University of Nairobi.

School of Engineering.

USE OF GEOSPATIAL TECHNOLOGY IN MONITORING OF WATER QUALITY: CASE STUDY LAKE NAIVASHA, KENYA.

BY

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Declaration.

I, Mwongera Murungi, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

Mwongera Murungi ………………

Name of student Date

This project has been submitted for examination with our approval as university supervisor(s).

………………………………………… ………………

Name of supervisor Date

Dedication.

I wish to dedicate this work to my family: parents, brothers and sisters whose affection, love, encouragement and prayers of the day and night make me achieve this goal. I also wish to appreciate all hard working and respected members staff of Geospatial and Space Technology (GST) department, University of Nairobi.

Acknowledgement.

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Abstract.

Lake Naivasha has an important ecological, economic and social role in Kenya. There are justified and substantiated concerns on the health of Lake Naivasha. The main issues are: deterioration of water quality, increase of nutrient inflow into the Lake (Eutrophication), and waste emanating from agriculture zones and settlements. The objective of this study was to examine water quality in terms of three parameters; turbidity, total suspended matter and chlorophyll concentration over a period of 10 years, to establish the values and trend of water quality parameters and evaluate if they conform to the stipulated acceptable standards. Medium Resolution Imaging Spectrometer (MERIS) satellite images were used to extract the surface water quality parameters understudy. These images were obtained from European Space Agency (ESA) online portal. A water parameter extraction algorithm in the Basic ERS and Environmental Satellite (EnviSat) (A) Aster and MERIS (BEAM) tool box was used to extract the water quality parameter values.

The conventional methods of water quality measurement and monitoring are expensive, and it is very difficult to use conventional field methods to monitor more than a small fraction of this large resource. Satellite remote sensing can be used since it is a cost-effective way to gather the information needed for regional water quality assessments in water bodies such as Lake Naivasha. Results of this study have shown that Lake Naivasha has high level of eutrophication with chlorophyll concentration above 44 mg/m^3. The Total Suspended Matter (TSM) levels were found to be within Kenya's National Environment Management Authority (NEMA) stipulated values of 30 mg/l while the turbidity parameter values were found to above the European Commission stipulated standard of 1 NTU. The lake trophic state was found to be eutrophic based on the chlorophyll concentration from the analysis of 44.2 mg/m^3 – 49.73 mg/m^3 which is within the stipulated range of 20 mg/m^3 to 56 mg/m^3.

The study has demonstrated that Geospatial Technology can be used successfully to extract water quality parameter values and for the purpose of monitoring the trend over a large extent of the lake, within a shorter time frame and more cost effectively than the traditional / conventional methods of water quality parameter measurements.

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Acronyms.

AGU	American Geosphysical Union
AOP	Apparent Optical Properties
ATSR	Along Track Scanning Radiometers
AVHRR	Advanced Very-High-Resolution Radiometer
AVNIR	Advanced Visible and Near Infrared Radiometer
BEAM	Basic ERS and EnviSat (A) ATSR and MERIS Toolbox
CDOM	Colored Dissolved Organic Matter
DN	Digital Number
EnviSat	Environmental Satellite
EO	Earth Observation
EPA	Environmental Protection Agency
ERS	European Remote Sensing
ESA	European Space Agency
FDOM	Fluorescent Dissolved Organic Matter
FNU	Formazin Nephelometric Units
FR	Full Resolution
GEOSS	Global Earth Observation System Of Systems
GIS	Geographical Information Systems
GPS	Global Positioning Systems
GSM	Garver-Siegel-Maritorena model
IOP	Inherent Optical Properties
ISO	International Organization for Standardization
IWSM	Integrated Water Shed Management
LNRA	Lake Naivasha Riparian Association
LULC	Land Use Land Cover
LUT	Look Up Table
MAPP	MERIS Application and Regional Products Project
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer

NDVI	Normalized Difference Vegetation Index
NEMA	National Environmental Management Authority
NTU	Nephelometric Turbidity Unit
RCMRD	Regional Centre for Mapping of Resources for Development
RR	Reduced Resolution
RS	Remote Sensing
SPM	Suspended Particulate Matter
SWAT	Soil And Water Assessment Tool
TOA	Top Of Atmosphere
TSM	Total Suspended Matter
USGS	United States Geological Survey
VIS-NIR	Visible And Near Infra-Red Radiation

CHAPTER 1: INTRODUCTION.

1.1. Background.

Geospatial technology is a useful tool for monitoring water quality over an extensive area. The remote sensing technique is useful for monitoring total suspended mater, water turbidity and extent of Chlorophyll on the surface of the water. Since remote sensing technology relies on reflectance collected by the satellite sensor, for effective results, it has to be integrated with *in situ* measurements to determine the absolute values (Ritchie Jerry C. et al, 2003). Remote sensing sensors are equipped with airborne imaging spectrometers which are used to collect the reflectance information over a large area within a short time. Establishing the relationship between water quality and land cover change using earth observation integrates information from the catchment, land cover and economic activities (Kauffman J. and Bhomia R., 2014). Extensive changes in land cover affects weather conditions and associated future trends in climate change, carbon balance, and nutrient cycling and water quality (Sun, J. et al, 2013).

Lake Naivasha has a high ecological and biodiversity value with high potential of agricultural activity especially greenhouse farms exporting flowers. The importance of the Lake as a wetland became internationally known by 1999 when it was nominated by the Kenya Government for Ramsar status due activism from local action Lake Naivasha Riparian Association (LNRA) (Everard M. and Harper, 2002) and eventually gazettement by the Kenyan government in 2004 (Otiang'a-Owiti and Oswe, 2007). Fluctuations of water volumes in the Lake are common since it is shallow and has a high demand for domestic and commercial farming activities especially flower farms. The resulting surface run off from the nearby farms ends up in the lake bringing in other pollutants such as siltation, pesticides used on flowers and at times sewer effluents. The resulting water in the Lake like many other lakes in the world have been degraded due to pollution from organic and inorganic products from human activities in the recent decades, (Harper and Mavuti 2004); (Kitaka et al, 2002).

Geospatial Technology has potential to offer quick and reliable information based on the reflective property of the water body on the resulting water quality in terms of impurities present in the water such as suspended matter, Chlorophyll concentration and turbidity among others. Calibrated sensors have the capability to collect such information in one scene which can be analyzed for decision making. Use of geospatial technology is useful for regional trend studies as well as an approach suitable for long term water quality analysis with reliable earth observation data. Complete comprehension of water quality issues often requires plenty of diverse data. Timely collection of relevant data on water is crucial which might not be practical within a very short time using the traditional methods of collecting data using fieldwork. Inaccessibility of some remote areas coupled with bad weather can make data collection costly and unreliable; hence use of geospatial technology is the best available alternative. Geospatial Technology provides alternative reliable source of data with ability to offer explanation to observable changes within landscape with reliable accuracy from space instruments (Wang and Shi, 2008).

Lake Naivasha is classified as one of the wetland lakes in Kenya. Lake Naivasha water volume has been fluctuating over time. This has created the need for multiscale information to aid in decision making especially on the quality of the water of the lake. This study was done to cover a period of ten (10) years with a time stamp of five (5) years using earth observation data derived from spectral response. The findings of this study provide information on changes in water quality and insights on the nature of spectrally detectable products which have altered natural ecosystem of the lake.

1.2. Study Area.

This study was carried out in Lake Naivasha in Kenya. Lake Naivasha is a Ramsar site of wetlands of international importance. The research area lies between 36° 14' 12.15" E and 36° 28' 05.35" E longitude, and 0° 38' 21.48" S and 0° 52' 03.72" S latitude at an altitude of approximately 1890m. "Administratively the area is part of Naivasha Subcounty of Nakuru County" (López, 2002). Lake Naivasha is located 80 km South of the Equator and 100 km northwest of Nairobi, the capital of Kenya, in the bottom of the Eastern Rift Valley. The Lake is the second-largest freshwater lake in Kenya after the Kenya portion of Lake Victoria. "It has a surface area of 139 km^2 and an average depth of 3.35 m, with the deepest point being seven meters (7 m) though these values vary with extreme conditions" (Otieno et al, 2014).

The overall climate of the Eastern Rift Valley is semi-arid. The Lake is fed by two perennial rivers, the Malewa and the Gilgil Rivers contributing 80% and 20% of the total inflow respectively. The Karati River drains the area East of the Lake, being ephemeral and flowing approximately 2 months per year. The area South of Lake Naivasha does not produce much runoff reaching the lake. The drainage from the Mau Hills and Eburu to the West infiltrates before it reaches the lake. About 25% of the surface water inflow recharges the aquifers and flows to the South and North. This outflow causes the lake to be a fresh water lake (Becht, 2007).

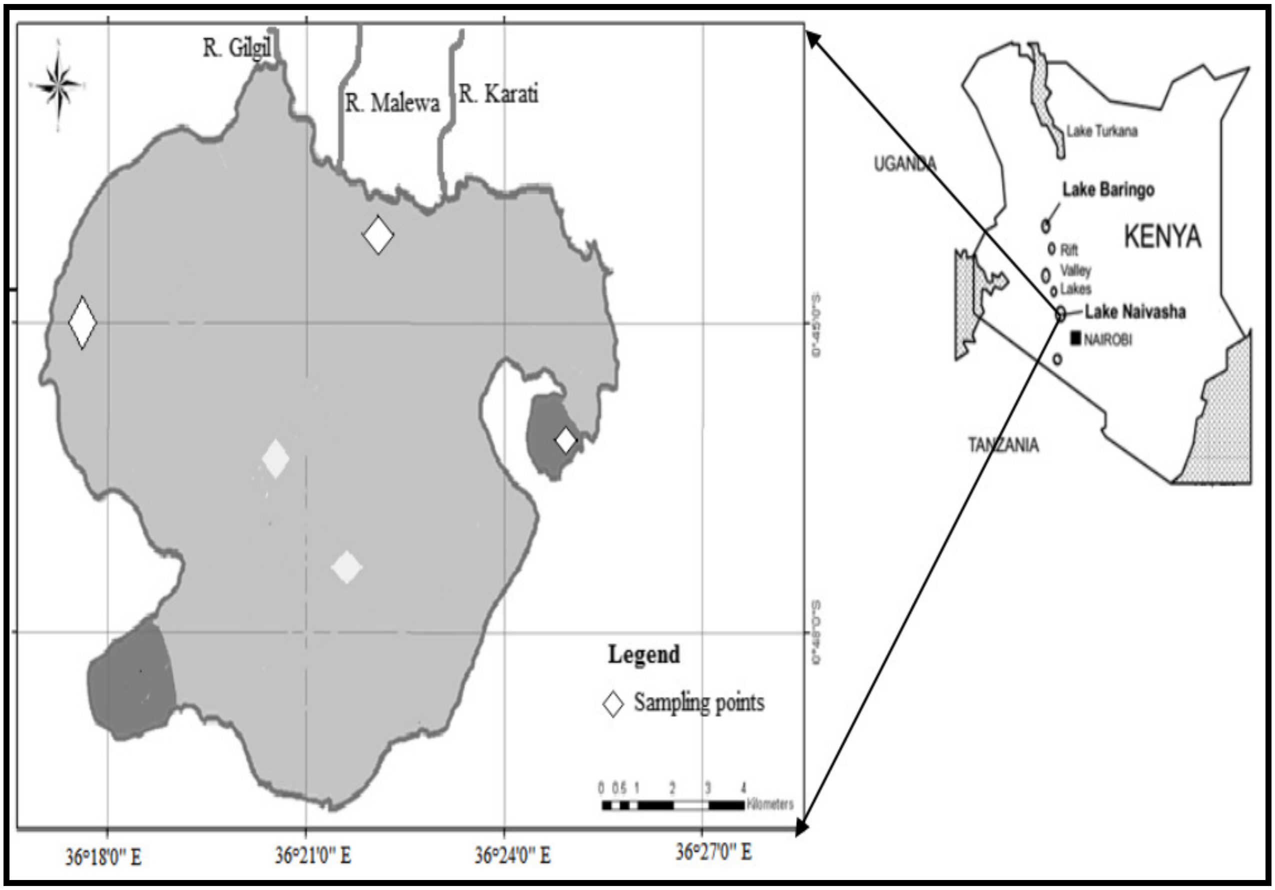

Figure 1.1: Map of Lake Naivasha.
Source: (Otieno et al, 2014).

The Lake Naivasha drainage basin experiences semi-arid conditions influenced by morphology of the drainage basin, namely floor of the Rift Valley, and wet conditions influenced by Aberdare mountain ranges. The monthly temperature ranges from 15-18˚ C with Equatorial climate with heavy rains experienced between March and April and rains short are experienced from October to December and drier period from December to February. Lake Naivasha has four basins, where the main basin is circular with the deepest point in the South with steady decrease towards the North which has the inflow as shown in figure 1.2.

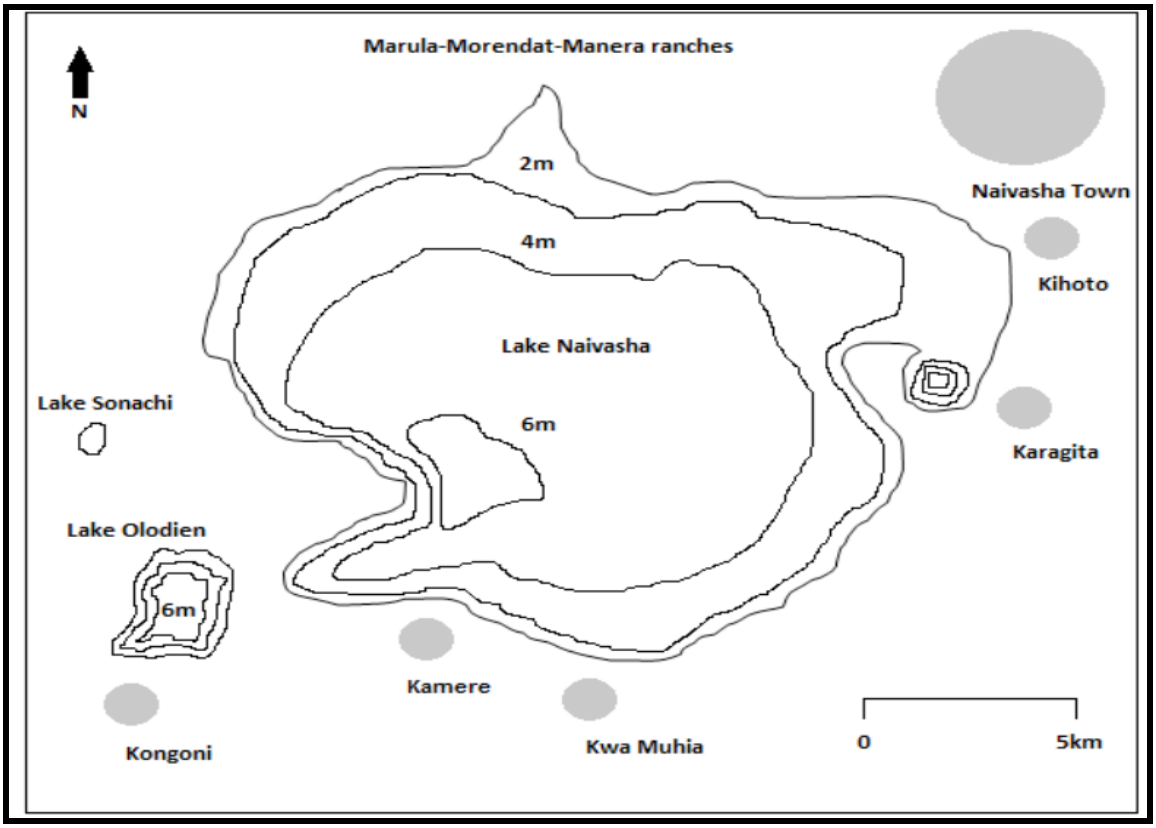

Figure 1.2: Lake Naivasha with its constituent basins and informal settlements.
Source: (Harper et al, 2011).

The basin has plenty of hydrological networks with numerous tributaries (Figure 2) which contributes to a greater percentage of the Lake Naivasha discharge. Other than rivers Malewa and Gilgil, river Karati contributes to approximately 120 km^2 of basin with waters from Mau and Eburu though the volume is not regular due to seasonality of the river. (Figure 1.3.) (Lukman, 2003).

