,2014) estimated that between 32 and 50 billion tonnes of sand and gravel are extracted globally each year with demand increasing, specifically in developing countries. After water sand is the most consumed natural resource in the world (Rentier, Cammeraat, 2022), it has come to the point where sand is called "the new gold" and the indiscriminate extraction of this new gold is destroying physical and biological environments all over the world (Barton and Mini, 2013).

Studies worldwide have documented the economic significance of sand mining, and their findings tend to corroborate that it is a highly viable economic activity (Bruce, 2015; Rajesh & Anushiya, 2013). However, in most parts of the world, it is being carried out in an unregulated manner, thus causing it to yield adverse environmental impacts. For instance, Brendan T. et al. (2015) did research on the Morphological Evolution of a Lower Mississippi River Chanel Bar After Sand mining. They observed morphological evolution of a large (1.46 million m3) borrow pit mined at lateral sandbar in the lower Mississippi River using a time-series of multibeam bathymetric surveys. During a 2.5-year time-series, only 53% of the pit was filled with new sediments. This simply tells us that

sand mining is not sustainable if the extraction does not balance with the sediments being deposited. Research by Peduzzi (2014) shows that the current levels of sand exploitation globally are not sustainable. As a result, this activity should be regulated through the appropriate mechanisms so as to achieve sustainable development. The level of sand consumption is directly proportional to the rate of economic growth as well as the economic status of a country. This is clearly depicted by the facts on sand mining that places the United States of America, Australia, Austria, South Africa and Kenya respectively as the leading nations in sand mining (Wambua, 2015). In addition, a country like Dubai which is economically fair, depleted its marine sand reserves during the construction of the beautiful island of Palm Jumeirah between year 2001 and 2006. Today, it is importing sand for its local consumption from Austria (Bruce, 2015). Sand mining has been reported widely across the world. For instance, in China, sand mining has been reported along many rivers such as river Pearl and its tributaries, whereby channel incision has ensued as a result of unregulated sand mining (Lu *et al.*, 2007). In Europe, Rinaldi *et al.*, (2005) conducted a study on five rivers in Poland and Italy and found out that the activity was being carried out unregulated, and had resulted in some adverse environmental impacts such as river channel incision, banks instability as well as the river bed armouring.

In South Africa, sand mining is said to be taking place uncontrolled, a factor that has resulted in environmental degradation especially in the river beds as well as on the riparian zones (Mkando 2004). A similar case has been reported in South Africa by Amponsah-Dacosta & Mathada (2017) on river Nzhelele in Limpopo province. In Nigeria, Nabegu (2014) reported that unregulated sand mining had caused modification of the river channel morphology at the active sites of mining, an effect which is negative. Sand mining was also reported to cause lowering of the water table in the sand aquifers along river Kano in Nigeria (Nabegu, 2013). Despite many negative effects resulting from sand mining, the activity has been credited on some economic grounds. For instance, Atejioye & Odeyemi (2018) and Madyise (2013) established that sand mining had empowered the sand miners economically in Nigerian and Botswana respectively. In Ghana, Salifu (2016) established that sand mining had enabled people to acquire assets from the proceeds of sand mining.

In Malawi, sand mining is taking place mainly in rivers like Shire, Lilongwe, Linthipe, among others due to the rapidly rising demand for housing as well as roads construction and other infrastructures. Sand mining is also taking place in the area of T/A Chimaliro in Thyolo due to also urbanisation of this area. Sand in this area is mined in river like Luchenza, Chibvu, Nansadi and other tributaries of Luchenza river. In this area sand mining rate has increased in the past 15 years due to construction of Malawi University of Science and Technology (MUST). Sand was mined excessively to meet the high demand of MUST construction and now sand mining is still increasing its rate due to urbanisation of MUST surrounding villages.

1.2 Problem statement

A significant number of studies have shown that unregulated sand mining within river channels have greatly accelerated natural geomorphic processes resulting in negative consequences such as modification of channel morphology, lowering of ground water table, streambank instability, flood flow increases and several other biological impacts (Kondolf, 1997; Nabegu, 2013; Rinaldi *et al.*, 2005). At the moment, sand mining in all river channels in Malawi is uncontrolled, basically due to lack of informing principles and guiding policies to this activity. As noted by Kondolf (1997) and Nabegu (2013), such high rates of uncontrolled sand mining leads to degradation of the river environment, mainly the river channel morphology and the riparian vegetation zones. Going by that, this study was carried out to examine the phenomena in order to understand its effects on the river channel morphology to help devise suitable mechanisms and strategies of promoting sustainable sand mining activity.

1.3 Main and Specific Objectives

1.3.1 Main Objective

The main objective of this study is to examine the morphological effects of sand mining in Lichenza River.

1.3.2 Specific Objectives

In order to achieve the main objective, the study addressed the following specific objectives:

(i) To determine the extent of sand mining along the Luchenza river channel.

(ii) To identify the factors influencing abundance of sand in the Luchenza River channel.

(iii) To examine the effects of sand mining on physical dynamics of Luchenza River.

1.4 Research Questions

i. What are the impacts of sand mining on river morphology?
ii. Where are these impacts mostly pronounced, and what factors influence their spatial distribution?
iii. How do sand mining activities alter river morphology?
iv. Why is it important to control the morphological impacts that are being caused by sand mining?

1.5 Significance of study

Due to rapidly growing building and construction industry in T/A Chimaliro area and beyond, riverine sand mining is on rise. This has led to a considerably high rate of sand mining on river beds. In Malawi, sand mining is being carried out in a highly unregulated and uncontrolled manner, which is alarming. Such high rates of sand mining that may exceed the natural replacement rates leads to the occurrence of environmental problems to the river environment. Luchenza river was selected for the study owing to the unregulated state of sand mining that is taking place. Following that, this study was done to examine the activity in order to help develop intervention measures to save the environment from human destruction. With the increasing demand for sand in construction and infrastructure projects, there is a need to balance economic development with environmental sustainability. The results of this study will also help to have an insight on impact of sand mining in other main rivers here in Malawi.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Sand mining from rivers is an activity that has taken place for centuries across the world. However, demand for sand has risen significantly owing to the increase in demand from the construction industry aimed at meeting the housing needs for the increasing population across the world as well as the vast infrastructural developments that are being actualized (Peduzzi, 2014). The activity has been associated with adverse environmental effects in areas where it has been carried out unregulated thus raising need to undertake a study at the local setting to help enhance understanding of the activity. This chapter discusses the key literature pertaining to sand mining activity in line with the topic of study and the study objectives. The areas discussed include the spatial extent of sand mining, factors influencing abundance of sand along the river channel, effects of river sand mining on the river channel morphology. Finally, this chapter also discusses the conceptual framework which is drawn from the geomorphic concept of positive and negative feedback mechanisms of the river channel development.

2.2 Extent of Sand Mining

The ever-growing building and construction industry have prompted continued sand mining over the years with sand mining being carried out along the river channels, on the floodplains, and on the shores of the lakes and oceans (Orr & Krumenacher, 2015). According to Kondolf (1997), sand from such sites is usually clean, and its grains are angular, a factor that enhances the strength of the concrete. On the other hand, sand from the desert terrain is less preferred for construction purposes because its grains are rounded and smooth (Lu *et al,* 2007). Over the years, America had been the leading continent in terms of sand mining, with multiple cases of sand mining reported along the rivers and by the shores of the ocean (Peduzzi, 2014). According to Schloesser *et al.,* (2008) who carried out research on river sand mining in U.S.A., the activity was going on unregulated, leading to some environmental challenges. In view of their study which agrees with that of Kondolf (1997), the understanding of the geomorphic processes would help provide an insight into the effects of sand mining on the river systems.

On the other hand, Asia is the leading continent in sand mining today as depicted by its high volume of cement production and consumption which is rated at 58% of the

cement produced in the world (Peduzzi, 2014). In a global based study, Peduzzi (2014) pointed out that sand mining is taking place in an unsustainable way. The study estimated that about 40 billion tonnes of sand are mined each year which happens to be twice the estimated total amount of sediments carried by rivers of the world in a year. Going by that, it is evident that sand mining is a global issue which should be closely examined to protect the natural sand reserves from depletion as well as the environment from degradation.

In Africa, sand mining has been reported from different places such as on the shores of the lakes and oceans and mainly from the river channels (Mensah, 1997; Madyise, 2013). For instance, in Nigeria, sand mining has been reported in the river channels, an activity that has been discredited on the grounds that it is taking place unregulated thus breeding adverse environmental effects (Nabegu 2014; Ako *et al.*, 2014; Atejioye & Odeyemi, 2018). Similar findings have been arrived at in South Africa by Kori & Mthanda (2012) in a study on effect of river sand mining. As established by Chevallier (2014) sand mining is an activity that is directly proportional to the economic level of development of a country. Following that, countries such as South Africa, Egypt, Nigeria and Kenya which are economically fair have been ranked as the leading sand consumers in Africa (Wambua, 2015). Additionally, the trend of sand mining has been noted to increase gradually over the years, with the highest rates being witnessed at present time (Kori & Mathada, 2012). This has resulted from the rapid rate of urbanization that is taking place across the continent as well as across the world, a factor that has raised demand for the construction sand.

2.3 Factors Influencing Sand Abundance in River Channels

The presence of sand in a river channel is a function of several natural watershed factors such as erosion status, slope angles, vegetation cover density, and the climate of the area (Osterkamp *et al.* 1994; Raj & Azeez, 2012). Additionally, the channel width, depth and meanders also influence the amounts of sand deposited in a river channel, as stated by Charlton (2008) who also remarked that the stream velocity is higher at the constricted portions of the channel, a factor which promotes hydraulic erosion as opposed to the wider and shallower sections of the river where the deposition processes take place due to reduced velocity of the stream current.

