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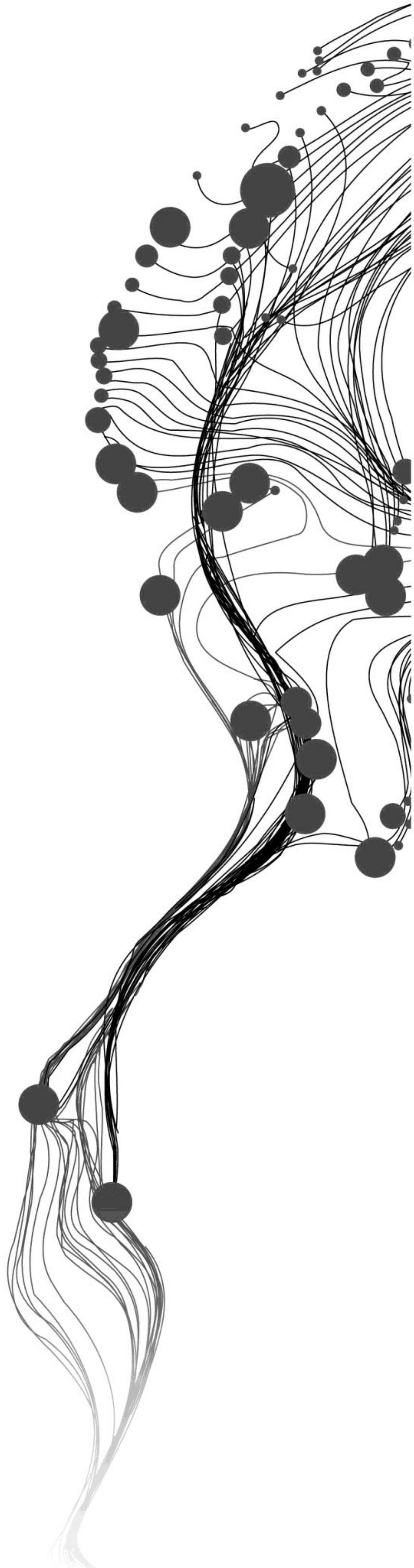

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ABSTRACT

For over five decades, Lake Victoria has been regarded as a highly eutrophic lake. Eutrophication which is the enrichment of the water by nutrients is the basis of this research. This research aimed at looking for spatial-temporal variations in remote sensing observable variables such as chlorophyll-a (chl-a) and diffuse attenuation coefficient (Kd) from MERIS sensor; and lake surface water temperature (LSWT) from (A) ATSR sensor. These supported the assessment and monitoring of the lake water quality. A spatial-temporal analysis of MERIS derived Chl-a and Kd was performed; both Kd and Chl-a concentrations show a remarkable spatial and temporal variation although the temporal variations were not well defined. Spatially, high concentrations of chl-*a* were observed on littoral zones which are characterized by shallow depth, high nutrients from the external sources and from the nitrogen fixing cyanobacteria which have high proliferation in the littoral zones. The trophic status of the littoral zones ranges from eutrophic to hypereutrophic. Low chl-a concentrations were observed in pelagic zones where light is limited because of the depth, the deeper the water the stronger the mixing and consequently the higher the light attenuation. The open pelagic zones range from oligotrophic to eutrophic.

However the temporal variations in some months were found to be concurrent to the rainfall seasons, wind speed and direction and the thermal stratification in the water column although the variations were small and irregular. Higher chl-*a* concentrations were observed during the wet and high temperature periods and vice versa for low chl-a concentrations. The highest was observed in May 2010 whereas the lowest was in December 2010. The correlation between MERIS and *in situ* chl-*a* for match-up data is non-linear but gave a significant correlation of $R^2=0.75$. This is the first study to explore a large dataset of LSWT derived from remote sensing. The time series analysis of LSWT revealed the seasonality in temperature variations. The highest LSWT was in April whereas the lowest was in July; these variations coincide with the March Equinox and June solstice respectively. The correlation between nutrients and chl-a concentration in L. Victoria was found to be very low and insignificant. The linear regression analysis produced almost zero correlations between nitrate-chl-a concentration and phosphate-chl-a concentration. Furthermore the comparison between the in situ and remote sensing derived eutrophication indices was significant suggesting the possibility of substituting *in situ* eutrophication index with the remote sensed one. Based on Carlson's and OECD's classification and by using only chl-a as the proxy to phytoplankton abundance, Lake Victoria falls under eutrophic lakes. This is according to the 2003, 2010 and 2011 observations.

Key words: Eutrophication, spatial-temporal variation, chlorophyll-a, diffuse attenuation coefficient, lake surface water temperature

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LIST OF ACRONYMS

AC	Atmospheric Correction
AE	Adjacency Effect
AOP	Apparent Optical Properties
ATBD	Algorithm Theoretical Basis Document
(A)ATSR	(Advanced) Along Track Scanning Radiometers
BEAM	Basic ERS & ENVISAT (A) ATSR and MERIS Toolbox
Chl-a	Chlorophyll a pigment
C2R	Case-2 Regional
CDOM	Coloured Dissolved Organic Matter
DO	Dissolved Oxygen
EARS	East African Rift System
EI	Eutrophication Index
ENVISAT	European Environmental Satellite
EOLISA	Earth Observation Link Stand-Alone
ERS	European Remote-Sensing Satellite
ESA	European Space Agency
FR	Full Resolution
GPS	Geographical Positioning System
ICOL	Improved Contrast over Ocean and Land
IOP	Inherent Optical Properties
LSWT	Lake Surface Water Temperature
LV	Lake Victoria
LVBWO	Lake Victoria Basin Water Office
Mcg	Micrograms
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NIR	Near Infra-Red
NN	Neural Network
PCA	Principal Component Analysis
RMSE	Root Mean Square Error
RR	Reduced Resolution
RS	Remote Sensing
RSEI	Remote Sensing Eutrophication Index
SD	Secchi Depth Transparency
T	Temperature
TL	Tanzania Littoral
TOA	Top of Atmosphere
TP	Tanzania Pelagic/ Total Phosphorus
TSI	Trophic State Index
TSM	Total Suspended Matter
UTM	Universal Transverse Mercator
VIS	Visible part of the spectrum

LIST OF SYMBOLS

Symbols	Meaning
Z_{eu}	Euphotic depth
NO_3^-	Nitrate
NO_2	Nitrite
NH_4	Ammonium
PO_4	Phosphate
K_d	Diffuse attenuation coefficient
NH_3	Ammonia
SD	Secchi depth
Z_{SD}	Secchi disk depth
ln	Natural log
α	Slope
y	Concentration of variables
y_0	Initial concentration of variables
Z_0	Initial depth
ΔZ	Change in depth

1. INTRODUCTION

1.1. Background

Eutrophication is globally recognized as one of the most striking problems in inland waters. Ferreira et al. (2011), defines eutrophication as the excessive enrichment of water by nutrients typically nitrogen and phosphorus which triggers the growth of phytoplankton. Harmful algal blooms and an increase in anoxic conditions are its major symptoms.

The eutrophic events can occur naturally or can be induced by humans through rapid population growth which leads to the increase of developmental activities such as urban expansion, industrial activities and intensive agricultural activities (Haande et al., 2011).

Eutrophication has many undesirable side effects to aquatic ecosystems including serious decrease in species diversity, increase in domestic and drinking water treatment costs. Others include degradation of the water quality, formation of algal bloom and red tides, occurrence of anoxic condition (hypoxia), increase cases of fish kills and extinction of some fish species as well as the decrease in the aesthetic value and transparency of water among others (Ansari et al., 2010).

Lake Victoria falls under case two waters which are known by its optical complexity and high spatial-temporal variations. The complex nature of case two waters is due to the presence of many independent constituents. In order to simplify the assessment, the use of indicators for assessment and monitoring is encouraged (Barth & Fawell, 2001).

Eutrophication indicators are divided into two major categories; chemical indicators and biological indicators. Chemical indicators include nutrients such as phosphate, nitrates, nitrites and ammonia, where as for biological chlorophyll-*a* concentration is normally considered. Phosphorous (P) and Nitrogen (N) are the major phytoplankton growth limiting factors (Hornung, 1999). Apart from biological and chemical variables, there are physical variables such as temperature and water transparency. The spatial temporal variations of phytoplankton are temperature dependent. The bloom is high during higher temperature seasons and drops when the temperature is low. For that reason, the Lake Surface Temperatures (LSWT) will be used in this research as one of the eutrophication indicator. On the other hand the water transparency is also an important indicator as it can be used to characterize the trophic status.