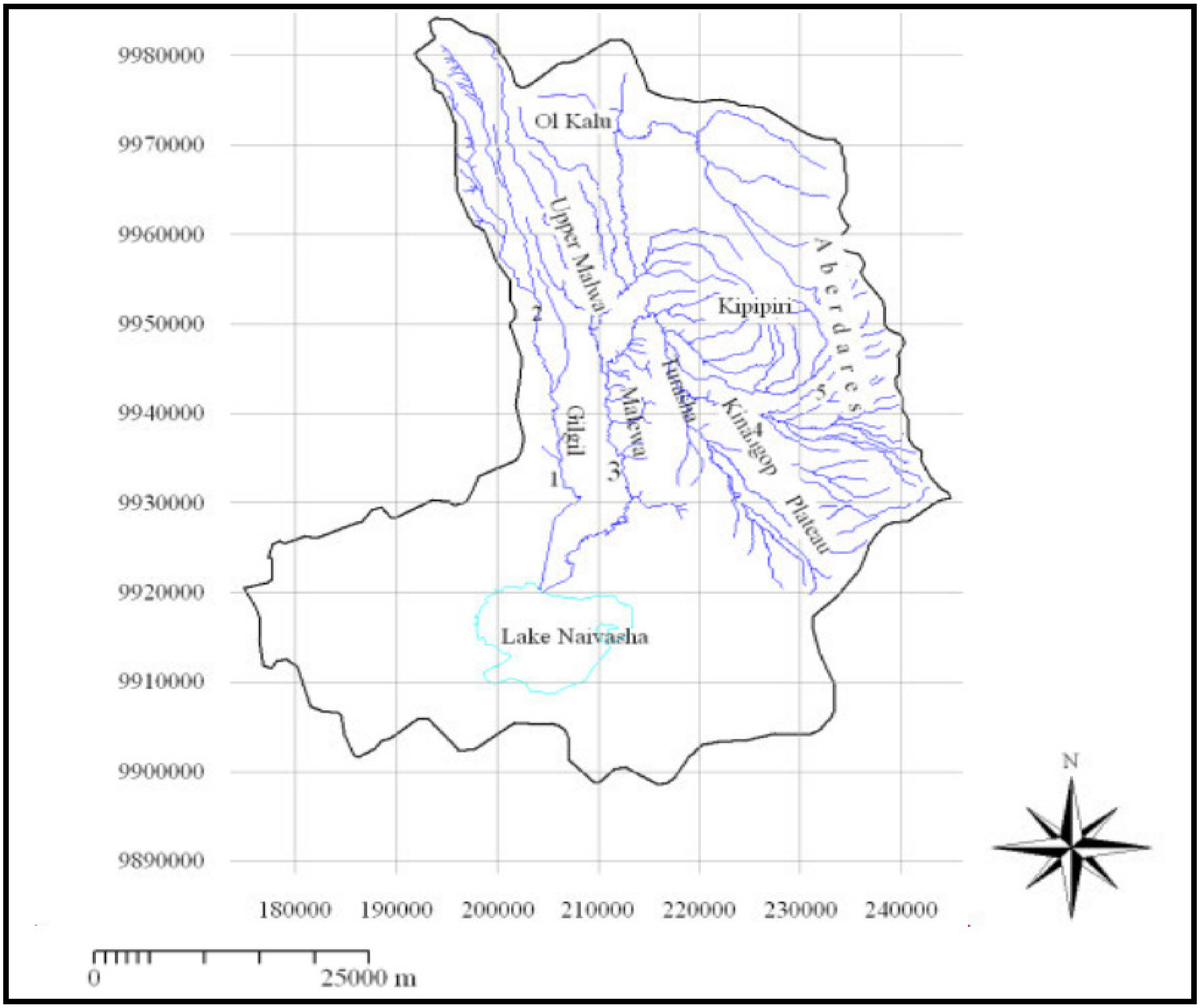

Figure 1.3: Main rivers of Lake Naivasha water catchment.
Source: (Lukman, 2003).

1.3. Problem Statement.

Human activities within the vicinity of Lake Naivasha catchment have altered the natural ecosystem of the lake catchment and its drainage basin. The supply and demand of water within the lake basin have increased due change in rainfall patterns which resulted into irrigation activities using both surface and underground water sources. The surface water in rivers draining into the lake and the lake itself forms a larger source of water for domestic use and farming activities. Since the lake is extensive, "*in situ"* measurements of the water quality parameters would take a long time if the whole lake was to be studied with good accuracy. This has created the need to understand the water quality in terms of water reflective properties such as Turbidity, presence or absence of Chlorophyll and presence of Total Suspended Matter (TSM).

According to Becht (2007), the reduction of water in Lake Naivasha due to overexploitation has been a threat to sustainable development of the Lake based economic activities due high demand from farmers using the water for irrigation, industrial development such as geothermal exploration activities and demand from domestic users. The situation was worsened during the year 2009-2010 when the lake receded to lowest point since 1940s (Becht, 2007). The degradation to ecological quality that results from organic pollution causing turbidity and eutrophication which increases Chlorophyll concentration among others have resulted to degraded water quality both in content and appearance.

The watershed of Lake Naivasha is unique because it is semi-arid with scare surface and underground water resources. Land use changes since Independence have led to rapid shift from the initially pastoralist economy area to commercial farming, tourism activities and eventually geothermal production. The areas around the Lake Naivasha have registered rapid land subdivision which as affected the land cover changes and eventually affecting the quality of water whether surface or underground due to varying demand for various activities. High demand of natural resources exploited from the Lake Naivasha ecosystem has created pressure in watershed and eventually threatens its sustainability. This study therefore, focuses on monitoring water quality form satellite image and assessing the trend of water quality over a period of time with the objective of identifying if the conform to stipulated water quality standards. In addition this will aid in take information based Lake management interventions to ensure acceptable Lake water quality for various uses.

1.4. Objectives.

1.4.1. Main Objective.

The objective of the project is to monitor the trend water quality parameters (Chlorophyll, Total Suspended Matter (TSM) and Turbidity) and determine the trophic state of Lake Naivasha using geospatial technologies data from Medium Resolution Imaging Spectrometer (MERIS) satellite images.

1.4.2. Specific Objectives.

The above main objective will be accomplished by fulfilling the following specific objectives:

1. To extract the concentration and spread of water quality parameters values of Lake Naivasha (Chlorophyll concentration, TSM and Turbidity) for the period under study, (2002 to 2012).
2. To identify Lake Naivasha's trophic state and the trend of water quality parameter values (Chlorophyll concentration, TSM and Turbidity) over a period of ten years (2002 to 2012).
3. Identify the level to which Lake Naivasha water quality parameter values for (Chlorophyll concentration, TSM and Turbidity) study conform to internationally acceptable water quality standards, National Environment Management Authority (NEMA) and European Communities COUNCIL DIRECTIVE 98/83/EC on the quality of water intended for human consumption.

1.4.3. Research Questions.

The research questions listed below give focus on the specific expected outcome of the study project.

1. What are the values of water quality parameters (Chlorophyll concentration, TSM and Turbidity) for the period under study 2002 to 2012 in Lake Naivasha?
2. What is the trophic state and the trend water quality parameters under study (Chlorophyll concentration, TSM and Turbidity) in Lake Naivasha and the trend understudy over the period of study 2002 to 2012?
3. Does the Lake Naivasha water quality parameter value under study (Chlorophyll concentration, TSM and Turbidity) conform to the stipulated standards of domestic and irrigation use by NEMA and European Communities COUNCIL DIRECTIVE 98/83/EC on the quality of water intended for human consumption?

1.5. Justification for the Study.

The area under study has plenty and diverse aspects of agricultural and non-agricultural activities such as tourism and sport fishing among others. There has been observed decline in water volume and presence of foreign substances in the water which needs to be investigated to determine their nature (Becht, 2007). The conventional method of measurement includes either submersible turbidity meters or secchi disk for turbidity. TSM is conventionally determined by weight method which involves filtration of water sample, drying and weighing where as a chrolophly concentration conventional measurement method is by use of chlorophyll sensor. The three parameter conventional method are done *"in situ"* which required qualifies staff, specialised equipment and sampling at many different points in addition to laboratory analysis for TSM. Conventional methods are used to regularly monitor only a small percentage of inland water. The "big picture" view of water quality is not practical with conventional point sampling methods due to limited resources. Satellite remote sensing is a viable option for current synoptic measurement and historic assessment of important water quality variables due to improved computer software and hardware as well as the availability of free or in expensive satellite imagery. The state in the lake water quality parameters needs to be monitored and any changes need to be investigated to determine their nature and extent. It is upon this basis that this research project was conducted.

1.6. Scope and Limitations of the Study.

The study was conducted using satellite image data from MERIS sensor of Lake Naivasha. Main investigation shall be based on spectral properties of lake water surface as collected by the sensors above. Due to lack of funding, this study used freely available data from Global Earth Observation System of Systems (GEOSS). The investigation of the study did not involve detailed analysis of individual drivers of land use, however, water quality information is quantified from the satellite data and estimation of areal extent is established..

1.7. Structure of the Report.

This MSc project report is structured as follows. Chapter One gives the introduction of the study which includes the background, problem statement, objectives justification and scope of work of the study project. Chapter Two contains literature review relating to the subject of study. Chapter Three gives materials and methods used in execution of the project. Chapter Four gives the results and discussions and Chapter Five gives the conclusion and recommendations.

CHAPTER 2: LITERATURE REVIEW.

2.1. Lake Trophic State.

Classification of lakes is done using a term that describes how "green" the lake is as measured by the amount of algae biomass in the water. Eutrophication is a term used to describe a directional movement over time towards the eutrophic trophic state from a lower trophic state. Three lake trophic state classes are utilized to portray lakes as they become dynamically greener: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are bigger, more profound lakes with clear water, rough or sandy shorelines, low phosphorus advancement, constrained established plant development, low algal development and sufficient broke down oxygen all through. Mesotrophic lakes are middle of the road classifications with attributes between the other two gatherings. Eutrophic lakes are littler, shallower lakes with dirty bottoms, broad established plant development and exhausted broke up oxygen in the base waters; frequently tea-shaded, at times dinky from planktonic algal development. "Lake trophic state pointers incorporate; Water Lucidity, Chlorophyll, Established Plant Development, Phosphorus, Broke down Oxygen" (Simpson and Dark colored, 2016).

Lakes for the most part change trophic state gradually, bit by bit ending up more eutrophic after some time, where time is estimated in a large number of years. This procedure is called normal eutrophication. The procedure is regularly extraordinarily quickened because of human movement (called social eutrophication). Social eutrophication can be controlled by overseeing human movement inside the watershed and on the lake. Watershed controls that lessen phosphorus spillover and disintegration into a lake will help ensure the lake and moderate its development toward a more eutrophic state (DES, 1997).

2.2. Water Types and Classification.

A bipartite classification scheme, according to which oceanic waters are partitioned into; Case 1 or Case 2 waters, was introduced by Morel and Prieur (1977), as described below:

Case 1 waters: - These are defined as waters for which phytoplankton and their associated materials (such as debris, heterotrophic organisms and bacteria, excreted organic matter) control the optical properties. Chlorophyll retrieval in Case I water is relatively simple because only plankton influence optical properties, and scattering and absorption by debris is correlated with

Chlorophyll concentrations. They are typical of the open ocean, away from coasts and river mouths

Case 2 waters: - These are found in coastal zones influenced by land drainage or suspended sediment In addition to phytoplankton. Optical properties are typically controlled by three independent components:

• Phytoplankton and their associated debris,

• Dissolved organic matters of terrigenous origin, known variously as yellow substance, Gelbstoff, Gilvin or CDOM (coloured dissolved organic matter).

• Mineral particles and various suspended sediments. See figure 2.1 below.

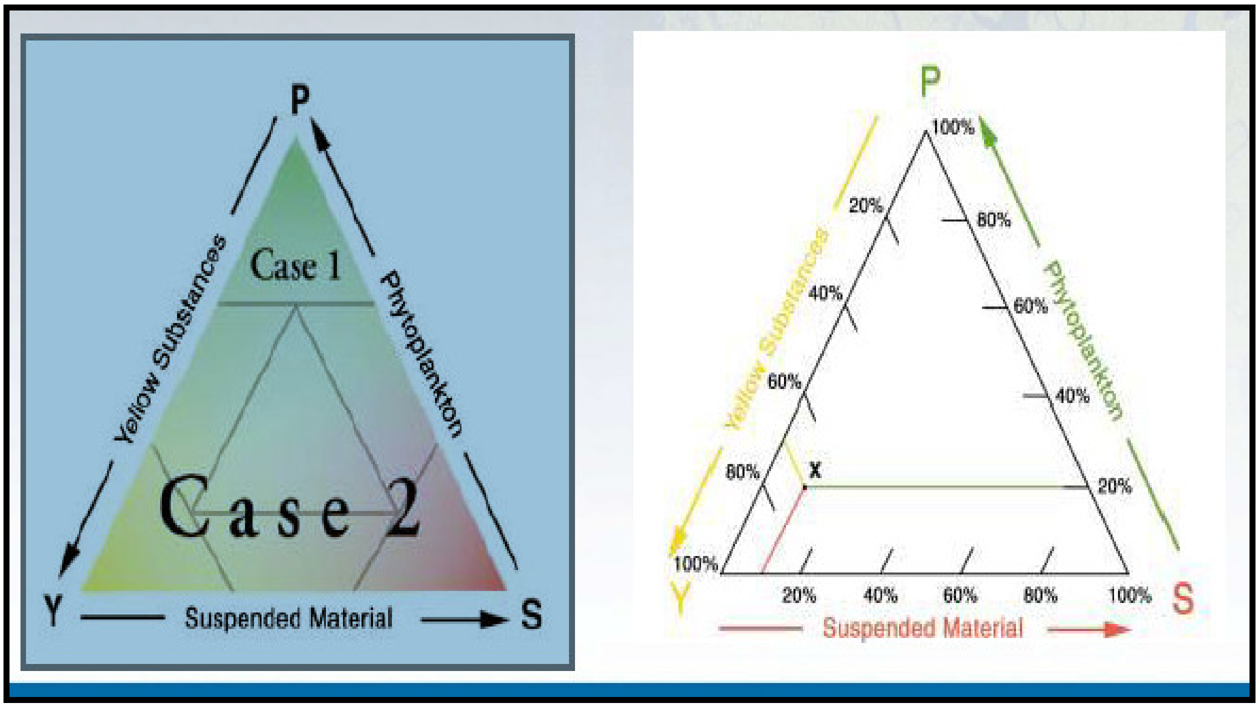

Figure 2.1: Diagrammatic representation of case I and II waters.
Source: (IOCCG, 2000).

2.3. Optical Properties of the Water.

The ***bulk*** or large-scale, optical properties of water are conveniently divided into two mutually exclusive classes: inherent and apparent

1. Inherent Optical Properties (IOP).

These are those properties that depend only upon the medium, and therefore are independent of the ambient light field within the medium. The two fundamental Inherent Optical Properties (IOP's) are the absorption coefficient and the volume scattering function. Other IOP's include the index of refraction, the beam attenuation coefficient and the single-scattering albedo. There are various IOP that affect reflectance of natural water. The IOP can be categorized into three namely: first IOP category being, absorption by water molecules, phytoplankton, dissolved organic matter (yellow matter), organic detritus, mineral particles; The second IOP category being scattering by water molecules, organic particles, mineral particle, air bubbles; and the third IOP category being remittance by Raman scattering (the inelastic scattering of a photon upon interaction with matter.), fluorescence by phytoplankton, fluorescence by yellow matter, bio-luminance (IOCCG, 2000).

2. Apparent Optical Properties (AOP).

These are those properties that depend both on the medium (the IOP) and on the geometric (directional) structure of the surrounding light field, and that show enough consistent highlights and security to be valuable descriptors of the water body generally utilized AOP are the irradiance, reflectance, the normal cosines, and the different diffuse lessening coefficients

2.4. Water Quality.

Water quality testing is an imperative piece of natural observing. At the point when water quality is poor, it influences amphibian life as well as the encompassing biological system too. These properties can be physical, synthetic or natural components. Physical properties of water quality incorporate temperature and turbidity. Synthetic attributes include parameters, for example, pH and broke up oxygen. Natural pointers of water quality incorporate green growth and phytoplankton. These parameters are applicable not exclusively to surface water investigations of the sea, lakes and streams, yet to groundwater and mechanical procedures also. "Water quality checking can enable scientists to foresee and gain from normal procedures in the earth and decide human effects on a biological community. These estimation endeavors can likewise aid rebuilding ventures or guarantee ecological principles are being met" (Fondriest, 2015).

2.4.1. Chlorophyll.

Chlorophyll is a shading color found in plants, green growth and phytoplankton. This atom is utilized as a part of photosynthesis, as a photoreceptor. Photoreceptors assimilate light vitality, and Chlorophyll particularly retains vitality from daylight. Chlorophyll influences plants and green growth to seem green since it mirrors the green wavelengths found in daylight, while retaining every single other shading.

Be that as it may, Chlorophyll isn't really a solitary particle. There are six (6) unique Chlorophylls that have been distinguished. The distinctive structures (A, B, C, D, E and F) each reflect somewhat extraordinary scopes of green wavelengths. Chlorophyll An is the essential particle in charge of photosynthesis. That implies that Chlorophyll An is found in each and every photosynthesizing life form, from arrive plants to green growth and cyanobacteria. The extra chlorophyll shapes are embellishment shades, and are related with various gatherings of plants and green growth and assume a part in their ordered disarray. These different Chlorophylls still ingest daylight, and in this way aid photosynthesis. As adornment colors, they exchange any vitality that they ingest to the essential Chlorophyll A rather than straightforwardly taking an interest simultaneously.

A simpler and more effective technique is to utilize a chlorophyll sensor. As all phytoplankton have Chlorophyll, a Chlorophyll sensor can be utilized to identify these living beings in-situ. Notwithstanding giving prompt information, it can be utilized for ceaseless or long haul checking and recording. Nonetheless, as Chlorophyll Sensor expect all green growth and cyanobacteria have similar levels of Chlorophyll, it just gives a harsh gauge of biomass. It additionally can't be utilized to distinguish particular species. Indeed, even with its restrictions, "in-situ" Chlorophyll estimations are suggested in Standard Strategies for the Examination of Water and Wastewater to gauge algal populaces. Chlorophyll Sensors are additionally an "in-situ" technique for deciding the trophic state (supplement rich, stable, or supplement poor) of an oceanic framework. A high Chlorophyll estimation is a pointer of eutrophication.

Chlorophyll is estimated in micrograms per liter (µg/l). Chlorophyll sensors depend on fluorescence to appraise phytoplankton levels in light of chlorophyll focuses in an example of water. Fluorescence implies that when the chlorophyll is presented to a high-vitality wavelength (around 470 nm), it emanates a lower vitality light (650-700 nm). This returned light would then be able to be estimated to decide how much chlorophyll is in the water, which thus appraises the phytoplankton focus. These appraisals are then used to create parameter limits for waterways (Fondriest, 2015).

