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DEPARTMENT OF CHEMISTRY

ASSESSMENT OF WATER QUALITY TRENDS USING REMOTE SENSING DATA "CASE STUDY OF LAKE NAIVASHA IN THE RIFT VALLEY OF KENYA"

BY

VINTON JEFFERSON JOHNSON

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DECLARATION

This thesis is my original work and has not been presented for a degree in this university or any other university.

Signature________________________ Date______________________

Vinton Jefferson Johnson

I56/69104/2013

SUPERVISORS DECLARATION

This thesis has been submitted for review with our approval as supervisors.

1. Signature ________________________________ Date ______________________

   Professor David K. Kariuki

   Department of Chemistry, University of Nairobi

   Supervisor

2. Signature _________________________________ Date ______________________

   Professor David. N. Kariuki

   Department of Chemistry, University of Nairobi

   Supervisor

DEDICATION

This project is dedicated to the loving memories of my late grandparents Rev.Dr. & Mth.G. Franklin Holt Sr. and my late father Hon. Charles Jefferson Johnson Sr.

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Firstly, I want to thank the Almighty God for giving me the endurance to complete this challenging and awesome task. Thanks and appreciations go to the following personalities Professors David K. Kariuki, David N. Kariuki, Amir Yusuf, for their support and encouragement given to me through this journey. Thanks and appreciations also go the Arcelor Mittal Family for the financial support given me in the actualization of this dream. I will be very ungrateful if I do not reference the followings individuals, Dr.John Wanjohi, Dr. Albert Ndakala, Dr. John Onyata, Dr.Damaris Mbui, Mr. Ephantus Mwangi, Mr. Leonard Sweta of the Regional Mapping Center in Kasarani and the University of Nairobi for the level and quality of knowledge achieved. Further thanks and appreciation go to Dr.Abira, Joseph Wendott and the entire support staff of WRMA Sub Region Office for the relevant pieces of information and support given me through the conduct of this study.

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ABSTRACT

This study was conducted using remote sensing data for the establishment of water quality trends of Lake Naivasha from 2003 to 2011. Laboratory analysis was also conducted for three months from September 2014 to November 2014 by collecting samples from six sampling points. These sampling points were located using the Global Positioning System (GPS) for easy reference. The results obtained from the remote sensing data were correlated with the laboratory analysis using the Chi Square correlation method. Parameters analyzed by the remote sensing method included total suspended matter(TSM), turbidity, coliform (chlorophyll a) and back scattering suspended matters (conductivity). Water quality information was defined from Medium Resolution Imaging Spectrometer (MERIS). Parameters analyzed *insitu* during the laboratory analysis were: pH, temperature, turbidity, conductivity and dissolved oxygen. Parameters analyzed in the laboratory were total suspended solid, total dissolved solid and coliform.

The study findings showed that the measurements conducted *insitu* on the lake for pH ranged from 6.8 to 7.8. The temperature readings were ranging from 20.6^{O}C to 24.7^{O}C. The dissolved oxygen levels were ranging from 4.53mg/l to 6.79mg/l.

The trends of the Total Suspended matter (TSM) from 2003 to 2011showed continuous rise and fall with the highest level in November 2006 of 16.61mg/l and the lowest level in November 2011 of 4.27mg/l. The trend in turbidity level from 2003 to 2011 showed rise and fall in the trends with the highest level in 2007 of 14.16FNU and the lowest value in 2011 of 2.31FNU. The trends in the conductivity of the lake showed consistency for 2003, 2005 up to 2010 at the same level of 0.3mg/l. In 2011 the reading was found to be 0.18mg/l and the lowest value recorded in 2004 of 0.15mg/l.

Parameters considered for correlation using the remote sensing data and the laboratory analysis included TSS, turbidity and conductivity using the chi-square correlation coefficient. From the three parameters correlated only turbidity showed a positive or direct correlation. The result from the correlation coefficient was 0.916.

TABLE OF CONTENTS

DECLARATION....................i
SUPERVISORS DECLARATION....................i
DEDICATION.................... ii
ACKNOWLEDGEMENTS.................... iii
ABSTRACT....................iv
LIST OF ACRONYMS AND ABBREVIATIONS....................xii
CHAPTER ONE....................1
INTRODUCTION....................1
1.1Background of the Study....................1
1.2 Statement of the Problem....................2
1.3 Objective of the Study....................3
1.3.1 General Objective....................3
1.3.2 Specific Objectives....................3
1.4 Research Questions....................3
1.5 Justification of the Study....................4
CHAPTER TWO....................5
LITERATURE REVIEW....................5
2.1 Water Quality of Aquatic Ecosystems....................5
2.2 Issues of Eutrophication to Water Quality....................6
2.3 Lake Naivasha Water Quality and Related Issues (Eutrophication)....................7
2.4 Demography of Lake Naivasha....................10
2.5 Water Flow of Lake Naivasha....................10
2.6 Remote Sensing Technique to Assess Water Quality....................11
CHAPTER THREE....................13
MATERIALS AND METHODS....................13
3.1 Study Area....................13

3.2 Sampling Point 14
3.3 Research Design 16
3.4 Apparatus and Reagents Used 16
3.5 Sampling Procedures 17
3.6 Sample Analysis 17
CHAPTER FOUR 22
RESULTS AND DISCUSSION 22
4.1 Introduction 22
4.2 Laboratory Analysis 22
4.3 Results and discussions from Remote Sensing Data (2003- 2011) 38
4.3 Correlation between Remote Sensing and Laboratory results. 64
CHAPTER FIVE 67
CONCLUSION AND RECOMMENDATION 67
5.1 Conclusion 67
5.2 Recommendations 68
References 69
APPENDICES 74
Appendix I: The water parameters to be analyzed on the file data sheet 74
Appendix II: Images showing the Water Quality Parameters of Lake Naivasha for November 2003 75
Appendix III: Images showing the Water Quality Parameters of Lake Naivasha for November 2005 77
Appendix IV: Images showing the Water Quality Parameters of Lake Naivasha for September 2006 80
Appendix V: Images showing the Water Quality Parameters of Lake Naivasha for November 2007 82
Appendix VI: Images showing the Water Quality Parameters of Lake Naivasha for September 2008 84

Appendix VII: Images showing the Water Quality Parameters of Lake Naivasha for October 2010 85

LIST OF FIGURES

Figure 1: Sampling Points in Lake Naivasha………………………………………………….14
Figure 2. The water samples collection from the sampling points along the lake.......................17

Figure 3:Average pH readings of the for the month of September 2014...................................24

Figure 4: Average Temperatures from sampling sites for the month of September 2014………..25

Figure 5: Average Dissolved Oxygen (mg/l) readings from sampling sites for the month of September 2014……………………………………………………………………........26

Figure 6: Average Suspended Solids (mg/l) readings from sampling sites for the month of September 2014…………………………………………………………………………….27

Figure 7: Average Dissolved solids (mg/l) readings from sampling sites for the month of September 2014…………………………………………………………………………….28

Figure 8: Average Turbidity (FNU) readings from sampling points for the month of September 2014...29

Figure 9: AverageConductivity (µS/cm)readings from sampling point for the month of September 2014. 29

Figure 10:Average pH for the month of October 2014. 30

Figure 11: Average Temperatures (^{O}C) from sampling points for the month of October2014......31

Figure 13: Average Suspended Solids (mg/l) readings from sampling points for the month of October 2014. 32

Figure 14: Average Dissolved solids (mg/l) readings from sampling points for the month of October 33

Figure 15: Average Turbidity(NFU) readings from sampling points for the month of October....33

Figure 16: Average Conductivity (µS/cm) readings from sampling point for the month of October 2014...34

Figure 17. Average pH from sampling points for the month of November 2014.........................35

Figure 18. Average Temperatures (^{O}C) from sampling points for the month of November 2014. 35

Figure 19. Average Dissolved Oxygen reading from sampling points for the month of November 2014...36

Figure 21. Average Dissolved solids (mg/l) readings from sampling points for the month of November. 36
Figure 22: Average Turbidity(FNU) readings from sampling points for the month of November 2014. 37
Figure 23: Average Conductivity (µS/cm)readings from sampling points for the month of November 2014. 37
Figure 24: GIS Readings for the Remote Sensing imaging of the Various Sampling Points. 38
Figure 25: 2003 Results 39
Figure 26: Chlorophyll – September 2003 40
Figure 27: Total Suspended Matters – September 2003 40
Figure 28: Turbidity – September 2003 41
Figure 29: 2004 Results Back Scattering Suspended Matters November 2004 42
Figure 30: Chlorophyll – November 2004 42
Figure 31: Total Suspended Matters November 2004 43
Figure 32: Turbidity – November 2004 44
Figure 33: Results for 2005 Back Scattering Suspended Matters September 44
Figure 35: Total Suspended Matters September 2005 46
Figure 37: Back Scattering Suspended Matters November 2006 47
Figure 39: Total Suspended Matters – November 2006 48
Figure 40: Turbidity – November 2006 49
Figure 41: Results for 2007 49
Figure 42: Chlorophyll – October 2007 50
Figure 43: Total Suspended Matters – October 2007 50
Figure 44: Turbidity – October 2007 51
Figure 45: Back Scattering Suspended Matters October 2008 51
Figure 46:Chlorophyll-a Concentration for October 2008 52
Figure 47: Total Suspended Matters – October 2008 53
Figure 49: Results for 2009 Back Scattering Suspended Matter November 2009 54

Figure 50: Chlorophyll – November 2009 55
Figure 51: Total Suspended Matters – November 2009 55
Figure 52: Turbidity – November 2009 56
Figure 53: Results for October 2010 Back Scattering Suspended Matters 56
Figure 54: Chlorophyll – October 2010 57
Figure 56: Turbidity – October 2010 58
Figure 57: Results for November 2011 Back Scattering Suspended Matter 59
Figure 58: Chlorophyll – November 2011 59
Figure 59: Total Suspended Materials – November 2011 60
Figure 60: Turbidity – November 2011 60
Figure 61. Gives the trends of the Total Suspended Solids (TSM) from 2003 to 2011 61
Figure 62 Gives the trends of the turbidity levels in Lake Naivasha from 2003 to 2011. 62
Figure 63. The trends in the Conductivity/Back Scattering levels of the lake from 2003 to 2011.63
Figure 64. The chlorophyll a levels of the lake from 2003 to 2011. 64

LIST OF TABLES

Table1: Sampling sites and GPS Coordinates 15

Table 2. The sampling points and GPS readings that were used to carry out the sampling activities along the lake 23

Table 3. The average readings of the various parameters from each sampling point for the month of September 2014. 23

Table 4. The maximum Dissolved Oxygen value that should conform with the different Temperature range……………………………………………………………………….26

Table 5. The average readings of the various parameters from each sampling point for the month of October 2014…………………………………………………………………………….30

Table 6. The average readings of the various parameters from each sampling point for the month of November 2014………………………………………………………………………….34

TABLE 7. TRENDS IN THE TOTAL SUSPENDED MATTERS CONCENTRATION OF THE LAKE FROM 2003 to 2011…………………………………………………………………60

Table 8. Showing Trends in the Turbidity Levels of the lake from 2003 to 2011……………..61

Table 9. Showing Trends in the Conductivity/Back Scatter Suspended Matters of the lake from 2003 to 2011…………………………………………………………………………………62

Table 10. Trends in the Coliform/Chlorophyll a Levels of the lake from 2003 to 2011………..63

Table 11: Chi- Square Correlation for the TSM, turbidity and Conductivity…………………..65

LIST OF ACRONYMS AND ABBREVIATIONS

APHA	-	American Public Health Association
DO	-	Dissolved Oxygen
EMS	-	Electromagnetic Spectrum
ESA	-	European Space Agency
FNU	-	Formazin Nephelometric Unit
GPS	-	Geographic Positioning System
GIS	-	Geographic Information System
MG/L	-	Milligram per Liter
MERIS	-	Medium Resolution Imaging Spectrometer
pH	-	Hydrogen Ion Concentration
RS	-	Remote Sensing
TSM	-	Total Suspended Matter
TSS	-	Total Suspended Solid
TDS	-	Total Dissolved Solid
WRMA	-	Water Resource Management Authority
µS/cm	-	Micro Siemens per Centimeter
^{O}C	-	Degree Celsius

CHAPTER ONE

INTRODUCTION

1.1Background of the Study

This study was conducted using methodological approach of establishing the water quality trends of Lake Naivasha from 2003 to 2011 where remote sensing data was employed. Laboratory analysis was also conducted for three months from September 2014 to November 2014 by collecting samples from six sampling points. These sampling points were located using the Global Positioning System (GPS) for easy reference. The results from the remote sensing data were correlated with the laboratory analysis using the Chi Square correlation method. Parameters analyzed by the remote sensing method included total suspended matter(TSM), turbidity, coliform(chlorophyll a) and back scattering suspended matters (conductivity). Water quality information was defined from Medium Resolution Imaging Spectrometer (MERIS). Data collection via the remote sensing techniques is heavily dependent upon electromagnetic radiation. This method is very active in the presence of sunlight for data generation by the MERIS image. Parameters analyzed insitu during the laboratory analysis were: pH, temperature, turbidity, conductivity and dissolved oxygen. Parameters analyzed in the laboratory were total suspended solid, total dissolved solid and coliform.

Lake Naivasha is a fresh water lake situated 80KM North West of Nairobi in the Kenyan Rift valley. Lake Naivasha and other Fresh water resources are losing their natural qualities as a result of anthropogenic and natural activities, thereby causing major threat to human and aquatic life. Remote sensing and routine laboratory analysis of water sample from the Lake is one of the best methods for continuous water quality monitoring.

Many freshwater lakes are experiencing global challenges relative to changes in water quality. Some of the challenges relative to these changes are associated with rapid urbanization, agricultural developments and other forms of anthropogenic activities in water body surroundings (Sala *et al* 2000). Changes in hydrological balance of these lakes are associated with variation in rainfall, specifically in the catchment surroundings. That is frequent fluctuations of water levels in lakes globally.

Global warming has also contributed significantly, by causing further increase in water temperatures of lakes, impacting the lakes biota (Schlinder *et al* 1996). Both abiotic and biotic factors control the dynamics of lakes as natural systems (Hansson, et al 1998). The abiotic factors and biotic factors differ greatly between regions and between lakes. Henceforth, a lake provides abiotic conditions such as nutrient concentrations, light availability, oxygen concentration, pH and temperature. These conditions determine the survival and reproductive nature of organisms (Bronmark and Hansson, 2002).

Changes in the abiotic conditions of lakes have a strong effect on biota altering species composing of phytoplankton, zooplankton, benthic invertebrate and fish (Magnusson et al 1997). The situation in Lake Naivasha is very similar to what is obtaining in other tropical lakes globally. Lake Naivasha is a tropical fresh water lake and has experienced rapid changes in human population over the last two decades as a result of commercial farming mainly specializing on flower and horticultural farming (Kitaka *et al* 2002). A large number of people have been seeking employment in these farms. Consequently, many poorly planned buildings mostly without proper sewer systems have been erected to house these people. During heavy rainfall, many of these sewers burst sending their runoff into the lake. On the other hand, the rapid expansion of the flower industries has caused high water abstraction from the lake, and greater usage of fertilizers and pesticides, thus leading to the seepage of agrochemical residues ending up into the lake. The use of remote sensing in monitoring and analyzing the water quality trend will also be employed. The capability of this technology offers great tools of how the water quality monitoring and managing can be operationalized. Remote sensing is a science that deals with scanning of the earth by satellite or highflying aircraft in order to obtain information about it. Remote sensing techniques allow taking images of the earth surface in various wavelength region of the electromagnetic spectrum (EMS). Therefore, it is a useful tools in providing information on the water quality parameters. Water quality is the process to determine the chemical, physical and biological characteristics of water bodies and identifying the source of any possible pollution or contamination which might cause degradation of the water quality. Hence, this study was conducted to establish the levels and trends of the water quality in Lake Naivasha from 2003 to 2011 using remote sensing technology and to correlate the results from the remote sensing data with that of the laboratory analysis carried out for the three months period.

1.2 Statement of the Problem

Water quality is used to evaluate basic water chemistry and to determine if the water meets the minimum standard for bacterial and chemical content.

The quality of water in Lake Naivasha plays an integral part to the life and the entire maintenance of the ecosystem. The natural quality of the lake's water is being continually altered by anthropogenic activities such as floriculture, horticulture, human settlement and animal grazing in the surroundings. As a result, there is a need to continually assess the quality of the lake's water. There have been many studies conducted addressing the water quality of Lake Naivasha over the years but they have not been consistent with trends using remote sensing method.

1.3 Objective of the Study

1.3.1 General Objective

To establish the water quality trends of Lake Naivasha from 2003- 2011.

1.3.2 Specific Objectives

The specific objectives of this study were:

1. To determine the pH, temperature, conductivity, turbidity, total suspended solids, total dissolved solids, dissolved oxygen, and coliforms in Lake Naivasha using laboratory methods.
2. To determine the conductivity, turbidity, total suspended solids and coliforms in Lake Naivasha using Remote Sensing methods.
3. To relate the results of the remote sensing and laboratory methods.
4. To establish the trends of water quality of Lake Naivasha over the period from 2003 to 2011 using remote sensing method.

1.4 Research Questions

The following constitute the research questions for this study.

1. What key parameters will be used to reflect the overall water quality of Lake Naivasha?
2. What are the current levels and trends of the water quality in Lake Naivasha?

3. How does remote sensing technology complement the water quality analysis of Lake Naivasha?
4. How do the results from the water quality analysis in the laboratory and remote sensing techniques relate?

1.5 Justification of the Study

The findings gathered from this study will serve as a guide for future researchers in assessing the water quality trends of Lake Naivasha using Remote Sensing techniques and laboratory methods simultaneously. The information gathered during the conduct of this research will also be useful to the caretakers of the lake, fishermen and other stakeholders for the proper management of the lake. This study is very important because Lake Naivasha is Kenya’s second largest freshwater lake supporting a rich ecosystem with about 350 bird’s species, papyrus fringes filled with hippo, riparian grass lands with waterbuck, giraffe, zebra and various antelope graze, dense patches of riparian acacia forest with buffaloes, bushbuck and other creatures, beautiful swampy areas where waterfowl breed and feed. It is an important biodiversity ecosystem and received RAMSAR recognition in 1995(Santiago M, 2002). Hence forth, the water quality of the lake has a direct and integral relationship on the surrounding ecosystem’s biodiversity.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Quality of Aquatic Ecosystems

Water quality is used to evaluate basic water chemistry and to determine whether the water meets the minimum criteria for bacterial and chemical content. Water quality key basic parameters (i.e. the physico- chemical parameters) include temperature, pH, turbidity, total suspended solids, total dissolved solids, dissolved oxygen, color, and coliforms. Water has two dimensions that are linked, quality and quantity. Quality deals with the physical, chemical, biological and aesthetic (appearance and smell). A healthy environment is one in which the water quality supports a rich and varied community of organisms and protects public health (Barton and Grant 2010).

The maintenance of water quality standards in lakes and reservoirs is partly necessary to avoid excessive growth of aquatic flora, which is a problem to aquatic biota and humans. In many tropical lakes, temporal and spatial changes in the physico-chemical parameters are common in response to surface water runoff, direct precipitation, groundwater recharge, rate of evaporation and human interference. These changes have impact in the flora and fauna by imposing physiological and behavioral adaptation (Kemdirim 2005).

Water is essential to human life and the health of the environment. As a natural resource, it comprises marine, estuarine, fresh water (river and lakes) and ground water environments. Global freshwater is the most precious human resource. The earth is called the blue planet because water covers about 75% of the earth. Most of the water on the earth is characterized by high level of salinity with the exception of 5% of the water that is fresh (Herdendorf, 1990), and most of this water is in the ice caps, glaciers and groundwater. The remaining is deposited as lakes, streams and soil moisture. An estimated 68% of the fresh water is in 189 lakes with surface areas greater than $500km^2$(Reid and Beeton 1992).

In this twenty-first century, we are faced with the challenge imposed by water scarcity, pollution and water quality degradation (Mokaya *et al* 2004). Moreover, the need to produce more food for the geometrically growing population has a direct relationship to the issue of water quality as it results in increased soil erosion, chemical pollution by fertilizers and pesticides (Novotny, 1999). Aquatic environments are more difficult to protect than terrestrial environments.

This is due to the fact that they depend on the quality and quantity of water, which can be affected at any time by changes in the catchment and the given system (Shumway-1999).

Changes in land use the pattern lead fundamentally to spatial and temporal heterogeneity of the limnological characteristics, thus influencing ecological structure and functioning of aquatic ecosystems (Nogueira et al 1999).

2.2 Issues of Eutrophication to Water Quality

Eutrophication continues to be the most common water quality problem globally. Nutrients such as phosphorus and nitrogen naturally enter water bodies by way of drainage, which can be a runoff after heavy rainfall and via groundwater. Manmade activities also greatly enhance eutrophication through the discharge of untreated and partly treated sewage, domestic and industrial effluents, as well as through residue fertilizer seepage from farming activities around a water body. The nutrients specifically phosphorus and nitrate are needed in low amount for primary production. A small increase above the normal levels of phosphorous and nitrate may cause changes in the aquatic ecosystems (Smol, 2002).

There are other problems associated with eutrophication in the aquatic ecosystems such as choking of the littoral zones of the water bodies with excessive growth of aquatic macrophytes, which can impair recreational and industrial activities as well as alter the structure of the food web. It also causes blue green algal blooms, which can cause serious management problems of the aquatic ecosystems. These include the production of toxins that may harm or even kill mammals, deep-water oxygen depletion which interferes with the distribution and abundance of fish and other biota inhabiting deep water regions of the anoxic lakes (Smol, 2002 Op.Cit).

In tropical lakes nutrient enrichment is not well understood as in the temperate areas. Many lakes, reservoirs and rivers studied within the tropical region have an increase in eutrophication specifically Southern Africa (Twinch, 1986). In Zimbabwe, Lake Chivero, a eutrophic reservoir, has experienced problems with blue green algal blooms for many years, raising concern for the toxins produced by microcystis Spp and the possible effects of the toxins on the health of the population who drink the water (Ndebele and Magadza 2006). The water quality of many tropical lakes has been deteriorating, for example Lake Victoria has experienced dramatic changes in water quality over the past few decades, specifically in regard to eutrophication as a result of increased nutrient inputs (Lunga' Ya *et al* 2000: Mugiddle *et al*, 2005). These changes have been manifested in the occurrence of algal blooms, low levels of oxygen in water, frequent fish kills and the spreading of the water hyacinth (Hecky, 1993).

Eutrophication has also been observed to cause great reduction in fish species composition, size distribution and quantity (Kubecka, 1993). The density of the fish at the onset increased, and later fell drastically with the number of species and their body length continually decreasing, in reported studies (Bachmann *et al*, 1996; Jeppesen *et al,* 2000). Temperature is of fundamental significance to the livelihood of aquatic organisms affecting metabolic and growth rates. Therefore, an increase in the temperature may affect the hatching date with far reaching effects on the size at reproduction and the availability of food (Chen and Folt, 1996).

2.3 Lake Naivasha Water Quality and Related Issues (Eutrophication)

Lake Naivasha is a freshwater lake supplied by 3 rivers and has no surface outlets other than underground outflows. River Malewa rises in the western slopes of the Aberdare ranges in central Kenya and flows south through highly manipulated small and large-scale farms before making its entry into the lake on the northern shores. Lake Naivasha is one of the inland freshwater lakes of economic importance in Kenya. Apart from being a vital source of water in a seemingly semi-arid environment, the lake supports a flourishing business in horticulture and floriculture. These activities earn the country a substantial amount of foreign exchange in the form of export earnings. The lake is also famous for sport fishing, tourism and recreation. It is a natural aquatic ecosystem that is highly valued due to its rich biological diversity. It has received immense scientific research attention dating as early as 1929 (Jenkins, 1994).

The lake has experienced fluctuations in the water levels over the last century, with cycles of short term; lake level rises and falls, against long term patterns of lake level decline. The water seeps out of the lake through an underground aquifer, probably southwards towards Longonot and northwards towards Gilgil (Vincent *et a*l., 1979, Gaudet and Melack 1981, Clark *et al*, 1990). These fluctuations are normally accompanied by significant variations in limnological factors and productivity within the lake (Harper *et al*., 1990). Notable changes in water quality characteristics, specifically on the solute levels have been recorded by Gaudet and Melack (1981), who found the water to be alkaline bicarbonate with sodium and calcium as the major cations. The freshness of the lakes' water was attributed to dilute river inflows, combined with solute uptake by sediment and some solute loss through seepage (Gaudet and Melack, 1981). Two highly productive and damaging exotic floating plants appeared in the lake that is the aquatic fern, salvinia molesta, in the 1960s and Water Hyacinth, Eichhornia Crassipes in 1988. Both plants are from dense mats which out compete less vigorous water plants for light and space (Adams *et al* 2002).

Salvinia molesta was abundant up to the 1980s when it occupied about 25% of the lake surface in mobile mats (Johnson *et al* 1998). Towards the end of 1990s, Eichhornia Crassipes cover in the lake was negligible and formed a narrow fringe of about 0-5m wide, with larger mats occurring in the sheltered bays and inlets. These mats were found to be a habitat for oligochaetes, insects and arachnids (Adams *et al* 2002). These mats were found to have an important role in the biology and chemistry of the lakes' water. Papyrus (Cyperus papyrus), the dominant emergent vegetation in lake Naivasha, have been documented to have culms growing to a height of 5m and above ground standing phytomass which often exceed 12t Cha-1 . Living papyrus vegetation often overlies several metres of depth of detritus or peat which forms in the oxygen depleted environment below established floating rhizome mats (Jones and Muthuri 1985, 1997).

Cyperus papyrus has been found to filter and retain nutrients in organic particles in the detritus and also have an important role in nutrients recycling (Gaude 1979, Njuguna, 1982). Recent development in intensive horticulture around Lake Naivasha, especially in the 1980s and 1990s, has been reported to have accelerated papyrus clearance (Boar *et al* 1999). In shallow lakes, like Lake Naivasha, variations in light intensity have an important effect on the water column productivity (Schallenberg and Carolyn, 2004; Hubble and Harper, 2001). Hubble and Harper, (2002a) found Lake Naivasha to be dominated by *Aulaacoseira italica* following eutrophication, probably due to land use changes in the early 1980s. He also found a strong spatial homogeneity in the phytoplankton community controlled by light and nutrient availability, with diatoms which are indicative of high nutrients levels being observed. Nutrients availability and seasonal variations are important factors in controlling phytoplankton abundance in lakes.

According to Njuguna (1982) diatoms and chlorophytes were dominant in Lake Naivasha with eutrophication occurring as a result of natural loading. A study conducted between 2001 and 2005 in Lake Naivasha by Ballot *et al*., (2009) found that phytoplankton community was dominated by cyanobacteria, Chlorophytes and Bacillariophytes. Kitaka *et al* (2002b) found the loss of phosphorus from the catchment of Lake Naivasha to be 0.2kg ha -1 per annum, 76%

particulate in the months following 1997- 98 El Nino rains. In the 1980s, Lakes Naivasha zooplankton was found to consist of 2 cyclopods, 1 calonoid copepod, 11 cladocera and 13 rotifera with the composition being fairly stable with minor seasonal changes.

In the littoral zone area, fish fry of black bass, M. Salmoides and adult Gambusia affinis exerted predatory pressure on the zooplankton (Mavuti 1990). The lake was observed to exhibit continuous wind induced mixing after midday with no major changes in the dial vertical distribution of limnetic zooplankton. Bottom dwelling organisms were usually more exposed to contaminated sediments, although this may not induce direct toxicity to benthic community, as bioavailability of the contaminants depends on the prevailing conditions and interactions with the organisms (Mavuti 1992). The ecological stability of Lake Naivasha is threatened by the impact of both internal and external factors. Internal factors are the exotic species introductions and accidental arrivals while external factors are the impacts of intensive horticultural industry (Kitaka *et al* 2002b). Water in the lake is slowly becoming more and more concentrated with nutrients, more alkaline and higher level of planktons.

A sizeable area of the lake basin is currently under large scale production of flowers, vegetables, and fruits mainly for exports markets, occupying about 4,000 hectares. The agricultural production depends heavily on irrigation from the lake, rivers and from underground water (boreholes). To sustain these intensive agricultural activities the farmers apply inputs of fertilizers and pesticides. This industry has employed some 25,000 people directly with a similar number also indirectly (Becht *et al* 2005).

The lake shores is also important for wildlife such as hippopotamus amphibious, waterbuck, buffalo, giraffe, eland, zebra, bushbuck, otters, rodents, Thomson’s and Grant’s Gazelles and various snakes. The lake when first studied had only one fish species, the endemic Aplocheilichthys antinori which was last recorded in 1962,(Elder *et al* 1971). Since 1925 various fish introductions have been made (Litterick *et al* 1979, Muchiri and Hickley, 1991). Over the last decade the fish stocks have drastically declined due to the use of undersize nets, more fishing activities than permitted and seining by illegal fishers (Muchiri and Hickley, 1997). Since 1989 the Lake Naivasha Riparian Association has been active in promoting a variety of environmental issues in order to conserve the lake’s natural resources. Following initiatives by the Association, the Kenya Government in 1995 nominated Lake Naivasha as its second Ramsar site. Formally gazetted into law in October 2004, within weeks it became (and still remains today) sub-judice

(Government of Kenya 2001).

2.4 Demography of Lake Naivasha

According to the population census published by the Government of Kenya in 2009, Naivasha division had a population density of 89 persons per square kilometer, thereby summing up to a total population of 158,679 persons in the area covering 1782 square kilometers. Presently, the population is estimated at 650,000 persons, with an annual growth rate of 3.1%.

2.5 Water Flow of Lake Naivasha

The important of Lake Naivasha to the national and local economy is great. The lake serves as a supplier to the water demands for nearby towns e.g. Nakuru. The rivers that drain the catchment have been increasingly exploited by water abstraction.

The surface inflows of the lake arise from rivers; Gilgil and Malewa which are perennial and Karati which is seasonal. River Malewa contributes 90% of the water discharged into the lake. The average air temperature is moderate with monthly mean varying from 15.9- 18.5 degree Celsius.

The combination of low temperature, low relative humidity, and low rainfall make January and February the months with the highest evaporation (Gaudet and Melack 1981). Rainfall is bimodal taking place in April and July for the long rains and October- November for the short rains. Direct precipitation in the lake is minimal although occasionally, torrential rains are experienced. Inconsistency in the pattern of rainfall is very common. Rainfall on the surrounding highlands quickly percolates into the ground and form there quickly and seeps through into the lakes (Gaudet and Melack, 1981).

Rainfall in the basin is the highest in the Nyandarua Mountains (1,400- 1,600 mm per year). Lake Naivasha is located in the shadow of rain and receives between 500-700mm yearly. Richardson and Richardson (1972) approximated evaporation from the water surface to be around 1366mm annually. This shows that the lake depends on rainfall at higher altitude, discharged through river Malewa and underground seepage for its survival.

The main annual temperature of the lake varies with altitude ranging from $25^{O}C$ on the shores of the lake to 16◦c in the Aberdare Mountains, with a daily temperature ranging from $5^{O}C$ to $25^{O}C$. The months of December to March are the hottest periods. July is the coldest month with a mean temperature of $23^{O}C$ (Mireri, 2005). The Aberdare mountain ranges cast a rain shadow over the rest of the basin collecting moisture from the trade/monsoon winds. The average rainfall in the lake basin ranges from 1350mm in the Aberdare mountains to 600mm on the shores of the lake. Rainfall is bimodal and is distributed between two rainy seasons in April- May (long rains), and October – November (short rains). Most upper parts of the catchment are considered to be semi-humid and are suitable for rain- fed agriculture, whereas, the area around the lake is classified as semi-arid (Mireri, 2005).

There is a range of other ephemeral rivers carrying storm water runoff to the lake. The largest of this is the Karati, which flows for two months of the year and drains to the area east of the lake. It only reaches the lake in the high rains. The drainage from the west infiltrates before reaching the lake and there is not much runoff reaching the lake from the south (Mireri, 2005).

The Malewa mouth is experiencing increase in nutrient load that can be alluded to the farming and human settlement activities in the surrounding areas. Also, the lake faces a range of water quality issues ranging from increase in nutrients loads resulting in increased growth rate of water hyacinths and sewage (either from the municipal sewage facility, surface runoff or through seepage from pit latrines).

Lake Naivasha is the only fresh water lake amongst its neighboring lakes in the Rift Valley (Magadi, Elementatia, Nakuru, and Bogaria) that is not having a surface outflow. This means that the lake has a subsurface outflow as there needs to be a regular flow to stop the mineral salts in the lake's water.

2.6 Remote Sensing Technique to Assess Water Quality

Remote Sensing- is a science that deals with scanning of the earth by satellite or highflying aircraft in order to obtain information about it. Remote sensing techniques allow taking images of the earth surface in various wavelength region of the electromagnetic spectrum (EMS). One of the major characteristics of a remotely sensed image is the wavelength region it represents in the EMS. Some of the images represent reflected solar radiation in the visible and the near infrared regions of the electromagnetic spectrum, others are the measurements of the energy emitted by the earth surface itself i.e. in the thermal infrared wavelength region. The energy measured in the microwave region is the measure of relative return from the earth's surface, where the energy is transmitted from the object itself. This is known as active remote sensing, since the energy source is provided by the remote sensing platform. Whereas the systems where the remote sensing measurements depend upon the external energy source, such as sun are referred to as passive remote sensing systems. Remote sensing has proven to be an efficient way to monitor water resource. Henceforth, Remote Sensing techniques can be used to monitor water quality parameters. Optical and thermal sensors on boats, aircrafts and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for management practices to improve water quality (Ritchie, J.C *et al*, 1976). Use of remote sensing in assessing water quality has expanded due to increased scanning of water bodies within a short time. The main parameters examined in this study are coliforms (Chlorophyll) concentration, water turbidity due to erosion and water pollution as well as total suspended materials (TSM). All these cause changes in the color of the water bodies on the various wave lengthens of the electromagnetic spectrum. Assessing regional water quality is necessary but limited by scarcity of data. In this study, we have compared changes in water quality of Lake Naivasha using remote sensing data with results obtained via laboratory analysis to ascertain the level of accuracy between both methods. We did mapping to provide ability to identify turbid and clear water with focus of producing water quality using the MERIS images. The Meris is a Medium Resolution Imaging Spectrometer. MERIS is one of the main instruments on board the European Space Agency (ESA)'s Envisat platform. It is very useful for the measurement of water quality parameters. The instrument is composed of five cameras disposed side by side, each equipped with a push broom spectrometer.

Although remote sensing techniques have been used extensively for assessing wetlands, very little data are available on their uses for detecting noxious macrophytes (weeds) in waterways. Research efforts at the United States Department of Agriculture- Agriculture Research Service (USDA-ARS) Kika de la Gorza Agricultural Research Laboratory, Weslaco, Texas, Utilizing Remote Sensing, the Global Positioning System (GPS), and Geographic Information System (GIS) for detecting and mapping noxious aquatic weeds has focused on three species ; water hyacinth (*Eichhornia Crassipes*), Salvinia Molesta and Salvinia Spp (Mitchell, D.S., 1976).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

Lake Naivasha is located in the Africa's Eastern Rift Valley in Kenya, (0.45^{O}S, 36.26^{O}E) 1,890 m above sea level and covers approximately 140 km^2. Lake Naivasha is Kenya's second largest freshwater lake supporting a rich ecosystem with about 350 bird species, papyrus fringes filled with hippos, riparian grass lands with waterbuck, giraffe, zebra and various antelopes graze, dense patches of riparian acacia forest with buffaloes, bushbuck and other creatures, beautiful swampy areas where waterfowl breed and feed. It is an important biodiversity ecosystem and received RAMSAR recognition in 1995 (Santiago M, 2002). Lake Naivasha lies on the floor of Africa's Eastern Rift Valley and is the second largest fresh water lake in Kenya (Ase, 1986) .The Lake is saddled between the Kinangop Plateau and Eburru hills. It covers a surface area variation between 120km2 and 150km2 during the dry and wet spells respectively. It fresh water condition is maintained due to the catchment area, biogeochemical sedimentation and underground seepage (Gaudet and Melack 1981). The lake ecosystems are made of the main lake and two smaller ecologically vital lakes called Lake Oloidien and Lake Sonachi.

In this study MERIS images were used. Earth observation data from MERIS images were selected for ten years interval i.e. 2002 to 2012. Parameters analysis by the MERIS images were turbidity, coliform (chlorophyll), Total suspended matters (TSM) or Total suspended solids, and back scattering suspended matters (conductivity). Water quality information was defined from MERIS push broom imaging spectrometer satellite images full resolution.

The MERIS images were subjected to sunlight to generate water quality information on chlorophyll concentration on the lake, turbidity, total suspended materials and back scattering suspended matters via electromagnetic radiation. From the resulting information, comparison was carried out to determine the trend in changes of water quality information in the lake using this remote sensing method compared to the laboratory method to ascertain the level of accuracy.