The retrieval of remote observable water quality variables and the determination of their spatial temporal variability is the basis of this study. Nutrients do not have much of a spectral response in the VIS/NIR wavelength domain and therefore direct retrieval from remote sensing (RS) is impossible. Taking an example of nitrate; the estimation of nitrate concentrations from RS can only be achieved through the use of proxies with the remote sensing observable water quality variables such as surface water temperature and chlorophyll-a (Goes, 1999).

Remote sensing /earth observation has for several decades now shown a great improvement over the convectional techniques (Simis et al., 2007). For that reason, Medium Resolution Imaging Spectrometer (MERIS) satellite on board ENVISAT will be used.

MERIS was chosen due to its high spatial and temporal resolution (Gómez et al., 2011). There is MERIS Full Resolution (FR) and Reduced Resolution (RR) with 300m and 1200m respectively, only MERIS FR will be used in this research.

1.2. Research Problem

Lake Victoria (LV) has many economical and social benefits to the surrounding community and to the world at large. It is inhabited by a number of diverse ecosystems. This lake is threatened by eutrophication and poor water quality just like most lakes and/or inland waters. Due to these alarming threats, many initiatives to rescue LV and its catchment were undertaken and some are still on-going. Regardless of the efforts engaged, the implementation of their objective is still a challenge. This is because of over reliance on the conventional techniques in solving the problem. Conventional techniques are sparse, irregularly spaced, labour intensive, costly and have low temporal coverage (Machiwa, 2003). A lot of information on many parameters can be obtained but only from a single point (Hadjimitsis & Clayton, 2009). For these reasons the methodologies used in monitoring and analyzing the spatiotemporal of water quality need to be advanced. This may be achieved by employing the remote sensing techniques. The utilization of the satellite images from ocean colour sensors such as MERIS might provide promising results.

1.3. Research Objectives

1.3.1. Main Objective

The main objective was to analyse the spatial-temporal variability and the status of eutrophication of Lake Victoria using remote sensing derived water quality variables.

1.3.2. Specific Objectives

The specific objectives of this research were to:

- Retrieve remote sensed chlorophyll-*a* (Chl-*a*) concentration and diffuse attenuation coefficient (Kd) from MERIS satellite data.
- Validate the retrieved Chl-*a* concentration and Kd using the *in situ* chl-*a* concentrations and euphotic depth (Z*eu*) measurements, respectively.
- Retrieve Lake Surface Water Temperature (LSWT) from (A) ATSR dataset and perform a time series analysis of the retrieved LSWT.
- Determine the relationship between *in situ* chlorophyll-*a* concentrations and nutrients (P and N) in Lake Victoria.
- Determine and compare the *in situ* and remote sensing derived eutrophication indices.

1.4. Research Questions

- Is it possible to estimate chlorophyll-*a* (Chl-*a*) concentration and diffuse attenuation coefficient (Kd) in Lake Victoria from MERIS satellite data?
- Is there spatial-temporal variability of the water quality and eutrophication levels in the lake?
- What is the eutrophication status of Lake Victoria?
- Is there a relationship between *in situ* chlorophyll-*a* concentrations and nutrients (P and N) in Lake Victoria?

1.5. Thesis Structure

- **Chapter one:** This chapter gives a brief background which contain introduction, research problem, research objectives with its respective research questions.
- **Chapter two:** Contains; literature review, concepts and its relevance to the study and theoretical framework
- **Chapter three:** This chapter depicts background information about the study area and the data set used.
- **Chapter four:** Research Methodology and the models used are described.
- **Chapter five:** presentation of the findings/results on the topics with much emphasis on the answers of the research questions.
- **Chapter six:** A thorough discussion of the findings presented in chapter five.
- **Chapter seven:** A concrete conclusion and recommendation

2. LITERATURE REVIEW

2.1. Eutrophication

2.1.1. Definition

Eutrophication can be defined in many different ways; some definitions include the causal, response and the impacts while others tend to leave one or two of the factors above. Vollenweider et al. (1992) gave a more elaborate definition of eutrophication, he stated it as: *"Eutrophication – in its more generic definition that applies to both fresh and marine waters – is the process of enrichment of waters with plant nutrients, primarily nitrogen and phosphorous that stimulates aquatic primary production and its more serious manifestations leads to visible algal blooms, algal scums, enhanced benthic algal growth of submerged and floating macrophytes"*. Eutrophication and hypoxia ranks the top serious pollution problems in aquatic ecosystem (Jørgensen et al., 2012).

2.1.2. Eutrophication Indicators

There are several indicators of eutrophication which are not the same in all types of water bodies. However, the most commonly known indicators in lakes are divided into two major categories; physicochemical indicators and biological indicators. Physicochemical includes; nutrients (P and N), dissolved oxygen (DO), temperature and water transparency where as biological indicators involve phytoplankton species and biomass (productivity), chlorophyll-a, diversity and stability (O'Shea & Brosnan, 2000; Portielje & Van der Molen, 1999).

2.1.3. Causes and Responses

Eutrophication is primarily caused by excessive nutrients enrichment in the water body; whereby P and N are said to be the major growth limiting factors for aquatic submerged and floating plants. The massive increase of phytoplankton and macrophytes biomass in less turbid water bodies is the response of over enrichment of P and N (Smith et al., 1999). For the highly turbid waters the case is different, the tendency of phosphorous to be attached to sediments and other particulate matter makes it un-available for microphytic growth (USEPA, 2000). The increase in nutrients stimulates the growth of microphytes and macrophytes as a result decrease the water transparency (Carlson & Simpson, 1996). The decrease of transparency is the response of the increased biomass.

2.1.4. Effects/Impacts

- Hypoxia
- Reduced species diversity both flora and fauna. (Smith & Schindler, 2009)
- Pose a threat to the supply of drinking and domestic water by increasing the water treatment costs.
- Eutrophication endangers public health.
- Decrease the aesthetic value of the lake and water bodies at large.
- Increase the biomass of benthic and suspended macrophytes and microphytes.
- Unpleasant algal scum
- Increased rate of fish kills
- Reduce transparency by obscuring light
- Result in to odour and increased nuisance levels

2.1.5. Trophic Level Classification

In this study two types of trophic level classification will be used, the OECD fixed boundaries for trophic levels (Mssanzya, 2010; OECD, 1982; Stednick & Emile, 2001) and the Carlson Trophic State Index (TSI)(Carlson & Simpson, 1996; Stednick & Emile, 2001). The variables used for predicting the trophic state are the same in both cases; these are chlorophyll-*a* concentration, the concentration of total phosphorous (TP) and Secchi depth (SD) which determines the lake clarity. According to Carlson and Simpson (1996), Chlorophyll-*a* is the main predictor of phytoplankton abundance. It can independently be used to predict the index unlike TP and Secchi depth. The Table 2.1 shows the fixed trophic boundary as per OECD and Figure 2.1 shows the Carlson's TSI classification.

The trophic status of the water body is mainly categorized in to three to five categories by many scholars, although more categories do exist as it was portrayed by Naumann (1929). Oligotrophic, Mesotrophic and Eutrophic are the common categories. However, the terms ultra-oligotrophic and hypereutrophic are sometimes used for extremely low values and high values respectively.
The characteristics of the trophic state categories are as follows:

Oligotrophic: This is characterised by high water clarity, high oxygen, low primary production, low values of nitrogen (N) and phosphorous (P).

Mesotrophic: This is moderately fed, the water clarity, productivity, amount of oxygen and nutrients are all in moderate condition.

Eutrophic: This is characterized by high concentration of nutrients (N and P), high productivity, high biomass which led to low water clarity and very low oxygen content.

Hyper-eutrophic: This is characterized by extremely high values of nutrient concentration, extreme productivity, hypoxia; they are smelly and have very poor water clarity.