According to Davis (1999), the stage of the river significantly influences the abundance of sand in the river channel whereby increasing amount of sand is noted from the youthful to the old stage where the main activity is deposition. From the findings by Davis (1999), there is little sand deposits at the youthful stage of the river because the rivers main activity is erosion coupled with a steep channel gradient which promotes removal of the eroded materials. The middle stage of the river is marked by a near equilibrium state between the inflow of water and sediments, a factor that causes a constant river bed elevation, thus moderate amounts of sand. The old stage of the river is characterized by aggradation of the river channel due to deposition that takes place, primarily promoted by the gentle slope gradient thus causing abundance of the sand.

On a study on the perennial river channel evolution, Duvall *et al.,* (2004) established that changes along the river channel such as local uplift, change in resistance of the rocks over which the stream flows as well as discharge variation may influence abundance of sand on a river channel. This is because such factors promotes river rejuvenation, a factor that acts against deposition of materials on a river channel. A study on ephemeral rivers in Spain by Sandercock & Hooke (2011) focused on the significance of vegetation on a river system. The study established that presence of riverine vegetation along the river banks helped reduce the bank erosion hence protecting the sand reserves deposited on the shifting banks of the rivers. The roots of such vegetation bound the sand materials thus making them firm and resistant to quick removal by the river current.

2.4 Effect of Sand Mining on the River Morphology

Lu *et al.,* (2007) studied sand mining in river Pearl which is the second largest river in China in terms of river discharge, mainly focusing on how the activity affected the river morphology. The findings indicated that sand mining had led to river channel incision, an outcome which closely agrees with that of Nabegu (2014); Rinaldi *et al.* (2005) and Kondolf (1997). Elsewhere in India, a study aimed at establishing the environmental effects of sand mining was carried out in Chalakudy, Periyar and Muvattupuzha rivers by Sreebha & Padmalal (2011). From the findings, sand mining was taking place uncontrolled due to lack of a proper informing policy, a factor that had led to modification of the river channel morphology. To address this, the study recommended that scientific assessments be carried out in rivers suffering from the same to help in formulating suitable

river management strategies. Since this situation is evident in Malawian rivers today, this study conducted an assessment in Luchenza river in a bid to help come up with suitable strategies to carry out sand mining without causing negative environmental effects.

In Europe, Rinaldi *et al.* (2005) carried out a study on some five rivers (Tagliamento, the Brenta, the Arno, the Ropa and Wisloka), basically looking at the effect of sand mining to the channel morphology. The study compared aerial photographs for four past decades and their findings ascertained that sand mining was positively contributing to the adjustment of the river channel. Preciso *et al.* (2012) also carried out a study on the impacts of land use change and sand mining to the change in river Reno channel morphology in Italy. The study employed aerial vertical photographs to compare the longitudinal river profiles for the past three decades. Their findings agreed with those of Rinaldi *et al.* (2005) which found out that high levels of sand mining had led to modification of the river channel.

Studies have been carried out in Africa regarding the effect of sand mining to the river morphology. For instance, Ta *et al.* (2014) studied the effects of sand mining to the soils and land in southern Nigeria using field observations and laboratory tests. The study established that rampant sand mining had led to collapsing of the river banks thus affecting the river geometry negatively. In Botswana, a study on the environmental effects of sand mining by Madyise (2013) established that sand mining had led to an increase in river channel depth and width. Further, it also pointed out that this activity had led to the degradation of the river water quality emanating from the oil spills of the loading tracks. The study by Madyise employed a purely descriptive approach while this study used both qualitative and quantitative approaches. Elsewhere in Nigeria, Nabegu (2014) carried out a study on the morphological impacts of sand mining on river Kano. The study employed the Analysis of Variance (ANOVA) to compare the variation in the channel morphological aspects at the active site of mining and the control sites. The study established that sand mining had contributed to alterations in the river channel morphology. In addition to that, the study also pointed out that this alteration had led to other environmental effects to the river system such as river incision and destruction of the riparian vegetation.

Hemalatha *et al.* (2005) carried out a study on sand mining in Uttara Pinakini River in India, and the study findings confirmed that sand mining contributed to depletion of the sand reserves along the river. Elsewhere in Europe, Salit and Ioana-Toroimac (2013) undertook a study in Siret and Buzau Rivers and found out that sand mining had caused sediment deficit in the rivers leading to channel incision up and downstream of the mining areas. The study used aerial photos of the last three decades and closely assessed the morphological impact of the sand mining in the stretch of the river visa-a-vis the increasing extraction of sand due to increasing demand. Similar results were obtained by Nabegu (2013) in Nigeria on a study conducted in Wudil river channel.

In their research, Mmom and Chukwu-Okeah (2012) found out that sand mining in the new Calabar river in Nigeria had resulted in significant down-cutting of the riverbed. In addition, it had caused an increase in channel slope angles which led to significant increase in stream velocity. This, in turn, increased the sediment transport capacity which accelerated channel incision causing some significant changes in channel morphology. However, the study did not inform on the best sand mining practices to be adopted. The findings of that study agreed with those of Lu *et al.*, (2007); Nabegu (2013); and Rinaldi *et al.* (2005) who also found out that sand mining had resulted into negative environmental effects such as alteration of the river channel morphology.

Chapter Three: Methodology

3.1 Research Design

This study used both quantitative and descriptive research designs. According to Cooper et al., (2013) descriptive research design is concerned with finding out the what, where and how of a phenomenon. On the other hand, quantitative research design involves the numerical presentation and manipulation of observations for the purpose of describing and explaining the phenomena that those observations reflect (Sukamolson, 2010). This research design enabled the researcher to obtain physical measurements on the current status of sand mining in Luchenza River with respect to the existing conditions. Additionally, it enabled the researcher to obtain and hence describe the socio-economic effects resulting from sand mining in the Luchenza River locality.

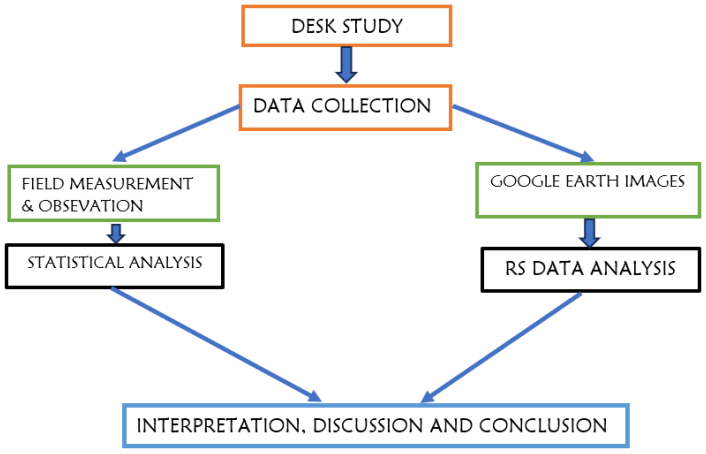


Figure 1 Showing a Flow Chart of Research Methodological Design Employed

3.2 Study Area

This research was conducted in Luchenza River which forms a boundary between Thyolo district and Chiradzulu district. Luchenza river section on which this study focused lies between longitude 8241373 and 8242425, and latitude 740155 and 736036 (Figure 1). Luchenza river is located in a mountainous area (refer to figure 3 below) which cause a lot of water to be directed to it during rainy season. This indicates that all eroded sediments

are deposited in this river. Luchenza river was selected because sand mining is taking place unregulated thus causing negative environmental effects on the river.