Considering the several benefits RS can provide this approach can surely be considered as a powerful tool for monitoring of water quality status as well as for water ecosystems preservation. All water study applications make use of the passive optical RS technique, which requires the sun as the only source of electromagnetic light. This electromagnetic energy interacts with different surfaces and finally is recorded by specific instruments called radiometers, able to measure the reflected/emitted radiance from several spatial distances (satellite and airborne platform or even manual instruments). The so captured water leaving energy, measured between 400 and 900nm wavelengths, can provide several useful information about Optically Active Parameters inside the water body (Lindell *et al.*, 1999). We define "optically active" as those parameters able to modify the spectral behavior of the water, contributing in the absorption and backscattering light processes.

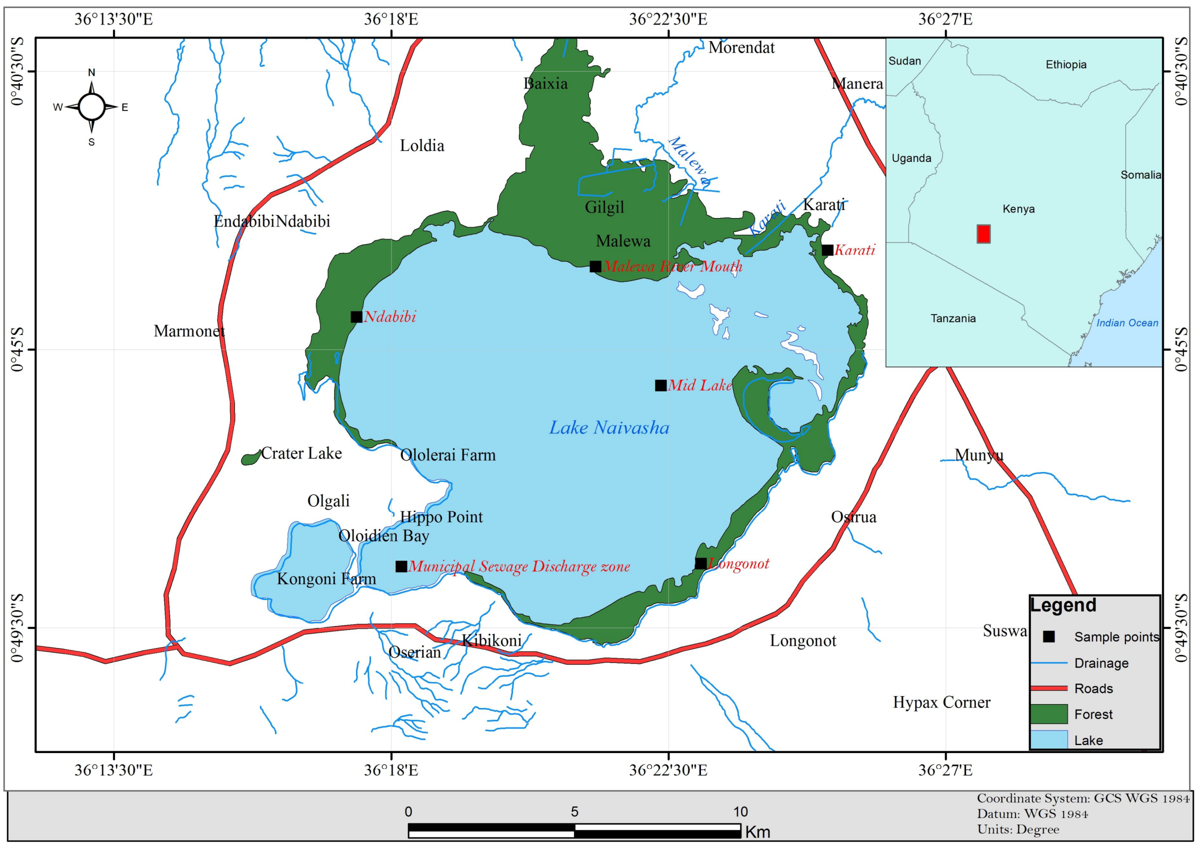

Figure 1: Sampling Points in Lake Naivasha

3.2 Sampling Point

Sampling location will be geographically identified using Global Positioning System (GPS) in order to locate them easily during the sampling period, as characterized in the sampling points below.

Table1: Sampling sites and GPS Coordinates

NO	SAMPING POINTS	GPS COORDINATES	SITES DESCRIPTION	NUMBER OF SAMPLES
1.	**Ndabibi Catchment**	$00^{O}44'52''E$, $36^{O}24'42''S$	In this site, the aquifers are approximately 100-300m depth and serve as a source of ground water recharge in the lake. The main agriculture activity of this catchment includes small scale and large scale subsistence and cash crops cultivation.	Eight(8)
2.	**Malewa River Mouth**	$00^{O}45'33''E$, $36^{O}22,22''S$	This is a site where water from the surrounding community enters into the lake and is about 1m in depth.	Eight(8)
3.	**Mid Lake**	$00^{O}43'39''E$, $36^{O}21'18''S$	The middle part of the lake where there is very little or no anthropogenic activity ongoing. This site is off shore with a depth of about 5m.	Eight(8)
4.	**Karati/ Naivasha point**	$00^{O}47'23''E$, $36^{O}19'03''S$	This site is made up of a stream located along the lake and the largest part of the lake and drains the area east of the lake. The main activity of this region is farming.	Eight(8)
5.	**Municipal Sewage Discharge zone**	$00^{O}48'30''E$, $36^{O}18'09''S$	This site is adjacent to the municipal council sewage plant. It is partly sheltered with papyrus as subsistence farming is carried out close to the littoral zone of the lake and has a depth of about 1m.	Eight(8)
6.	**Longonot**	$00^{O}44'08''E$,	This site is found in the vicinity of the	Eight(8)

		$36^{O}23'42''S$	lake where hippo are also present. This area also contains a small national part that serves an active site for tourism.	

3.3 Research Design

This study was carried out through field survey approach in which representative sampling sites were identified using the GPS. Water samples were also collected by grabbing method for the purpose of conducting laboratory analysis. The physico-chemical properties of water including pH, temperature, turbidity, dissolved oxygen and conductivity were determined in *situ* using their respective metres as follows: pH and temperature measurements were done using membrane pH meter model HANNA HI 8314 which was equipped with a temperature sensor. Conductivity was determined using conductivity meter model HANNA HI 98304. Dissolved oxygen was determined using DO meter.

These sites represented potential influence on the lake's water quality from catchment areas. Remote sensing technique was also employed to ascertain the water quality in the lake over the period under reviewed. The study was carried out from August to December 2014.

3.4 Apparatus and Reagents Used

Apparatus

1. Portable pH meter
2. Dissolved oxygen meter
3. Turbidity meter
4. Conductivity meter
5. Drying Oven
6. Filter papers
7. 100ml Volumetric flasks
8. Conical flasks

Reagents

Lactose fermentation broth

5ml of medium and bromothymol blue indicator

Sterile -1ml pipettes

Sterile-5ml pipettes

3.5 Sampling Procedures

The water samples were collected using glass bottles of 1liter capacity with stopper. Each bottle was washed with 2% Nitric acid and rinsed three times with distilled water. The bottles were preserved in a clean place. The bottles were filled with the water sample from the sampling points with water of the lake leaving no air space, and then sealed to prevent leakage. Each container was clearly marked with the name of the sampling point and date of sampling. The determination of the water quality of the lake were inclusive of pH, temperature, dissolved oxygen, turbidity, total suspended solids, total dissolved solids, and coliforms that were determined via laboratory procedures and remote sensing techniques. The water samples were collected from the six sampling points on the lake using the grabbing method as shown below in the photo.

Figure 2. The water samples collection from the sampling points along the lake.

3.6 Sample Analysis

pH

pH of the water was measured insitu using a portable pH meter with a probe. Measurement of the pH of the water was carried out 5cm from the surface to the depth at each of the sampling point. The pH probe was placed in the water sample and connected to the pH metre. At the tip of the probe there is a thin glass bulb. Inside the bulb are two electrodes that measure voltage. One electrode is contained in a liquid with a fixed pH. The other electrode responds to the pH of the water sample. The difference in voltage between the two probes is used to determine the pH.

Procedures

1. The pH meter and the probe were calibrated in accordance with the manufacturer's specification.
2. The water samples were collected in clean glass container deep enough to cover the top of the probe. Splashing or agitating of the water samples collected were avoided as much as possible so as to not make the pH reading to be inaccurate or erroneous.
3. The probe was rinsed with water from the sample before placing it in the sample container.
4. Upon rinsing the probe with water from the sample, the probe was placed in the sample.
5. The meter was adjusted for temperature where it was required for a temperature adjustment in accordance with the manufacturer's specifications.
6. Waited for the meter to come to equilibrium. The meter was equilibrated when the measurement became steady.
7. Finally the pH measurement of the sample from the probe was read in accordance to the manufacturer's specifications

Temperature

Temperature measurements was carried at the same time as the pH reading using the same portable pH meter with the temperature sensor mode located at the tip of the pH probe. Temperature was measured at the water surface and at the bottom also. The temperature was measured with the pH meter temperature sensor mode immersed directly in the water body at a depth of 5cm for 2minutes to allow the meter to come to the exact temperature of the water and the reading was recorded.

Procedures:

1. The temperature was measured by lowering the temperature sensor mode so the tip is a few inches below the water surface (5cm) below the water surface or place in the sampling container.

2. It was allowed to come to equilibrium and read immediately.
3. The time of the day was recorded.

Dissolved Oxygen

Dissolved oxygen measurements were carried out on site using the portable pH meter at the D.O. mode as the pH and temperature measurements. The measurement of the dissolved oxygen was also carried out 5 to 7cm from the surface to the depth at each of the sampling points.

Procedures:

1. The probe was calibrated according to the manufacturer's suggestion.
2. The water sample was collected in a sample container carefully to avoid aerating the sample.
3. The probe was placed in the sample afterward, allowing the meter to equilibrate. The dissolved oxygen concentration was read directly off the scale. The probe was gently stirred to aid water movement across the membrane.

Turbidity

The turbidity of the water was measured on site using the turbidimeter to determine the measure of the intensity of light that passes through the water. The sample was placed into a transparent glass sample cell and put in the sample chamber. The device read its turbidity value illuminating the sample and recording the scattered light. It is a simple measurement that requires the use of the turbidimeter to compare a reference solution to a sample. Turbidity measurement does not require any sample preparation, other than shaking the bottle well before analysis. The sample is simply poured into a glass tube, placed inside the instrument with a reference solution and the result is read directly from the instrument.

Total Dissolved Solids

The total dissolved solids of the water were established in the laboratory using the standard laboratory procedures from the water sample collected from the lake. Total Dissolved Solids are the unfilterable solids that remain as residue upon evaporation and subsequent drying at defined temperature. It gives the measure of ions dissolved in the water.

In the electrometric measurement of TDS, the conductivity measurements are used to calculate Total Dissolved Solids by multiplying conductivity (µS/cm) by an empirical factor, which vary between 0.55 to 0.9, depending upon the soluble components and temperature of measurement.

INSTRUMENT: Instrument for the measurement of pH, Temperature, Dissolved oxygen and Total Dissolved Solids (Model: Combo) manufactured by Hanna Instruments (P) Ltd.

The Total Dissolved Solids (in mg/l) of the water samples will be obtained by immersing the electrodes in a well-mixed sample.

Total Dissolved Solids are the total amount of mobile charged ions, including minerals, salts or metal dissolved in any given volume of water. Dissolved solids are related directly to the purity and quality of water. Water purification systems also affect everything that consumes, lives in, or uses water, whether organic or inorganic. Dissolved solids is directly linked to the conductivity of water. The higher the conductivity the higher the dissolved solids in water.

Total Suspended Solids

As in the case of the Total dissolved Solids, the Total suspended Solids were established in the laboratory using laboratory procedures. The total suspended solids determination was carried out by filtration using glass filter paper within a period of at least 2 hours. That is after evaporation.

Procedure:

1. Before sampling, filter papers were prepared by first soaking them in the distilled water samples, drying them at 103^{O}C, and they were weighed and their weights were recorded.
2. The dried, weighed paper were placed onto a filtering flask- wrinkled side up. The sample bottle were shaken first, then poured in the water. The amount of water needed to filter changed from one sample to another depending on how fast the water filter through. The volume of the water filtered were recorded
3. The filter was dried at 103 to 105◦C, and allowed to cool at room temperature and weighed. Dred, cooled, and weighed again. Continued until the fiber reached a constant weight. Finally, the end weight was recorded.
4. The increase in the weight of will represent the total suspended solids by using the equation below:

   TSS (mg/l^{-1}) = ([A – B) * 1000)/C

   Where A = End weight of the filter

   B = Initial weight of the filter

C = Volume of the water filtered

COLIFORM/BACTERIA TESTING

Presumptive Test

The coliform test was conducted qualitatively to include all aerobic, gram negative, non-spore forming rods which ferment lactose with the formation of gas in 24hrs at a temperature of 37◦C. The pre-sumptive test for the presence of coliform was based on the ability to ferment lactose with the production of acid and gas. The formation of gas within 24hrs constitutes presumptive evidence for the presence of members of the coliform groups. The absence of gas after 24hrs constitutes a negative test and further examination will not be required. The presumptive test was conducted under the requirement.

Requirements

1. Water samples were taken from each sample
2. Five tubes of lactose fermentation broth each containing 20ml of medium and bromothymol blue indicator were added
3. Two tubes of lactose fermentation broth each containing 5ml of medium and bromothymol blue indicator were added
4. Sterile -1ml pipettes
5. Sterile -10ml pipettes

Procedures

1. Five tubes of lactose fermentation broth, containing 20ml of medium each with 10ml of water sample was inoculated.
2. One tube of the lactose fermentation broth, containing 5ml of medium, with 1ml of water sample was inoculated.
3. The other tube of lactose fermentation broth, containing 5ml of the medium, with 0.1ml of the water sample was also inoculated.
4. All the tubes were incubated at 37◦C.
5. At the end of the 24hrs incubation period, all the tubes were examined for the presence of acid and gas.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

During the conduct of this study a total of four visitations were made to the study area in which forty eight (48) samples were collected from the six sampling points and taken to the laboratory for analysis. The sampling points included Ndabibi catchment, Malewa River Mouth, Mid Lake, Karati/Naivasha point, Municipal Sewage Discharge Zone, and Longonot. During these field visitations the following parameters were analyzed insitu which included pH, temperature, turbidity, dissolved oxygen, conductivity. The remaining parameters which included dissolved solids. Suspended solids, and coliform concentrations were analyzed in the laboratory under standard laboratory procedures. The results collected from the laboratory analysis were recorded.

In the study remote sensing data were collected using MERIS images. Water quality data from MERIS images were collected from 2003 to2011. Parameters analysis by the MERIS images were turbidity, coliform (chlorophyll a), Total suspended matters (TSM) or Total suspended solids, and back scattering suspended matters (conductivity). Water quality information was defined from MERIS push broom imaging spectrometer satellite images full resolution.

The MERIS images were subjected to beam to generate water quality information on chlorophyll concentration, turbidity, total suspended materials and back scattering suspended matters. From the resulting information, the data were analyzed to determine the trends of water quality information in the lake using this remote sensing method. Both the remote sensing and laboratory results were correlated using chi square correlation. Between the years 2003 to 2011, the water quality in Lake Naivasha has undergone enormous changes.

4.2 Laboratory Analysis

During the four field visits a total of 48 samples were collected from the six sample points with eight samples from each point. Some parameters were measured insitu, pH, temperature, turbidity, dissolved oxygen, and conductivity. The remaining parameters were analyzed in the laboratory which included total suspended solids, total dissolved solids and coliform. Below are the GPS coordinates used for each sampling points.

Table 2. The sampling points and GPS readings that were used to carry out the sampling activities along the lake

Sampling points	GPS Readings
Ndabibi Catchment	00^{O}44'52''E 36^{O}24'42''S
Malewa River mouth	00◦45'33''E 36^{O}22'22''S
Midlake	00^{O}43'39''E 36^{O}21'18''S
Karati	00^{O}47'23''E 36^{O}19'03''S
Municipal Sewage Discharge zone	00^{O}48'30''E 36^{O}18'09''S
Longonot	00^{O}44'08''E 36^{O}23'42''S

From the laboratory test conducted for each field visit, the following results were obtained and are being expressed in table format giving the monthly average results for the various parameters analyzed in the laboratory.

Table 3. The average readings of the various parameters from each sampling point for the month of September 2014.

Sampling Points	pH	Temperature	Dissolved Oxygen mg/l	Suspended Solids mg/l	Dissolved Solids mg/l	Turbidity FNU	Conductivity µS/cm
Ndabibi	±7.83	±22.2	±6.90	±0.0019	±0.292	±12.0	±260
Malewa	±7.6	±24.1	±5.24	±0.0016	±0.14875	±10.57	±248
Midlake	±7.6	±24.1	±5.24	±0.0011	±0.32715	±9.45	±256

Karati	±7.6	±24.1	±5.21	±0.0030	±1.33205	±12.30	±245
Municipal	±7.26	±22.1	±6.93	±0.0042	±2.2679	±12.60	±270
Longonot	±7.8	±24.1	±6.16	±0.0016	±0.2162	±12.30	±243

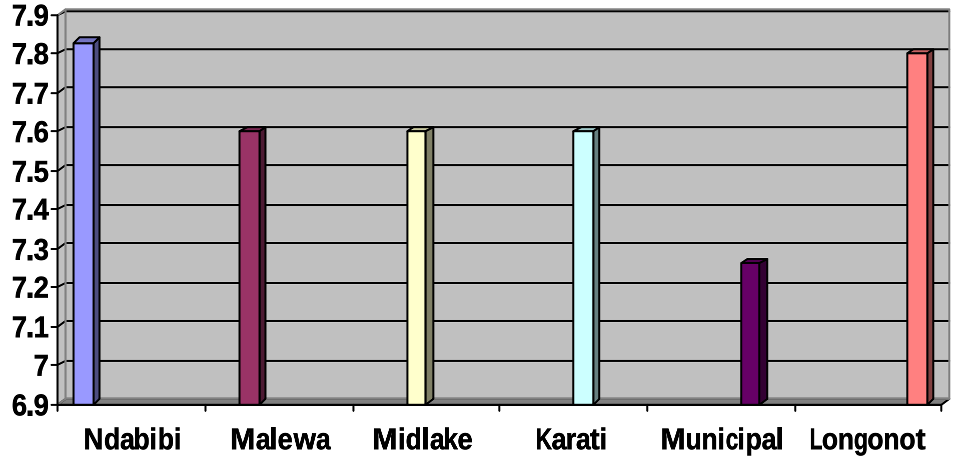

Figure 3: Average pH readings of the for the month of September 2014.

PH determines how acidic, basic or neutral the water is. It is determined based on defined scale, similar to temperature. This means that the pH of water is not a parameter that can be measured as a concentration or in a quantity. However, the measurement is between 0-14 thereby illustrating how acidic, or basic the water body is. The lower the number, the more acidic the water is. The higher the number above a pH of seven the more basic the water is. A pH of 7 is considered neutral. Henceforth, from the above figure representing the average pH values from the various sampling points of Lake Naivasha for the month of September, it is very clear to conclude that the average range of all the pH values is above 7. This indicates that the pH of the water dominantly is basic. This also suggests that each number above seven is 10 times more basic than the previous number on the logarithmic scale when counting above seven.

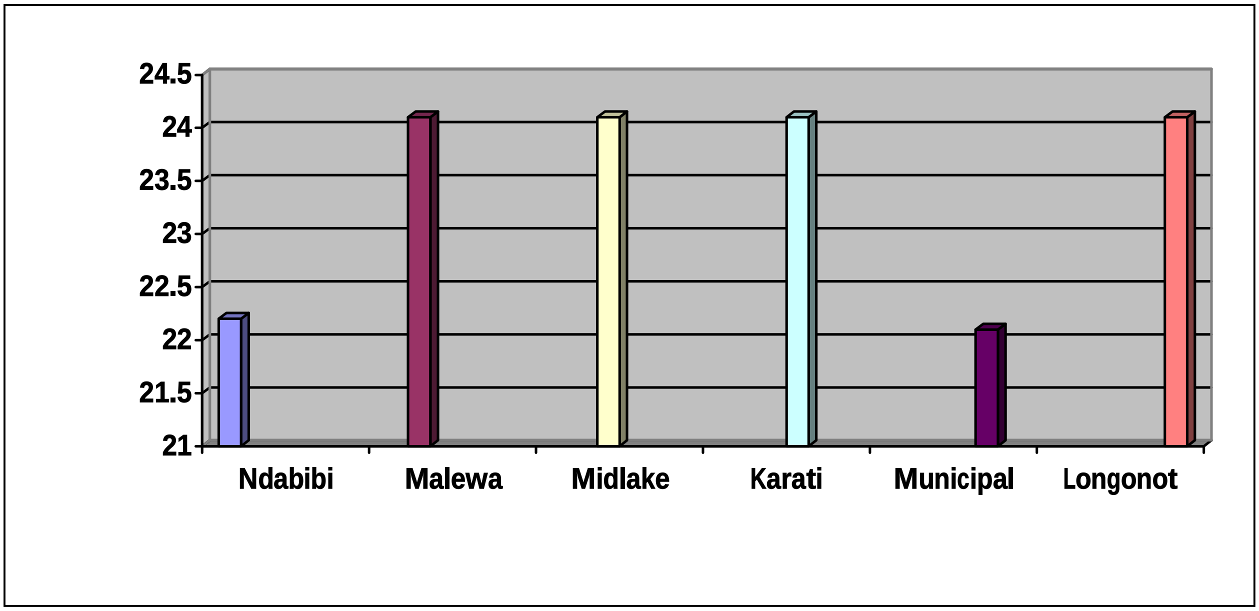

Figure 4: Average Temperatures (OC) from sampling sites for the month of September 2014.

When accessing water quality, it is very important to note that temperature and pH have an inverse relationship. The higher the temperature the lower the pH, and the higher the pH the lower the temperature. From the tables above giving the average temperature ranges for the various sampling points considered in this study it is very clear to conclude that the average temperature range for the months of September, 2014 as recorded were found between 20.6^{O}C to 24.75^{O}C. this correlates with the findings as postulated that the main annual temperature of the lake varies with altitude ranging from 25^{O}C on the shores of the lake to 16^{O}C in the Aberdare Mountains, with a daily temperature ranging from 5◦c to 25^{O}C (Mireri, 2005).

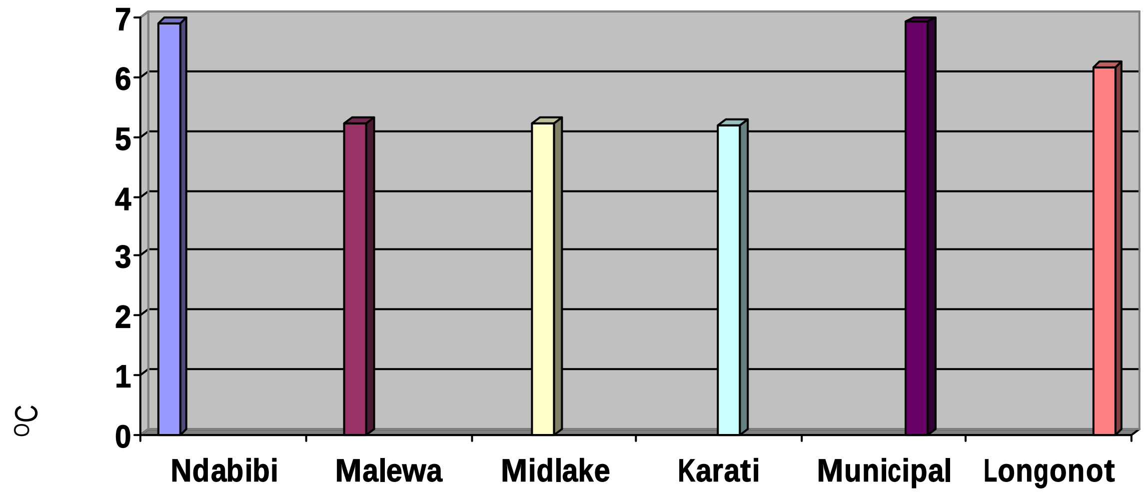

Figure 5: Average Dissolved Oxygen (mg/l) readings from sampling sites for the month of September 2014.

Dissolved oxygen is a very vital water quality parameter. It influences the livelihood of aquatic organisms that require oxygen. As a matter of fact, adequate levels of dissolved oxygen are critical to fish and other aquatic organisms' life. Concentrations are commonly measured in Milligrams/ Liter (mg/l) or as a percentage saturation (100%) as published in the article entitled "Computation of Dissolved Gas Concentrations in Water as functions of Temperature", seen in this chart below.

Table 4. The maximum Dissolved Oxygen value that should conform with the different Temperature range

Temperature ◦C	*Saturated Dissolved Oxygen Concentration (mg/l)*	
	Fresh Water	*Sea Water (35Ppm)*
0	**14.6**	**11.5**
15	**10.1**	**8.1**
20	**9.1**	**7.4**
25	**8.2**	**6.8**
30	**7.5**	**6.5**

REF. Colt. J., (1984) Computation of dissolved gas concentrations in water as a function of Temperature.

Henceforth, with the average temperatures for the months of September in Lake Naivasha found to be between 20.6^{O}C to 24.75^{O}C, and the main annual temperature between 16^{O}C to 25^{O}C, it is clear to note that the lake still maintains a fairly good dissolved oxygen level that ranges from 4.53mg/l to 6.79mg/l as recorded in table 11, 12 and 13. Notwithstanding, there is a need to maintain or improve on this fairly good dissolved oxygen level because with the rate of pollution in the lake the dissolved oxygen level could be depleted, if nothing is done to curtail the pollution of the lake.

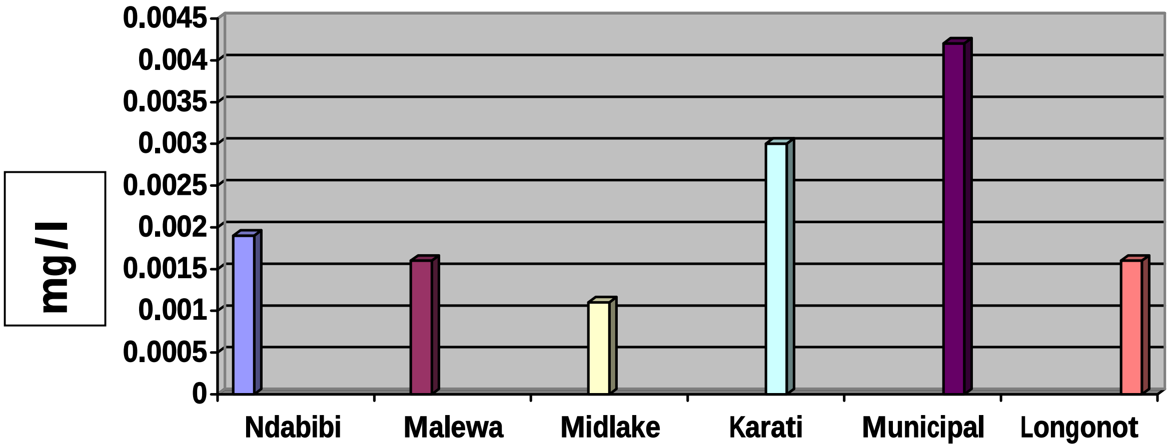

Figure 6: Average Suspended Solids (mg/l) readings from sampling sites for the month of September 2014.

Total Suspended Solids are the materials, including organic and inorganic matters that are suspended in the water. These could include silts, planktons and industrial wastes. High concentrations of suspended solids lower the water quality by absorbing light. Water becomes warmer and reduces the ability to hold oxygen necessary for aquatic life. This is because aquatic plants receive less light, photosynthesis decreases and less oxygen is produced. The combination of warmer water, less light and less oxygen makes it impossible for some forms of life to exist in the water. Suspended solids also clog fish gills, reduce growth rates and decrease resistance to disease, and prevent eggs and larval development. Prevention methods include protecting of the land in our water shed from erosion by the use of conservation tillage measures and giving urban run-off time to settle out before reaching the surface waters. The Table 11 from September showed that the Municipal Sewage Discharge zone had the highest average values of Total Suspended Solids.

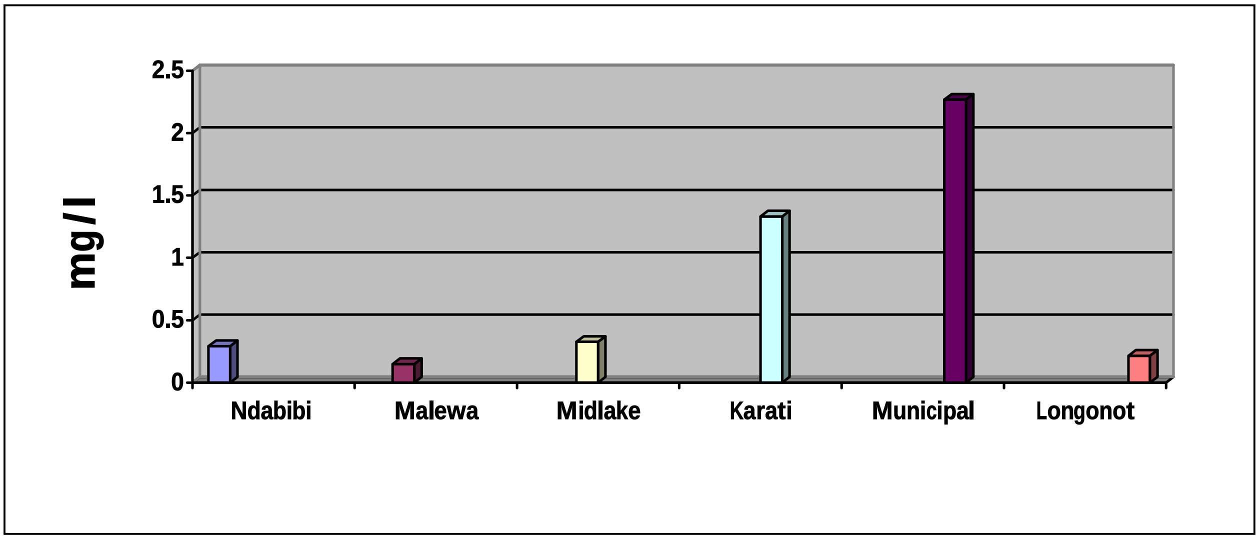

Figure 7: Average Dissolved solids (mg/l) readings from sampling sites for the month of September 2014.

Total Dissolved Solids are the total amount of mobile charged ions, including minerals, salts or metal dissolved in any given volume of water. Dissolved solids are related directly to the purity and quality of water. Water purification systems also affect everything that consumes, lives in, or uses water, whether organic or inorganic. Dissolved solids is directly linked to the conductivity of water. The higher the conductivity the higher the dissolved solids in water. From the above average dissolved solid levels as calculated and recorded in Tables 11, 12, and 13, it was observed that the Municipal Sewage Discharge zone had the highest value of Total Suspended Solids for the month of September.

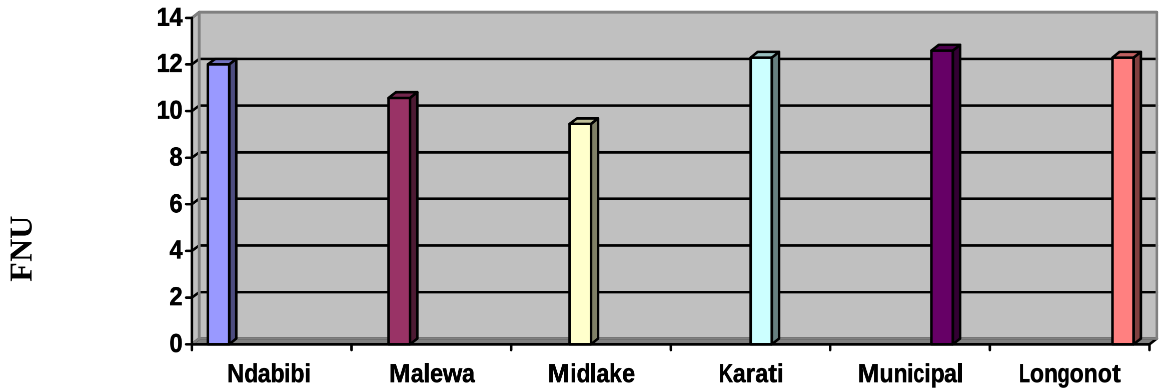

Figure 8: Average Turbidity (FNU) readings from sampling points for the month of September 2014.

The turbid nature of the water refers to the cloudiness or haziness of the water resulting from the large numbers of individual particles that are not seen with the naked eyes, similar to smoke in air. From the average readings for the sampling points for the month of September ranging from 9.45NFU to 12.60FNU, it was observed that the Municipal Sewage Discharge zone had the highest turbidity level.

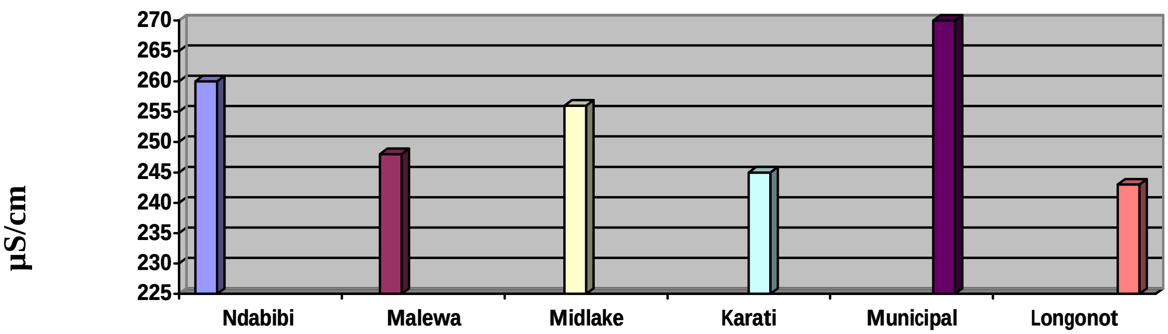

Figure 9: AverageConductivity (µS/cm)readings from sampling point for the month of September 2014.

Conductivity is the measure of the ability of water to pass an electrical current. Conductivity is usually about 100 times the total cations or anions expressed as equivalents. Typically, the higher the conductivity the higher the Total dissolved solids. The geology of an area as in the case of Lake Naivasha, affects the conductivity levels, i.e. the area through which the water flows. Conductivity is also affected by temperature. The warmer the water, the higher the conductivity (APHA, 1992). From the results above showing the average conductivity levels for the various sampling points for the months of September, 2014 it was observed that during the month of September the Municipal Sewage Discharge zone showed the highest conductivity value. This concord with the fact that the higher the total dissolved solids, the higher the conductivity as in the case of the Municipal Sewage Discharge zone. .

Table 5. The average readings of the various parameters from each sampling point for the month of October 2014.

Sampling Points	pH	Temperature °C	Dissolved Oxygen mg/l	Suspended Solids mg/l	Dissolved Solids mg/l	Turbidity NFU	Conductivity µS/cm
Ndabibi	±7.15	±24.25	±4.73	±0.0015	±0.2553	±11.71	±266.7
Malewa	±7.01	±24.75	±4.53	±0.0019	±0.1340	±16.09	±264.55
Midlake	±7.6	±243.2	±6.34	±0.0020	±0.3204	±9.68	±263.05
Karati	±7.26	±24.5	±5.03	±0.0025	±1.06705	±29.25	±265.55
Municipal	±7.25	±24.4	±6.92	±0.0035	±2.2132	±31.1	±277.15
Longonot	±7.5	±22.05	±6.99	±0.0021	±0.2252	±5.85	±256

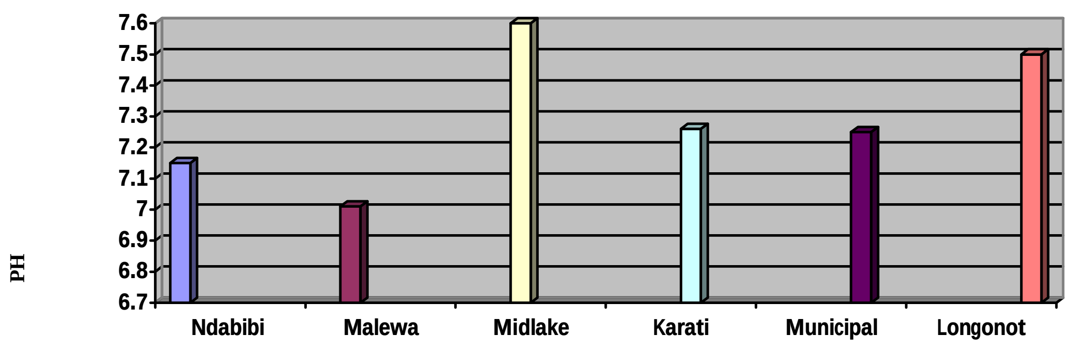

Figure 10:Average pH for the month of October 2014.