2.4.2. Total Suspended Matter (TSM).

Add up to Suspended Issue (TSM) are particles that are bigger than 2 microns found in the water segment. Anything littler than 2 microns (normal channel estimate) is viewed as a broken up strong. Most suspended solids are comprised of inorganic materials, however microbes and green growth can likewise add to the aggregate solids focus. These solids incorporate anything floating or gliding in the water, from residue, sediment, and sand to tiny fish and green growth. Natural particles from breaking down materials can likewise add to the TSM focus. As green growth, plants and creatures rot, the disintegration procedure enables little natural particles to split away and enter the water segment as suspended issue. Indeed, even concoction accelerates are viewed as a type of suspended issue. Add up to Suspended Issue is a noteworthy factor in watching water lucidity. The more solids display in the water, the less clear the water will be.

Add up to Suspended Issue, as an estimation of mass are accounted for in milligrams of solids per liter of water (mg/L). Suspended dregs is additionally estimated in mg/L. The most exact strategy for deciding TSM is by sifting and measuring a water test. This is regularly tedious and hard to quantify precisely because of the accuracy required and the potential for mistake because of the fiber channel. Much of the time, an Aggregate Suspended Solids focus beneath 20 mg/L seems clear, while levels more than 40 mg/L may start to seem overcast (Fondriest, 2015).

2.4.3. Turbidity.

Turbidity is an optical assurance of water clearness. Turbid water will seem overcast, cloudy, or generally shaded, influencing the physical look of the water. Suspended solids and broke up hued material decrease water clearness by making a misty, murky or sloppy appearance. Turbidity estimations are regularly utilized as a pointer of water quality in view of clearness and evaluated add up to suspended solids in water (Fondriest, 2015). The Turbidity of water depends on the measure of light scattered by particles in the water section. The more particles that are available, the all the more light that will be scattered. In that capacity, turbidity and aggregate suspended solids are connected. In any case, turbidity is definitely not an immediate estimation of the aggregate suspended materials in water. Rather, as a measure of relative lucidity, turbidity is frequently used to show changes in the aggregate suspended solids fixation in water without giving a correct estimation of solids. Turbidity can originate from suspended residue, for example, sediment or earth, inorganic materials, or natural issue, for example, green growth, tiny fish and rotting material.

Notwithstanding these suspended solids, turbidity can likewise incorporate Colored Dissolved Organic Matter (CDOM), Fluorescent Dissolved Organic Matter (FDOM) and different colors. CDOM is otherwise called humic stain. Humic stain alludes to the tea shading created from rotting plants and leaves submerged because of the arrival of tannins and different particles. This staining is regularly found in marshes, wetlands or other water bodies with high measures of rotting vegetation in the water. CDOM can make water seem red or dark colored, contingent upon the kind of plants or leaves exhibit. These broke up substances might be too little to be tallied in a suspended solids focus, yet they are still piece of a turbidity estimation as they influence water clearness. Turbidity is frequently estimated with a turbidity meter. Turbidity is accounted for in units called a Nephelometric Turbidity Unit (NTU), or a Jackson Turbidity Unit (JTU). A turbidity perusing underneath 5 NTU seems clear, while a perusing of 55 NTU will begin to look shady and a perusing 500 NTU will show up totally misty. Universal Organization for Standardization (ISO) alludes to its units as Formazin Nephelometric Units (FNU) (Fondriest, 2015).

2.4.4. Water Clarity.

Water clarity is a physical trademark characterized by how clear or straightforward water is. Clearness is dictated by the profundity that daylight enters in water. The further daylight can come to, the higher the water lucidity. The profundity daylight comes to is otherwise called the photic zone. The clearer the water, the more profound the photic zone and the more prominent the potential for photosynthetic generation. The photic zone (and along these lines water lucidity) has a greatest profundity of 200 m in view of the light retention properties of water.

Water clarity is identified with Turbidity, as Turbidity is a measure of water clearness. The transparency of water is influenced by the measure of daylight accessible, suspended particles in the water segment and broke up solids, for example, hued disintegrated natural material (CDOM) introduce in the water. Water clearness, when not estimated regarding turbidity, is estimated by Secchi profundity. This estimation depends on the profundity that a high contrast Secchi circle can be brought down into a waterway. At the point which perceivability is lost, the profundity of the plate is recorded, and is known as the Secchi profundity. High Secchi profundities compare with low turbidity levels, while low Secchi profundities are related with large amounts of suspended solids. This strategy is for the most part just valuable in seas, lakes and profound, low-stream waterways (Fondriest, 2015).

2.4.5. Importance of Chlorophyll, Turbidity and Total Suspended Matter.

Turbidity and TSM are the most noticeable markers of water quality. These suspended particles can originate from soil disintegration, spillover, releases, mixed base silt or algal sprouts. While it is workable for a few streams to have normally abnormal amounts of suspended solids, clear water is generally viewed as a pointer of sound water. A sudden increment in turbidity in a formerly clear waterway is a reason for concern. Over the top suspended residue can hinder water quality for amphibian and human life, obstruct route and increment flooding dangers. They likewise influence, impact or are pointers of water science, photosynthesis, disintegration, tainting, human exercises. Minute phytoplankton play a portion of the greatest parts in atmosphere control, oxygen supply and food production

These single-celled organisms are responsible for more than 40% of Earth's photosynthetic production. That process uses up carbon dioxide, which helps regulate carbon dioxide (CO_2) levels in the atmosphere, and produces oxygen for other organisms to live. Phytoplankton are an imperative part of a solid waterway. Green growth and cyanobacteria help to give oxygen and nourishment to amphibian living beings. As a key segment, an unevenness of phytoplankton levels can cause significant issues. On the off chance that an excessive number of supplements are accessible, it can trigger an algal blossom. Algal blossoms and overproduction of phytoplankton can cause dangerous red tides and fish murders. Then again, phytoplanktonic profitability can be constrained by an absence of required reactants, for example, daylight. This reduction in profitability can likewise prompt fish slaughters (Fondriest, 2015).

2.5. Background Information.

Land use affects land cover which eventually affects the quality of ecosystems and ecosystems derived benefits such as water provision in terms of volume, recharge capacity and water quality. The global initiative on climate change resulting from unsustainable land use practices have led to use of geospatial technology in mapping out carbon credits across the globe (Bateman et al, 2013). Earth Observation (EO) data provides adequate opportunity to investigate the trend, acreage and associate patterns that have occurred on land cover and the resulting impacts such as food provision capability, denudation aggravation and water supply especially on the surface natural reservoirs such as lakes, springs, river and oceans (Hertel et al, 2010). Natural reservoirs such lakes rely on surface runoff as main source of water. Surface run offs are products of rain that falls within the catchment. Understanding how activities within catchment affects affect rainfall patterns and volume is crucial attempt in comprehending changes in water quality within a given lake. It is also prudent to investigate the human induced parameters such as use of fertilizers, pesticides and discharge of industrial and human waste into the natural reservoirs such lakes (Hertel et al, 2010).

Investigation of water quality of a given natural reservoir such as Lake Naivasha requires integration of data from diverse sources with capability of providing information on spectral reflective property of the surface; since lakes inlets are surface runoff. "*In situ"* analysis of water samples at various stations is useful but inadequate in providing complete picture of intrinsic drivers in observable water quality differences such as eutrophication, presence of coliforms, algae, turbidity, sedimentation and chlorophyll concentration (Zhao et al, 2009). Landscape ecology and geographic distribution of land use activities have great impacts on water catchment, surface degradation and rainfall patterns within the drainage basin. Undisturbed ecological zones are likely to exhibit signs of fair to excellent in terms of water quality. Regions with intense agricultural activities such around flowers definitely use plenty of water through irrigations since they are greenhouse farms. Further, investigation is necessary to determine the extent to which the surface runoffs from the surrounding farms are managed by farmers or their representatives.

Water infiltration is affected due to heavy rainfall and loose surface coupled with poor percolation, then water quality constituents are transported into surface water bodies by the surface run off. Transportation of pollutants depends on the quality of watershed which is also affected by Land Use Land Change (LULC) activities within the watershed. Resulting water quality parameters such turbidity and chlorophyll concentration are captured by MERIS sensor.
Water quantities such as peak flows and surface run off volumes are affects by climate variability (Wrona et al, 2006). However, since LULC does not have linear relationship, it makes

it difficult to quantify the mechanistic understanding of catchments hydrological response (Allan, 2004). Consequently distinguishing the clear transition of effects of LULC from present climate variability is still a major challenge (Tollan, 2002).

2.6. Geospatial Technology in Monitoring Water Quality.

Remote sensing techniques play increasingly important role in assessing and monitoring of global climate change and water quality of water bodies. Deteriorating aquatic water quality is often driven by among others; the ever-increasing needs of growing populations for agricultural, industrial, recreational and drinking water. The pollution is often by overland runoff from point and non-point sources.

The spectrum characteristics of water and pollutants are essential to water quality monitoring and assessment. The spectral characteristics of the signal received from water are a function of hydrological, biological and chemical characteristics of water, and other interference factor (Dekker and Seyhan, 1998). Suspended sediments increase the radiance emergent from surface waters in the visible and near infrared proportion of the electromagnetic spectrum (Ritchie, et al, 2003). It is promising and feasible to detect water pollutants using spectral signatures in the visible and near infrared band. The Geospatial methods have a specific capacity to obtain information almost simultaneously over large geographic areas; observations from satellites are useful for studying global processes also in coastal waters and large lakes.

2.7. MERIS (Medium Resolution Imaging Spectrometer).

MERIS is one of the main instruments on board the European Space Agency (ESA)'s EnviSat platform. MERIS is a medium spatial resolution imaging spectrometer, operating in push-broom mode on a swath width of 1150 km. It provides simultaneously 15 spectral bands selectable in the visible and near-infra-red domain (390 to 1040 nm wavelength at 1.25 nm sampling interval). Each MERIS pixel has a field of view of 0.019°. Due to the wide instrument field of view (68°), spatial sampling varies in the across track direction, between 0.26 km at nadir and 0.39 km at swath extremities. Along-track sampling is close to 0.29 km.

MERIS has the capability to output data sampled at the Full Resolution (FR) – pixel size 300m by 300m with the spatial sampling described above, and Reduced Resolution (RR) data subsampled at 1.2 km by 1.2 Km. It has different levels of data namely: Level 0 (L0) which is raw data; Level 1 (L1b) which is calibrated radiance at the with satellite coordinates; Level 2 (L2) which is geophysical values depending on surface types after atmospheric correction and geophysical processing with satellite coordinates; Level 3 (L3) data which is spatial / temporal integration of L2 with map projection (Brockmann Consult, 2001). MERIS spectral bands and their application are summarized in table 2.1.

Table 2.1: MERIS Spectral Bands and applications.

No.	Band centre (nm)	Band width (nm)	Application
1	412.5	10	Yellow substance and detrital pigments
2	442.5	10	Chlorophyll absorption maximum
3	490	10	Chlorophyll and other pigments
4	510	10	Suspended sediment, red tides
5	560	10	Chlorophyll absorption minimum
6	620	10	Suspended sediment
7	665	10	Chlorophyll absorption & fluorescence reference
8	681.25	7.5	Chlorophyll fluorescence peak
9	705.0	10	Fluorescence reference, atmosphere corrections
10	753.75	7.5	Vegetation, cloud
11	760.625	3.75	O_2 R- branch absorption band
12	775	15	Atmosphere corrections
13	865	20	Vegetation, water vapour reference
14	885	10	Atmosphere corrections
15	900	10	Water vapour, land

Source: (Brockmann Consult, 2001).

The primary objective of MERIS is to observe the color of the ocean, both in the open ocean (clear or Case I waters) and in coastal zones (turbid or Case II waters). These observations are used to derive estimates of the concentration of Chlorophyll and sediments in suspension in the water, for instance. See Table 2.2 below.

Table 2.2: Technical Specifications of MERIS.

Accuracy:	Ocean colour bands typical S:N = 1700
Spatial Resolution:	Ocean: 1200m x 1200 m, Land & Coast: 300m x 300m
Swath Width:	1150km, global coverage every 3 days
Waveband:	VIS-NIR: 15 bands selectable across range: 390 nm to1040 nm (bandwidth programmable between 2.5 and 30 nm)

Source: (ESA, 2016).

Various processing algorithms for MERIS data have been developed for monitoring optically complex waters. In lakes and coastal zones, optical properties of water are influenced by bloom of various phytoplankton species, total suspended matter originating from the shallow bottom or shores, and high amount of coloured dissolved organic matter carried into water by rivers. Basic ERS and EnviSat (A) ATSR and MERIS (BEAM) is an open-source toolbox and development platform for viewing, analyzing and processing of remote sensing raster data. It was originally developed to facilitate the utilization of image data from EnviSat's optical instruments but now supports a growing number of other raster data formats such as GeoTIFF as well as data formats of other earth observation (EO) sensors such as (MODIS), (AVHRR) and (AVNIR). Within the BEAM software algorithms developed for processing MERIS images included for waters far from land and for open oceans (Case 1 Waters) and for coastal and lake waters (Case 2 Waters). In (Case 1 Waters) the only variation of water quality is caused by the phytoplankton, thus resulting in relatively simple algorithms for EO data processing. In the optically complex (Case 2 Waters) there are suspended solids, dissolved matters, and other factors complicating the detection.

A physically based algorithm is used for automatic processing of MERIS level 1B full resolution data. The algorithm is originally used with input variables for optimization with different sensors (channel recalibration and weighting), aquatic regions (specific inherent optical properties) or atmospheric conditions (i.e. aerosol models). For operational use, however, a lake-specific parameterization is required, representing an approximation of the spatio-temporal variation in atmospheric and hydro optic conditions, and accounting for sensor properties. The algorithm performs atmospheric correction with a Look Up Table (LUT) for at-sensor radiance, and a downhill simplex inversion of chl-a, TSM and yellow substances (y) from subsurface irradiance reflectance. These outputs are enhanced by a selective filter, which makes use of the retrieval residuals (Odermatt et al., 2008).

2.8. Case Studies.

Lake Naivasha has been exposed to pollution which has adverse effects on water quality. In response to pollution threats, a study was carried out to determine the source of pollution and quantify the nutrient loads using Soil and Water Assessment Tool (SWAT) with focus on Nitrogen and Phosphorus modeling with inputs from sediment data. The results of the study showed that nitrogen and phosphorus percolation was high regions where grazing and fertilizer application was rampant due to surface run-off with significant increases observed in kilograms for each year of application (Tiruneh, 2004). Current studies on hydrological modeling of LULC impacts are based on predefined inputs of rainfall and stream discharge at small scale mainly weather stations and stream gauges. These measurements only provide information on the location with limited spatial extent, however, quantifying impacts of LULC on water spectral response requires comparative study rather interpolation of one variable observations only. Prior studies have also investigated effects of afforestation and reforestation on watershed and catchment management with focused on paired catchment approach (DeFries and Eshleman, 2004).

Calibrating Earth Observation (EO) analysis with "*in situ*" measurements contributes greatly in generation of more informative and accurate products. It also possible to monitor changes in water quality using EO data processing tools since EO data are always collected with synchronization of periods of times such monthly, weekly, etc. through EO analysis, it also possible to quantify changes in water quality over the area on which a given variable is being investigated which offers reliable basis for decision making (Anderson et al., 2012). Findings derived from other studies suggest hydrological response is due LULC is mainly influenced by geological system, climatic condition, soil variability and at times vegetation growth status (King et al., 2005).

Climatic variability remains a major challenge in hydrological modeling with major influence from LULC (Qi et al., 2009). Most of these studies have linked the LULC on water quality, however little have been investigated between spectral response of water quality and LULC change with attention to water quality parameters only. Importance of surface water spectral formed the basis of launching MERIS satellite which only collects water quality parameters from surface water bodies only. This study presents innovative approaches in extracting water quality from EO data and using water quality information to generate yearly trends of water quality to show the pattern over the ten (10) years period. MERIS sensor also provides additional information on the spread of the water quality parameters which are practically costly using conventional methods of extent estimation.

CHAPTER 3: MATERIALS AND METHODOLOGY.

3.1. Materials and Equipment.

In the execution of the research project, different materials were used and the methodology adapted as discussed below.

3.1.1. Software Used.

BEAM VISAT software was used for processing MERIS data to derive water quality information and water quality maps. This is open source software specifically developed to facilitate the utilization, viewing and processing of ESA MERIS, (A) ATSR and ASAR data. It is specifically dedicated to the handling of EnviSat MERIS and AATSR products.

3.1.2. Hardware Used.

The following hardware was used in the project study process;

1. Desktop computer with processor I5, hard disk 250 GB, and 4 RAM
2. Printing papers and other miscellaneous stationary.

3.1.3. Sources and Acquisition of Data Used.

The data used for the purpose if this project study was MERIS Level 1 (L1) data which was obtained from GEOSS website. Level 1 (L1) data is calibrated radiances at the Top Of Atmosphere (TOA) with satellite coordinates. The data is freely downloadable upon registration on the web portal. MERIS is an instrument aboard the Environmental Satellite (EnviSat), its objective is, among others, remote sensing of water quality. See Appendix A.

3.2. Methodology.

In this study, MERIS images were used at full resolution with capability to collect spectral properties of water and resulting water quality based on appearance of water within the broad spectral wavelengths. Level 1 (LI) images were downloaded from GEOSS website for each year 2002 to 2012. The full resolution images of MERIS push broom spectrometer were subjected to BEAM image processing software where Digital Number (DN) values of the images were converted into reflectance. The resulting product was subjected to neural network algorithm to generate water quality information.