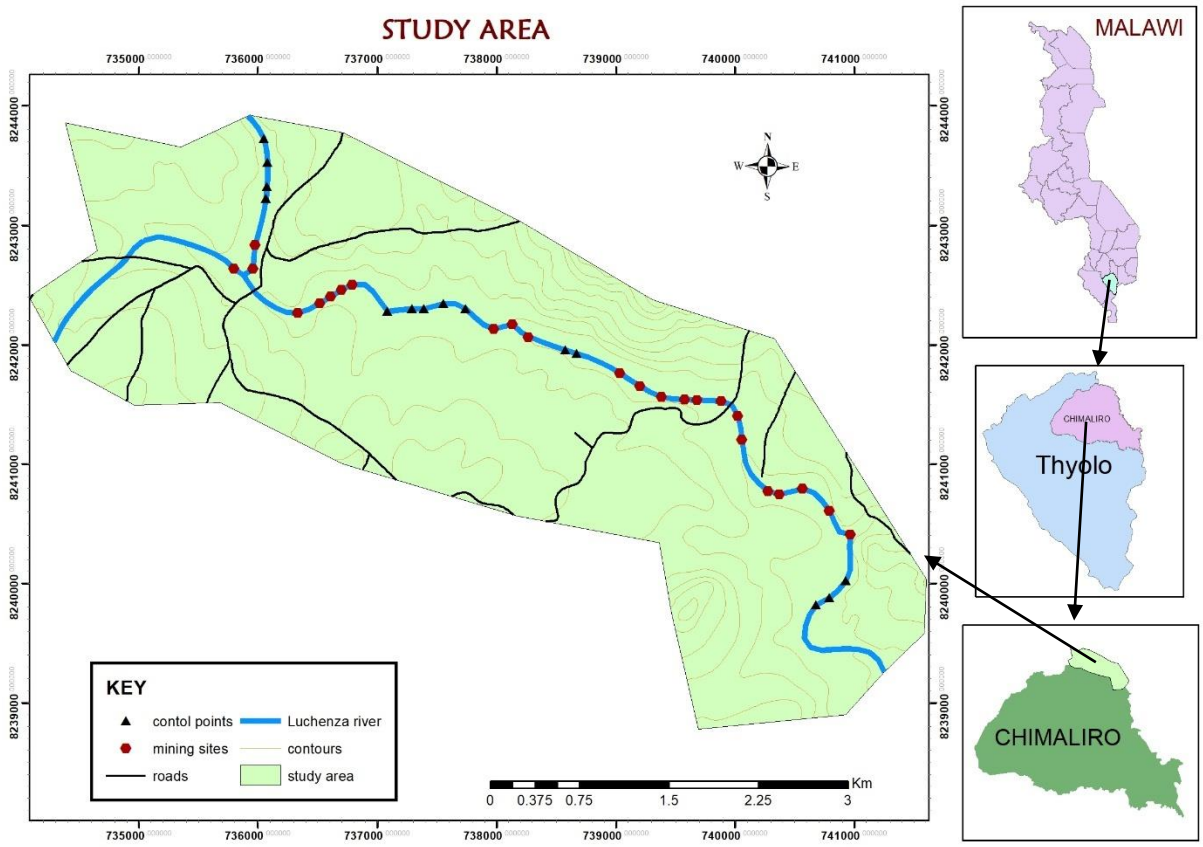


Figure 2Map of study area

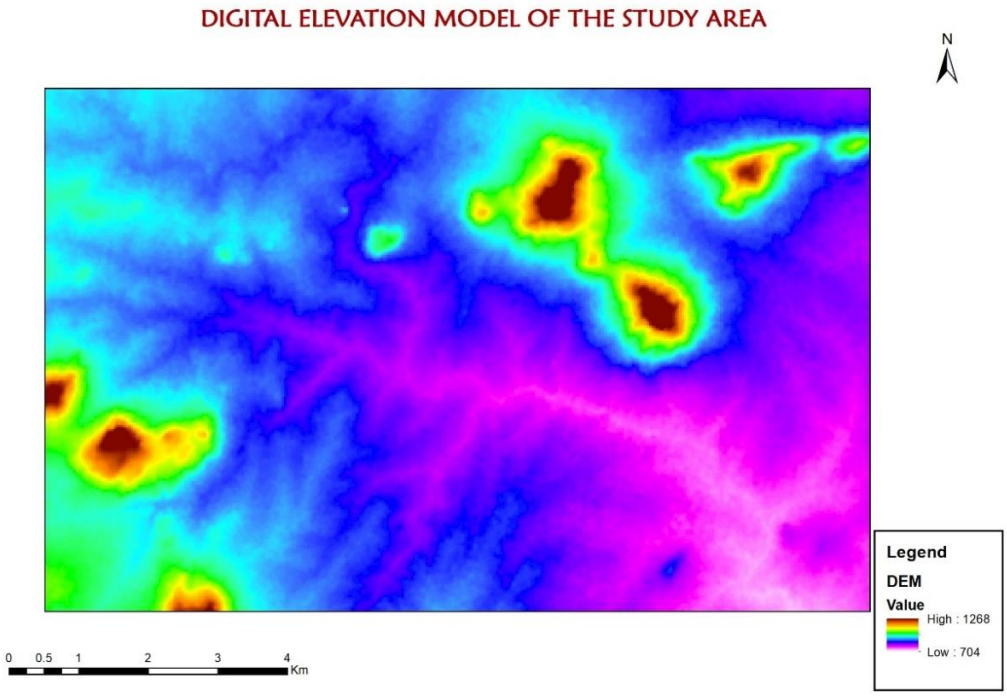


Figure 3 Digital elevation model

3.3 Materials and Methods

Materials which were used are: Tape measure, Garmin GPS, compass, SPSS software, QGIS software, ArcMap GIS and a computer.

3.3.1 Sample collection

3.3.1.1 Sampling of Sand Mining Sites

Data on the spatial extent of sand mining was collected using a GPS to give the actual geographic references for locations or sites with active sand mining activities along the river channel. While data for temporal extent of sand mining was obtained by asking few of the miner about when was sand mining pronounced to be a big deal for them.

To establish the morphological factors influencing sand abundance in Luchenza river, data on the independent variables influencing sand abundance was obtained through measuring and application of set rules of logic.

Along the river channel sites were selected up and downstream of the active site to act as control sites (Figure 2). The adjacency of the sites made it possible to obtain data on parameters with similar characteristics thus enabling comparison between the active and control sites, a concept that was used by Brown et al. (1998) to determine the morphometric response of the river channel to sand mining.

Data on bank position of the sites along the river channel was obtained through observation while data for slop angles of the river channel were obtained through physical measurements by using compass (the way we do when measuring dip angles). Data on vegetation cover, weathering status/geology and erosion status was acquired through use of observation and application of the set rules of logic. For the river channels width and depth aspects, physical measurements using a tape measure were conducted. (Appendix 1)

To analyse the impacts of sand mining in the river channel, time-series of Google earth images was used. Google earth images of 2013, 2016 and 2024 were used and analysed using QGIS software to find formation and extent of point bars and channel bars, as well as changes in the area of river water bodies and river bodies through those years. A historical photo on Google Earth shows that the 2013 image was the oldest with better resolution of the study area. Thus, the year 2013 became a reference to see the morphology and physical dynamic conditions of Luchenza river.

3.4 Data Analysis and Presentation

For objective one which was in determining the extent of sand mining along Luchenza river, the GPS generated data was downloaded into QGIS software for further processing and mapping to provide spatial and/ or location-based information for characteristics of sand mining sites. For objective two which was to establishing the morphological factors influencing sand abundance along Luchenza river (dependent variable), data on variables namely the bank position, slope angles of the channel, vegetation cover, weathering status/geology, erosion status and the river channels width and depth were imported into SPSS statistical software environment and the binary logistic regression analysis was carried out. The marginal effects and p-values generated helped to point out the significant morphological variables influencing abundance of sand in the river channel. Objective three, to determine if there is impact sand mining of sand mining on physical dynamics of Luchenza river, a multiple logistics regression analysis was implemented and Google Earth images were collected to analyse and observe the differences that has been occurring from 2013-2024 to the river channel.

3.4.1 Binary Logistic Regression

To establish the morphological factors influencing abundance of sand along Luchenza river, a binary logistic regression analysis was applied. This predicts the presence or absence of a characteristic or outcome based on values of a set of predictor variables. This procedure is similar to linear regression but is suited to models in which the dependent variable is dichotomous (Tranmer & Elliot, 2008). In this study, sand abundance status is dichotomous in that a point along the river may be having either high (1) or low (0) sand abundance status as predicted by the independent variables stated above. Equation 3.1 shows a binary logistic regression model.

$$Y = \frac{e^{(\beta_0 + \beta_1 X_1)}}{1 + e^{(\beta_0 + \beta_1 X_1)}} \quad (3.1)$$

Whereby "e" is the exponential function and the "$ß_0 + ß_1X_1$" is the familiar equation for the regression line.

3.4.2 Google Earth Images Processing

The downloaded Google images were inserted into QGIS to see the changes that have been happening to river channel due to sand mining in the river. This was done by pointing out channel bars, point bars and river width along the river channel. The river was divided into three segments, the upstream (Nansadi), the mid (Dam) and lower segment. These segments were analysed separately and observe the changes that has been occurring through the given range of years.

3.4.2 Multiple Logistic Regression

In examining the effect of sand mining on the morphology of Luchenza river, multiple logistic regression analysis was carried out using SPSS software. This classified subject based on values of a set of predictor variables. This type of regression is similar to binary logistic regression, but it is more general because the dependent variable is not restricted to two categories (Starkweather & Moske, 2011). See Equation 3.2 showing the multinomial logistic model.

$$Y = \frac{e^{[(\alpha^1 - (\beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_n X_n)]}}{1 + e^{[(\alpha^1 - (\beta_0 + \beta_1 X_1 + \ldots\ldots + \beta_n X_n)]}} \qquad (3.2)$$

Whereby, Y is the river morphology, e is the exponential value, α is the intercept value in the normal linear regression model, $ß_i$ is the gradient for an independent variable X_i while $ß_n x_n$ represents the gradient values multiplied by the respective independent variables considered in this case, up to the last value.

A data set with dependent variable namely the river morphology and the independent variables namely sand volume leaving the site daily (as provided by sand miners), the river channels depth and width, and channel slope angles was used (Appendix 2). All these were imported into SPSS software environment and multiple logistic regression analysis was employed. The multiple logistic regression provided information on whether there was a change in river channel morphology and also showed the magnitude of this change. This ability was important as it provided information which was used in devising a mechanism to recommend on safe sand mining practices.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Results

This chapter presents results of the study according to the data collected from the field and analysed using various methods.. The results are also presented and discussed as per the study objectives in order to draw the study conclusions.

4.1.1 The Extent of Sand Mining in Luchenza River

The study sought to establish the extent of sand mining in Luchenza river by assessing the temporal and spatial.

4.1.1.1 Temporal Extent of Sand mining in Luchenza River

History of the study area indicates that sand mining flourished during the construction of Malawi University of Science and Technology way back in 2012. This was followed by people migrating to this area for business purposes. In light of that, it is logical to infer that cumulatively, significant amount of sand has left the river Luchenza channel over time, a factor that may have contributed to the negative effects facing the channel such collapsing of the banks, depletion of sand reserves and loss of riparian vegetation.

4.1.1.2 Spatial Extent of Sand Mining in Luchenza River

Three sites where active sand minig was taking place were identified along Luchenza river. Locational data was plotted using ArcMap GIS to show the spatial distribution of the sites (Figure 2). The siting of the identified sand mining sites was influenced by the ease of accessibility as well as abundance of sand reserves along the river for mining. Ease of accessibility promotes exploitation since it eases the transportation process while sand abundance enhances large scale exploitation which in turn attracts more income. Presence of many sand mining sites along Luchenza river is an indicator that a lot of sand leaves the channel per year. The effects of that are evident in the river channel which include instability of the banks, loss of riparian vegetation as well as widening of the river channel.