From the above figure representing the average pH values from the various sampling points of Lake Naivasha for the months of October 2014, it can be noted that the average of all the pH values from the sampling points ranged from 7.01 to 7.26 with the lowest value recorded from the Malewa river mouth and the highest value recorded from the Karati point. This indicates that the pH of the water was acidic basic.

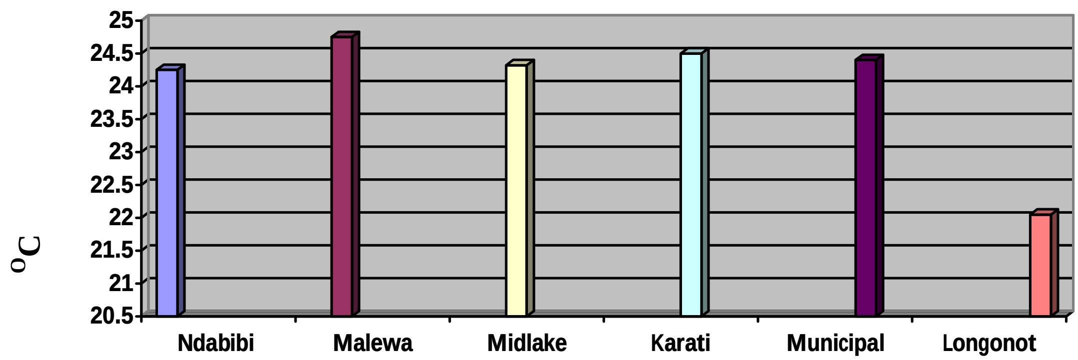

Figure 11: Average Temperatures (^{O}C) from sampling points for the month of October2014.

From table 5 and the figure above the average temperature ranged from 22.05^{O}C to 24.75^{O}C for the month of October 2014 for the various sampling points considered in this study.

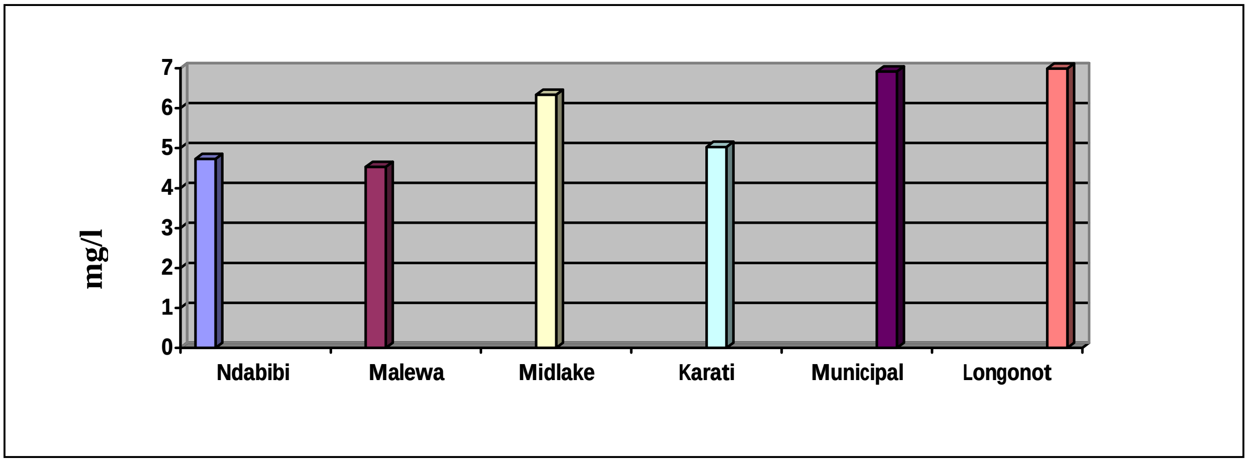

Figure 12: Average Dissolved Oxygen (mg/l) readings from sampling points for the month of October 2014.

The dissolved oxygen level of the lake for the month of October 2014 ranged from 4.53mg/l to 6.99mg/l. The highest reading was recorded from the Longonot sampling point and the lowest reading was recorded from the Malewa river mouth along the lake.

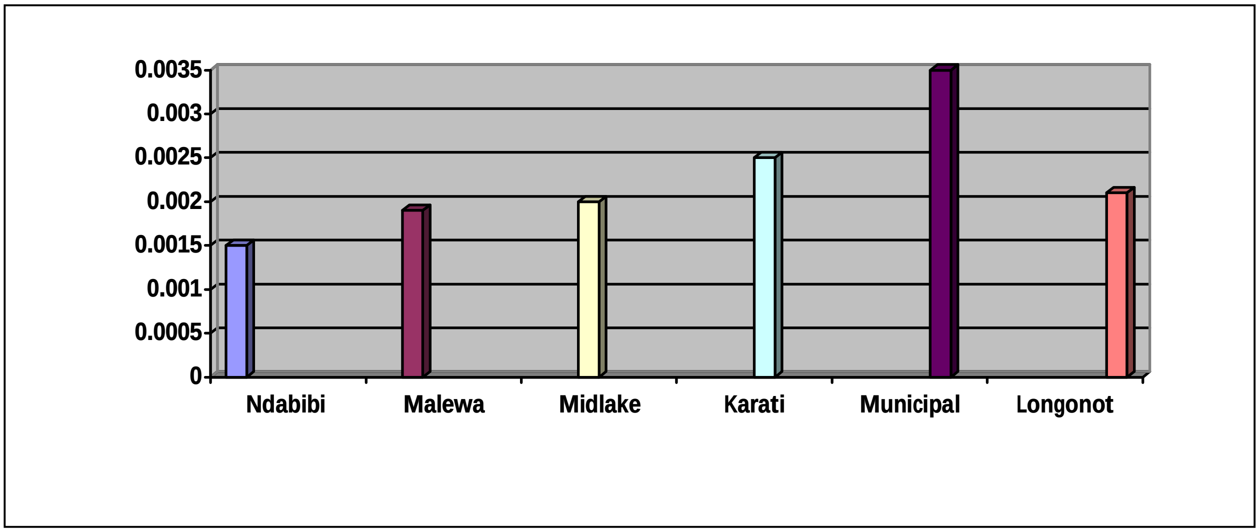

Figure 13: Average Suspended Solids (mg/l) readings from sampling points for the month of October 2014.

Total Suspended Solids are the materials, including organic and inorganic matters that are suspended in the water. These could include silts, planktons and industrial wastes. The readings showed that the Municipal Sewage Discharge zone had the highest avera.ge values of Total Suspended Solids and the Ndabibi catchment had the lowest reading for the month of October 2014. The range of the readings from highest to lowest were recorded as 0.00035mg/l to 0.0015mg/l.

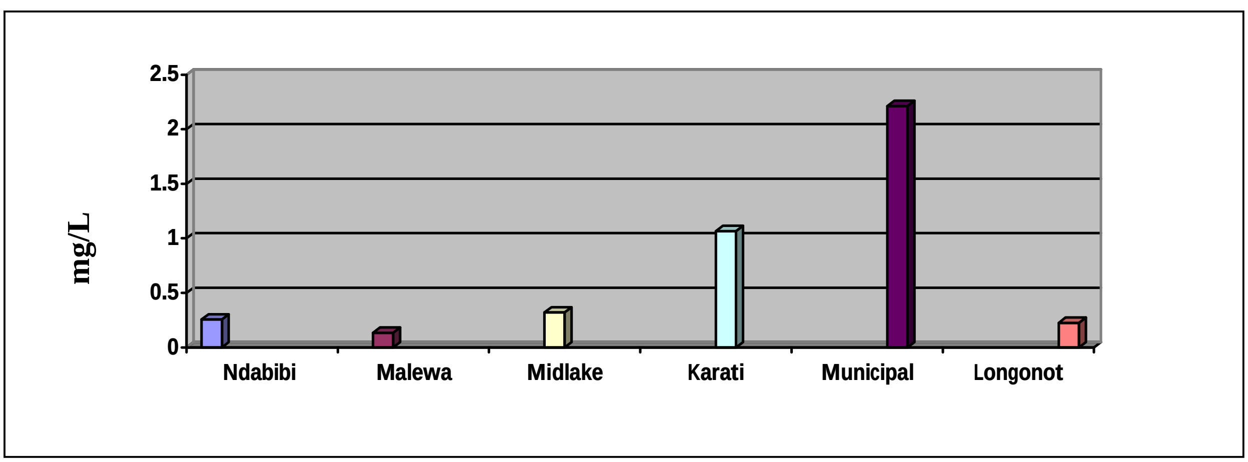

Figure 14: Average Dissolved solids (mg/l) readings from sampling points for the month of October

The chart above represents the total dissolved solids for the month of October 2014. The average readings from the various sampling points of the total dissolved solids ranged from 0.1340mg/l to 2.2132mg/l. The highest readings were recorded from the Municipal sewage discharge zone and the lowest reading was recorded along the Malewa river mouth.

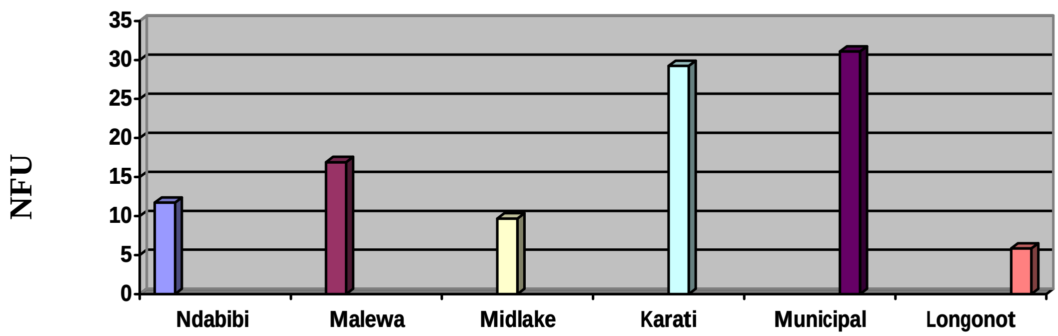

Figure 15: Average Turbidity(NFU) readings from sampling points for the month of October.

From the average readings for the sampling points for the month of October 2014 ranging from 5.85NFU to 29.250NFU, it was observed that the Karati sampling point had the highest turbidity level and the longonot sampling point had the lowest reading.

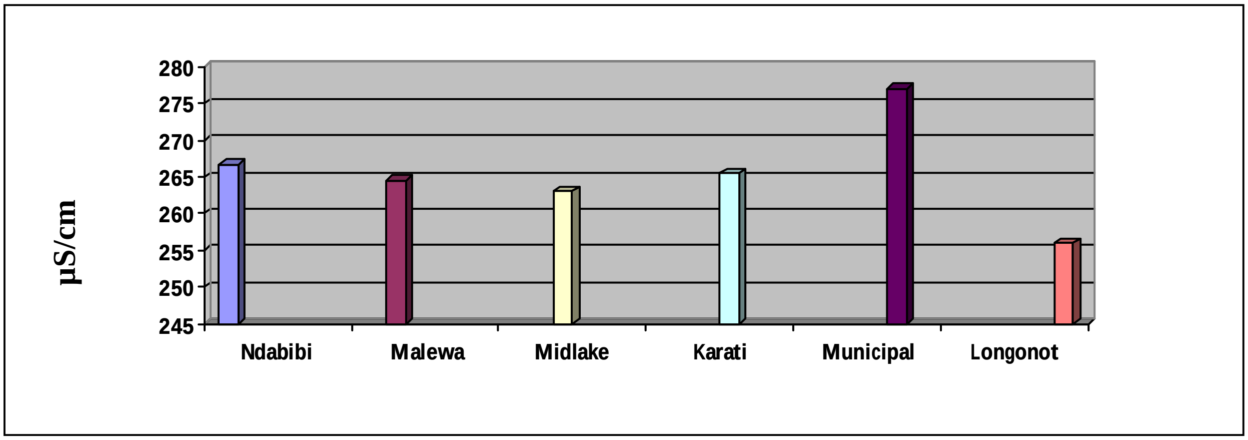

Figure 16: Average Conductivity (µS/cm) readings from sampling point for the month of October 2014.

The results above showed the average conductivity levels for the various sampling points for the month of October 2014, it was observed that during the month October 2014 the Municipal Sewage Discharge zone showed the highest conductivity value and longonot had the lowest reading. The average conductivity values from the sampling points ranged from 256 µS/cm to 277.15 µS/cm that is from lowest to highest.

Table 6. The average readings of the various parameters from each sampling point for the month of November 2014.

Sampling Points	**pH**	**Temperature ^{o}C**	**Dissolved Oxygen mg/l**	**Suspended Solids mg/l**	**Dissolved Solids mg/l**	**Turbidity FNU**	**Conductivity µS/cm**
Ndabibi	±7.68	±21.7	±6.79	±0.0013	±0.3113	±11.14	±250.
Malewa	±7.37	±22.9	±6.59	±0.0018	±0.12675	±12.74	±252.29
Midlake	±8.07	±20.6	±6.24	±0.0017	±0.30215	±11.48	±247.1
Karati	±7.43	±21.2	±6.19	±0.0020	±1.0616	±20.7	±250.6
Municipal	±7.72	±21.3	±6.19	±0.0036	±2.13795	±20.7	±250.6
Longonot	±7.32	±22.4	±5.35	±0.0021	±0.2001	±6.34	±251.5

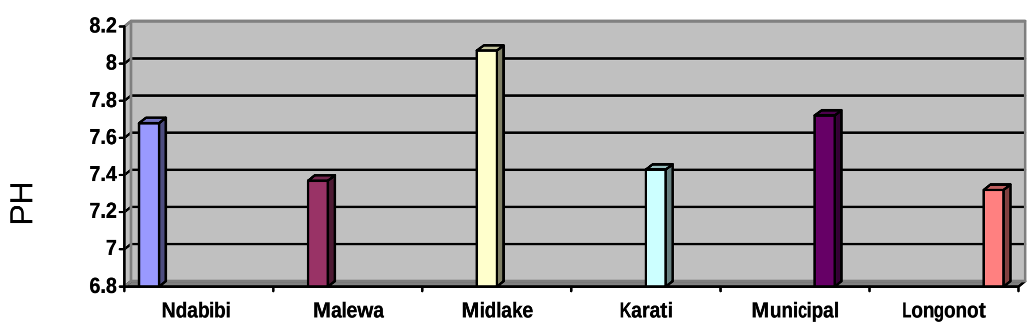

Figure 17. Average pH from sampling points for the month of November 2014.

The above figure representing the average pH values from the various sampling points of Lake Naivasha for the month of November 2014, it is very clear to conclude that the average range of all the pH values is above 7, ranging from 8.07 to 7.32. The highest reading was recorded from the Midlake and the lowest reading was recorded from longonot. This indicates that the pH of the water dominantly is basic.

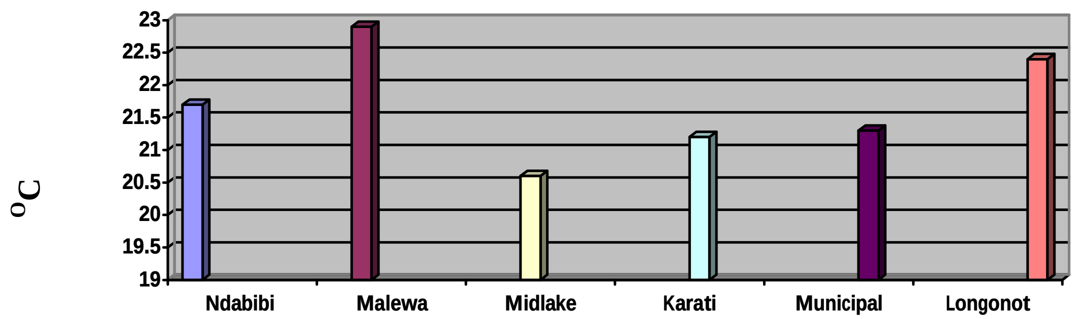

Figure 18. Average Temperatures (^{O}C) from sampling points for the month of November 2014.

The chart above gives the average temperature range for the various sampling points considered in this study for the month of November 2014. It is very clear to conclude that the average temperature range for the months of November, 2014 as recorded were found between 20.6^{O}C to 23^{O}C with Midlake having the lowest value of 20.6^{O}C and Malewa river mouth having the highest value of 22.9^{O}C.

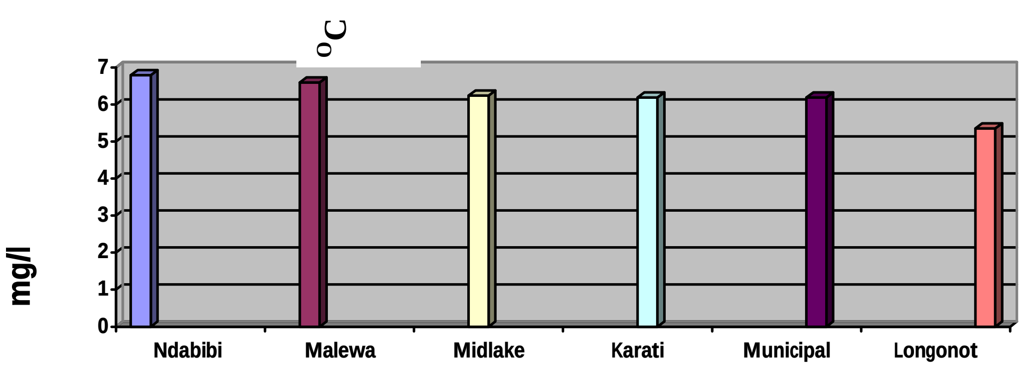

Figure 19. Average Dissolved Oxygen reading from sampling points for the month of November 2014.

From the above chart, the dissolved oxygen level ranged from 5.35mg/l to 6.79mg/l. The highest value was recorded along the Ndabibi catchment and the lowest reading was recorded along the longonot sampling point for the month of November 2014.

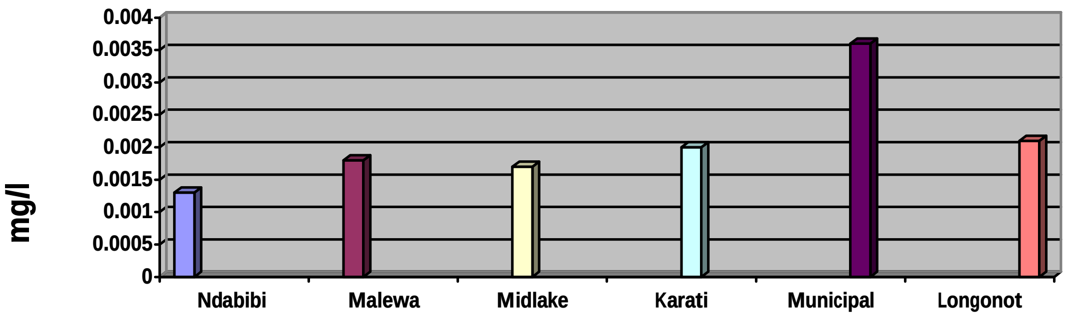

Figure 20. Average Suspended Solids (mg/l) readings from sampling points for the month of November 2014.

The chart above gives the average of the total suspended solids for the month of November 2014. The data showed that the Municipal Sewage Discharge zone had the highest average values of Total Suspended Solids of 0.0036mg/l and the Ndabibi catchment had the lowest value of 0.0013mg/l.

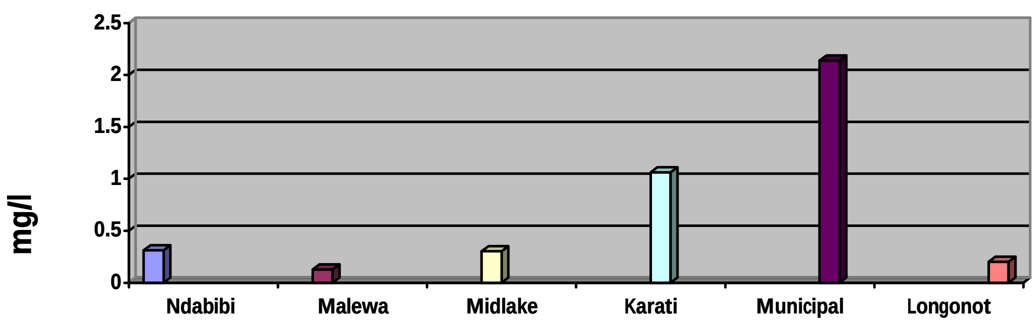

Figure 21. Average Dissolved solids (mg/l) readings from sampling points for the month of November.

From the above average dissolved solid levels as calculated and recorded in Table, it was observed that the Municipal Sewage Discharge zone had the highest value of Total Suspended

Solids for the month of November 2014 with a value of 2.137mg/l and the Malewa river mouth with the lowest value of 0.1267mg/l.

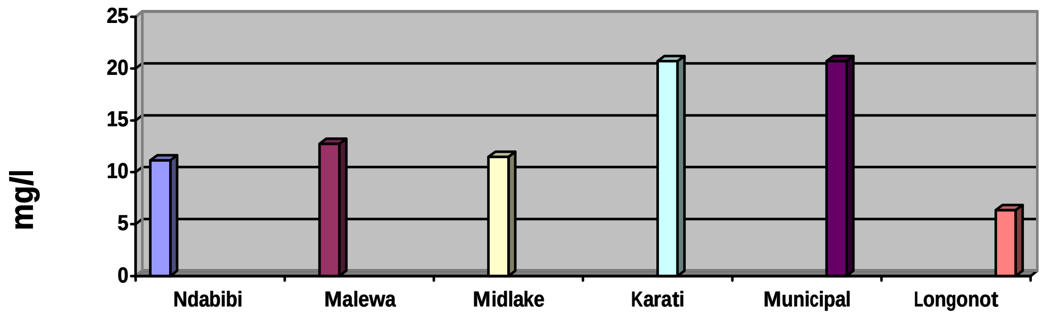

Figure 22: Average Turbidity(FNU) readings from sampling points for the month of November 2014.

The average readings for the sampling points for the month of November 2014 ranging from 6.34FNU to 20.7FNU, it was observed that the Karati and Municipal sampling points had the highest turbidity level 0f 20.7FNU and the lowest value was recorded along the longonot sampling point of 6.34FNU.

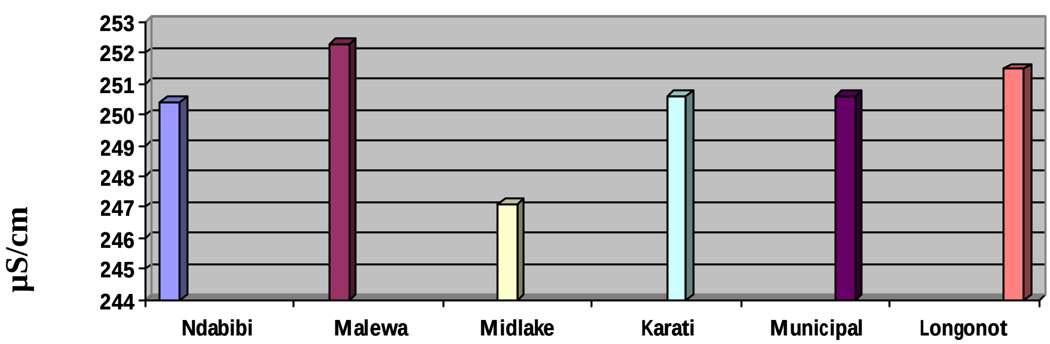

Figure 23: Average Conductivity (µS/cm)readings from sampling points for the month of November 2014.

From the results above showing the average conductivity levels for the various sampling points for the month 0f November 2014, it was observed that the Malewa River Mouth showed the highest conductivity value of 252.2 µS/cm and the Midlake had the lowest value of 247.1 µS/cm.

4.3 Results and discussions from Remote Sensing Data (2003- 2011)

In the study for the collection of the remote sensing data MERIS Beam Visat images were used. Earth observation data from MERIS images were selected for the period 2003 to 2011. The MERIS images were subjected to beam to generate water quality information on chlorophyll concentration on the lake (coliform), turbidity, total suspended materials and back scattering suspended matters via electromagnetic radiation. Water quality information was defined from MERIS Beam Visat imaging spectrometer satellite images full resolution. Data collection via the remote sensing techniques is heavily dependent upon electromagnetic radiation. This method is very active in the presence of sunlight for data generation by the MERIS image. One of the major characteristics of a remotely sensed image is the wavelength region it represents in the Electromagnetic Spectrum.

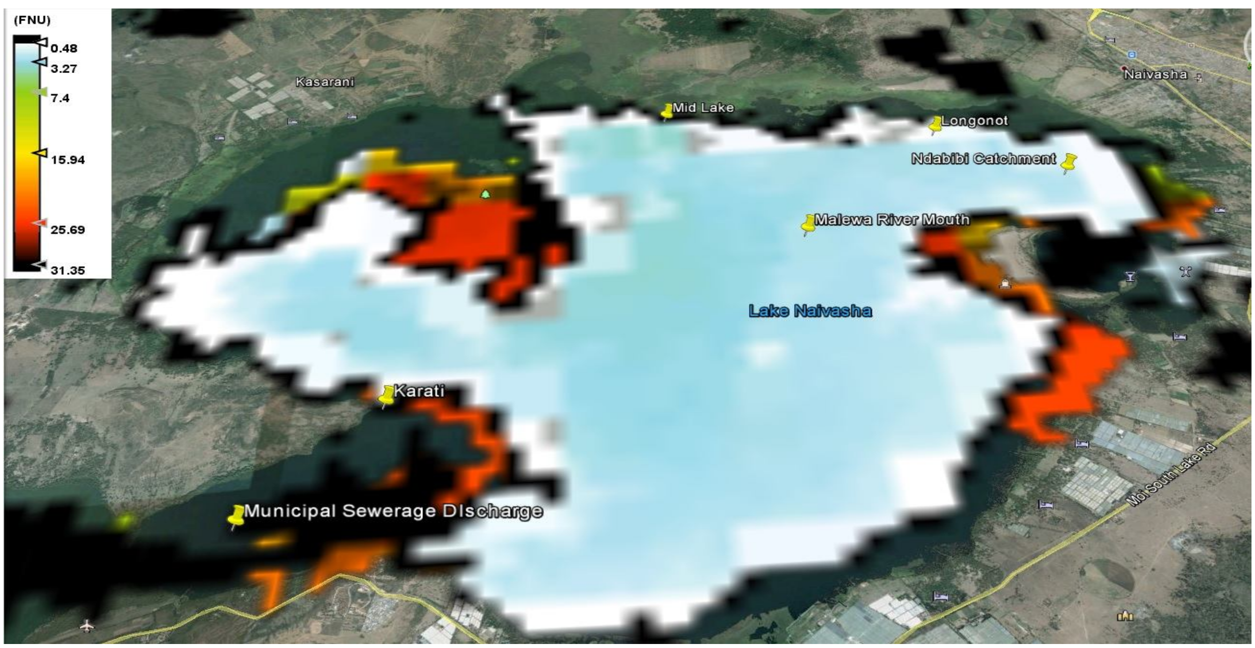

Figure 24: GIS Readings for the Remote Sensing imaging of the Various Sampling Points.

<u>2003 RESULTS</u>

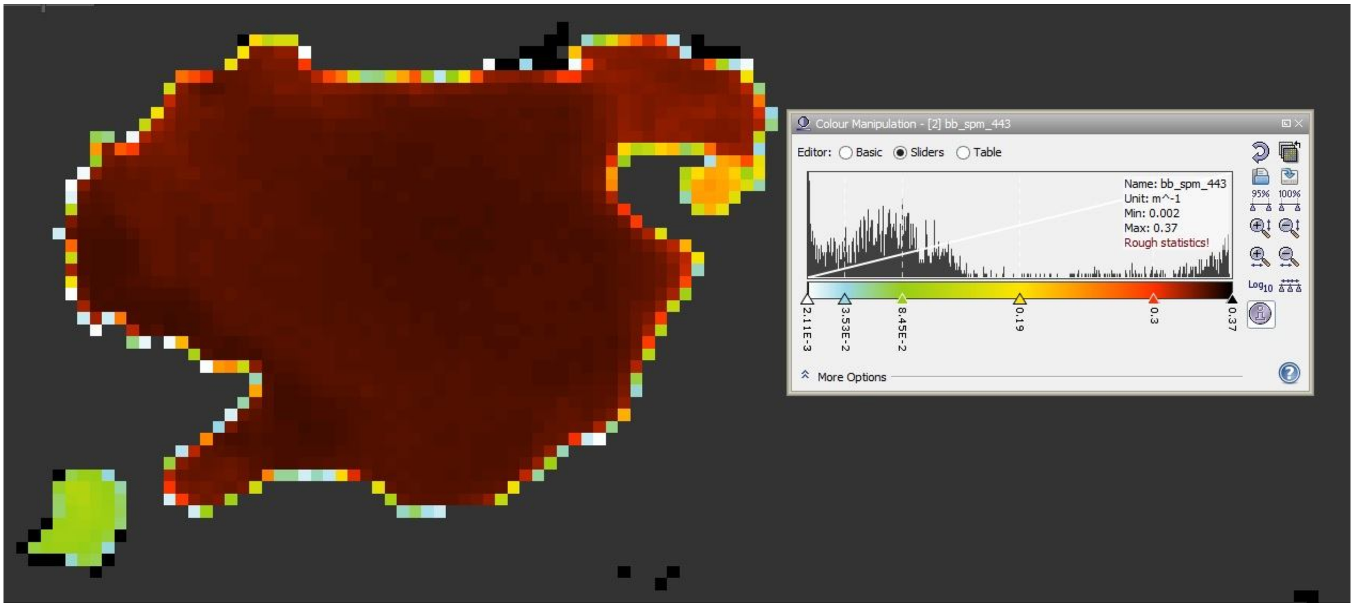

Figure 25: 2003 Results

Back Scattering Suspended Matters September2003

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of September 2003. In the month of September 2003 the satellite readings showed a high level for the Back Scattering Suspended matters as seem above in the range of 0.3 µS/cm as compared to the highest value on the of about 0.37 µS/cm. The range on the scale is from minimum to maximum 2.11E-3 to 0.37 µS/cm.

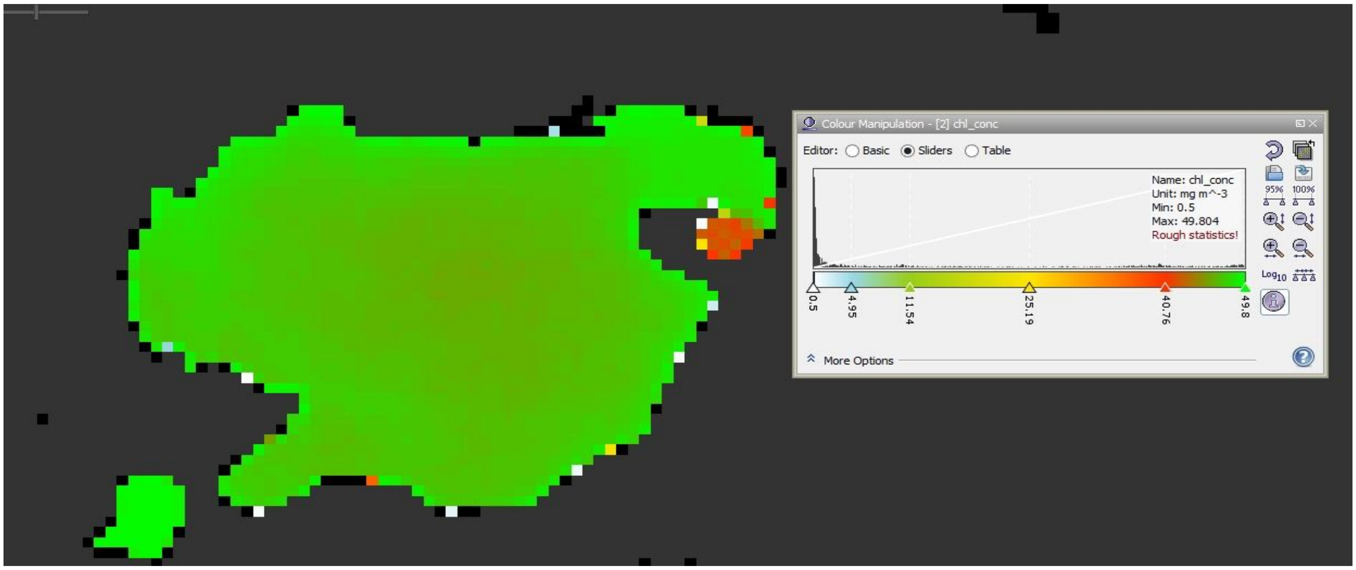

Figure 26: Chlorophyll – September 2003

The above image shows the Chlorophyll level of the lake for the month of September 2003. This indicates that the chlorophyll level in the lake was very high. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum that is from 0.5 to 49.804mg/l. The above image shows the chlorophyll level of the lake in September 2003 was very high in the range of the maximum level.

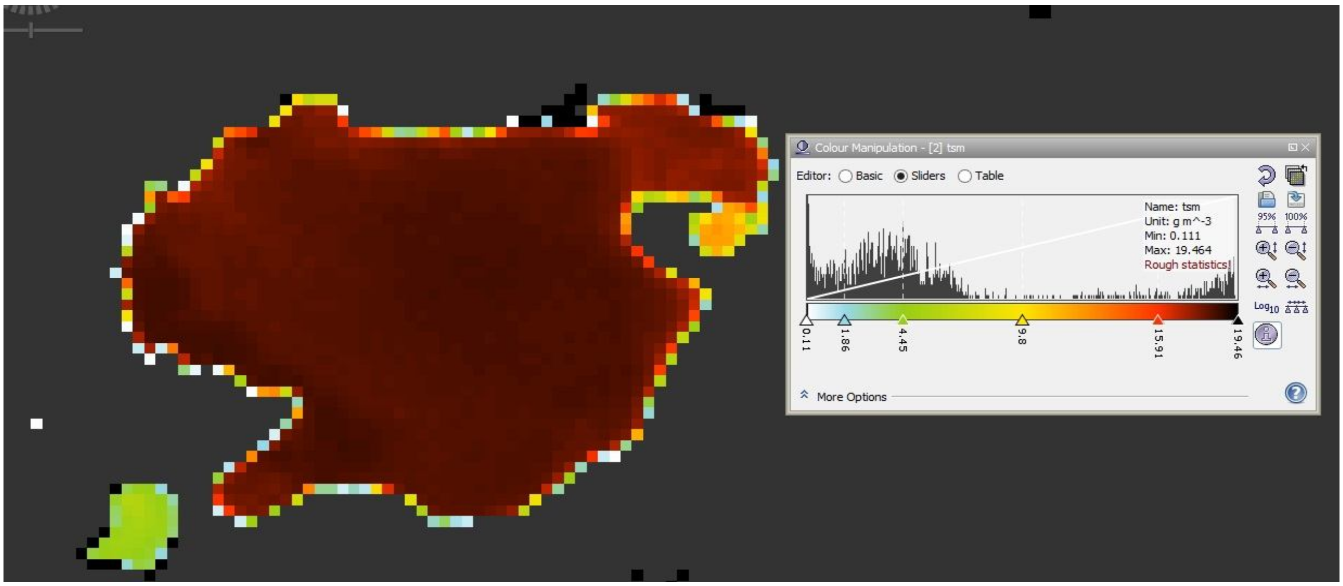

Figure 27: Total Suspended Matters – September 2003

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of September 2003. The levels as shown above in the rough statistics range from minimum to maximum 0.111- 19.464mg/l. The Total suspended matter level of the lake was found to be approximately 15.91mg/l. This shows that the Total suspended matter level of the lake for the month of September 2003 was high.