Earth Observation data of MERIS was used for the period chosen because; MERIS stopped broadcasting images in the year 2012. MERIS was has since been replaced by Sentinel data which are yet to be processed since Sentinel started broadcasting its data reliably in 2015. Water quality information was extracted through optical domain method for mapping water quality parameters such as Secchi depth, Kd PAR, tripton and CDOM (Colored Dissolved Organic Matter). Through this approach, substrate cover types analyzed include algae, lake grass, sand, silt, or pollutes (Phinn et al., 2005). Concentration of dissolved organic matter was realized through band ration (ratio of band 2 and 3). The extraction of water quality parameters from MERIS image using the BEAM Visat software involves the use of inbuilt software tools and predefined algorithms the analytical Gordon model is useful for analysis of deep and shallow waters. It exploits the subsurface irradiance and reflectance. The input to the model are inherent optical properties showing water absorption $a(\lambda)$ and backscattering $b_b(\lambda)$ at a given wavelength. This is further integrated with Zenith θ_s and viewing angle θ_v alongside surface wind speed. For shallow water such as Lake Naivasha, bottom albedo and depth are also necessary inputs into the parameterization to provide complete of equation for remote sensing signals R_{rs}. The complete analytical Gordon model equation is defined below:

$$R_{rs}(\lambda) = \frac{t^2}{n_w^2} \sum_{i=1}^{2} g_i \left(\frac{b_b(\lambda)}{b_b(\lambda) + a(\lambda)} \right)^i \qquad \textbf{(3.1)}$$

Source: (Salama M.S, 2013).

Where;

Rrs (λ): *This is the remote sensing reflectance leaving the water surface*

$\boldsymbol{g_1}$*=0.0949,* $\boldsymbol{g_2}$ *=0.0745, are subsurface expansion coefficients due to internal refraction, reflection and sun zenith;*

$\boldsymbol{t}$ *= 0.95 and* $\boldsymbol{n_w}$ *=1.34 are the sea air transmission and water index of refraction, respectively.*

$\boldsymbol{b_b(\lambda)}$ *and* $\boldsymbol{a(\lambda)}$ *are the bulk scattering and absorption coefficients of the water column (subset of the water inherent optical properties IOP). These IOP characterize the optical behavior of the medium and are directly related to the concentrations of water constituents.*

The light field in the water column is assumed to be governed by five optically significant constituents, namely: water molecules, Chlorophyll-a (phytoplankton green pigment, Chl-a), colored dissolved organic matter (CDOM), detritus and suspended particulate matter (SPM).

The bulk absorption ***a(λ)*** and backscattering b_b***(λ)*** coefficients are modeled as being the sum of the constituent's absorptions and backscattering. Case II water is considered with three independently varying constituents, namely: Chlorophyll-***a*** (Chl-***a***), detritus and dissolved organic matter (dg) and suspended organic matter (SPM). The complete equations for absorption and backscattering used in the algorithm is summarized as follows:

$$a(\lambda) = a_w(\lambda) + a_{ph}(\lambda) + a_{dg}(\lambda) \quad \textbf{(3.2)}$$

$$b_b(\lambda) = 0.5 b_w(\lambda) + \alpha b_{spm}(\lambda) \quad \textbf{(3.3)}$$

Source: (Salama, et al., 2009).

The absorpotion and scattering coefficients of water molecules, a_w and b_w were assumed constants. Their values obtained from (Pop and Fry, 1997; Mobley, 1994), respectively.

According to Lee et al., (1999) the total absorpotion of phytoplankton pigments a_{ph} is approximated as:

$$a_{ph}(\lambda) = a_0(\lambda) a_{ph}(0.44) + a_1(\lambda) a_{ph}(0.44) \mathrm{In} a_{ph}(0.44) \quad \textbf{(3.4)}$$

Where $a_0(\lambda)$ and $a_1(\lambda)$ are empirical coefficients. The absorption effects of detritus and dissolved organic matter are combined due to the similar spectral signature (Maritorena et al., 2002) and approximated using the model (Bricaud et al., 1981):

$$a_{dg}(\lambda) = a_{dg}(440) \exp[- s (\lambda - 440)] \quad \textbf{(3.5)}$$

Where *s* is the unknown spectral exponent. According to Kopelevich, (1983) the scattering coefficient of SPM b_{spm} is parameterized at 550nm as:

$$b_{spm}(\lambda) = b_{spm}(550) \left(\frac{550}{\lambda}\right)^y \quad \textbf{(3.6)}$$

Where *y* is the unknown spectral shape parameter. According to Petzold (1977) the backscattering fraction α is estimated from the "San Diego harbor" scattering phase function

The invesrion of the GSM model is adapted to derived five parameters in visible bands covering the wavelenghts from 400nm to 850nm. These parameters are called the set of IOPs and denoted as a vector ***iop:***

$$iop = \begin{bmatrix} a_{ph}(440) \\ a_{dg}(440) \\ b_{spm}(550) \\ s \\ y \end{bmatrix} \quad (3.7)$$

The image is loaded into the software as shown in Figure 3.1.

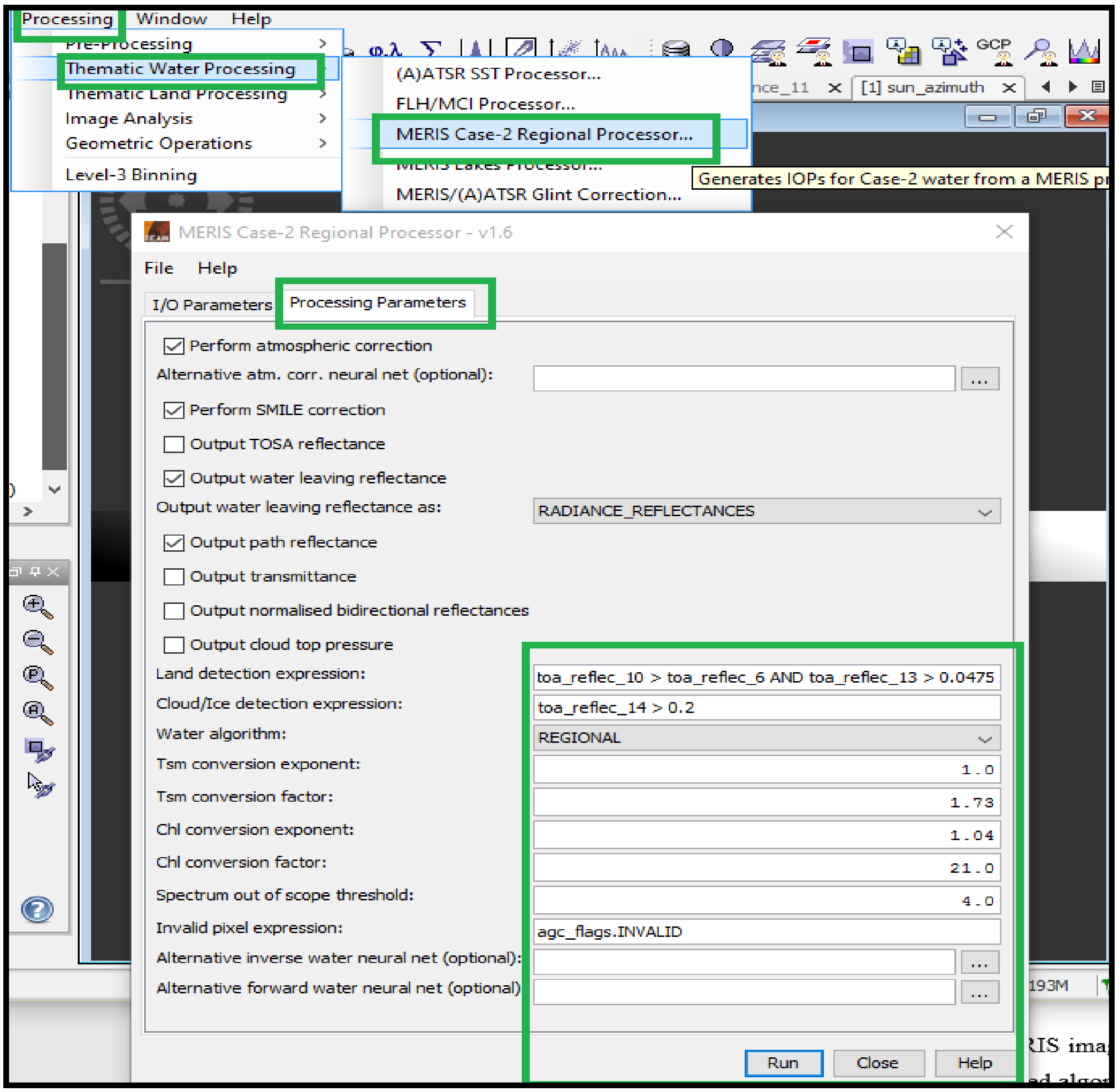

Figure 3.1: Image processing in BEAM VISAT software.

The study adopted regional processor case 2 water algorithm since it has better calibration for collecting water quality information; and the algorithm is further calibrated for total suspended matter and Chlorophyll a concentration. The methodology in a nutshell is summarized as shown in Figure 3.2.

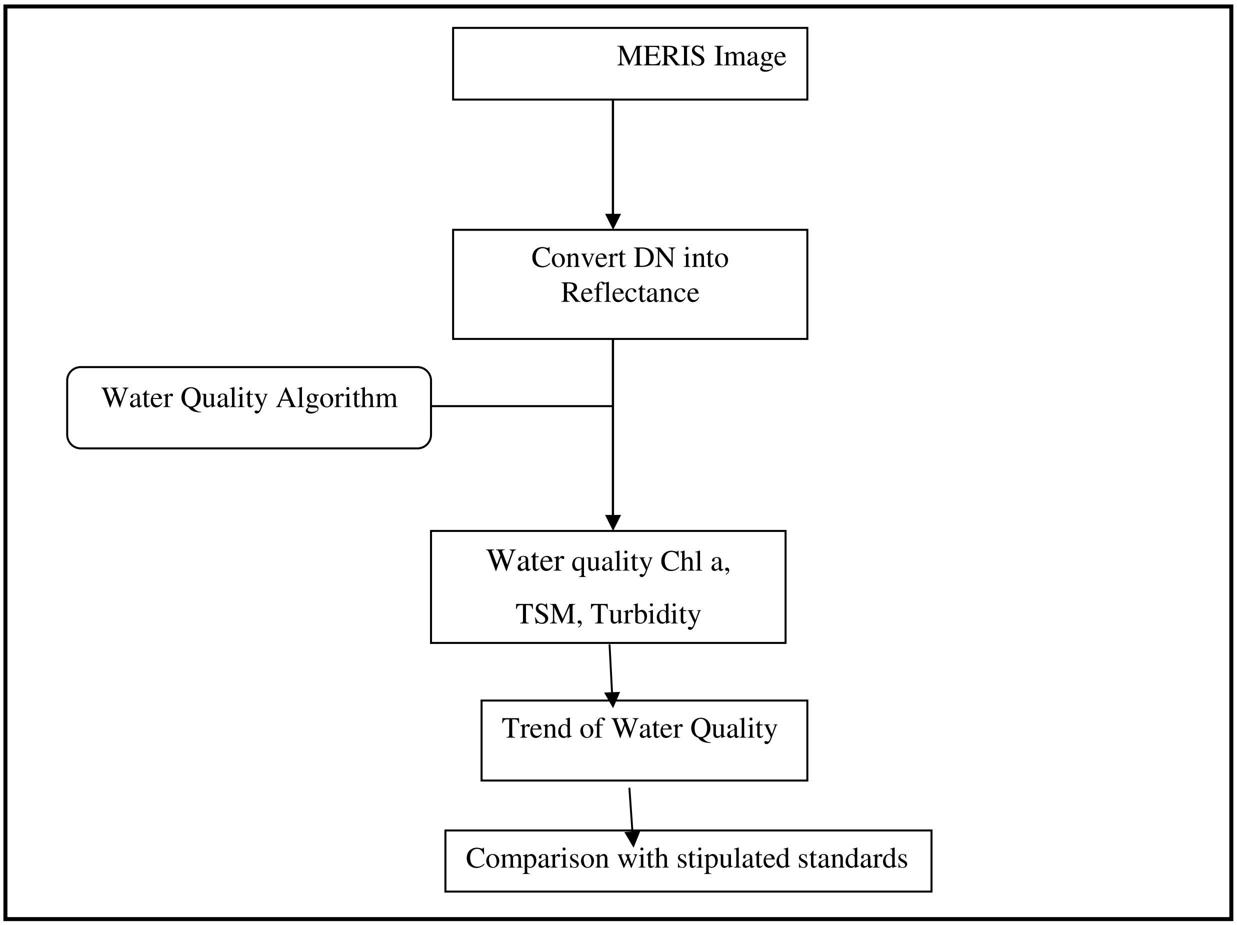

Figure 3.2: Summary of the methodology adopted.

Accessing MERIS images is made possible with support from ESA through data portal of MERCI where potential users access the data using user name and password. The login interface redirects to query products page data parameters such region, time range and type of information are entered. The query is submitted and the product to be downloaded is submitted, in this study, Kenya region was selected and the resulting image path contained a number of lakes from which Lake Naivasha was clipped through image subset from view since Lake Naivasha could be seen clearly from Red Green Blue (RGB) display of bands 8, 9 and 10. See Appendix B. The subset was subjected to MERIS case 2 water algorithm; the resulting product was assigned color palettes of *meris_case.cpd*.

The resulting water quality information for each variable was derived by analyzing inherent optical properties from the image bands with focus on back scatter from total suspended materials, chlorophyll concentration and turbidity which are all derived from Top Of Atmosphere (TOA) radiances with a total of 15 bands. The derived water quality information was then tabulated for each year against each water quality variables. The information is then transferred into Excel and transposed to produce the desired trends. Comparison of water quality parameters against the stipulated standards was done by comparing the water quality information from EO against the table with detailed list against the variable that was extracted from MERIS data. Extraction of water quality variables from the image was carried out by examining the majority of pixels' distribution within the range provided by the slider in the image. Maximum values in the slider are avoided if the distribution is less and arrange within the majority of pixel distribution is taken and recorded against the yearly score of the year. Comparison of the water quality parameters extracted from MERIS satellite images against the stipulated standards was done.

CHAPTER 4: RESULTS AND DISCUSSIONS.

4.1. Water Quality Parameters from MERIS Satellite Images.

This section gives and discusses the results of the study. The result are presented in tables for extracted parameter values, images representation of the processed parameter values and graphs show the trend of the parameter value for the period of study 2002 to 2012.

4.2. Chlorophyll Concentration.

Eutrophication level in the lake increased over time from the year 2002 to 2012 as evidenced by the increase in Chlorophyll concentration throughout the years. Actually the water of Lake Naivasha is not clear when observed from the shore. The results of this study shows that the Chlorophyll level remained above 49.5 mg/m^3 with exception of the year 2007 when it dropped to 44.2 mg/m^3 which can be attributed to low rainfall during that year and less farming activities due to election violence hence there was less surface run off. At five-year interval, a close examination of the distribution of Chlorophyll concentration shows that the spread of the Chlorophyll concentration was enormous on the entire lake as shown in Figure 4.1, 4.2 and 4.3 It also emerged that from the year 2007 to 2012, the distribution of Chlorophyll changed where the spread was observed to be enormous within range of 44.2 mg/m^3 in 2007 to 49.73 in 2010 mg/m^3. The percentage change in Chlorophyll concentration for five (5) years interval between the years 2002 to 2007 and years 2007 to 2012 is – 10.7 % and 12.4 % respectively. (See Tables 4.1. and 4.4. and Figure 4.1., 4.2 and 4.3. for details of Chlorophyll concentration in percentage change and spread).

Table 4.1: Summary of Chlorophyll concentration at 5 years interval.