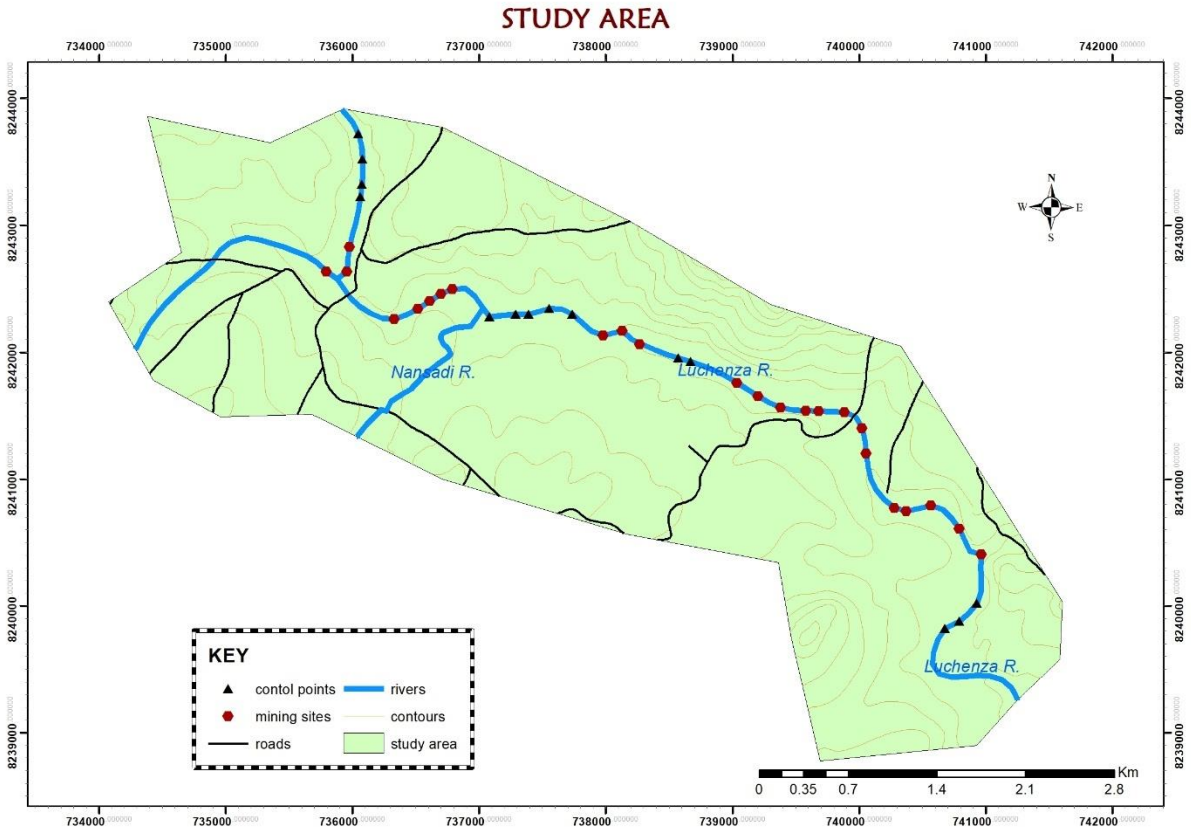


Figure 4 Spartial extent of sand mining; sample points

4.1.2 Morphological Factors Influencing Abundance of Sand in Luchenza River

The study sought to establish the morphological factors influencing abundance of sand in Luchenza river channel, by examining data on variables such as the river bank position, channel width, depth, slope angles, vegetation cover status, weathering status and erosion status along the river channel. A binary logistic regression model was employed to determine the influence of the previously stated variables to sand abundance in the river channel. Data was imported into SPSS software whereby it was divided into model training data (70%) and model testing data (30%) (Kim et al., 2018). Training data was used to develop a Binary Logistic Regression model as well as optimizing its accuracy, while the testing data was used to test the accuracy of the model. The model testing results arrived at indicated that the model was able to predict the placements of the data with an accuracy of 85%. In addition, the model gave out marginal effects and P-values which showed the level of significance of each variable in influencing abundance of sand in Luchenza river channel. The results pointed out that the river bank position, channel width, depth and slope angles were the significant variables influencing sand abundance in the river channel.

Table 1 shows the logistic regression outputs for individual variables as predicted by the model.

Table 1: The Binary Logistic Regression Model Output

Variables	Marginal Effects	Std. Err.	Z	P>|z|
Bank position	-0.749897	0.065864	-11.386	2.2e-16 ***
Slope Angles	-0.234497	0.050459	-4.6473	3.363e-06 ***
Width	0.146518	3.9948	0.036677	6.474e-05 ***
Depth	-1.44542	0.29134	-4.9613	7.001e-07 ***
Vegetation Status	-0.021309	0.112042	-0.1902	0.8492
Erosion Status	-0.083333	0.099355	-0.8387	0.4016
Weathering Status	0.076923	0.099510	0.773	0.4395

*Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

4.1.2.1 Effect of River Bank Position on Sand Abundance

The results showed that river bank position had actively contributed to abundance of sand in a river channel as seen from the marginal effects and p-values of river bank position in table 1 respectively. This implies that sand quantity increased by 74.9% as one moved from concave to convex bank, which is significant as indicated by the respective p-value 2.2e-16. As a result, the convex banks have more sand compared to the concave banks. The finding of this study agrees with those of Hugget (2007) who established that the convex banks were characterized by deposition while the concave banks were characterized by active erosion. In the same vein, the findings agree with those of Cameron & Baucher (2014) who expressed that the concave banks experience greater hydraulic impact of the river water current, a factor that weakens the river bank thus promoting removal of materials unlike in the convex banks.

4.1.2.2 Role of Slope Angles on Sand Abundance

The results indicated that slope angles were active contributors of sand abundance on the river channel as seen from the marginal effects and p-values in table 1 respectively. This means that a unit reduction in slope angle led to 23.44% increase abundance of sand, which is significant as indicated by the respective p-value 3.363e-06. The convex banks were established to have lower slope angles and high

sand abundance compared to the concave banks. According to Cameron & Baucher (2014), low river channel angles characterizing the convex banks encourage deposition of sand since it facilitates slow movement of water. On the other hand, Varouchakis et al., (2016) pointed out that concave banks are characterized by active erosion, a factor that discourages deposition and accumulation of sand since the slope angles on such banks are high.

4.1.2.3 River Channel Width and Sand Abundance

The results indicated that slope angles were active contributors of sand abundance on the river channel as seen from the marginal effects and p-values in table 1 respectively. As deduced from marginal effects and p-values in table 4.3, a unit increase in river channel width led to 14.65% increase in sand abundance, which is significant as pointed out by the respective p-values 6.474e-05. This implies that sand abundance increases with increase in width of a river channel. The study established that an increase in channel width causes spreading out of the river water thus compromising its speed hence the load carrying ability. Reduced speed of the river water leads to deposition at wider sections of the river channel as opposed to the narrow sections of the channel which are often characterized by high speed of water flow which in turn promotes erosion as opposed to deposition. Elliott (2006) arrived at similar results in a study on sand mining in a perennial river.

4.1.2.4 River Channel Depth and Sand Abundance

The channel depth was established to influence sand abundance along the river channel. Regarding this, the marginal effects and p-values in table 1 indicate that a unit decrease in the river channel depth leads to 144.54% increase in sand abundance, which is significant as indicated by the respective p-value 7.001e-07. Going by this, it is evident that shallower sections of the river channel are characterized by high sand deposition and accumulation. This agrees with findings by Varouchakis et al, (2016) that narrow and deep sections of the river channel are characterized by high speed of the river current since they act as constrictions, a factor that promotes erosion processes as opposed to deposition. Increase in depth of a river channel is usually coupled with increasing slope angle, a factor that discourages deposition. Additionally, sections of the river channel characterized by

great depths experience more erosion since they are characterized by softer rocks, and this discourages sand deposition process in such sections. On the other hand, active deposition of sands on a river channel leads to reduced depth and slope angles, an aspect that promotes presence of high sand abundance.

The marginal effects (ME) and p-values obtained for some variables such as the river channel width (ME=0.146518, P= 6.474e-05), depth (ME=-1.44542, P=7.001e 07), slope angle (ME=-0.234497, P=3.363e-06), and bank position (ME= -0.749897, P=2.2e-16) indicate that there were some variables that significantly influenced sand abundance in the Luchenza river channel. This informed the rejection of the null hypothesis of 'There are no significant morphological factors influencing sand abundance in the Luchenza river' and adoption of the alternative hypothesis.

4.1.3 Effects of Sand Mining on the Morphology of the River Channel

4.1.3.1 Statistical Method

The study sought to establish the effect of sand mining to the river morphology. Data on variables such as the sand mined, river channel width, depth and slope angles from the control and active sites was imported into SPSS whereby multiple logistic regression technique was applied to analyse it. The data was divided into model training (70%) and testing portions (30%), whereby the training data was used to develop the model as well as optimizing its accuracy. The model was able to compare data from the control and active sites while taking low as the reference category. This enabled the model to generate an output indicating whether sand mining activity had either caused modification of the channel morphology or not. The test results using the testing data showed that the model was able to predict the categorical placements of the data variables with an accuracy of 87%.

4.1.3.1.1 Sand Mining and the River Channel Width

Sand mining was established to significantly contribute to the increase in the river channel width, as seen from the marginal effects and p-value in table 2.