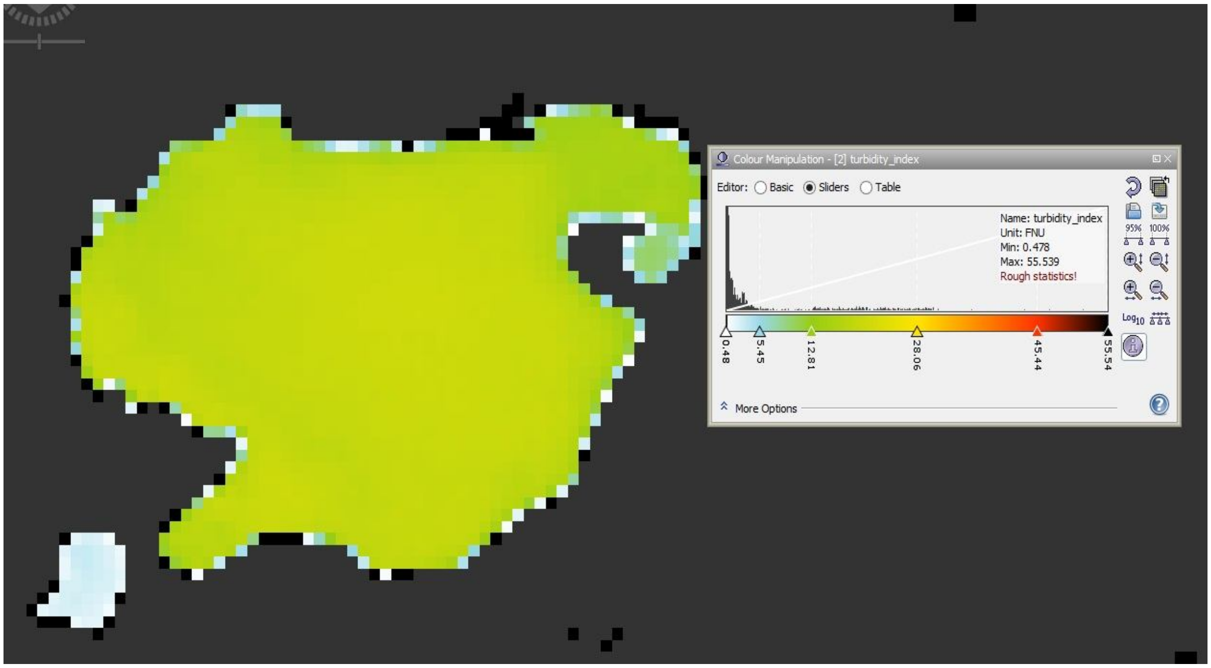

Figure 28: Turbidity – September 2003

The above image shows the Turbidity level of Lake Naivasha for the month of September 2003. The image shows the turbidity level of the lake during the month of September 2003. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum i.e. from 0.478- 55.539 FNU. The lake shows a turbidity level of approximately 12.81FNU, which indicates that it was fairly low.

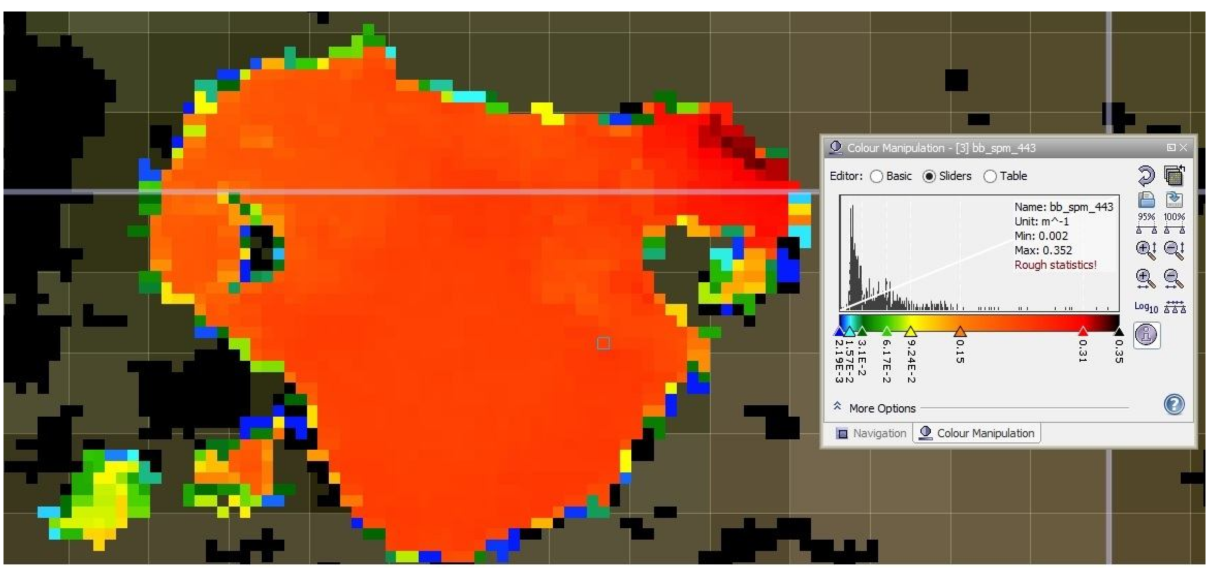

Figure 29: 2004 Results Back Scattering Suspended Matters November 2004

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of January 2004. In the year 2004 the only satellite reading captured was for January .This image shows a moderately high or medium level for the Back Scattering Suspended matters. The value of the Back Scattering Suspended matters was found to be 0.15 µS/cm as compared to the highest value of about 0.35µS/cm. The range on the scale is from minimum to maximum (2.19E-2 to 0.35).

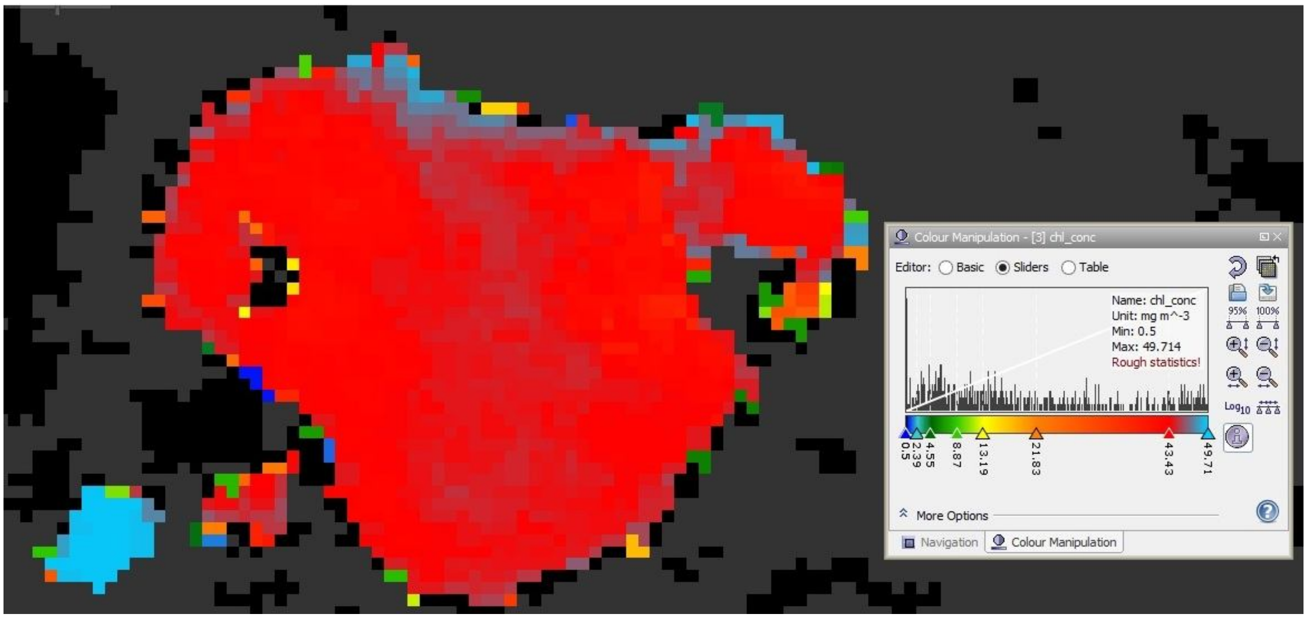

Figure 30: Chlorophyll – November 2004

The above image shows the Chlorophyll level of the lake for the month of November 2004. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum (i.e. 0.5mg/l to 49.74mg/l). The above image shows the chlorophyll level of the lake in November 2004 was very high in the range of the 43.43 mg/l as compared to the highest level of 49.74mg/l. This indicates that the chlorophyll level in the lake was very high.

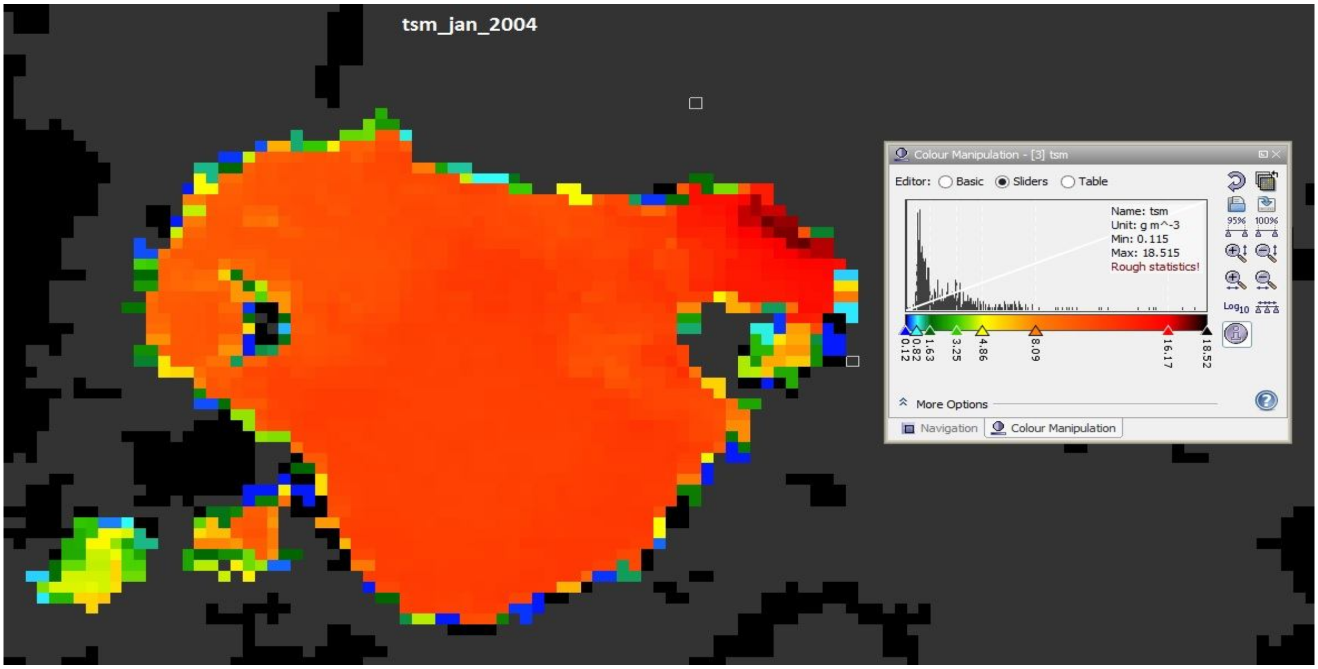

Figure 31: Total Suspended Matters November 2004

The above image shows the Total Suspended Matters level of Lake Naivasha for the month of November 2004. The levels as shown above in the rough statistics range from minimum to maximum are from 0.115 to 18.515mg/l. Henceforth, for the month of November 2004, the lake had an approximate level of 16.17mg/l, which shows that the Total suspended matter level of the lake for the month of November 2004 was high.

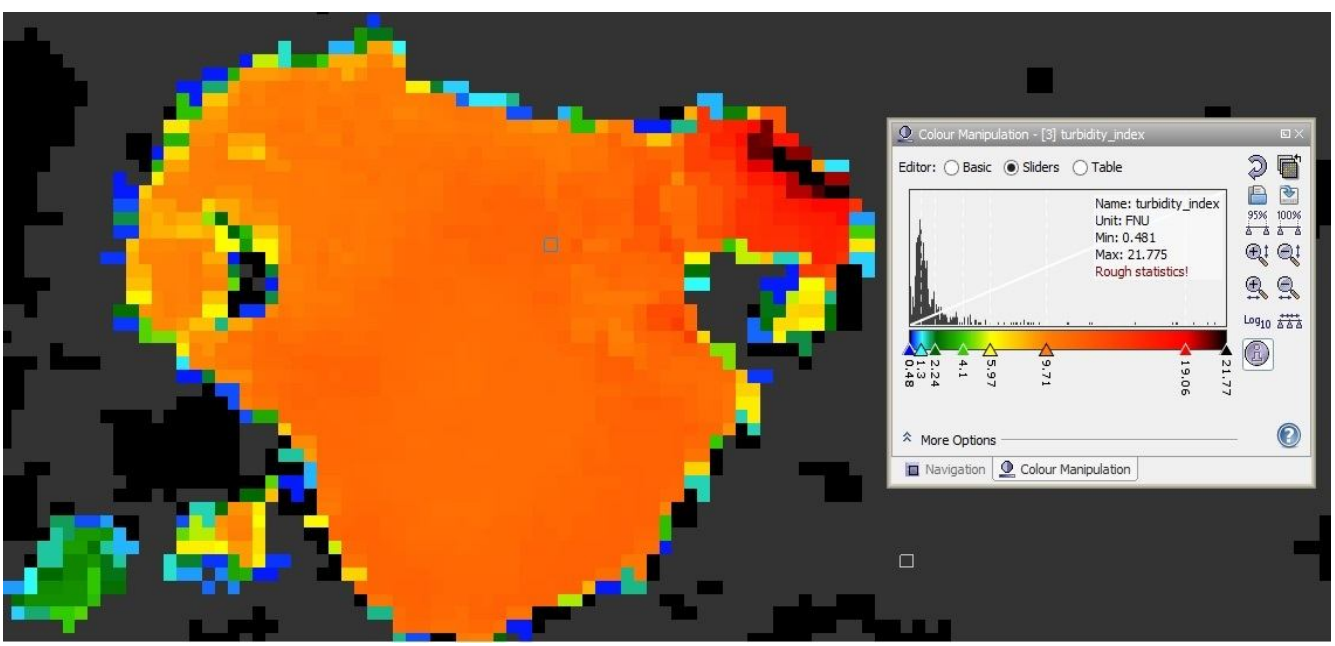

Figure 32: Turbidity – November 2004

The above image shows the Turbidity level of Lake Naivasha for the month of November 2004. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum was from 0.481- 21.775FNU. The lake shows a turbidity level of approximately 9.71FNU, which indicates that it was moderately high.

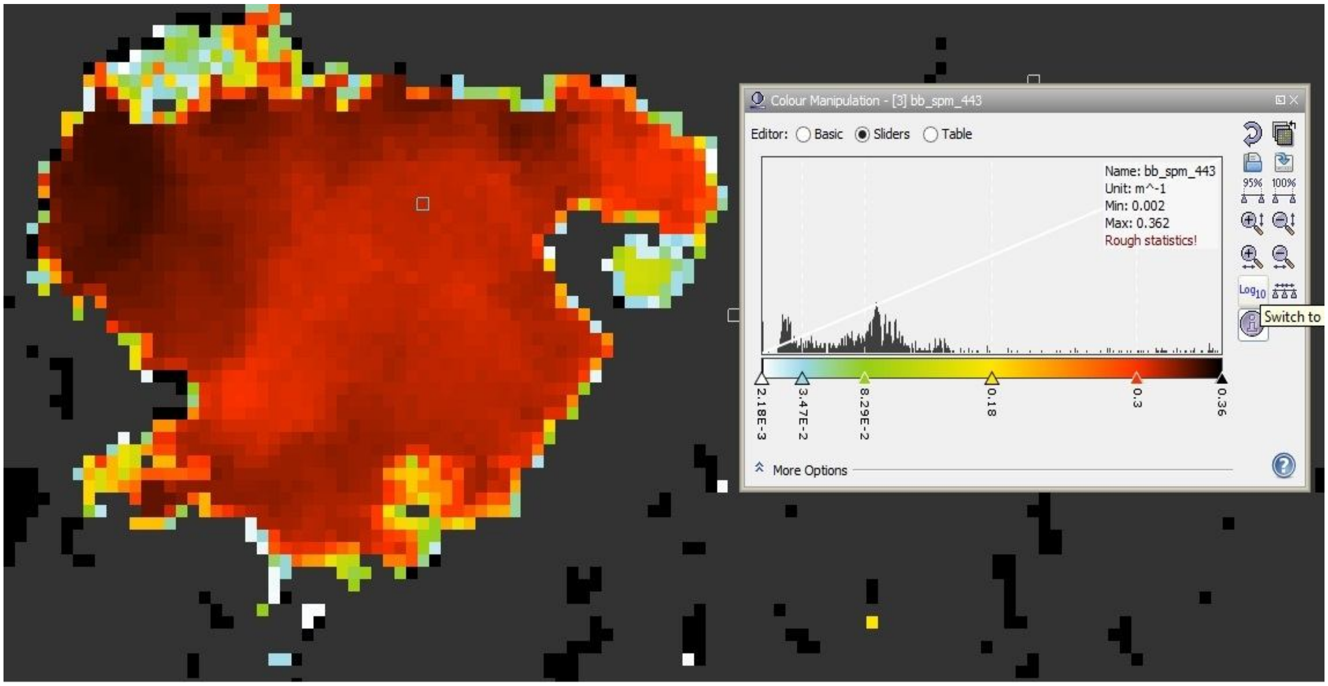

Figure 33: Results for 2005 Back Scattering Suspended Matters September

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of September 2005. In the month of September 2005 the satellite readings showed a value of 0.3 µS/cm as compared to the highest value of 0.36 µS/cm. The range on the scale is from minimum to maximum of 2.18E-3 to 0.36 µS/cm. This indicates a high level for the Back Scattering Suspended matters as seem above in

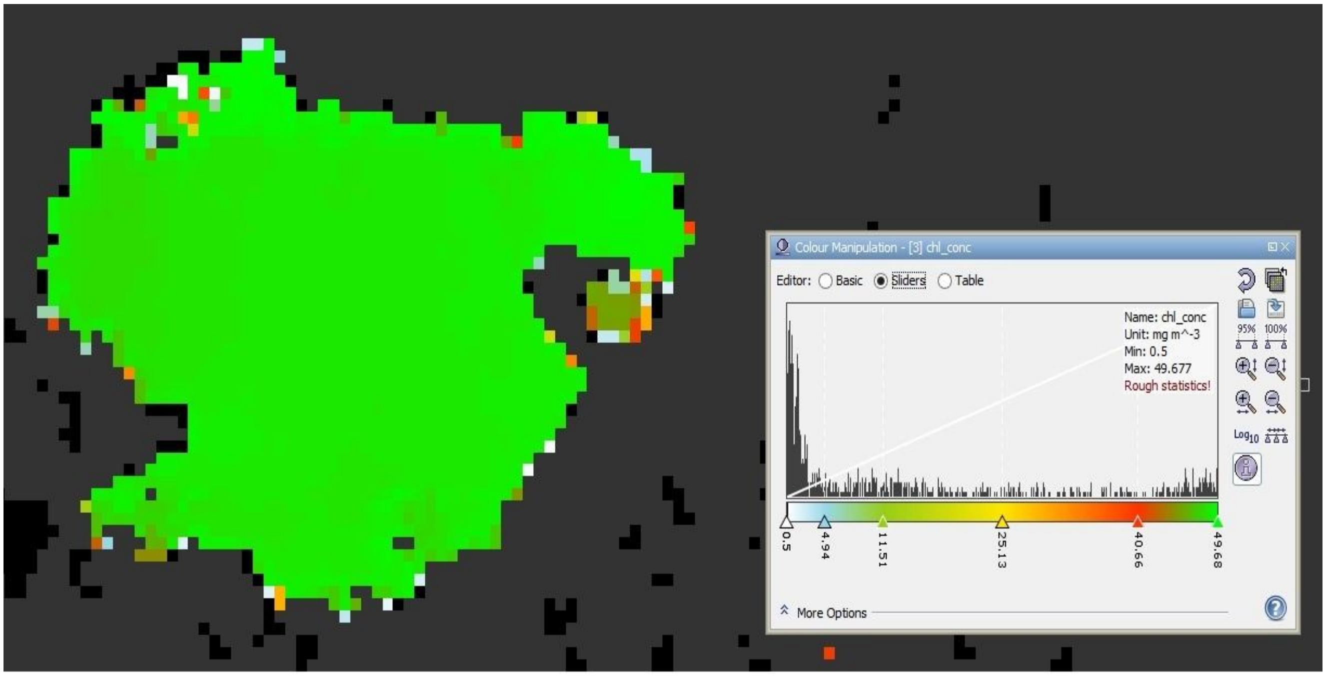

Figure 34: Chlorophyll – September 2005

The above image shows the Chlorophyll level of the lake for the month of September 2005. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum of 0.5mg/l to 49.677mg/l. The above image shows the chlorophyll level of the lake in September 2005 was very high in the range of the maximum level.

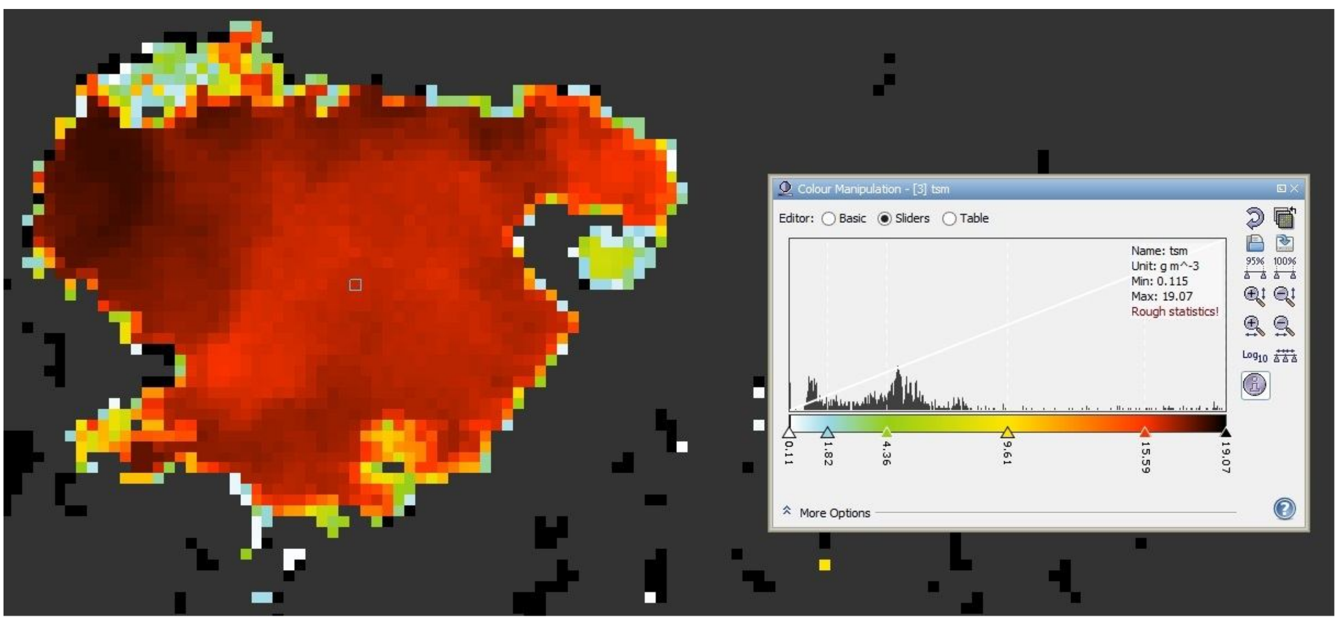

Figure 35: Total Suspended Matters September 2005

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of September 2005. The levels as shown above in the rough statistics range from minimum to maximum 0.115mg/l to 19.07mg/l. The Total suspended matter level of the lake was found to be approximately 15.59mg/l. The image shows that the Total suspended matter level of the lake for the month of September 2005 was high.

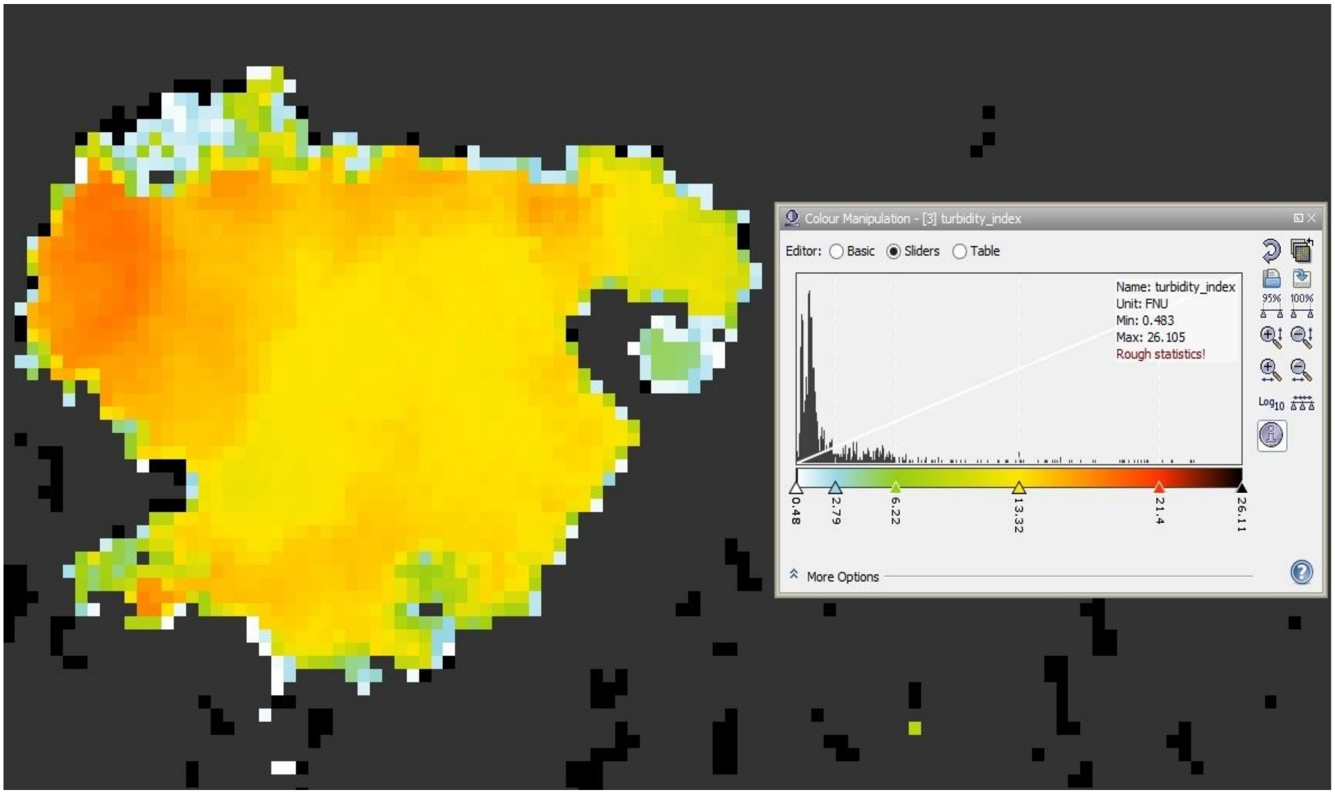

Figure 36: Turbidity – September 2005

The above image shows the Turbidity level of Lake Naivasha for the month of September 2005. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum was from 0.48-26.11FNU. The lake shows a turbidity level of approximately 13.32FNU, which indicates that it was fairly high.

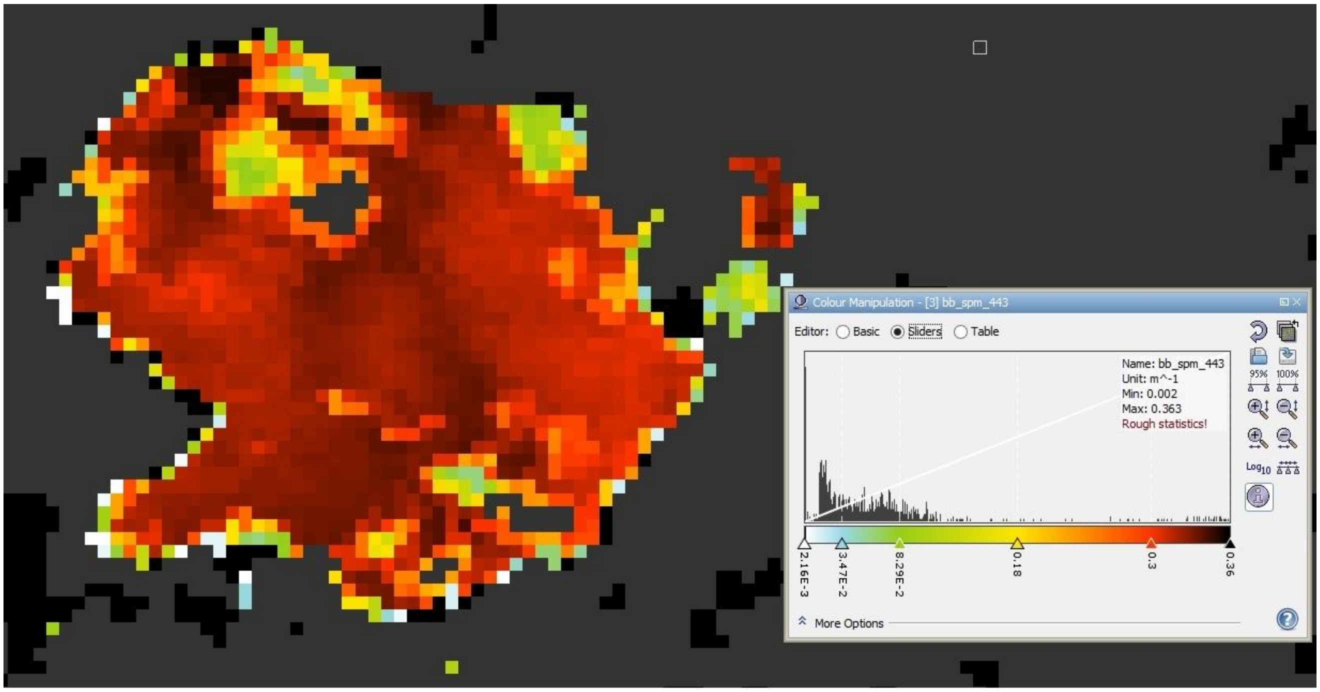

Figure 37: Back Scattering Suspended Matters November 2006

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of November 2006. As seem above the value of the Back Scattering Suspended matter was 0.3µS/cm as compared to the highest value of 0.36 m^1. The range on the scale is from minimum to maximum 0.002 to 0.36µS/cm. This indicates that the Back Scattering Suspended matters of the month of November 2006 in the lake was very high.

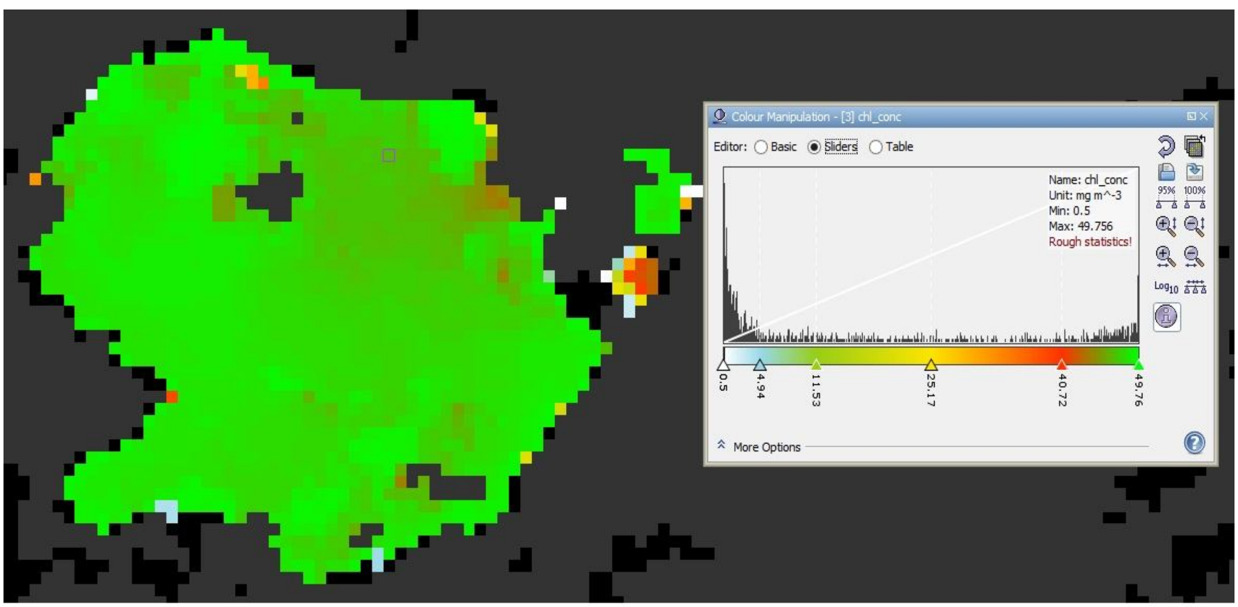

Figure 38: Chlorophyll – November 2006

The above image shows the Chlorophyll level of the lake for the month of November 2006.. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum i.e. 0.5 to 49.756mg/l. The above image shows the chlorophyll level of the lake in November 2006 was very high in the range of the maximum level.

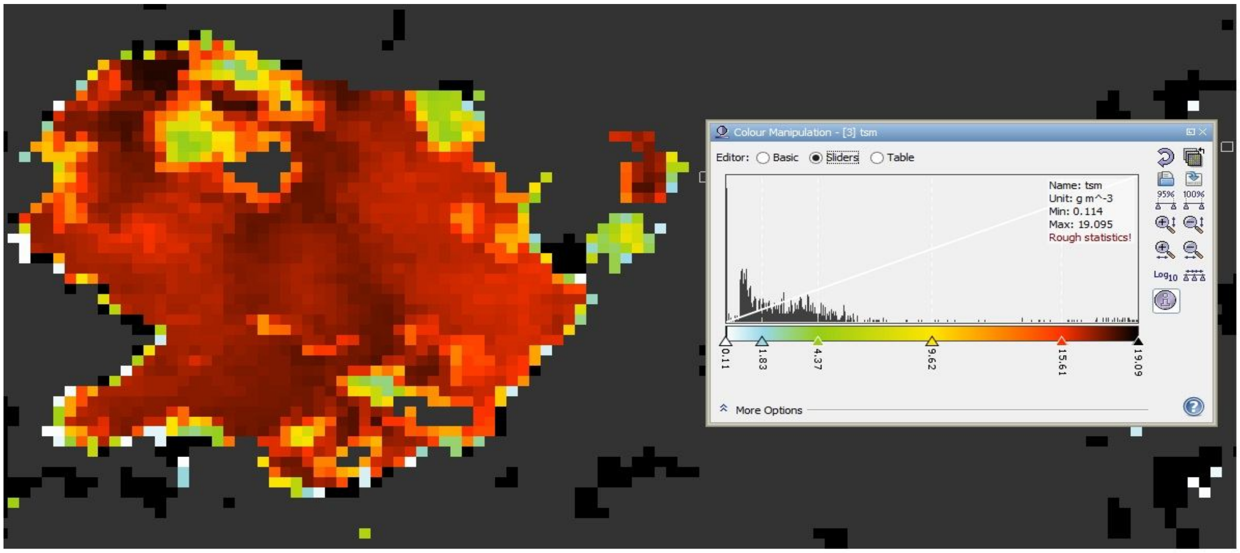

Figure 39: Total Suspended Matters – November 2006

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of November 2006. The levels as shown above in the rough statistics range from minimum to maximum (i.e. 0.114- 19.095mg/l). The Total suspended matter level of the lake was found to be approximately 16.61mg/l. This indicates that the Total suspended matter level of the lake for the month of November 2006 was high.

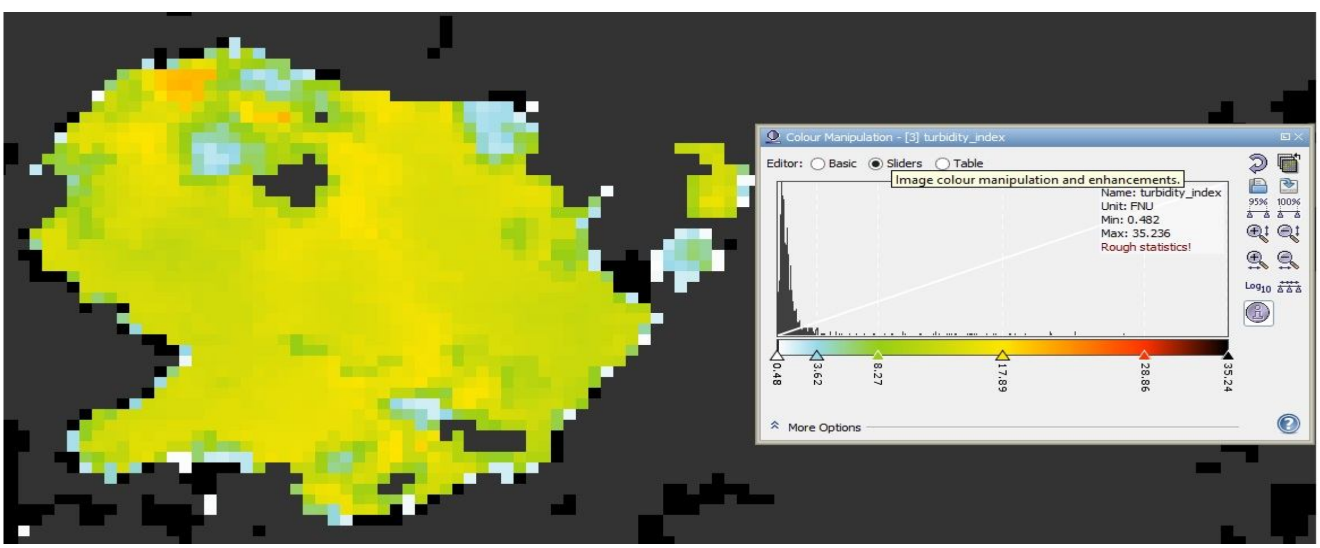

Figure 40: Turbidity – November 2006

The above image shows the Turbidity level of Lake Naivasha for the month of November 2006. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum was from 0.482FNU to 35.236FNU. The lake shows a turbidity level of approximately 8.27FNU, which indicates that it was low.

