THE POLYTECHNIC

FACULTY OF THE BUILT ENVIRONMENT

DEPARTMENT OF LAND SURVEYING AND PHYSICAL PLANNING

ASSESSING THE IMPACT OF LAND USE ON WATER QUALITY USING GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING: A CASE STUDY OF MUDI RIVER, BLANTYRE.

A dissertation submitted by

MISS SARAH CHANANGA CHIRWA

OCTOBER,2021

UNIVERSITY OF MALAWI

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF LAND SURVEYING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE IN LAND SURVEYING

OCTOBER,2021

DECLARATION

I, Sarah Chananga Chirwa, do hereby declare that this dissertation represents my own work and that, to the best of my knowledge, it has not been previously submitted to this or any other university for the award of a degree.

Signature : ____________________________

Date : ____________________________

CERTIFICATE OF APPROVAL

This dissertation by Sarah C Chirwa has been approved as fulfilling part of the requirements for the award of the degree of Bachelor of Science in Land Surveying by the University of Malawi.

Supervisor's name		Signature	Date
MR. C. C Kapachika	:	____________________	____________
MR. C.C Kapachika	:	____________________	____________

DEDICATION

I dedicate this work to my Late grandmother Mrs. Racheal Chananga Mwase and My Late Dad Mr. James Chirwa. You will always be in my heart because I know that in there you are still alive. I know that love triumphs over death, I love you so much my guardian angels.

ACKNOWLEDGMENTS

Sacrifice, hard work and sleepless have all accumulated in the accomplishment of this dissertation. Accordingly, I would like to express my gratitude and appreciation to the following people for, their support made this dissertation to be possible.

I would like to thank my supervisor Mr. C.C. Kapachika, for the support, encouragement and guidance during the course of the dissertation. May God bless you Sir

I would also like to thank Ms.C. Mphamba for believing in me even in the times when I couldn’t believe in myself. Thank you for supporting me emotionally and spiritually.

My parents Anna Nyondo and George Chirwa, my sister Angela, my brother Happy my cousin Peace, my nephews and my niece, thank you for constantly praying me and supporting me financially. Long Live my people!

All my friends and relatives, your support is appreciated.

Above all, praise the LORD oh my soul and all that is within me (Psalm 103:1) for He is the one who gave me the ability, courage and strength to reach this far. Abba Father, I can’t thank you enough!

ABSTRACT

Landuse categories within a river's catchment are one of the key factors to water quality changes worldwide. The water quality of Mudi river has been reported by various researchers to be deteriorating. The main objective of this study was to assess the impact of landuse on water quality using GIS and RS in Mudi river. Water samples were collected from seven sampling points along the selected Mudi river stretch in June 2021. The measured water quality parameters were compared to the WHO and MBS water quality recommendations. It was noted that PH, EC, turbidity and nitrates exceeded the WHO and MBS recommendations in some of the sample stations. TDS was below the recommendations in all the seven sample stations. The Kriging interpolation technique was used to determine the spatial variation or distribution of the measured water quality parameters in the un sampled areas and the results indicated that most water quality parameters increase in concentration as the river flows downstream. The watersheds based on the sample points were delineated using the hydrological toolset which is under spatial analyst tool in ArcMap 10.8. The downloaded land use TIF was thus added in ArcMap, clipped and classified into three distinct land use categories namely built-up area, cropland and forestland. This enabled the determination of land use categories associated with each delineated watershed. Using excel, the correlation analysis between the landuse categories in the watersheds and the measured water quality parameters was carried out. The results of the analysis showed that there was a positive correlation between the measured water quality parameters and the land use categories within the watersheds. Based on the water quality results, it was concluded that the water quality parameters that exceeded the WHO and MBS recommendations are the ones that may lead to deterioration of the water quality in Mudi River. The results of the correlation analysis also lead to a conclusion that land use categories within a river's catchment area have an impact on the quality of water within that river. The study recommended continuous monitoring of Mudi river using Geospatial technologies such as GIS to determine the status of the water.

***KEYWORDS**: GIS, Land use, water parameters, Watersheds, WHO, MBS recommendations*

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ABBREVIATIONS AND ACRONYMS

GIS	Geographic Information System
RS	Remote sensing
TIF	Tagged Image File
WHO	World Health Organization
MBS	Malawi Bureau of Standards
EC	Electric conductivity
PH	Power of Hydrogen
TDS	Total dissolved solids
IDW	Inverse Distance Weighted
COD	Chemical Oxygen Demand

CHAPTER 1

1.0 INTRODUCTION

1.1 Background Information

Water is one of our most valuable resources, thus it is critical to safeguard it. Water quality is described as the ability of water to support various applications or activities, according to the World Health Organization (WHO) (1996). Water's physical, chemical, and biological properties will be required for each given application (Meybeck, Kuusisto Mäkelä, and Mälkki, 1996).

Rivers are important sources of water for a variety of human activities, including drinking, irrigation, industrial usage, power production, navigation, and leisure (World Wide Fund for Nature). Many rivers and streams, particularly in developing nations, are heavily polluted, according to research (Ogbozige, Adie, & Abubakar, 2018).

However, many rivers and streams, particularly in developing nations, have been found to be heavily polluted as a result of unregulated industrial and municipal wastewater discharges, as well as agricultural runoff (Ogbozige, Adie, & Abubakar, 2018).

The aforementioned scenario is evident in Blantyre, Malawi's second biggest city and commercial center, which is located in the southern area and has a population of over 800,000 people (Blantyre city council, 2020). Mudi, one of the city's major waterbodies, is one of the most impacted rivers in this region. The catchment region of the river has a diverse range of land uses, including industries, towns, and urban agriculture.

The human use of terrestrial space for economic, residential, recreational, conservation, and government reasons is referred to as land use (Camara, Jamil, & Abdullah, 2019). When evaluating changes to a land area, human requirements, and the consequences that these changing land uses have on water quality within a catchment region, a connection is frequently discovered (Bowden et al, 2015). Because the number of water contaminants rises as the population grows, and land that was previously uninhabited is altered to provide resources for humans, the ideas of land use and water quality are intertwined (McManus, 2000).

Mudi River had good fresh water in the 1980s and was home to a variety of aquatic living creatures. Despite the existing waste management regulations and policies enacted by the government of Malawi under the Environmental Management Act 1996 section 42(1) and the National Environmental Healthy Policy 2010, that is no longer the present status of the Mudi river. Several researchers, including but not limited to Kumwenda and others in 2012 and Ruth Chaima in 2015, have previously stated that the water quality of the Mudi river is severely harmed. These studies, on the other hand, did not assess the potential sources of contaminants, which is what this study aims to do.

1.2 PROBLEM STATEMENT

Despite the government of Malawi's implementation of waste management laws and regulations, human activities continue to damage the quality of water in the Mudi river. Many researchers, including but not limited to Kumwenda et al 2012, conducted study on the determination of physical, biological, and chemical pollutants in this river, while Chaima 2015 utilized GIS to create a pollution danger map in the Mudi river. However, there is a gap in the research since GIS was not employed as a decision support system tool for evaluating pollution sources utilizing the ArcGIS hydrological toolset. Against this background, this study aims at assessing the impact of land use (as one of the primary sources of pollution) on water quality in Mudi river.

1.3 OBJECTIVES

1.3.1 MAIN OBJECTIVE

The main objective of this study is to assess the impact of landuse on water quality in Mudi river using GIS and RS.

1.3.2 SPECIFIC OBJECTIVES

- To record the location of sample stations and measure water quality parameters
- To determine the spatial variations of the measured water quality parameters
- To delineate watersheds along the selected Mudi river stretch based on the sample point

- To carry out the correlation analysis between the landuse categories and measured water quality parameters

1.4 RESEARCH QUESTIONS

- What are locations of the sample points and level of water pollution in Mudi River?
- What is the spatial variation of the parameters along Mudi River?
- What are the land use categories associated with the delineated watersheds?
- What is the relationship between the measured water quality parameters and the landuse categories within the delineated watersheds?

1.5 JUSTIFICATION OF STUDY

The results of this project provided the general public with the recent water quality status of Mudi river. This will help in assessing the water quality patterns over time and space thereby understanding and managing the influencing factors such as land use categories within the catchment. Additionally, the study mainly focused on point source pollution. This will aid prioritizing on particular areas that require immediate improvements. Finally, understanding the correlations between various land use categories and water quality parameters will help in identifying land use categories that are primary threats to the quality of water. In general, the study intends to contribute to the sustainable management of rivers in Malawi.

CHAPTER 2

2.0 LITERATURE REVIEW

The aim of this chapter is to analyze the existing literature available and to justify the choice of methodologies to be employed based on what previous researchers have done.The chapter also presents the necessary information gathered from past studies related to this topic.

This review will give an analytical presentation of the existing literature related to land use categories, water quality parameters, the impacts of various land use categories on water quality and application of GIS in water quality assessment

2.1 WORLDWIDE WATER QUALITY SITUATION

Water quality is becoming a global problem as a result of the significant economic and social significance it plays (Du Plessis et al., 2014). As the human population expands, industrial and agricultural activities expand, and climate change threatens to produce substantial changes in the hydrological cycle, deteriorating water quality has become a global problem (UN-Water, 2011). Water quality concerns are complicated and varied, and they require immediate worldwide attention and action (UN-Water, 2011). Developing nations such as Malawi frequently have fewer resources to enhance water quality and therefore they rely on lower-quality water for a number of purposes, including drinking water (Zimmerman et al., 2008). Water-intensive industrial sectors in China consume a lot of water and produce a lot of effluent, which can pollute drinking water (Grady et al., 2014).

Water downstream of industrial operations in Malawi has been found to be potentially hazardous to human consumption (Grady et al., 2014). It has been shown in South Africa that the quality of accessible freshwater sources has deteriorated due to rising pollution produced by industry.

Estuaries have been severely influenced by numerous anthropogenic activities and disturbances, according to the National Oceanic and Atmospheric Administration (NOAA) National Ocean Service, and many have been severely damaged by pollution. Toxic substances like chemicals and heavy metals, nutrient pollution (which causes eutrophication), and pathogenic bacteria and viruses are the pollutants that have the greatest impact on the health of estuarine waters [4]. Estuaries, by definition, are transitional zones between the land and the sea, containing both freshwater and saltwater environments and accumulating the effects of both land and water activities.

2.3 TRENDS FOR WATER QUALITY ASSESSMENT

Water quality assessment refers to the entire process of evaluating the physical, chemical, and biological properties of water in relation to human impacts and planned applications (Mwangi, 2014). Water quality evaluation involves trend monitoring and providing information that allows for the identification of cause-effect linkages (Organization, 2013, WMO, 2013). Furthermore, it is stated that trends analysis of water quality data is an important catchment environment diagnosis (Zamani et al., 2013). The presence of trends in water chemistry indicates environmental changes and raises awareness of contributing factors such as land use and management changes.

2.4 LAND USE CATEGORIES

Land use features were divided into three groups in a research done by Camara and colleagues in Malaysia. These were the three types of land: urban, agricultural, and forest. Residential (built-up), industrial, commercial, and recreational areas make up the urban land. Rubber plantations, farmland, and marsh were all part of the agricultural land (Moriken, Jamil, & Abdullah, 2019).

Mawenda, John in their study (Analysis of Urban Land Use/Land Cover Changes in Blantyre City, Southern Malawi 1994–2018), John Mawenda and colleagues classified land use features in Blantyre into four categories:

- Bare land: regions with little or no vegetation, exposed rocks, quarries, steep clear-cut areas, and other idle fallow land that is occasionally illegally exploited for agriculture are all examples of bare land.
- Built-up area includes all sorts of urban buildings, including residential, industrial, commercial, public facilities, roads/highways, and other similar structures.
- Forest: parks, and permanently tree-covered regions

- Croplands: grassland, bushes, and plantation
- Water bodies: rivers,lakes and constructed dams/ponds (Mawenda, Watanabe, & Avtar, 2020).

This study also adopted the Anderson's classification scheme with slight modifications to fit the study area.

2.5 WATER QUALITY PARAMETERS

The criteria to be examined for water quality are chosen based on the assessment's goals and objectives (Patil, Sawant, & Deshmukh, 2012). As a result, the goal of this study is to evaluate water quality metrics that are linked to various landuse categories throughout the Mudi River's catchment region.

Chemically, physiologically, physically, and hydrologically, a variety of landuse categories have an impact on water quality. Agricultural (cropland) and forest land uses, for example, deteriorate water quality by altering physical and chemical water quality parameters, whereas urban land use, which includes settlements, industries, and other uses, affects water quality by altering the physical and chemical water quality parameters.

2.5.1 POTENTIAL OF HYDROGEN

The hydrogen potential (pH) is a measurement of the alkalinity or acidity of a water sample or solution (Matshakeni, 2016). The pH scale has a range of 0 to 14, with 7 being the neutral value. Water with a pH less than 7 is considered acidic, whereas water with a pH more than 7 is considered basic or alkaline (APEC-WATER, n.d.). When the pH is low (acidic), water has a sour flavor; when the pH is high (alkaline), it has a soapy taste (Matshakeni, 2016). When it comes to determining water quality, the pH of the water is a critical factor. Not only does the pH of a stream affect organisms living in the water, a changing pH in a stream can be an indicator of increasing pollution or some other environmental factor (USGS, n.d.). Furthermore, a high pH value decreases the effectiveness of chlorine disinfection (Omer, 2019).

2.5.2 ELECTRIC CONDUCTIVITY

Water's electric conductivity (EC) is a measurement of a solution's capacity to transport or conduct an electric current (Omer, 2019). The conductivity of a solution rises as the concertation of ions increases, since electric current is transmitted by ions in a solution. The EC is sensitive to changes in dissolved solids, primarily minerals (Elbag, 2006). The EC is affected by the degree to which these dissolved materials breakdown into ions, as well as the temperature of the water body (Hubert & Wolkersdorfer, 2015).

2.5.3 NITRATES

Nitrates are inorganic intermediate products produced when bacteria react with ammonia and other nitrogen-containing substances (Oram, 2020). Fertilizers and sewage treatment plants are two sources of nitrate that can pollute surface water (Plessis, 2014). Algal growth is stimulated by nitrates. This might lead to a rise in the number of fish in the area. However, if algae grow too quickly, oxygen levels in the water drop, resulting in water pollution. As a result, it is critical to test and monitor the nitrate content in the water body on a regular basis.

2.5.4 TURBIDITY

Turbidity is the measure of relative clarity of the water. It is an optical characteristic of water and it determines the ability of light to pass through the water (Omer, 2019). It is caused by suspended materials such as clay, silt and other particulate materials in water; making the water look unappetizing. Turbidity increases the cost of water treatment since the particulates can provide hiding places for harmful microorganisms. Turbidity is mostly associated with industrial and agricultural land uses (Berkey-Water-Filters, 2020).