Table 2: Logistic Regression Model Output Effect of Sand Mining on River Channel Width

Factor	AME	SE	|Z|	|P|
Sand mined on Width	0.1192	1.516870	-1.7850840	9.959148^{e-03}***

*Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

As deduced from the marginal effects, a unit increase in sand mined led to 11.92% increase in the river channel width as compared to the control sites, an increase which is significant as indicated by the p-value ($9.959148^{e-}03$). The study finding agrees with those of Muiruri & Amimo (2017) who established that uncontrolled sand mining leads to increased width of the river channel especially if carried out at higher levels than the natural replenishment. In this case, sand replenishment rates are low since the river channel only gets water during the rainy season. According to results in this study, sand mining has also caused steepening and collapsing of the channel banks in the active mining sites. This has in turn caused loss of some riparian vegetation along such banks, a factor that affects the environment adversely as shown in figure 4.1. This agrees with a study by Nguru (2007) which established that high rates of sand mining had led to loss of riparian vegetation as one of the negative environmental effects. Therefore, it is logical to infer that sand mining rates in Luchenza river could be taking place at a higher rate than the natural replenishment rates since positive geomorphic feedback response of the channel is evident.

4.1.3.1.2 Sand Mining and River Channel Depth

The results indicated that sand mining had a significant influence on the river channel depth.

Table 3: Regression Output on Influence of Sand Mining on the River Channel Depth

Factor	AME	SE	|Z|	|P|
Sand mined on Depth	0.3088	1.998685	-2.82307997	$7.193669^{e-}02$***

*Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

The marginal effects in table 3 shows that a unit increase in sand mined led to 30.88% increase in in channel's depth compared to the control sites. This increase was significant as suggested by the p-values ($7.193669^{e-}02$). Other studies on sand mining by Kondolf (1997) and Amponsah-Dacosta & Mathada (2017) also indicate that uncontrolled sand mining results in increased depth of the channel, a factor that comes about due to depletion of sand reserves. Those studies agree with this study, which established that sand

mining had caused increased depth of the river channel. According to Nabegu (2014), change in river channel morphology comes about in cases where sand mining rates exceed the replenishment rate through natural means. Following that, it is logical to infer that sand mining in Luchenza river is being undertaken at high rates which are not sustainable as confirmed by the positive geomorphic feedback response of the river channel. This was proven further by elevation profile on Google earth pro, areas where sand mining was taking place there was sharp decrease in elevation (as indicated by black dots in figure 5).



Figure 5 Elevation profile of Luchenza river

4.1.3.1.3 Sand Mining and River Channel Slope Angle

As deduced from the marginal effects of sand mined on channel slope angle in table 4, sand mining had caused a significant increase in channel slope angle.

Table 4: Logistic Regression Model Output of Sand Mining on the river Channel Slope Angles

Factor	AME	SE	|Z|	|P|
Sand mined on Slope Angle	0.2894	1.789966	-0.2283078	9.378761^{e-03}***
*Significance Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*				

A unit increase in sand mined led to 28.94 % increase in the river channel slope angles compared to slope angles of the control sections, which is significant as pointed by the p-

value (9.378761^{e-}03). This implies that sand mining has contributed to increased channel slope angle, a factor that is associated with adverse environmental effect such as accelerated stream flow resulting to channel erosion. That agrees with Kondolf (1997) who established that high rates of sand mining had led to increased slope angle of the channel, a factor that promotes increased instability of the channel. The study indicated that sand mining zones were characterized by unstable banks, with some collapsing thus leading to loss of riparian vegetation. High channel slope angle led to accelerated erosion, a factor that promoted positive feedback process of the river system.

4.1.3.2 Remote Sensing

4.1.3.2.1 Change in Morphological and Physical Dynamics in Luchenza River in 2013

Data from 2013 shows the condition of the Luchenza River with a smaller amount of water body compared to sedimentation, which forms point bars and channel bars. River curves in 2013 look sharper to form meandering where dominant sedimentary deposits occurred (Figure 3). The map of 2013 shows sediments deposits forming a point bar with an area of approximately 26,657m^2, as shown in table 5. In addition to sediments that form a point bar, there are also sediments that formed a channel bar with an area of approximately 9,694m^2 (Table 5). Sediment deposits that formed point bars left a body of Luchenza river water with an area of approximately 12,239m^2 (Table 5).