2.1.5.1. OECD Trophic Level Classification

Trophic Category	Annual Mean Total Phosphorus (µg/m^3)	Annual Mean Chlorophyll (µg/m3)	Annual Maximum Chlorophyll (µg/m3)	Annual Mean Secchi disc transparency (m)	Annual Mean Secchi disk transparency (m)
Ultra-oligotrophic	≤ 4.0	≤1.0	≤2.5	≥12.0	≥6.0
Oligotrophic	≤10.0	≤2.5	≤8.0	≥6.0	≥3.0
Mesotrophic	10.0 - 35.0	2.5 - 8.0	8.0 - 25	6.0 - 3.0	3 - 1.5
Eutrophic	35 - 100	8.0 - 25	25 - 75	3 -1.5	1.5 - 0.7
Hypertrophic	≥100	≥25	≥75	≤1.5	≤0.7

Table 2.1: Adopted OECD Fixed boundary for trophic levels

2.1.5.2. Carlson Trophic State and Index Classification

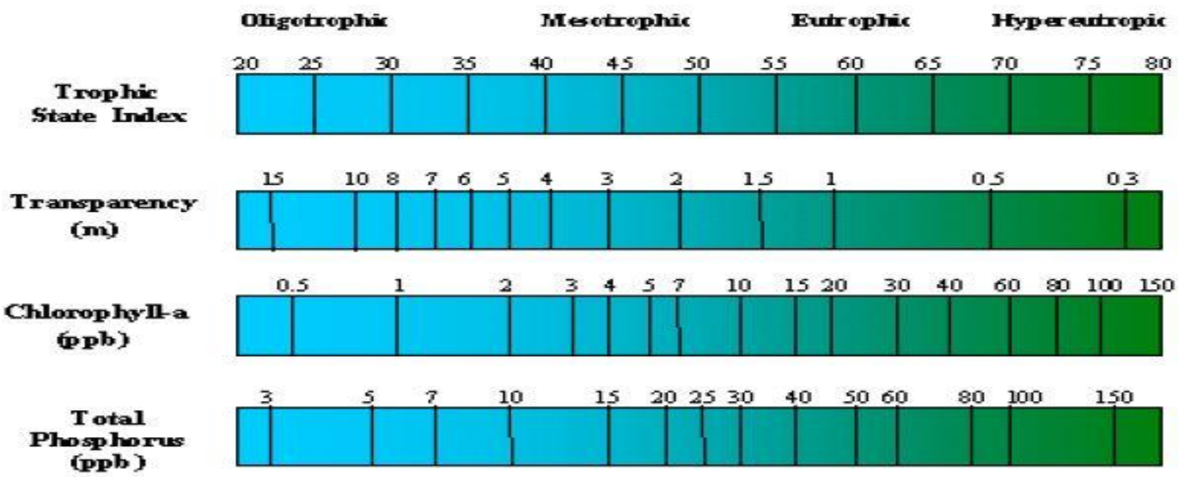


Figure 2.1: Carlson trophic state and TSI classification (Adopted from Stednick and Emile (2001))

2.1.5.3. Calculation of Carlson Trophic State Index

The Carlson Trophic State Index (TSI) can be calculated by involving the annual mean of each variable as shown in equations 2.1-2.3 below (Upadhyay et al., 2013).

Secchi disk: $TSI (SD) = 60-14.41*Ln (SD)$ Equation 2.1

Chlorophyll a: $TSI (Chl\text{-}a) = 9.81*Ln (Chl\text{-}a) +30.6$ Equation 2.2

Total phosphorus: $TSI (TP) = 14.42*Ln (TP) +4.15$ Equation 2.3

Ln means natural logarithm

2.2. Diffuse Attenuation Coefficient (Kd)

The diffuse attenuation coefficient governs the amount of propagated light that can penetrate through the water. It is not constant throughout the water body and its variation depends on the water body's composition (Ashraf et al., 2013). The unit for Kd is inverse meters. The high Kd values implies more attenuation and less water transparency, the vice versa is true for low Kd values. Kd is very useful in giving the information about the water clarity as well as classifying the status of water bodies in terms of trophic levels.

2.3. Chlorophyll-*a* (Chl-*a*)

Chlorophyll-*a* is the green pigment responsible for photosynthesis in most aquatic macrophytes and microphytes such as phytoplankton (Kordi, 2012). Chlorophyll-*a* also facilitates the trophic state classification as it is used as the major estimator for the growth and abundance of the phytoplankton (Balali et al., 2013). In remote sensing it is used as the proxy to phytoplankton abundance and productivity. The estimation of its concentration is made by making use of the relationship between the observed optical variation and wavelength specific light reflectance (Moses et al., 2009). For case 1 waters; it uses the reflectance in the visible part of the spectrum, 400-700nm wavelength. The situation is different for case two waters; the reflectance in this region is interfered by the dissolved coloured substances' absorption and the scattering of suspended solids (Dall'Olmo & Gitelson, 2005).

2.4. Lake Surface Water Temperature (LSWT)

Lake Surface water temperature plays a major role in the biology and chemistry of the inland waters. It influences the conditions of aquatic ecosystem as most of the biochemical processes are temperature dependent. LSWT is also useful for meteorological forecast and environmental monitoring studies and predictions (Merchant, 2011; Oesch, 2005). Regardless of the presence of other driving forces; LSWT aid the up and down movement of water and its constituents such as nutrients and carbon. Not only that but also the LSWT is a crucial component in hydrological cycle and facilitates the understanding of other physical processes taking place in the lake (Oesch, 2005). The spatial temporal variations of eutrophication can easily be studied using LSWT since it supports lake water dynamic and it enhances mixing during thermal stratification in the water column (Ochumba, 1996).

In spite of its importance, the documentation of LSWT for L. Victoria is still a challenge to date. According to Muhindo (2011), a wide and consistent temporal and spatial coverage can only be achieved by employing the remote sensing techniques Also he suggested a study that will involve a large dataset of LSWT in order to better understand its variations at a wide temporal coverage.

3. STUDY AREA AND DATA SETS

3.1. Description of the Study Area

Lake Victoria (LV) is the World's second largest freshwater body by surface area which is only exceeded by North America's Lake Superior. It has the surface area of approximately 69,000 km^2, with a North to South extension of about 300 km and 280 km from East to West. However, this lake is shallow with a maximum depth of 79 m and a volume of 2700 km^3 (Kendall, 1969). The lake is shared by three East African countries; Tanzania, Uganda and Kenya. The largest portion of the lake is in Tanzania (51%) followed by Uganda (43%) and 6% is in Kenya (Odada et al., 2009).

Lake Victoria lies within latitudes 0° 31' N- 3° 05'S and longitudes 31° 35'- 34° 54' E. The interest of this research is the Tanzanian part which is found within 1° -3° S latitude and longitude 31° 35'- 34° 05'E (Kassenga, 1997).

The lake is an equatorial down-warping basin which resulted from the tectonic uplift (movement) of the two East Africa Rift System (EARS); the Eastern and Western branches of the rift valley (Rach, 1992). Lake Victoria Basin covers an area of approximately 184,000 km^2 with an altitude of about 1134 m above mean sea level. It extends up to Burundi and Rwanda making a total of five East African countries. However, 46% of the total basin area which is equivalent to 84,640 km^2 is in Tanzania (Kassenga, 1997; Onyutha & Willems, 2013).

Many rivers drain in LV, but the most important and major contributing affluent is the Kagera River in the Western shore followed by Katonga River in the North Western shore. However, the White Nile or Victoria Nile is the only river that outflows through the Northern shore. The Nile's outflow exceeds the inflow of the whole catchment (Odada et al., 2009).

Most of the physical regimes such as wind speed, temperature and rainfall within the lake basin are influenced by the Inter Tropical Convergence Zone (ITCZ) (Muhindo, 2011). The dry South Easterly wind blows over the lake to South Westerly carrying with it the moisture which is then deposited in the Western part; this is normally in the dry months of January to February and June to September. It is also noted that sometimes there is a great wind interference caused by the dry North East winds from the Ethiopian Highlands. Its effects are experienced just before the end of dry period in February (Okonga, 2005). The strong westerly wind shifts towards the North, this wind is moist as it carries the deposited moisture from the Western part and it takes place during the months of March to May and October to December (Ssebuggwawo, 2005).

In line with this, high temperatures are experienced in March-May after the sun is overhead the equator (March equinox). There is a considerable temperature drop in July due to the shift of the overhead sun from Equator to the Tropic of Cancer (June Solstice).

Apart from that the strong thermal stratification is experienced between the months of February and April and the weak one between September and November. The lake assumes full mixing between the months of June and August whilst the partial mixing is experienced between December and January (Mugidde, 2001).

Moreover the rainfall pattern also follow the same trend, it is divided in to three seasons; February – May (FMAM) which is categorized as long rain, June – September (JJAS) as dry period and finally the short rain period of October – January (ONDJ). The maximum monthly rainfall is mostly experienced in April where as the minimum is in July (Okonga, 2005).

This lake is ecologically and socio-economically important in East Africa as it provides important habitat for a diverse ecosystem. It also supports the livelihood of the riparian community and the people of East Africa at large (Kassenga, 1997). Despite its importance, the water quality and health of this lake is highly threatened by the increasing eutrophication which was reported during the last five decades (Haande et al., 2011; Ssebiyonga et al., 2013).