2.5.5 TOTAL DISOLVED SOLIDS

Total dissolved solids (TDS) are the inorganic salts and tiny quantities of organic materials that are present in solution in water. Calcium, magnesium, sodium, and potassium cations, as well as carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions, are the most common components. Water's taste may be affected by the presence of more than recommended or standard dissolved solids. According to Malawi Bureau of Standards and World Health Organization recommendations, water with TDS values less than 1000 mg/litre is typically suitable to consumers, however this varies depending on the conditions. High levels of TDS in water, on the other hand, may be unpleasant to customers due to the resultant taste and excessive scaling in water pipes, heaters, boilers, and home appliances. Water with exceptionally low TDS concentrations may be unpalatable to customers due to its flat, insipid flavor; it is also frequently harmful to water-supply infrastructure (WHO, 1996).

2.5.6 TEMPERATURE

Water temperature is a physical characteristic that expresses how hot or cold the water is. It may also be described as a measurement of a substance's average thermal energy (Fondriest-Environmental-Learning-Center, n.d.). Temperature is an important factor to consider when evaluating water quality since it affects the types and quantities of aquatic life, impacts odor, and speeds up chemical and biological reactions (Omer, 2019). Changing air temperature, climatic events, and a variety of physical elements connected to the stream and the watershed can all cause variations in stream temperature.

2.5.7 DISSOLVED OXYGEN

The amount of gaseous oxygen dissolved in water or other liquids is referred to as dissolved oxygen (DO) (Dallas & Day, 2004). Because of its impact on living creatures in a body of water, it is a crucial criterion in determining water quality. Dissolved oxygen levels that are too high or too low can be harmful to aquatic life and have an impact on water quality (Fondriest-Environmental-Learning-Center, n.d.). DO is impacted by both natural and human causes. DO is generated naturally as a waste product of photosynthesis by phytoplankton, seaweed, and other aquatic plants. Human factors include land development as well as the loss of riparian areas (river banks). Excess organic matter is deposited into streams as a result of activities such as building and forestry. The more organic waste there is in a stream, the less DO there will be owing to microorganisms (Plessis, 2014).

2.5.7 CHEMICAL OXYGEN DEMAND

The amount of oxygen necessary to oxidize all organic materials susceptible to oxidation by a powerful chemical agent such as dichromate is known as the Chemical Oxygen Demand (COD) (Du Plessis 2014). The water quality parameter is used to indicate and evaluate the amount of organic matter in a body of water. Changes in COD and color are said to be closely related to organic matter and nutrient inputs into the water quality. The oxygen requirement of the organic substance or combination must be measured. COD, although being defined as non-specific, identifies oxidised material and distinguishes between current organic and inorganic stuff in the water body. COD is seen as a valuable variable since it may be easily quantified in the case of industrial waste (Du Plessis 2014). It can assess the oxidation susceptibility of both organic and inorganic materials in water, as well as effluents from sewage and industrial processes.

2.6 EFFECTS OF LAND USE ON WATER QUALITY

Because of a shortage of information on the temporal and spatial range of the land cover that influences water quality, the effects of land use on water quality, linked with human activities and natural causes, are poorly identified (Chu, Liu, & Wang, 2013). In general, the influence of land use on water quality is investigated by examining the connections between land use and water quality indicators or parameters.

In Malaysia, a research was undertaken to determine the influence of land use on water quality. The study's goal was to analyze and review the primary links between land use and water quality, as well as to visualize the major causes and processes of river water pollution in Malaysia (Moriken, Jamil, & Abdullah, 2019). According to the findings, 87 percent of the reviewed studies cited urban land use as a major source of pollution, 82 percent cited agricultural land use, 77 percent cited forest land, and 44 percent cited other land uses.

The correlation analysis revealed that agricultural and forest-related activities had a greater impact on water quality due to a significant positive correlation with physical and chemical indicators of water quality, whereas urban development activities had a greater impact on water quality due to changes in hydrological processes such as runoff and erosion. However, in order to collect water quality data, the researcher did not perform field measurements or laboratory tests. As a result, the goal of this study was to conduct both field measurements and lab studies in order to determine absolute values for the specified water quality indicators.

M.D Sharif Hossain did a research in 2017 that also revealed that the quality of stream water in a watershed is affected by the land use category connected with that watershed. A number of previous research were reviewed to better understand the link, and it was discovered that water quality variables are connected with land use and land cover change. The study's main goal was to review previous research on land use change and its effects on stream water. Modeling techniques for determining the influence of land use on water quality were also examined (Hossain, 2017). It was determined that agricultural land use had a higher influence on stream water quality.

2.7 LAND USE AND WATER QUALITY CASES

Water quality is becoming a global problem as a result of the significant economic and social significance it plays (Plessis, 2014). Water quality degradation has become a global concern as the human population rises and previously uninhabited terrain is converted to provide resources for humanity (McManus, 2000). With the rising population, several land uses like as industry, habitation, and agricultural activities are spreading, producing significant changes in the physical and chemical composition of water in bodies of water and the hydrological cycle in general (UN-Water, 2011).

According to McManus 2000, the notions of land use and water quality are linked since the number of water contaminants rises as population grows. For example, in Malawi, water downstream of industrial practices has been shown to be potentially harmful for human consumption (Grady, Weng, Ernest, & Blatchley, 2014), and in South Africa, freshwater quality has declined due to increased pollution caused by industry, urbanization, mining, and agriculture activities (Musingafi & Tom, 2014). Water-intensive industrial sectors in China consume a lot of water and produce a lot of effluent, which can pollute drinking water (Grady, Weng, Ernest, & Blatchley , 2014).

Moriken Camara et al. 2019 found that agricultural and forest-related activities had a greater impact on water quality due to their significant positive correlation with physical and chemical indicators of water quality, whereas urban development activities had a greater impact on water quality due to altering the hydrological processes such as runoff and erosion (Moriken, Jamil, & Abdullah, 2019).

It was proposed in Nigeria that farming activities along the Kaduna River's river banks be prohibited since fertilizers used by farmers readily flow into the river, increasing phosphorus and COD concentrations (Ogbozige, Adie, & Abubakar, 2018). As a result, farmland or agricultural land usage had a negative influence on the physical composition of the river's water.

2.8 GIS AND ITS APPLICATION IN WATER QUALITY ASSESSMENT

2.8.1 DEFINITION OF GIS

A geographic information system (GIS) is a computerized system that helps with data entry (georeferenced data), data analysis, and data display (de By, et al., 2001). GIS technology was only utilized to produce digital cartographic tools that offered a spatial display of certain elements in the early 1960s. GIS was able to show the dynamics of phenomena in terms of time and space as the system evolved (Budzynski, 2018). Geographic information systems (GIS) have recently been used in a variety of disciplines, including water quality monitoring, by connecting attribute data to spatial data. Geographic information systems (GIS) have many applications in hydrology that use spatial analytic tools to a greater or lesser extent (Silberbauer, 1997).

2.8.2 DEFINITION OF REMOTE SENSING

The collection of physical data from an item without touch or contact is what is known as remote sensing. (Simonett and Lintz, 1976). Imagery is captured using a sensor other than (or in addition to) a standard camera. A scene is captured, for example, by electronic scanning, radar, thermal, infrared, ultraviolet, and multispectral film and camera. Various techniques are used to analyze and interpret remote sensing pictures in order to provide conventional maps, landuse maps and resource surveys (Wynne & Campbell , 2011)

2.8.3 APPLICATION OF RS AND GIS IN WATER QUALITY MONITORING

Recent advances in remote sensing and geographic information systems (GIS) have allowed large-scale water quality monitoring studies to be conducted. Water quality parameters such as turbidity, suspended sediments, and mineral content in water bodies, such as rivers and groundwater are being monitored at a lower cost and with greater accuracy using improved spectral and spatial resolution sensors and geospatial modeling techniques. Integration of these technologies with various land use categories within the rivers catchment has effectively assisted in the identification of contaminated zones and sources of pollution, as well as the development of remediation methods (Ramadas & Samantaray, 2017) .

2.8.3.1 WATERSHED DELINEATION USING GIS

Watersheds may be defined in Geographical Information Systems (GIS) by recording the flow direction and the number of upstream points for each grid point in a DEM. Once the watershed has been defined, it may be used to harvest data from other levels (such as land cover, area, and so on) that are helpful in hydrology. This study used the analysis toolset in ArcGIS toolset.

2.8.4 WATER QUALITY ASSESSMENT AND MAPING USING INVERSE DISTANCE WEIGHTED

D.B Adie and colleagues utilized ArcGIS GIS software to map and interpolate the water quality indicators of Nigeria's Kaduna River (Ogbozige, Adie, & Abubakar, 2018). Water samples are often taken at specified sampling locations rather than at every point along the river, posing the problem of determining the quality condition of the none sampling points in between sampling places. Interpolation, which is the act of estimating unknown values that lie between known values, may be the solution to this problem (Abbas, 2013).

The researchers sought to map the water quality of the River Kaduna (middle stretch) using the Inverse Distance Weighted (IDW) interpolation method (an ArcGIS tool) in order to estimate the water quality condition of the river's non-sampled locations. To analyze and map the water quality of the Kaduna River, the researcher focused on the Inverse Distance Weighted (IDW) interpolation approach. However, for more exact and reliable findings, IDW interpolation requires sampling points to be sufficiently spaced out in the region of investigation. Because a river is often classified as a linear feature, the sampled points are not evenly distributed, impacting the interpolated findings. Rather of utilizing IDW interpolation, this research will interpolate the unsampled points using the Kriging interpolation approach.

2.9 CREATING A HAZARD MAP OF POLLUTANTS IN MUDI RIVER USING GIS

2.9.1 DEFINITION OF A HAZARD MAP

Hazard maps are created to highlight regions that are impacted or exposed to a certain hazard. Hazard maps are tools that, when used correctly by planners, developers, and engineers, may save lives and save economic losses by avoiding exposure to some dangers while planning other projects to minimize or neutralize the potential negative impacts of these hazards.

2.9.2 GIS VS HAZARD MAP CREATION

Geographic information system (GIS) technology is rapidly being employed in spatial decision support systems. GIS has emerged as a powerful risk assessment tool in recent years, and it is now being used to assess the risk to property and life posed by natural hazards such as earthquakes, hurricanes, cyclones, floods as well as hazards posed by human activities. The risk and hazard data may be manipulated, analyzed, and graphically shown inside a GIS system, and because these data have related location information that is also kept within the GIS, their spatial interrelationships can be identified and employed in computer-based risk assessment models. This assessment can be used by insurance companies to help them decide on insurance policy rates, by land developers to decide on project feasibility, and by government planners to improve disaster preparedness. (Lavakare, 2010)

Ruth R. Chaima (2015) also used the GIS technology to produce a hazard map which showed some sampled points in Mudi river and stated how polluted they were. The map showed that pollution increased downstream and that points of lower elevations were more polluted than points on higher elevations. Thus it can be noted that GIS was used as a tool that facilitated quick dissemination of the water quality state in Mudi river through the graphical representation; the hazard map. The study however did not identify what could be the possible sources of pollution in the areas where the hazardous map showed as more polluted. This study therefore will emphasize on determining both the water pollution levels (by measuring the water quality parameters) and identifying the possible land use category that might be responsible for pollution.

This study will make use of Geographic Information System (GIS) in the identification of the spatial distribution of the measured parameters, delineation of watersheds, determining the land use categories associated with different watersheds and developing a model that will address the water quality issues in Mudi River.

2.10 RELATED STUDIES

Related research about water quality assessment using GIS has been done by many scholars. This section will include such studies, the gaps that are noted and how the study intends on meeting such gaps.

2.10.1 CONTRIBUTION OF GIS TO EVALUATE SURFACE WATER POLLUTION BY HEAVY METALS.

Yazidi et al 2017 conducted a study titled *Contribution of GIS to evaluate surface water pollution by heavy metals: Case of Ichkeul Lake (Northern Tunisia).* In this study, the concentrations of nutrients and heavy elements in the surface water of the lake Ichkeul were measured to evaluate the impacts these chemicals had on water quality. The results showed that the highest concentrations of nutrients were located in part of the lake where there were uncontrolled releases of domestic and industrial wastewater. In order to study the spatial distribution of heavy metals, spatial interpolation (IDW) was used. This method was achieved using the ARCGIS software. The study used interpolation to study the spatial distribution of heavy metals.

The Inverse Distance Weighting interpolator, on the other hand, implies that each measured location has a local impact that decreases with distance. It gives more weight to points closest to the processing cell than to those far. Thus it would only provide reliable interpolated results to the points that are near to the sampled points and the reliability of the interpolated results decreases as the distance increases. For more reliable interpolated results, IDW requires the set of points to be dense enough.

Thus this gap would introduce outliers on the distribution of chemical elements. In an attempt to fill this gap, this study aims at using kriging interpolation technique which outperform IDW technique. Thus by densifying the number of sampling points, kriging interpolation technique will be used to come up with a true reflection of how the water quality parameters are spatially distributed in the selected stretch of Mudi river.

2.10.2. EVALUATION OF THE IMPACTS OF LANDUSE ON WATER QUALITY: A CASE STUDY OF CHAOHU LAKE BASIN

Huang J et *al 2013* conducted a study titled *evaluation of the impacts of land use on water quality: a case of Chaohu lake basin.* The purpose of this study was to examine the impact of various land use patterns on water quality in the Chaohu Lake Basin using water quality monitoring data and Remote sensing data from 2000 to 2008, with the small watershed serving as the main unit of analysis. The study of the relationship between the proportion of land use types and water quality in the Chaohu Lake Basin ended up finding that built-up land was generally positively related to water quality indicators, while forest land, grass land, and water area were negatively related to water quality variables, while the influence of cultivated land on water quality was frustrating. Furthermore, built-up land, grassland, and forest land all had a substantial impact on various water quality indices.

This study presents a gap since the analysis was only based on a watershed level, land use categories beyond the watersheds were not considered in the analysis. The gap would introduce bias in the results or output as the land use categories beyond the catchment also have a bearing on water quality status. To address the gap, the delineated watersheds of this study will consider the land use categories that are happening beyond the catchment region.

2.10.3 WATER QUALITY MAPPING AND ASSESSMENT USING IDW: A CASE STUDY OF KADUNA RIVER NIGERIA

Several researchers studied the water quality of the upper and lower stretches of Kaduna river. However, no work was done on the mapping of the aforementioned river. Ogbozige 2015 used IDW to monitor the middle stretch of the river during both the rainy season and dry season. Water was sampled in 15 different locations to generate data for water quality mapping. The river's temperature was found to be within the allowable limits set by the US EPA and the other water quality parameters that were measured with an exception of tuebidity and PH deteriorated more during the dry season. Furthermore, COD and total phosphorus were discovered to be the only parameters that did not meet the US EPA standards throughout the sampling period, regardless of sampling location or season. IDW interpolation technique was used to estimate or interpolate the values of the measured water quality parameters in the areas that were not measured. It was suggested that farming activities along the river's catchment area should be prohibited because fertilizers used by farmers easily drained into the river.

The study's use of IDW interpolation technique presents a problem that has been addressed in this study. The accuracy of IDW depends on the closeness of the unsampled points with the sampled points. This study used kriging interpolation technique.