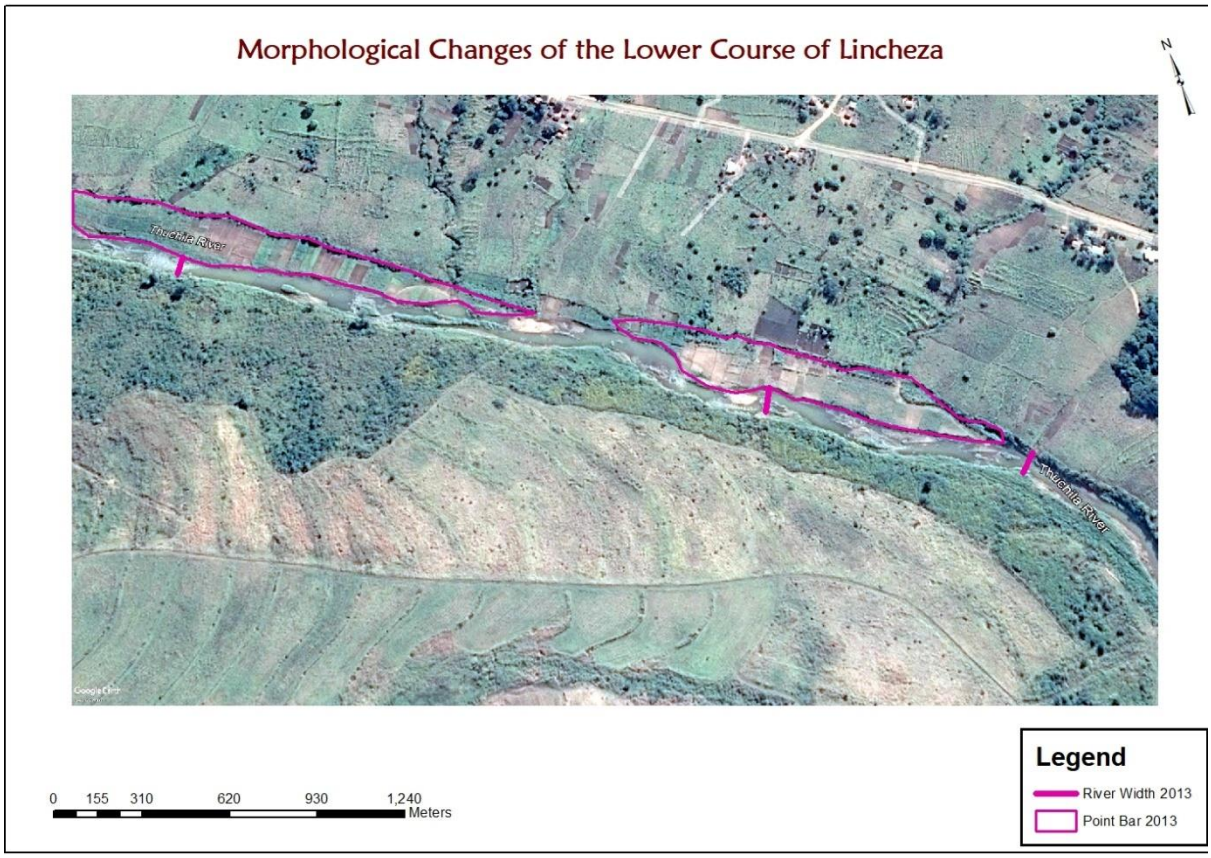


Figure 6 Lower course of Luchenza river 2013

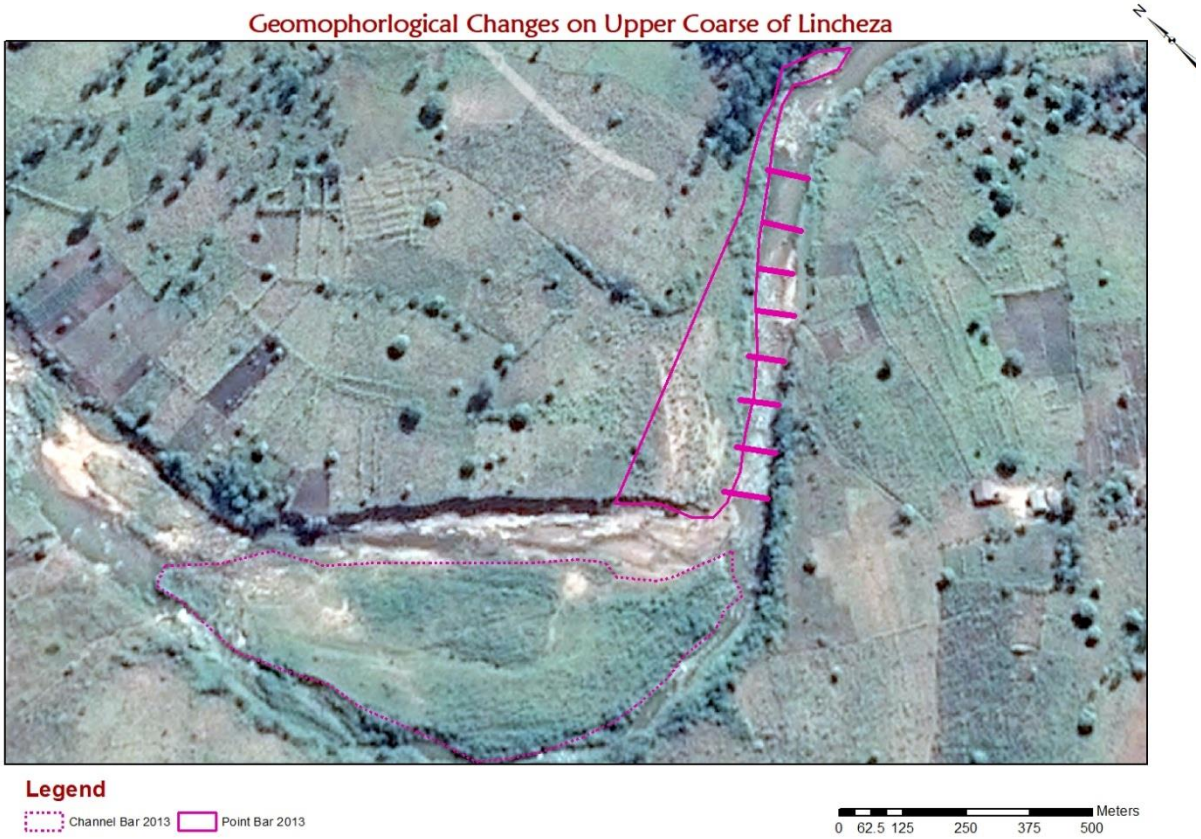


Figure 7 Upper course of Luchenza river 2013

4.1.3.2.2 Changes in 2016

Data of 2013 was the oldest Luchenza River dataset with best resolution I got from Google Earth, so the 2013 data became s reference in looking at changes in morphology and physical dynamics conditions of the Luchenza River. The 2013 data was compared with 2016 data to see changes in morphological shape of Linchza River. Data on the area of river water bodies, the extent of point bars, and channel bars along with the accompanying changes are important to understand the extent of morphological changes and the dynamic physical conditions of the Luchenza River from year to year. Data for 2014 show that the area of a river water body or river water body is 14,672m^2, the area of the channel bar is 10,914m^2, and the area of the point bar is 14,805m^2 (Table 5). When compared with 2013 data, in 2016 the river water body increased by 2,433m^2 compared to the river water body area in 2013 that was only 12,239. In 2016 the area of point bar decreased, namely the area of point bar in 2013 covering an area of 26,657m^2 reduced to 14,805m^2. Thus, a reduction in the area of the point bar amounted to 11,805m^2. In

addition, the area of the channel bar also experienced an increase in area, i.e. the area of the channel bar in 2013 of 9,694m^2 was increased to 10,914m^2 in 2016. Data on changes in the area of river water bodies, point bars, and channel bars are listed in Table 5.

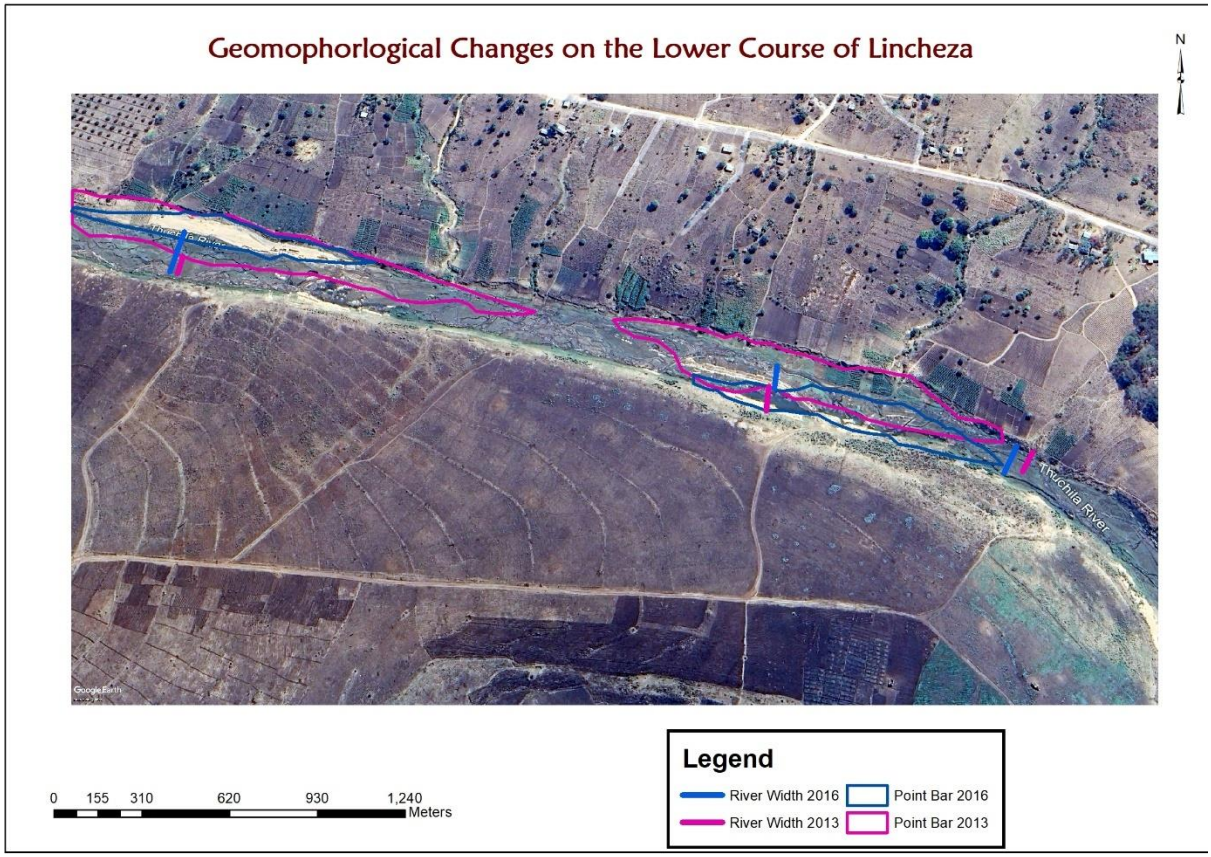


Figure 8 Morphological changes in 2016

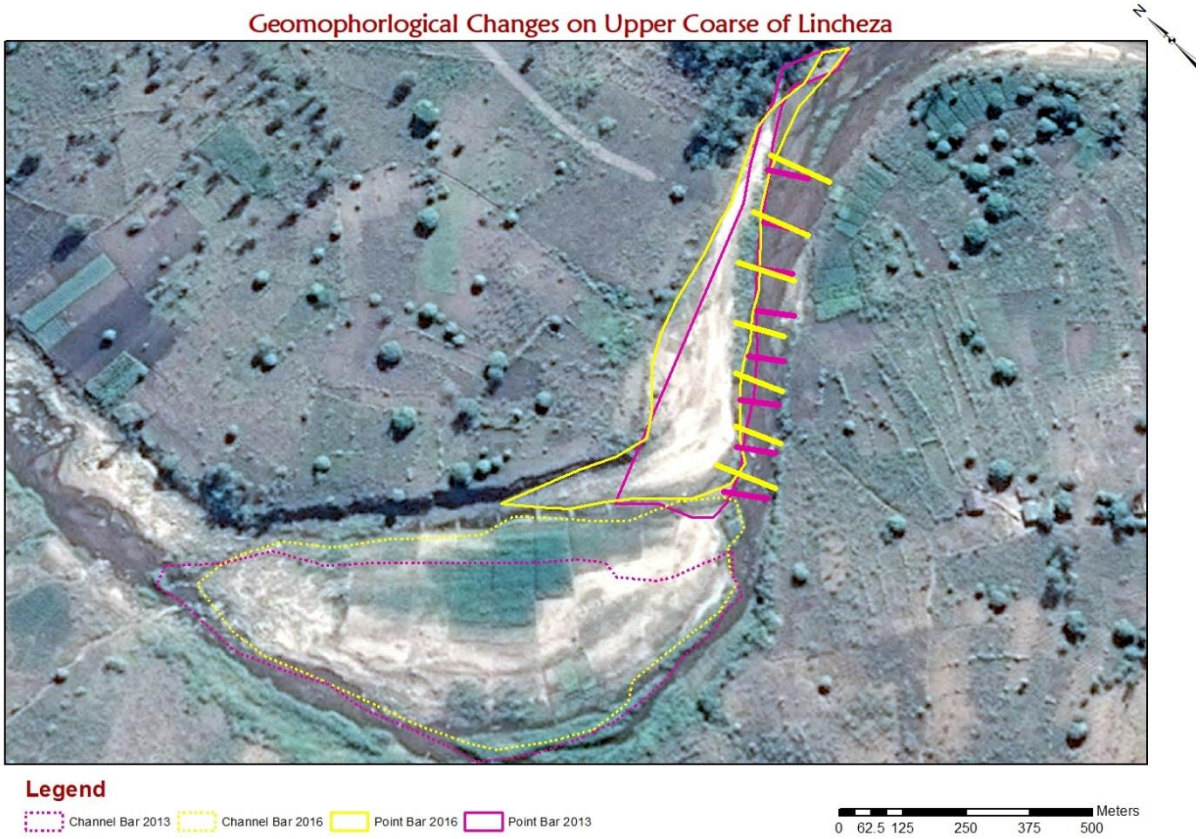


Figure 9 Morphological changes in 2016

4.1.3.2.3 Changes in 2024

On the map in 2024, there are lines with different colours. This was done to indicate different years to provide information about the situation and condition of the physical dynamics of the Luchenza River from 2013 to 2024. Thus, the map in 2024 collects all the conditions of the river morphological changes in Luchenza River from 2013 to 2024. In 2024. Luchenza water body has an area of 31,418m^2, point bar has an area of 6,784m^2 and channel bar has an area of 12,937m^2.