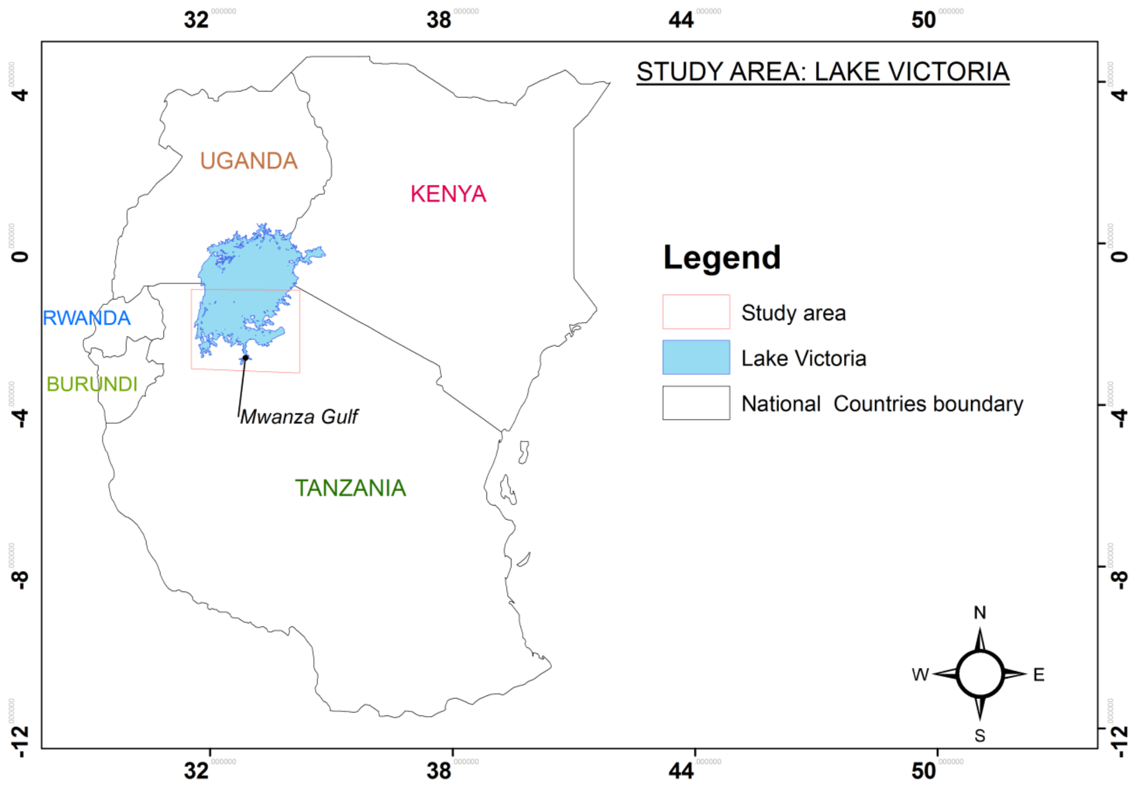


Figure 3.1: MERIS image showing the study area and the distribution of water quality monitoring stations in L. Victoria

3.2. Data Set

3.2.1. In-situ Data

Two sets of *in situ* water quality (WQ) data were obtained from Lake Victoria Basin Water Office (LVBWO), Mwanza, Tanzania. One set was collected consecutively from 2000-2005 and the other from 2010-2011. All the data sets contained the parameters of interest for this research as they either have direct or indirect impact on eutrophication. Such parameters are; chlorophyll-*a*, total suspended solids, nitrates, nitrites, ammonia, total nitrates, phosphorus, total phosphorous, temperature and secchi depth. The instruments used in parameter measurements are; filtration unit/pressure pump for the total suspended solids, Colorimeter for ammonia, nitrate, nitrite and phosphates. UV-spectrophotometer is used for chlorophyll-*a* after sample filtration and grinding. The data were collected from littoral zones (denoted TL on the map) and from pelagic zones (denoted TP on the map) to have the whole representation of the lake (Figure 3.1). For all the data used refer Appendix A.

3.2.2. Field Sampling and Data Analysis

For determination of *in situ* chemical and physical water quality parameters, a field campaign was carried out in September 2013. On 13th and 14th of September, 2013, water samples were collected from different stations within Lake Victoria. The sampling stations were selected on the basis of their surrounding environment and the distance from the shoreline. The idea behind was to get a good representation of the whole lake. Samples from both littoral and pelagic zones which are turbid to near clear/clear water respectively were collected, some samples were collected at a distance exceeding 2.5km to avoid turbidity and the effects due to land adjacency. In total 23 samples from 8 stations were collected, kept in a cooler box and taken to Mwanza Water Quality Laboratory (MWQL) for analysis. The geographical location at every site was achieved through the use of Garmin 12 Global Positioning System (GPS). The parameters and instruments used in this campaign are outlined in Table 3.1 below. All the parameters were analysed in the Mwanza Water Quality Laboratory (refer Appendix B and C for in situ measurements used).

S/N	Parameter	Devices/Methodology
1	Total Suspended Matter (TSM)	Gravimetric method
2	Chlorophyll-a (Chl a)	Spectrophotometric method
3	Transparency of the lake (Z_{eu})	Secchi disk
4	Nitrates (NO_3)	Colorimetric method (cadmium reduction)
5	Phosphates (PO_4)	Colorimetric method (ascorbic acid)
6	Ammonia (NH_3)	Colorimetric method
7	Geographic location	GPS (UTM)

Table 3.1: Instruments and devices used for sampling during the fieldwork

3.2.3. Remote Sensing Data

3.2.3.1. MERIS FR Level 1B and 2 for Water Quality Variables

MERIS FR level 1b & 2 acquired between 2003 and 2011 were requested through ESA's Earth Observation link (https://earth.esa.int/web/guest/pi-community/apply-for-data/full-proposal). Visual inspection was conducted and more than 70 images were ordered through Eolisa http://earth.esa.int/EOLi/EOLi.html. It was so unfortunate that 100% cloud free images could not be found. A thorough inspection of the image quality and suitability for this study was again conducted, thirty six (36) level 1b and 2 images were found to be suitable as they covered a big part of the study area and had reasonable clarity. These images were pre-processed and processed by using BEAM toolbox, open source software (http://www.brockmann-consult.de/cms/web/beam/).

Below is the Table 3.2 showing the characteristics of the available MERIS level 1 and 2 data set.

Processing Level	Year	Specific Date	Metadata of available images
MERIS Level 1b Images	2003	26/07/2003	MER_FR__1PNEPA20030726_074644
		30/08/2003	MER_FR__1PNEPA20030830_074659
	2005	25/06/2005	MER_FR__1PNEPA20050625_074705
		28/26/2005	MER_FR__1PNEPA20050628_075244
		14/07/2005	MER_FR__1PNEPA20050714_074954
		17/07/2005	MER_FR__1PNEPA20050717_075533
		30/07/2005	MER_FR__1PNEPA20050730_074702
		2/8/2005	MER_FR__1PNEPA20050802_075241
		8/8/2005	MER_FR__1PNEPA20050808_080359
		3/9/2005	MER_FR__1PNEPA20050903_074657
	2010	30/01/2010	MER_FR__1PNEPA20100130_074641
		21/05/2010	MER_FR__1PNEPA20100521_075758
		22/06/2010	MER_FR__1PNEPA20100622_075218
		15/12/2010	MER_FR__1PNEPA20101215_074947
	2011	10/7/2011	MER_FR__1PNEPA20110710_080329
		11/9/2011	MER_FR__1PNEPA20110911_075429
MERIS Level 2 Images	2003	26/07/2003	MER_FR__2PNUPA20030726_074644
		30/08/2003	MER_FR__2PNUPA20030830_074703
	2005	17/07/2005	MER_FR__2PNUPA20050717_075533
		8/8/2005	MER_FR__2PNUPA20050808_080401
	2010	17/01/2010	MER_FR__2PNEPA20100117_075529
		22/06/2010	MER_FR__2PNEPA20100622_075235
		25/06/2010	MER_FR__2PNEPA20100625_075815
		11/7/2010	MER_FR__2PNEPA20100711_075526
		14/07/2010	MER_FR__2PNEPA20100714_080106
		24/07/2010	MER_FR__2PNEPA20100724_074657
		27/07/2010	MER_FR__2PNEPA20100727_075237
		2/8/2010	MER_FR__2PNEPA20100802_080357
		30/01/2010	MER_FR__2PNUPA20100130_074641
		21/05/2010	MER_FR__2PNUPA20100521_075759
	2011	2/2/2011	MER_FR__2PNEPA20110202_075412
		11/4/2011	MER_FR__2PNEPA20110411_080204
		14/05/2011	MER_FR__2PNEPA20110514_075245
		10/7/2011	MER_FR__2PNEPA20110710_080329
		10/6/2011	MER_FR__2PNUPA20110610_080307
		11/9/2011	MER_FR__2PNUPA20110911_075429

Table 3.2: Selected MERIS L1b and 2 images of the study area.