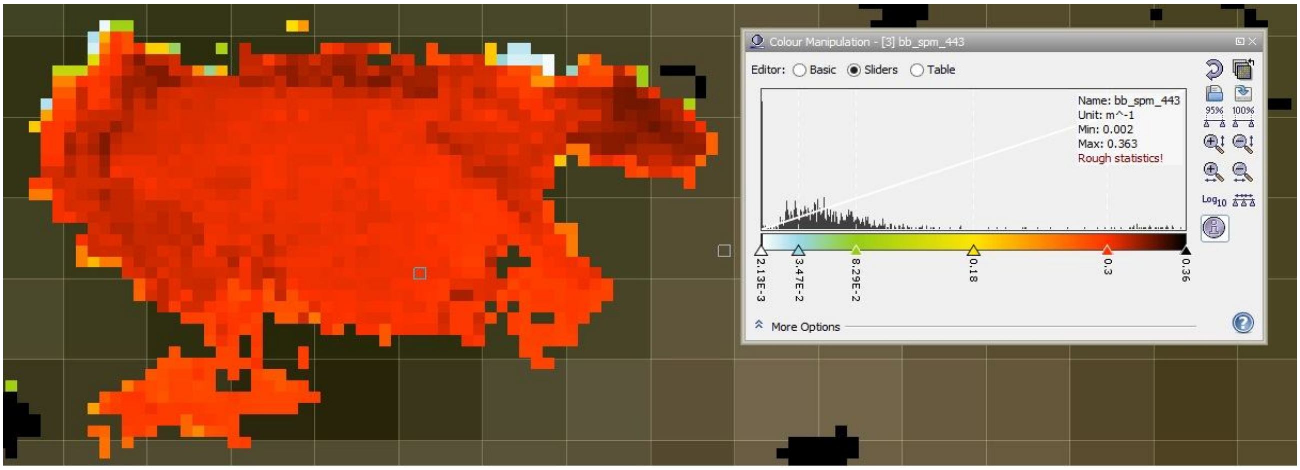

Figure 41: Results for 2007

Back Scattering Suspended Matters October 2007

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of October 2007. The rough statistics as seem above showed a back scattering suspended matter level of 0.3 µS/cm as compared to the highest value on the of about 0.36. The range on the scale from minimum to maximum is 0.002 to 0.363 µS/cm. This indicates that the level was high in the month of October 2007.

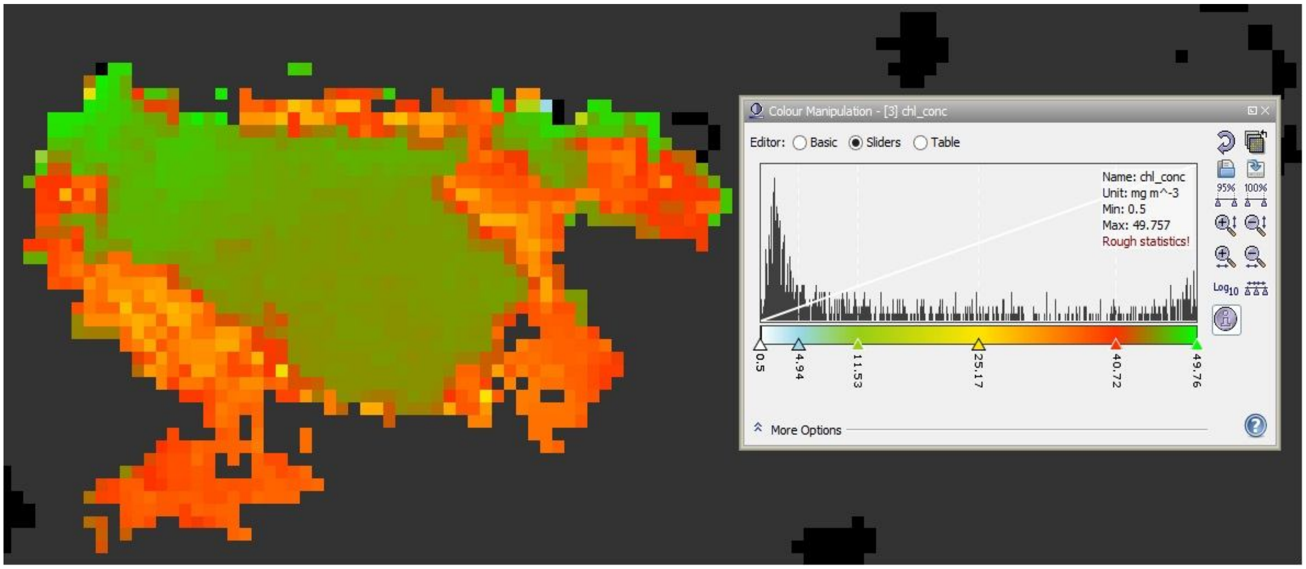

Figure 42: Chlorophyll – October 2007

The above image shows the Chlorophyll level of the lake for the month of October 2007. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum of 0.5 to 49.757mg/l. The above image shows the chlorophyll level of the lake in October 2007 was very high in the range of the maximum level.

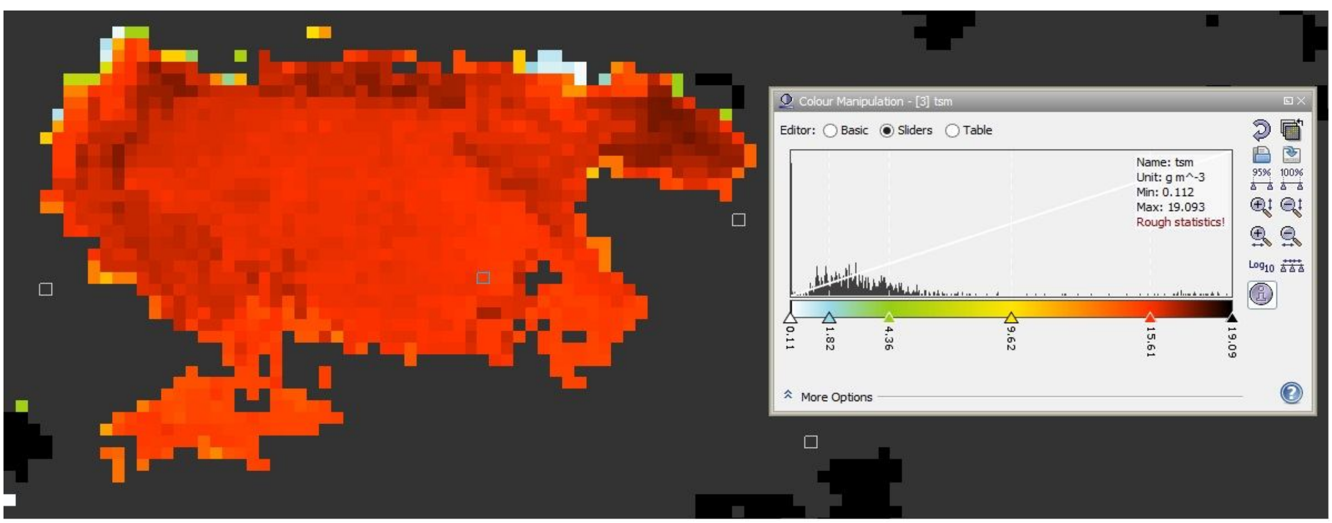

Figure 43: Total Suspended Matters – October 2007

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of October 2007. The levels as shown above in the rough statistics range from minimum to maximum i.e. 0.112mg/l to 19.093mg/l. The Total suspended matter level of the lake was found to be approximately 15.61mg/l. This shows that the Total suspended matter level of the lake for the month of October 2007 was high.

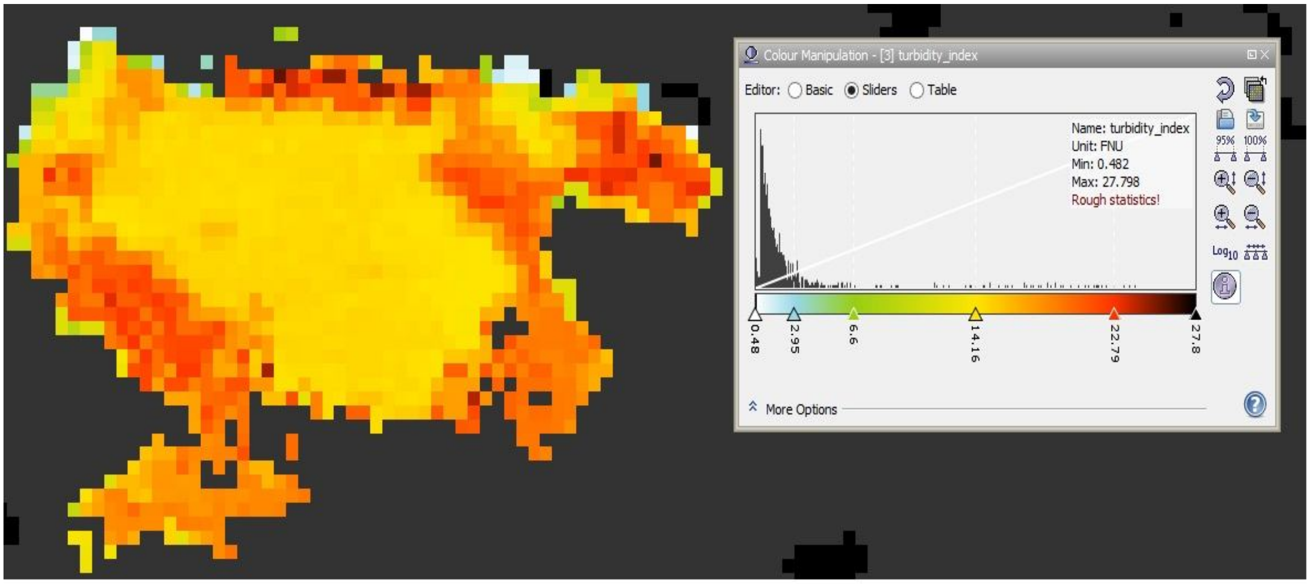

Figure 44: Turbidity – October 2007

The above image shows the Turbidity level of Lake Naivasha for the month of October 2007. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum i.e. from 0.482 to 27.798FNU. The lake shows turbidity level of approximately 14.16FNU, which indicates that it was fairly high.

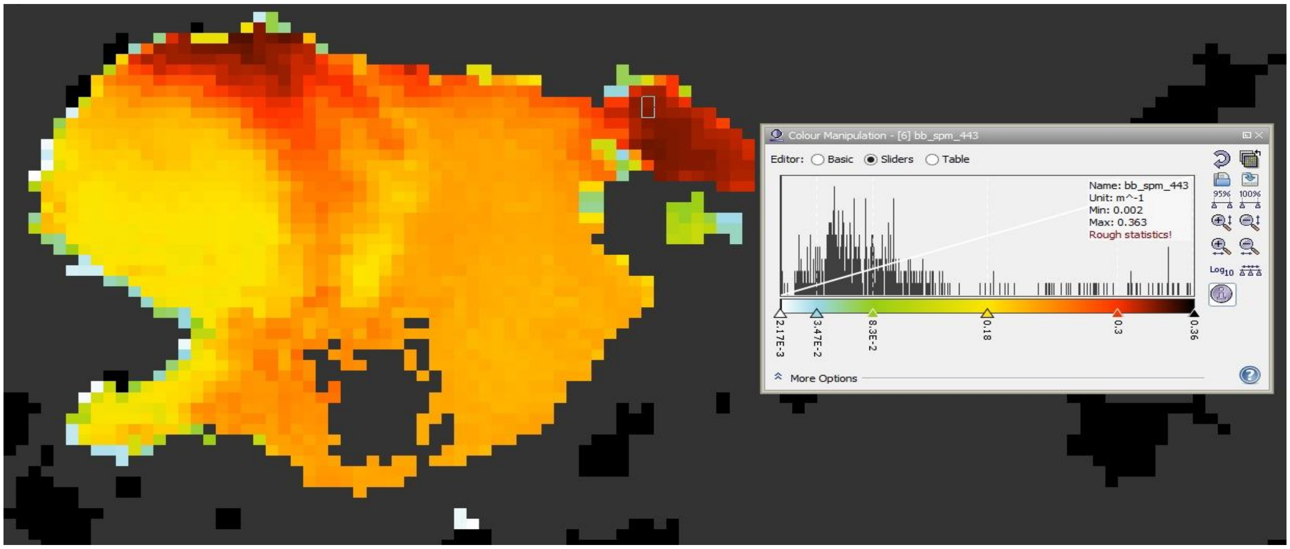

Figure 45: Back Scattering Suspended Matters October 2008

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of October 2008. In the month of October 2008 the satellite reading showed the Back Scattering Suspended matters of 0.3 µS/cm as compared to the highest value on the of about 0.363µS/cm. The range on the scale is from minimum to maximum 0.002 to 0.363µS/cm. This indicates that it was high.

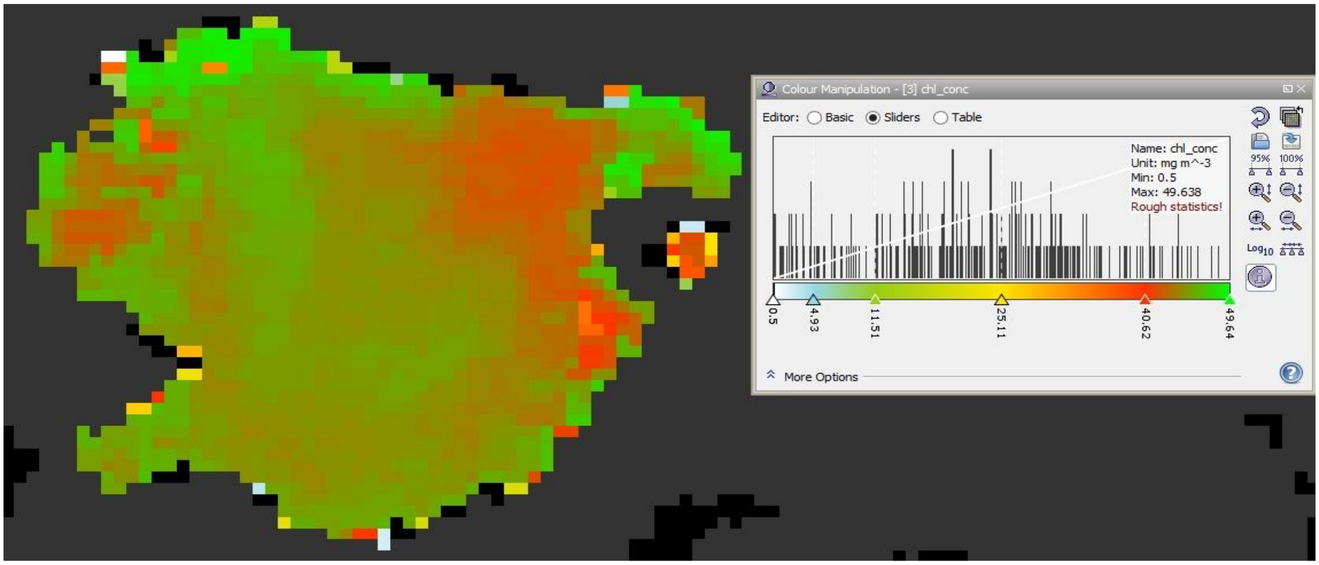

Figure 46:Chlorophyll-a Concentration for October 2008

The above image shows the Chlorophyll level of the lake for the month of October 2008. This indicates that the chlorophyll level in the lake was very high. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum i.e. 0.5 to 49.675mg/l. This indicates that the chlorophyll level in the lake was very high.

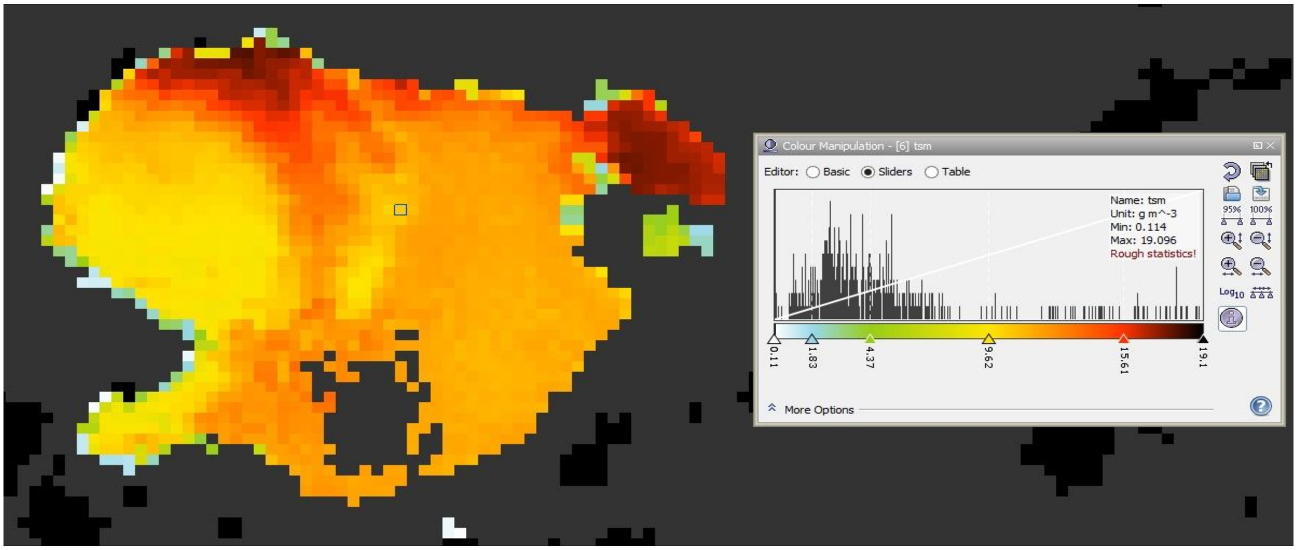

Figure 47: Total Suspended Matters – October 2008

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of October 2008. The levels as shown above in the rough statistics range from minimum to maximum is from 0.115 to 19.096mg/l. The Total suspended matter level of the lake was found to be approximately 15.61mg/l. This shows that the Total suspended matter level of the lake for the month of October 2008 was high.

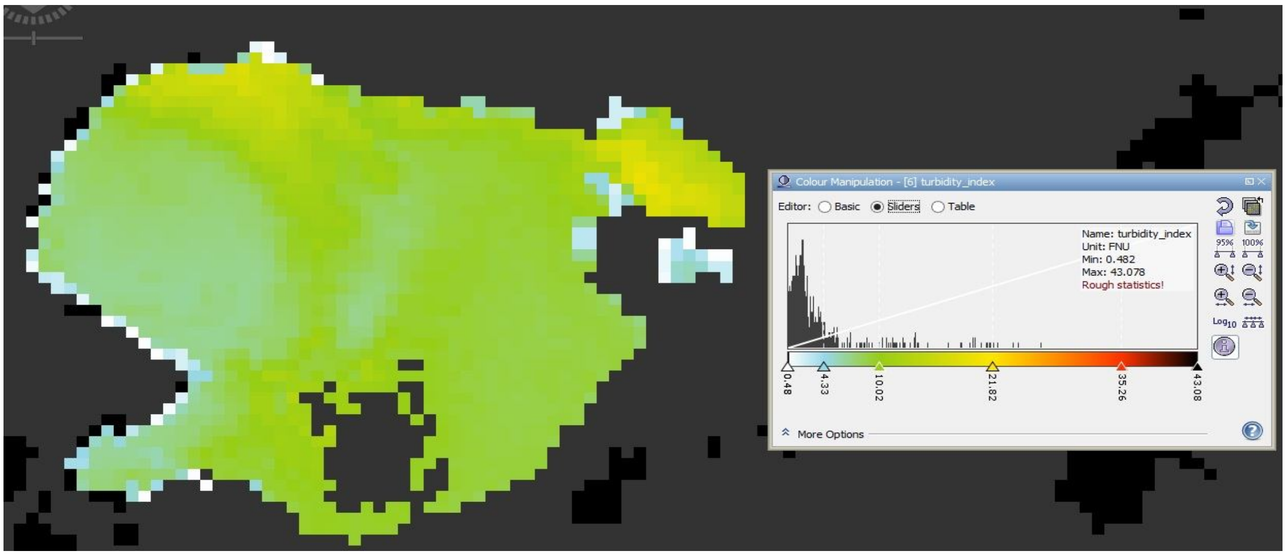

Figure 48: Turbidity – October 2008

The above image shows the Turbidity level of Lake Naivasha for the month of October 2008. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum was from 0.482-43.078FNU. The lake shows a turbidity level of approximately 10.02FNU, which indicates that it was fairly low.

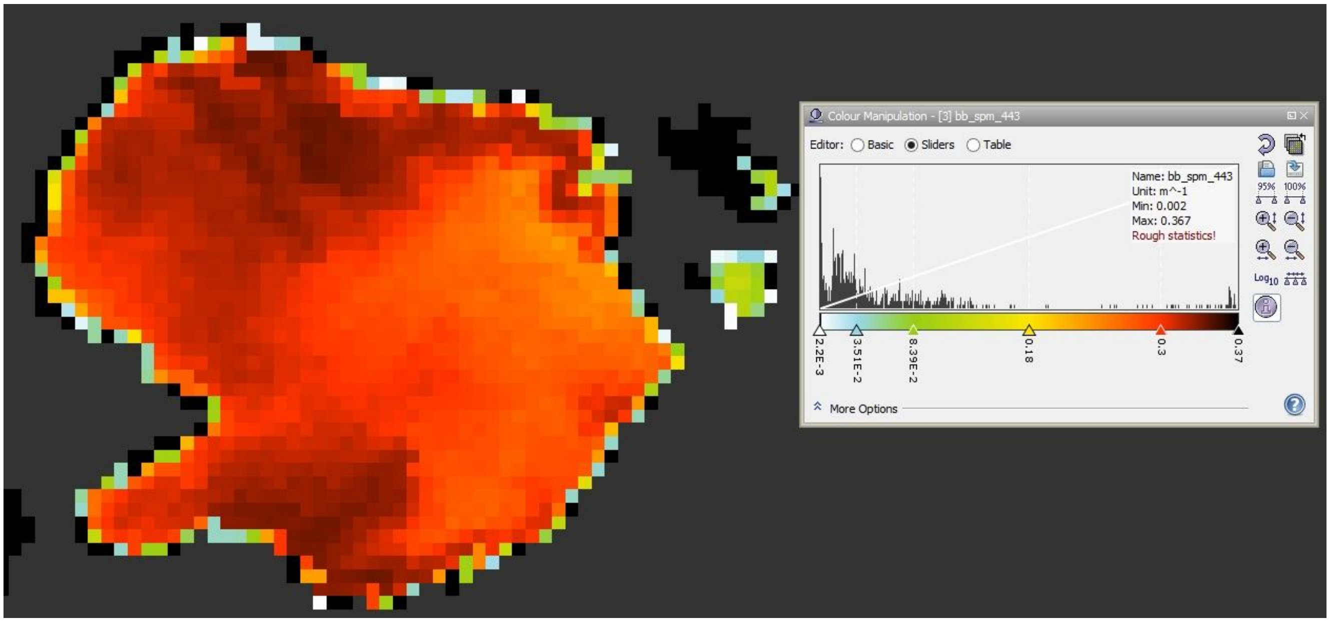

Figure 49: Results for 2009 Back Scattering Suspended Matter November 2009

The above image shows the Back Scattering Suspended matters for the month of November 2009. In the month of November 2009 the satellite readings showed level for the Back Scattering Suspended matters of 0.3 µS/cm as compared to the highest value of about 0.367 µS/cm. The range on the scale is from minimum to maximum i.e. 0.002 to 0.367 µS/cm. This indicates that the level was high.

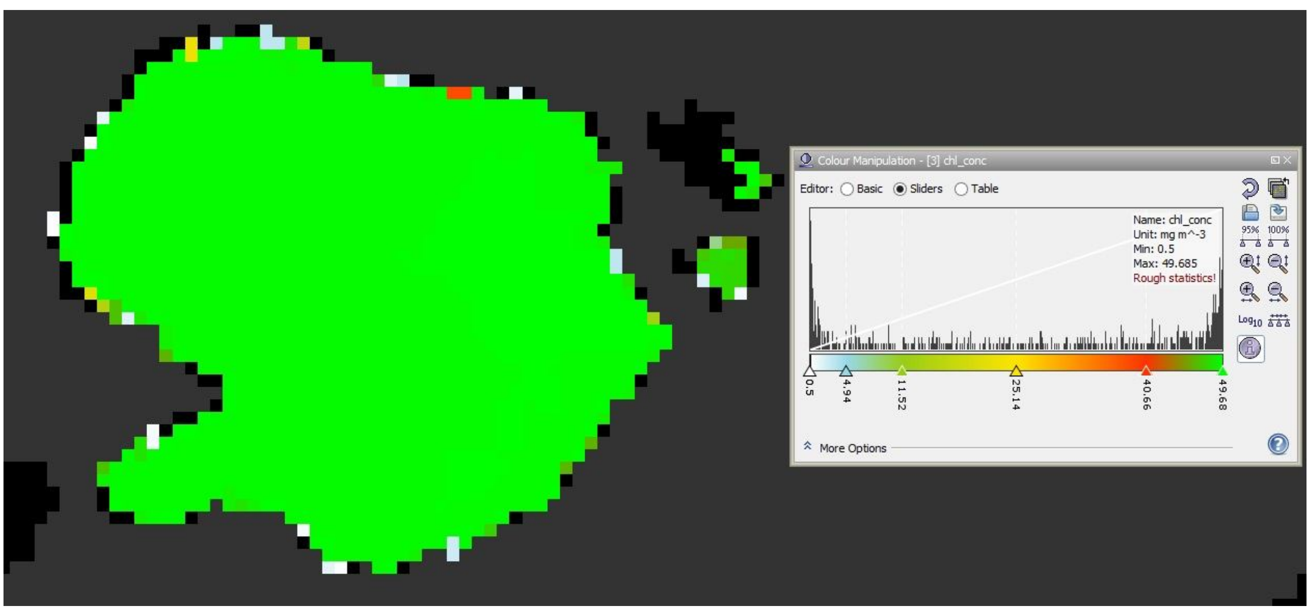

Figure 50: Chlorophyll – November 2009

The above image shows the Chlorophyll level of the lake for the month of November 2009. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum i.e. 0.5mg/l to 49.685mg/l. The above image shows the chlorophyll level of the lake in November 2009 was very high in the range of the maximum level.

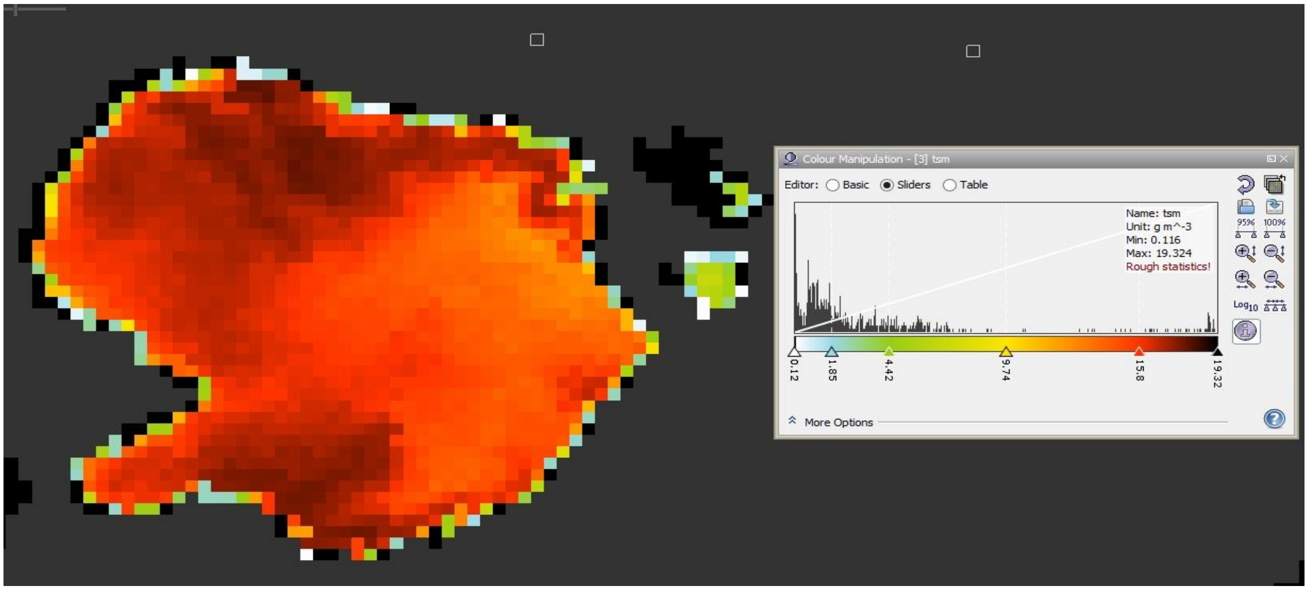

Figure 51: Total Suspended Matters – November 2009

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of November 2009. The levels as shown above in the rough statistics range from minimum to maximum i.e. 0.116mg/l to 19.324mg/l. The Total suspended matter level of the lake was found to be approximately 15.8mg/l. This shows that the Total suspended matter level of the lake for the month of November 2009 was high.

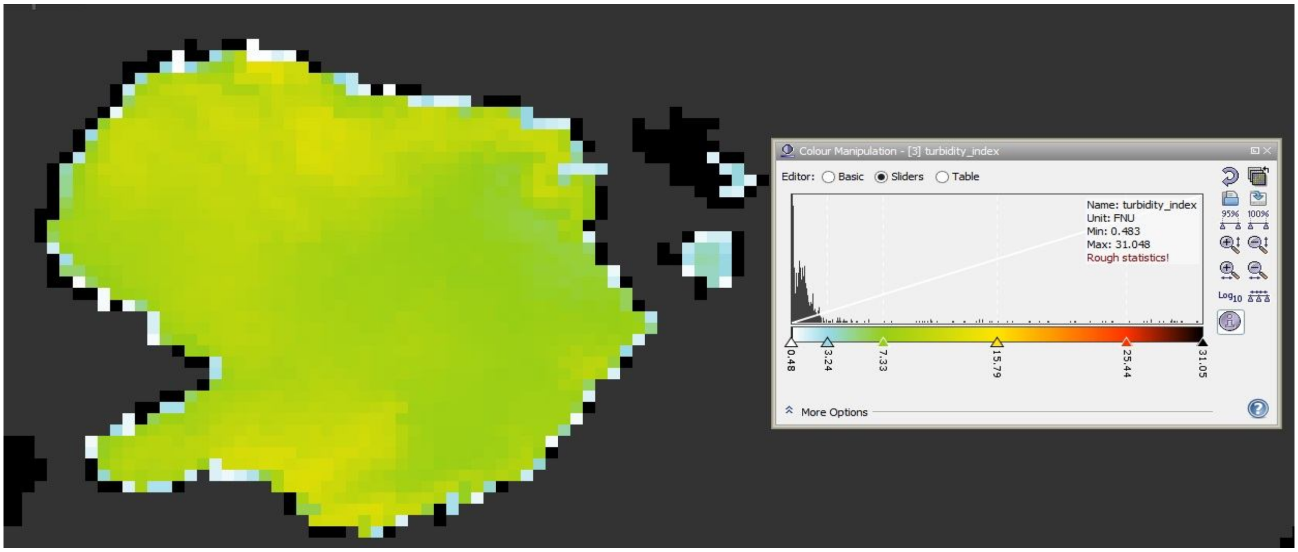

Figure 52: Turbidity – November 2009

The above image shows the Turbidity level of Lake Naivasha for the month of November 2009. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum was from 0.483-31.048FNU. The lake shows a turbidity level of approximately 7.33FNU, which indicates that it was fairly low.

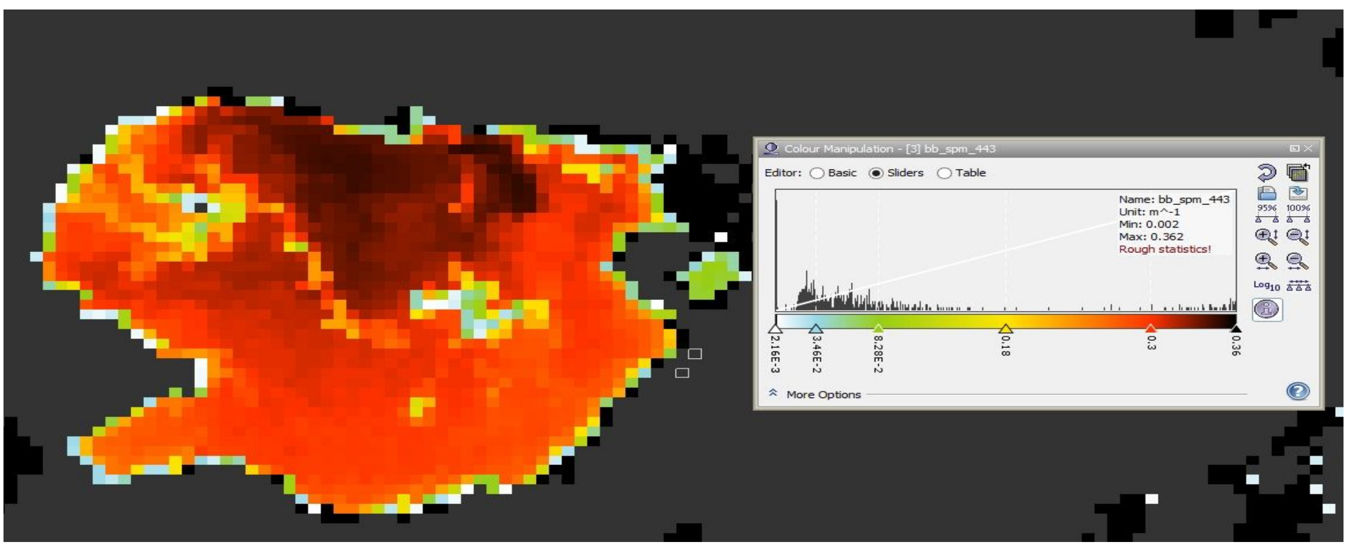

Figure 53: Results for October 2010 Back Scattering Suspended Matters

The above image shows the Back Scattering Suspended matters, which is the same as the conductivity for the month of October 2010. In the month of October 2010 the satellite readings showed the level of 0.3 µS/cm as compared to the highest value of 0.362µS/cm. The range on the scale is from minimum to maximum 0.002 to 0.362 µS/cm. This indicates that the level was high.

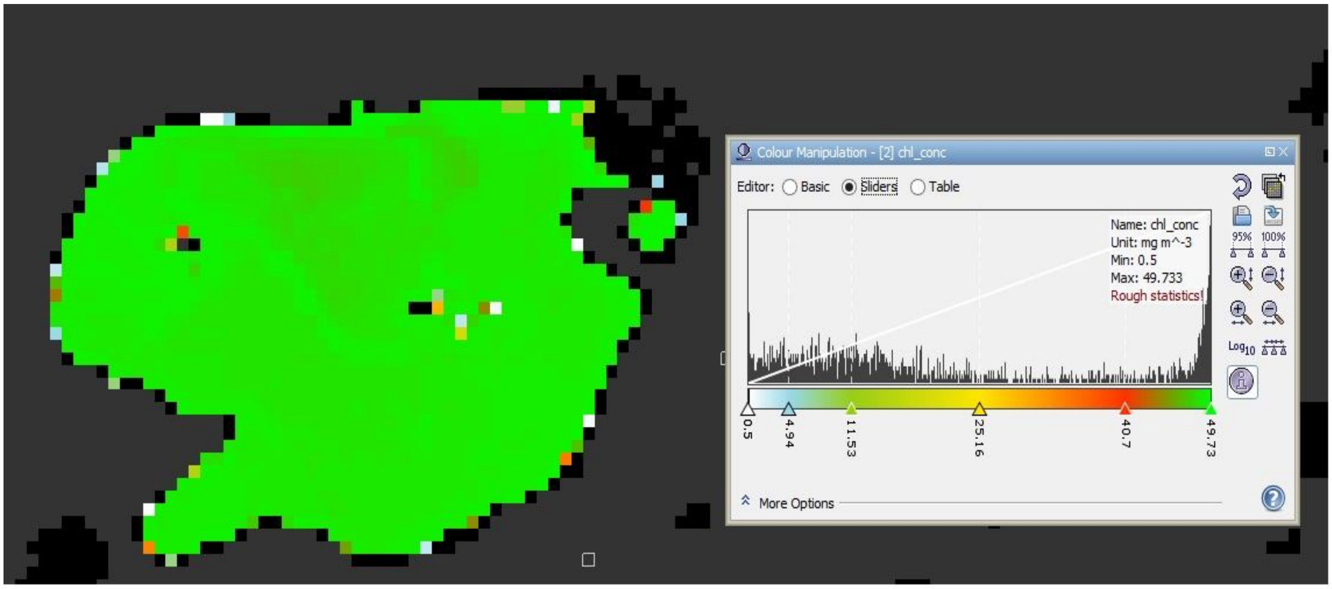

Figure 54: Chlorophyll – October 2010

The above image shows the Chlorophyll level of the lake for the month of October 2010. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum i.e. 0.5-49.733mg/l. The above image shows the chlorophyll level of the lake in October 2010 was very high in the range of the maximum level.