CHAPTER 3

3.1 INTRODUCTION

3.0 METHODOLOGY

This chapter illustrates the research methodology that will be utilized in the study to ensure validity and reliability of the results**.** A detailed account of the research design, study area, sampling technique, data collection methods and materials that will be used to achieve the objectives and data analysis tools have been outlined in this chapter.

3.2 STUDY AREA

Mudi river is located in Blantyre, southern region of Malawi. The river is one of the city's major streams. It flows in a north-south direction passing through Makata industrial area to Blantyre market and ends at stella Maris thereabout. The river's catchment area encompasses various land uses such as forestry, settlement, agriculture and industrialization (Kumwenda et all 2012).

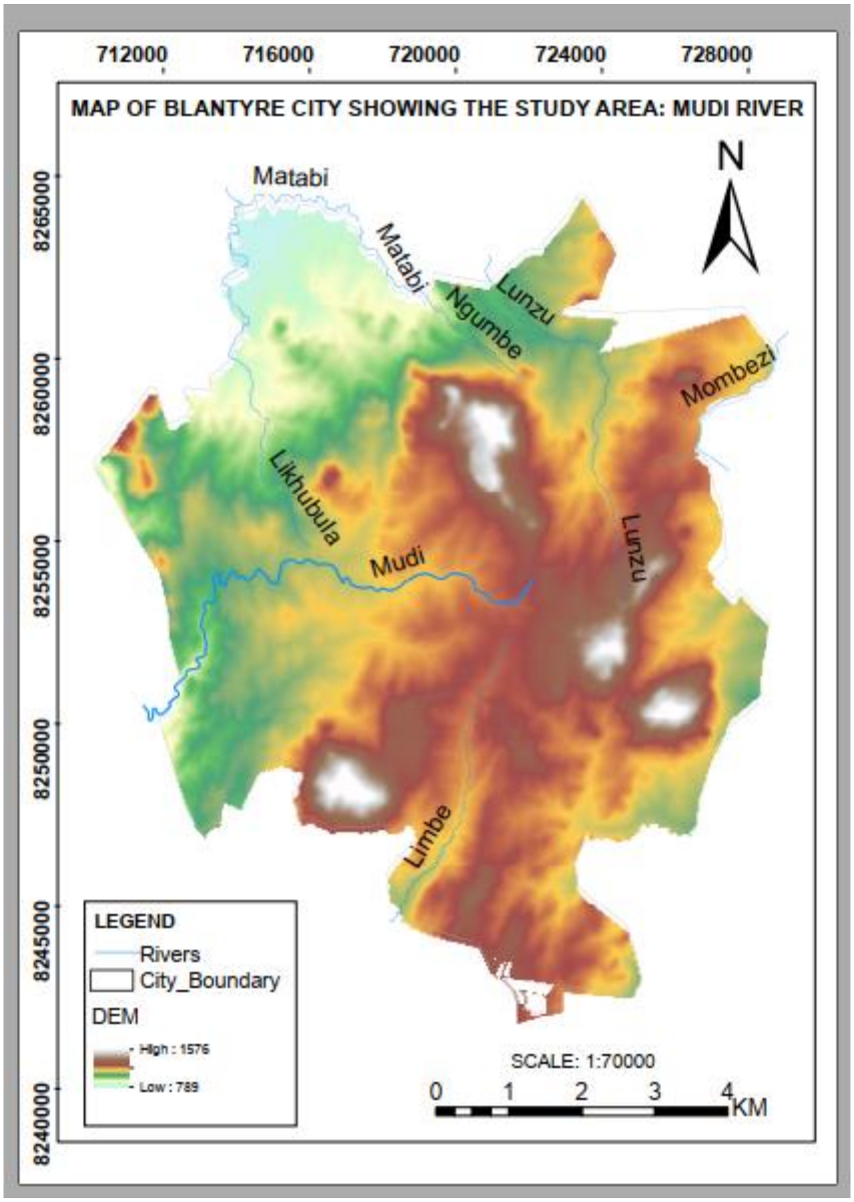

Figure 1: *showing Map of Blantyre city showing the Study area*

3.3 RESEARCH DESIGN

The study will adopt quantitative relationship-based research design. The intention of this design was to find the connection between various land use categories in catchment areas and their impacts on the quality of water in the rivers (Creswel, 2014). Thus the quantitative data in this study were the coordinates of sampling stations, the acreage of the land use categories and the numerical values of the measured water quality parameters. The World Health Organization and Malawi Bureau of Standards also formed part of the quantitative data.

3.4 SAMPLING TECHNIQUE

Purposive sampling technique will be utilized in this study. This sampling technique has been chosen on the basis that sample points will be chosen based on the purpose of the study hence fulfilling the research objectives. According to J.P Guilford 1973, a purposive sampling technique gives a good representation of the total population. A sum of 7 points will be selected with three water samples collected at each point; enabling the calculation of the most probable value of the water quality parameters being measured.

3. 5 DATA COLLECTION

This section covers the data collection materials and methods that will be used that will be used to collect both primary and secondary data which will be needed to achieve both the main objective and the specific objectives.

3.5.1 MATERIALS

The study will use both primary and secondary data in order to achieve the objectives. Primary data will include the coordinates of the sampling points and the field and laboratory measurements of the water quality parameters. The secondary data will be the land use dataset and the Digital Elevation Model (DEM) for Blantyre city.

The study will involve a great amount of both office and field work. In order to carry out the field survey, the following materials will be utilized:

- *Etrex 20x* Garmin handheld GPS
- Equipment batteries
- Polyethylene bottles

- Thermometer
- Potential meter
- Conductivity meter
- Notepad
- Pen

The resources to be used in the office are:

- A laptop computer
- Microsoft Office Word and Excel.
- ArcGIS 10.8

3.5.2 METHODS

3.5.2.1 COORDINATES OF THE SAMPLING POINTS

To record the precise location of sample points, the coordinates of the sampling points will be collected using a Garmin handheld GPS. Due to the GPS' accuracy, the coordinates of the sampling points will be off by ±3m. Thus it would be necessary to adjust these coordinates. To adjust the coordinates, a known point's coordinates (an established beacon for instance) will be recorded using the Handheld GPS. The measured coordinates will be compared to the known coordinates of that particular point. The difference which is the correction will be applied to the rest of the sampling points. The datum to be used is the Arc 1950 zone 36s**.**

The coordinates will then be saved as a CSV comma delimited excel spread sheet. This format will be chosen to make the data compatible with Arcmap software.

3.5.2.2 MEASURING WATER QUALITY PARAMETERS

A part of the river with a good steady flow was chosen as the sampling point. Thus the samples were not collected where there is stagnated water to avoid getting false results of the water quality parameters. Polyethylene (PE) bottles will be used for collecting the water samples after being sanitized by soaking in 50% Hydrochloric Acid (HCl) for three days and rinsed with river water for three times. Water quality parameters such as temperature, electric conductivity, PH and dissolved oxygen will be tested on site. This is so because these water quality parameters can easily be affected by temperature of the surrounding environment. Nitrates and turbidity will be further analyzed in the laboratory using the collected water samples. The sample ID, the date and time of sampling will be labelled on the bottle. Environmental factors on the sample collection day that can influence the results (such as heavy rainfall) will also be recorded in a notepad.

PARAMETER TO BE MEASURED	**ABBREVIATION**	**TECHNIQUE**	**UNITS**
Power of Hydrogen	PH	Potential meter	pH units
Nitrates	NO	Spectrophotometer (AAS)	µmhocm-1 (Ns)
Turbidity	TURB	Potable turbidity meter	NTU
Electric conductivity	EC	Conductivity meter	µmhocm-1 (Ns)
Total dissolved solids	TDS	TDS meter	Mg/l

Table 1: *Showing the water quality parameters that were measure*

3.5.2.3 SPATIAL DISTRIBUTION OF MEASURED WATER QUALITY PARAMETERS

Spatial interpolation is the technique of estimating values at other places by utilizing known values at points with known values. Spatial interpolation is generally performed to a raster, network and point datasets in GIS applications. Spatial interpolation is therefore a technique for generating surface data from sample points. Control points are points whose values are known. They offer the information required for the creation of a spatial interpolator. The number and distribution of control points can have a significant impact on spatial interpolation accuracy (Spatial interpolation elements, n.d.)

There are several spatial interpolation methods that are frequently used to estimate values of parameters in locations where the samples are not measured. Some of these methods are inverse distance weighted (IDW), kriging, spline and trend.

The IDW (Inverse Distance Weighted) tool employs an interpolation method that estimates cell values by averaging the values of sample data points in each processing cell's neighborhood. The greater the influence, or weight, a point has in the averaging process, the closer it is to the center of the cell being estimated (Scheeres , 2016). In IDW interpolation method, as the distance increases from the measured sample point, so the does the weight of accuracy of estimation hence the name inverse distance weighted.

The Spline tool employs an interpolation approach that estimates values by employing a mathematical function that minimizes total surface curvature, resulting in a smooth surface that passes over the input points perfectly.

Trend is a global polynomial interpolation that fits the input sample points to a smooth surface specified by a mathematical function (a polynomial). The trend surface progressively evolves and captures coarse-scale trends in the data.

Kriging is an advanced sort of spatial interpolation that use complex mathematical formulae to estimate values at unknown places based on known values. The accuracy of kriging interpolation does not depend on the closeness or proximity of the points to be estimated with the measured or sampled point.

Spatial interpolation is useful in a number of scenarios, such predicting rainfall, groundwater and surface water contamination, temperature, and disease propagation. It aids in 'filling in the blanks' between known data points (Scheeres , 2016).

The study therefore used the kriging interpolation technique to determine the spatial distribution of the measured water quality parameters. Kriging technique was adopted because it outperforms most interpolation techniques with a major advantage of providing a measure of error or uncertainty of the estimated surface.

3.5 DATA ANALYSIS TECHNIQUES

This section outlines how the data will be analyzed and presented. It incorporates the tools and techniques that will be used to carry out the analysis process.

3.5.1 ARCMAP 10.8

ArcMap is the centerpiece of Esri's ArcGIS suite of geospatial processing programs, and it is primarily used to view, edit, create, and analyze geospatial data. ArcMap enables users to explore data within a data set, symbolize features, and create maps. This is accomplished through the program's two different portions, the table of contents and the data frame (ESRI, 2020). The study will use ArcMap version 10.8 for creating watersheds within the river based on the sampling points, determining the spatial variation of the measured water quality parameters and the determination of landuse categories associated with each delineated watershed.

- **Creating watersheds based on the sampling points**

A watershed is an upslope region or area that contributes flow (usually water) to a common exit or pour point. (ARCGIS PRO HELP, Understanding the watershed toolset). Watersheds may be defined from a DEM by calculating the flow direction and entering it into the Watershed tool.

To identify the contributing region, first build a raster depicting the flow direction using the Flow Direction tool. The next thing is to specify the places with a need to calculate the catchment area.

Source sites may be features; such as dams or rivers where the contributing area characteristics is being identified. A flow accumulation threshold can also be used. When the threshold is used to define a watershed, the watershed's pour points are the connections of a stream network formed by flow accumulation.

This study will use ArcMap to accomplish the objective of delineating the watersheds. The watershed tool determines the contributing area above a set of cells in a raster. Thus a CSV comma delimited file of the recorded coordinates will be added in ArcMap together with a DEM and the contributing area to each particular sampling point will be delineated accordingly.

- **Conversion of a catchment in raster format to polygon format**

The delineated watersheds were then be converted to polygons to enable the determination of their extents. This will be achieved by using the raster to polygon tool under conversion tool which is located by following the path conversion tools→from raster→raster to polygon. Converting the watersheds to polygons enabled further analyses to be done on the delineated watersheds such as area calculations.

- **Determination of land use categories associated with each delineated watershed**

Various land use categories within a river's catchment area have the potential to pollute river water in some way. Chemical farm inputs, for example, may make their way into the river, and individuals residing close or along the watershed may use the river as a dumping place, contaminating the river. Wetlands slow the flow of runoff water, enabling suspended particles to settle. Some of the suspended particles usually result in the entry of pollutants such as fungicides into the river (wetland functions and values, 2020). To determine the land use categories associated with the delineated watersheds, the land use shape file was intersected with each delineated catchment using the intersection tool under the Spatial Analyst toolset.

The intersect tool under the spatial analyst tool set computes the geometric intersection of multiple feature classes and feature layers. The features or portions of the features that are shared by all inputs (those that intersect) are contained in the output feature class (ARCGIS PRO HELP). In this study, the feature classes shared by the watersheds and the land use categories were included in the output. This made it easier to determine the land use categories that were associated with a particular delineated watershed.

3.5.2 Ms EXCEL

- **Correlation Analysis Toolpak add in**

Excel's Correlation analysis tool (also accessible via the Data Analysis command) measures the connection between two sets of data (Nelson & Stephen). To assess the impact of land use on water quality, the Analysis Tool pak add-in excels will be used. Thus correlation coefficients between the land use acreages of the watersheds and the water quality parameters will be generated. This helped in determining how a particular water quality parameter changes in relation to the size of the watershed and the associated land use. To check the validity or reliability of the analysis, the regression model whose primary purpose is to explain the goodness of the model will also be carried out.

The following are the steps that were followed to perform the correlation analysis:

- Open Microsoft Excel and click the data analysis button at the far left of the window
- When Excel shows the Data Analysis dialog box, click OK and then choose the Correlation tool from the Analysis Tools list.
- Determine the range of X and Y values to be analyzed. In this case the land use categories in the watershed were the independent variables or the X values and the water quality status which depend on the land use categories were the Y values.
- The output location was then selected as a new spreadsheet with the first row containing the IDs.

  Excel then calculated the correlation coefficients between the land use categories and the measured water quality parameters.

3.6 METHODOLOGICAL WORKFLOW

Below is a flow diagram depicting the methodology of this study. The data that was collected included both spatial and non-spatial data. Spatial data included the geographic locational coordinates of the sample points and the non-spatial data included the numerical values of the water quality parameters.