After the inspection and selection of the images shown in Table 3.2 above, clear images especially in the southern part of the lake were preferred. Below in Figures 3.2 and 3.3 are the quick looks of some selected images. Some of which fully cover the whole study area and some are not.

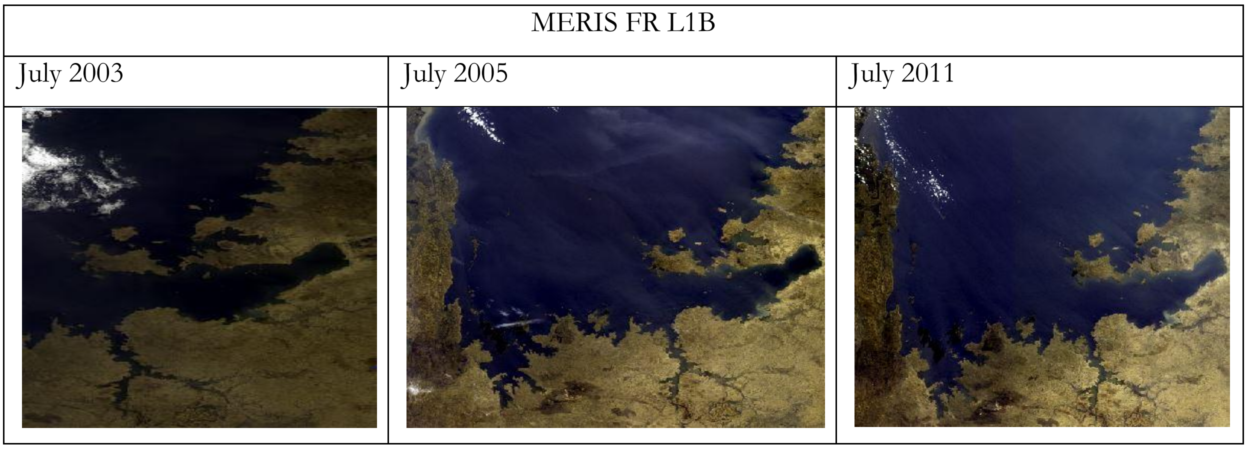


Figure 3.2: A quick look of some MERIS FR L1b images

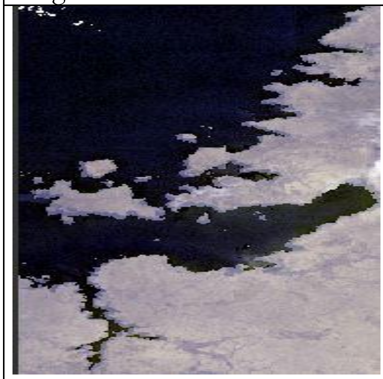
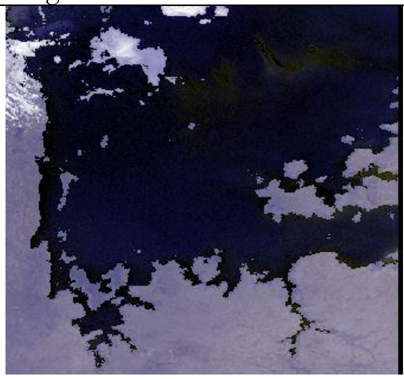
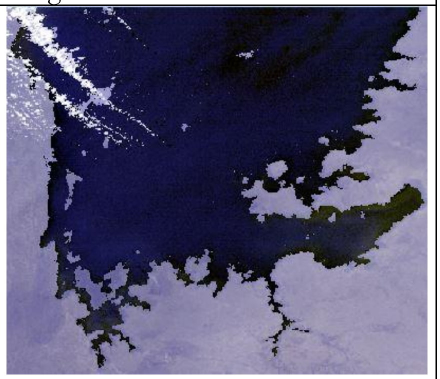
MERIS FR L2 Images		
August 2003	August 2005	August 2010
		

Figure 3.3: A quick look of some MERIS FR L2 images

3.2.3.2. (A)ATSR Derived Lake Surface Water Temperature

The remote sensed Lake Surface Water Temperature (LSWT) of the study area was downloaded from the ARC-Lake project's website (http://www.geos.ed.ac.uk/arclake/). These are (Advanced) Along Track Scanning Radiometers (ATSR) sensors derived LSWT. ARC-Lake stands for ATSR Reprocessing for Climate - Lake Surface Water Temperature and Ice Cover. ARC-Lake project is the European Space Agency (ESA) funded project which covered 258 major lakes in the world from 1991-2011 (MacCallum, 2013). The ARC-Lake dataset uses ATSR data from three ATSR instruments, respectively flown on-board of the ERS-1, ERS-2 and ENVISAT satellite platforms of ESA.

The downloaded data were in NetCDF format therefore after un-packing; the data were imported as raster data NetCDF (generic) product to BEAM VISAT (version 4.11) software for reading and processing. It was necessary to process a total of 24 files in order to know the exact temporal coverage. From these products the numerical values of temperature and the corresponding temporal coverage were extracted. The metadata provided the temporal information in form of number of days and the counting started from 1st January, 1970. Therefore the conversion of given number of days to normal date was made. Three time series files (1991-2011) were tested for use in this research due to its wide temporal coverage. The files contain one observation data obtained during day time and two reconstructed data which were collected day and night of the stated time period. After testing all the three data, the observation data was found suitable for the study. Refer to the highlighted files in Table 3.3 below. The LSWT facilitated the understanding of the ecological conditions of the lake as well as the spatial and temporal variations of eutrophication status in the water bodies.

File Metadata	START (DAYS)	FINAL DATE	END (DAYS)	FINAL DATE
ALID0003_PLOBS1D.nc	7884.5	15/06/1991	8315.5	19/08/1992
ALID0003_PLOBS2D.nc	9290.5	18/04/1995	9809.5	19/09/1996
ALID0003_PLOBS3D.nc	11893.5	29/05/2002	12243.5	13/05/2003
ALID0003_PLOBS9D_TS004SR	7896.5	13/07/1991	15293.5	14/10/2011
ALID0003_PLOBS9D_CA004LM.nc	11732.5	20/01/2002	12006.5	20/09/2002
ALID0003_PLOBS9D_CA012LM.nc	11703.5	22/11/2001	12037.5	20/10/2002
ALID0003_PLOBS9D_CA024LM.nc	11695.5	14/11/2001	12044.5	27/10/2002
ALID0003_PLOBS9N_TS004LM.nc	7896.5	27/06/1991	15293.3	13/09/2011
ALID0003_PLOBS9N_TS012LM.nc	7897.5	28/06/1991	10910.5	22/09/1999
ALID0003_PLOBS9N_TS024SR.nc	7889.5	20/06/1991	9396.5	27/10/2002
ALID0003_PLREC1N.nc	7882.5	13/06/1991	7981.5	21/09/1991
ALID0003_PLREC3D.nc	11890.5	26/05/2002	11989.5	19/09/2002
ALID0003_PLREC9D_CA004LM.nc	11732.5	20/01/2002	12006.5	20/10/2002
ALID0003_PLREC9D_CA012SR.nc	11703.5	22/11/2001	12037.5	20/10/2002
ALID0003_PLREC9D_CA024SR.nc	11695.5	14/11/2001	12044.5	27/10/2002
ALID0003_PLREC9D_CA366SR.nc	12418.5	5/11/2003	12517.5	12/2/2004
ALID0003_PLREC9D_TS004SR.nc	7896.5	27/061991	15293.5	13/09/2011
ALID0003_PLREC9D_TS012SR.nc	7897.5	28/06/1991	10910.5	22/09/1999
ALID0003_PLREC9N_CA004SR.nc	11732.5	20/01/2002	12006	19/09/2002
ALID0003_PLREC9N_CA012SR.nc	11703.5	22/11/2001	12037.5	20/10/2002
ALID0003_PLREC9N_CA024SR.nc	11695.5	14/11/2001	12044.5	27/10/2002
ALID0003_PLREC9N_CA366LM.nc	12418.5	5/11/2003	12517.5	12/2/2004
ALID0003_PLREC9N_TS004SR.nc	7896.5	27/06/1991	15293.5	13/09/2011
ALID0003_PLREC9N_TS012SR.nc	7897.5	28/06/1991	10910.5	22/09/1999

Table 3.3: A dataset for LSWT for Lake Victoria

4. RESEARCH METHODS

4.1. Pre-Processing of MERIS L1b Images for Retrieval of WQ Variables

To improve the accuracy; the retrieval of water quality variables from MERIS FR level 1b images involved a number of pre-processing steps. This research dealt with the correction of atmospheric and adjacency effects. BEAM toolbox allows remote sensed data such as MERIS and MODIS to be viewed, analysed and processed. It has different case 2 water processors as plug-ins which are specifically meant for coastal and inland waters (Attila et al., 2013). Case 2 regional processor (C2R) was used for atmospheric correction and retrieval of water quality variables. Improved Contrast over Ocean and Land (ICOL) processor is for adjacency effect correction (Santer & Zagolski, 2008).