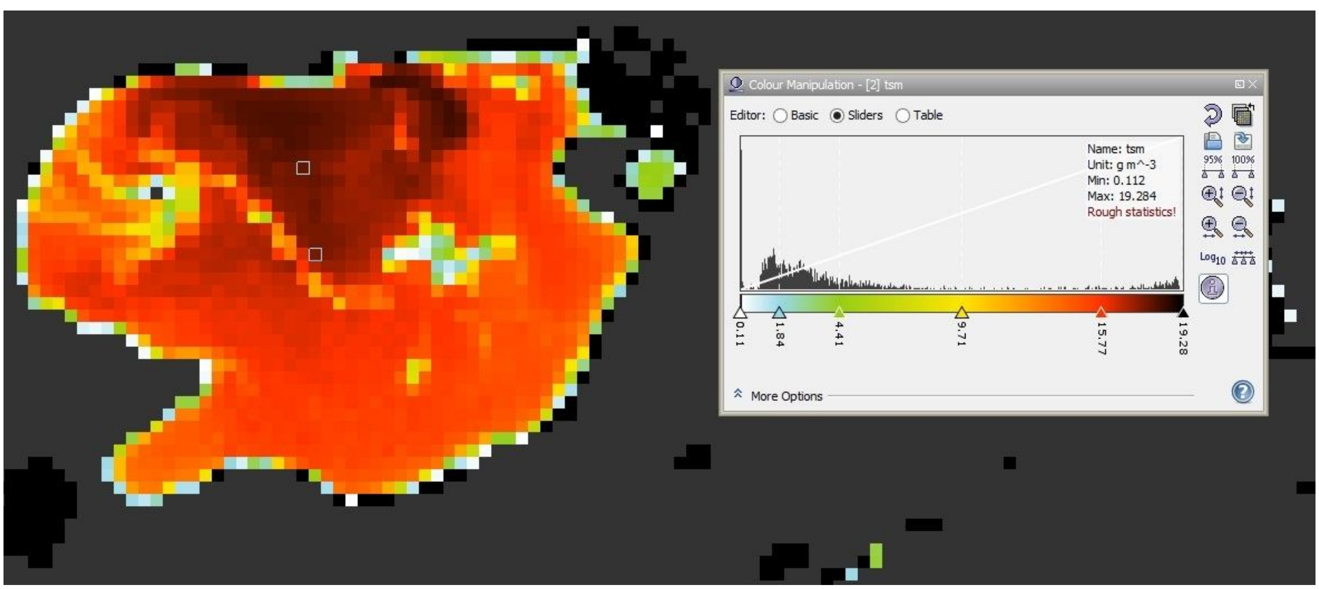

Figure 55: Total Suspended Matters – October 2010

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of October 2010. The levels as shown above in the rough statistics range from minimum to maximum i.e. from 0.112 to 19.284mg/l. The Total suspended matter level of the lake was found to be approximately 15.77mg/l. The image shows that the Total suspended matter level of the lake for the month of October 2010 was high.

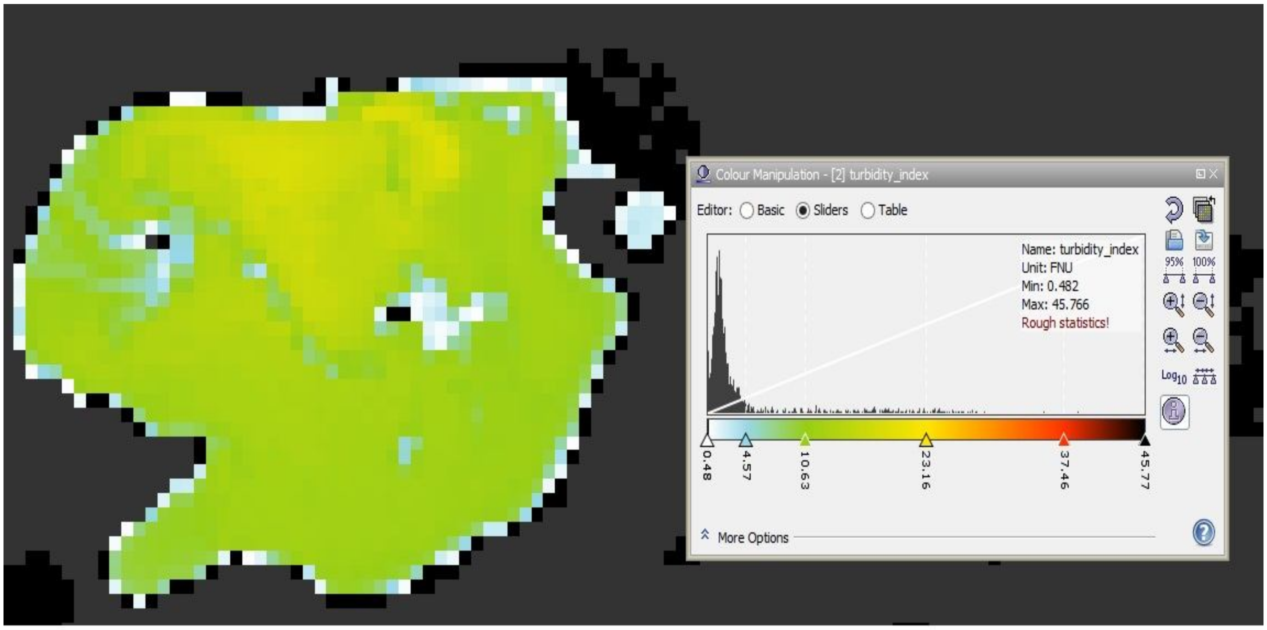

Figure 56: Turbidity – October 2010

The above image shows the Turbidity level of Lake Naivasha for the month of October 2010. From the rough statistics as shown above the turbidity level of the lake range from minimum to maximum i.e. from 0.482 to 45.766FNU. The lake shows a turbidity level of approximately 10.63FNU, which indicates that it was fairly low.

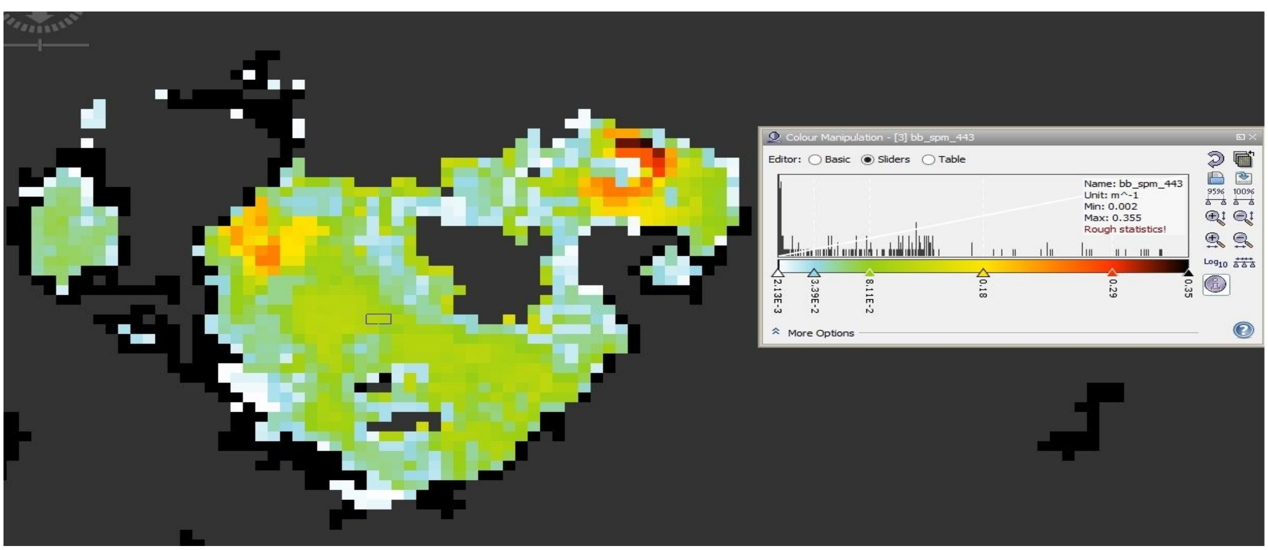

Figure 57: Results for November 2011 Back Scattering Suspended Matter

The above image shows the Back Scattering Suspended matters, for the month of November 2011. In the month of November 2011 the satellite readings showed the level for the Back Scattering Suspended matters of 0.18 µS/cm, as compared to the highest value of 0.355 µS/cm. The range on the scale is from minimum to maximum 0.002 to 0.355µS/cm. This indicates that the level was fairly high.

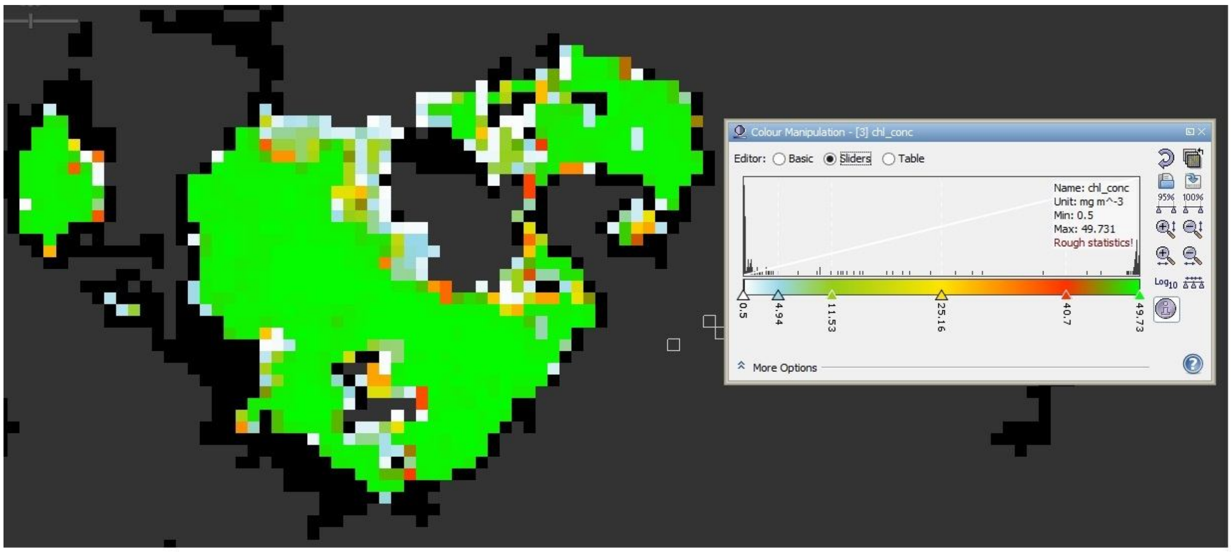

Figure 58: Chlorophyll – November 2011

The above image shows the Chlorophyll level of the lake for the month of November 2011. The rough statistics as shown above gives the range of the chlorophyll level from minimum to maximum 0.5 to 49.731mg/l. The above image shows the chlorophyll level of the lake in November 2011 was very high in the range of the maximum level.

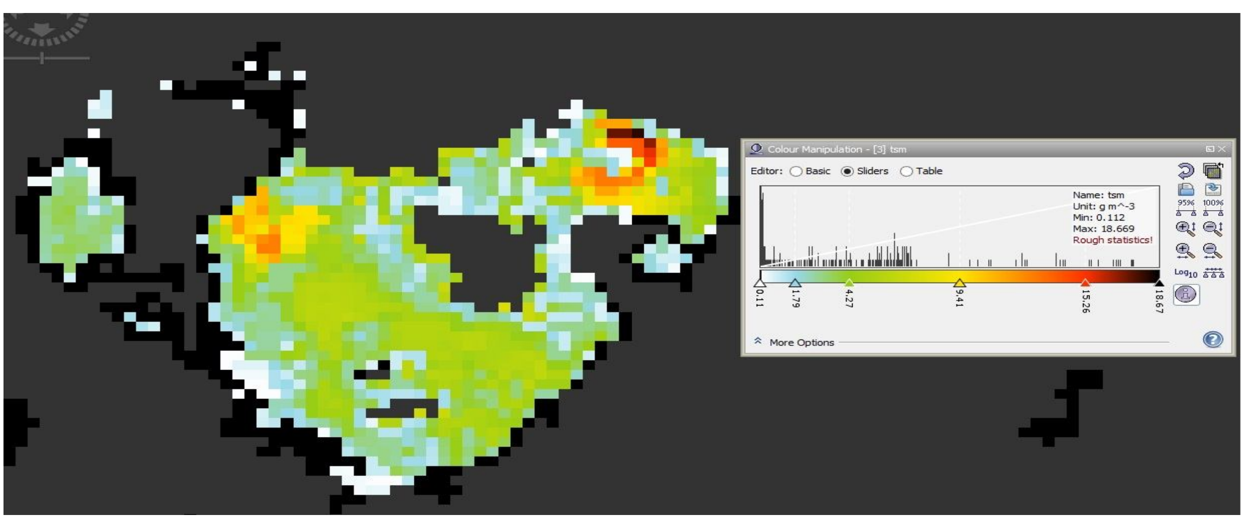

Figure 59: Total Suspended Materials – November 2011

The above image shows the Total Suspended Matter level of Lake Naivasha for the month of November 2011. The levels as shown above in the rough statistics range from minimum to maximum i.e. from 0.112mg/l to 18.669mg/l. The Total suspended matter level of the lake was found to be approximately 4.27mg/l. The image shows that the Total suspended matter level of the lake for the month of November 2011 was fairly low.

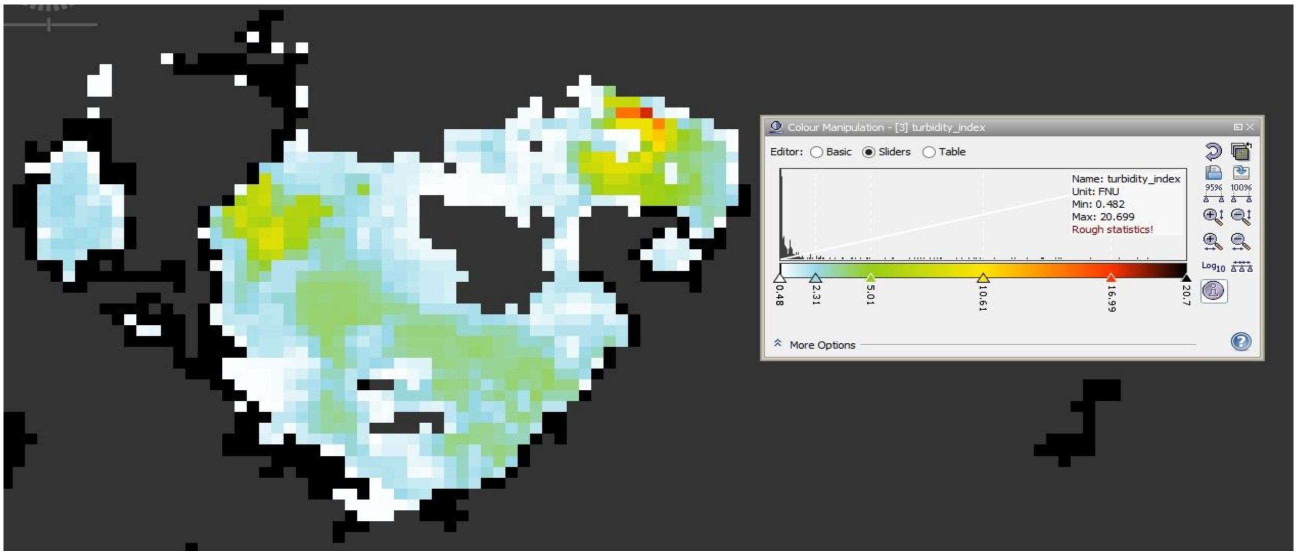

Figure 60: Turbidity – November 2011

The above image shows the Turbidity level of Lake Naivasha for the month of November 2011. From the rough statistics as shown above the turbidity level of the lake from minimum to maximum i.e. from 0.482-20.699FNU. The lake shows a turbidity level of approximately 2.31FNU, which indicates that it was fairly low.

TABLE 7. SHOWING TRENDS IN THE TOTAL SUSPENDED MATTERS CONCENTRATION OF THE LAKE FROM 2003 to 2011

2003 Sept.	2004 Nov.	2005 Sept	2006 Nov.	2007 Oct.	2008 Oct.	2009 Nov.	2010 Oct	2011 Nov.
15.91mg /l	16.17mg /l	15.59mg /l	16.61mg /l	15.61mg /l	15.61mg /l	15.8mg /l	15.77gm /l	4.27mg /l

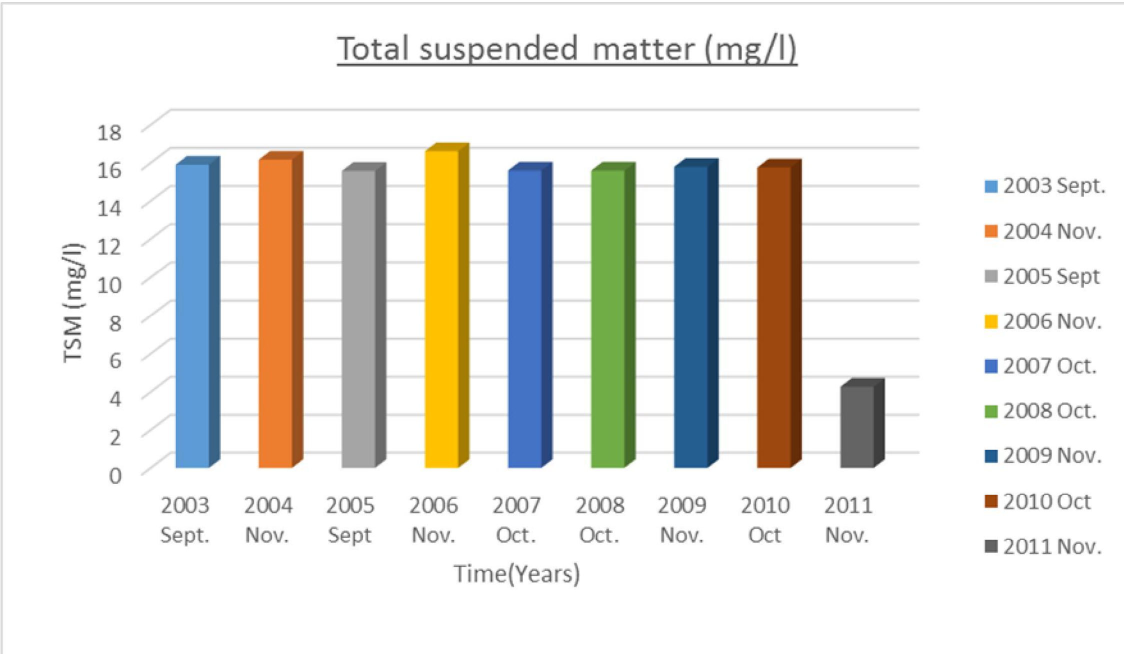

Figure 61. Gives the trends of the Total Suspended Solids (TSM) from 2003 to 2011

The above figure gives the trends of the Total Suspended matter (TSM) from 2003 to 2011. The data further showed that from 2003 to 2011 the trends in the total suspended solids from the lake experienced continuous rise and fall in the trends. 2003 to 2004 showed a 2% increment. 2004 to 2005 showed a slight reduction of 3.6%. From 2005 to 2006 there was an increment of 6.5%. 2007 to 2008 was consistent at the same level of 15.61mg/l. 2009 showed an increment of 1.21% as compared to 2007 and 2008. In 2010 the trend dropped slightly by 0.19%. In 2011 there was a high reduction in the trend by 73% compared to 2010.

Table 8. Showing Trends in the Turbidity Levels of the lake from 2003 to 2011

2003 Sept.	2004 Nov.	2005 Sept	2006 Nov.	2007 Oct.	2008 Oct.	2009 Nov.	2010 Oct.	2011 Nov.
12.81FNU	9.71FNU	13.32FNU	8.27FNU	14.16FNU	10.02FNU	7.33FNU	10.63FNU	2.31FNU

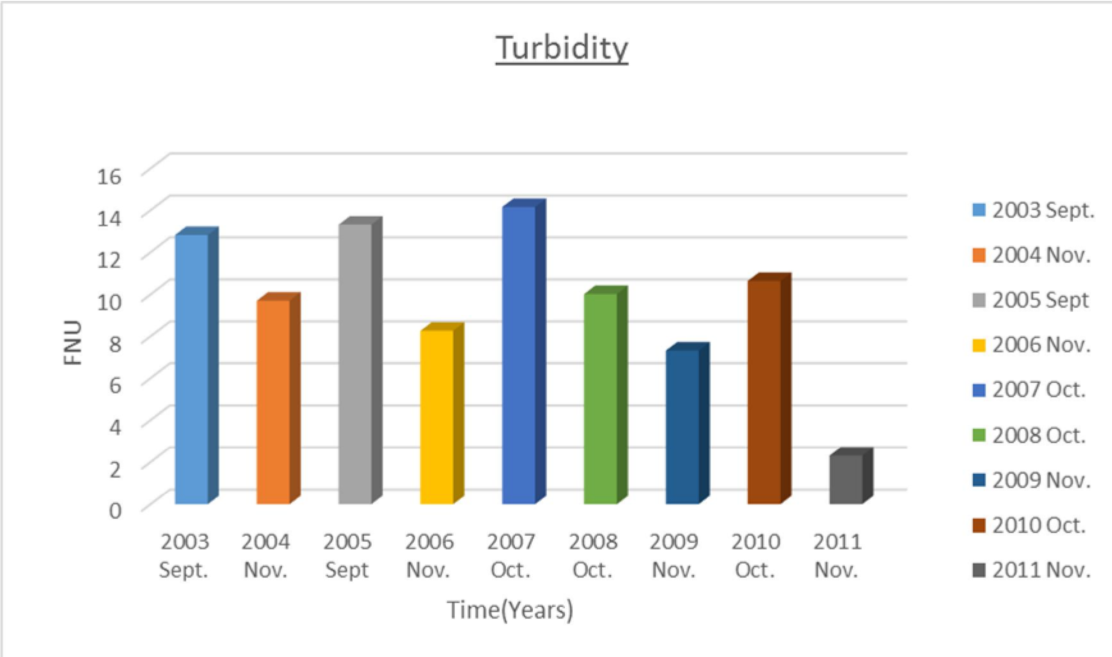

Figure 62 Gives the trends of the turbidity levels in Lake Naivasha from 2003 to 2011.

The above figure gives the trends of the turbidity levels in Lake Naivasha from 2003 to 2011. From the data representation between 2003 and 2011the have been irregular rise and fall in the trends of the turbidity level of the lake. From 2003 to 2004 the trend showed a 24% reduction. From 2004 to 2005 there was an increment in trends of 27%. The trends from 2005 to 2006 showed reduction of 38%. From 2006 to 2007 there was an increment in trends of 58%. From 2007 to 2008 there was a reduction in trends of 29%. From 2008 to 2009 the trends reduced further by 27%. 2009 to 2010 the trends increased by 31%. From 2010 to 2011 there was a sharp reduction in the trends by 78%.

Table 9. Showing Trends in the Conductivity/Back Scatter Suspended Matters of the lake from 2003 to 2011

2003 Sept.	2004 Nov.	2005 Sept	2006 Nov.	2007 Oct.	2008 Oct.	2009 Nov.	2010 Oct.	2011 Nov.
0.3mg/l	0.15mg/l	0.3mg/l	0.3mg/l	0.3mg/l	0.3mg/l	0.3mg/l	0.3mg/l	0.18mg/l

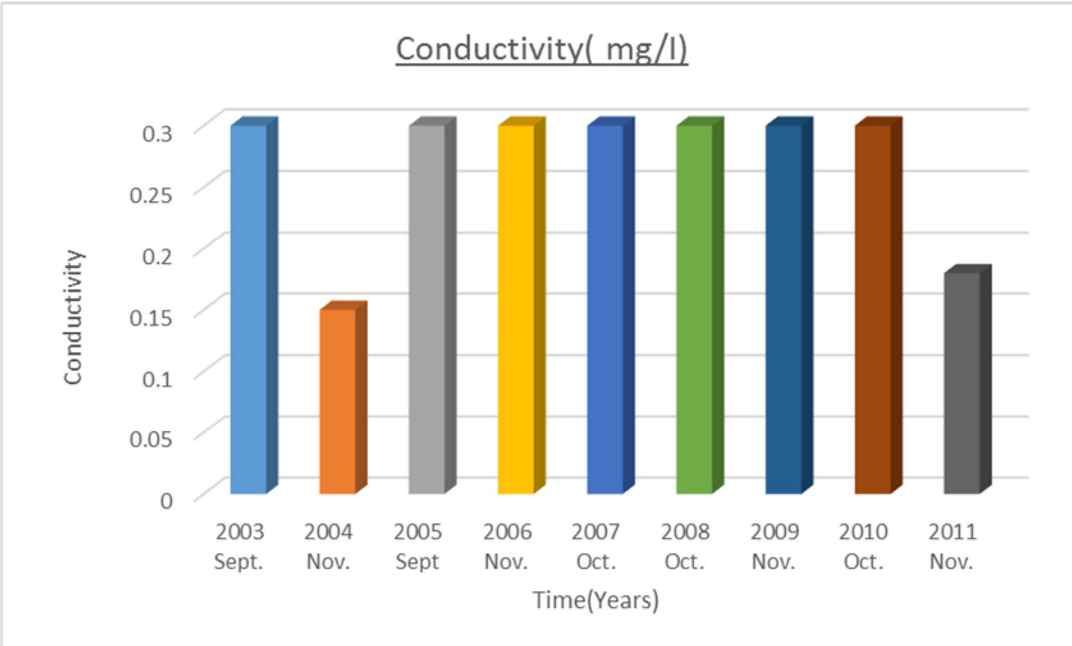

Figure 63. The trends in the Conductivity/Back scattering levels of the lake from 2003 to 2011.

The above figure shows the trends in the Conductivity/Back Scattering levels of the lake from 2003 to 2011. The data showed that the trend in conductivity of the lake have been consistent at the same level from 2005 to 2010 with the exception of 2003, 2004 and 2011 that experienced rise and fall. From 2004 to 2004 there was a reduction by 50%. From 2005 up to 2010 which was five years interval, the trends were very consistent at the same level of 0.3mg/l. From 2010 to 2011 there was a 60% reduction in trend.

Table 10. Showing Trends in the Coliform/Chlorophyll a Levels of the lake from 2003 to 2011

2003 Sept.	2004 Nov.	2005 Sept	2006 Nov.	2007 Oct.	2008 Oct.	2009 Nov.	2010 Oct.	2011 Nov.
49.804 mg/l	43.43mg/ m^3	49.677 mg/l	49.756 mg/l	49.757 mg/l	49.675 mg/l	49.685 mg/l	49.733 mg/l	49.731 mg/l

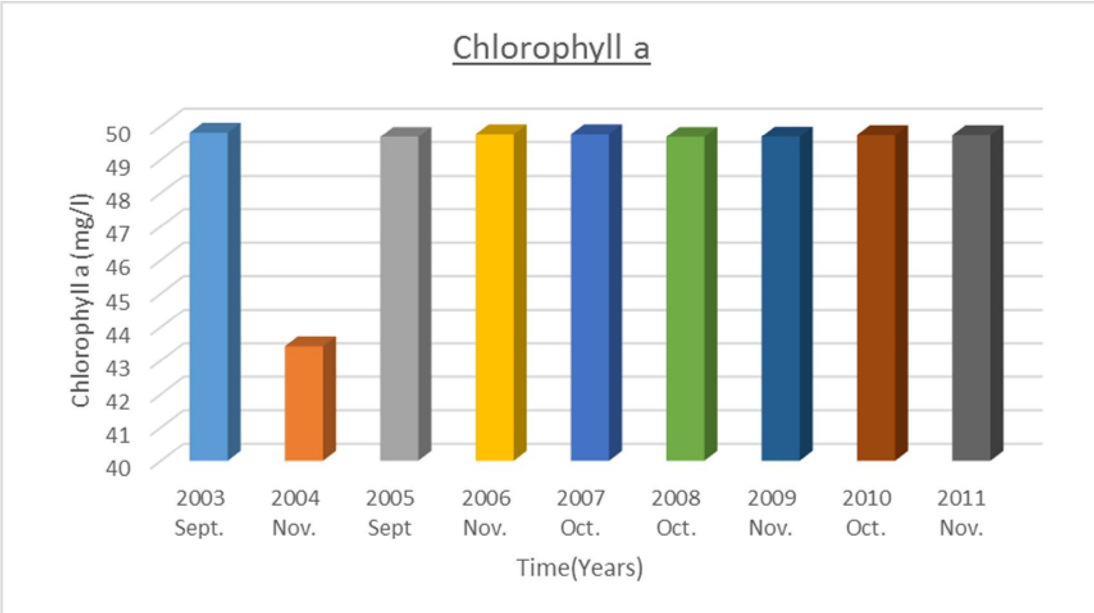

Figure 64. The chlorophyll a levels of the lake from 2003 to 2011.

The above figure shows the chlorophyll a levels of the lake from 2003 to 2011. The trends have been rising and falling at different interval. From 2003 to 2004 there was a reduction in trend of 13%. From 2004 to 2005 there was an increment in the trend of 12.6%. From 2005 to 2006 the trend slightly increased by 0.2%. From 2006 to 2007 the trend was consistent at the same level of 49.75mg/l. From 2008 to 2009 were almost the same with very negligible reduction that is from 49.675mg/l in 2008 to 49.685mg/l in 2009. From 2010 to 2011 the trends were consistent with the value of 49.73mg/l.

4.3 Correlation between Remote Sensing and Laboratory results.

The results from the remote sensing data were correlated with the laboratory results using the Chi-square correlation. Chi-square is a statistical test commonly used to compare observe data with data we would expect to obtain according to a specific test. This is to know the level of deviation which is the differences between observed and expected.Chi square test is always testing what scientists want to validate, whether, there is any significant difference between the expected and the observed unit. The formula for calculating chi-square (□ ^{2}) is: □^{2}= **(o-e) □^{2}/e.**

Field					
Month	**Sept**	**Oct**	**Nov**		
Suspended Solids	0.002233	0.00225	0.002083333		
Turbidity	11.53667	17.28	13.85		
Conductivity	253.6667	265.5	250.3483333		
Suspended solids	***Sept***	***Oct***	***Nov***	**Correlation**	***Chisqr Test***
Observed (Field)	0.002233	0.00225	0.002083333		6.52083E-11
Expected(RS)	15.51	15.61	15.8	-0.9059358	
Turbidity					
Observed (Field)	11.53667	17.28	13.85	0.91639644	0.628701693
Expected(RS)	12.81	14.1	12.81		
Conductivity					
Observed (Field)	253.6667	265.5	250.3483333	-0.308623	0
Expected(RS)	1	0.3	0.3		

Table 11: Chi- Square Correlation for the TSM, turbidity and Conductivity.

The above data shows the correlation level between the results from the remote sensing data and the laboratory data. The observed represents the field data (laboratory results), whereas the expected represents the remote sensing data. The chi square correlation was used to correlate the results for the total suspended solid, turbidity and conductivity.

TOTAL SUSPENDED SOLIDS

From the above table, correlation between the total suspended solid for both the observed (Laboratory) and expected (remote sensing) showed a negative or inverse correlation. The result from the correlation coefficient is -0.906. This conforms to the chi-square correlation theory which states that when the coefficient value is less than zeros the correlation is negatively or inversely related.

TURBIDITY

The table also gives the correlation between the turbidity for the observed and the expected which showed a positive or direct correlation. The result from the correlation coefficient was 0.916.This also conforms to the chi-square correlation theory which states that when the coefficient value is greater than zero the correlation is positively related or directly related.

CONDUCTIVITY

The table also shows the correlation between conductivity for the observed and the expected which gives a negative or inverse correlation. The result of the correlation coefficient is -0.308623.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study findings showed that the pH measurements insitu on the lake was in the range of 6.8 to 7.8. The temperature readings were in the range of 20.6^{O}C- 24.75^{O}C. The dissolved oxygen was measured insitu during all the field visits and findings showed that the dissolved oxygen levels of the lake ranges from 4.53mg/l to 6.79mg/l.

The trends in parameters for TSM, turbidity, conductivity, and chlorophyll-a experienced a continuous rise and fall at different intervals. The trends of the Total Suspended matter (TSM) from 2003 to 2011showed continuous rise and fall with the highest level in November 2006 of 16.61mg/l and the lowest level in November 2011 of 4.27mg/l. The trend in turbidity level from 2003 to 2011 showed rise and fall in the trends with the highest level in 2007 of 14.16FNU and the lowest value in 2011 of 2.31FNU. The trends in the conductivity of the lake showed consistency for 2003, 2005 up to 2010 at the same level of 0.3mg/l. In 2011 there was a reduction in trend to 0.18mg/l and the lowest value recorded in 2004 of 0.15mg/l. The trends in the chlorophyll levels of the lake have been rising and falling at different interval the highest level was recorded in November 2006 and October 2007 and the lowest value in November 2004. Parameters considered for correlation using the remote sensing data and the laboratory analysis included TSS, turbidity and conductivity using the chi-square correlation coefficient. From the three parameters correlated only turbidity showed a positive or direct correlation. The result from the correlation coefficient was 0.91639644.This conforms to the chi-square correlation theory which states that when the coefficient value is greater than zero the correlation is positively related or directly related.

Finally, remote sensing is a useful tool for large-scale monitoring of inland and coastal water quality. Its advantages have long been recognized such as the provision of a valuable tool for monitoring and assessing the entire waterways. It is integrated with GPS and GIS technologies and provides a permanent geographically located image database as a baseline for future studies and comparisons. Compared to the conventional traditional method that is more time consuming, remote sensing is faster and efficient method of analyzing water quality with no multi-temporal or multi-site application. The change in water quality parameters, both in space and time as well as in reflectance signature from point to point, makes this method very convenient.

5.2 Recommendations

- More studies should be conducted regularly on the water quality trends of the lake via laboratory analysis and remote sensing concomitantly.
- There should be a long term mechanism in place to monitor the lake so as to provide information on the trends to facilitate immediate and prompt interventions when necessary.
- An empowerment scheme should be put into place for improved agricultural farming methods for the general maintenance of the natural quality of the lake's water.
- Continuous financial assistance should be given by the relevant authorities to ensure that the satellite imaging continue to function from time to time so as to always have the needed data of the water quality information during clear weather or sunshine.