Year / Parameter	**2002**	**2007**	**2000 – 2007 % Change.**	**2012**	**2007 – 2012 % Change.**	**2002 – 2012 Overall % Change.**
Chlorophyll a concentration (mg^-m^3)	49.5	44.2	-10.7	49.7	12.4	0.4

* 1 ug / l = 1mg / m^3

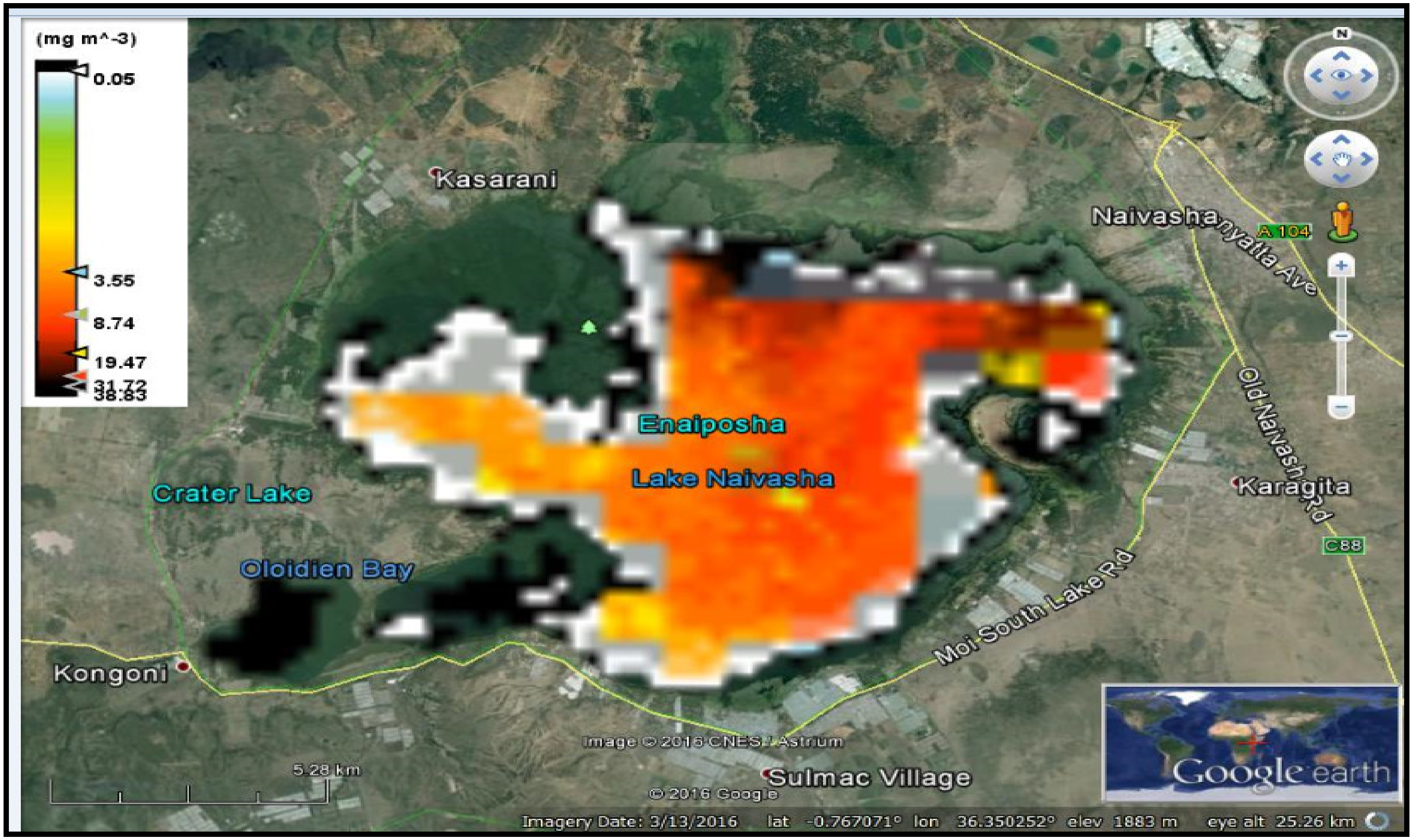

Figure 4.1: Chlorophyll concentration over Lake Naivasha, 2002.

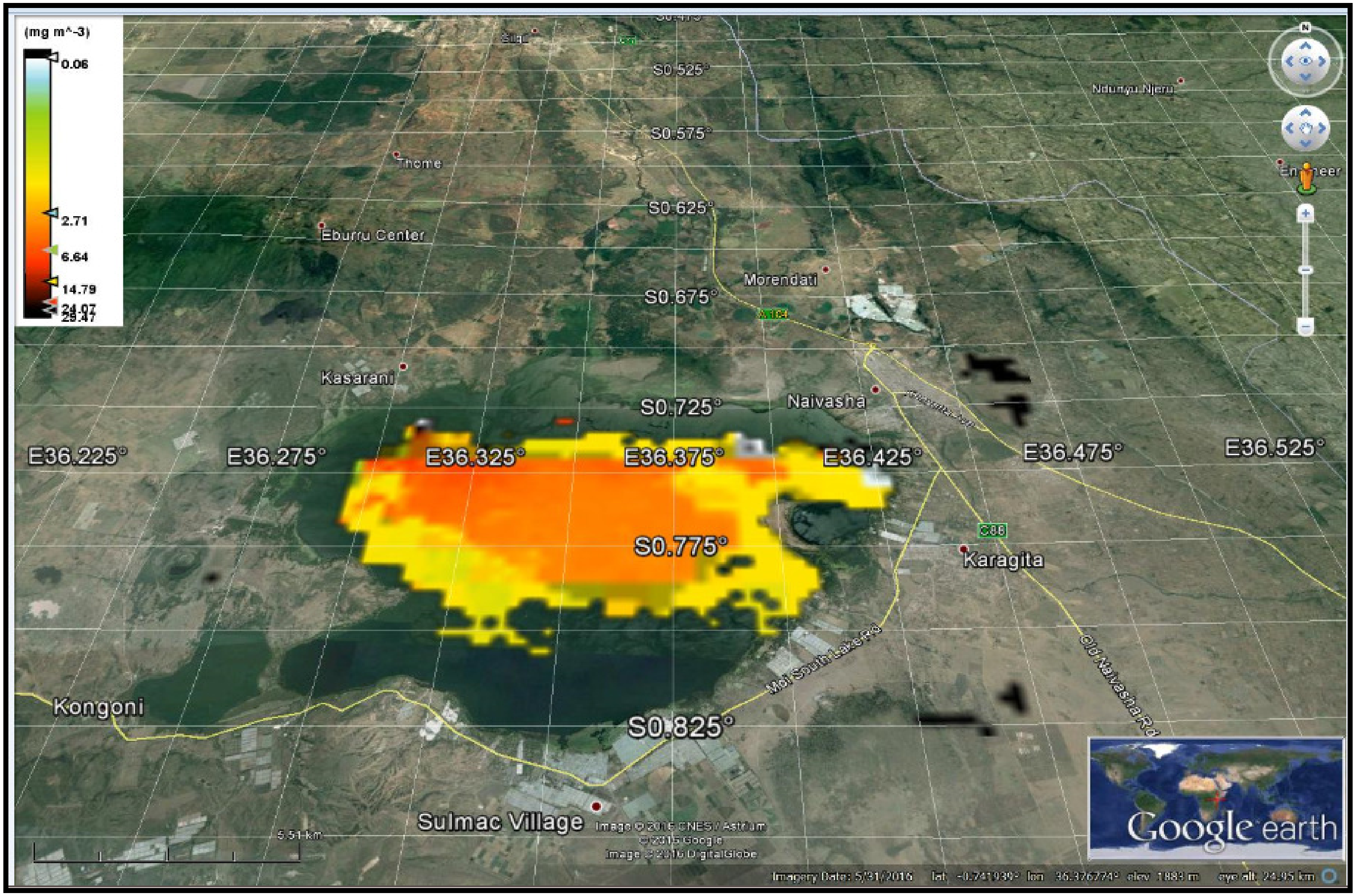

Figure 4.2: Chlorophyll concentration over Lake Naivasha, 2007.

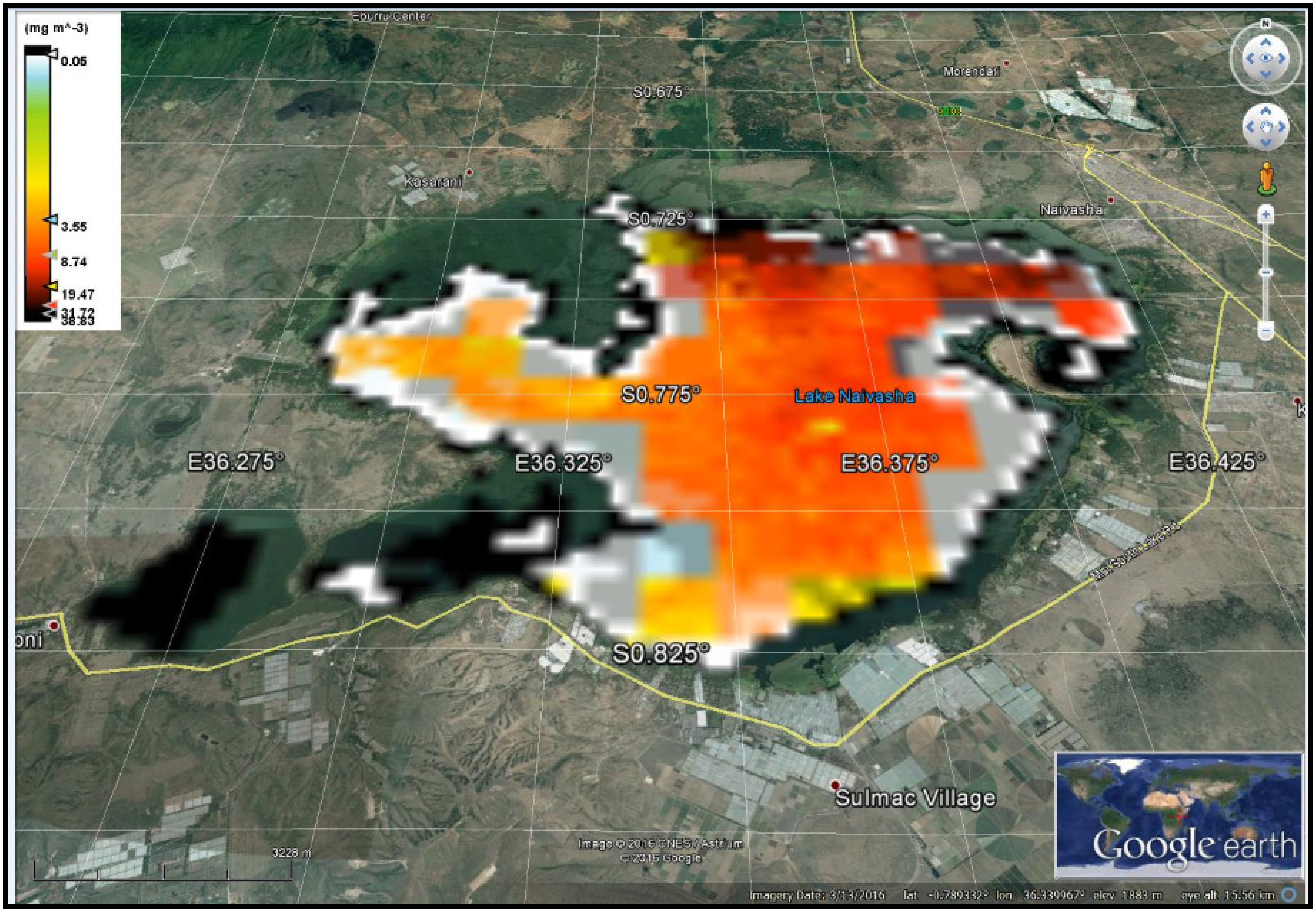

Figure 4.3: Chlorophyll concentration over Lake Naivasha, 2012.

4.3. Total Suspended Matter (TSM).

The TSM over the lake increased from 15 g^-m^3 in the year 2002 to maximum of 19.3 g^-m^3 in the year 2010. Initially the lake was three quarters covered with TSM matter in the year 2002, which increased to full lake by 2007 and later decreased greatly in the year 2012 by more than half with approximate value of 9 g^-m^3 . The TSM values were found to be within NEMA stipulated standards for domestic water for suspended solids this is an indication of good water quality for domestic use and irrigation systems. The TSM and percentage change values for five (5) years interval for years 2002 to 2007 and years 2007 to 2012 was 26.7 % and – 40% respectively. The spread of TSM over the lake is extensive as shown in tables 4.2, and 4.4 and figures 4.4. , 4.5, and 4.6.

Table 4.2: Summary of TSM values at 5 years interval.

Year / Parameter	**2002**	**2007**	**20002 – 2007 % Change.**	**2012**	**2007 – 2012 % Change.**	**2002 – 2012 Overall % Change.**
TSM (g^m^3)	15	19	26.7	9	-52.6	- 40
NEMA Standard TSM (mg / L)	30				* 1 milligram / liter = 1 gram / cubic meter	

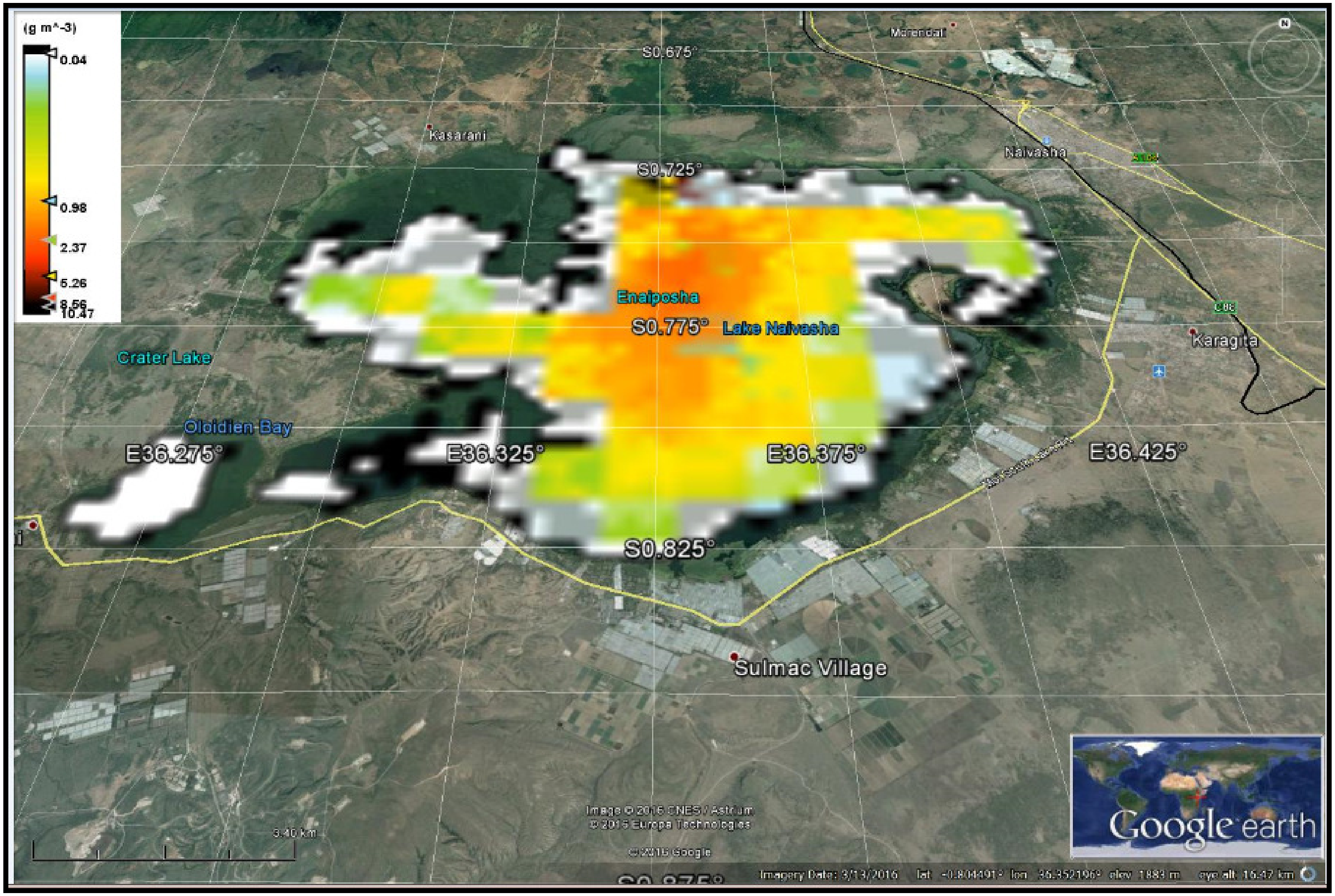

Figure 4.4: TSM over Lake Naivasha, 2002.

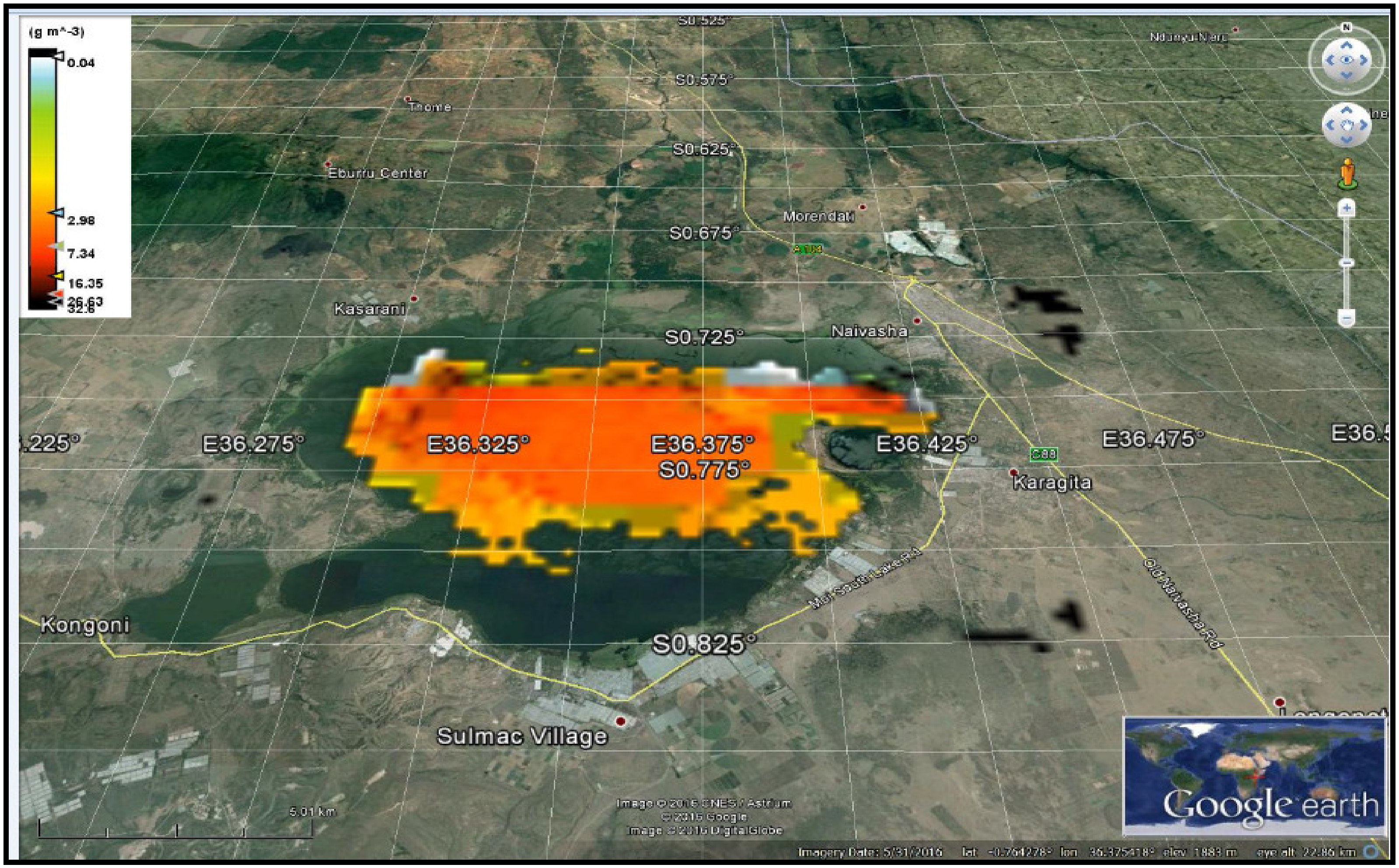

Figure 4.5: TSM over Lake Naivasha, 2007.