Moreover, the re-projection of the image and spatial sub-setting had to be conducted prior to other pre-processing steps. Spatial sub-setting was very crucial as it reduces the processing time. The images were re-projected to UTM zone 36 in the Southern hemisphere.

4.1.1. Correction for Adjacency Effects (AE)

It is evident that the land has higher reflectance than water; thus the signals received by the satellite sensor from the shorelines are no doubt a mixture of both land and water. Therefore to avoid that, 16 MERIS FR level1b images as shown in Table 3.2 were first corrected to remove the effects due to adjacency using ICOL processor. ICOL is a prototype processor which was developed by Santer et al. (2007) with the main objective of correcting the adjacency effects from land over case two waters. The correction is further extended to the sun glint affected pixels. It is vital to consider the removal of the radiances from land by performing the correction for AE to avoid overestimation of the atmospheric radiances. The latter action will not only help in removing the noise in the atmospheric radiances but also reduces the chances of underestimating the water leaving radiances. The computation produces the top of atmosphere (TOA) radiances which are free from adjacency effects especially in the infrared regions (Kratzer, 2010; Ruiz-Verdú et al., 2008; Santer & Zagolski, 2009).

ICOL processor uses all 15 L1b MERIS bands as input, only 13 bands will be changed at the final stage with the exception of bands at 761nm and 900nm. Next to that is the correction for gaseous transmittance as well as the transformation of TOA radiances to TOA reflectance. This is followed by pixel correction; all the pixels especially those which are in the vicinity of land within a distance of about 30km have to be corrected to remove the effects from Rayleigh scattering and Fresnel's reflection. Next is the correction of aerosol reflectance which is coupled with the Fresnel reflection. Finally, level 1c radiances were generated (Santer & Zagolski, 2009). See appendix H & I for the settings in BEAM VISAT and the process flow chart of ICOL processor respectively.

The effectiveness of ICOL processor was assessed in different waters and has been proven to improve the spectral reflectance over coastal and inland waters (Kratzer, 2010; Ruiz-Verdú et al., 2008).

4.1.2. Correction for Atmospheric Effects

The atmospheric correction was carried out to all sixteen (16) MERIS FR level1b images (refer Table 3.2) in order to remove the effects of atmosphere from the retrieved reflectance. The correction was done by using Case 2 Regional (C2R) processor algorithms developed by Doerffer and Schiller (2008). C2R is the plug-in in BEAM toolbox/software. The toolbox makes use of the twelve of fifteen MERIS bands; band 1-10, then 12 and 13. In order to avoid extrapolation errors and negative water leaving reflectance values, bands 11, 14 and 15 had to be left out. The basis of C2R atmospheric correction was the use of radiative transfer simulations. The outcome of the simulations was then used for training the neural network which was consequently used to parameterise the relationship of the top of atmosphere and the water leaving radiance reflectance (Ruiz-Verdú et al., 2008). Appendix J indicates the settings for C2R processor.

4.2. Retrieval of Water Quality Variables from MERIS L1B and 2

Apart from performing atmospheric correction, MERIS C2R processor is also used for the retrieval of water quality constituents/variables. The processor has the masking manager which enables masking of unwanted pixel signals. The images were masked for land, glint risk, duplicated, invalid and case 2 invalids pixels before retrieval of WQ variables was done.

However, it was not possible to get MERIS level 1b images which coincides with the dates of *in situ* measurements, this therefore urge the necessity for seeking both MERIS L1b and L2 images.

From MERIS L1b, chlorophyll-*a* (chl-*a*) concentration and the diffuse attenuation coefficient (Kd) were extracted; on the other hand only Chl-*a* concentration was extracted from MERIS L2 (Appendix D). The study of these variables sharpened our understanding of the characteristics of L. Victoria. However, Chl-*a* concentration and Kd were used in the retrieval of remote sensing eutrophication index. Below are the quick looks of an un-processed image and the processed water quality variables for the 21/05/2010.

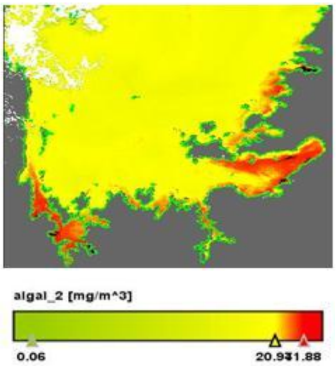
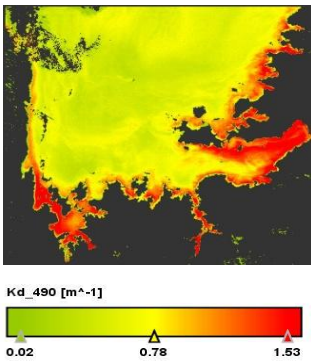
Un-processed L1b Image – 21/05/2010	Algae 21/05/2010	Kd 21/05/2010
		

Figure 4.1: Quick looks of some of the remote observable water quality variables as observed in May, 2010

4.3. Match-up and Validation of Remote Sensed Variables

A matchup test was carried out and only one L2 image out of 36 MERIS FR L1b & 2 was found to match with the exact date with which the *in situ* water quality data was collected. However, there were two images which were close to match with the *in situ* dates. The differences of the remaining two images were almost a month for a 22/06/2007 image and a week for 15/12/2010 image, see Table 4.1. It is only the matchups with N=11, which were used for validation of MERIS chl-*a*.

The validation of Kd was not possible because the data used for match-up were MERIS level 2 which do not contain Kd values.

	Date of MERIS Overpass	Date of In situ Data Collection
Direct Match-up	14/05/2011	14/05/2011
Near Match-up	22/06/2003	26/07/2003
	15/12/2010	22/12/2010

Table 4.1: Match-up and near match-up in-situ and MERIS data

4.4. (Advanced) Along Track Scanning Radiometers (A)ATSR

The time series data for the (A) ATSR derived Lake Surface Water Temperature (LSWT) were imported in BEAM v.4.11 as raster data NetCDF (generic) file. BEAM version 4.11 has the module for processing the time series data; therefore after importation, the data were processed to retrieve the LSWT. The file named ALID0003_PLOBS9D_TS004SR had a total of 82 maps which were captured from different time of the year from 13/07/1991- 14/10/2011 (see data in Appendix E). The observations were done on quarterly basis which means four observations per year. The LSWT was used as one of the eutrophication indicators in calculating the remote sensed eutrophication index. Figure 4.2 presents the quick look of the LSWT products.

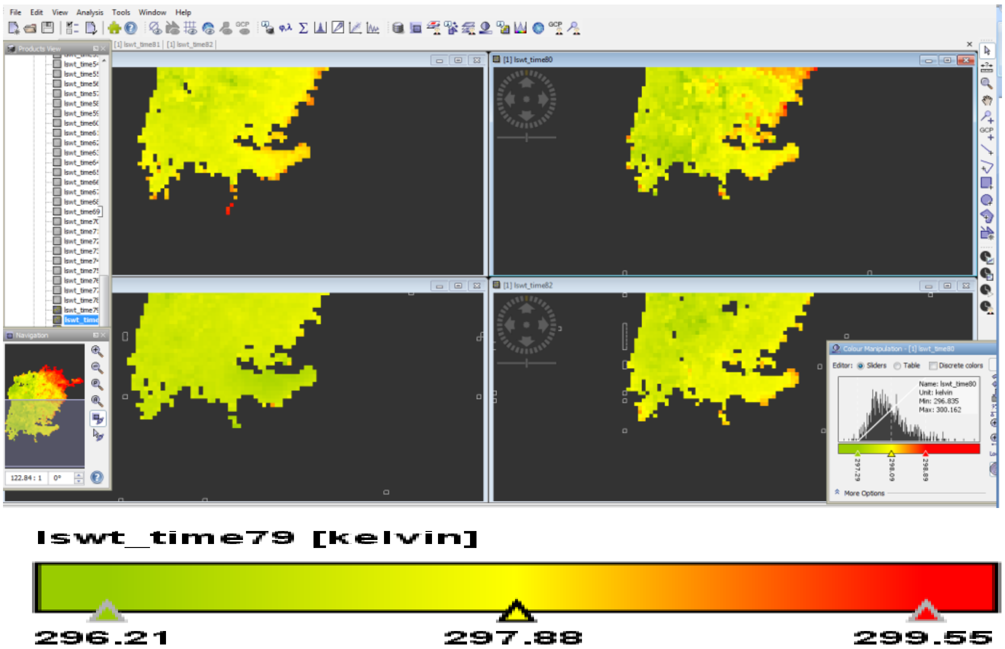


Figure 4.2: A quick look of the processed LSWT products for the four quarters of 2003

4.5. Relationship between *In situ* Chl-*a* and Nutrients

A preliminary data analysis and processing was performed prior to any analysis. This involved depth integration of *in situ* data and regression analysis. Regression analysis gives the relationship between the variables (It provides a quick understanding and visualization of the relationship and likeliness of the variables in subject). Depth integration is preferred to other averaging methods as it helps to avoid bias. Its procedures are clearly described below.