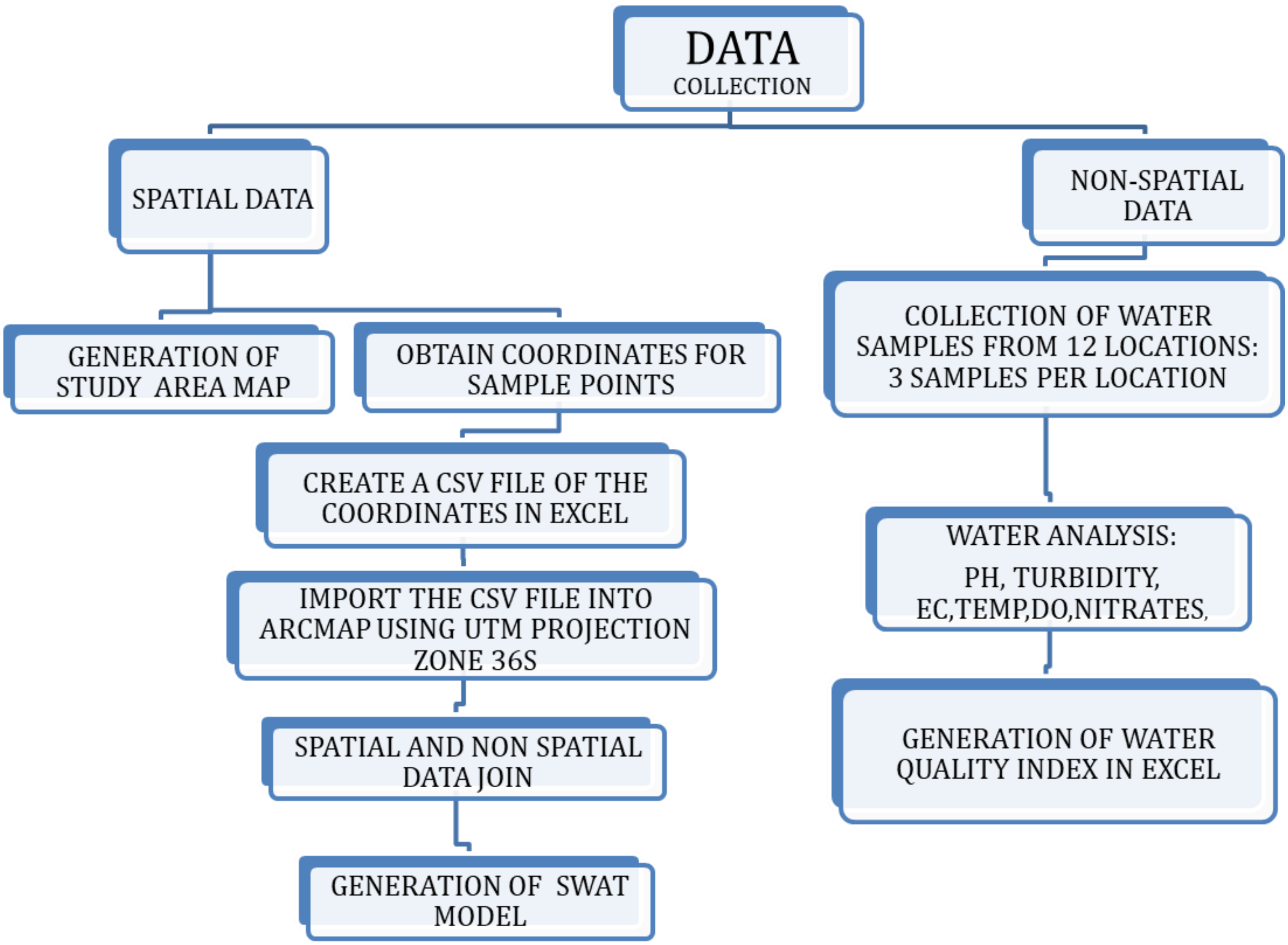

Figure 2: *methodological flow work*

CHAPTER 4

DATA ANALYSIS AND RESULTS

4.0 INTRODUCTION

This section represents the analysis of data collected from a research which was conducted in Mudi river, in Blantyre. The main purpose of the study was to assess the impact of land use on water quality using GIS and RS techniques. Further the study was aimed at: recording the precise location of sample stations, measuring water quality parameters, determining the spatial variations of the measured water quality parameters, creating watersheds of Mudi river based on the sample points, determining the land use categories associated with the delineated watershed and detecting the possible sources of pollution within the watershed.

4.1 LOCATION OF THE SAMPLE POINTS

Purposive sampling techniques were used to collect water samples from seven sampling points (BWB, MAK1, MAK2, EPH, CLOCK T, BT market and sunnyside park) along the Mudi River. BWB was located near Blantyre water board, Mak 1 and Mak 2 were located near Makata industrial area, ESP was located near ESCOM, clock T was located near the clock tower, Bt market sample was located at the Blantyre market bridge and the last sample was located at sunnyside park. A Garmin handheld GPS was used to collect the locational coordinates (the eastings and northings) of these sample points. The selected datum was Arc 1950 zone 36s.

Figure 3: *Location of sample points on google earth image*

ID	DESCRIPTION	EASTING	NORTHING	ELEV
BWB	Bridge near BT water board	718150	8252993	1066
MAK 1	Makata 1	717842	8252968	1065
MAK2	makata 2	717655	8252965	1060
EPH	Escom power House	717169	8253043	1043
CLOCK T	Bridge near clock tower	715727	8253774	1028
BT MARK B	bridge at BT market	715067	8253685	1016
v.H/PARK	Sunnyside park Bridge	714724	8253154	1007

Table 2: *Location of the sample points*

4.2 MEASURING WATER QUALITY PARAMETERS

ID	DESCRIPTION	EC	TDS	PH	TURB	TEMP	NITRATES
BWB	Bridge near BT water board	242.7	153.4	8.02	7.35	19.7	80.4
MAK 1	Makata 1	242.8	153.3	8	13.94	19.9	86.7
MAK2	makata 2	311.1	198.3	7.5	3.92	19.4	88.01
EPH	Escom power House	403.4	216.7	7.89	3.55	21	90.03
CLOCK T	Bridge near clock tower	678.03	448.03	8.17	23.06	22.9	102.2
BT MARK B	bridge at BT market	723.2	479.1	8.56	13.78	22.24	123.3
V.H/PARK	Sunnyside park Bridge	711.9	464.9	8.64	11.61	23.6	126.8

Table 3 : *showing the sample points and measured water quality parameters*

The study was conducted in June 2021 and water quality parameters such as pH, electrical conductivity, total dissolved solids, turbidity, temperature and , nitrates were measured and analyzed. At each site a water sample was collected in the middle of the river using a sterile white plastic bottle of 250 ml (Elbag, 2006). The plastic bottles were used for sampling because they are relatively cheap and the do not change the chemical composition of the samples when preserved. The results of these physical and chemical parameters for the Mudi River were analyzed and compared with the standards of the World Health Organization (WHO) & Malawi Bureau of Standards (MBS).

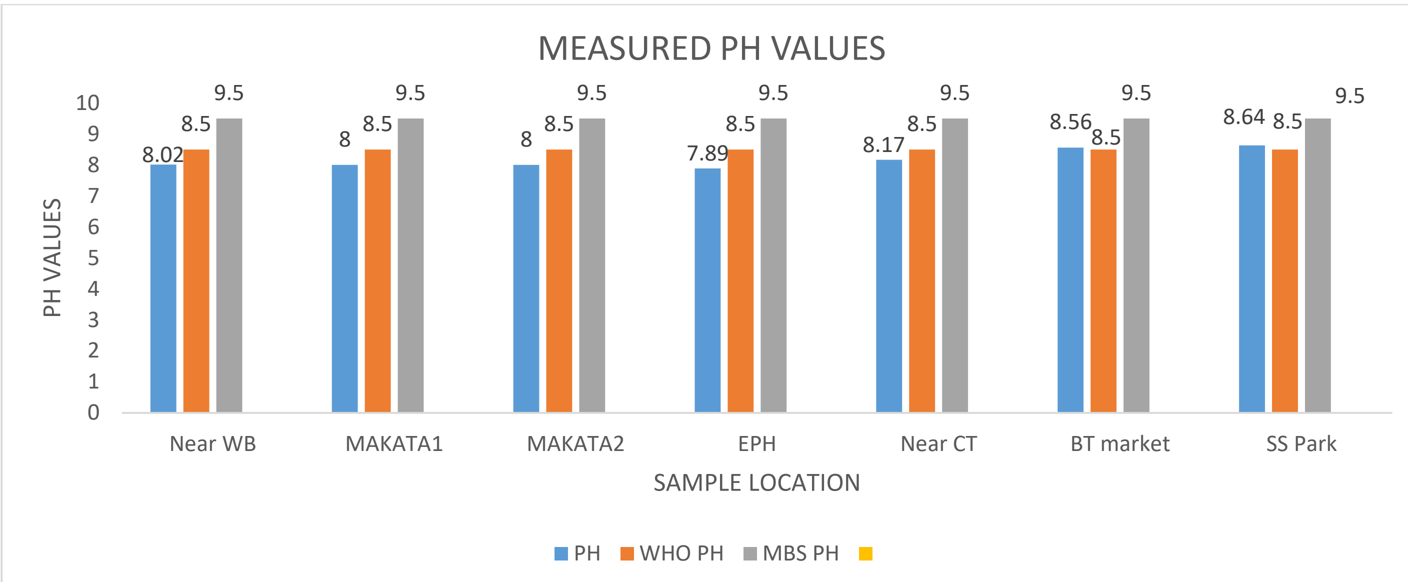

Figure 4: *showing PH concentration in Mudi river June 2021*

The above graph presents the measured PH along the selected stretch along Mudi river. The measured PH is being compared to the WHO and MBS recommendations. The graph shows that the PH concentration in most sample sites within Mudi river were below the WHO and MBS recommendations except for Blantyre market and the sample near sunny side park. The differences were 0.06 and 0.14 respectively. Though these might seem as slight differences, research has revealed that when the PH of water becomes greater than 8.5, water taste can become more bitter. While this higher pH does not pose any health risks, it can cause skin to become dry, itchy and irritated (Ashley, 2018).

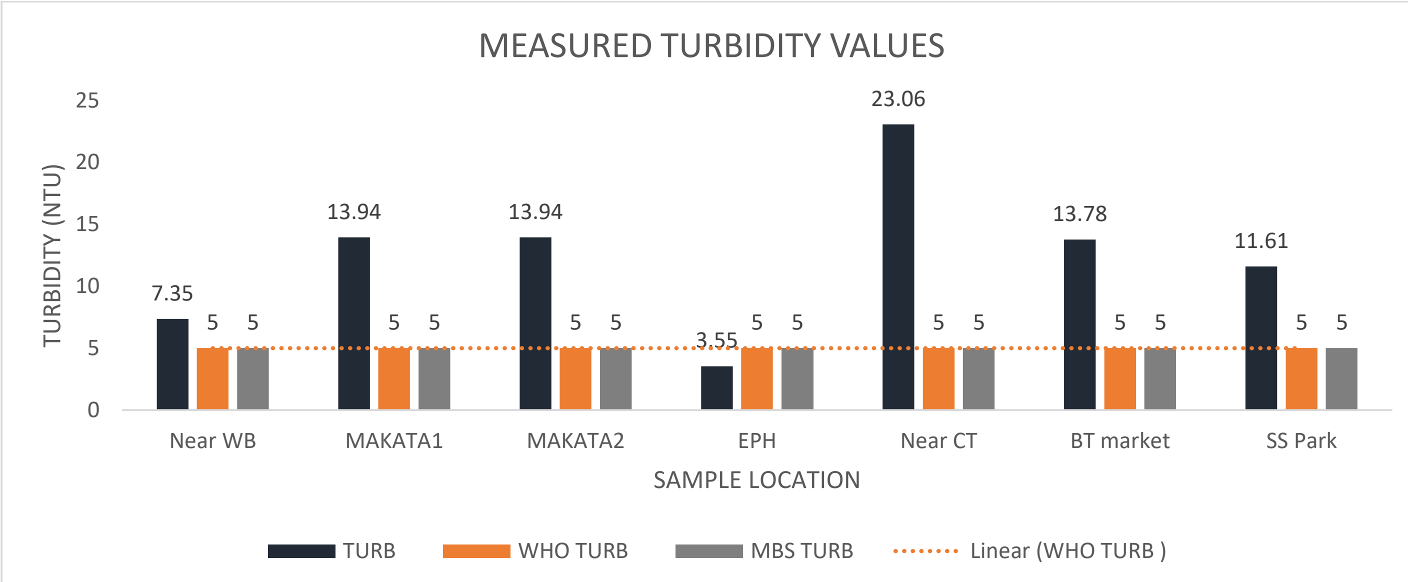

Figure 5: *showing Turbidity concentration in Mudi River June 2021*

Figure 5 shows that the turbidity concentration within the sampling sites is high except for sample site labelled EPH. The rest of the sample sites exceeded the guidelines (WHO and MBS standards). At the samples labelled near WB, Makata 1, Makata 2, Near CT, BT market and SS park, turbidity exceeded the standards by 2.35ntu,8.98ntu,8.94ntu,18.06ntu,8.78ntu and 6.61 respectively. These are noteworthy differences as high turbidity levels can decrease the aesthetic quality of rivers and increase the cost of water treatment (Minnesota pollution control agency, 2008). The latter is of major concern to Blantyre water board since Mudi river supplies water to Mudi dam which is a reservoir for Blantyre water board.

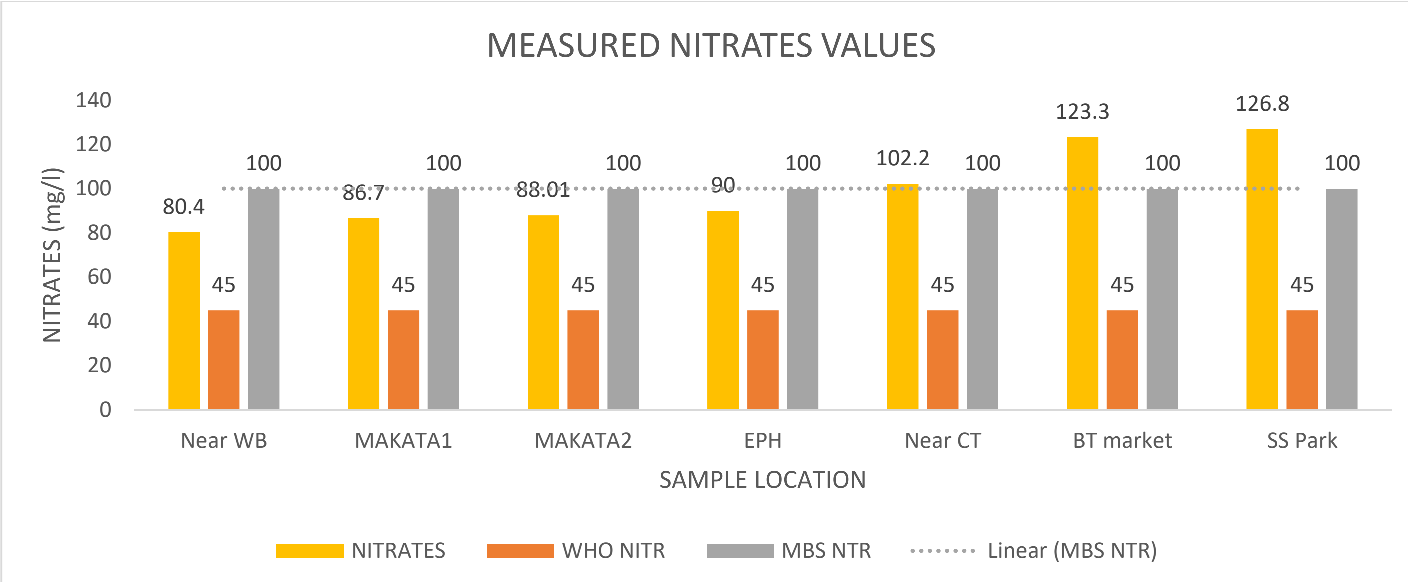

Figure 6:*showing* Nitrates *concentration in Mudi River June 2021*

As illustrated on Figure 11, the nitrates concentration is increasing from site labelled *Near CT*. However, sites labelled *BT Market* and *SS Park* exceeded the MBS guides and all sites surpassed the WHO recommendations. Near CT nitrates exceed by 2.2mg/l,23.3 mg/l and 26.8mg/l for BT market and SS park sample sites respectively.