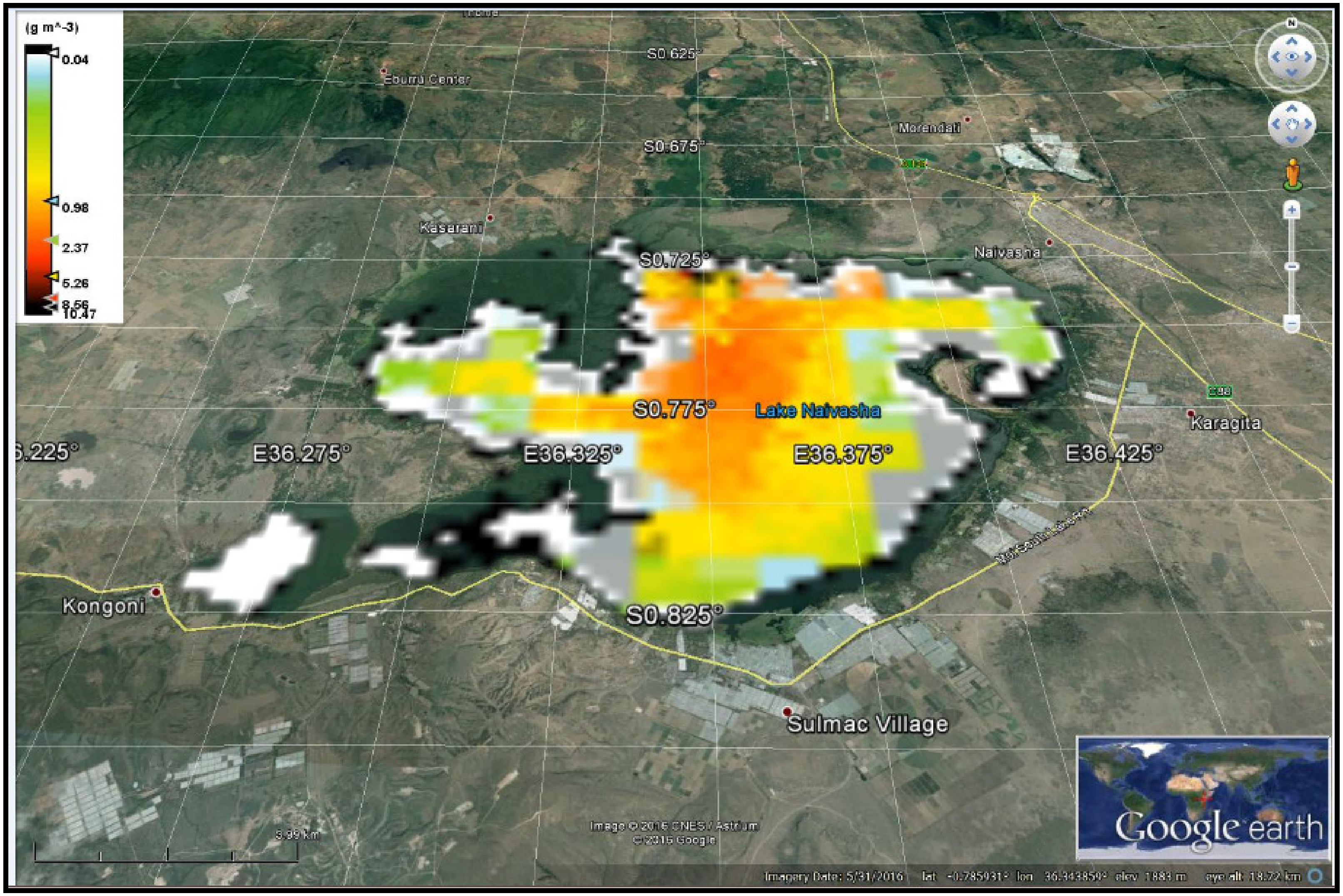

Figure 4.6: TSM over Lake Naivasha, 2012.

4.4. Turbidity.

Turbidity over the lake increased steadily from 2002 to 2011 with a minimum of 7.2 NTU in the year 2002 to maximum value of 24.9 NTU being recorded in the year 2006. However, by the year 2012, Turbidity dropped to value of 9 NTU. The Turbidity values from the analysis of the Lake during the study period was found to be above the stipulated European commission standard of 1 NTU. These high Turbidity values is evidence of high levels of silts which have been transported into the lake by surface run-off. It also an indication that water is less suitable for domestic use since the solutes change the color of the water making it less suitable for domestic use. Moreover, siltation is also an indicator of possible flooding from the lake since silts raise the floor of the lake. See tables 4.3 and 4.4 and figures 4.7. , 4.8 and 4.9.

Table 4.3: Summary of turbidity values at 5 years interval.

Year / Parameter	**2002**	**2007**	**2000 – 2007 % Change**	**2012**	**2007 – 2012 % Change**	**2002 – 2012 Overall % Change**
Turbidity (FNU / NTU)	7.2	23	219	9	- 60.8	25
EC Directive Turbidity Standard(NTU)	1					

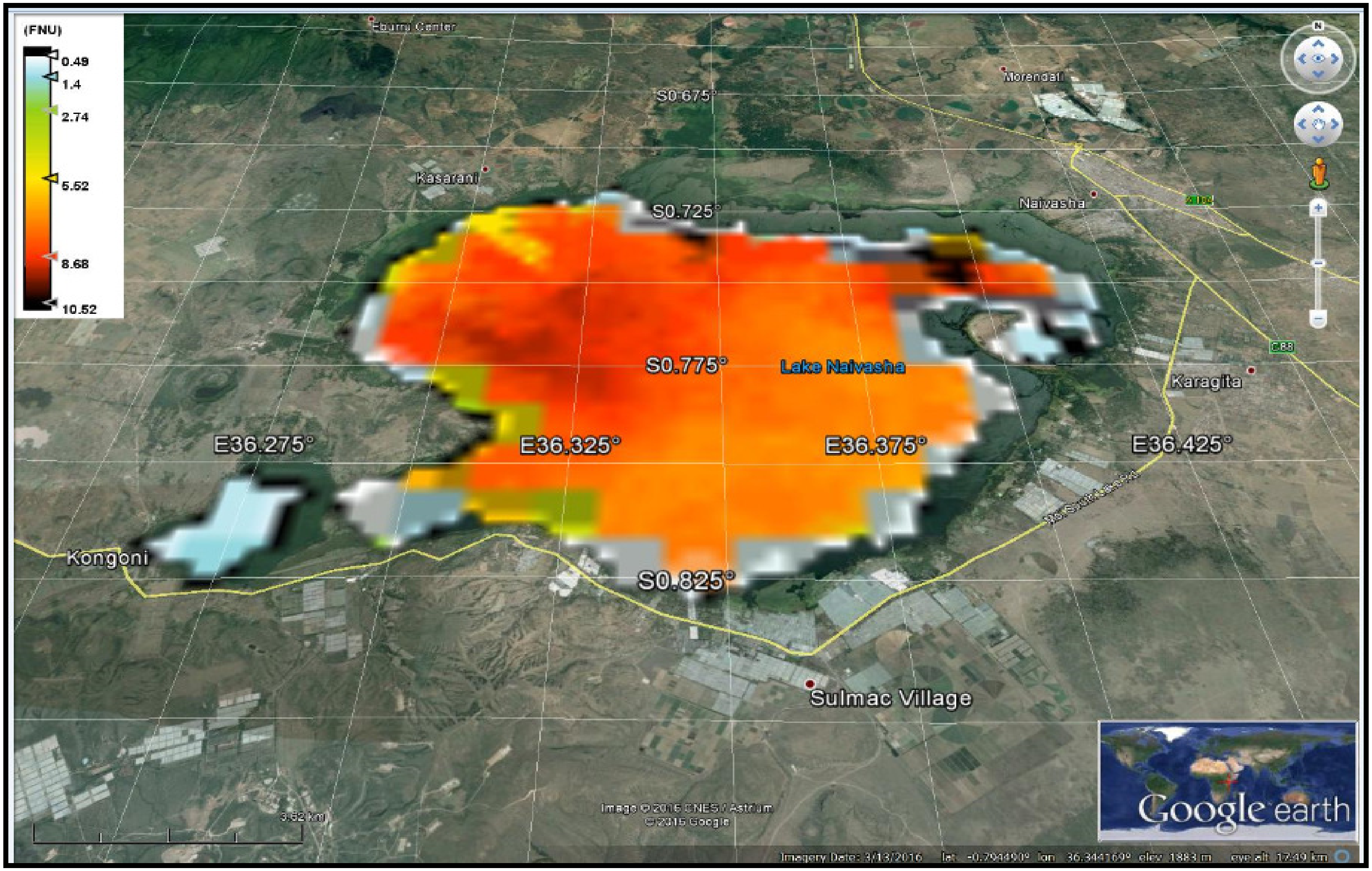

Figure 4.7: Turbidity levels over Lake Naivasha, 2002.

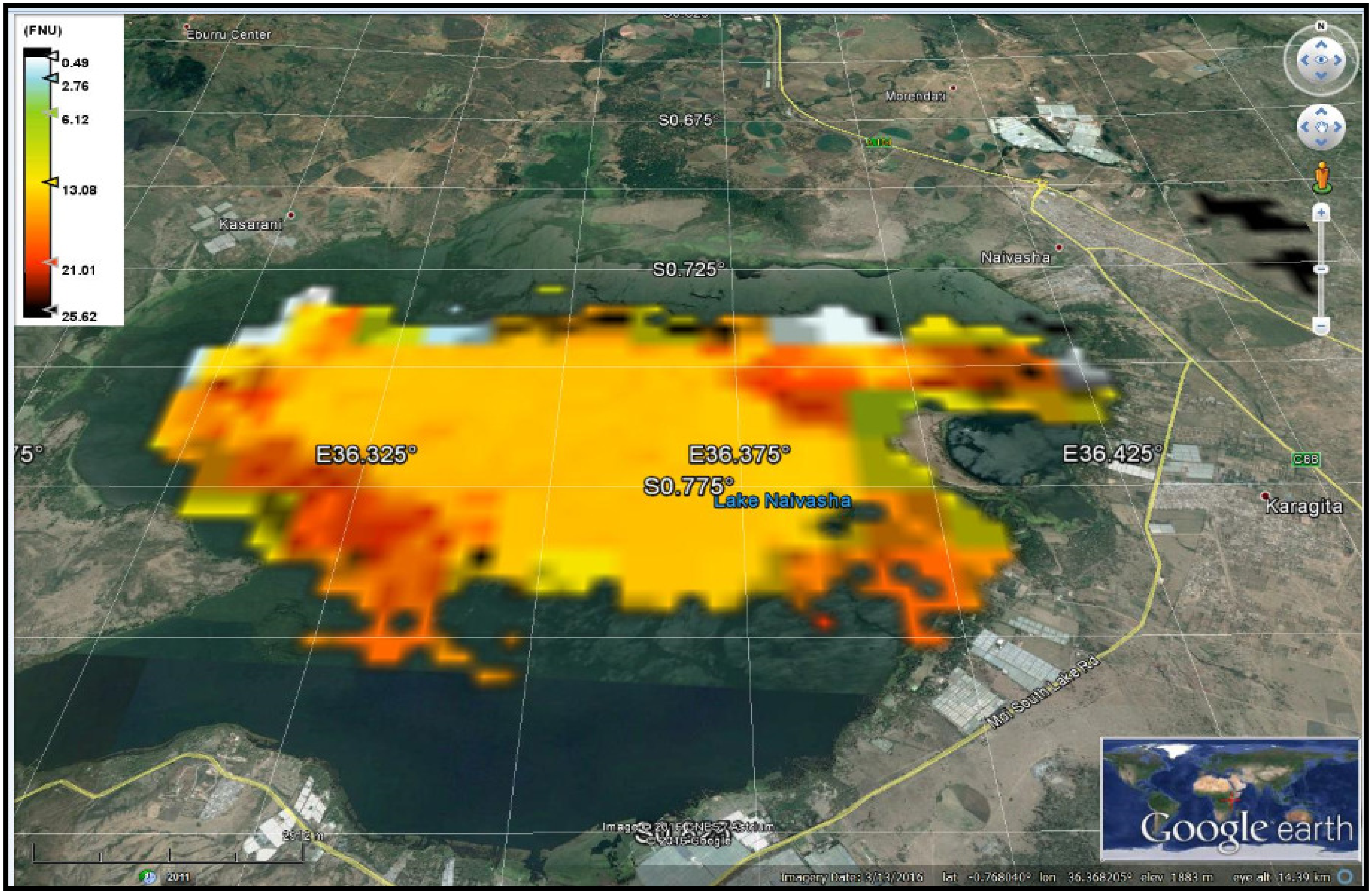

Figure 4.8: Turbidity levels over Lake Naivasha, 2007.

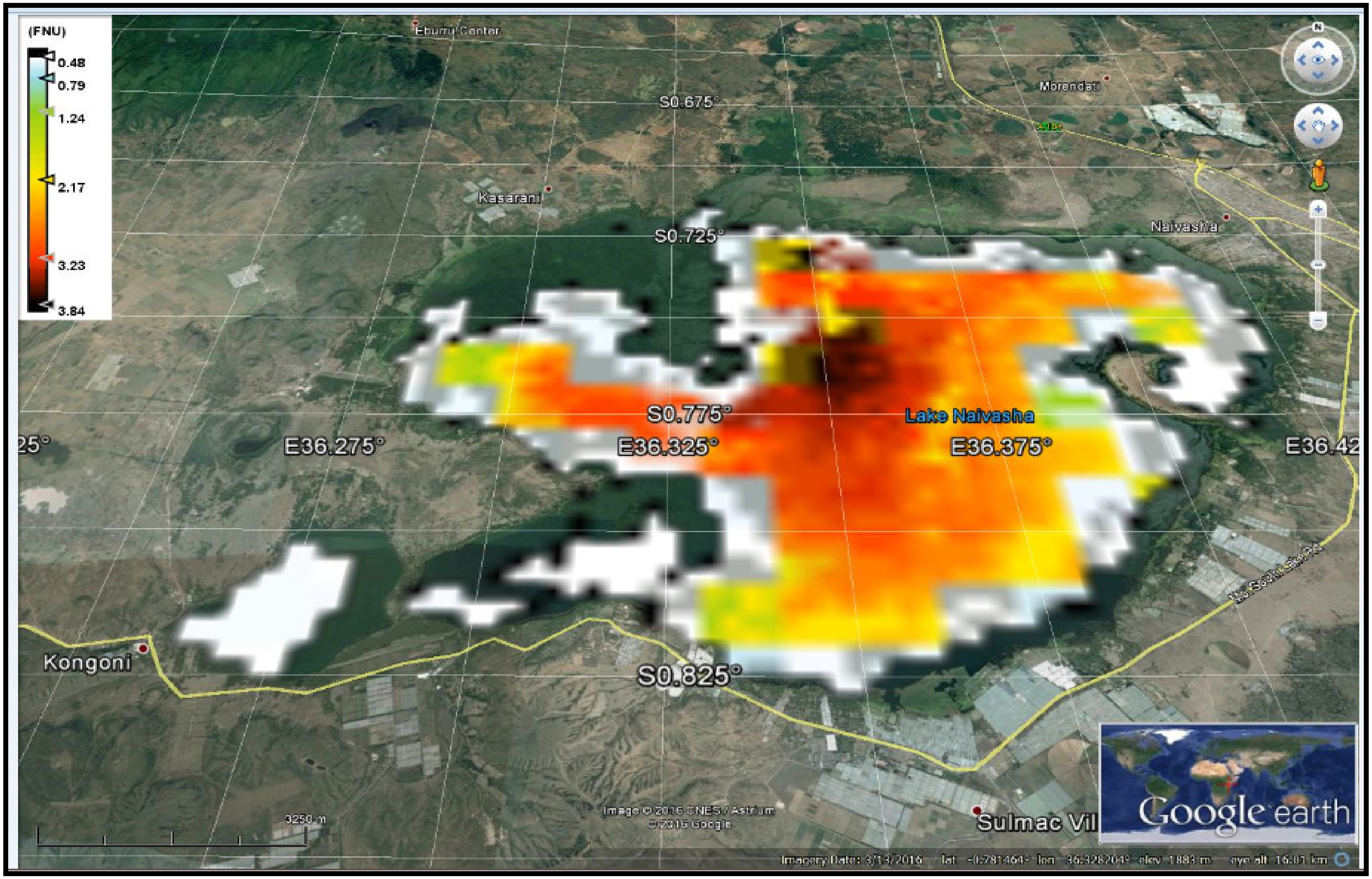

Figure 4.9: Turbidity levels over Lake Naivasha, 2012.