4.5.1. Depth Integration of In-situ Data

The *in situ* data collected include the Secchi depth, chlorophyll-*a*, and nutrients (ammonia, nitrates, and orthophosphates) concentrations. The data were collected at 0.5 m depth, at the Secchi depth and at the euphotic depth. To get the mean concentrations per sampling station, euphotic concentrations were calculated first using the following equation:

$$y_{eu} = \alpha Z_{eu} + y_0 \qquad \text{Equation 4.1}$$

Where:

α = The difference between the concentration at secchi depth and concentration at the surface divided by the difference between the Secchi depth and the surface depth (depth at which the surface data was collected)

y_0 = variable concentration in μg/L taken at the surface (0.5m)

Z_{eu} =Euphotic depth (m)

The Z_{eu} was calculated from the secchi depth readings as follows:

$$Z_{eu} = \left(\frac{4.605}{1.7}\right) Z_{SD}$$ Equation 4.2

Where

Z_{SD} = Secchi Depth (m)

The mean concentration was then calculated through depth integration using the following equation:

$$\overline{y_{eu}} = \frac{1}{\Delta z} \int_{z0}^{Z_{eu}} y dz$$ Equation 4.3

Where; y = concentration of variables (μg/L)

$z_0 =$ Surface depth in meters (taken 0.5m from the surface)

Δz = Change in Depth (m)

$\overline{y_{eu}} =$ Mean concentration of variables (μg/L)

The mean concentrations of the variables obtained after the integration were used to carry out the correlation between the variables, principal component analysis and subsequently the retrieval of *in situ* eutrophication index.

4.6. Determination and Comparison of Eutrophication Indices

This study aimed at determining the eutrophication indices from remote observable variables (chl-*a*, LSWT and Kd) and from *in situ* variables. The two indices was then compared to see how far they are related to one another and if the remote sensed one can substitute the *in situ* derived index.

4.6.1. Derivation of *In situ* Eutrophication Index

Although temperature, light and nutrients have significant impact on the synthesis of chlorophyll-*a* and other photosynthetic pigments, nutrients such as nitrates and phosphorous are considered to be the main cause of eutrophication in the water bodies. This is because of the inability to control temperature and light as they are naturally available. These nutrients are positively responded by the growth of algal biomass and other species diversity (Karydis, 2009).

Despite the fact that the cause-effect of eutrophication is well known and understood, its quantification is still a problem to date. For these reasons, a need for proper inter-correlation method between the physico-chemistry and biology of water was sought. The use of multivariate statistical methods which relates the chemical, physical and biological variables was suggested by many scholars. Primpas et al. (2010) came up with a Principal Component Analysis (PCA) whereby the algorithms relating nutrients such as phosphates (PO_4), nitrates (NO_3), nitrites (NO_2), ammonia (NH_3) and chlorophyll-*a* (chl-a) was developed, it enables the calculation of *in situ* Eutrophication Index (E.I) as the first principal component. In this research the algorithm was modified to include the euphotic depth (Z_{eu}), which is a physical indicator representing the water transparency. Also on the side of nutrients, only PO_4 was used for Phosphorous loadings in L. Victoria has found to be increasing for several decades now and it stimulates the algal growth (Gikuma-Njuru et al., 2005). The previous studies also pointed out that the nitrate concentration depends much on nitrogen fixing cyanobacteria which have high proliferations on the littoral zones and less on open pelagic zones (Mugidde et al., 2003); the algal growth in Lake Victoria are N-limited (Mugidde, 2001). For this reason it was found unfit to be used as eutrophication indicator. However, nitrite was not used because of low concentrations. It is usually transformed to nitrate using nitrifying bacteria (Nitrobacter) and/or denitrified to nitrogen gas (N_2) by being incorporated in joint anaerobic oxidation of NH_4 by Archaea bacteria (Fiore et al., 2010). The replacement of nitrogen compounds by Z_{eu} will modify equation 4.4 to equation 4.5 below

$$E.I = aC_{PO_4} + bC_{NO_3} + cC_{Z_{eu}} + dC_{NH_3} + eC_{chl-a}$$ Equation 4.4

$$E.I = aC_{PO_4} + bC_{Z_{eu}} + cC_{chl-a}$$ Equation 4.5

From the above Equations 4.4 and 4.5; C stands for variable values (depth, concentrations) where as a, b, c, d and e are the derived coefficients from PCA analysis. PCA analysis was performed by using XLSTAT an add-In in Microsoft Excel (See Appendix F for data used).

4.6.2. Derivation of Remote Sensed Eutrophication Index (RSEI)

After derivation of Kd, LSWT and Chl-*a* concentrations; a multivariate statistical analysis was performed to retrieve RSEI. Moreover, it was vital to know the variable inter-relationship since more than one variable was dealt with. Correlation matrix based on Principal Component Analysis (PCA) was carried out and thus, the PCA coefficients was obtained (Parinet et al., 2004; Primpas et al., 2010). To find out which approach was more accurate, the derived RSEI was compared to the in-situ based EI. Equation 4.5 below was used in calculating the RSEI.

$$R.S.E.I = aC_{chl-a} + bC_{Kd} + cC_{LSWT}$$ Equation 4.6

Where; C stands for Kd and LSWT values as well as Chl-*a* concentrations whereas the small letters a, b and c are the derived first principal coefficients from PCA analysis.