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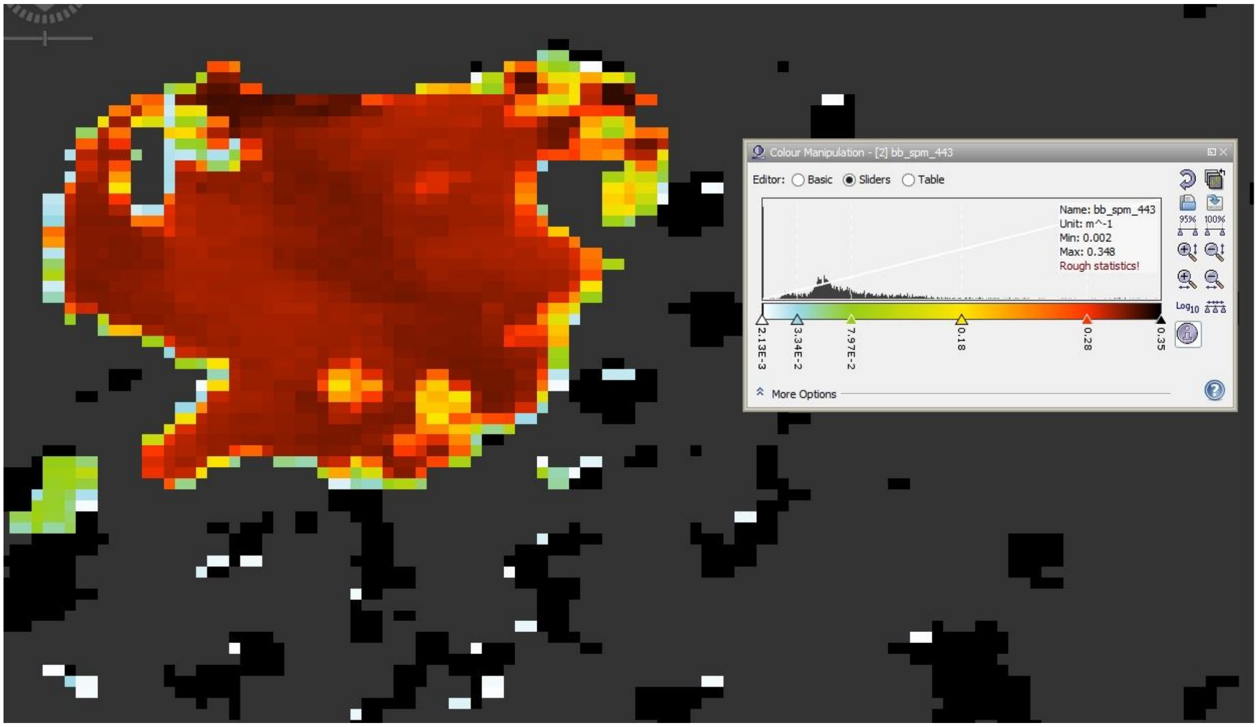
APPENDICES

Appendix I: The water parameters to be analyzed on the file data sheet

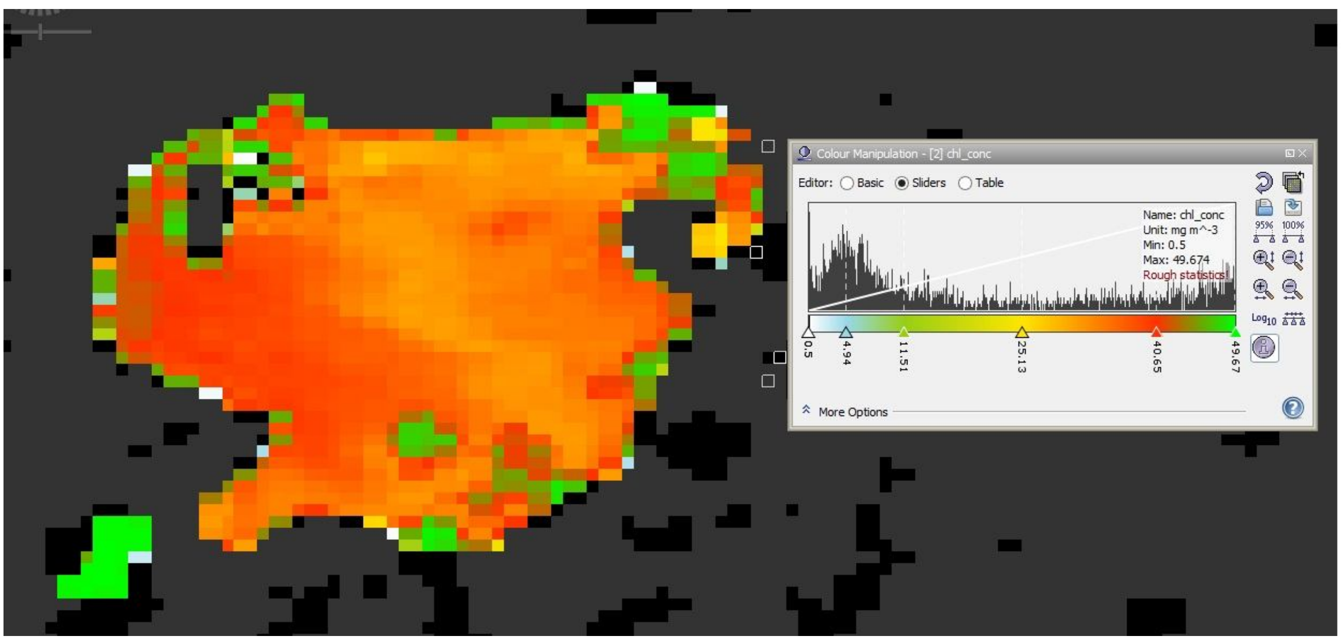
File Data Sheet No: ------------------ Date -------------------

WATER QUALITY MONITORING IN LAKE NAIVASHA					
SITE DESCRIPTION		**SAMPLE DESCRIPTION**		**FIELD ANALYTICAL DATA**	
SITE NAME		SAMPLE NO:		WATER TEMPERATURE	
SITE NO:		SAMPLE CODE		AIR TEMPERATURE	
GIS READINGS		SAMPLE TYPE		pH	
LONGITUDE		SAMPLING TIME		DO	
LATITUDE		SAMPLING DATE		TURBIDITY	
ALTITUDE		PRESERVATION		TSS	
WEATHER		SAMPLE VOLUME		TDS	
				COLIFORM	
PARAMETERS TO BE ANALYZED					
NAME:	SIGNATURE__________________ SAMPLING OFFICER		DATE___________________		
TRANSPORT DATE___________________			SIGNATURE _______________________ WATER QUALITY OFFICER		

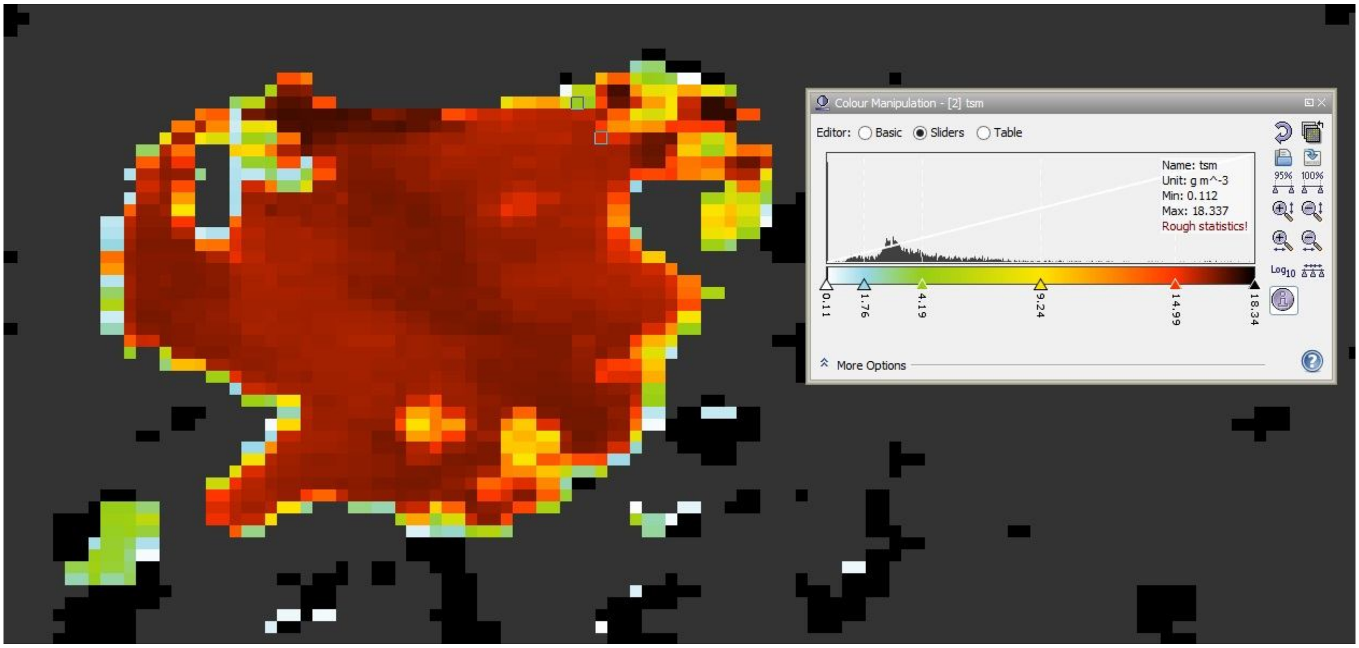
Appendix II: Images showing the Water Quality Parameters of Lake Naivasha for November 2003



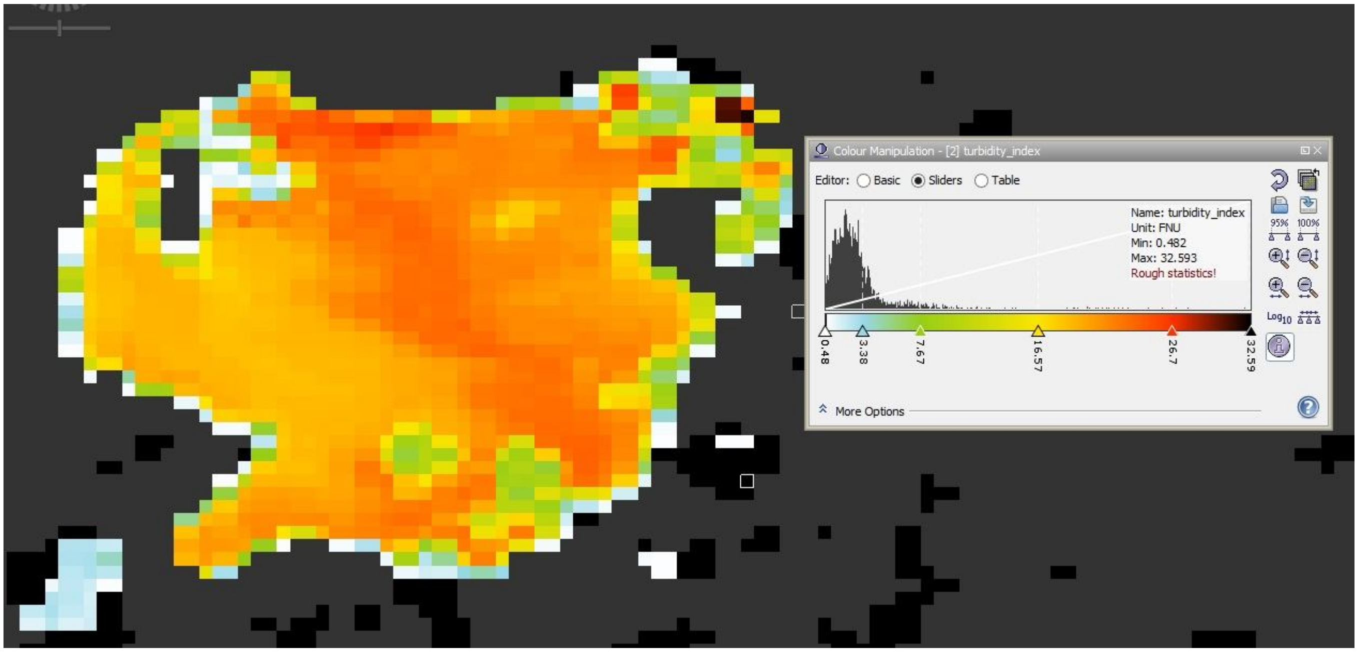
Back Scattering Suspended Matters November 2003



Chlorophyll – November 200

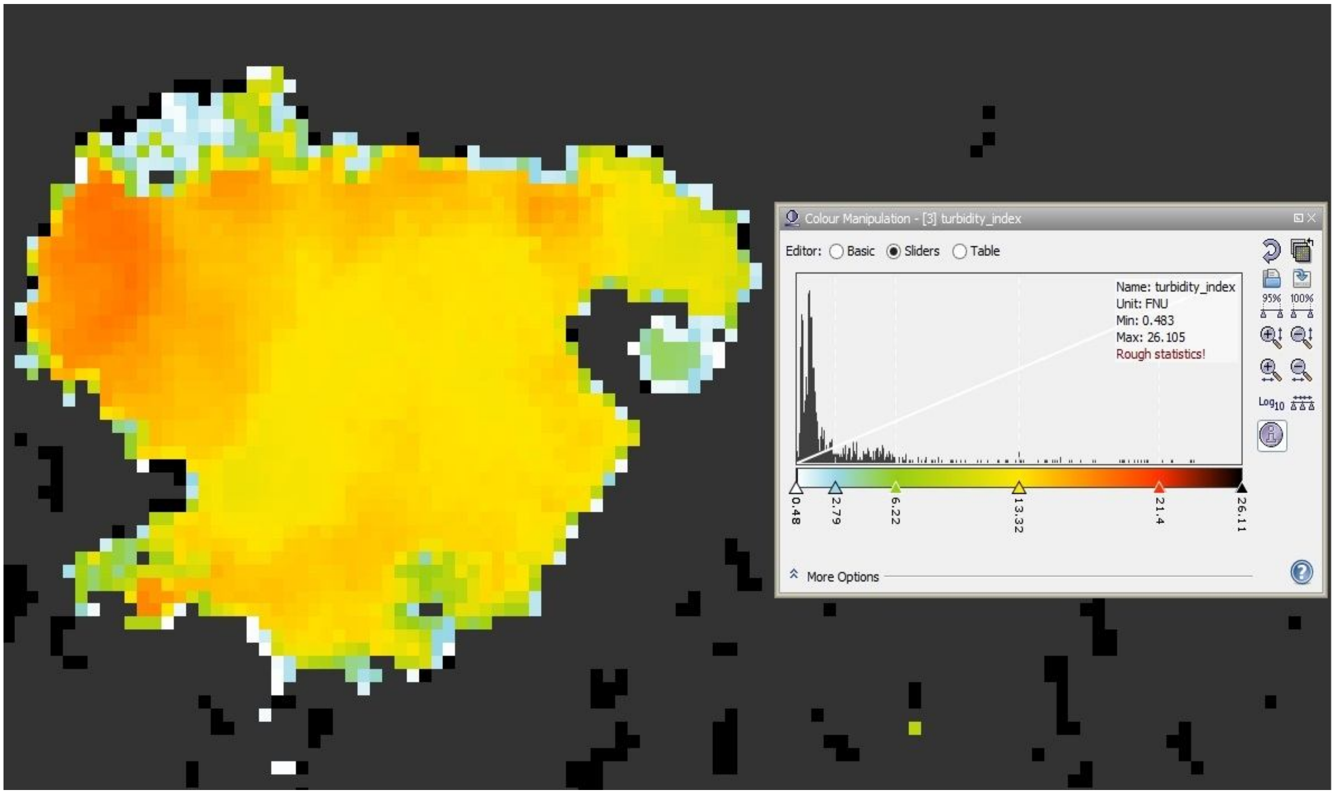


Total Suspended Matters – November 2003

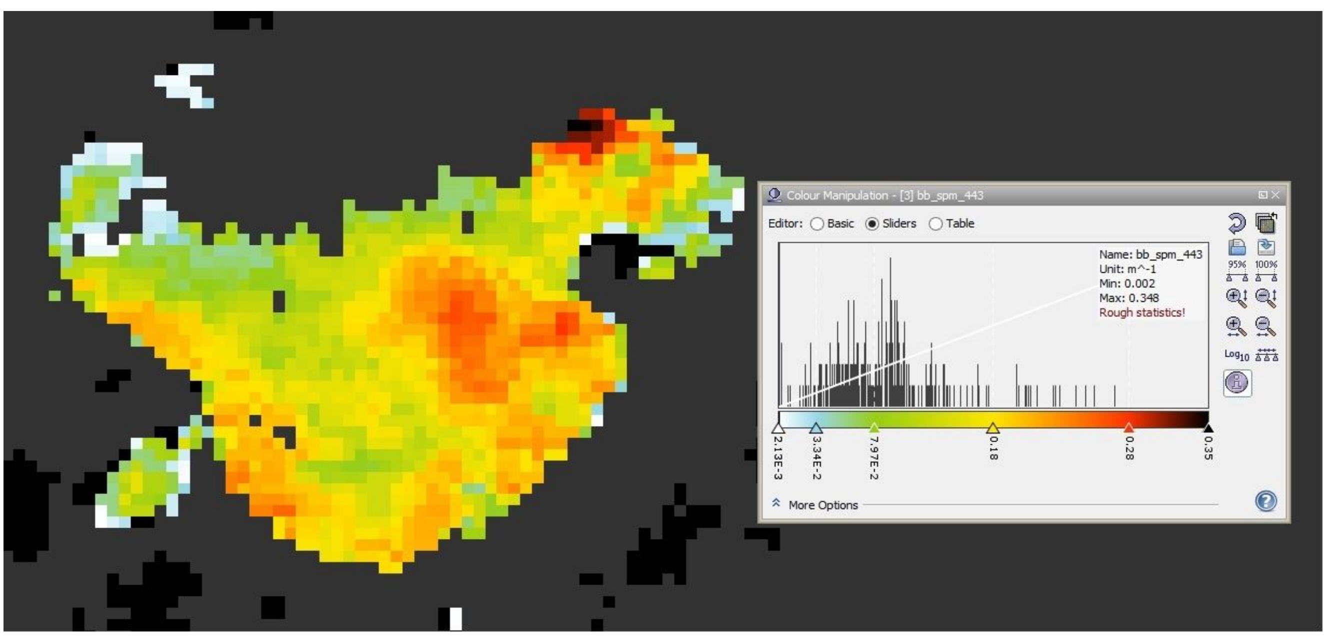


Turbidity – November 2003

Appendix III: Images showing the Water Quality Parameters of Lake Naivasha for November 2005



Turbidity – November 2005



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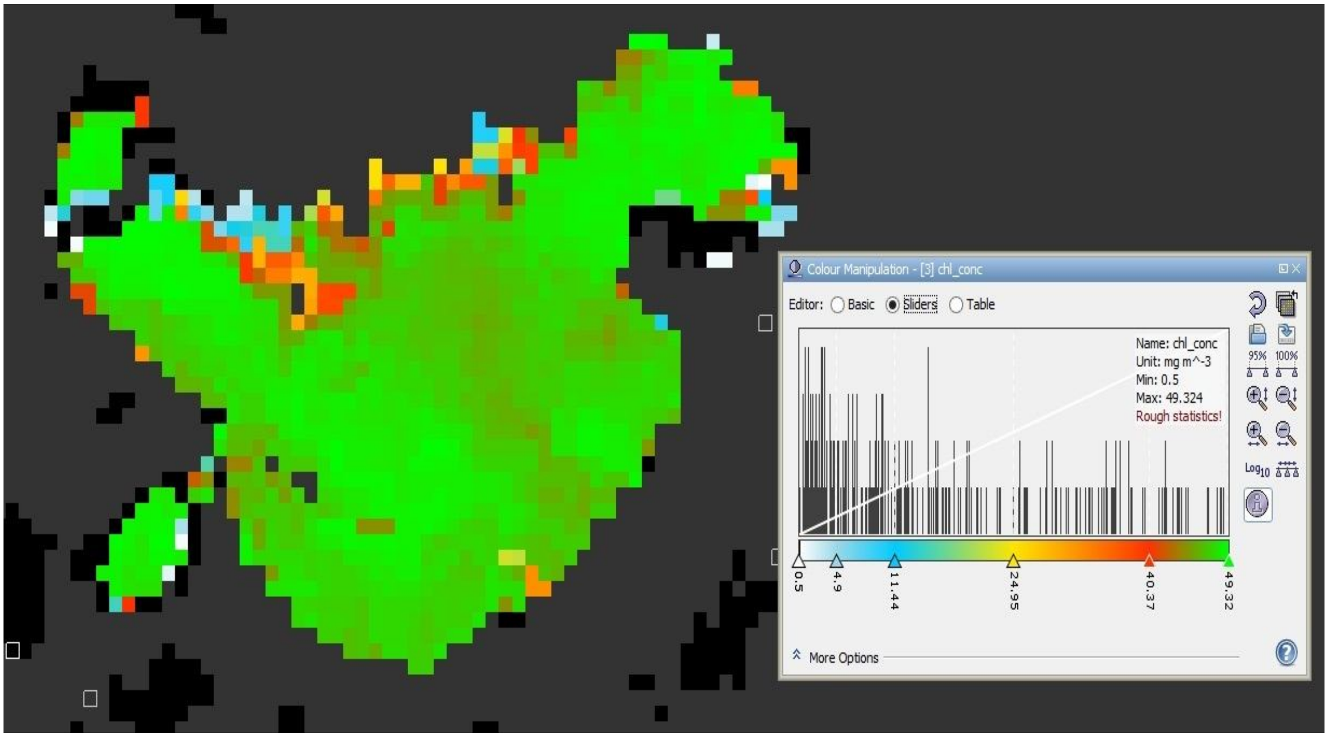
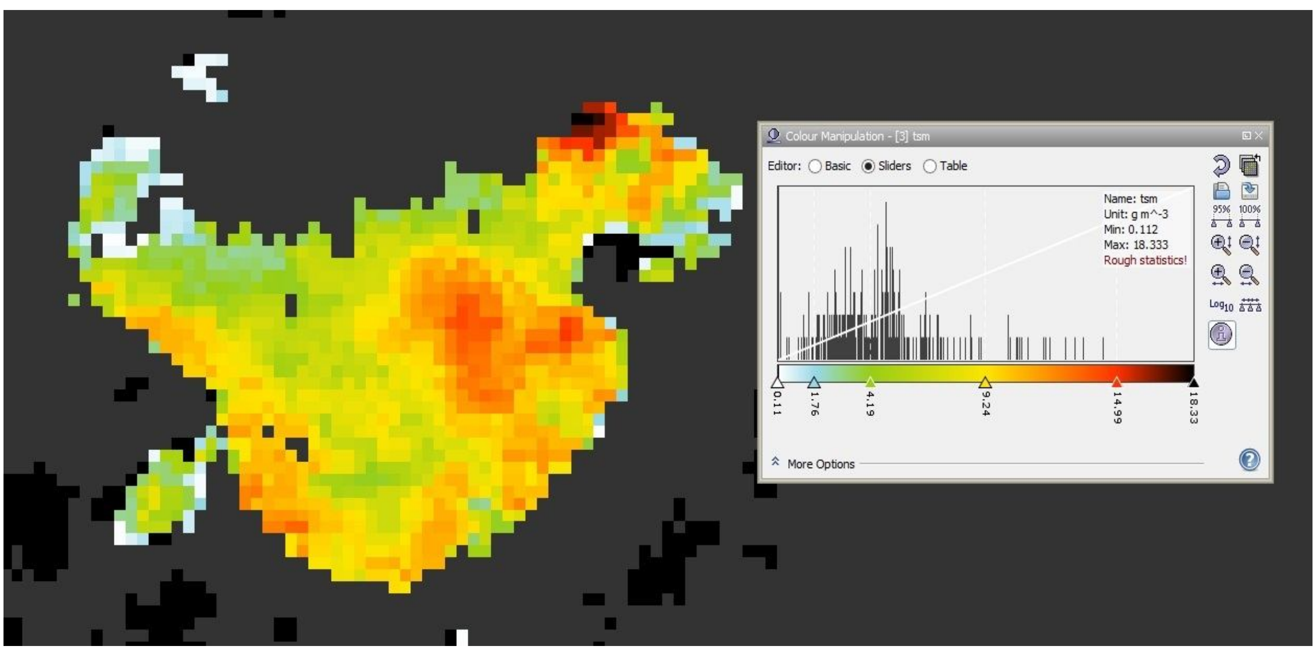
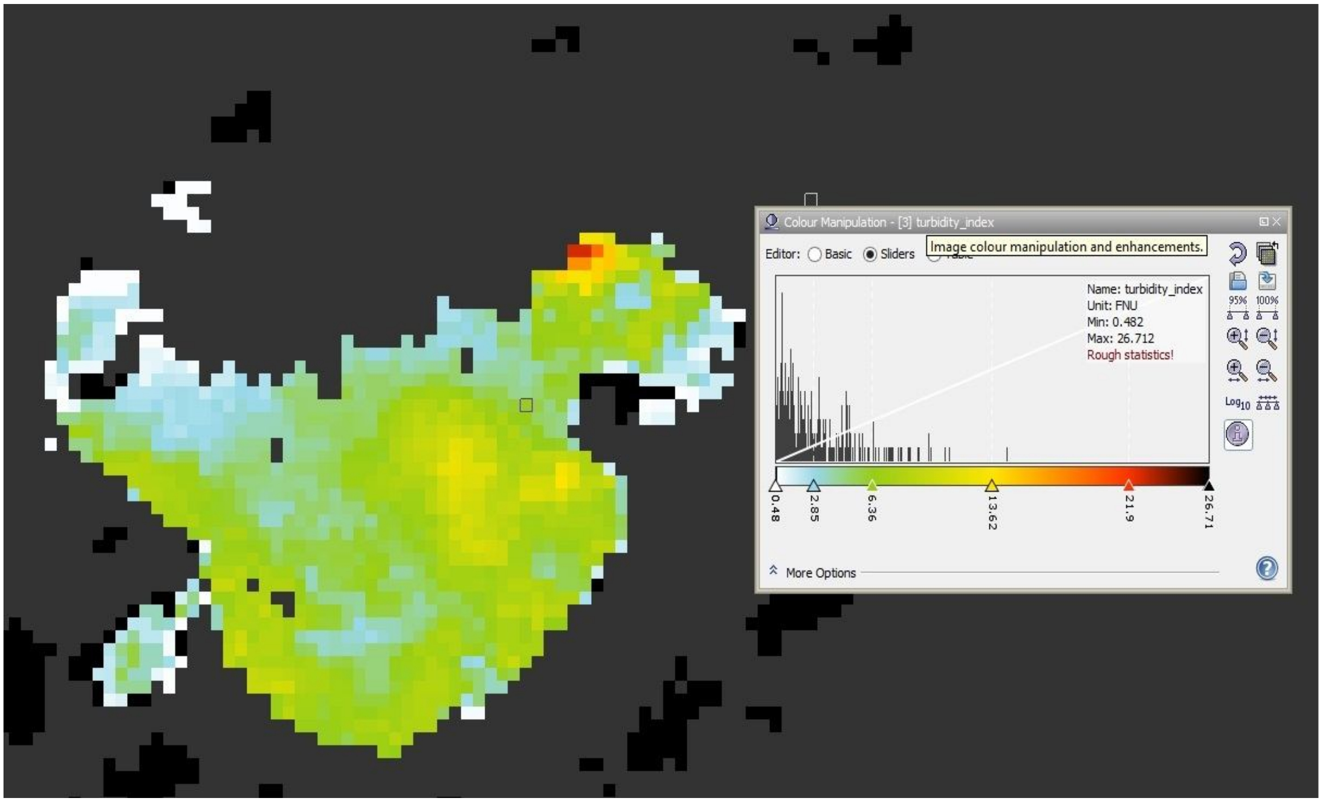


Chlorophyll – November 2005

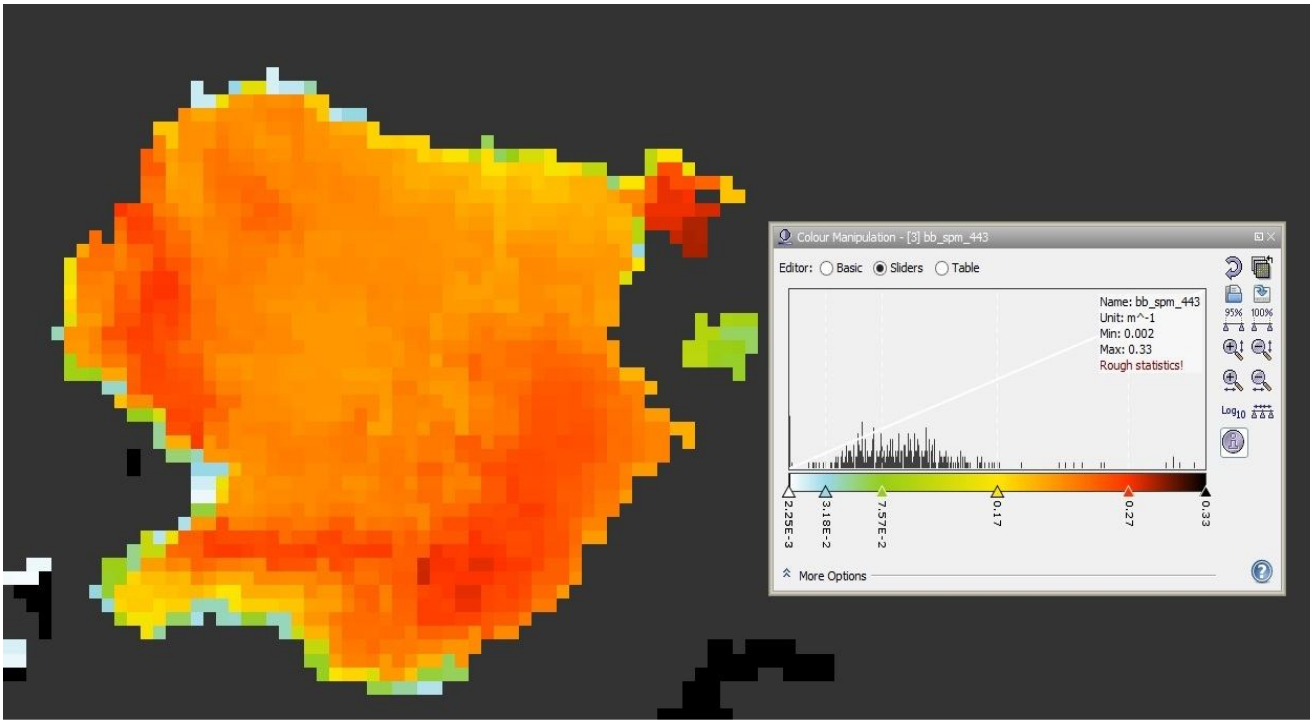


Total Suspended Matters November 2005

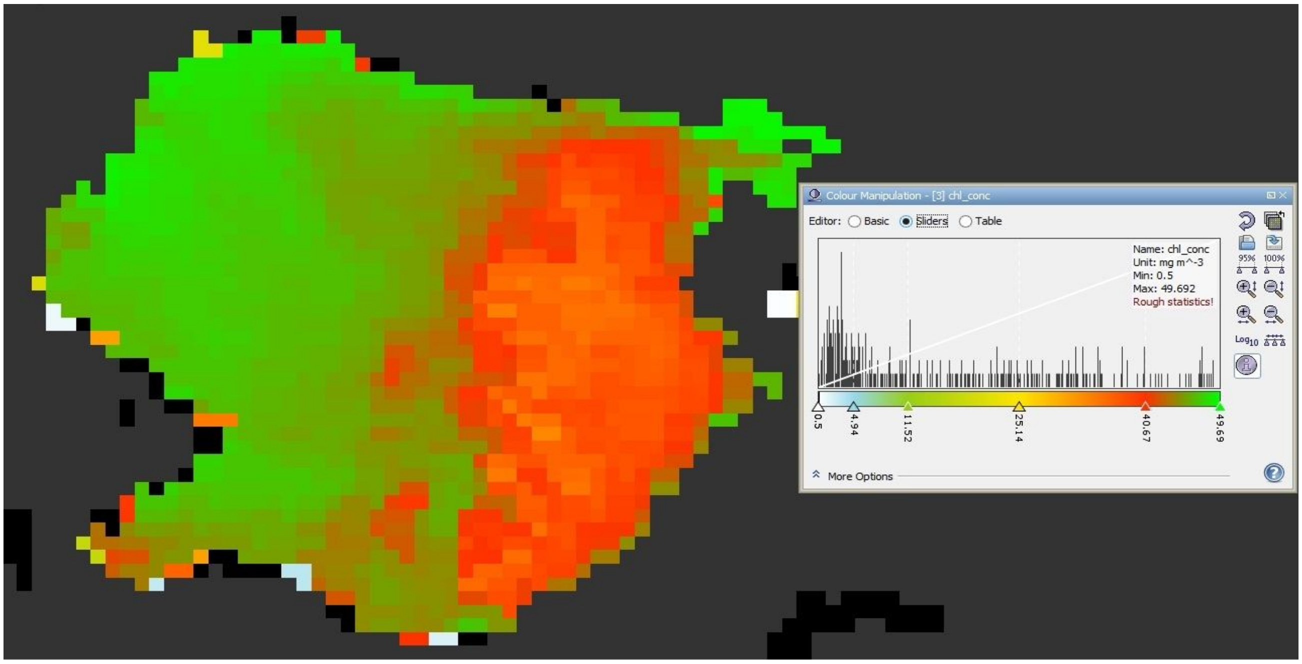


Turbidity – November 2005

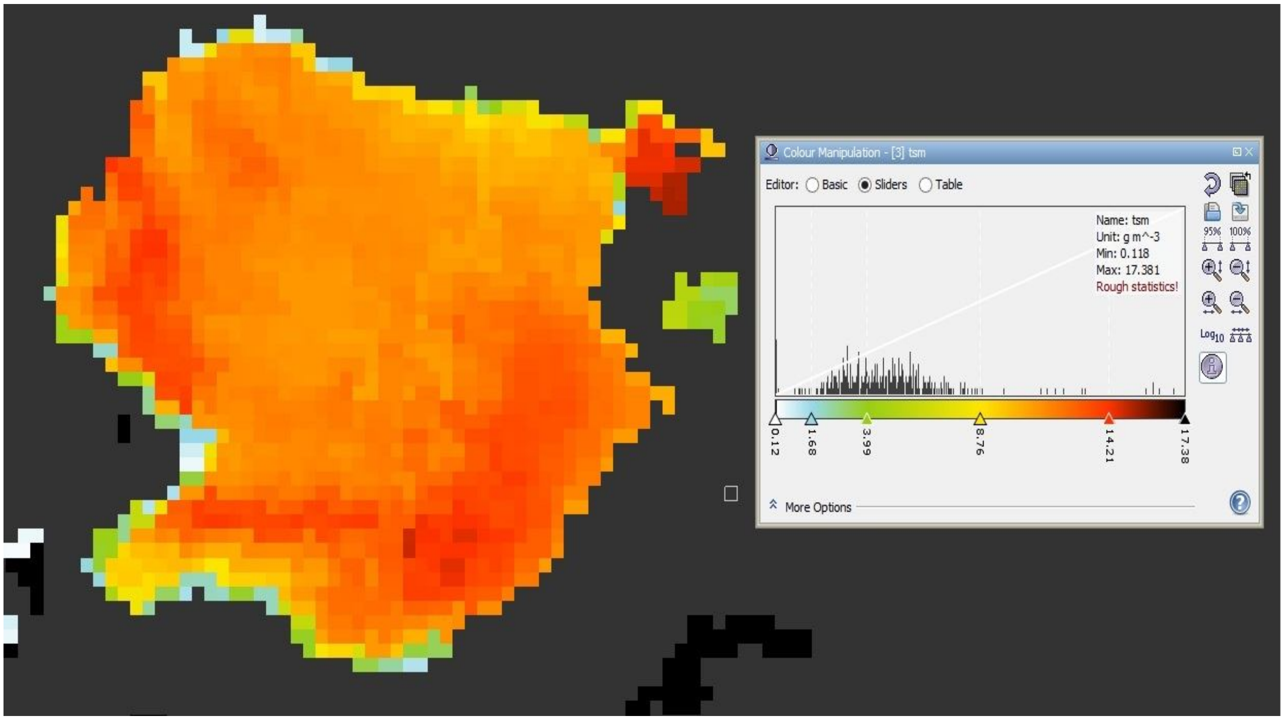
Appendix IV: Images showing the Water Quality Parameters of Lake Naivasha for September 2006



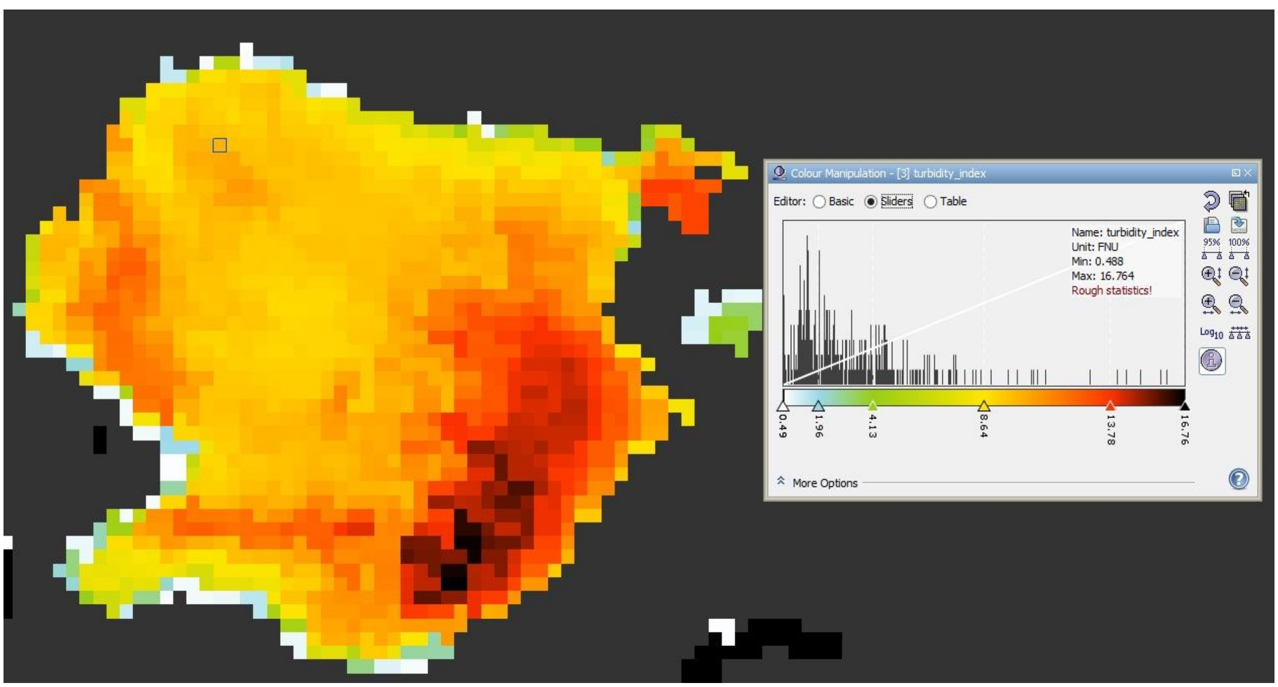
Back Scattering Suspended Matters September 2006