4.5. Comparative Analysis between Earth Observation Water Quality Parameters and Stipulated Standards of Domestic and Irrigation.

Chlorophyll a concentration range of 44.2 mg / m^3 in 2007 to 49.73 mg / m^3 in 2010 as obtained from the analysis for the period of the study were found to be within the stipulated trophic range of 20 mg / m^3 to 56 mg / m^3 (see table 4.4) which put Lake Naivasha within the trophic state categorization of eutrophic. Eutrophic categorized lakes are considered to eutrophicated. This state of eutrophication is an indication of the process of physical, chemical, and biological changes associated with nutrient enrichment of Lake Naivasha. The enrichment of the lake with the nutrient is the cause of the high Chlorophyll concentration values as seen from the extracted values from Lake Naivasha.

Turbidity over the lake shows that the levels of dissolved solutes and other solvents was far more than the required threshold for domestic use. From the extracted results, the levels range from 7 - 24 NTU European Communities COUNCIL DIRECTIVE 98/83/EC on the quality of water intended for human consumption stated threshold of 1.0 NTU. See appendix C for stipulated water quality for various use by NEMA and European Union Commission. The Lake water therefore can be said to be unsuitable for human consumption based on European Communities COUNCIL DIRECTIVE standards since turbidity are above the stated standard threshold. This calls for close monitoring of the sources of turbidity especially on catchment of the lake.

TSM values over the lake extracted from the satellite images ranges from 9 to 19.3 which were found to be within the NEMA recommended threshold of 30 (mg/L) See appendixes D and E.

Table 4.4: Summary of parameter comparative analysis with stipulated standards.

Years / Water quality variable	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Chlorophyll a (mg^-m^3)	49.5	49.7	49.71	49.7	49.72	44.2	49.7	49.7	49.73	49.3	49.7
Turbidity (FNU / NTU)	7.2	26.7	19.1	21.4	24.9	23	22.8	19.8	23.2	24	9
EC Directive Stipulated Turbidity Standard(NTU)	1 NTU										
TSM (g^-m^3)	15	18.3	16.2	18.3	19.2	19	17	19.2	19.3	18.8	9
NEMA stipulated TSM Standard.	30 (mg / L) * 1 milligram / liter = 1 gram / cubic meter										

4.6. Lake Naivasha Trophic State and the Trend of Water Quality Parameters.

The lake has high levels of Chlorophyll concentration, and turbidity parameter values above the stated thresholds throughout the study period 2002 to 2012. The Turbidity values from the analysis were found to be between a low of 9 NTU to 24.9 NTU against the stipulated European commission standard of 1NTU. (Table 4.5 and Figures 4.11). In reference to trophic state condition expressed as a range of Chlorophyll a concentration as characterized in the scientific literature by Carlson R.E. and J. Simpson (1996). See appendix F. Chlorophyll a concentration range a low of 44.2 mg/m^3 in 2007 to a high of 49.73 mg/m^3 in 2010 as obtained from the analysis for the period of the study is within the stipulated trophic range of 20 mg / m^3 to 56 mg / m^3. This put the lake within the trophic state categorization of eutrophic.

High presence of Chlorophyll concentration values is associated with high production of oxygen to water bodies as a byproduct of photosynthesis process of the aquatic organisms. The decay of such plants and bacteria can lead to death of organisms that rely on oxygen from water bodies such as fish. The trend of water quality parameter further indicates that only year 2007 registered a drop in chlorophyll levels but it remained steady throughout the 10 years' period that was investigated in this study. Since high presence of nutrients is associated with more production of more biomass which leads low transparency of water and presence of less oxygen.

The TSM values obtained from the analysis were found to be of between a low of 9 g/m^3 to a high of 19.2 g/m^3 (see table 4.5) against a standard of 30 g/m^3. This is within the NEMA stipulated levels throughout the study. Based on the trend of water quality this means that the aquatic photosynthesis organism have access to more of light to carryout photosynthesis and increase supply of oxygen eventually leading to a bloom..

Table 4.5: Trend of water quality over 10 years period, 2002 - 2012.

Years / Water quality variable	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Chlorophyll a (mg^-m^3)	49.5	49.7	49.71	49.7	49.72	44.2	49.7	49.7	49.73	49.3	49.7
Trophic State Based on Chlorophyll Carlson eta al standards (ug / l)	Oligotrophic - 0—2.6 Mesotrophic - 2.6—20 Eutrophic - 20—56 Hypereutrophic - 56—155+ * 1 ug /l = 1mg / m^3										
Turbidity (FNU / NTU)	7.2	26.7	19.1	21.4	24.9	23	22.8	19.8	23.2	24	9
TSM (g^-m^3)	15	18.3	16.2	18.3	19.2	19	17	19.2	19.3	18.8	9

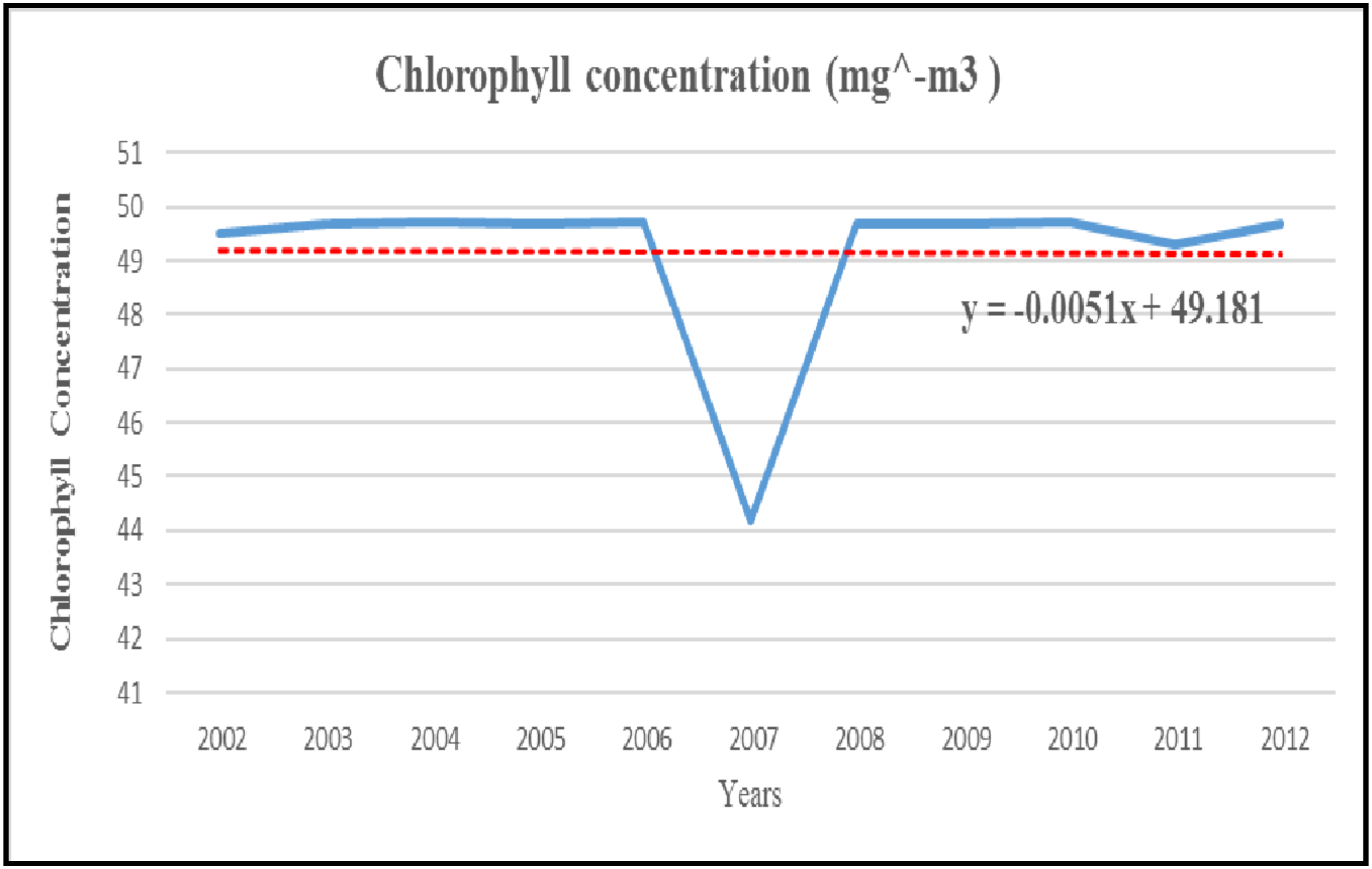

Figure 4.10: Trend of chlorophyll concentration over Lake Naivasha, 2002 to 2012.

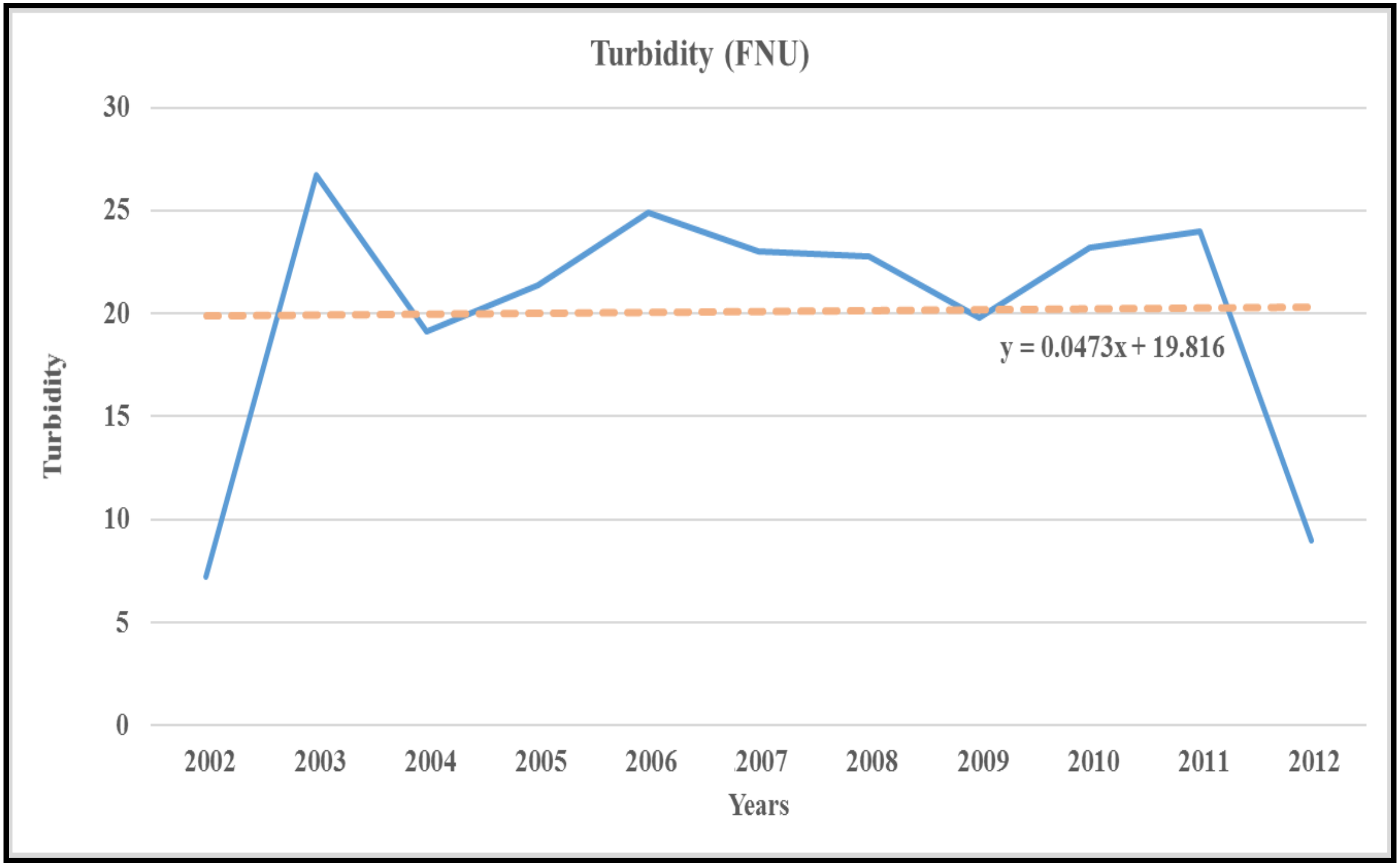

Figure 4.11: Trend of Turbidity over Lake Naivasha, 2002 to 2012.

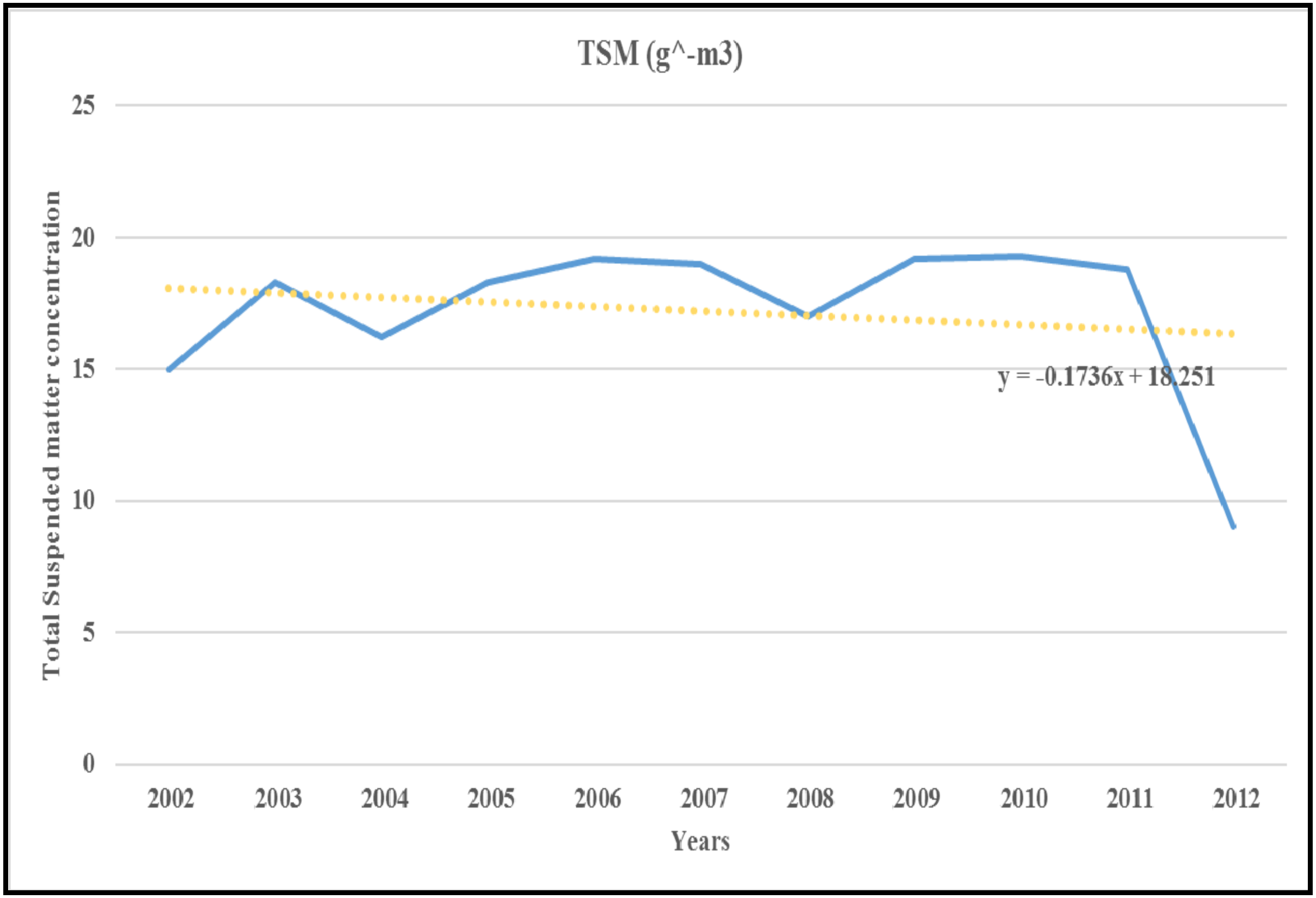

Figure 4.12: Trend of TSM over Lake Naivasha, 2002 to 2012.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS.

This project set out to study the use geospatial technology to extract water quality parameters of Lake Naivasha. The study further set out to determine the trophic state of the Lake based on the values of the water quality parameters extracted. The study also sought to evaluate the level to which the water quality parameter of the Lake conforms to the stipulated water quality standards; NEMA and European Commission standard were used.

5.1. Conclusion.

This study was able use the geospatial technology to extract the water quality parameters values for Chlorophyll concentration, Total Suspended Matter (TSM) and Turbidity. The study in addition was able show the tread of the water quality based on the parameters over a period of ten years 2002 to 2012. This demonstrates that it is possible to successfully apply this technology in water quality parameter monitoring and measurement. In addition the study was able to determine that the trophic state of Lake Naivasha over the period of study, 2002 to 2012 was eutrophic. This is based on the water quality parameter values extracted and their trend over the period. The study was able to verify that extracted water quality parameter values for Total Suspended Matter (TSM) did not conform to stipulate European commission standards. While Turbidity level throughout the study period were found to within acceptable ranges NEMA standard. In addition the study was able to conclude that the Lake Naivasha was Eutrophicated during the period of study 2002 to 2012. This is based Chlorophyll concentration values and subsequent categorization of Lake Naivasha as eutrophic based on these values.