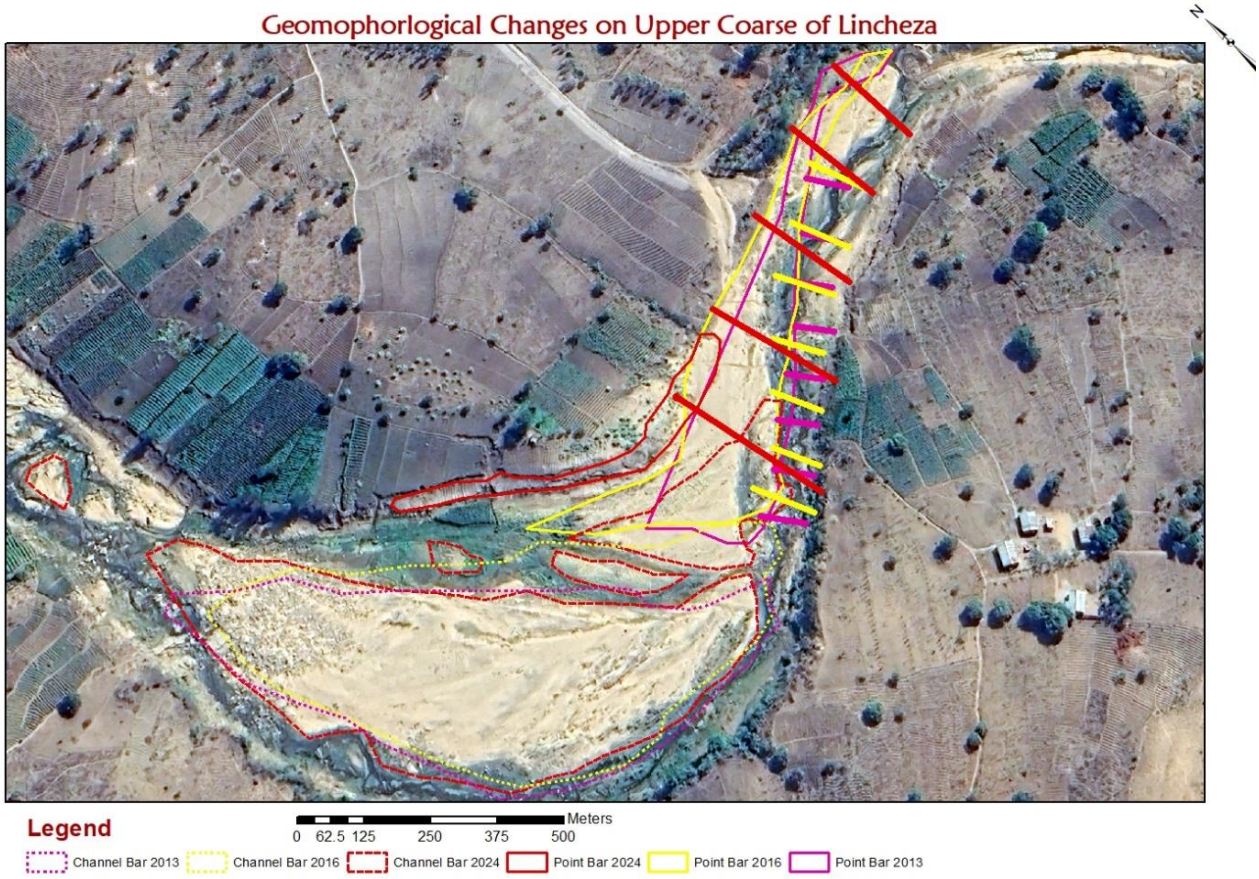


Figure 10 Morphological Changes in 2024

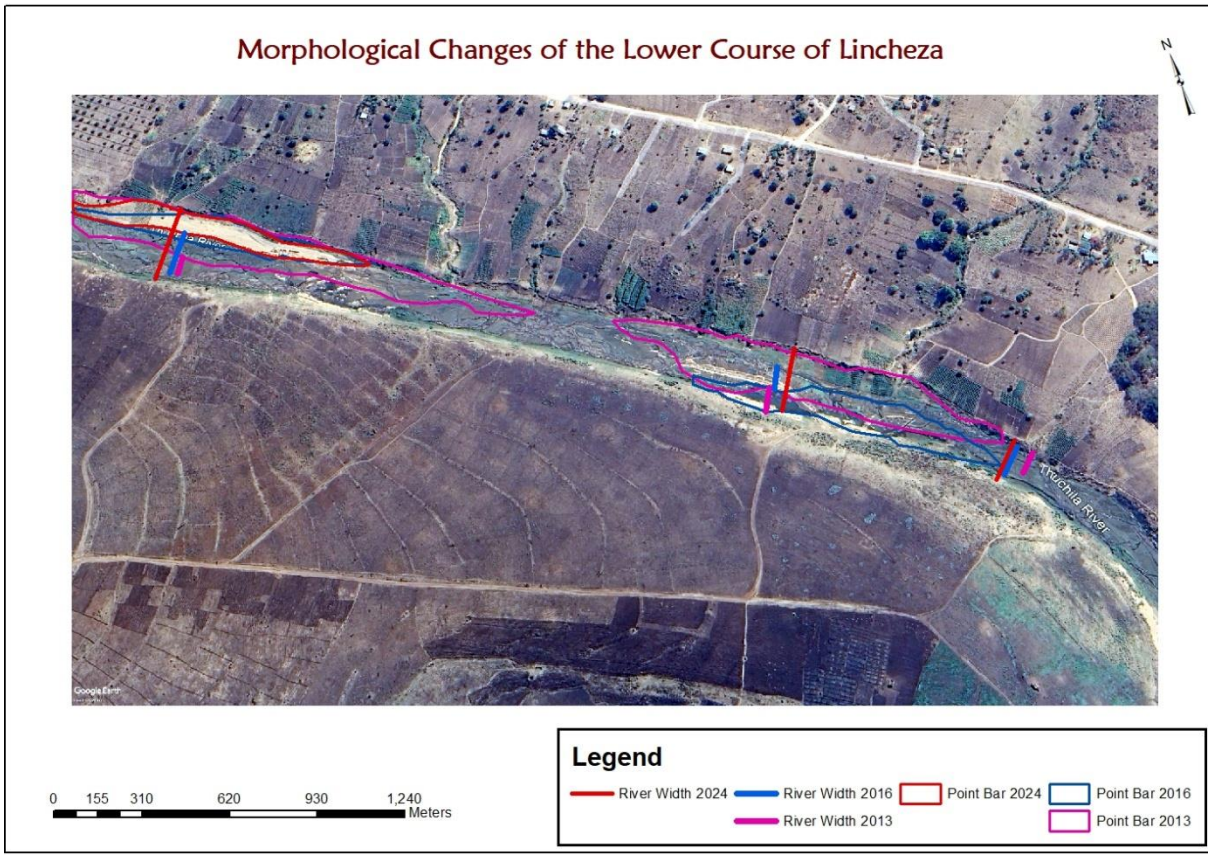


Figure 11 Morphological changes in 2024

Based on observation from Google Earth image, it can be seen that there were changes in the pattern of river flow and sediment deposition in Luchenza River which takes place from year to year. Analysis of river's physical condition, especially changes in flow direction and river meandering due to mining activities based on time periods by utilizing geographic information systems (Sheela et al., 2018). Condition of Luchenza River in 2016 is very different from the situation in 2024. There has been a considerable change morphology of the river. According to Buffington et al. (2012), rivers can exhibit a broad range of responses to changing in time scales from small-scale adjustment of channel characteristics (grain size, width, depth) to large scale alteration of reach morphology. Figure 7&8 shows changes in river flow patterns between the year 2013, 2016 and 2024. Based on satellite imagery, in 2013 there were still sharp turns, after 2016, the turns tend to be increasingly sloping along with the growing river water bodies. By using remote sensing data, the management of Luchenza River sand mining can provide a complete picture related to the changes in morphology and physical dynamics conditions of the river, based on time-series data. Google earth image data shows that river flow changes

occur in places or areas where there are mining stations that are operating. This description is very helpful in the effort to manage sand mining in the Luchenza River. Table 5 summarizes changes in the extent of river water bodies, point bars, and channel bars in 2013, 2016 and 2024.

Table 5: Compilation of extent of river water bodies, point bars, and channel bars

Description	2013	2016	2024
River water body area (m^2)	12,239	14,672	31,418
Point bar area (m^2)	26,657	14,805	6,784
Channel bar area (m^2)	9,694	10,914	12,937

The reduced sediment deposition is caused by the increasingly widespread mining of sand in the Luchenza River. River sediment extraction also triggers changes in river morphology, such as river bends (meandering), direction of flow, river width, and river depth. This was stated by Kondolf (1997), Luo et al. (2007) and Melton (2009), that the magnitude of the impact arising from sand mining in river flows depends on the amount of extraction relative to the sediment transport supply load.

4.2 Discussion

The test results have indicated that sand mining have significantly influenced the channel morphology through causing increased channel width (AME=0.1192, P = 9.959148e-03), depth (AME=0.3088, P=7.193669e-02) and slope angle (AME= 0.2894, P=9.378761e-03) as informed by respective marginal effects and p-values. Following that, the study rejected the null hypothesis thus adopting the alternative hypothesis. The fact that the said morphological parameters have been modified at the active mining sites by sand mining in Luchenza river implies that sand mining is taking place at high rates which are unsustainable. This agrees with findings by Ashraf *et al.,* (2010) who established that high rates of sand mining bring about negative effects to the river channel such as modified river morphology. According to Muiruri et al. (2020), "sand mining had significantly increased river channel's width, depth and slope angles at active mining sites compared to control sites" (p. 12).