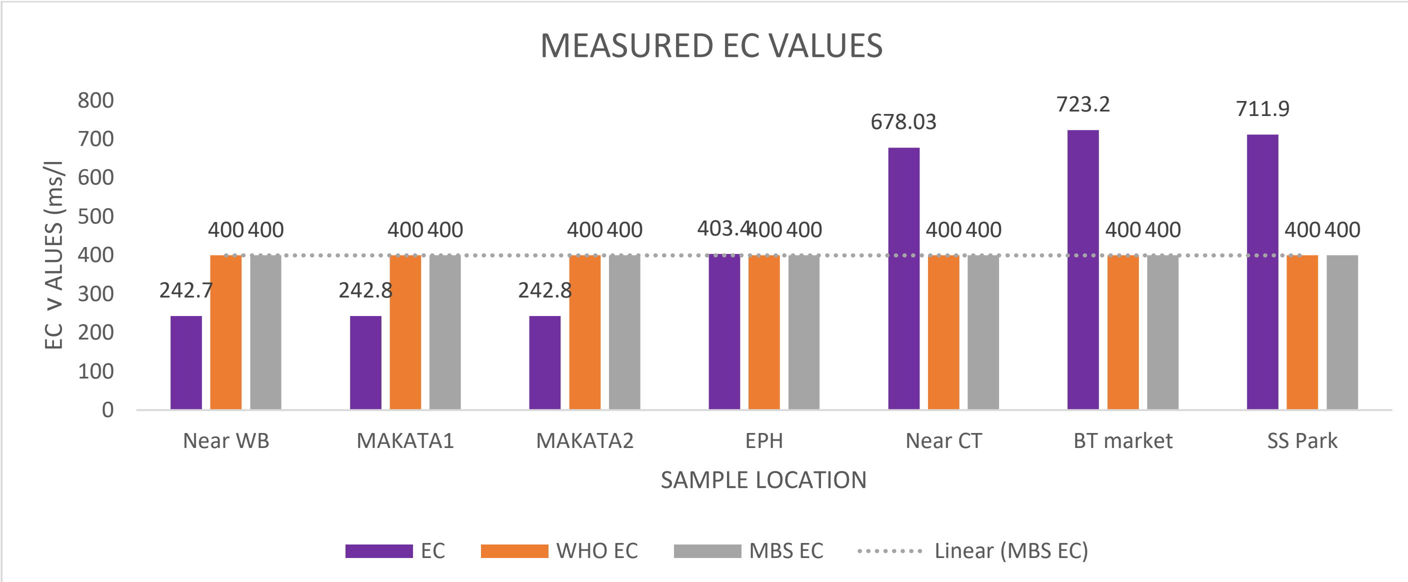

Figure 7: *showing Electric conductivity concentration in Mudi River June 2021*

As illustrated on Figure 12, EC concentration is increasing from site labelled *Near CT* and this site plus sites

labelled *BT Market* and *SS Park* exceeded the MBS and WHO guides. These sites have deviated from the standards by 278.03mg/l, 323.2 mg/l and 311.9 mg/l. These are large differences.

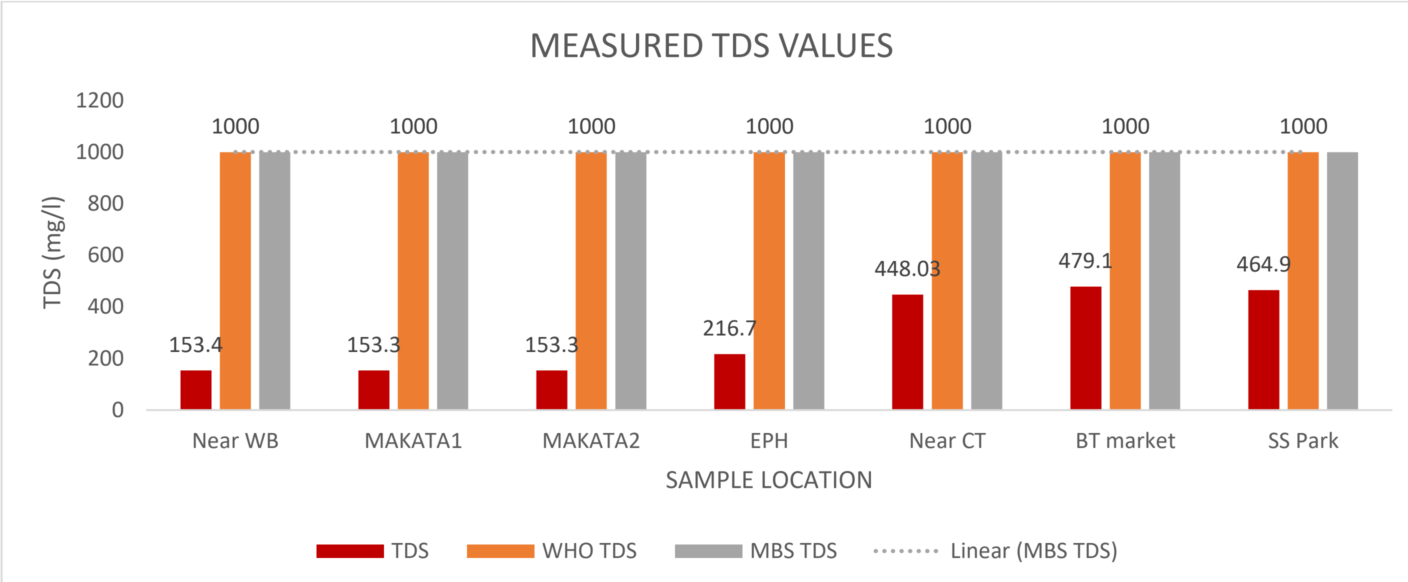

Figure 8:*Showing TDS conductivity concentration in Mudi River June 2021*

Figure 8 illustrates that TDS is low, that is below the standards within the selected stretch of Mudi river and no site exceeded the WHO and the MBS recommendations.

4.3 DETERMINING SPATIAL VARIATION OF THE MEASURED WATER QUALITY PARAMETERS

Kriging interpolation technique was used to determine the spatial variations of the measured water quality parameters. This technique was adopted because it outperforms most interpolation techniques. Below are snapshots of the spatial distribution pattern of water quality parameters that were measured namely; nitrates, total dissolve solids, electric conductivity, turbidity and PH.

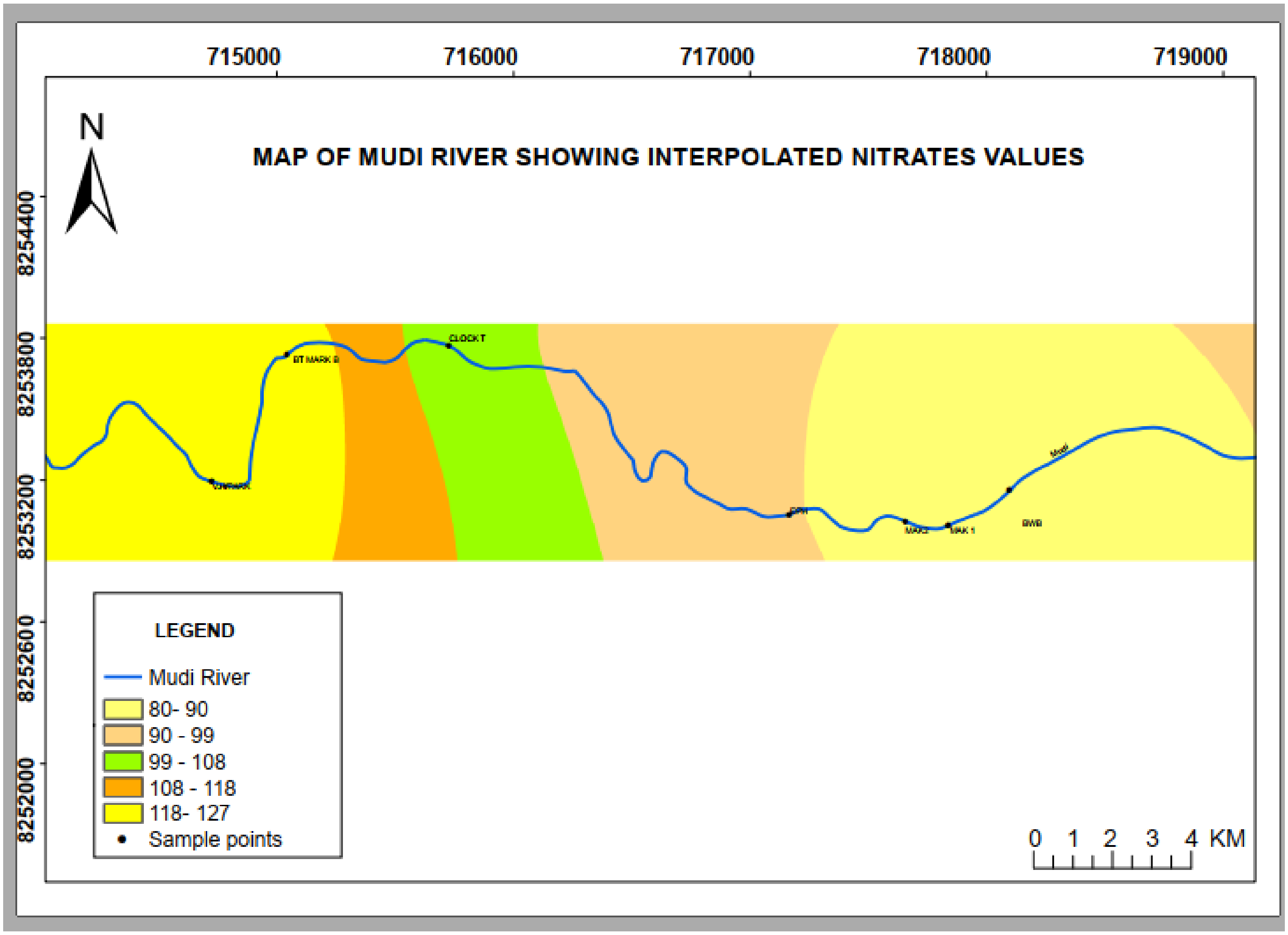

Figure 9:*showing Interpolated nitrates values*

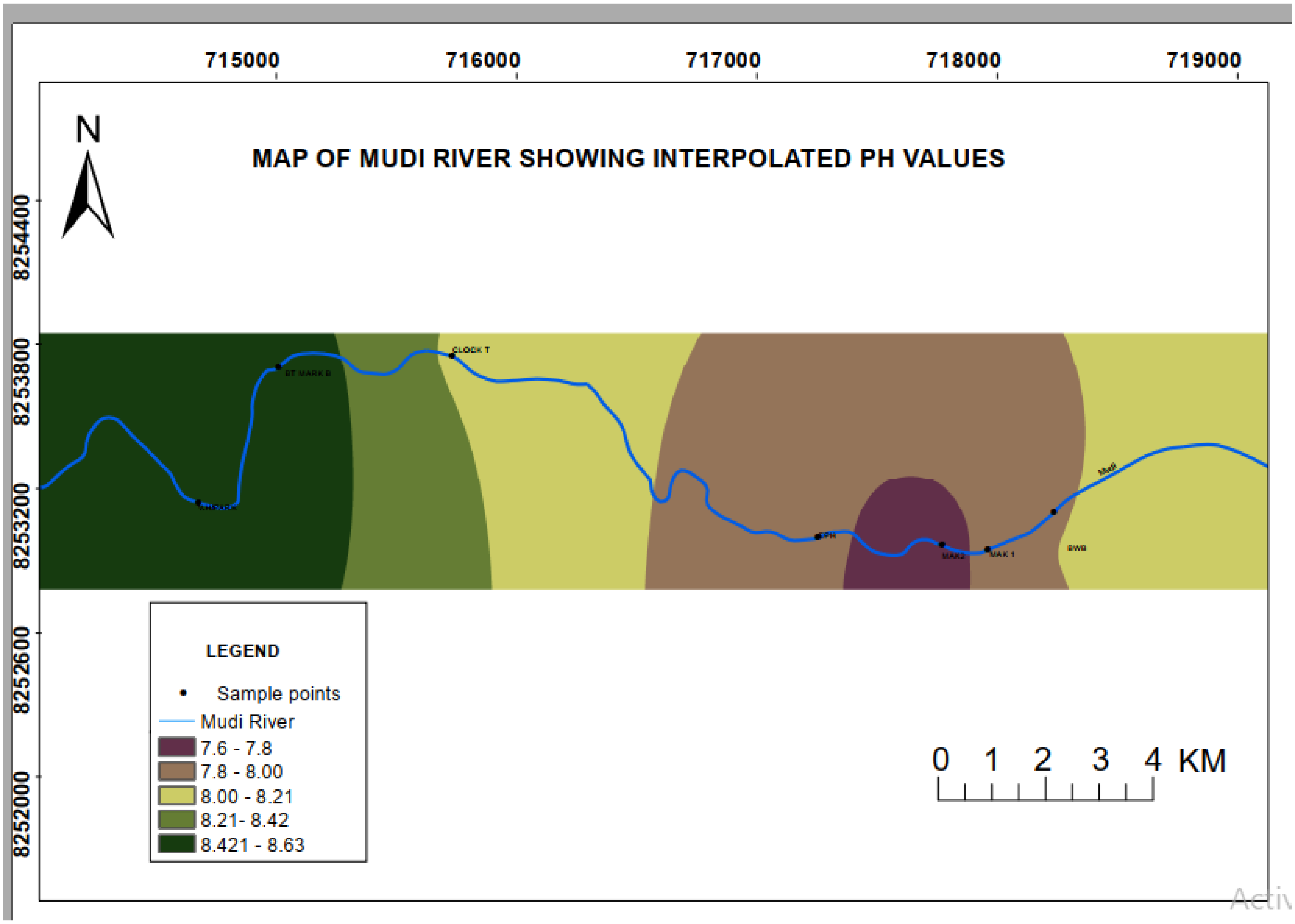

Figure 10: *Interpolated ph values*

The distribution of pH recorded high PH concentration in the sample sites labelled *BT Market* and *park*. pH concentration range varied from 7.6 to 8.6 and the values significantly increased from east to western part of the river.

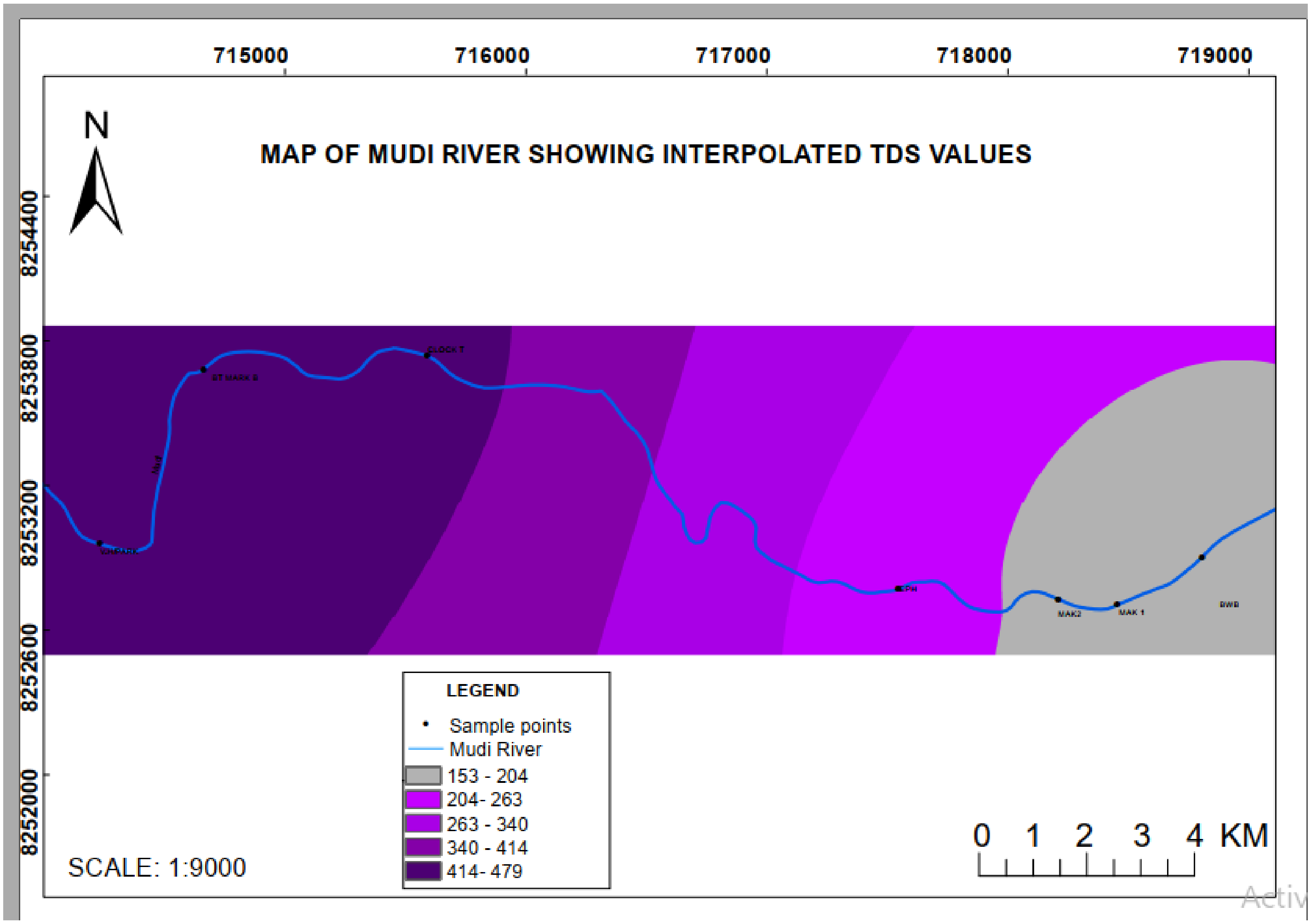

Figure 11: *Showing Interpolated TDS values*

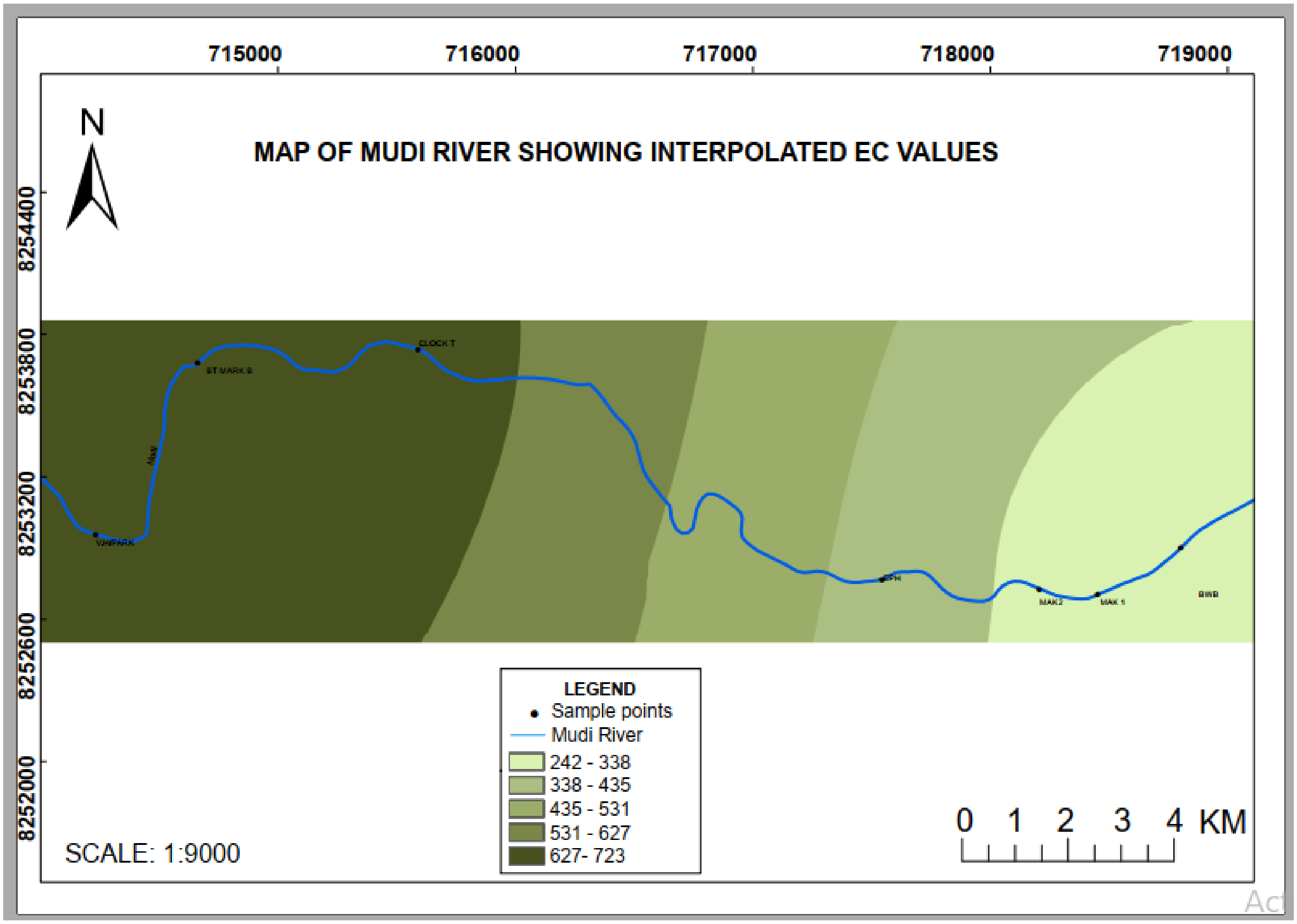

Figure 12:*Showing Interpolated EC values*

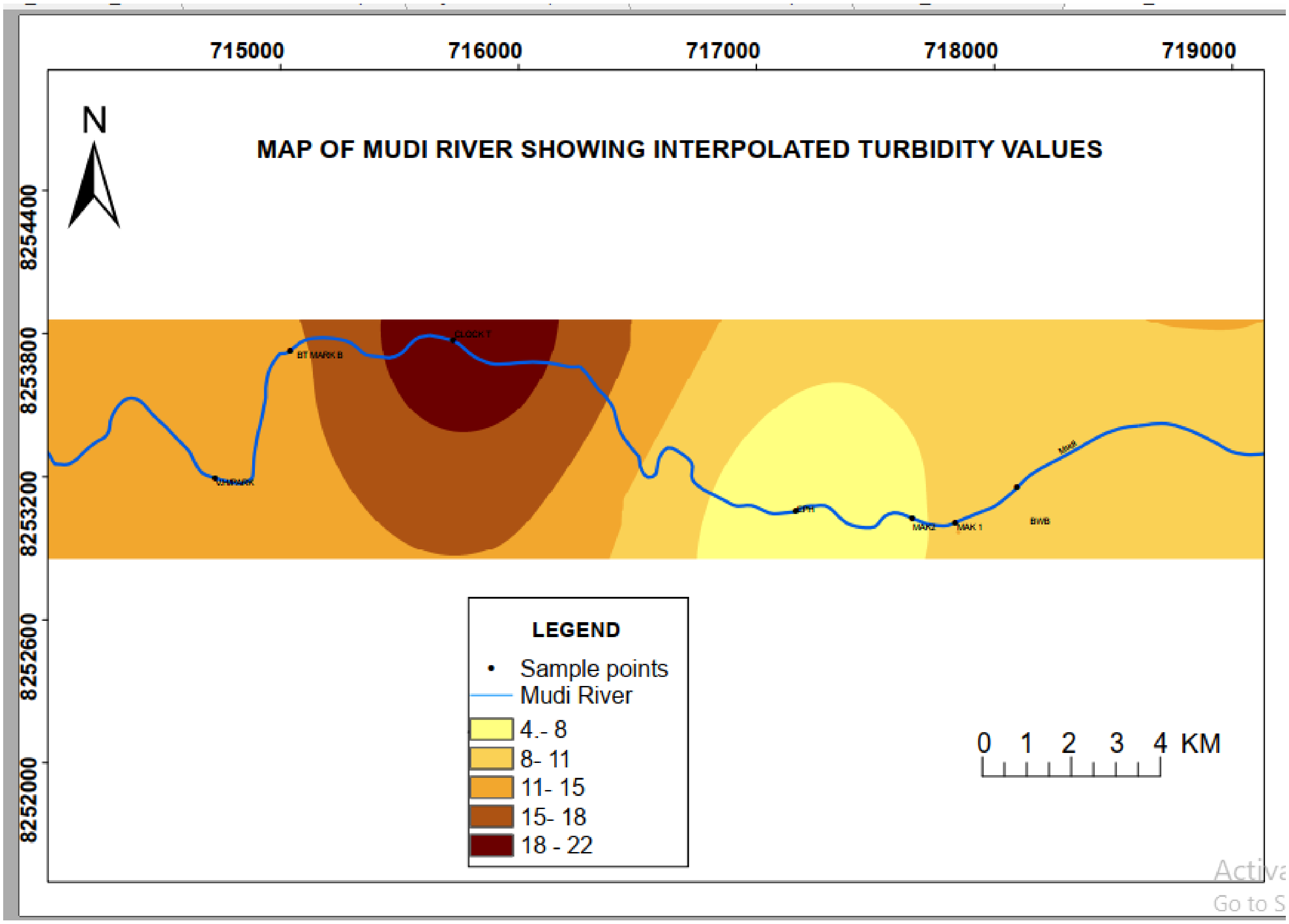

Figure 13: *Showing Interpolated turbidity values*

4.4 CREATING WATERSHEDS

Hydrology toolset under the spatial analyst tool was used to delineate watershed along Mudi river. A Digital Elevation Model (DEM) of Blantyre city with a 30m resolution was used to determine flow-path directions and flow accumulation in ArcGIS version 10.8. The river's flow direction and accumulation were determined after removing the small imperfection using the fill tool. Using the sampling sites as the outlet point or pour point, the watershed tool was used to delineate catchment areas for each sample site. It should be noted that a catchment delineated for a lower stream site includes the catchment area corresponding to upper watersheds. It should also be noted that the watersheds that were created did not only cover the land use categories along the catchment of the selected stretch but they covered the area beyond the river's catchment since the activities happening upstream also have an impact on the quality of water downstream.

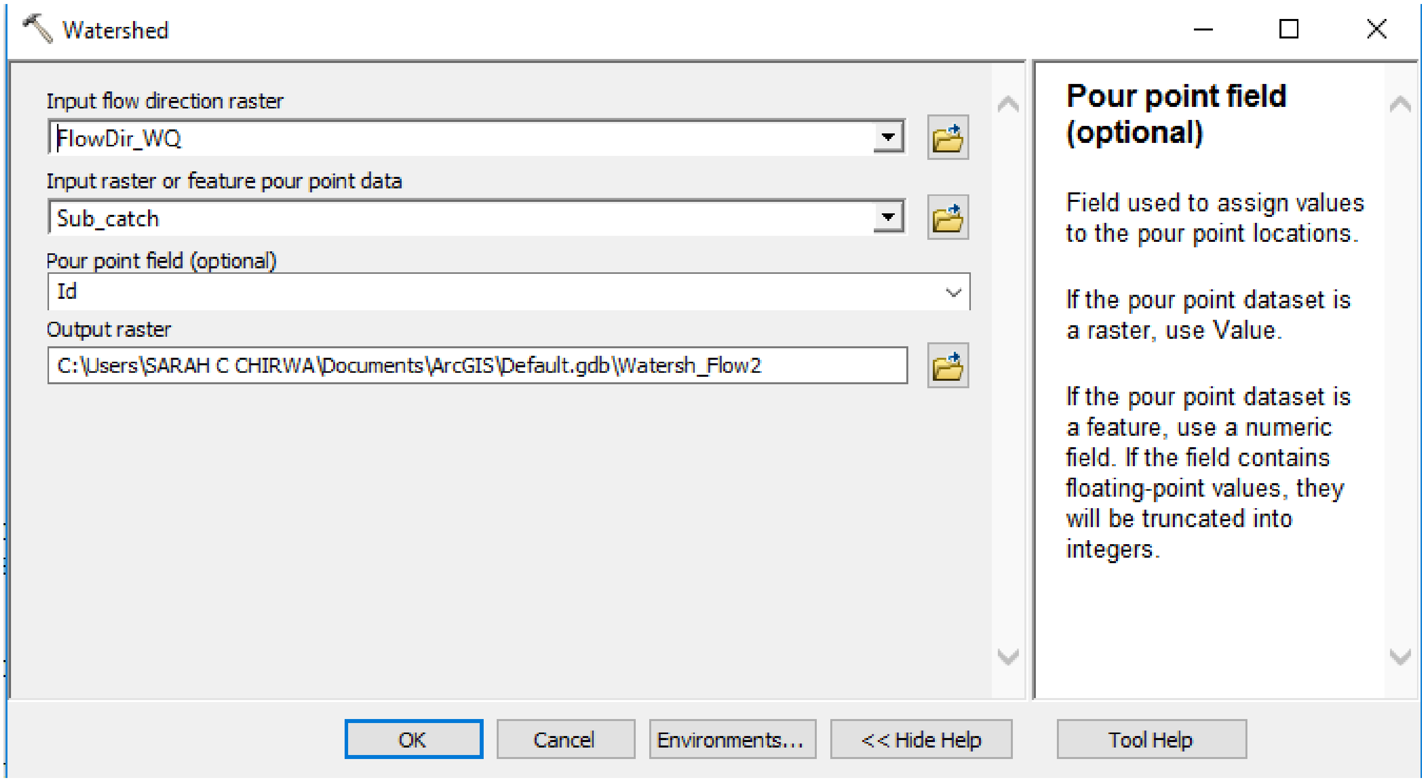

Figure 14: *showing watershed tool in Arcmap*

The watersheds corresponding to the sample sites were generated. These generated watersheds were in raster format hence there was need to convert them into polygons in order to allow further analyses. To achieve this, the *raster to polygon tool* under data management tools was used. Below is a snapshot of the polygons created

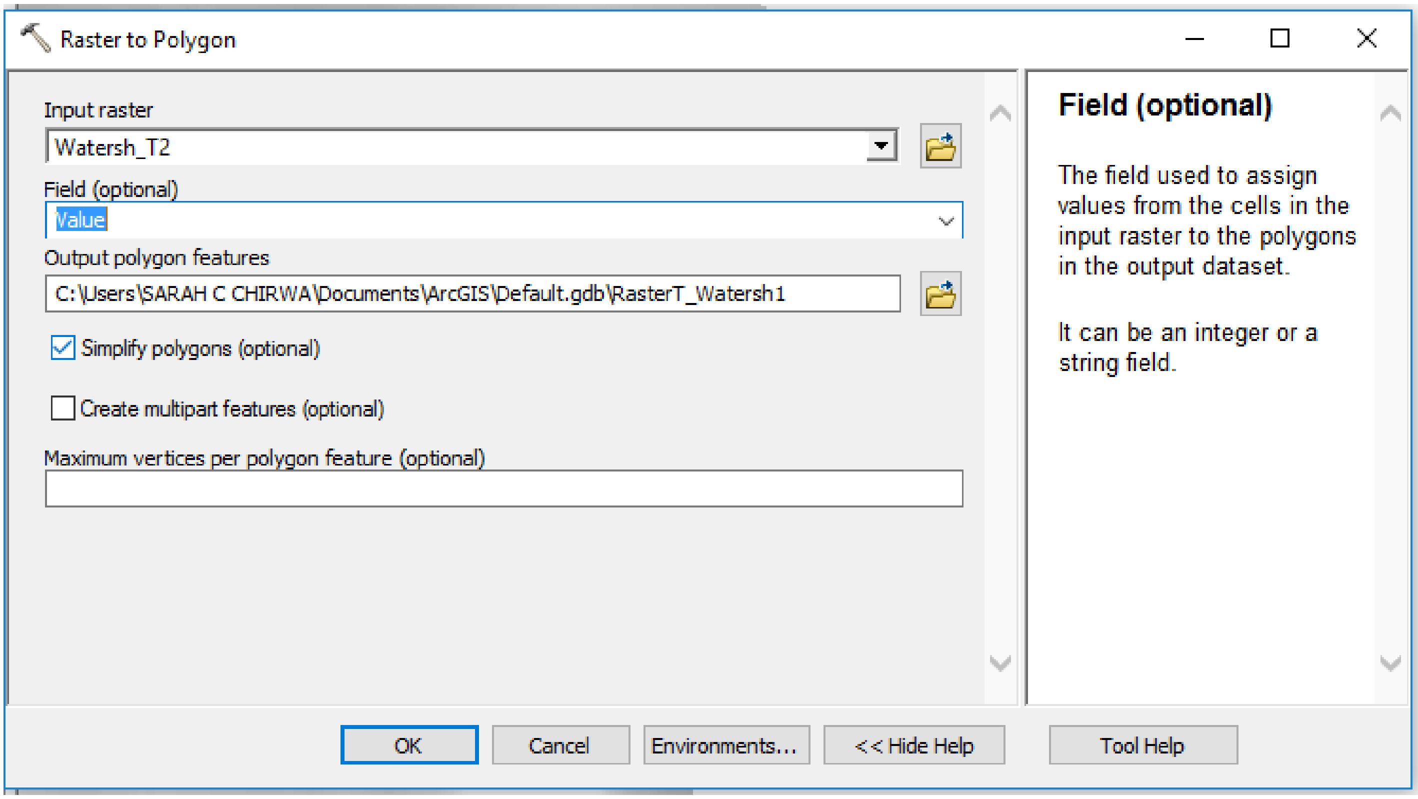

Figure 15: showing *raster to polygon tool*

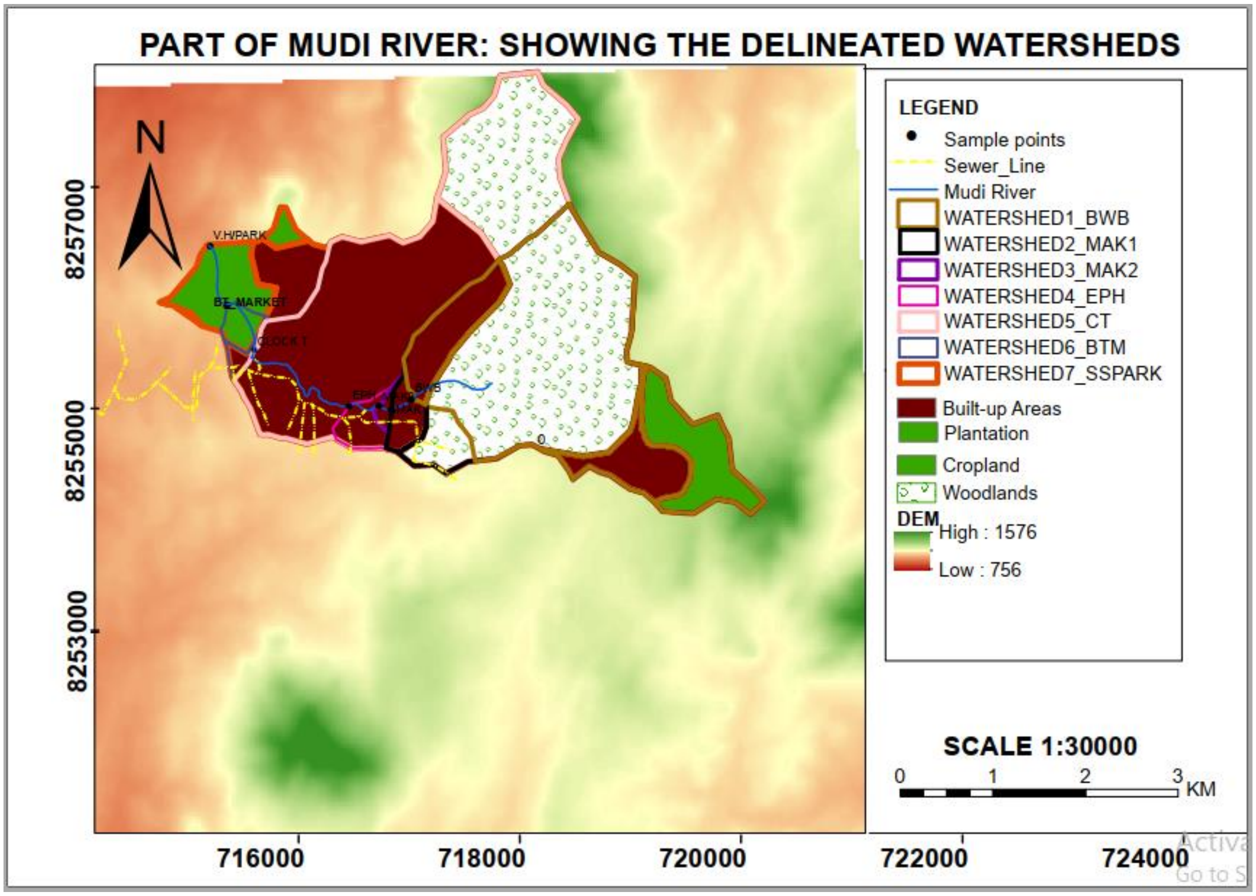

Figure 16: *Showing the delineated watersheds in polygon*

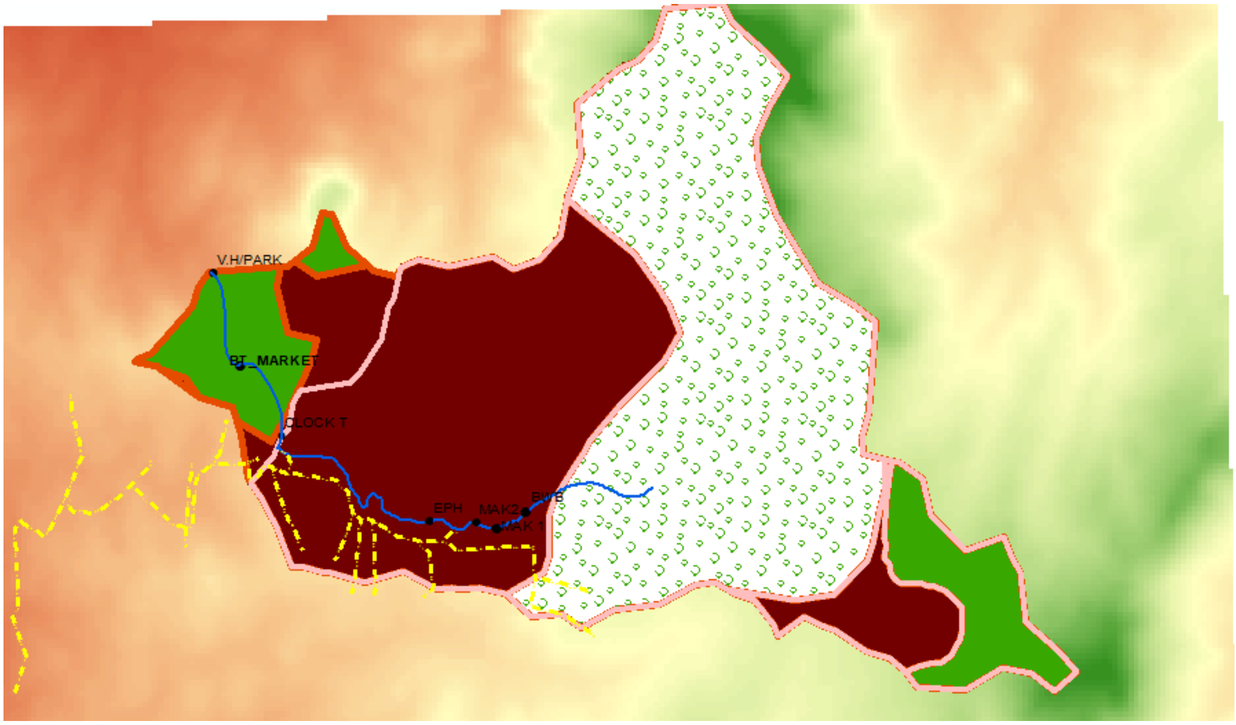

Figure 17: *showing the clock tower delineated watershed*

4.5 OBTAINING DATA FOR LAND USE MAP

The land use data was obtained from the USGS website http://glovis.usgs.gov. This website helps people to obtain geo spatial data across the globe. This site was chosen due to the fact that it is a free online data source and the datasets are easily downloaded (Kibena et al. 2014). The website also provides recent data unlike other sources which contain out dated data sets. All you need is to have an USGS account and good internet connection. The downloaded file was a Tagged Image File of Africa land use dataset. ArcGIS software was then used in the clipping and classification of the downloaded Tagged Image File (TIF).

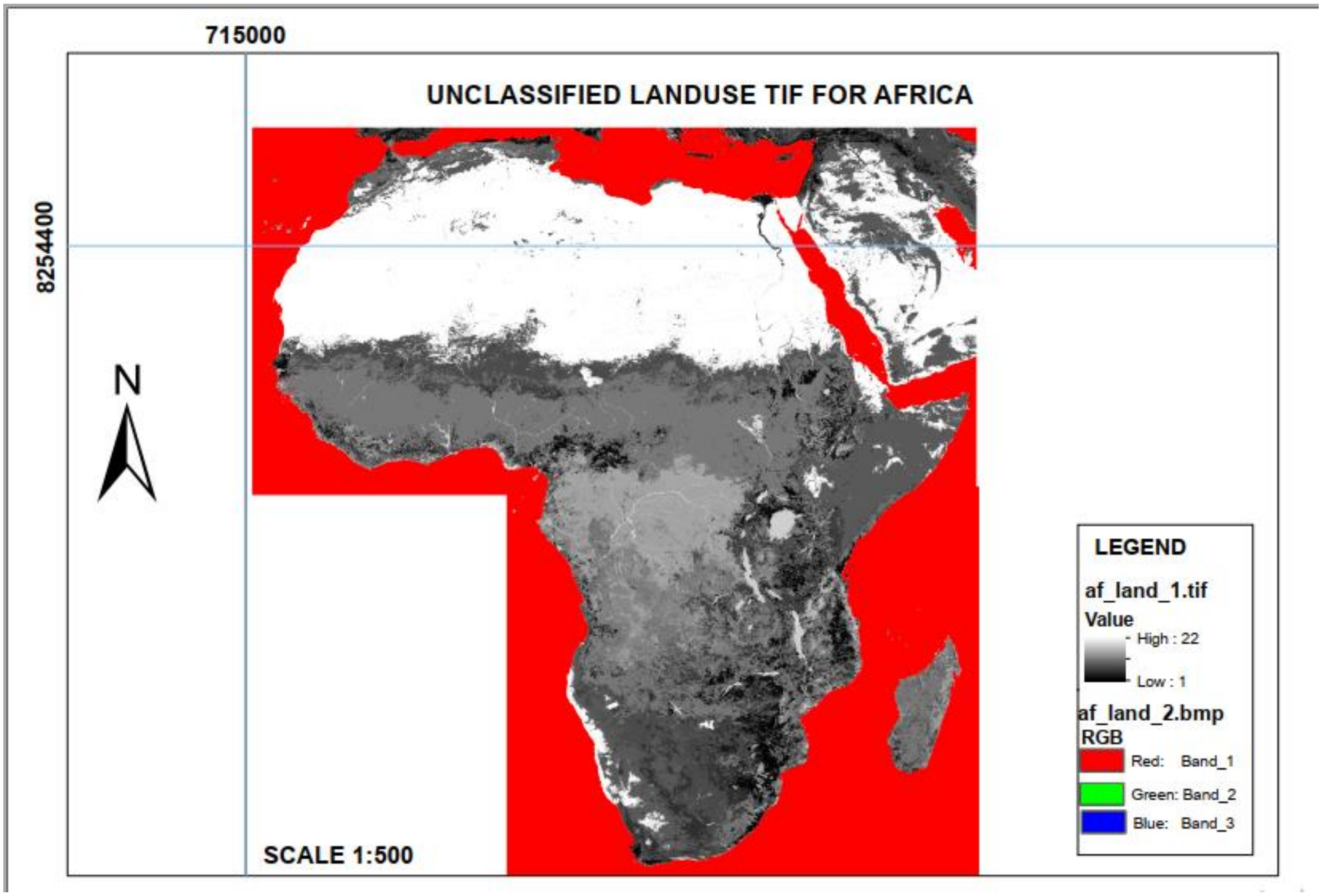

Figure 18: *showing Unclassified land use TIF for Africa*

By using the clip tool under the data management tools in ArcMap (Data management tools→ Raster→ Raster Processing→ Clip), the Africa land use TIF was clipped using Blantyre city boundary as a clip.

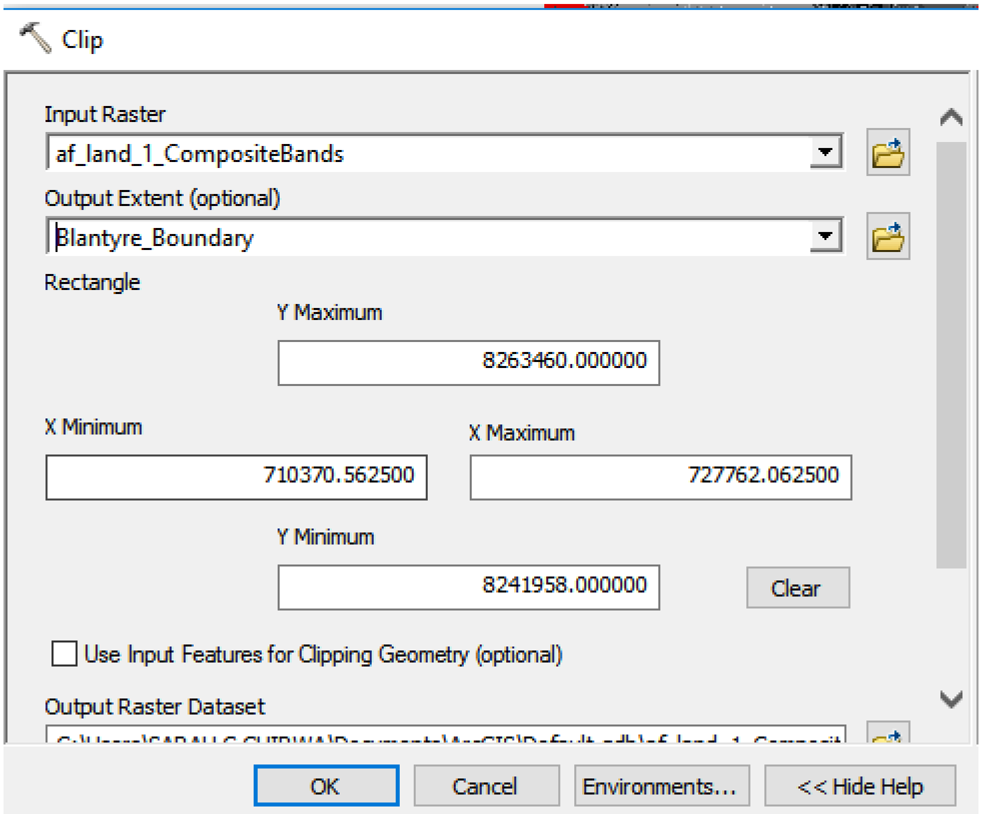

Figure 19: *showing Clipping Africa Land use Raster*

The clipped TIF land use dataset was then further classified into different land use categories such as

- Built-up area: Urban structures of all types: residential, sewers, industrial and other similar facilities
- Cropland: temporary croplands, grassland, shrubs and other vegetation
- Woodland: forests
- Marsh

The classification was based on the prior knowledge of the study area and additional information from the previous studies (Mawenda, Watanabe, & Avtar, 2020).

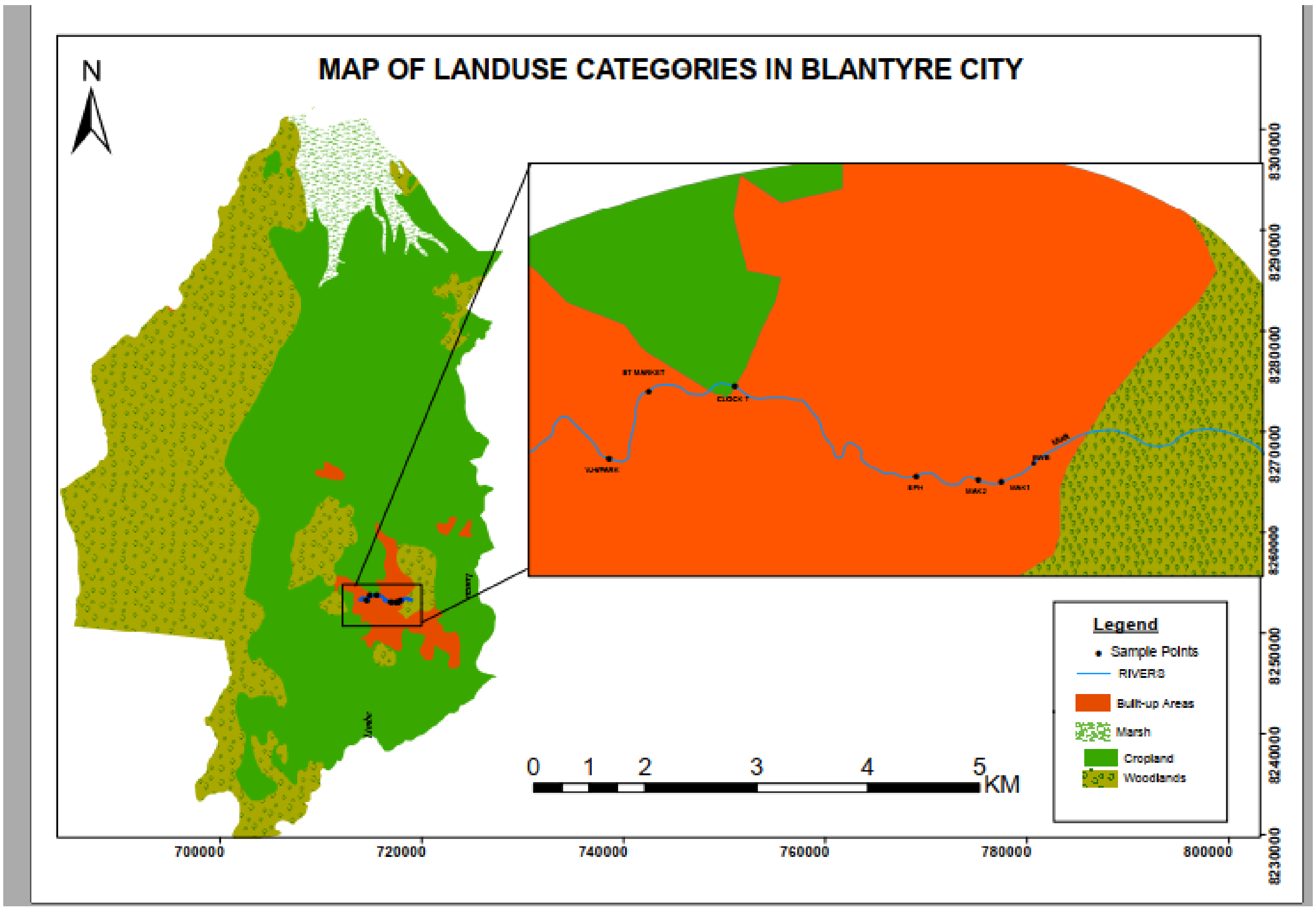

Figure 20: *showing Classified land use categories in Blantyre District*

4.6 CORRELATION ANALYSIS BETWEEN THE LAND USE CATEGORIES AND THE MEASURED WATER QUALITY PARAMETERS WITHIN THE WATERSHEDS

After GIS analysis was used to establish the relationship between the water quality variables and the land use variable in the catchment through watershed division; the established relationship was quantitatively analyzed in excel using the correlation analysis. Correlation analysis was carried out to determine the strength and the type of relationship between the landuse categories and the measured water quality parameters within the delineated watersheds. The correlation coefficient has a value between positive one and negative one depending on the strength of the relationship. As the correlation coefficient value approaches zero, the relationship between the two variables becomes less, whereas a correlation coefficient around one suggests a greater relationship. The sign of the coefficient shows the direction of the relationship; a positive sign indicates a positive relationship and a negative sign indicates a negative relationship (Kendall & Gibbons, 1990)

	EC	TDS	PH	TURB	TEMP	NITRATES	CROPLAND
EC	1		-	-	-	-	-
TDS	0.99398	1	-	-	-	-	-
PH	0.781835	0.791038	1	-	-	-	-
TURB	0.56108	0.606996	0.511505	1	-	-	-
TEMP	0.94781	0.932555	0.822858	0.590347	1	-	-
NITRATES	0.92075	0.923378	0.857249	0.39246	0.869042	1	-
CROPLAND	0.97670	0.998283	0.931509	0.999492	0.82722	0.9987	1

Table 4: *showing relationship between measured water quality parameters and cropland*

The figure shows a positive correlation between cropland and the measured water quality parameters. Ec, TDS, TURB and nitrates displayed a very strong relationship with cropland. Specifically, this correlation could be linked to the high rates of farming chemicals upstream of the river that leads to increase in the concentration of water quality parameters.

These findings are consistent with the findings of a review published in 2019 by Moriken Camara et al, who discovered that agricultural and forest-related activities had a strong positive association with physical and chemical markers of water quality (Moriken, Jamil, & Abdullah, 2019).This was also observed in Nigeria as it was recommended that farming activities at the river banks of Kaduna river should be banned since the fertilizers used by farmers easily drain into the river and increase the concetration of chemicals in the river (Ogbozige, Adie, & Abubakar, 2018).

Thus from the results of these related studies and the results of this study, it can be concluded that cropland or agricultural land use has a negative impact on the physical and chemical composition of water in Mudi river.

	EC	TDS	PH	TURB	NITRATES	WOODLAND
EC	1	-	-	-	-	-
TDS	0.99398821	1	-	-	-	-
PH	0.78183456	0.79103789	1	-	-	-
TURB	0.56108425	0.60699566	0.511505	1	-	-
TEMP	0.94780633	0.93255497	0.822858	0.59034733	-	-
NITRATES	0.92074842	0.92337795	0.857249	0.392455971	1	-
WOODLAND	0.95961558	0.9836446	0.762889	0.77392116	0.8791415	1

Table 5: *relationship between measured water quality parameters and woodland*

A positive correlation was also revealed between woodland and the measured water quality parameters in the river. Among the measured parameters, EC and TDS displayed a very strong relationship. This relationship could be linked to high rates of deforestation upstream leading to soil erosion hence the decline of water quality in the river. Loss of forest cover can increase runoff, which can speed up soil erosion and increase the sediment load and turbidity of water sources, lowering water quality (Mapulanga & Naito., 2019)

	EC	TDS	PH	TURB	NITRATES	BUILT UP AREA
EC	1	-	-	-	-	-
TDS	0.993988	1	-	-	-	-
PH	0.781835	0.791038	1	-	-	-
TURB	0.561084	0.606996	0.511505	1	-	-
TEMP	0.947806	0.932555	0.822858	0.590347	-	-
NITRATES	0.920748	0.923378	0.857249	0.39246	1	-
BUILT UP AREA	0.29317	0.36718	0.64644	0.73299	0.32374	1

Table 6: *showing relationship between measured water quality parameters and Built_up Area*

4.5 REGRESSION ANALYSIS

Regression analysis process is primarily used to explain the goodness of a predictive model that explains the relationships between variables (Malik, 2018).

Interpreting values of variables in a regression model

MULTIPLE R	0.998283326
R SQUARE	0.996569598
ADJUSTED R SQUARE	0.993139196
STANDARD ERROR	1.01076477

Table 7: *Showing summary output of regression statistics*

Multiple R & R Square

The multiple R and R squared (The R squared is also known as coefficient of determination) explain how well the regression fits the observed data. These two values measure the quality of fit of the regression model. Higher R squared value indicates a better fit for the model and a small R squared value indicate that the data does not properly fit the model.

Adjusted R Square

The adjusted R square is used to assess the reliability or dependability of the correlation and how much of it is affected by the addition of independent variables. Because the adjusted R square varies when additional independent variables are added, it may also be used to compare the quality of fit for regression models with varying numbers of independent variables. When the adjusted R square values are high, the model is reliable.

Standard Error of the regression

The standard error of the regression also known as the standard error of the estimate expresses how wrong the regression model is. Smaller values are better because they indicate that the results are closer to the fitted line.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The study recorded the locational coordinates of the sample points, measured the water quality parameters and compared the findings with the WHO and MBS recommendations, determined the spatial variation of the measured water quality parameters, delineated the watersheds based on the sample points and carried out a correlation analysis to determine the relationship between the measured water quality parameters and the land use categories.

The following conclusions were made from the study:

- Based on the water quality results, some of the water quality parameters (such as TDS) are within the MBS and WHO water quality standards. However, some parameters (such as turbidity) exceeded the MBS and WHO water quality standards. These are the parameters that may lead to deterioration of the water quality in Mudi River.
- The interpolation or spatial variation results showed that most water quality parameters were increasing in concentration downstream of the selected stretch. This was indicated by parameters such as nitrates, PH and EC which recorded higher concentration values at the downstream samples such Clock Tower, Blantyre market and sunny side park compared to samples in the upstream of the selected stretch.
- It was discovered that land use categories have an impact on the water quality of Mudi River. There was a strong significant and positive relationship between some water quality parameters and land use categories. The parameters that had strong relationship were four (Turbidity, EC, nitrates and PH) out of the 5 measured parameters. For instance, the correlation between cropland and PH yielded a positive relationship of 0.999492.

5.2 RECOMMENDATIONS

Based on the results, the study also made the following recommendations:

- To improve quality of water in the rivers, the city needs to improve management approaches such as environmental awareness and strict regulations by the Department of Water and Sanitation or any other body concerned with the management of the rivers.
- This study also recommends continuous monitoring of the river using Geospatial technologies especially downstream to determine the status of water. The monitoring should not only be done in Mudi river but its major tributaries such as Nasolo as these also have a bearing on the water quality status of the river.
- The sewer line that passes along the river should also be periodically checked to ensure it's in a good condition to prevent it from making its leakage into the river.
- As a result, effective land-use planning and watershed management are necessary to improve the river's water quality.

5.3 CHALLENGES OR LIMITATIONS

The following are some of the challenges that were encountered during the study:

- Part of Mudi river is shielded by the Blantyre water board dam. It was therefore not possible to collect water samples from that part.
- The study aimed at measuring a number of water quality parameters, however, only five parameters were assessed due to lack of required instrumentation at the polytechnic Environmental Health Laboratory.
- Time factor is another limitation. Water quality status varies depending on wether the assessment is done in rainy season or dry season. This study was conducted in June.

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