5.2. Recommendations.

Based on the outcome of the project study it is recommended that;

1. Further studies should be done to determine the drivers and sources of high levels of values of water quality parameters above the stipulated standards in Lake Naivasha.
2. Water Resources Management Authority (WARMA) and National Environment Management Authority (NEMA) both Kenya national competent authorities should make effort to address the causes of these high levels of water quality parameter values above stipulated standard. Further the two agencies should take intervention measures within the Lake Naivasha catchment area. A good intervention measure recommended to deal with this problem is Integrated Water Shed Management (IWSM) approach for Lake Naivasha.

3. Water Resources Management Authority (WARMA) should adopt the use of geospatial technology in monitoring water quality especially for inland and coastal water bodies since this study has showed that the technology can be used successful for this purpose saving time, resources and over a large area.

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APPENDICES.

Appendix. A: Some Subset of MERIS Full Resolution MERIS Images of Lake Naivasha

Image 1:MERIS Image Subset for Chlorophyll Concentration.

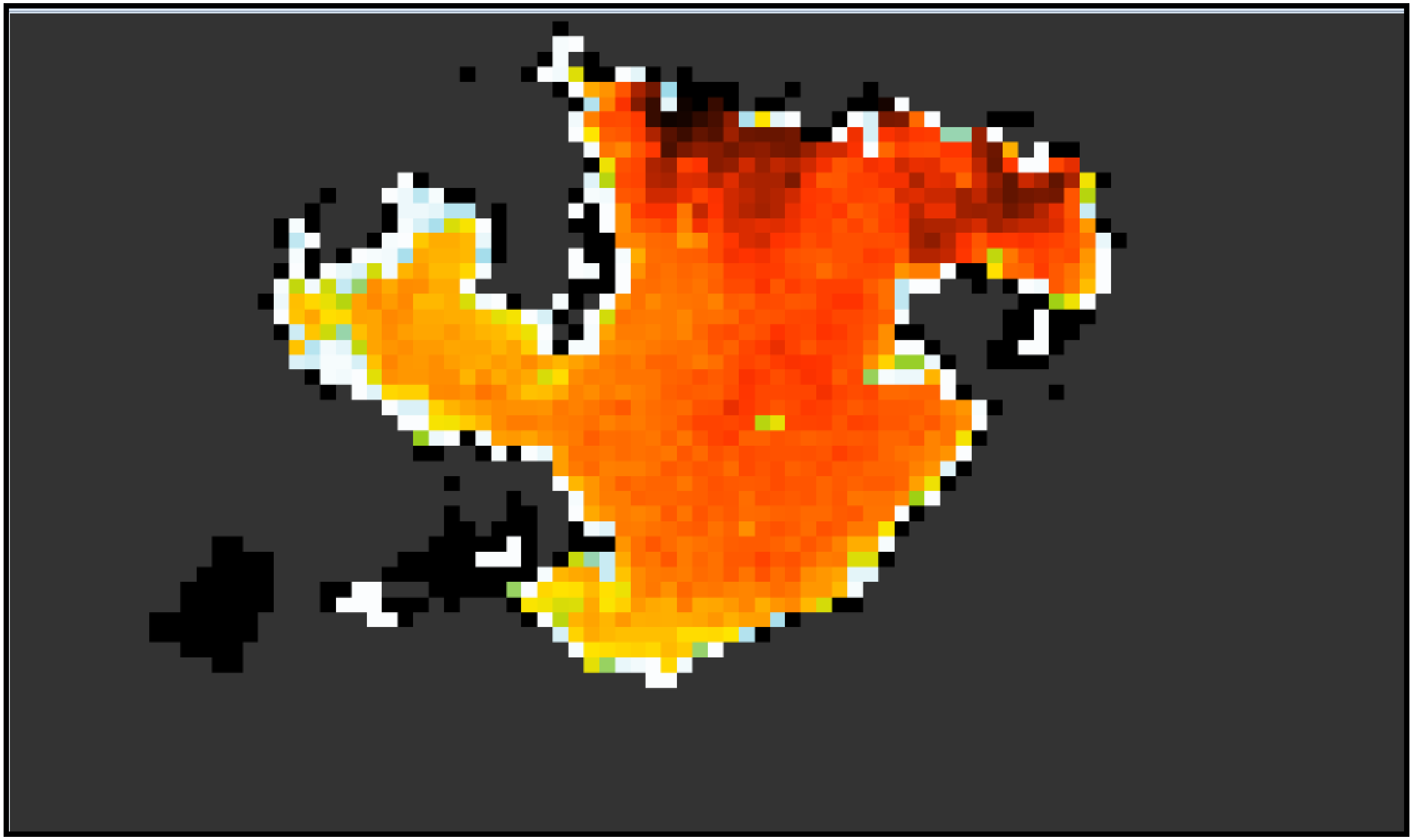
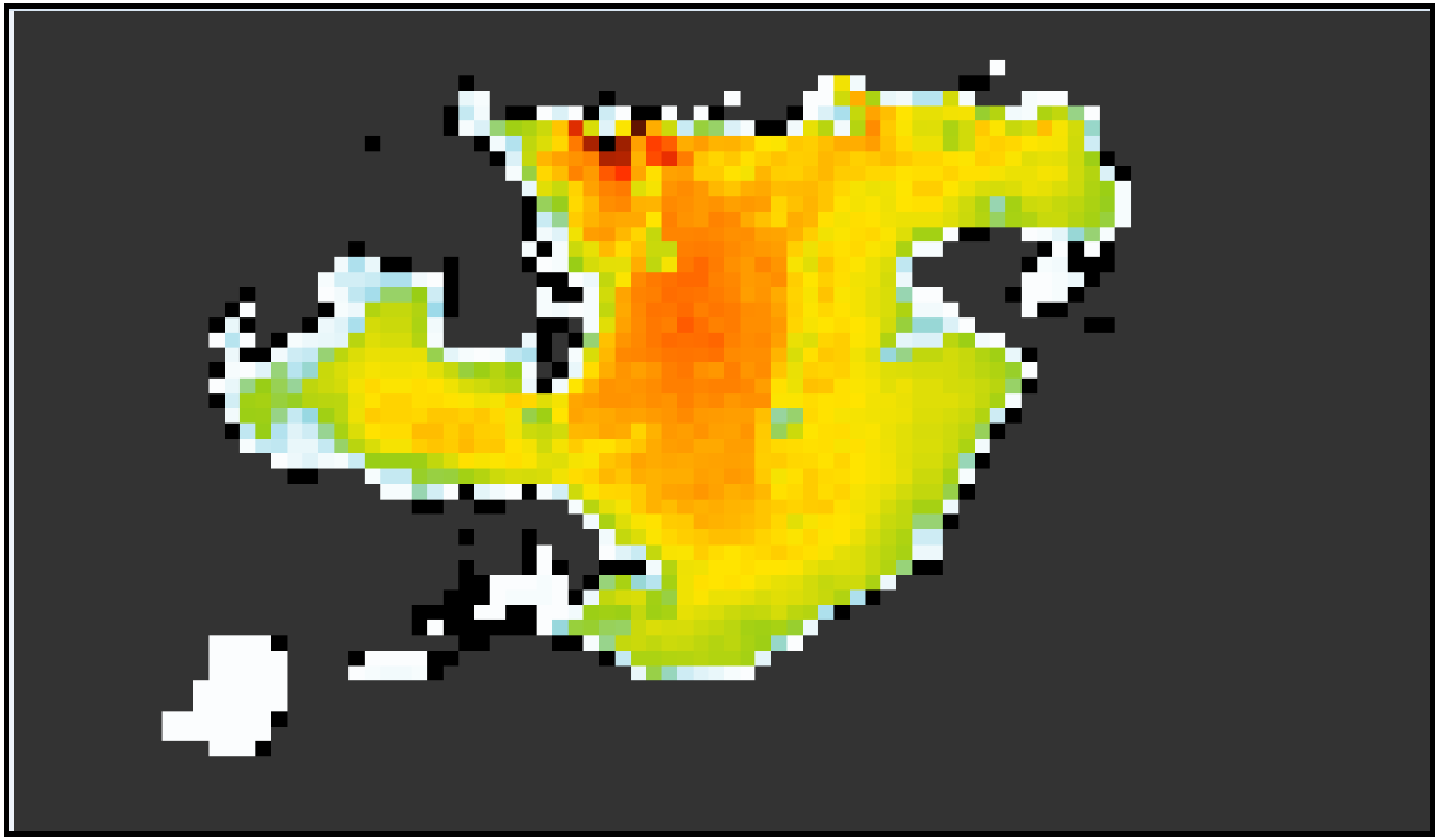
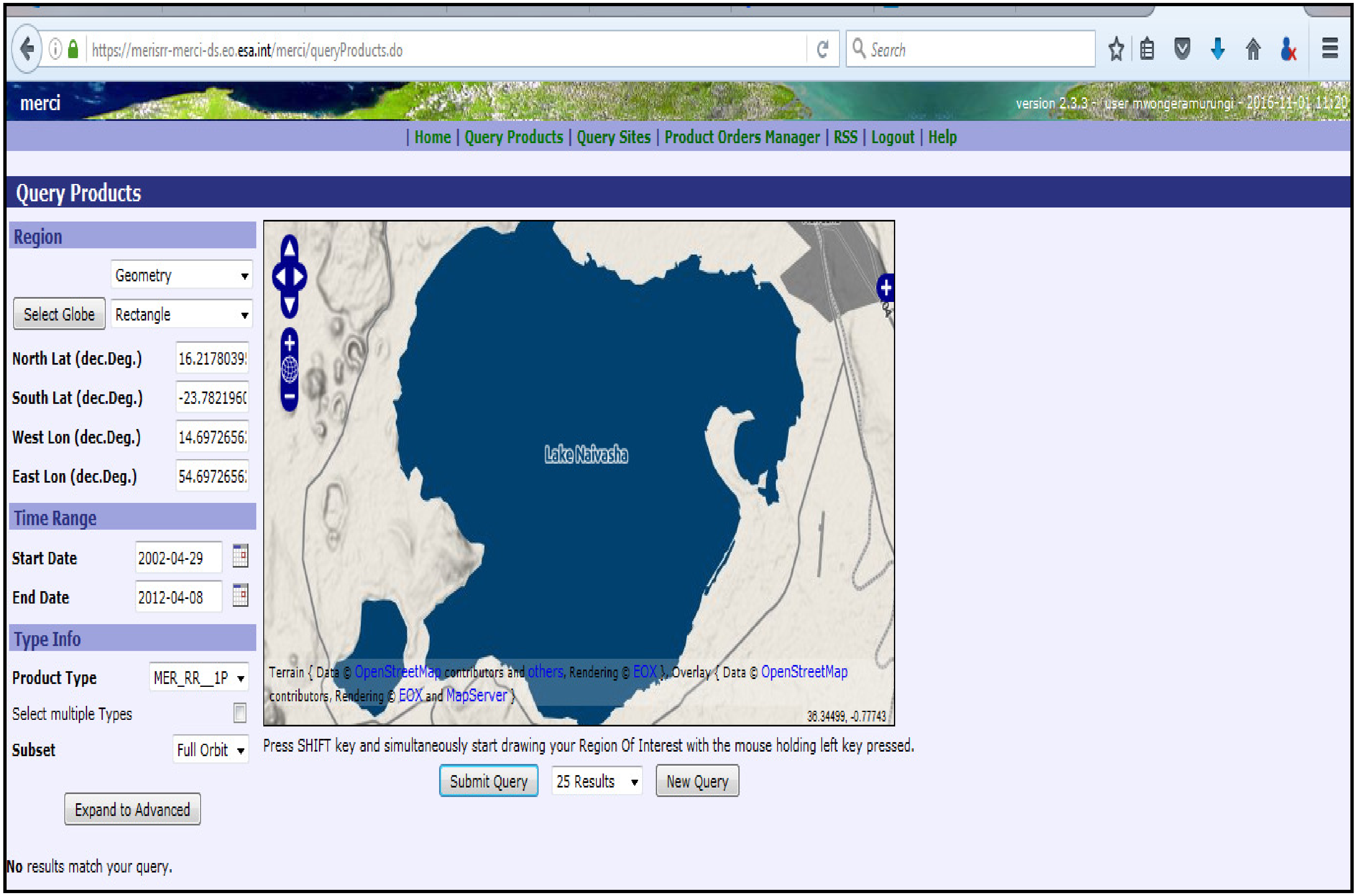


Image 2: MERIS Image Subset for TSM.



Appendix. B: Connecting to Merci and Selecting Lake Naivasha Study Area.



Appendix C: European Communities COUNCIL DIRECTIVE 98/83/EC on the Quality Of Water Intended for Human Consumption.

Indicator parameters

Parameter	**Parametric value**	**Unit**	**Notes**
Aluminium	200	μg/l	
Ammonium	0,50	mg/l	
Chloride	250	mg/l	Note 1
Clostridium perfringens (including spores)	0	number/100 ml	Note 2
Colour	Acceptable to consumers and no abnormal change		
Conductivity	2 500	μS cm-1 at 20 °C	Note 1
Hydrogen ion concentration $ 6	≥ 6,5 and ≤ 9,5	pH units	Notes 1 and 3
Iron	200	μg/l	
Manganese	50	μg/l	
Odour	Acceptable to consumers and no abnormal change		
Oxidisability	5,0	mg/l O2	Note 4
Sulphate	250	mg/l	Note 1
Sodium	200	mg/l	
Taste	Acceptable to consumers and no abnormal change		
Colony count 22°	No abnormal change		
Coliform bacteria	0	number/100 ml	Note 5
Total Organic Carbon (TOC)	No abnormal change		Note 6
Turbidity	Acceptable to consumers and no abnormal change		Note 7
RADIOACTIVITY			
Parameter	**Parametric value**	**Unit**	**Notes**
Tritium	100	Bq/l	Notes 8 and 10
Total indicative dose	10	mSv/year	Notes 9 and 10

Adopted from: European Union (EU), (1998).

Note 1: The water should not be aggressive.

Note 2: This parameter need not be measured unless the water originates from or is influenced by surface water. In the event of non-compliance with this parametric value, the Member State concerned must investigate the supply to ensure that there is no potential danger to human health arising from the presence of pathogenic micro-organisms, e.g. cryptosporidium. Member States must include the results of all such investigations in the reports they must submit under Article 13(2).

Note 3: For still water put into bottles or containers, the minimum value may be reduced to 4,5 pH units. For water put into bottles or containers which is naturally rich in or artificially enriched with carbon dioxide, the minimum value may be lower.

Note 4: This parameter need not be measured if the parameter TOC is analysed.

Note 5: For water put into bottles or containers the unit is number/250 ml.

Note 6: This parameter need not be measured for supplies of less than 10 000 m³ a day.

Note 7: In the case of surface water treatment, Member States should strive for a parametric value not exceeding 1,0 NTU (nephelometric turbidity units) in the water ex treatment works.

Note 8: Monitoring frequencies to be set later

Note 9: Excluding tritium, potassium -40, radon and radon decay products; monitoring frequencies

Note 10:

1. The proposals required by Note 8 on monitoring frequencies, and Note 9 on monitoring frequencies, monitoring methods and the most relevant locations for monitoring points in Annex II shall be adopted in accordance with the procedure laid down in Article 12. When elaborating these proposals the Commission shall take into account *inter alia* the relevant provisions under existing legislation or appropriate monitoring programmes including monitoring results as derived from them. The Commission shall submit these proposals at the latest within 18 months following the date referred to in Article18 of the Directive.

2. A Member State is not required to monitor drinking water for tritium or radioactivity to establish total indicative dose where it is satisfied that, on the basis of other monitoring carried out, the levels of tritium of the calculated total indicative dose are well below the parametric value. In that case, it shall communicate the grounds for its decision to the Commission, including the results of this other monitoring carried out.

Adopted from: European Union (EU), (1998).

Appendix D: NEMA Quality Standards for Sources of Domestic Water.

Parameter	**Permissible Level**
pH	6.5 – 8.5
Suspended solids	**30 (mg/L)**
Nitrate-NO_3	10 (mg/L)
Ammonia –NH_3	0.5 (mg/L)
Nitrite –NO_2	3 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Scientific name *(E.coli)*	Nil/100 ml
Fluoride	1.5 (mg/L)
Phenols	Nil (mg/L)
Arsenic	0.01 (mg/L)
Cadmium	0.01 (mg/L)
Lead	0.05 (mg/L)
Selenium	0.01 (mg/L)
Copper	0.05 (mg/L)
Zinc	1.5 (mg/L)
Alkyl benzyl sulphonates	0.5 (mg/L)
Permanganate value (PV)	1.0 (mg/L)

Adapted from: NEMA, (2006).

Appendix E: NEMA Standards for Irrigation Water.

Parameter	**Permissible Level**
pH	6.5-8.5
Aluminium	5 (mg/L)
Arsenic	0.1 (mg/L)
Boron	0.1 (mg/L)
Cadmium	0.5 (mg/L)
Chloride	0.01 (mg/L)
Chromium	1.5 (mg/L)
Cobalt	0.1 (mg/L)
Copper	0.05 (mg/L)
E.coli	Nil/100 ml
Fluoride	1.0 (mg/L)
Iron	1 (mg/L)
Lead	5 (mg/L)
Selenium	0.19 (mg/L)
Sodium Absorption Ratio (SAR)	6 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Zinc	2 (mg/L)

Adapted from: NEMA, (2006).

Appendix. F: Index Values Translate into Trophic Classes.

TI	Chl	P	SD	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5—<0.25	Hypereutrophic

Relationships between Trophic Index (TI), chlorophyll (Chl), phosphorus (P, both micrograms per litre), Secchi depth (SD, metres), and Trophic Class. Units are Ug/l (or mg/m3), [Adopted from: Carlson R.E. and J. Simpson (1996)]