Chlorophyll – September 2006

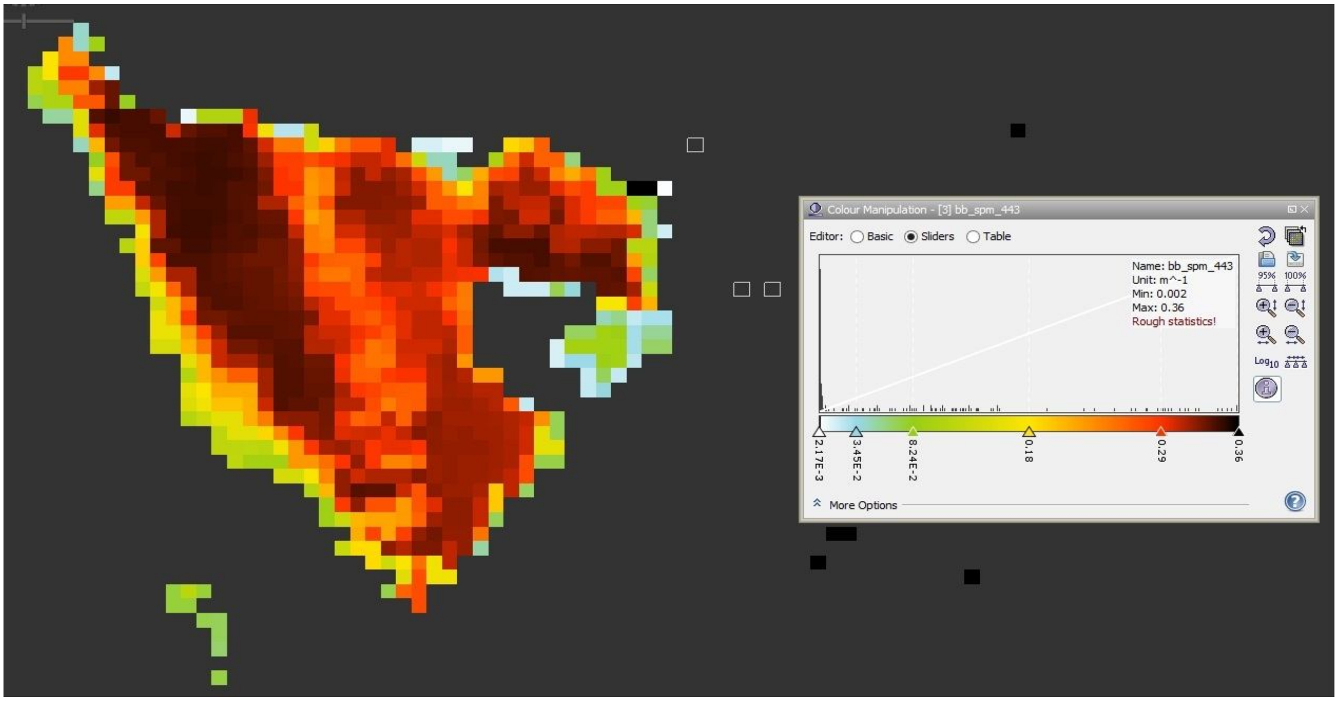


Total Suspended Matters – September 2006

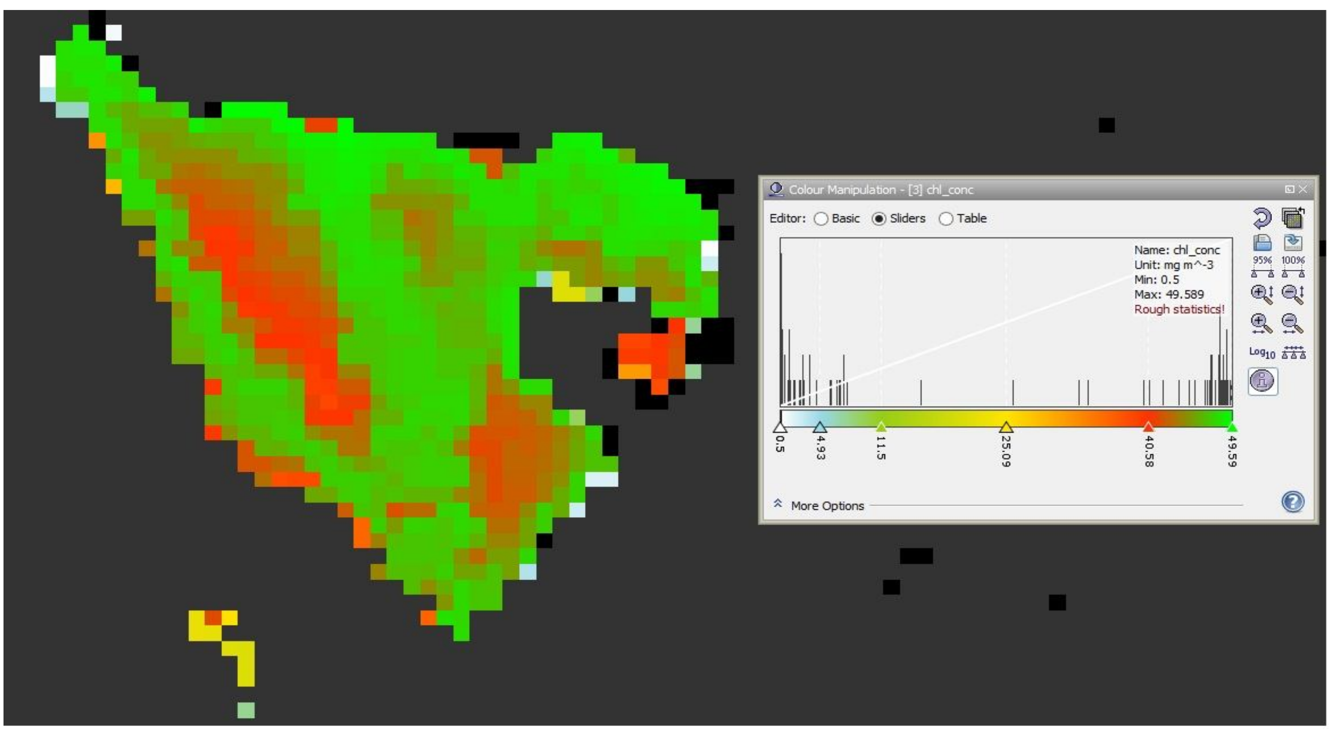


Turbidity – September 2006

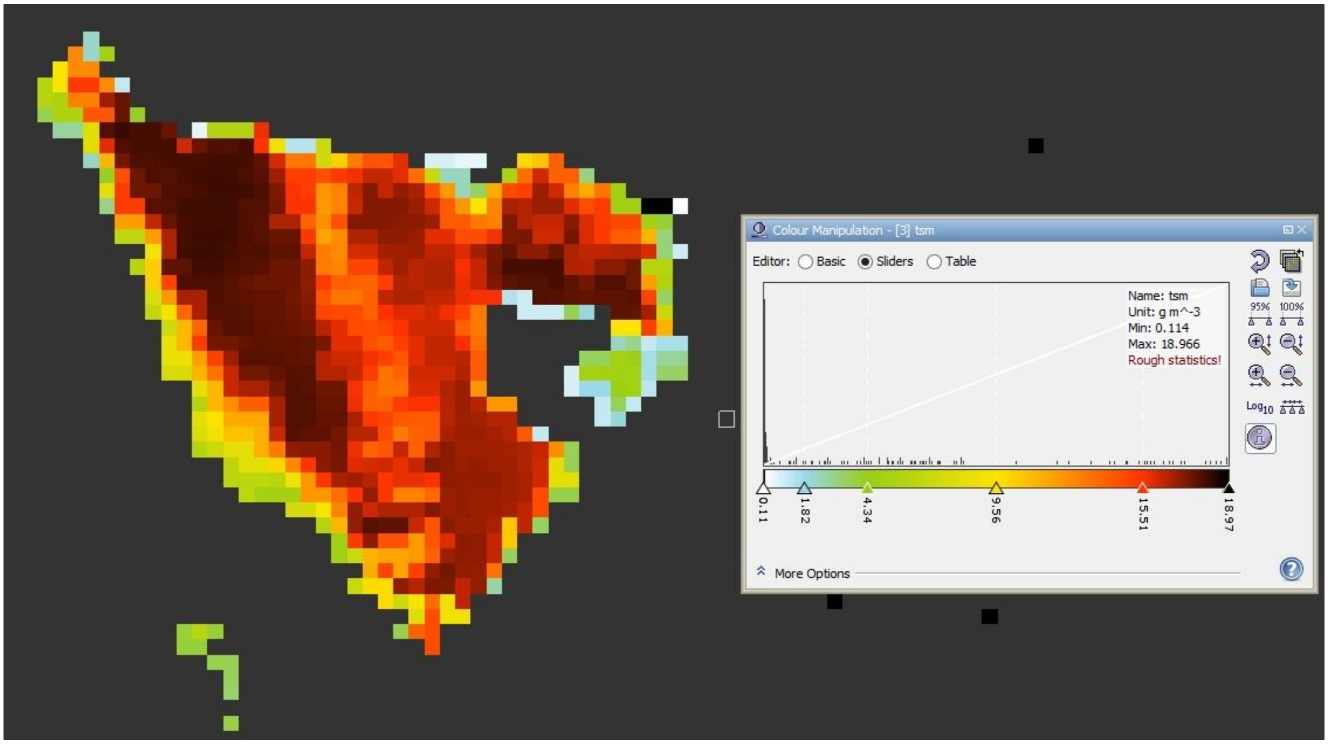
Appendix V: Images showing the Water Quality Parameters of Lake Naivasha for November 2007



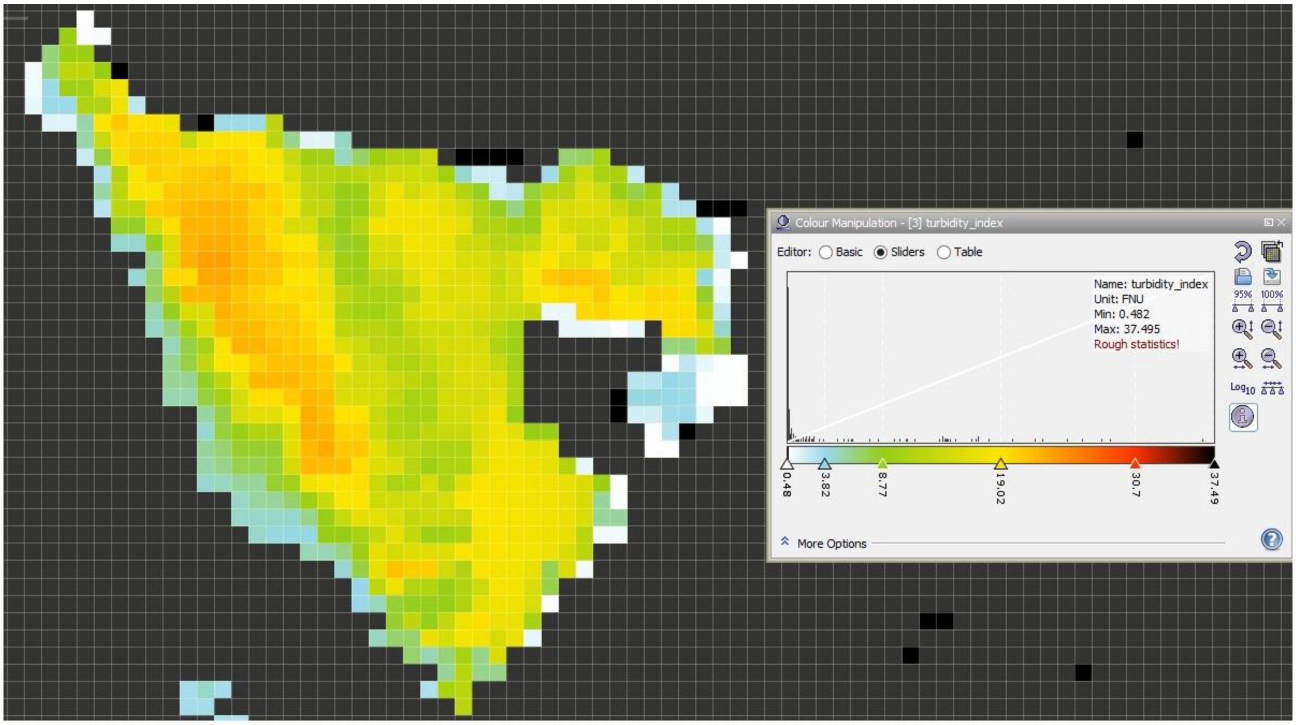
Back Scattering Suspended Matters November 2007



Chlorophyll – November 2007

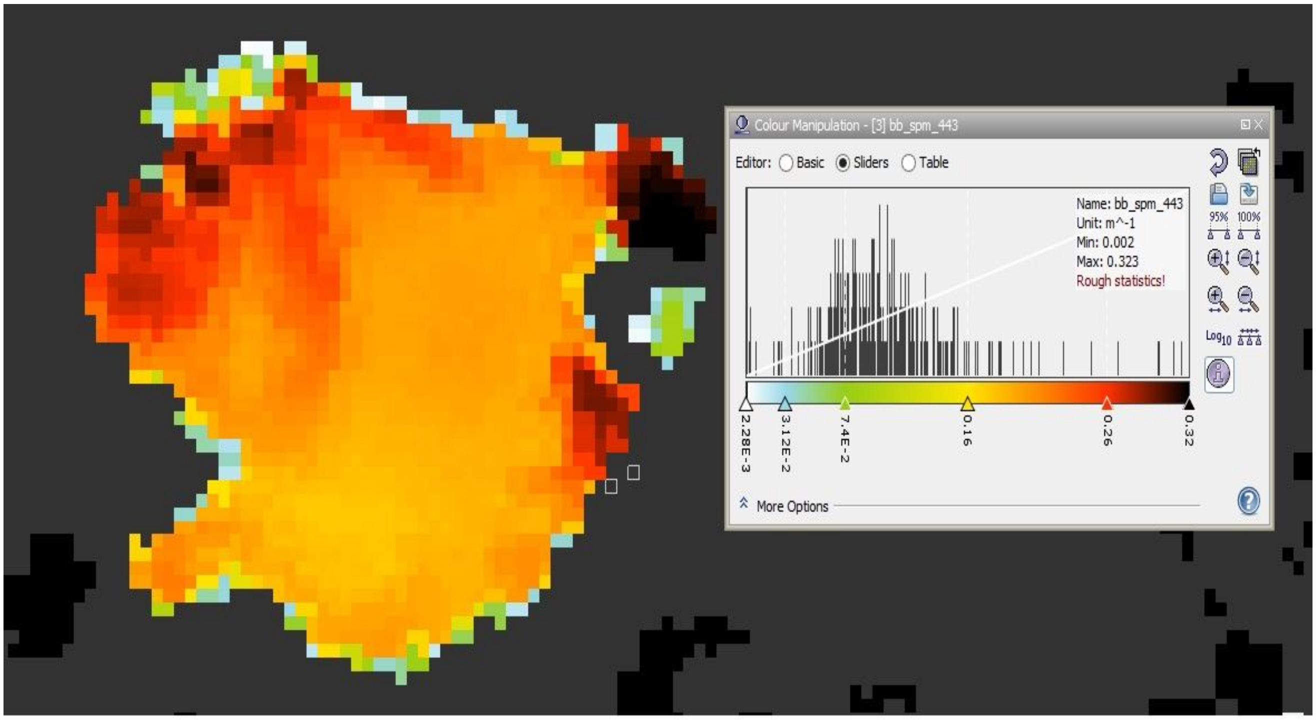


Total Suspended Matters – November 2007

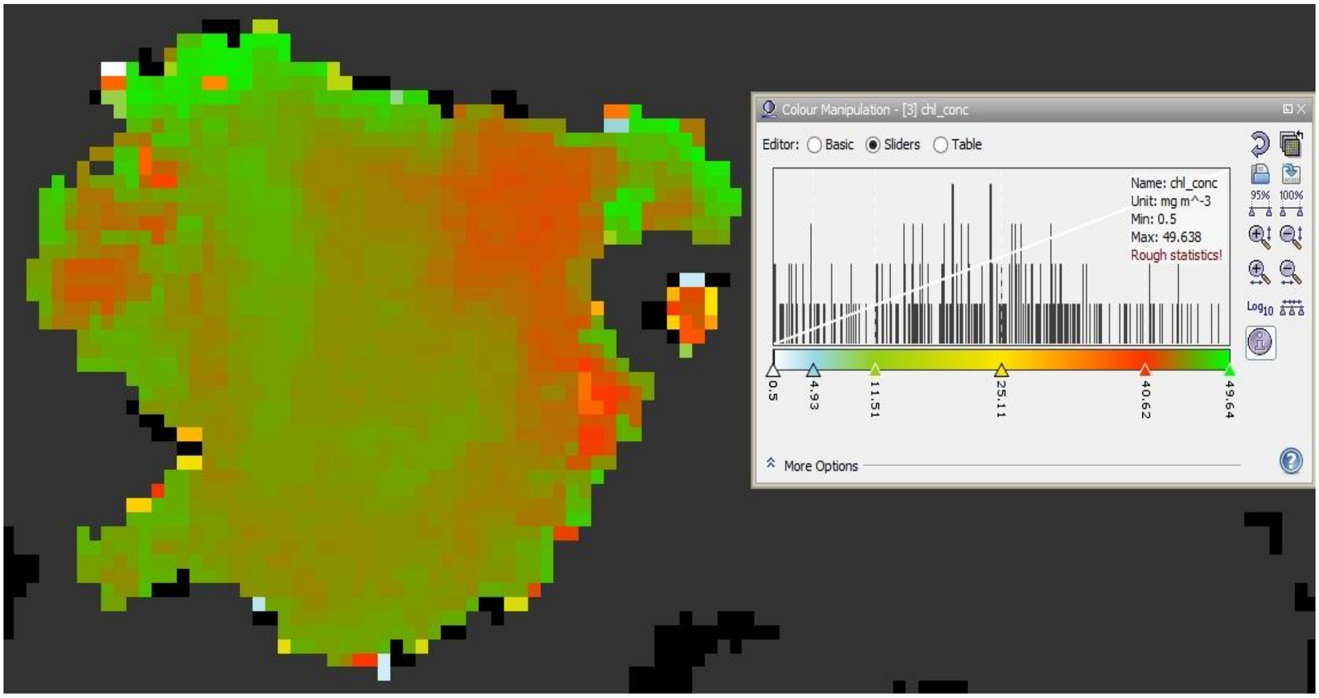


Turbidity – November 2007

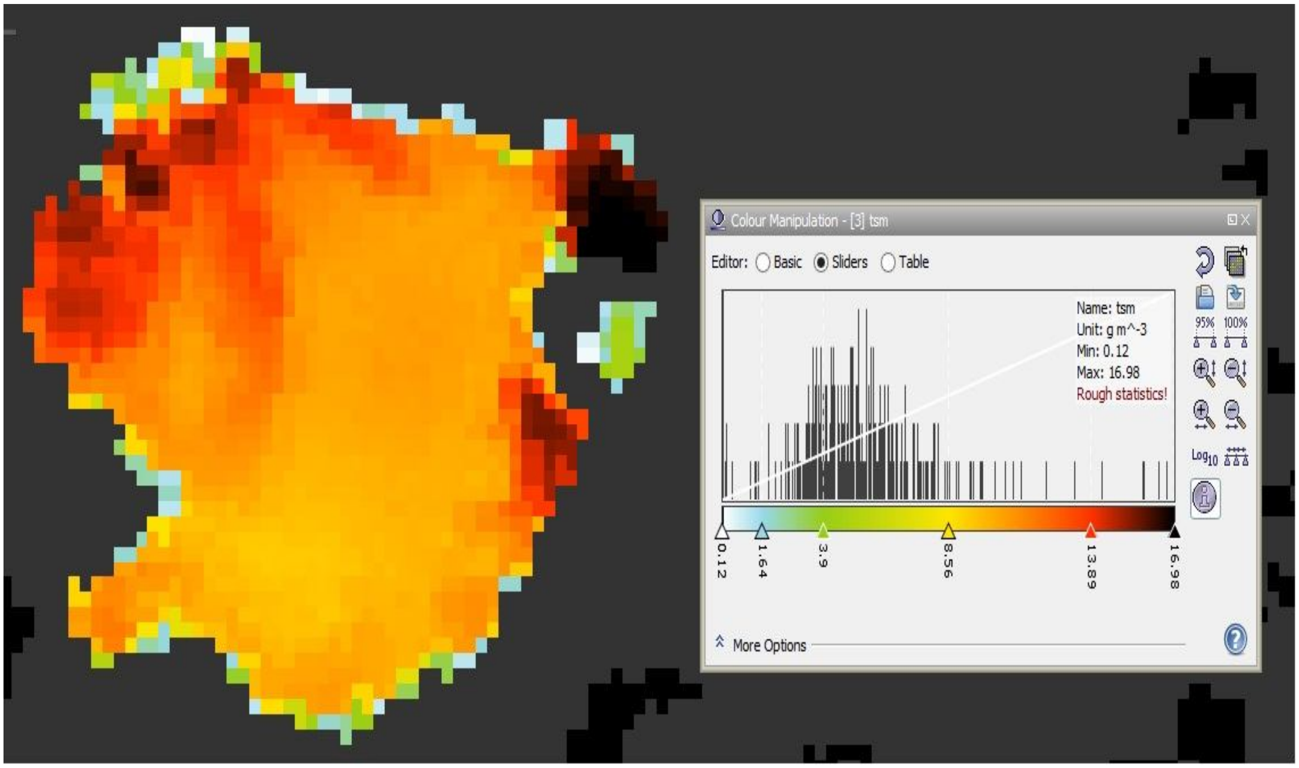
Appendix VI: Images showing the Water Quality Parameters of Lake Naivasha for September 2008



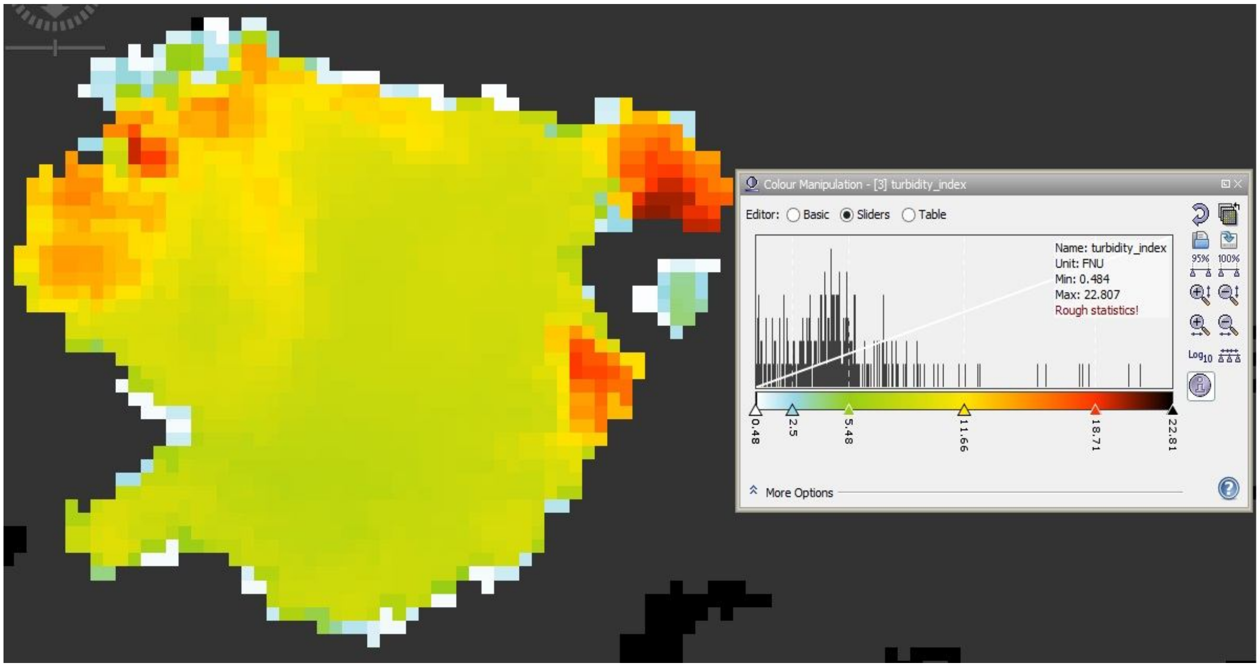
Back Scattering Suspended Matters September 2008



Chlorophyll – September 2008



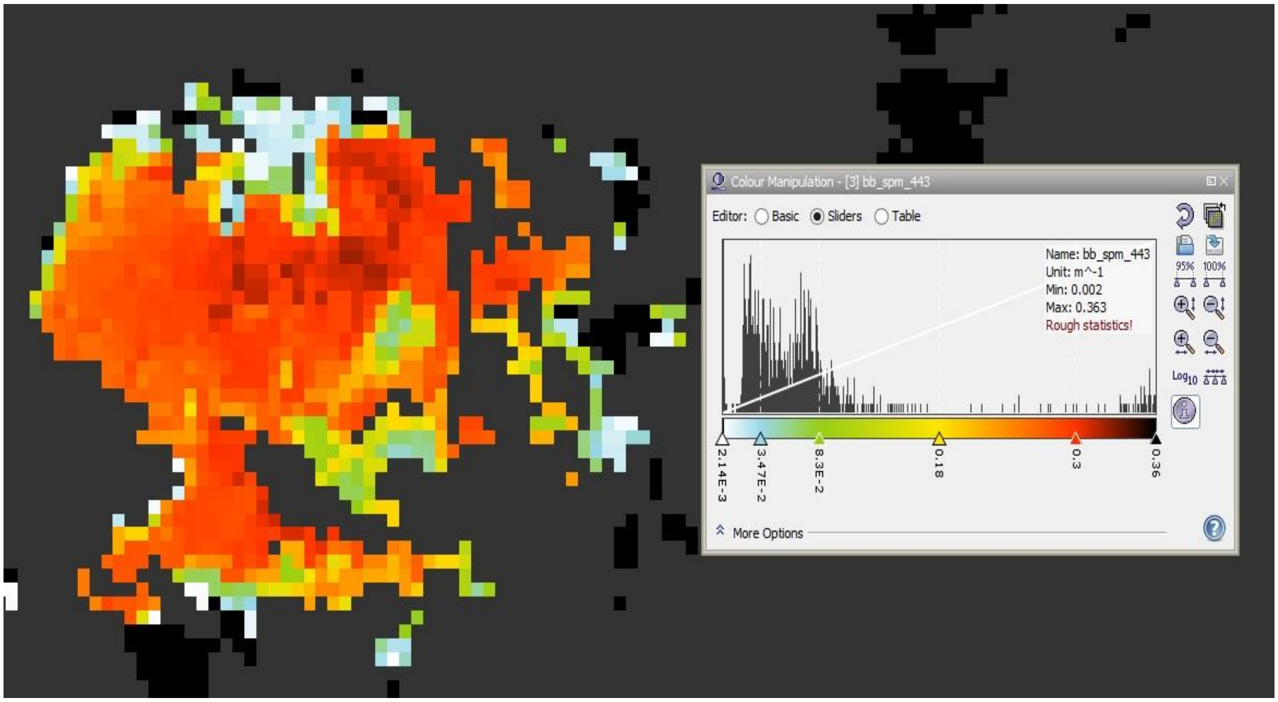
Total Suspended Matters – September 2008



Turbidity –September 2008

Appendix VII: Images showing the Water Quality Parameters of Lake Naivasha for

October 2010



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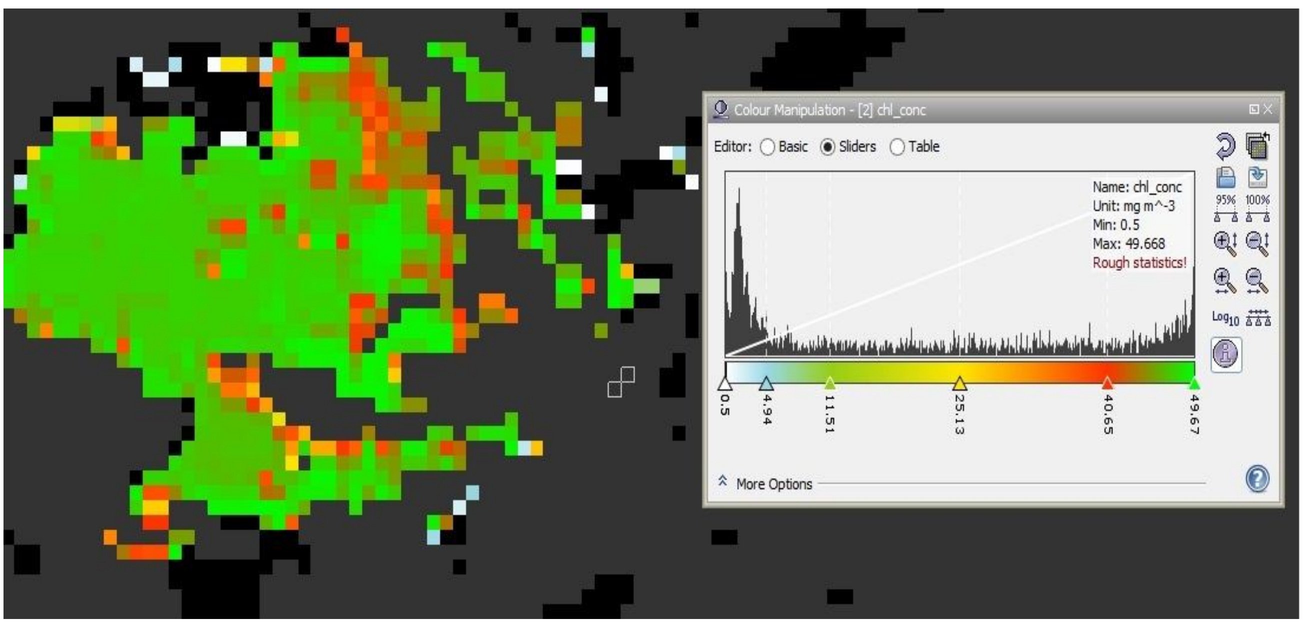
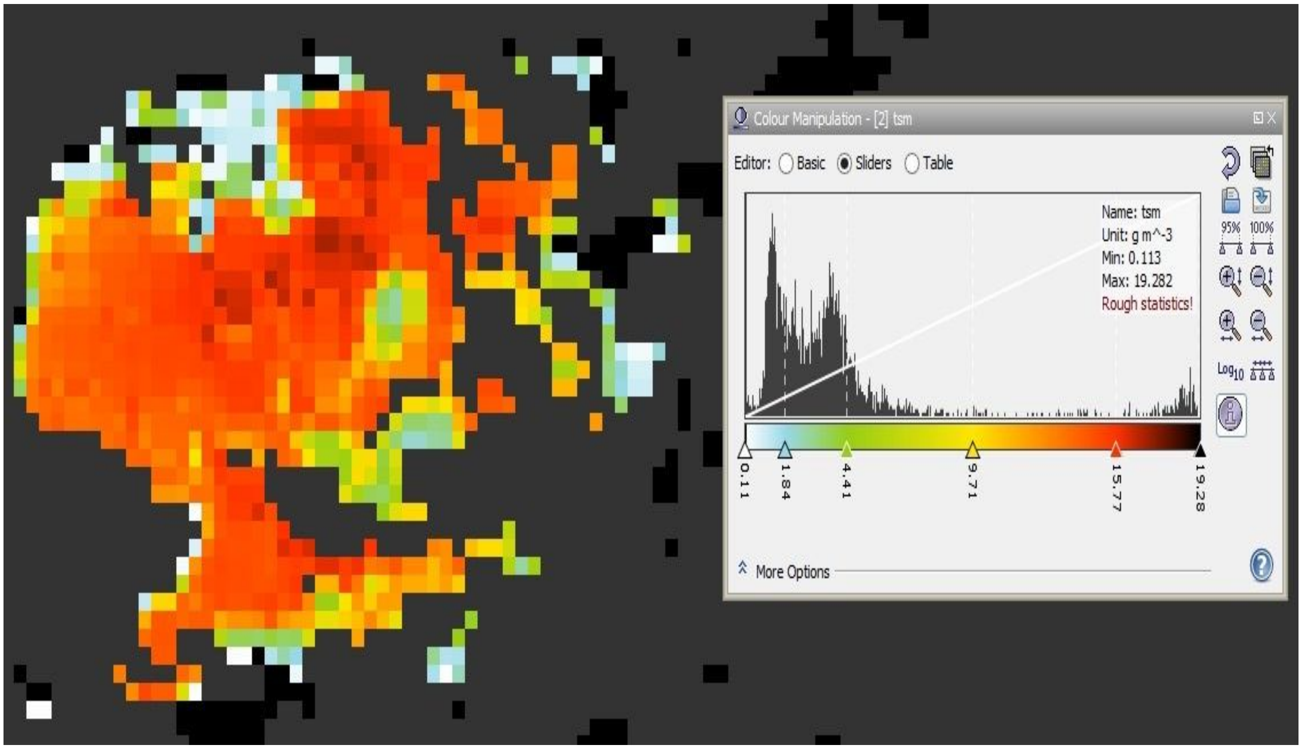


Chlorophyll – September 2010



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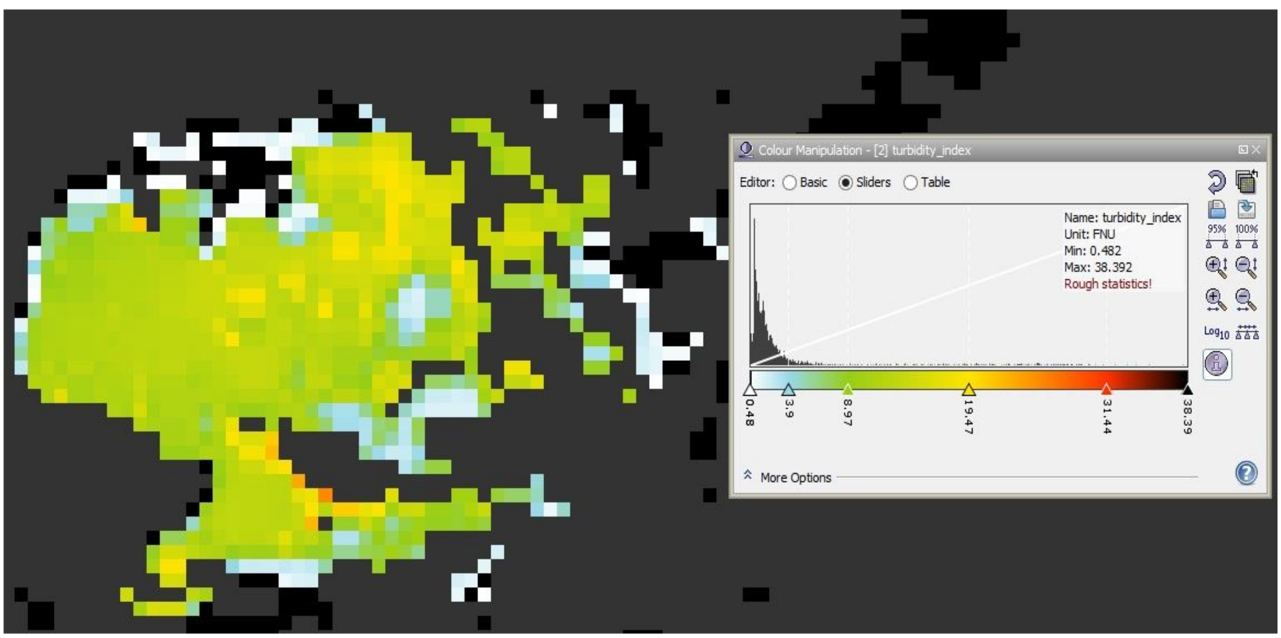

Turbidity –September 2010