Using the analysis of the physical dynamics' conditions of Luchenza River based on google earth imagery, it can be explained that the morphological changes and physical dynamics of Luchenza River showed their own patterns. If sediment deposits that form point bars or channel bars decrease, the area of river water bodies tends to increase accompanied by a tendency to reduce river width (Arsyad et al., 2020). Or in other words, the width of the river is inversely proportional to the increase in the area of the river water body if the area of sediment deposits that form the point bar and channel bar tends to decrease. Reduction of sediment in Luchenza River is useful to control flooding. Thus, sand mining helps to restore the ecological function of the Luchenza River in controlling and preventing flooding. Rinaldi et al. (2005) stated that exploitation of bed material from its channel might in some cases have beneficial effects for flood-control purposes, channel stability and restoration. Removal of material from a river can alter the channel, river hydraulics, or sediment budget, which in turn can alter the distribution of habitats and ecosystem functioning. These types of impacts can be difficult to attribute to sand mining, as they may require long time frames to emerge (Koehnken et al., 2020). Therefore, it is important to analyze time-series data in order to see the pattern of morphological changes over a long period.

CHAPTER FIVE: CONCLUSION AND RECOMENDATION

5.1 Conclusion

Based on the findings of this study, the following conclusions were arrived at: Firstly, the extent of sand mining in Luchenza river has over stretched in terms of temporal, spatial and quantity with mining having taken place over 14 years. Three sites were identified along the river where active sand mining was taking place, a factor that contributed to more sand leaving the river channel. Secondly, the abundance of sand along the Luchenza river channel was influenced by the river width, depth, slope angle and the position of the river bank. Therefore, there is need to observe these factors while siting sand mining sites so as to minimize adverse environmental effects to the river environment.

Lastly, sand mining is causing negative effects to the river system such as alteration of channel morphology and loss of riparian vegetation, a factor that shows that sand mining rate in Luchenza river is unsustainable since the channel is undergoing positive geomorphic feedback.

5.2 Recommendation

In a bid to ensure environmental sustainability and continued socio-economic benefits of sand mining to the community and the society at large, this study gave the following recommendations:

i. Legal authorities should undertake to regulate quantities of sand mined from Luchenza river through closure of some mines in order to reduce the spatial extent of sand mining. These shall occasion reduced unit quantities of sand leaving Luchenza river per year thus promoting sustainable sand mining.
ii. There is need to carry out regular Environmental Impact Assessment (EIA) and Environmental Audit (EA) by the regulatory authorities to help monitor the environmental effects resulting from sand mining. This will help detect early signs of high rates of sand mining such as increased slope angles, width and depth of the river channel and the bank instability in order to continuously inform on the best ways of sand mining.

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APPENDICES

Appendix 1: Rules of Logic Applied in Data Collection on Some Physical Variables as inspired by a study on ecological informatics by Ekström (2018)

(i) Data on sand abundance status: Sand occupying the river bed at levels above 1.5 metres from the top of the river bank was termed as high while that occupying the river bed at levels below 1.5 metres from the top of the river bank was considered low.

Longitude	Latitude	Sand Abundance Status		
		High (1)	Moderate (2)	Low (0)
739985	8241466			0
739927	8241478	1		
739891	8241486	1		
739821	8241511	1		
739649	8241558	1		
739589	8241571	1		
739545	8241584	1		
739476	8241593			0
739325	8241666			0
738993	8241753			0
738800	8241857			0
738559	8241947			
738411	8241999	1		
738123	8242104	1		
737942	8242165	1		
737745	8242321		2	
737161	8242157	1		
736352	8242214			0

736155	8242298	1		
736036	8242425	1		
736618	8242451	1		

(ii) Data on Vegetation Cover: A slope with less than 30% vegetation cover were deemed to have low vegetation, those with above 30% vegetation cover were termed high.

Longitude	Latitude	Vegetation Status	
		High (1)	Low (0)
739985	8241466		0
739927	8241478		0
739891	8241486		0
739821	8241511	1	
739649	8241558	1	
739589	8241571		0
739545	8241584	1	
739476	8241593		0
739325	8241666		0
738993	8241753	1	
738800	8241857	1	
738559	8241947	1	
738411	8241999	1	
738123	8242104		0
737942	8242165		0
737745	8242321		0
737161	8242157		0
736352	8242214	1	

736155	8242298	1	
736036	8242425	1	
736618	8242451	1	

(iii) Data on Erosion Status: Slopes characterized by both rills and gullies and are scantly vegetated were considered highly eroded, while those characterized by simple rills but without gulley's and were vegetated termed as lowly eroded.

Longitude	Latitude	Erosion Status	
		High (1)	Low (0)
739985	8241466	1	
739927	8241478	1	
739891	8241486		0
739821	8241511		0
739649	8241558		0
739589	8241571	1	
739545	8241584	1	
739476	8241593	1	
739325	8241666	1	0
738993	8241753		0
738800	8241857		0
738559	8241947		0
738411	8241999		0
738123	8242104	1	
737942	8242165	1	
737745	8242321	1	
737161	8242157	1	
736352	8242214	1	

736155	8242298		0
736036	8242425	1	
736618	8242451	1	

(iv). Data on Weathering Status/Geology: An area where the bedrock is wholly covered by the detritus derived from its degradation was termed as highly weathered and where the bedrock was partly covered and wholly visible due to the absence of surficial detritus was termed as lowly weathered.

Longitude	Latitude	Weathering Status	
		High (1)	Low (0)
739985	8241466	1	
739927	8241478		0
739891	8241486		0
739821	8241511		0
739649	8241558	1	
739589	8241571	1	
739545	8241584	1	
739476	8241593	1	0
739325	8241666		0
738993	8241753		0
738800	8241857	1	
738559	8241947	1	
738411	8241999	1	
738123	8242104	1	
737942	8242165	1	
737745	8242321		0
737161	8242157	1	

736352	8242214	1	0
736155	8242298		0
736036	8242425		0
736618	8242451	1	

(v) Data on slope angles:

Longitude	Latitude	Slop angle in degrees
739985	8241466	12
739927	8241478	13
739891	8241486	12
739821	8241511	15
739649	8241558	21
739589	8241571	22
739545	8241584	20
739476	8241593	19
739325	8241666	12
738993	8241753	11
738800	8241857	13
738559	8241947	12
738411	8241999	19
738123	8242104	16
737942	8242165	15
737745	8242321	13
737161	8242157	11

736352	8242214	10
736155	8242298	13
736036	8242425	12
736618	8242451	15

(vi) River Channel Width

Longitude	Latitude	River width (m)
739985	8241466	43.4
739927	8241478	48.6
739891	8241486	49.2
739821	8241511	51.5
739649	8241558	51.5
739589	8241571	51.2
739545	8241584	49
739476	8241593	50
739325	8241666	48
738993	8241753	50
738800	8241857	49
738559	8241947	50
738411	8241999	47
738123	8242104	82
737942	8242165	92
737745	8242321	30
737161	8242157	32

736352	8242214	26
736155	8242298	67
736036	8242425	62
736618	8242451	71

(vii) River channel depth

Longitude	Latitude	River depth
739985	8241466	2.6
739927	8241478	2.1
739891	8241486	2
739821	8241511	1.9
739649	8241558	3
739589	8241571	3.2
739545	8241584	3.6
739476	8241593	3.1
739325	8241666	2.9
738993	8241753	2.4
738800	8241857	2
738559	8241947	2.3
738411	8241999	3.5
738123	8242104	3.4
737942	8242165	2.3
737745	8242321	1.7
737161	8242157	1.6

736352	8242214	1.8
736155	8242298	1.5
736036	8242425	1.2
736618	8242451	1.3

(viii) River Bank Position:

Longitude	Latitude	River bank position	
		concave (0)	convex (2)
739985	8241466	0	
739927	8241478	0	
739891	8241486	0	
739821	8241511	0	
739649	8241558		1
739589	8241571		1
739545	8241584		1
739476	8241593	0	
739325	8241666	0	1
738993	8241753		1
738800	8241857		1
738559	8241947		1
738411	8241999	0	
738123	8242104	0	
737942	8242165	0	
737745	8242321	0	
737161	8242157	0	

736352	8242214		1
736155	8242298		1
736036	8242425	0	
736618	8242451	0	

Appendix 2: Data on Effect of Sand Mining to River Channels Depth, Width and Slope Angles

I.D	Sand mined (Tones)	Depth	Width	Slope Angle
1.	200	2	2	1
2.	120	2	2	1
3.	100	2	2	2
4.	100	3	2	2
5.	50	3	1	2
6.	0	3	2	2
7.	120	2	2	1
8.	160	2	2	1
9.	100	2	2	2
10.	100	2	2	2
11.	100	2	2	2
12.	100	2	2	2
13.	0	2	3	2
14.	0	3	3	3
15.	0	3	2	3
16.	0	3	3	3
17.	0	3	2	3
18.	100	2	2	2

19.	150	2	2	2
20.	120	1	2	2
21.	100	1	1	2
22.	110	2	1	2
23.	100	2	1	2
24.	100	2	1	2
25.	100	2	2	1
26.	100	2	2	1
27.	0	3	2	1
28.	0	2	1	1
29.	0	2	1	1
30.	10000	2	2	1
31.	100	2	2	1
32.	100	2	2	1
33.	10000	1	2	2
34.	0	1	1	2
35.	0	2	2	2
36.		2	3	2
37.	0	2	3	2
38.	0	2	3	2
39.	20	3	3	3
40.	40	3	2	3
41.	30	3	2	3
42.	100	2	2	2
43.	100	2	2	2
44.	100	2	2	2
45.	100	2	2	2

46.	100	1	2	2
47.	100	2	2	1
48.	100	2	1	1
49.	100	2	1	2
50.	100	2	1	2

Appendix 3: Questions

1. How much sand do you mine here per day?
   ……
2. How long have sand mining happening in this river channel?
   ……

Field images:







