EFFECT OF AGRICULTURAL PRACTICES ON WATER QUALITY IN NDAKAINI DAM, GATANGA, MURANGA COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other academic institution.

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This thesis has been submitted to Board of Postgraduate Studies with our approval as university supervisors.

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DEDICATION

To my father, Joseph Mwangi and mother, Adrine Waigwe for their moral support and dedication in ensuring that I got the deserved education; my sisters, Nelius and Peris for their moral and inspiration support, my friends for their social, moral support and constant prayers during the study period.

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LIST OF ABBREVIATIONS

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
GDAL	Geospatial Data Abstraction Library
GPS	Global Positioning System Library
GRASS	Geographical Resources Analysis Support System
LULC	Land Use/Land Cover
Masl	Meters above Sea Level
MFD	Multiple Flow Direction
NDVI	Normalized Difference Vegetation Index
OLI	Operational Land Imagery
Q GIS	Quantum Geographical Information System
ROI	Region of Interest
SAGA	System for Automated Geoscientific Analysis
SAM	Spectral Angle Mapping
SCP	Semi-Automatic Classification
SFD	Single Flow Direction
TWI	Topographical Wetness Index
USGS	United State Geological Survey
WQP	Water Quality Parameter

ABSTRACT

Change in Land Use and Land Cover (LULC) is inevitable and accuracy and time are important to detect the change in different seasons to monitor trends and status of water quality. Understanding LULC and Water Quality Parameters (WQP) is necessary for efficient water management and reduction of operation water treatment cost. Therefore, the effect of agricultural land uses on water quality in Ndakaini, Gatanga, Muranga County, the LULC and WQP were analyzed using Remote Sensing (RS), Geographical Information System (GIS) and R Studio. Landsat 8 OLI was used to classify different LULC using band 4, 3, 2. Semi-Automatic Classification Algorithm (SCP) was used to create a Region Of Interest (ROI) and Spectral Angle Mapping Algorithm (SAM) threshold of 90 and pixel size of 1500 was used to create thematic maps. Classification accuracy was 97.5 % overall accuracy and 0.90 kappa coefficiency in dry season, 97.8 % overall accuracy and 0.94 kappa coefficiency in a wet season. Digital Elevation Model (DEM) was also used to delineate channel network. Kiama (14), Kimakia (13), Chania (6) rivers were the longest and largest, and the slopes ranged between 2.78^{o} and 58.3^{o} The land surface factor values were 1.45 m/s, 3.5 m/s, 5.54 m/s, 7.59 m/s and 9.63 m/s. Topographical Wetness Index (TWI) had -1.28 T.U,-0.314 T.U ,0.654 T.U,1.62 T.U and 2.59 T.U and flow direction -1.0 m/s to 6.99 m/s. Water samples were collected and referenced in dry and wet seasons from 8 sampling rivers. Eight WQP including pH, turbidity, conductivity, color, No3, No2, COD, and alkaline analyzed in the laboratory correlated in a different season with WHO standards where p= 0.001. The results showed that LULC in the wet and dry season significantly influenced WQP.

CHAPTER ONE

1.0 Introduction

Agriculture is a fundamental component of the global economy, with farmers shifting to agricultural intensification to meet the increasing demand for food as a result of world's population pressure, which is projected to be 9 billion in a few decades to come (Godfray *et al.*, 2010). Agricultural intensification is the increase of commodity per unit area (Barretto *et al.*, 2013) continuously (Nijbroek and Andelman, 2015). Agriculture intensification has led to the massive use of pesticides and fertilizers, in developed countries (Ongley, 2000), and continuous use of land intensively using traditional methods in developing countries (Tscharntke *et al.*, 2012). Increased fertilizers and agriculture intensification have therefore contributed to increased solutes on surface water, thus decreasing the quality of drinking water (Mattikalli and Richards, 1996).

Water quality is dependent on two key variables such as temperature and rainfall which affect mobility and dilution of contaminants. Increased temperatures affect chemical kinetics while increased flow leads to a change of stream power hence sediments loads with potential to degrade water quality (Whitehead *et al.*, 2009). Agricultural practices, on the other hand, are impacting on soil quality resulting in water pollution due to nutrients leaching and transportation into water bodies (Zalidis *et al.*, 2002). Worldwide, watersheds are facing various challenges of water quality such as pollution and contamination (Smith *et al.*, 2015). Work done by Liu *et al.*, (2015) showed that there is a significant relationship between land use, nitrogen, and phosphorous content in water bodies. The pollution caused by land use had steadily increased in a span of 14 years from 3.11×104 to 3.49×104 tones, and studies done by

Tong and Chen, (2002) using Geographical Information System (GIS) showed that land use had significantly correlated positively with water quality parameters at p-value < 0.0001. However, agricultural intensification has been a global issue affecting water quality in both developing and developed countries (Kwa, 2001). In developed countries, agriculture is done in large scale and thus intensification gear towards the high fertilizers and pesticides use, which cause eutrophication and chemical contamination to water resources. (Tscharntke *et al.*, 2012). This is further supported by Africa statistics that 70 % of the people are food insecure and only 50 % are small-scale farmers in Africa (Omiti and Omiti, 2012). Therefore, use of fertilizers and pesticides are on the lower side, but reliance on associated ecological processes and biodiversity are on the higher side for global food. These ecological processes have led to land degradation associated with sediments as a result of agricultural intensification (Yeshaneh *et al.*, 2014).

Land degradation has resulted from the occurrence of runoff over highly unconsolidated sediments on agricultural areas which are hence transported to water bodies causing high turbidity (Singh, 2009). Studies done on rural highlands in developing countries show that pollutants deposit caused by runoff into water bodies are dependent on land use, type of land cover and the amount of rainfall in the small catchments and medium basins (Tittonell, 2014). In Kenya, the Aberdares is one of the water towers where Ndakaini Dam draws its water. Ndakaini Dam is the primary source of water supply to Nairobi residents and its surroundings, which is fed by Thika, Kimakia, Kayuyu, Kiama, Githeka, and China Rivers (Hunink and Droogers., 2015). The primary land use in Ndakaini dam catchment is agriculture with a bias towards cash crop and subsistence (Leisher, 2013). However, Ndakaini Dam faces challenges of sedimentation and chemical pollutants from nutrients enrichment, which have resulted in water quality degradation (Leisher, 2013).

1.1 Problem Statement

Agriculture is the backbone of the global economy where intensification is practiced to feed the hungry world. Agricultural intensification is said to increase yields globally and restrict human demand for land (Barretto *et al.*, 2013); through the adoption of sustainable agriculture by the international organization such as Food Agricultural Organization (FAO) which protect resources while increasing yields. Contrary studies done by Godfray *et al*. (2010) in Niger state showed that due to population growth sustainable intensification has become impossible. Tscharntke *et al*. (2012) working in Brazil showed that intensive land use affects hydrological, biological, chemical and aquatic systems. Intensive land use also results in disturbance of gradients which alter nutrient cycle and pollutant export process (Barretto *et al.*, 2013). However, in the developing countries such as Africa intensification is associated with sediments due to erosion, rainfall, steep and rugged terrain which are enhanced by agricultural intensification activities (Guzman *et al.*, 2013). Tu, (2009) in Ethiopia showed that sediments supply in the catchment is heterogeneous in time and space depending on climate, land use, slope, topography, soil type, vegetation and drainage.

In Kenya, agriculture is the engine of the economy accounting for 50 % of the country's gross domestic product (GDP) and 80 % employment (ROK, 2004). Kenya ranks high in the export of tea, coffee, and horticulture products in the world and comprises of both small scale and large scale farming which are said to be the most successful agricultural production regions in the continent (Von Braun, 2007). However, agriculture faces many challenges such as fragmented land size, poor farming skills and open flow of the market leading to growing commercial crops without considering soil conservation measures. As a result, environmental problems arise such as soil erosion, degradation, and infertility leading to increased sediments and nutrients in water bodies thereby degrading water quality (Agouridis *et al.*, 2005).

Dams are faced with sedimentation problem which has been reducing their storage capacity coupled with high costs of treatment. Hunink and Droogers, (2015) working in Kenya showed that suspended sediments had been a major issue in Ndakaini dam leading to increasing maintenance, treatment cost and reduced lifespan of the reservoir due to siltation. These deposits result from increased runoff of sediments and leaching of nutrients to water bodies (UNESCO, 2002). According to UNDP (2005), nutrients enrichment has become the planet's most widespread water quality problem mostly associated with nitrogen and phosphorous nutrients from agricultural runoff (Davison *et al.*, 2004). Nutrients pollutants, therefore, lead to eutrophication which produces toxic cyanobacteria that can affect humans. Also, agricultural intensification leads to erosion and sedimentation into river, lakes, and streams thereby changing chemical and physical processes of water bodies (Carr and Neary, 2008). Therefore maintenance of water quality through continuous monitoring of a vast number of parameters is essential.

1.2 Justification

With the ongoing land fragmentation which reduces the agricultural land size, farmers practice the continuous cultivation on the same land since practices like crop rotation are not feasible with the size of land they own. This method lowers the soil fertility making farmers to use an excess of inorganic and organic fertilizers to regain soil fertility which can lead to water quality deterioration hence the need to monitor the water quality is justified. The demand for food and land has led to agricultural intensification leading to the depreciation of water quality in

Ndakaini Dam and its sources. Knowledge of likely sources of non-point and point pollution, the amount of sedimentation and water quality status is essential in enhancing clean and safe water for consumers and saving water treatment and operational cost. Unsustainable agricultural practices, on the other hand, are posing risks to water quality downstream resulting in eutrophication, nutrients leaching and runoff and chemical waste runoff. Ndakaini dam being an important reservoir for Nairobi and neighboring residents produce 430,000 m^3 / day of water which is about 84 % of the total water supply, and has a storage capacity of 70,000,000 m^3. The facility is at 2,041 meters above sea level (masl), with an average depth of 65 m. Thus, there is need for the assessment of water quality parameters from the catchment to the end user. The assessment of WQP will enable effective management of water quality through identification of the major land uses that are a threat to water quality and address it effectively and sustainably.

1.3 Objectives

1.3.1 Broad/overall objective

To assess the effect of different land use / land cover classes in different catchment on water quality in Ndakaini Dam, Gatanga, Muranga County, Kenya

1.3.2 Specific objectives

i. Effect of flow direction and topographical wetness index on water quality

ii. Seasonal assessment of water quality parameters levels and concentrations in rivers of Ndakaini Dam catchment

1.4 Research Questions

a) Does different land use / land cover classes in different catchment have an impac water quality of Ndakaini dam?

b) Do flow direction and topographical wetness index have an effect on water quality?

c) Is there any correlation between water quality parameter levels and concentratioı rivers seasonally?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Water Resources

Water is life as it transports, dissolves, replenish nutrients and organic matters while carrying away waste (Suthar *et al.*, 2012), and used for consumption by humans and living organisms (Avvannavar and Shrihari, 2008). Globally, 97 % of water is saline present in the ocean and seas, 2 % frozen in the mountains and only 1 % are fresh water present in rivers, lakes, and groundwater (UNESCO, 2002). Rivers have been the most significant resources on which most developmental activities such as dams depend upon (Baskar *et al.*, 2013). The river system connects to form a watershed; small streams feed the large river, and contamination in any of the tiniest streams results to low water quality in rivers downstream (Toman, 2009). However, intensified competitions among users of water have posed a threat to water resources due to population growth and economic activities. According to UNESCO, (2002), 20 % of the world population lacks safe drinking water due to chemical, nutrient enrichment and sediment pollution, which is further coupled with water scarcity as a result of water quality degradation (UNDP, 2005). Nevertheless, studies done in major water towers of Kenya such as Mau Forest Complex, Mt Elgon, and Mt Kenya showed sediments and nutrients steady increase in rainy seasons into the rivers as a result of increased water overflows from agricultural lands leading to water quality degradation (Otieno and Ogalo, 2012).

2.2 Water Quality

Water quality is the term used to describe chemical and physical characteristics of water in respect to its suitability for a particular purpose (Sargaonkar and Deshpande, 2003). Water quality parameters selection for testing depends on their use and the need of quality. Some of the important quality parameters are discussed below.

2.2.1. Chemical characteristics of water

Chemical characteristics occur both naturally due to nature of dissolved substances from bedrocks and soils from watersheds, and artificially due to anthropogenic activities such as agriculture (Havelaar and Melse, 2003; Apha, 2005). Major chemical characteristics of water are pH, alkalinity, and conductivity. The pH is a measure of hydrogen ions in water. The ionization of water is HOH H+ + OH-, in neutral solutions [OH] = [H] hence pH = 7, therefore, if acidity increases, [H] increases and pH reduces from 7 (Avvanavar, 2008). However, pH in rivers ranges between 6 and 9 and is determined by pH meter after calibration using buffer 4 and 7 solutions in the laboratory (Apha, 2005). The pH is an important parameter in the water treatment process as the excess of pH causes corrosiveness in pipes, skin disorder to the consumers and also affects aquatic life (Leo and Dekkar, 2000).

Alkalinity is the capability of streams to neutralize acid pollution and resist change in pH, and it is measured using titration method with standard sulphuric acid (0.02 N) at room temperature with methyl orange indicator (Apha, 2005). Conductivity is the ability of water to conduct electrical current measured using conductivity meter in the field (Howard, 1933). Conductivity also measures other solids indirectly such as nitrate and phosphate, whereby an increase in conductivity indicates the presence of these substances in water bodies (Murdoch *et al.*, 1996).

Other chemical parameters of importance in monitoring water quality in the agricultural sectors include nitrogen and chemical; oxygen demand Nitrogen occurs naturally in the biogeochemical process, but human activities have interfered with the natural process by use of excess nitrogen fertilizers in agricultural fields. The excess nitrates in water surface causes eutrophication, and in the presence of drinking water it causes meth hemoglobin in red blood cells which is a lack of oxygen -carrying ability (Shah and Joshi, 2015). Nitrates and nitrites in the water are analyzed using UV spectrophotometer in the laboratory calibrated with standard measurements from the manufacturer (Drolc and Vrtovšek, 2010). Water pollution and quality degradation are becoming a threat to water bodies due to agricultural inputs such as nitrogen fertilizers and poor farming practices (Mulei, 2012). These inputs are contaminating aquatic ecosystems through leaching and runoff resulting in water chemistry change thus increasing the high cost of water treatment (Smith *et al.*, 2006).

2.2.2 Physical characteristics of water

A physical characteristic is a parameter that can be observed and measured in the field, or analyzed in the laboratory within a given period. These parameters include turbidity and Total Dissolved Solid (TDS), (Davison *et al.*, 2004). Turbidity measures the clarity of water caused by suspended solids which carry nutrients and pesticides through the stream system as a result of runoff (Murdoch *et al.*, 1996).Turbidity is measured using turbid meter calibrated by standard measurement from the manufacturer. Total dissolved solids are the amount of solutes that dissolve in water, and are significant in indicating some solids erosion has carried nearby or upstream for mitigations. Total dissolved solids are measured indirectly by measuring electronic conductivity in the field (Sargaonkar and Deshpande, 2003).

2.2.3. Impact of water quality on human health and water treatment system

Water quality safety is important in human health as it assists in the setting of quality standard for water quality guidelines (Havelaar and Melse, 2003). Water guidelines are rules that direct the use of water to protect public health while reducing the cost of treatment for safe water (Howard and Bartram, 2003). Clean water is the state at which water does not pose a high risk to the consumer and does not overwhelm the treatment process (Davison *et al.*, 2004).

Various Acts have been put in place to protect water catchment areas in Kenya. These Acts are Environmental Management Coordination Act (EMCA 1999) which prohibits pollution under section 72, Water regulation (2006) with regulation 4 preventing water pollution and regulation 6 deals with the protection of lakes, rivers, streams and springs. The Agricultural Act cap 318 provides the management of agricultural systems and practices. On the other hand, treatment is the process by which raw water undergoes disinfection before distribution to the consumers (Lechevailler and Au, 2004). Thus, monitoring of water quality is a crucial process which needs an approach from catchment where potential pollution both natural and anthropogenic influence water quality downstream and aquifers, impacting treatment steps and operation cost (LeChevallier and Au, 2013). However, an understanding of the variation of raw water and catchment characteristics that lead to pollution is crucial as it influences water treatment requirements (WHO, 2004). Individual priorities are considered in monitoring surface water from the source which includes protected and unprotected catchment, topography, geology and agricultural land use (Bartram and Ballance, 1996). Lack of proper management of land uses at the watershed contributes to sporadic turbidity causing major threats to the water treatment process. This renders disinfection inefficient allowing entry of pathogens in treated water and distribution systems (Pinheiro and Wagner, 2001).

2.3 Influence of Agricultural Practices on Water Quality

Agriculture being the mainstay of the global economy, has to have increased productivity to rest the current food crises impacting on farming practices such as plowing methods, this resulted in poor cultivation practices, deforestation and severe soil degradation worldwide (Tittonell, 2014), leading to sediments loads into the rivers. Sediments in rivers play an important role to stabilize water bodies and riverine systems (Dodds and Oakes, 2008). However, sediment supply and transport has been disturbed over a period through human activities such as agriculture, deforestation, and dams resulting in environmental problems. These environmental conditions include reservoir sedimentation associated with nutrients and contaminants in river systems (Rodríguez *et al.*, 2010), leading to water pollution (Cardinale, 2011).

In Africa, agriculture is vital in economic development which accounts for 25 % of the GDP in African countries (Henao and Baanante, 2006). However, African countries have immense challenges such as affordability of appropriate agricultural technologies and fertilizers since most of them are small-scale farmers (Tittonell, 2014). These Agricultural problems have resulted in inappropriate tillage practices (Mary and Gichuki., 2015), leading to the destruction of soil structure which affects the soil's water holding capacity (Thierfelder and Wall, 2009). Soils with poor structures result to nutrients leaching and surface runoff to water bodies' significantly affecting water quality (Turner and Rabalais, 2003).

Agricultural no-tillage conservation measures practiced over half a century around the world, and their role being to increase soil infiltration and soil moisture to retain nutrients in the soil (Thierfelder *et al.*, 2013). However, the term no-tillage has been having a contradiction since the system does not include crop mulch cover, extended fallow periods, alternative tillage methods and monoculture.This has resulted in reduced crop yields, high erosion rates and low infiltration rates and elevated fertilizers, which has resulted into water quality degradation (Derpsch *et al.*, 2014).

2.4 Influence of Rainfall on Agricultural Pollutants in Water Bodies

In Kenya, agriculture is mainly rain fed and entirely dependent on bimodal rainfall that is two cropping seasons in most of the country (Romano, 2009). Agriculture has several inputs such as nitrogen and phosphorous applied in farm fields for production (Braskerud, 2002). These pollutants enter into water bodies through runoff process (Ahuja and Lehman, 1983). Runoff is generated by excess infiltration or saturation which occurs when rainfall intensity exceeds the rate at which water can infiltrate into the soil. Saturation occurs mainly in humid areas where rains encounter soils that have reached saturation (Steenhuis *et al.*, 1995; Singh, 2009). Runoff transport nutrients from the fields in solution forms which contribute to accelerated nutrients and sediments decreasing water quality (Dexter *et al.*, 2004; Tu, 2009).

Pollutant transport relates to rainfall infiltration, runoff, subsurface flow and soil erosion which are affected by environmental factors such as rainfall intensity, rainfall duration, rainfall kinetic energy, slopes, vegetation and soil types (He *et al.*, 2015). Chen *et al.* (2012) working in china and Jiang *et al.* (2014) in south east China showed that nutrient losses are higher when rainfall intensity is strong, and the slope gradient is steep. About the degree of drought, rainfall intensity and duration determine the level of pollution in scenario models (Shi *et al.*, 2013). Nitrogen loss in the soil, as well as non-point source pollution and leaching rate of nitrogen, were positively correlated under the different scenario of drought and floods from a micro level (Ran *et al.*, 2012).

Studies done in dams showed a high rate of sedimentation which was accelerated by soil erosion due to the rapid deforestation and agricultural practices thereby degrading water quality (Saenyi and Chemilil, 2002). Maillarda and Santos, (2008) working in Brazil showed that LULC and turbidity had a healthy relationship in the dry and wet season, thus need for monitoring. The Wei River basin in China indicates that rainfall and agricultural activities are spatial-temporal factors that correspond to water chemistry which vary differently in the dry and wet seasons thus need for monitoring in both seasons (Yu, 2015). A dam is a hydraulic structure of somewhat impervious material built across a river to hold water for agriculture household, hydropower and other purposes (Maingi and Marsh, 2002).

Globally, dams are facing challenges of sedimentation as a result of agricultural practices these sediments have two dimensions namely physical and chemical. In the chemical aspect, the silt and clay fraction of the soils carry chemicals such as phosphorous and nitrogen into the rivers and finally to the dams, whereas with the physical the sediments drain into rivers (FAO, 1996). However, studies done in Ethiopia showed that deforestation and poor agricultural practices had been major causes of sedimentation in reservoirs which carry with them nitrogen and phosphorous (Bishaw, 2001). Over a decade, spatial-temporal analyses have been used to detect agricultural land use change and also water quality through the integration of remote sensing and geographical information system (GIS) (Weber, 2001). Studies done by Dodds and Oakes, (2008) in the United States (US) Showed riparian zone has an influence on hydrological condition due to intensive cultivation of river bank.

2.5 Spatial Analyses on Agricultural Land Use and Water Quality

Spatial analysis is a technique on the topological and geometry of particular location in specific time (Anselin, 2010). Spatial analysis data is dependent on the location described by geographic coordinates and attributes of the objects, which includes data such as rainfall, soil type, terrain, land cover and land use (Ding and Fotheringham, 1992). The spatial object describes polygons format that correspond to the measurement zones such as sampling points (Goodchild, 1987; Goodchild *et al.*, 1992).

Spatial tools have been used for decades to study agricultural land use patterns and water quality worldwide through the use of Remote Sensing (RS) and integration of GIS. Remote sensing is the science and art of obtaining an area through analysis of data acquired through a device that is not in contact with the area (Lillesand *et al.*, 2014). Lee *et al.*, (2009) working in South Korea showed that water quality parameters are significantly related to land use patterns including size, edge areas and shape complexity of agricultural land uses. Yu *et al.* (2015) in China also reported ($p < 0.05$) correlation between water quality and agricultural land uses.

Remote sensing and GIS have been used in the United States where seasonal patterns of surface water quality characteristics such as nutrients and suspended solids were observed and showed positive correspondence with the seasonality of agricultural production (Poudel *et al.*, 2013). Poudel, (2006) in US found that surface water quality parameters monitored using RS and GIS showed monthly, daily, seasonal and annual changes due to different agricultural practices with positive significance level (Lillesand *et al.*, 2014).Remote sensing has been used to develop a way forward for water resources problems through monitoring of the water quality and quantity, understanding land use and management of water resources both at local and regional scale (Tjandra *et al.*, 2003).

Remote sensing is useful in providing cost effective means to develop land use over large geographical regions (Lunetta *et al.*, 2006). It also has the capability of viewing various classes of vegetation at different stages and times using wavelength specific foliar reflectance (0.77-0.9µm), pigment absorption (0.45-0.69µm) and foliar moisture content (1.55-1.75µm) (Epiphanio *et al.,* 2010). Classification between different crop types in determining the land cover impact on water quality can be difficult thus combining similar classes in attaining classification accuracy is necessary (Brown *et al.*, 2013).

Geographical information system is used in the processing, analyzing and integrating of spatial data sets. The GIS has been used to analyze spatial variations of conductivity and land use in catchment where conductivity level showed a positive correlation with dissolved materials from land use. Conductivity is therefore correlated to land use and effects of land use due to pollution downstream (Wang and Liu, 2004). The integration of GIS with remote sensing enables the incorporation of a different source of data into change detection applications (Weng, 2002). Different algorithms are compared to get the best change detection; thus, there is a need to use diverse and sophisticated remote sensing data available from satellites imageries (Lu *et al.*, 2004).

The imageries range widely, but their acquisition depends on need and purpose. In agricultural LULC, Landsat and Normalized Difference Vegetation Index (NDVI) 30 m resolution have been used to monitor agricultural activities in Brazilian Amazons for decades to determine crop age and health efficiently (Almeida *et al.*, 2016). Landsat has been significant in analyzing agricultural activities for years due to their high resolution in vegetation detection (Brown *et al.*, 2013). Landsat provides valuable remote sensing data for land cover classification, an important factor for improving the performance of ecosystem and hydrological models (Song *et al.*, 2001; Ke *et al.*, 2015). Studies done shows that Operation Land Imager low resolution of imagery used to monitor water quality can affect model certainty (Cotter *et al.*, 2003). Therefore it is important to acquire the correct resolution to attain high classification accuracy.

Landsat imageries over the years have also been used to detect human activities due to their excellent spatial resolution. Different Landsat sensors have been launched over the years from Landsat 1 to 8, with Landsat 8 (OLI) recently launched in 2013. Landsat 8 has been a greater successor over Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM), due to new coastal aerosols band (0.43 to 0.45μm). The coastal aerosols have been helpful in retrieving aerosols properties as it covers shorter wavelengths than Landsat TM and ETM Plus blue bands and cirrus band (1.36 to 1.39μm) for detecting clouds (Vermote *et al.*, 2016).

A comparison of multiple sensors indicate that Landsat 8 OLI has a greater NDVI contrast between vegetation and water areas and provide higher spatial variability thus suitable for monitoring land cover mapping and spatial-temporal dynamics of water quality (Ke *et al.*, 2015). Nevertheless, remote sensing has been used in monitoring water quality parameters and non-point source pollution in different seasons (Marwick *et al.*, 2014). A study in RS indicated; increase of N in wet season at significant level of $p < 0.01$ and turbidity, Chemical Oxygen Demand (COD), electrical conductivity had significant level in wet season with $p < 0.01$ (Maillard and Santos, 2008).

2.5.1 Preprocessing and post processing of satellite data

Preprocessing has been used over the years to correct geometric and radiometric errors in imagery. Radiometric is a procedure that correctly estimates the target reflectance from the measured incoming radiation (Chen Chavez, 1996). The errors occur from sensor failure as well as an effect of atmospheric distortion. Therefore, it is important to remove stripping, missing data and intensity difference between bands caused by different sensitivity of the sensors (Hansen and Loveland, 2012). Pre-processing has been done using various GIS software such as ArcGIS, Enhanced Normal Vegetation Index (ENVI), Earth Resources Data Analysis System (ERDAS) and QGIS, whereby all convert Digital Numbers (DN) into reflectance values.

Reflectance is the ratio between reflected and incident energy on a surface, while DN is the number of pixels. Atmospheric correction of reflectance values is useful during preprocessing phase because the electromagnetic energy measured by a satellite which is affected by the atmospheric affect that is absorbed and scattered. Image conversion to reflectance improves classification results (Mather and Tso, 2016). Atmospheric correction is done using Dark Object Subtraction (DOS) Method in Landsat 8 which is more realistic on geographical object recognition on Normal Difference Vegetation Index (NDVI) and Normal Difference Water Index (NDWI) data (Chavez, 1988).

Post processing is the accuracy assessment of digital remotely sensed data on thematic maps classified. In the 1980's imageries were assumed to be 100 % accurate with the traditional method of photo interpretation been used (Biging and Congalton, 1989). However, as digital satellites upgraded and became more complicated, photo interpretation could no longer be used therefore accuracy validation method had to be invented (Congalton, 1991; Olofsson, *et al.*, 2013). Accuracy validation methods developed included user accuracy, producer accuracy, and Kappa in which all of them had different functions.

User accuracy corresponds to the error of inclusion whereby it calculates the numbers of pixel on a map are same as what is on the ground, while producer accuracy corresponds to exclusion whereby it calculates how many pixels on the thematic map are labeled correctly for a given class in reference plots. Kappa, on the other hand, reflects the difference between the actual agreement (GPS data) and protocol (classified map) expected by chance (Shao and Wu, 2008). Despite Kappa being dismissed as a less accurate method of validating classification accuracy, it has stood out to be the only method that verifies accuracy using spatial frequency of an image, homogeneity of the image (low spatial frequency) and heterogeneity of the image (high spatial frequency). Kappa uses United States Geological Survey (USGS) standard of image data classification > 85 % (Anderson, 1976). In this specification, the greater the accuracy of classification the higher the accuracy, on the other hand, balancing producer and user improved the accuracy (Shao and Wu, 2008). Post processing and pre-processing are therefore important in this study as they enhance the quality of the results which enable the monitoring of the actual water quality problems on the ground.

2.5.2 Use of remote sensing in water quality analysis

Satellite remote sensing has shown potential on monitoring water quality and other environmental phenomena (Nobuhle *et al.*, 2014). Water parameters data collection in developing countries have created a gap in water quality monitoring due to insufficient funds for collecting data on the ground (Harvey and Grabs, 2003). However, remote sensing has become a major tool for monitoring water resources especially physical parameter such as turbidity (Marrari *et al.*, 2006 and Shen *et al.*, 2010).

Reflectance from remote sensing data in detecting water in rivers; depends on the contribution of atmospheric and total signals that reach the sensors at the Top of the Atmosphere (TOA) which are important for turbidity detection (Dogliotti *et al.*, 2011). ShortWave Infrared (SWIR) bands have been used in turbidity detection whereby SWIR in atmospheric corrections assumes a black pixel in several bands algorithm, which has been of great importance in water reflection (Knaeps *et al.*, 2015). Total suspended matter leads to increase of backscattering which increases water reflections in SWIR due to absorption which is dependent on the dissolved and particulate matter (Knaeps *et al.*, 2012). Research done by Wang and Liu, (2004) in Korea show that in situ measurements of water quality parameters such as pH, turbidity, alkalinity, COD, nitrate, nitrite, conductivity are time consuming and expensive over large scale . Therefore, monitoring WQP using remote sensing which can cover a large area and has high spatial, spectral resolution than in situ becomes beneficial (Lim and Choi, 2015).

2.6. Statistical Analysis on Water Quality

Statistics is the computation method by which characteristics of a population interfered is observed and a representative sample from that population is made. It helps in the manipulation of ambiguous data to solve a problem. Statistical tools such as a Statistical Package for Social Science (SPSS) and Microsoft Excel have been used in research for decades to analyze water quality (Knott and Steube, 2010). However, users of R statistical programming software have been able to perform advanced spatial data analysis and compute big data (Harrington *et al.*, 2009). The R statistical programming software is a coding language that has a high capacity to compute statistics and graphics (Crawley, 2012), and has an interface that provides thousands of useful plugins (Kabakof, 2015).

On the other hand, the R-Studio software integrates development environment for reproducible research that allows keeping track of changes in the document and compatible with other programming tools such as JavaScript and Python (Tsou, 2004). JavaScript and Python are useful in web applications such as downloading imageries and also cut down on a server (Gandrud, 2013). The R has geostatistics packages which deal with point pattern analysis such as lattice, Rgdal, map tools, rgeo, raster and stat, which have enabled the software to conduct both statistical and spatial analysis (Pebesma, 2004). Studies in R have been done using the factorial analysis which is a technique that explains the correlation between water parameter variables observed, where correlation matrix had significant $p < 0.5$ (Yu *et al.*, 2003).

2.7 Hydrological Modeling

Hydrology is the study that encompasses occurrence, distribution, movement and quality of water on the earth (Singh and Fiorentino., 2013). Transport processes in water are crucial in monitoring physical and chemical parameters of the river system. Movement of water in rivers is both spatial and temporal derived by gravity and approximated by Digital Elevation Model (DEM) (Song *et al.*, 2001). Digital elevation model is a quantitative representation of the earth's surface providing necessary information about terrain relief which can be in a grid or Triangulated Irregular Network (TIN) format (Guth, 2006). Digital elevation model has been used widely in modeling water flow, route modeling, landform analysis and terrain visualization and mapping (Drover *et al.*, 2015). Computation of DEM has topographical secondary attributes and primary attributes. Primary topographical characteristics include slope, aspect, and curvature while secondary topographical attributes include topographical wetness index, stream power index, roughness, flow accumulation, flow direction (Jasiewicz *et al.*, 2015).

However, studies on hydrology analysis using ASTER DEM shows that spatial and temporal movement of water pattern in the catchment is important in the understanding of spatial characteristics of pollutants movement (Grabs *et al.*, 2009). A pollutant in the overland flow is affected by the contact time of an overland flow parcel with the soil surface. Spatial distributions of soil moisture significantly affect runoff mechanisms thus soil moisture condition act as the principal factor in estimating potential non-point source pollution (Song *et al.*, 2013).

2.7.1 Slope angle and Aspect

Slope describes the steepness of a surface in an area, important in determining the water flow direction in a water basin, flow accumulation, flow path and river extraction (Cadell, 2002). Water flow direction in a water basin, flow accumulation, flow path and river extraction flow are therefore calculated through methods such as; Deterministic 8 (D8) and Multiple Flow Direction (MFD) and Single Flow Direction (SFD) (Gruber and Packham, 2009). The D8 methods involve water flow in each pixel which is passed to the nearest neighbor using the steepest gradient resulting to 8 possible directions. The D8 method has been used in hill slope areas to model convergence where several cells drain into one cell, and divergence one cell flows into several cells. Multiple flow algorithms are essential in predicting flow path in the upper catchment while single flow algorithm predict flow path at lower watershed (Quinn *et al.*, 1991). Studies done in United Kingdom and Sweden by Quinn *et al.* (1991) and Sorensen and

Seibert (2007) indicated that TWI calculation by MFD algorithm had a high predicting power of soil moisture, influenced by curvature, which calculates the concave and convex of a slope whereby the convex is the ridge while the concave is the channel. Curvature has been used to interpret the effect of terrain on water flow and erosion while profile curvature affects the acceleration and deceleration of flow. Curvature has influenced erosion, deposition, and convergence and divergence of flow (Salvacion, 2016).

2.7.2. Topographical wetness index

Topographical wetness index is a numerical parameterization of infiltration and transmissivity which describe the tendency of the cell to accumulate water. The TWI index is calculated on slope, aspect and curvature computed from ASTER DEM. Successful TWI has been computed by Beven and Kirkby (1979) using the TOPMODEL framework as:

$TWI = \alpha/\tan\beta$

Where α = cumulative upslope area draining through a point per grid catchment cell

$\tan\beta$= slope angle at that point

This index describes the potential of water to accumulate at any point at the catchment (α), and the tendency of gravitational force to move water downslope expressed in ($\tan\beta$) (Quinn *et al.*, 1991). Therefore, high TWI can arise from large contributing drainage area or very flat slopes, whereas low index values arise from drier steep slope or small contributing areas. The resolution of the DEM and the flows route algorithms are therefore very important in determining topographical wetness index. The topography is important in hydrological behavior and saturation where the excess overland flow is simulated using topographical wetness index.

TWI is also important in studying vegetation, soil properties and hydrology in hill slope. Studies done by Singh, (2009) working in Himalayas compared the TWI with soil measurement, and found that TWI had a positive correlation ($p < 0.05$) with soil moisture (0.44). Thus, TWI forms an important tool for the current study. However, in situ measurements are methods which have been used in Africa and Kenya to monitor water quality. Though they have proven to be effective, they are expensive and laborious thus integration of remote sensing and GIS will be of significance to control WQP and hot spots area of pollution.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Area

3.1.1 Climate

The study was conducted at Ndakaini Dam located 50 km north off Nairobi, Kenya (Fig 3.1). Ndakaini catchment is located at latitude 00 49' 13'' S and longitude 360 51' 01'' E with an altitude of 1800 meters above sea level (masl). Ndakaini Dam covers 3sq km with a circumference of 41.5 km and depth of 60 m when full (Yatich *et al.*, 2009). Ndakaini catchment area has bimodal rainfall distribution from March to May (long rain) and October to December (short rain). The mean rainfall is 600 mm to the East and over 2300 mm to the northwest at the Abedares foothills. The mean annual temperature ranges between 20° C at 1400 m above sea level and 12.5° C at 2500 m above sea level (Yatich *et al.*, 2009).

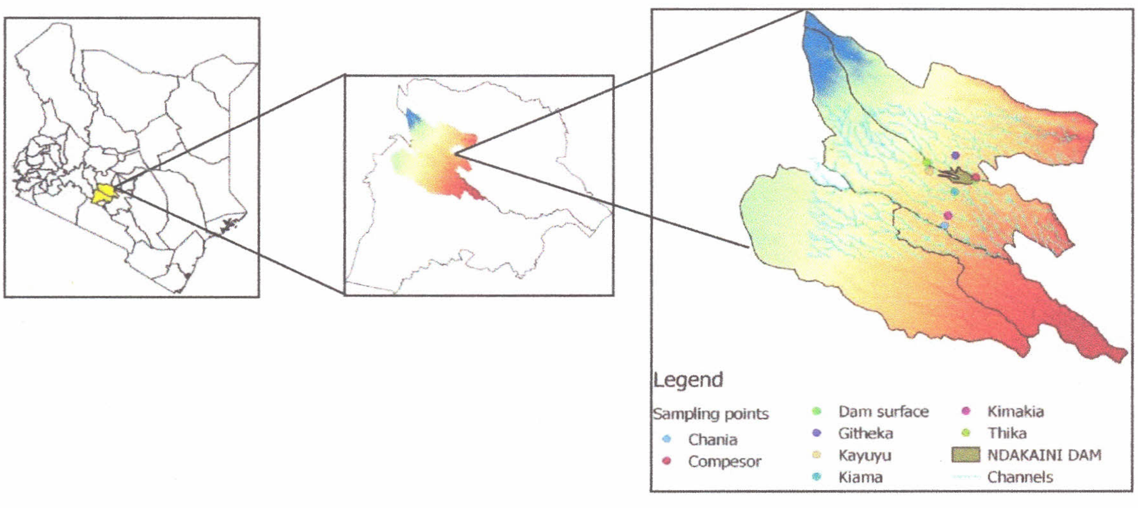


Figure 3.1: Location of Ndakaini Dam Catchment

3.1.2 Land use

Ndakaini has different agro- ecological zones. The upper catchment includes a forest zone with a land cover of bamboo and indigenous alpine trees. The upstream of the dam dominated by tea with an interspace of woodlots and boundary trees in the lands. Napier grass, maize, and vegetables also exist in small plots and lower catchment dominated by smallholder farmers mainly growing tea and small farms of food crops such as maize, beans, and cabbages with dairy cattle, sheep and poultry. In the downstream, the land use changed from tea to coffee and other food crops such as maize, beans, sweet potatoes and yams. Napier grass is also grown and fruit trees, (Okoba, 2005).

3.2 The Effect of Different Land Use / Land Cover Classes on Water Quality of Ndakaini Dam

3.2.1 Imagery acquisition

To determine the flow of water direction, soil moisture, water quality and agricultural land use / land cover, Landsat 8 Operation Land Imager (OLI) and Advanced Space borne Thermal Emission and Reflection Radiometer Digital Elevation Model (ASTER DEM) imagery were acquired from USGS glovis (Table 3.1). These imageries were acquired based on wet and dry season with < 10 % cloud coverage. The seasons used were categories based on Kenya Metrological Department (KMD) precipitation data. The seasons used were namely; a dry season from January to March, long rains from April to June, a short dry season from July to September, a short rain season from October to December for the years 2015 and 2016.

Table 3. 1: Satellite imageries description for Ndakaini Catchment

Satellite	Spectral band	Acquired date	Ground resolution (M)
ASTER DEM	1	2015/10/04	30
LANDSAT 8 OLI	2,3,4,5,6,7,8	2015/9/18 and 2016/02/25	30

3.2.2 Land use classification

Land use classifications were acquired through Landsat 8 OLI which was launched on February 11, 2013, by American satellite and has 2 sensors that acquire approximately 500 images per day worldwide. Landsat 8 has high- resolution spectrum than ETM and TM due to the additional coastal band and cirrus band (Roy *et al.*, 2014). Landsat8 OLI bands, 2 to 8 were used in the current study as shown in Table 3.2. The images were then preprocessed using semi-automatic classification (SCP) plugin in QGIS. Preprocessing included atmospheric correction using dark object subtraction (DOS) method (Chavez, 1988) and conversion of digital numbers to reflectance values to differentiate pixels. The composite of band 4, 3, 2 were used to classify different land uses in Ndakaini dam catchment using SCP plug in, to group homogenous areas with similar pixels.

The standard classification was carried out according to Anderson, (1976), to come up with 8 different classes. Spectral angle mapping algorithm (SAM) with the threshold of 90 and pixel size of 1500 classes were used to delineate classification of the area of study. Classification accuracy was validated using post processing algorithm via standard kappa measure < 85% (Anderson, 1976). Classification statistics were analyzed using System for Automated Geoscientific Analysis (SAGA GIS) plugin using 2 simple methods whereby the sum pixels, percentage, and area of land cover classes were calibrated (Lu *et al.*, 2004).

Table 3.2: Bands features of LANDSAT 8 OLI for land use classification in Ndakaini Catchment

Bands	Name of band	Wavelength (µm)
Band2	Blue	0.45- 0.51
Band3	Green	0.53- 059
Band4	Red	0.64- 0.67
Band5	NIR	0.85- 0.88
Band6	SWIR1	1.57- 1.65
Band7	SWIR	2.11- 2.29
Band8	Panchromatic	0.50- 0.68

3.3 Flow Direction and Topographical Wetness Index (TWI) and Their Effect on Water Quality.

3.3.1 Channel network and watershed model

Channel network model was derived from DEM using SAGA GIS plugin in QGIS version 2.14.3 (Fig. 3.3). Various algorithms were used to compute channel system of Kayuyu, Githeka, Thika, Kiama, Kimakia and Chania rivers. Preprocessing of raster data was first done by fill sink algorithm (Liu *et al.*, 2015) to modify the elevation value to enable flow in a cell.

Flow accumulation was then computed using the catchment area (parallel) algorithm which generated catchment (rivers) using D8 methods (O'Callaghan and Mark., 1984). The threshold of 10,000 was set to compute channel network. The threshold is essential in extracting the main channels of study; the larger the threshold the sparse the network channel and the smaller the threshold, the denser the network channel. Watershed basins algorithms were then computed to delineate the sub-basins corresponding to the channel network in vectors format.

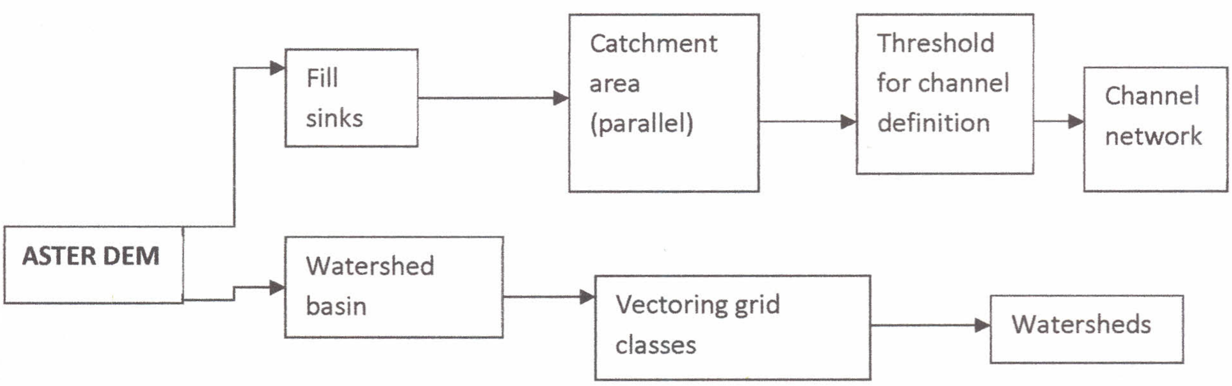


Figure 3.2: Model of channel network and water basin delineation

3.3.2 Topographic wetness index model

Topographical wetness index (TWI) was statistically computed using SAGA GIS plugin in QGIS version 2.14.3. The slope angle, aspect, and curvature were first calculated using ten parameter 3rd order polymon (Haralick, 1983) (Fig 3.4), where the accumulation of cell grid was determined. Multiple flows and single flow method were used to establish a flow path from upper catchment to downslope. Topographical wetness index was then statistically calculated according to Beven and Kirby, (1979) where:

$TWI = \alpha/\tan\beta$

Where α = cumulative upslope area draining through a point per grid catchment cell

$\tan\beta$= slope angle at that point

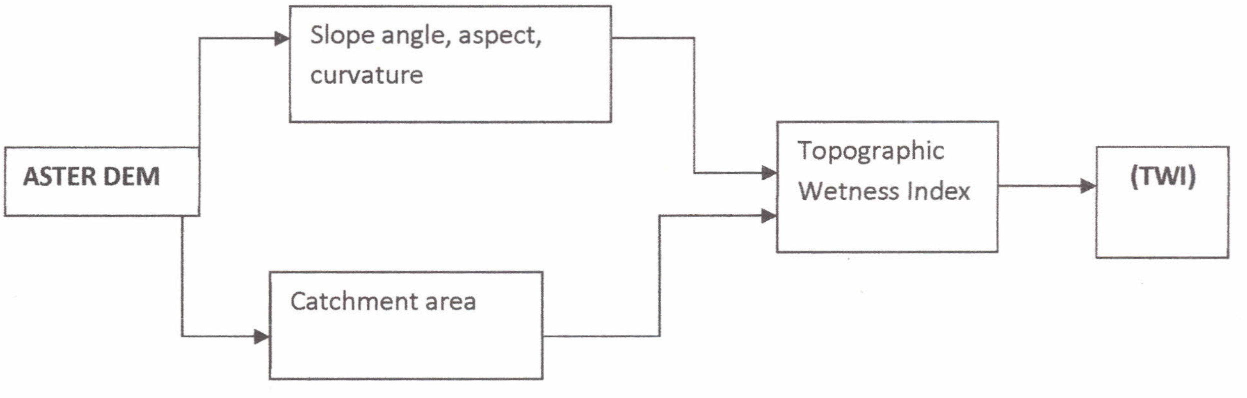


Figure 3.3: Model of topographical wetness index

3.4 Seasonal Assessment of Water quality Parameters Levels and Concentrations in Rivers of Ndakaini Dam Catchment

3.4.1 Collection and analyzing of water samples

Water samples were collected in May and January in the year 2015 using a seasonal interval of prolonged rain and long dry seasons. The water samples were collected seasonally (long rain and short rain) from 8 different rivers; Kayuyu River, Githeka River, Thika River, Kiama River, Kimakia River, Chania River, Chania Combined, Dam scouring and Dam surface at the middle catchment and the lower watershed and Mwangu intake, raw water and treated water collected monthly (January to December 2015). The water samples were collected in 2 L sterilized plastic bottles where waters bottles were first rinsed with sampling point water, at 1 m distance from the river bank before collecting to avoid contamination and GPS coordinate collected at that point. The samples were then well packed in a cooler box and transported to the Nairobi Water and Sewerage Company (NWSC) laboratory.

The samples were then analyzed for physico-chemical parameters namely; pH, alkalinity, nitrate, nitrite, and chloride, COD, electrical conductivity and turbidity using the recommended standard methods for drinking water analysis (WHO, 1993). Electrical conductivity was analyzed within 24 hours after collection in the laboratory where the probes were directly inserted into the sampling water and readings recorded (Howard, 1993; LaSota *et al.*, 2000). The pH analysis was conducted using pH meter where a solution of buffer 7 and 4 was first prepared. The pH probes were then inserted to buffer 7 to calibrate to the highest pH value of 7 and also inserted in buffer 4 to calibrate the lowest value of pH 4.

A plastic container measured 250 mL was then rinsed with distilled water and filled with sample water where probes were inserted and pH readings recorded after 15 minutes (LaSota *et al.*, 2000; Alpha, 2005).

Alkalinity was analyzed using acid titration where sulphuric acid was filled in the buret and sample water 30 mL filled in a conical flask, 3 drops of methyl orange indicator were added, after which it was titrated using sulphuric acid till it turned to pink and readings recorded (LaSota *et al.*, 2000). Nitrate and nitrite were analyzed using UV spectrophotometric method (Drolc and Vrtovšek, 2010). Analysis of chlorine was done with chlorimeter in haze units where starch-potassium iodide was added to the water sample, shaken, then inserted into colorimeter and read using chlorine disk.

Turbidity was analyzed using turbidity meter where the machine was zeroed, sample shaken and filled into 10 m L bottle and insert in turbidity meter for reading (LaSota *et al.*, 2000; Murdoch *et al.*, 1996). Chemical oxygen demand (COD) was analyzed using COD digester and UV spectrophotometer where 2.5 mL of water sample was added to the tubes and blank, 2.5 mL of distilled water added, then 1.5 mL of potassium dichromate and 3.5 m L sulphuric acid carefully added to all tubes one after the other. COD digester was then heated to 150° C then tubes were inserted for 2 hours cooled, and the reading is taken with the UV spectrophotometer and values recorded (Golterman, 1969).

3.4.2 Statistical analysis

The physico-chemical parameters analyzed were subjected to descriptive statistics. The median values obtained of individual parameters both for wet and dry seasons were correlated with the WHO standardized allowable values for safe drinking water using Wilcoxon Rank sign test (Gibbons and Chakraborti, 2011). The parameters level where analyzed using the deterministic method which depicted the variation of levels of different parameters in dry and wet season in a visual way through interpolation using Inverse Distance Weighting (IDW) in QGIS software.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 The Effect of Different Land Use / Land Cover Classes on Water Quality of Ndakaini Dam

4.1.1 Land use

The thematic maps for land use were classified into 4 macro classes of vegetation, built area, water bodies and bare soil to identify the major land use / land cover. The 4 macro classes were further classified into 8 micro classes' exotic forest, natural forest, tea, bare soil, roads, annual crops, rivers and dams (Fig 4.1a) (Fig 4.1b) using methods as described by Anderson, (1976) This was as a result of differentiation of different vegetation that existed in Ndakaini catchment. Differentiation of different crops types to determine land cover was difficult due to spectral reflection. Therefore, in this study, crops such as maize, Napier grass, vegetables were combined into one class to align classification accuracy for land under crops. Wavelength per pixel has been used to accurately differentiate Land Use Land Cover (LULC) in different times and stages in image processing (Epiphanio *et al.*, 2010).Therefore, in this study wavelength per pixel was useful in differentiating accurate land use / land cover in different times and stages.

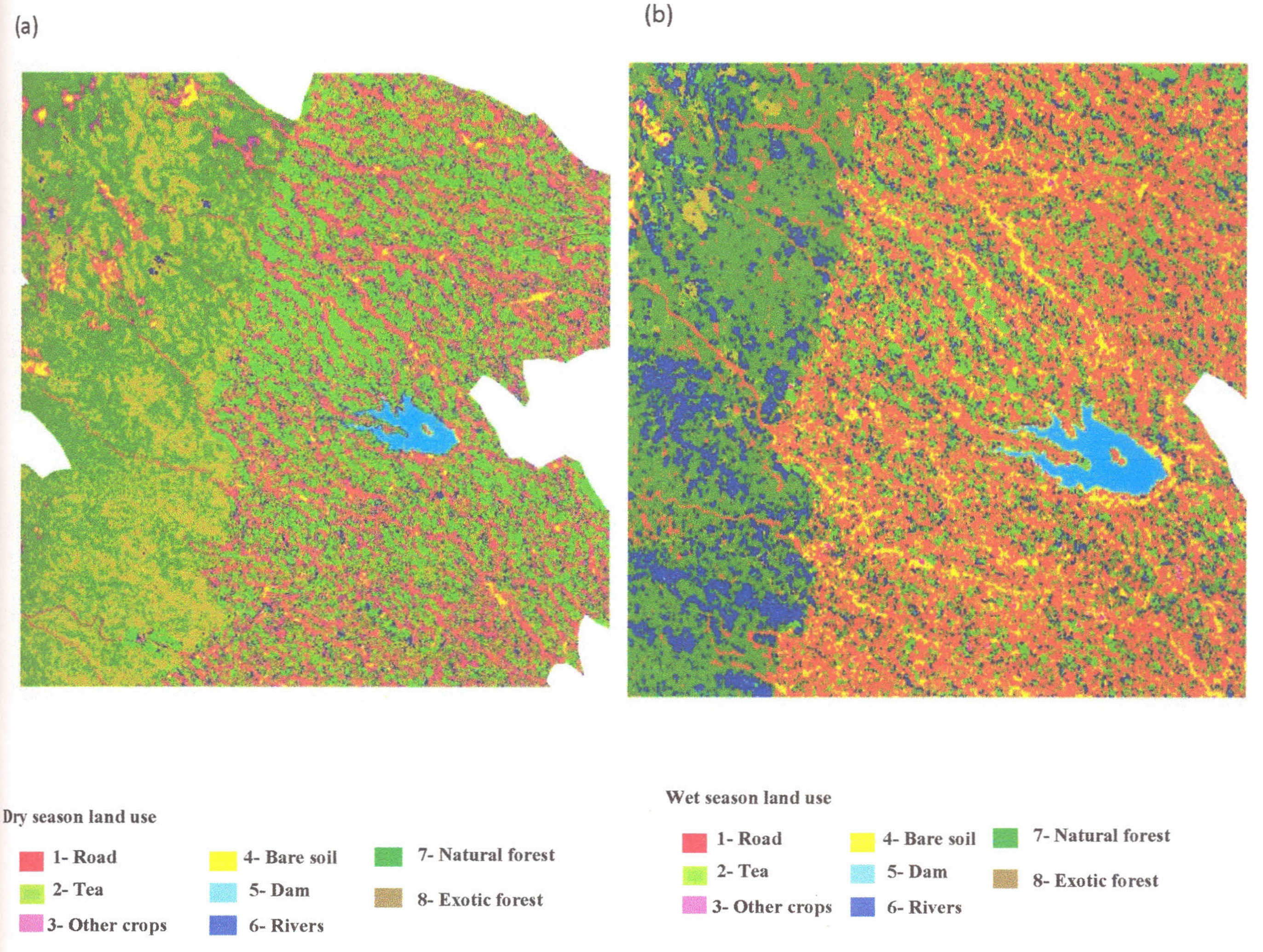
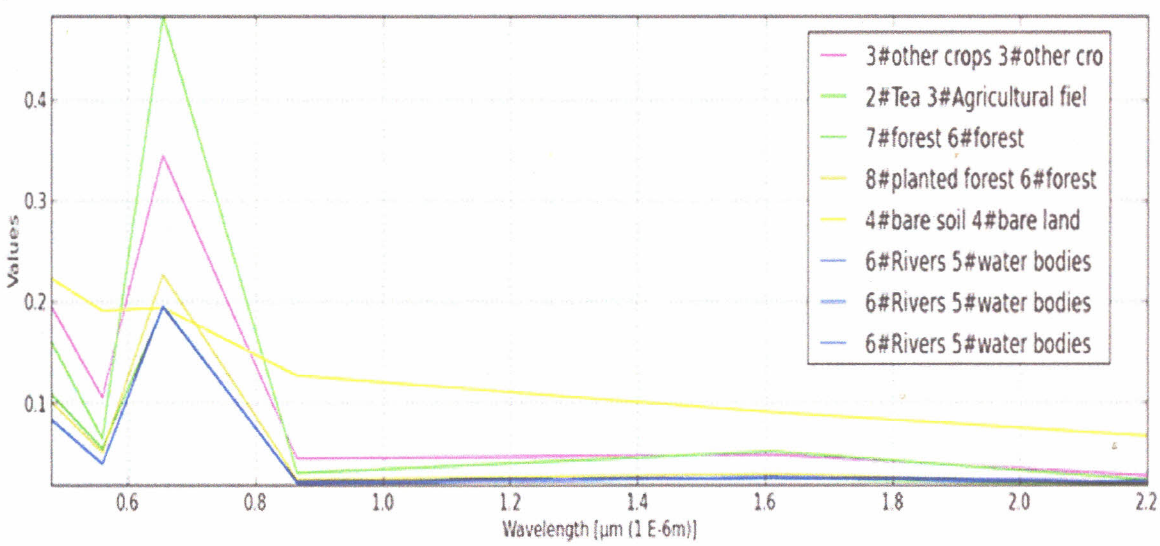


Figure 4.1: Land use /land cover thematic map (LANDSAT 8 OLI) (a) dry season and (b) wet season in Ndakaini Dam catchment

Wavelength influencing composite bands were used to differentiate LULC in the study which showed high reflection in the red band in the dry season and NIR in the wet season (Fig 4.2). This was as a result of the different levels of absorption, reflection, scattering, and transmission by different LULC classes. Reflection in vegetation was characterized by various factors such as chlorophyll pigment, the moisture of the leaves and structure of the leaves as described by (Epiphanio *et al.*, 2010).

Wavelength showed the differences in vegetation. In dry season's earth roads and bare soils started reflecting in a red band in wavelengths 0.69 μm and 0.68 μm respectively and dam and rivers with 0.60 μm. In the wet season, reflectance started at NIR in wavelength 0.89 μm on earth roads, 0.91 μm dam, and rivers and 0.50 μm bare soils (Table 4.1). The variation of the wavelength of earth roads and bare soil was as a result of the absence of vegetation and decreased moisture in the soil in the dry season which influenced reflection (Yu *et al.*, 2015) and increases in moisture and vegetation in wet season whereby absorption of the wavelength increased while reflection decreased. Water is said to backscatter when it has solid matters thus reflecting high (Knaeps *et al.*, 2015). The difference in water wavelength in rivers and dam during dry and wet seasons can, therefore, be explained as; during wet season the runoff was high thus increase of sediments in the rivers and dams, while in dry season there was no runoff hence decrease in sediments on surface of these water bodies thus high reflection in wet season in NIR and high reflection in dry season in red band.

(a)



(b)

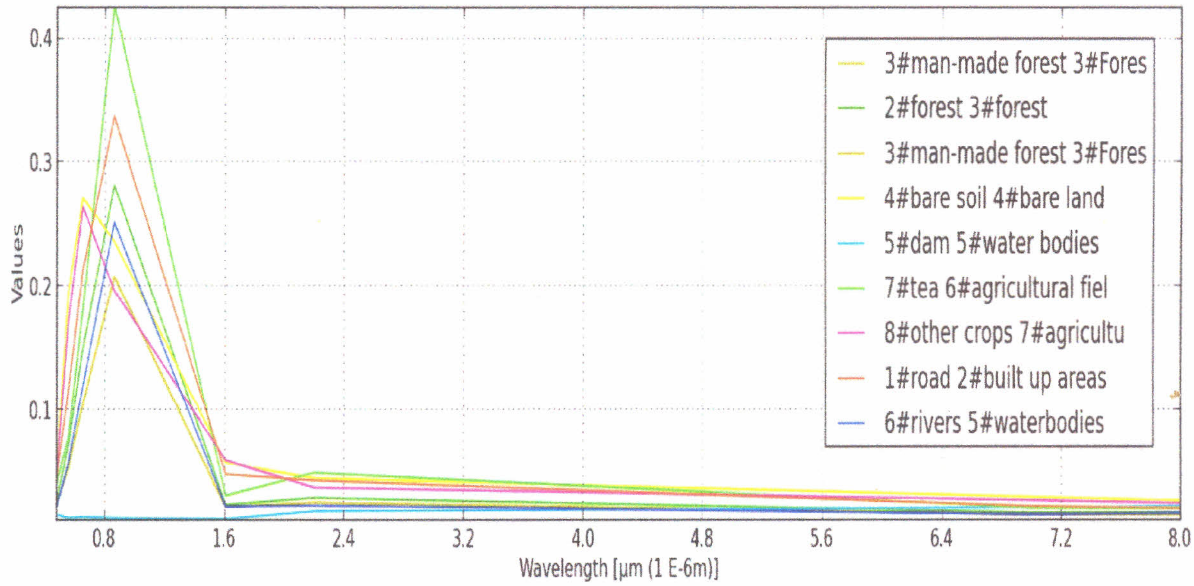


Figure 4.2: Wavelength reflection of (a) dry season and (b) wet season land cover of Ndakaini Dam Catchment

Percentage land total area for each land use was calculated from land cover thematic maps of the dry and wet season to observe the variation of land use / land cover in the two seasons. The percentage land total area was calculated using two grids for the dry season and wet season. The results showed the differences between wet and dry season. In the comparison of wet and dry season percentage land total area, there was a difference in the two seasons where earth roads ranked high with 12.45 % in dry season and 35.1 % in the wet seasons, The earth roads and soil were not easily differentiated as seen in the reflectance wavelength values in Table 4.1. Therefore, land with no vegetation in the dry and wet season was indicated as roads while extreme soils which had lost moisture reflected high. This, therefore, gave the higher land area coverage (%) of roads at 35.14 % in the wet season than in dry season which was 12.45 %.

These resulted in increasing of turbidity in rivers and dam. The exotic forest was 35.47 % in dry season and 0.25 % in the wet season. Exotic forest also had a high percentage of land area coverage in the dry season (35.46 %) than in wet season (0.25 %). This is due to the fact that in wet season leaves are moist and therefore the reflectance decreased thus resulting in decreasing in percentage in wet season and increase in the dry season. The dam had a difference of 0.81 % in dry season and 1.65 % in the wet season. This was as a result of an increase in water volume in the wet season and a decrease in the dry season which influence speed flow of sediments as shown in Figures 4.2 and 4.3. In the wet and dry seasons as shown in Plate 4.1 and 4.2, bare soils were high in the wet season as compared to the dry season as a result of land preparation as this was the planting season. Bare soil also had a high percentage which explained the percentage of other crops whereby in wet season they decreased while in the dry season they increased influencing on runoff rates. Natural forest was high with a small difference with the dry season as a result of regeneration of new trees. On the other hand, roads had increased in wet season this was as result of the difficulty in differentiation on roads and bare soil in the wet season thus classifying any land with no vegetation as the road.

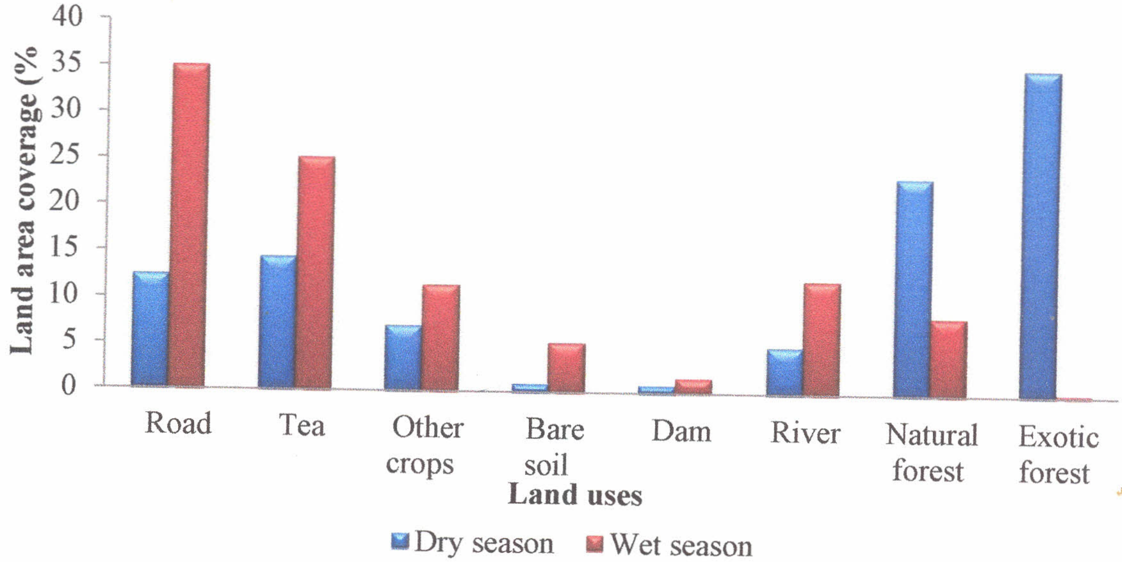


Figure 4.3: Percentage land total area (%) in wet and dry season in Ndakaini Dam Catchment

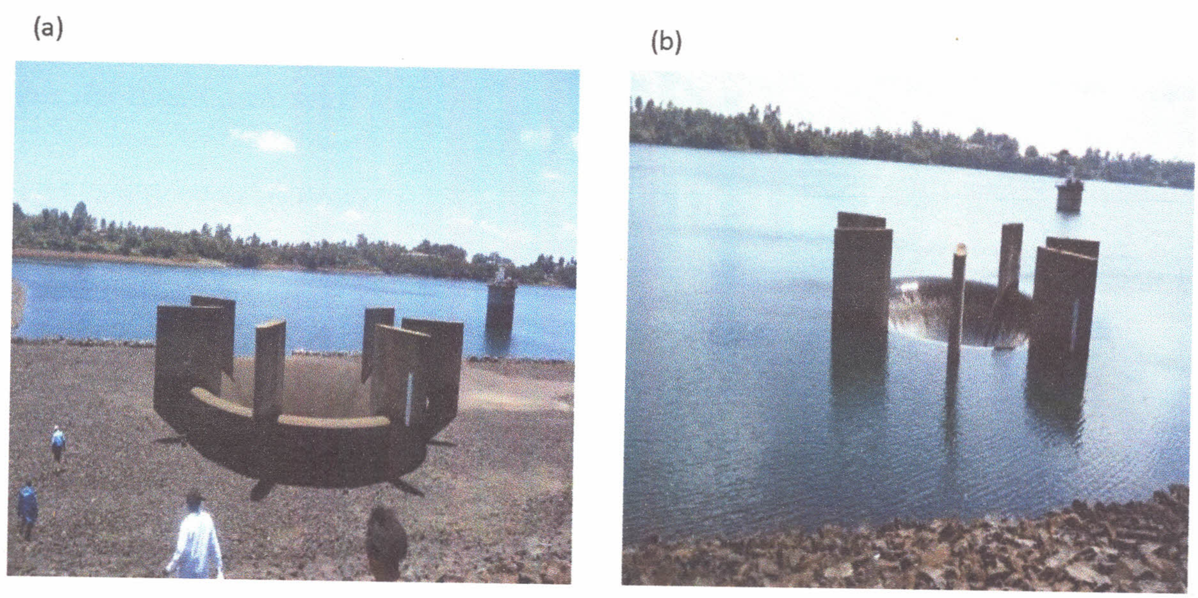


Plate 4.1: Status of Ndakaini dam in (a) dry season (b) wet season in Ndakaini Dam Catchment

(a)

(b)

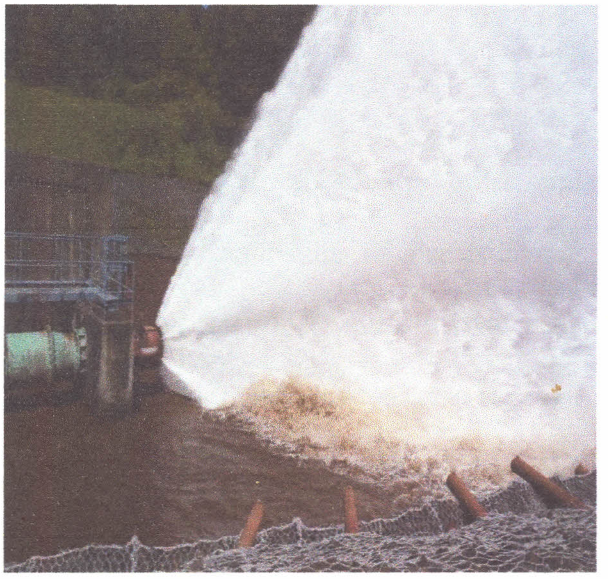


Plate 4.2: Status of Ndakaini dam scouring (entry point) (a) wet season (b) dry season in Ndakaini Dam Catchment

4.1.2 Classification accuracy

Classification accuracy is very crucial in land use classification as inaccuracy may result in wrong information and fault data. However, results in the dry season using spectral angle mapping (SAM) had the overall accuracy of 97.5 % and the Kappa coefficient of 0.90. In wet season overall accuracy was 97.8 % and kappa coefficiency of 0.94. This showed high accuracy classification of thematic map > 85 % as described by (Anderson, 1976).

4.2 Flow Direction and Topographical Wetness Index (TWI) and Their Effect on Water Quality

4.2.1 Channel network and watershed model

Channel network and watershed model derived features such as elevation, river order, and watershed. The results enabled water channel and terrain visualization of the Ndakaini catchment. Chania River showed variation in elevation ranging from 1793 masl to 2446 masl from the upper catchment to the downstream; though at the upper catchment there were high elevations at 2198. The highest elevation was observed in Kayuyu River ranging from 1961 masl to 2466 masl (Fig 4.4). This was significant as it enabled to explain the flow of water in different rivers.

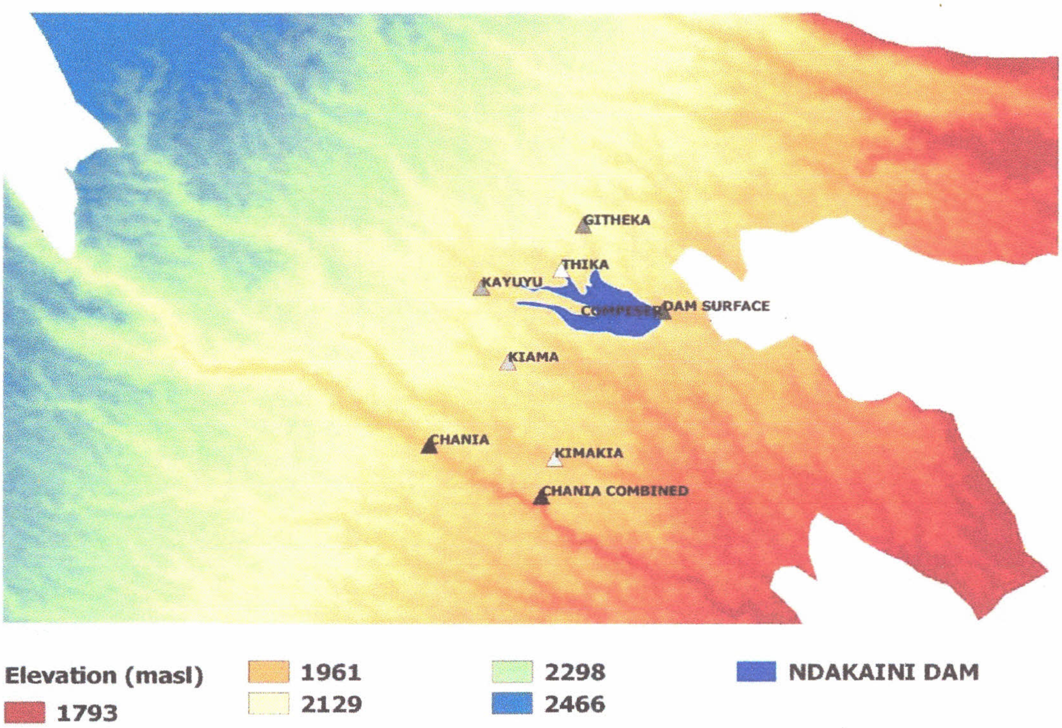


Figure 4.4: Elevation of Ndakaini Dam Catchment

The elevation is essential in the calculation of a number of drainage basins within water shade (Fig 4.5). Githeka, Kayuyu and Thika Rivers had the biggest drainage basin with 24 tributaries while Chania had the lowest water drainage basin ranging between 6 tributaries as shown in Fig 4.5. The streams drain into the river to form a watershed (Toman, 2009). Therefore, the number of rivers in each vectorized watershed indicated the length and type of rivers present in the watershed.; and the larger the range of channel network in the watershed the shorter the length of the river while the lowest range of channel network in watershed had the longest river. Chania was the longest while Thika, Kayuyu, and Githeka rivers had the shortest length as shown in Fig 4.5.

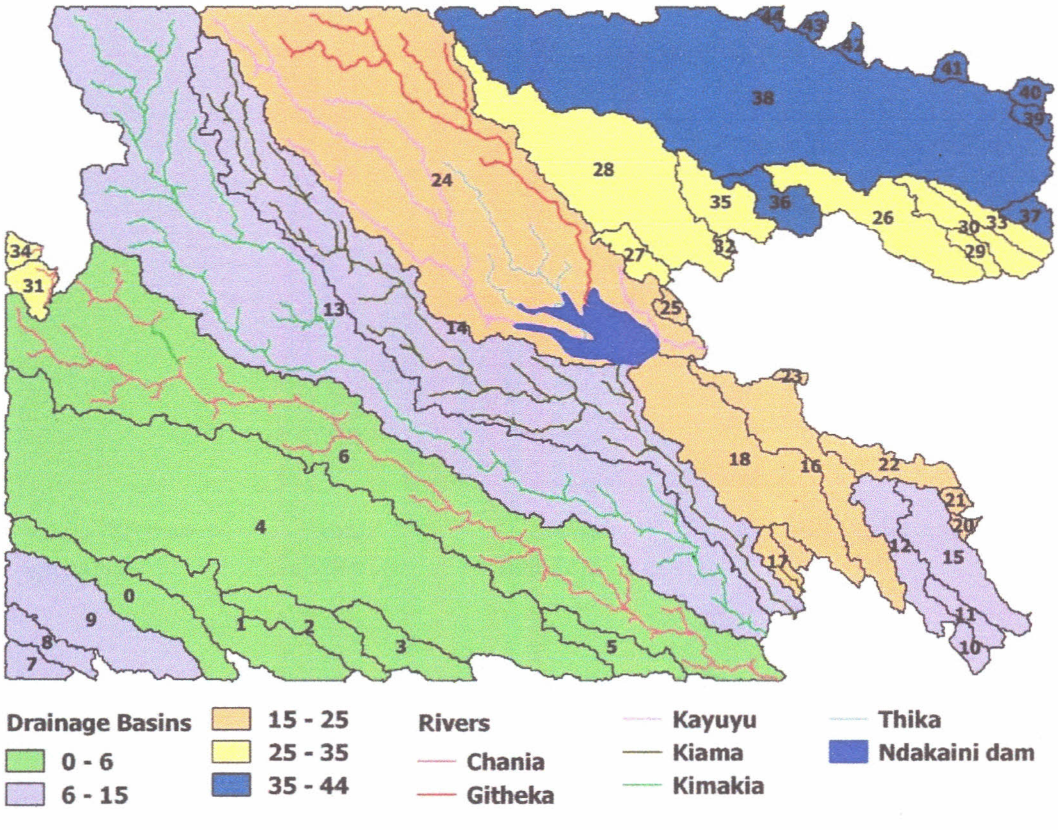


Figure 4.5: Channel network/ drainage basin of Ndakaini Dam catchment

The slope angle was also calculated in degrees using DEM. Chania River had the steepest slope along and around the river from catchment to downstream with values of 44.5° to 58.3°as observed in Fig 4.6. Kimakia also was observed to have steep areas along the river with 58.°at the middle catchment and 30.6° to 44.5°around the river at the farm lands. Kayuyu, Githeka, and Thika had steep slopes at the downstream. The slope results indicated Chania River and Kimakia to be prone areas of pollution than the other river.

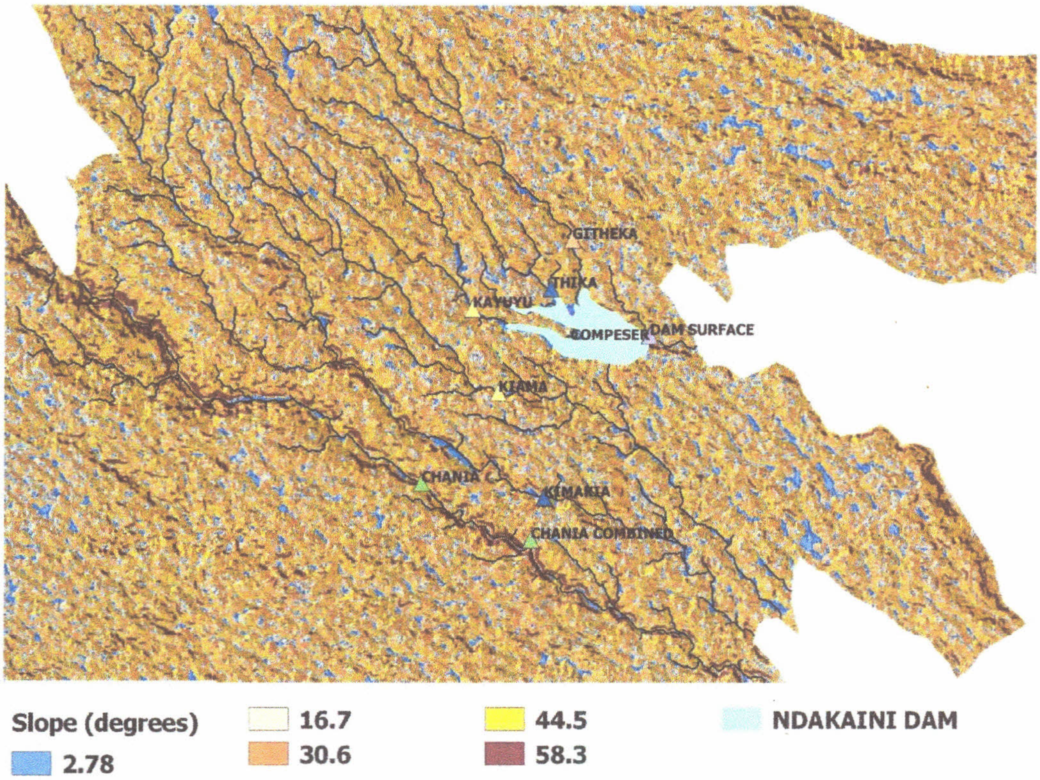


Figure 4.6: Slope angle of Ndakaini Dam Catchment

However, slope played a major role in determining the prone areas with runoffs and flow direction of rivers where several cells flow into one cell resulting in flow accumulation (Quinn *et al.,* 1991; Gruber and Packham, 2009). In Fig 4.7 Chania River and Kimakia River had the highest flow direction ranging from 4. m/s to 6.99 m/s and the least being -1.0 m/s. Concave and convex slopes determine convergence and divergence of the flow direction (Salvacion, 2016). As observed in the results in Chania River and Kimakia river had convex slopes which lead to high convergence while on concave slopes there was no convergence hence the negative value of flow direction. Areas with the low value of flow direction had a concave slope where water accumulated from convex slopes, thus high accumulation. However, flow direction was, important in determining areas with high runoff (Chen *et al.*, 2012), as they carry solid matter and nutrients with them to dams and rivers (Suthar *et al.*, 2012).

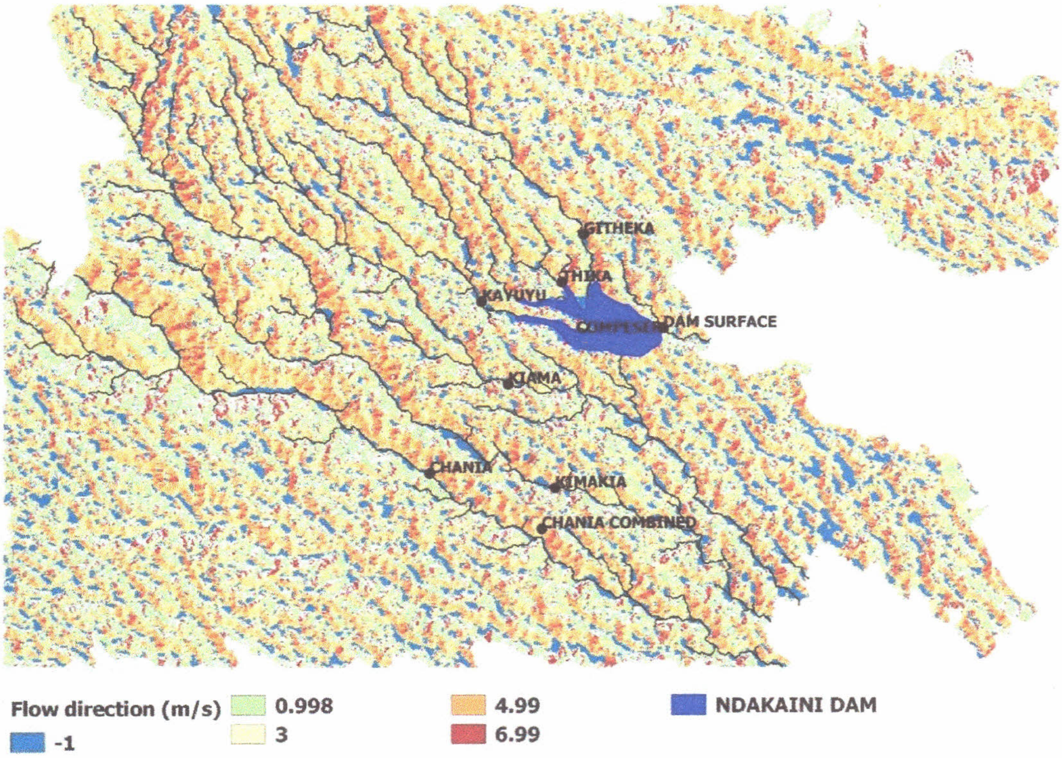


Figure 4.7: Flow direction of water in Ndakaini Dam catchment

4.2.2 Topographical wetness index model

Topographical wetness index (TWI) determined the potential of water to accumulate at any point at the catchment and tendency of gravitational force to move water downslope, which was highly influenced by slope, aspect, and curvature (Quinn *et al.*, 1991). Therefore, Chania had the highest topographical wetness index values ranging from 1.62 TWI values to 2.59 TWI values, while Thika had the lowest TWI values ranging from - 1.28TWI values to -0.65 TWI values as in Fig 4.8. The high TWI values were as a result of the steep slope in Chania River where runoff was gravitationally moved downslope. Therefore, the rate at which soil moisture exceeded infiltration at all hilly points were low making it prone to erosion into the water bodies. On the other hand, soil moisture which exceeded infiltration at steep areas accumulated in flat areas thus increasing TWI values downslope

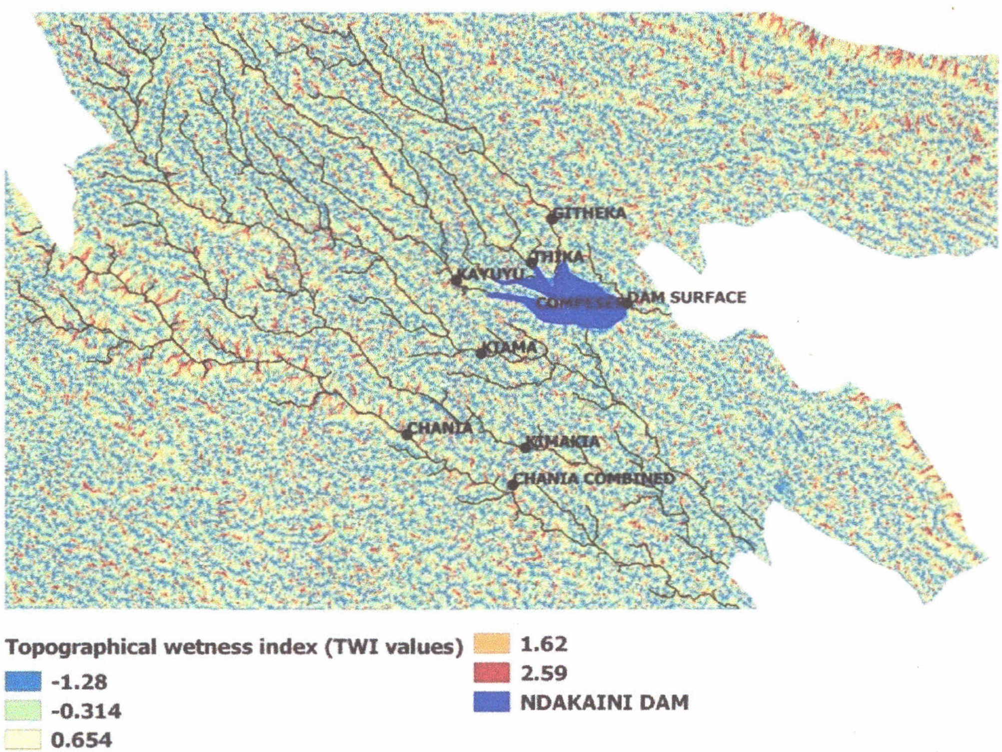


Figure 4.8: Topographical wetness index of Ndakaini Dam catchment

However, topographical wetness index is said to have negative values when an area has small numerous steep slopes and rugged slopes (Sighn, 2009) thus the outcome of negative TWI values in the results observed. TWI values are, therefore, crucial in determining soil saturation rate to define pollutant runoffs and seepage into the water bodies (Song *et al.*, 2001).

Land surface runoff described the amount of surface water that had not infiltrated which was influenced by the slope and land cover. Kimakia River was therefore observed to have high values of land surface runoff with 5.54 to 9.63 m/s while the lowest being Thika River with 3.5 m/s. On the other hand, at the peak of the slope, it was seen to have low values of land surface runoff at 1.45 m/s as in Figure 4.9. This was as a result of concave and convex slopes which affected the acceleration and deceleration of surface flow down slopes.

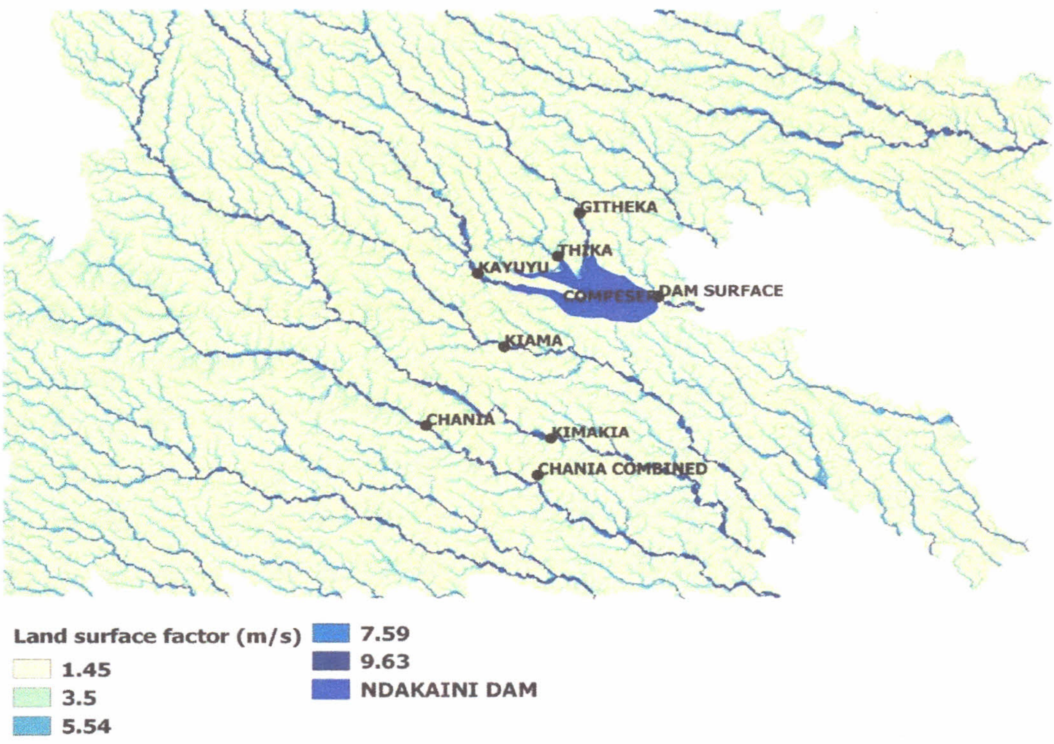


Figure 4.9: Land surface runoff of Ndakaini Dam catchment

Therefore the slopes are said to influence convergence and divergence of flow affecting infiltration rate thus high values of land surface runoff leading to increased turbidity (Salvacion, 2016).

4.3 Seasonal Assessment of Water quality Parameters Levels and Concentrations in Rivers of Ndakaini Dam Catchment

4.3.1 Statistical analysis results

Statistics have been used for decades to manipulate ambiguous water data to solve problems (Knott and Steube, 2010). In this analysis, Wilcoxon rank test (Gibbons and Chakraborti, 2011) was used to calculate the median of each individual parameter and correlated them with WHO standards where all parameters showed significance at $p = 0.001$ (Table 4.2). In wet and dry season turbidity and nitrate were excluded since they were outliers.

Therefore correlation results showed significance relationship between dry and wet seasons with water quality parameters being significant at $p = 0.01$. This result was in agreement with findings by Ahuja and Lehman, (1983); Dexter *et al.*, (2004); Tu, (2009). This was as a result of different land use in the different seasons which had a significant impact on water quality.

Table 4.2: Correlation matrix of water quality parameters in dry and wet seasons with

Parameters	WHO Standardized values	Wet season median difference	p-value	Dry season median difference	p-value
Turbidity (T.U)	≤ 5	0.21	0.83	0.21	0.81
pH (pH units)	6.5 – 8.5	3.1	0.02**	3.6	0.001**
Electrical conductivity (mg/l)	≤ 10	3.52	0.001**	3.62	0.001**
Color (haze)	≤ 15	1.98	0.001**	3.64	0.001**
Chlorides (mg/l)	250	3.58	0.001**	3.69	0.001**
COD (mg/l)	≤ 10	3.42	0.001**	4.12	0.001**
Nitrite (mg/l)	0.01	3.52	0.001**	3.65	0.001**
Nitrate (mg/l)	45	0.69	0.001**	3.62	0.49

WHO standards

$P < 0.5$ significant

**$p < 0.001$ significant

4.3.2 Water quality

Water quality monitoring has been a means of ensuring the safety of water to human beings and saving operation cost of water treatment (Davison *et al.*, 2004; WHO, 2004; and Pinheiro LeChevallier and Au, 2013;). Therefore, monthly interval results at the intake of the ponds (Mwangu intake), at the ponds (raw water) and treated water were compared to see variation in seasons (Weber, 2001; Yu *et al.*, 2015).

Turbidity levels were high in the month of April to June (long rains), followed by October to December (short rains), January to March (long dry) and June to August (short dry) in the intake and raw water. Mwangu intake turbidity level increased during wet season with 11 to 43 T.U in long rains, 12 to 38 T.U short rains and decreased in the dry season with 3 to 4 T.U long dry and 4 to 5 T.U short dry (Figure 4.10). In the wet season Mwangu intake received water only from Chania River and as observed in the interpolation map in Fig 4.11a turbidity level in Chania River was at 460 T.U which had exceeded WHO standards, also in the observation of physical factors such as slope, TWI, LS, LC and length Chania river had the steepest slope, bare soil, low values of TWI at its slopes and the longest. Therefore, turbidity level at Mwangu intake in wet season was accelerated by the presence of bare soil and the steep slope in Chania River where at the riparian agricultural activities were taking place. Bare soils at steep slopes reduce the rate of infiltration into the soil and increase the speed of runoff flow carrying away top soils into water bodies (Turner and Rabalais, 2003; Singh, 2009; Ran *et al.*, 2012; He *et al.*, 2015). In dry season Mwangu intake received water from Kiama, Kimakia, Kayuyu, Githeka and Thika through Ndakaini dam. As observed in the resulting turbidity had decreased due to increased crop coverage thus reducing bare soil surface since it was crop maturity season and also flow accumulation was reduced as result of decreased water content.

Mwangu intake and raw water in the ponds had a difference of 46 units in both long and short rains. This was as a result of churning of accumulated sediments in the ponds due to a high pressure of water as it enters the ponds; this was also observed in the interpolation map in the dam scouring which had 290 T.U (Figure 4.11a). However, comparisons of turbidity level in different rivers in the dry and wet season, showed turbidity to be high in the wet season than in dry season. (Fig 4.11a) (Fig. 4.11b).

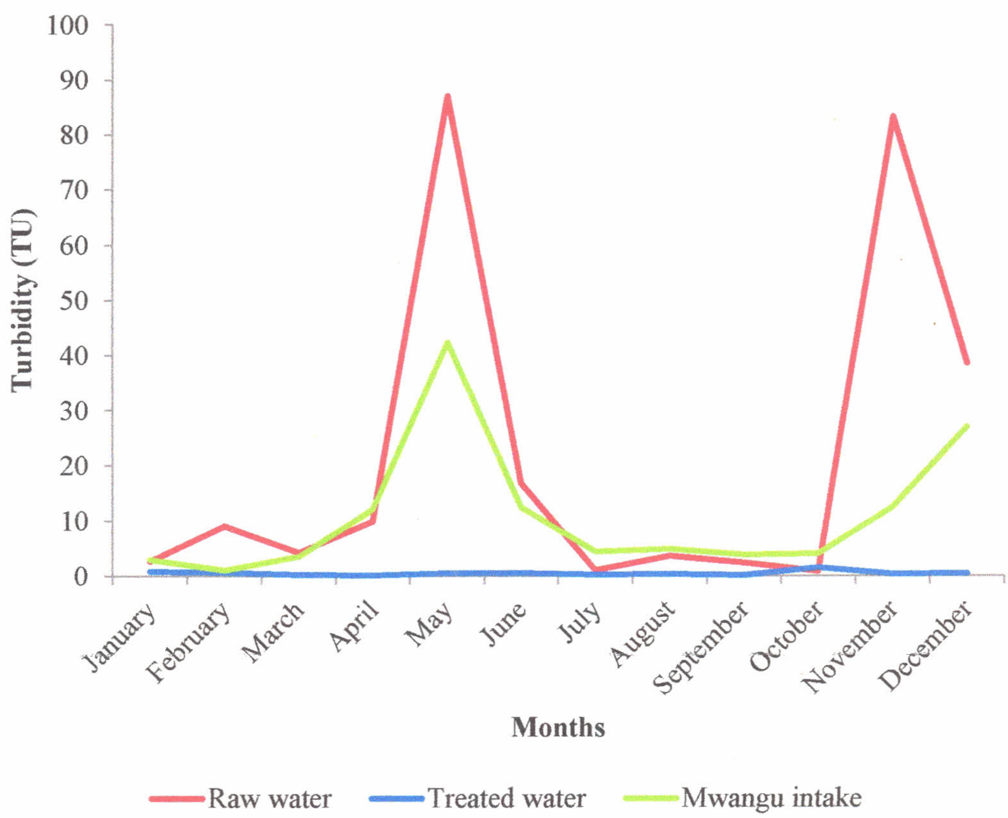


Figure 4.10: Level of turbidity in the Mwangu intake, raw and treated water in Ndakaini Dam Catchment

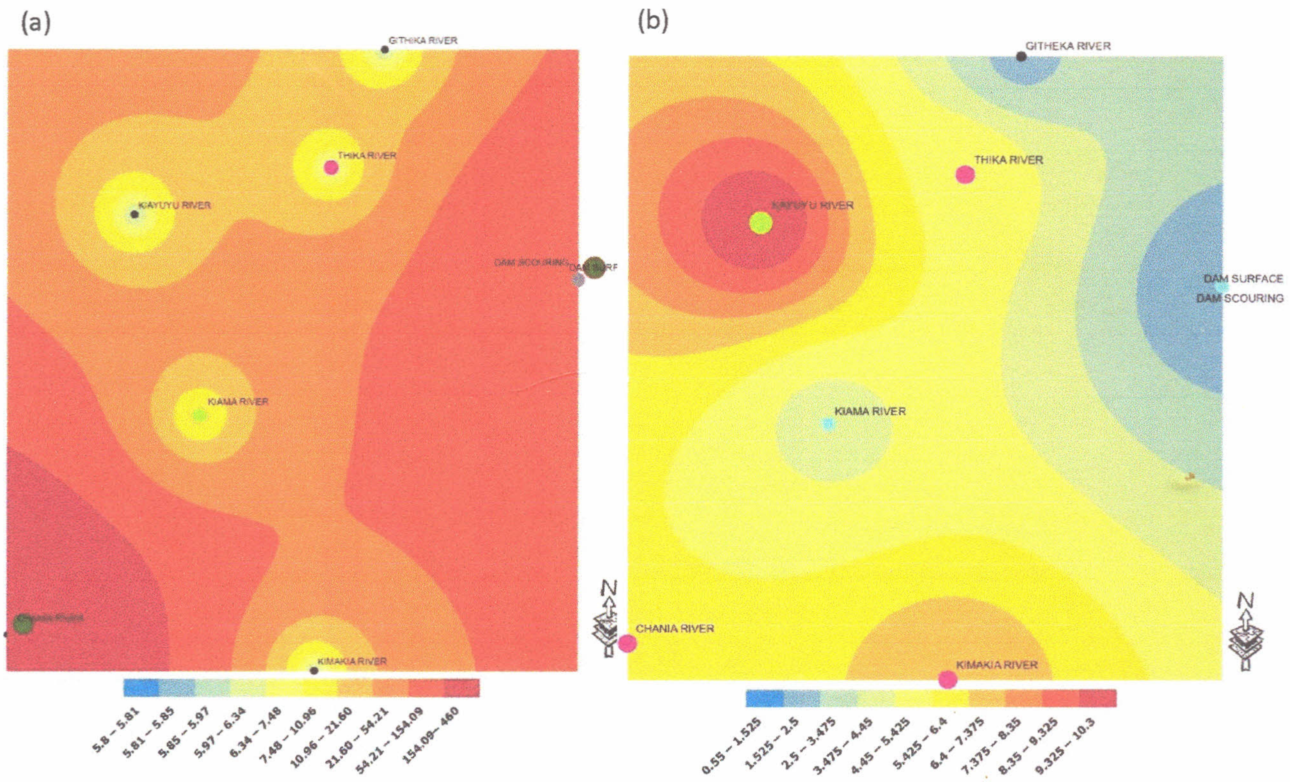


Figure 4 11: Interpolation map of Turbidity levels in different rivers in (a) wet seasons and (b) dry seasons in Ndakaini Dam Catchment

Conductivity was high in long rains from mid-March to May which was 49 to 450 mg/l and 450 mg/l at a high peak in the month of April. This was as a result of sediment deposit at the pond due to increased turbidity (Murdoch *et al.*, 1996). As observed in the study rivers absorbed and transmitted in red band 0.6μm which showed the presence of settled sediments at the bottom of the river. Conductivity increased at the beginning of the long rains in April thus increasing ions and cations. In the intake, it increased in mid-October peaking at November (100 mg/l) and decreasing in December to 50 mg/l (Figure 4.12).

This is was also further confirmed by what was observed in the catchment by interpolation maps where conductivity was higher in the wet season than in dry season (Figure 4.13), and Chania ranked high at 25.69 mg/l and Kimakia at 22.54mg/l.

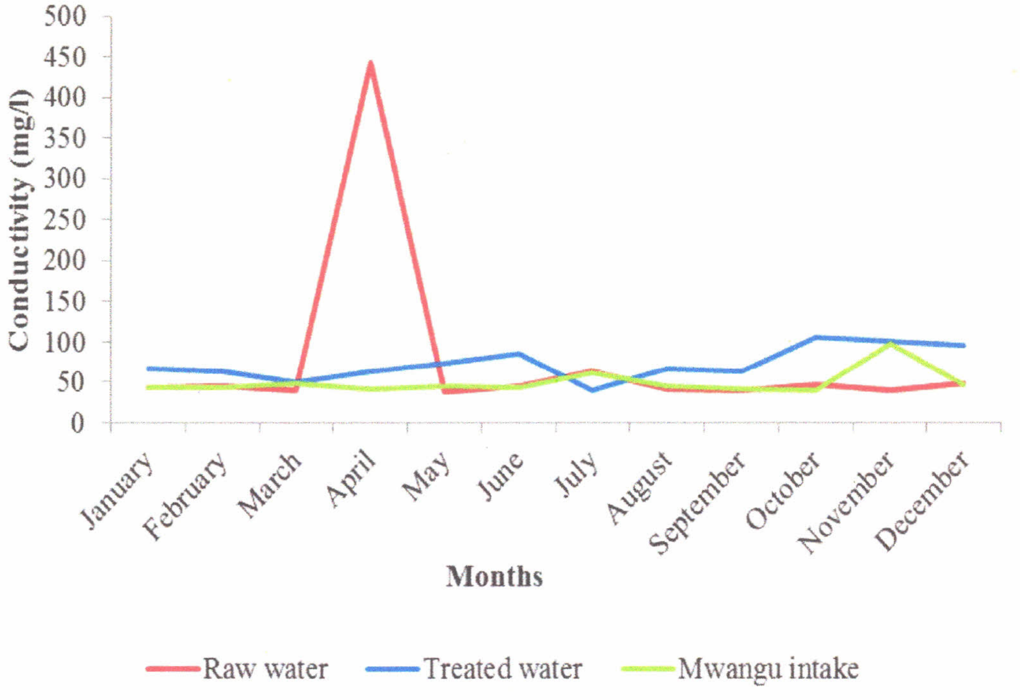


Figure 4.12: Conductivity levels at Mwangu intake, raw and treated water in Ndakaini Dam Catchment

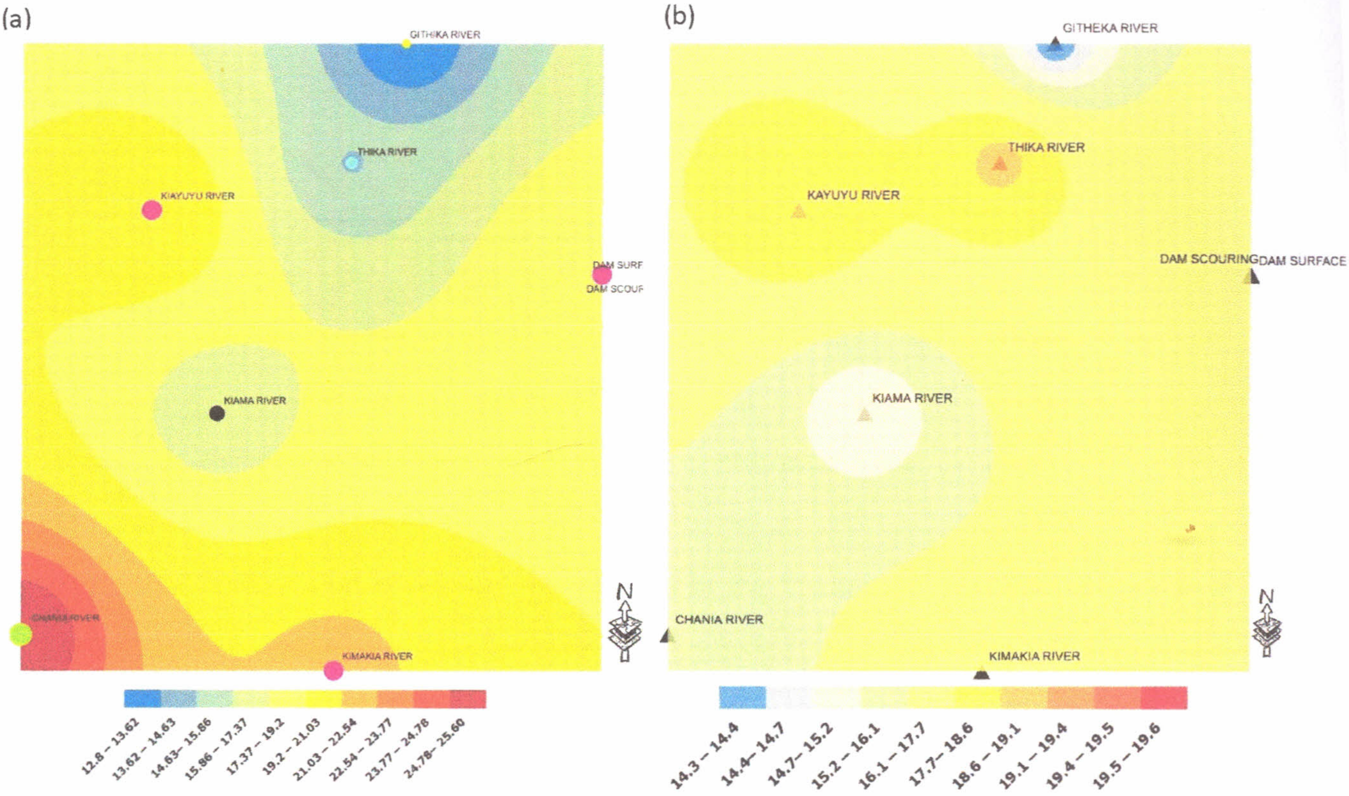


Figure 4.13: Interpolation map of conductivity level in (a) wet season (b) dry season In Ndakaini Dam Catchment

The color was also influenced by wet and dry season as a result of dissolved solids since both long rain and short rain periods had high peaks measuring 5 haze at intake (May) and 10 haze in December, ponds (raw) May 12 haze and November 20 haze (Figure 4.14).

The pH was neutral (7 pH units) throughout the year except in the month of February at the treatment which was slightly alkaline (8.0 pH units) (Figure 4.15). These pH values were in agreement with WHO water drinking standards. On the other hand pH, levels in different rivers in different seasons was observed (Fig 4.16a) (Fig 4.16b) where the values were neutral in wet season due to dilution in rivers thus lowering alkalinity.

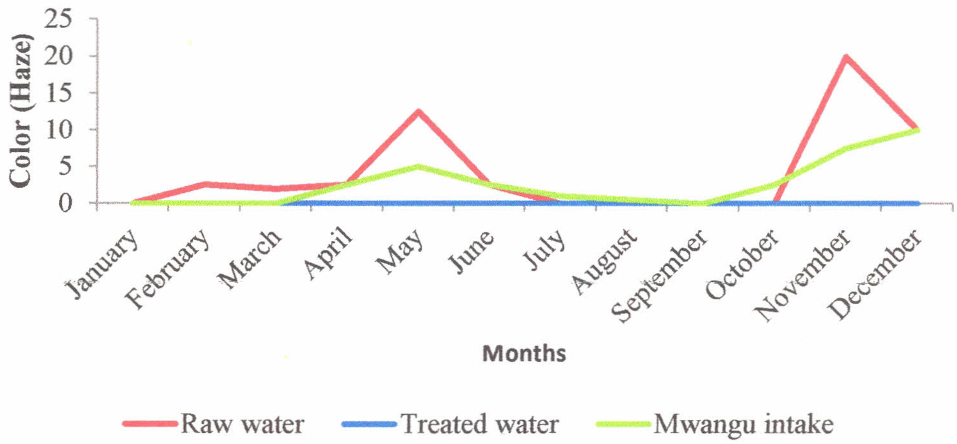


Figure 4.14: Water color in dry and wet seasons in the Mwangu intake, treated and raw water in Ndakaini Dam catchment

However, in the dry season pH was slightly acidic in Githeka River, Kayuyu River and Kimakia River ranging 5.8 pH to 5.87 pH. This was due to increased salts as a result of a decrease in water volumes as consumption increases as well as increased evaporation and transpiration

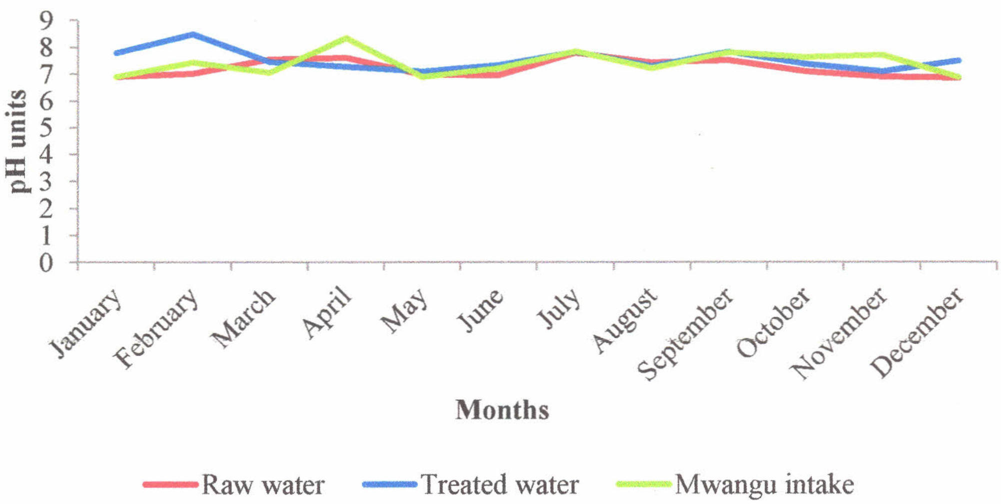


Figure 4.15: The pH levels of the Mwangu intake, raw and treated water Ndakaini Dam Catchment

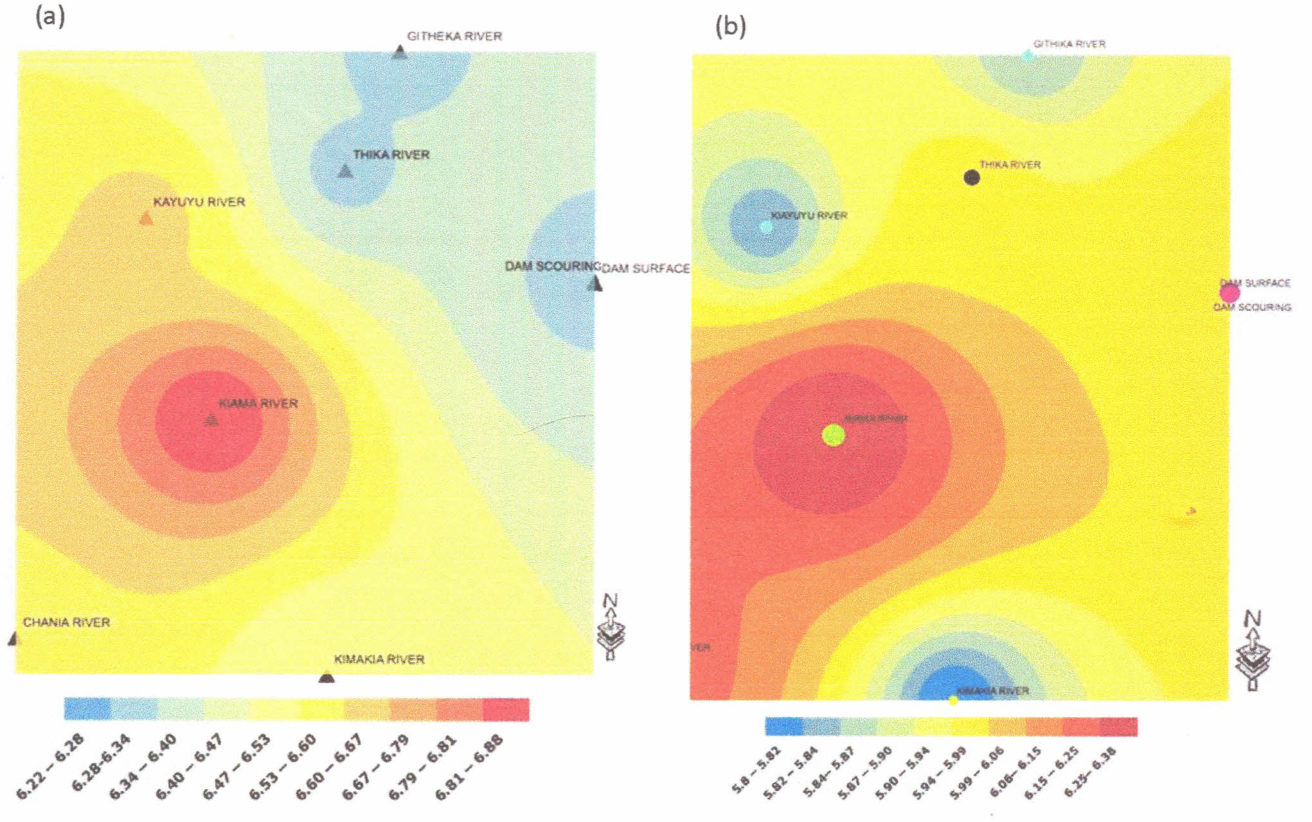


Figure 4.16: Interpolation map of pH level showing (a) wet season (b) dry season in Ndakaini Dam Catchment

Nitrogen occurs naturally in the biogeochemical processes but humans have interfered with cycle through intensive cultivation leading to being deposited into rivers in form of sediments and runoff water (Shah and Joshi, 2015; Kithiia, 2012). However, results in this study had 0mg/l nitrite in the long dry period, long rain, and short dry periods in treated water, raw water (ponds) and intake. Nevertheless, there was a drastic increase in the short rain period in treated water, Mwangu intake and raw water (ponds) where the levels were 5mg/l in raw water, 0.3mg/l in treated water and 0.2mg/l at the intake (Fig 4.17). On the other hand, nitrite increased in the dry season than in wet season attaining a peak of 15mg/l (Fig 4.18a) (Fig 4.18b) which was within the range of WHO water drinking standards.

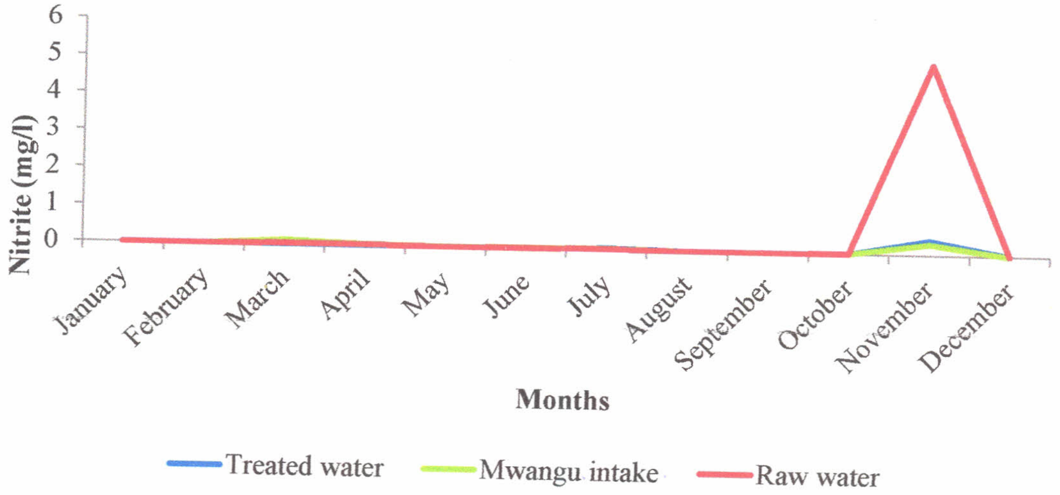


Figure 4:17: Levels of Nitrite in the Mwangu intake, treated and raw water Ndakaini Dam Catchment

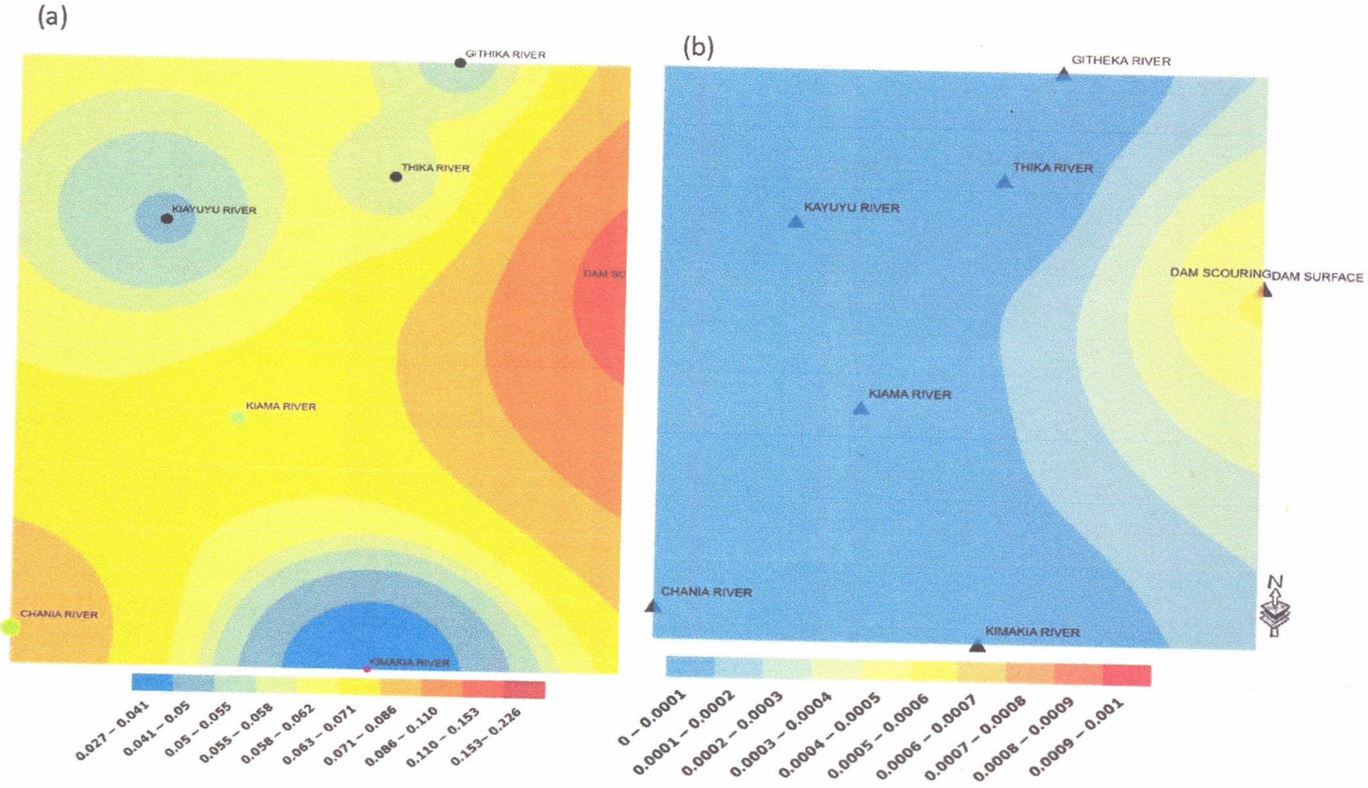


Figure 4.18: Interpolation map of Nitrite level showing (a) wet season (b) dry season in Ndakaini Dam Catchment

The result of nitrate levels for the different rivers and for the two seasons is shown in (Fig 4.19) and shows a comparison in the wet and dry season. In the dry season, the level of nitrate was 0 to 7.5 mg/l perhaps due to the decreased runoff. In the wet season Nitrate increased in Chania River, Kimakia, and Thika at 23.75 mg/l to 96.50 mg/l (Fig 4.20). This was due to the high percentage of bare soil observed along riparian and the upper catchment and steep slopes, thus accelerating runoff downslope.

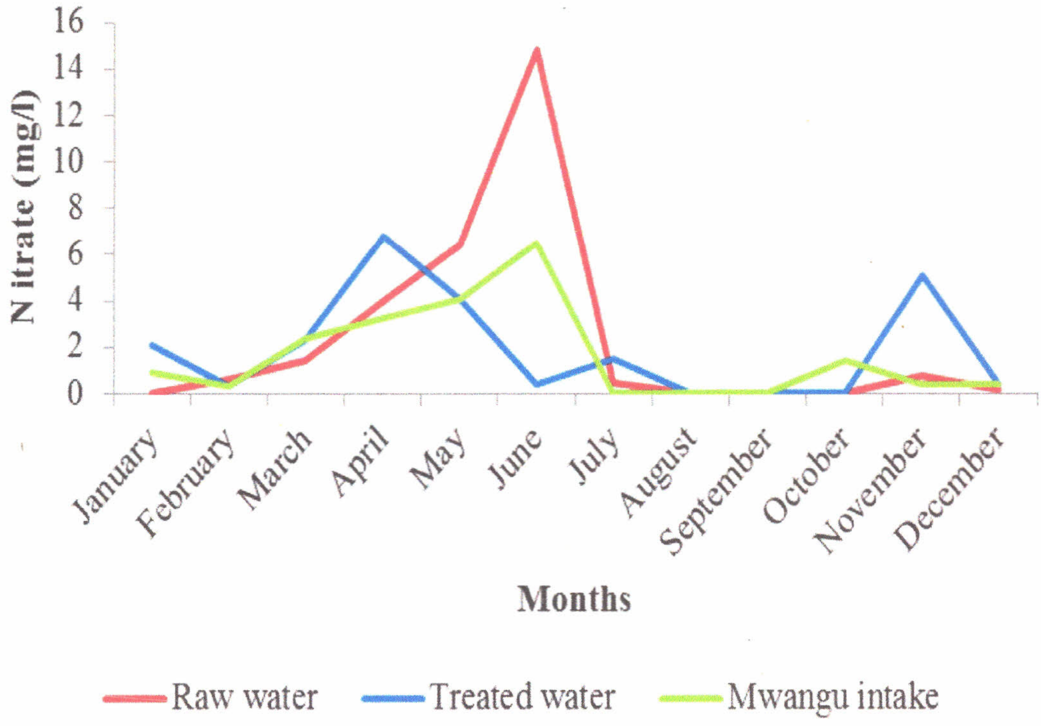


Figure 4:19: Levels of Nitrate in the Mwangu intake, treated and raw water in Ndakaini Dam Catchment

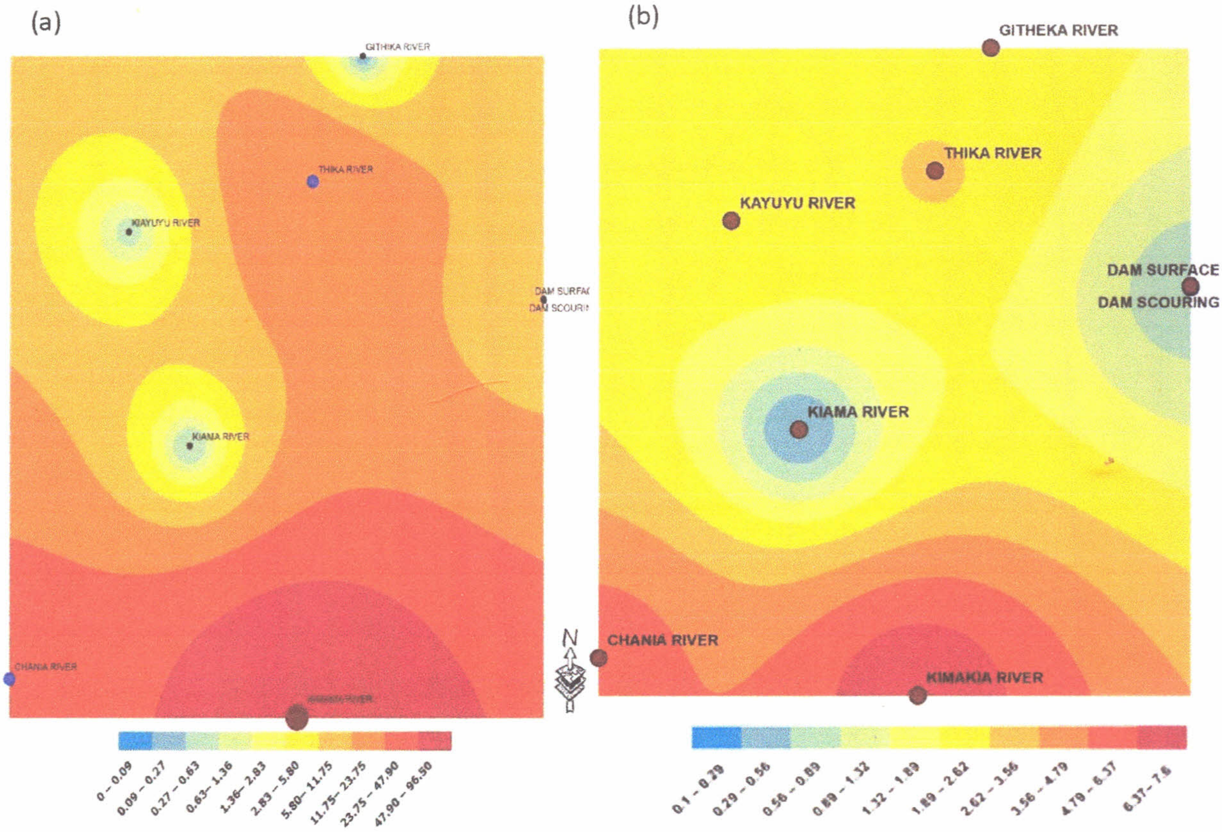


Figure 4:20: Interpolation map of Nitrate level showing (a) wet season (b) dry season in Ndakaini Dam Catchment

Chemical oxygen demand was not detected in the dry season but was detected in wet season where COD was high in Chania and Kiama River from 16.11mg/l to 17.9 mg/l (Fig 4.21). This was due to high nitrate levels in the wet season in Chania and Kiama River.

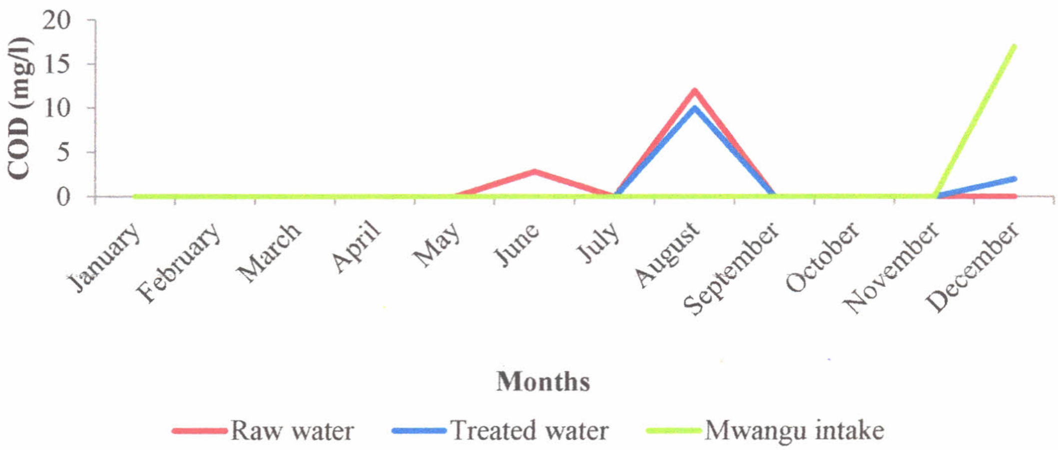


Figure 4:21: Levels of COD in the Mwangu intake, treated and raw water in Ndakaini Dam Catchment

(a)

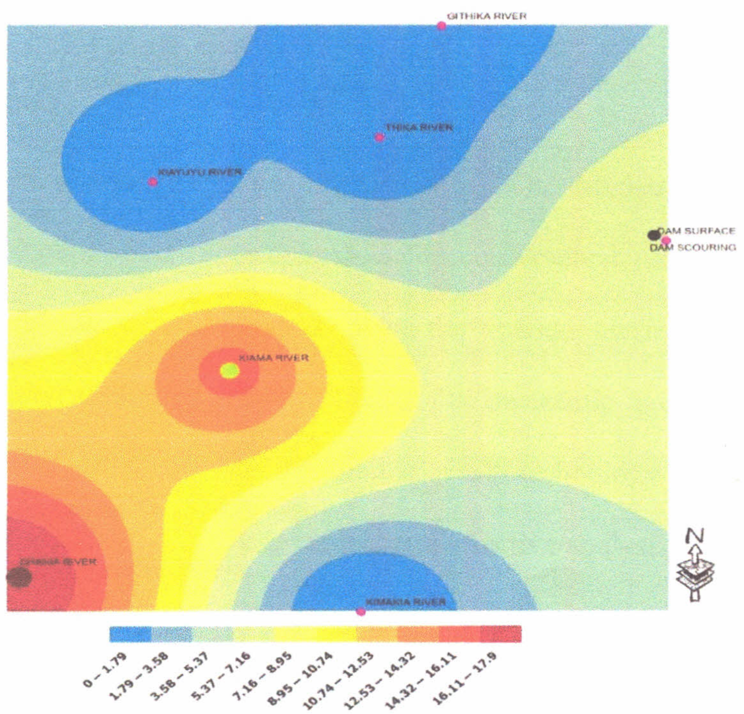


Figure 4:22: Interpolation of COD level during (a) wet season in Ndakaini Dam Catchment

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.2 Conclusions

Chania River was observed in this study to be the hotspot of pollution, as it had high levels of water quality parameters such as turbidity (460 TU) and conductivity (25.60 mg/l) in wet season. These water quality parameters were characterized by its physical factors such as slope ranging (44.5^0-58.3^0|), length of the river, LS (5.54 – 9.63 m/s) and TWI (0.654 – 2.59 m/s) On the other hand, Landsat 8 OLI was effective in the classification of the different land use types where by Thematic map showed Chania river to have high coverage of bare soil.

5.1 Recommendations

Ndakaini stakeholders (Farmers, NWSC, WARMA, CBOs, Ministry of agriculture, Tea factories and KFS) should come up with sustainable conservation plan focusing mainly on education on sustainable agricultural methods along the riparian, awareness on importance of water resources, participation in decision making for ownership purpose. This will curb sedimentation problem. On the other hand integration of GIS technology should also be adopted by Nairobi Water and Sewerage Company for fast and effective analysis of water management from the catchment to the treatment to cut the cost of management and also create an effective database for future follow up and repletion of research. Training should also be done to the staff in order to be able to use the technology.

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7.0 APPENDICES

Appendix 7.1: Wavelength Bands

Bands	Name of band	Wavelength (μm)
Band 1	Coastal aerosols	0.43-0.45
Band2	Blue	0.45-0.51
Band3	Green	0.53-059
Band4	Red	0.64-0.67
Band5	NIR	0.85-0.88
Band6	SWIR1	1.57-1.65
Band7	SWIR	2.11-2.29
Band8	Panchromatic	0.50-0.68
Band 9	Cirrus	1.36-1.38
Band 10	Thermal infrared	10.60-11.19
Band 11	TIRs	11.50-12.51

Appendix 7. 2:Water quality analytical methods

Parameters	Abbreviations	Units	Analytical methods
	pH	pH units	Ph. meter (electronic)
Alkalinity	ALKA	Mg / l	Titration
Color	Color	Hazen units	Comparator
Electro Conductivity	EC	10 µs cm^{-1}	Conductivity meter
Turbidity	TURB	<5NTU	Turbid meter
Nitrite	NO_2^-	Mg/ l	UV Spectrophotometer
Nitrite	NO_3^-	Mg/ l	UV Spectrophotometer
Chemical oxygen demand	COD	Mg /l	Chlorimetric and titrimetric using COD digester