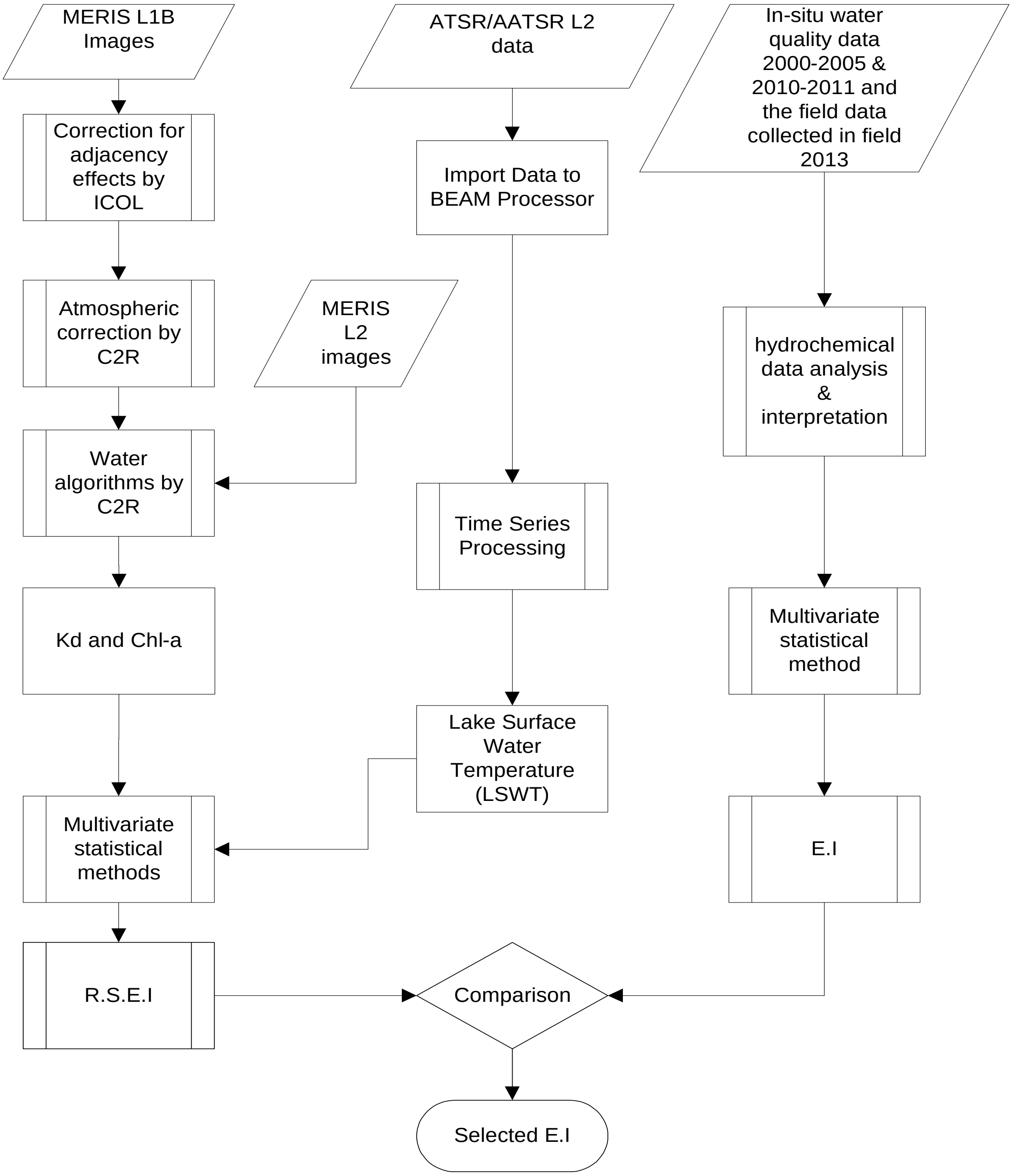


Figure 4.3: The schematic procedures for pre-processing, processing and derivation of Chla, Kd, and E.I

5. RESULTS

5.1. Spatial-Temporal Variation of MERIS Chl-*a* and Kd

5.1.1. Spatial – Temporal Variations of MERIS Chl-*a* Concentrations

Below are the quick looks of spatial temporal variations of MERIS chl-*a* concentrations for images obtained in 2010 and 2011. It was not possible to get the images for a full year due to cloud cover.

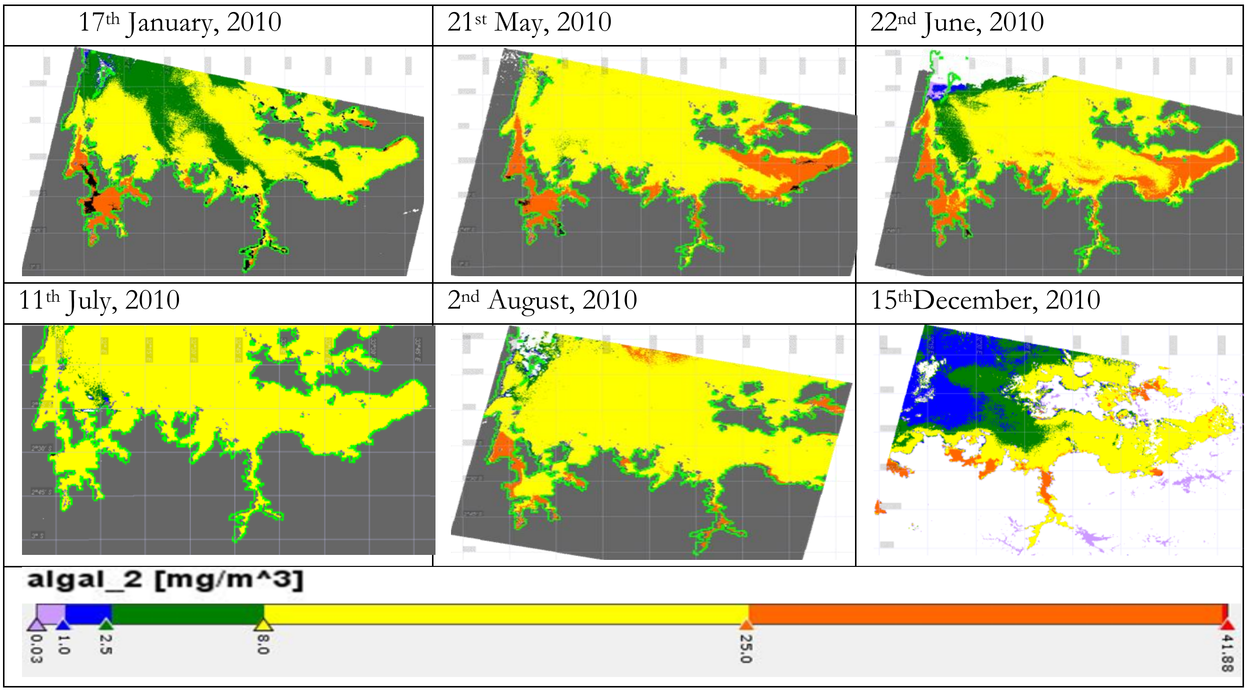


Figure 5.1: A quick look of spatial-temporal variation of MERIS Chl-a concentration for 2010

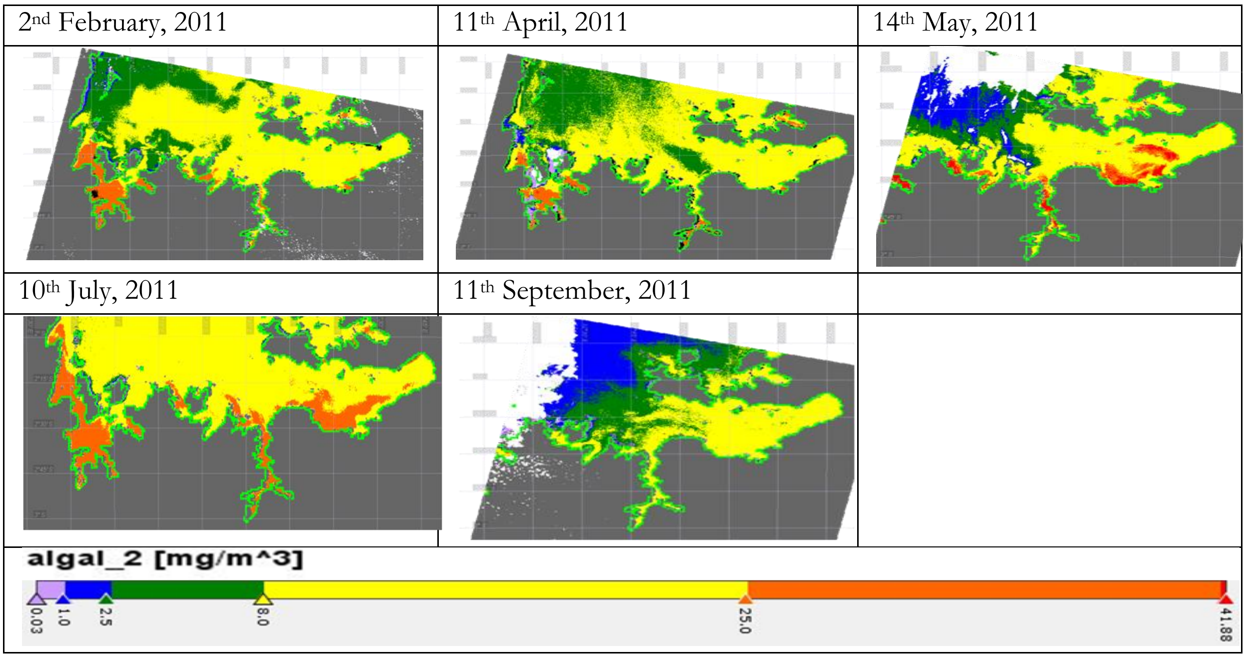


Figure 5.2: A quick look of spatial-temporal variation of MERIS Chl-a concentration for 2011

In Figure 5.2 above; the purple colour (≤1.0) stands for ultra oligotrophic, blue (1.0-2.5) denotes oligotrophic, green (2.5-8.0) is for Mesotrophic, yellow (8.0-25.0) stands for eutrophic and lastly orange (≥25.0) is for hypereutrophic. This categorization is in accordance to OECD classification. The observations indicate that the littoral zones fall under eutrophic to hypereutrophic while its counterpart falls under oligotrophic to eutrophic. The sedimentation resulting from anthropogenic activities and from the rivers discharging to the lake could be one of the reasons of higher levels of eutrophication status in littoral zones as compared to pelagic zones. In addition to that, the presence of many nitrogen fixing cyanobacteria and shallowness of littoral zones also contributes to the above observations (refer to chapter six).

5.1.2. Spatial – Temporal Variations of MERIS Derived Diffuse Attenuation Coefficient (Kd)

The diffuse attenuation coefficients were only available in MERIS L1b images; with L2 images, Kd cannot be retrieved. Figure 5.3 show the spatial and temporal variation of Kd for the year 2005 and 2010. The Kd values in the inshore were higher than in the offshore especially for 30th January 2010 and 21st May 2010 image.

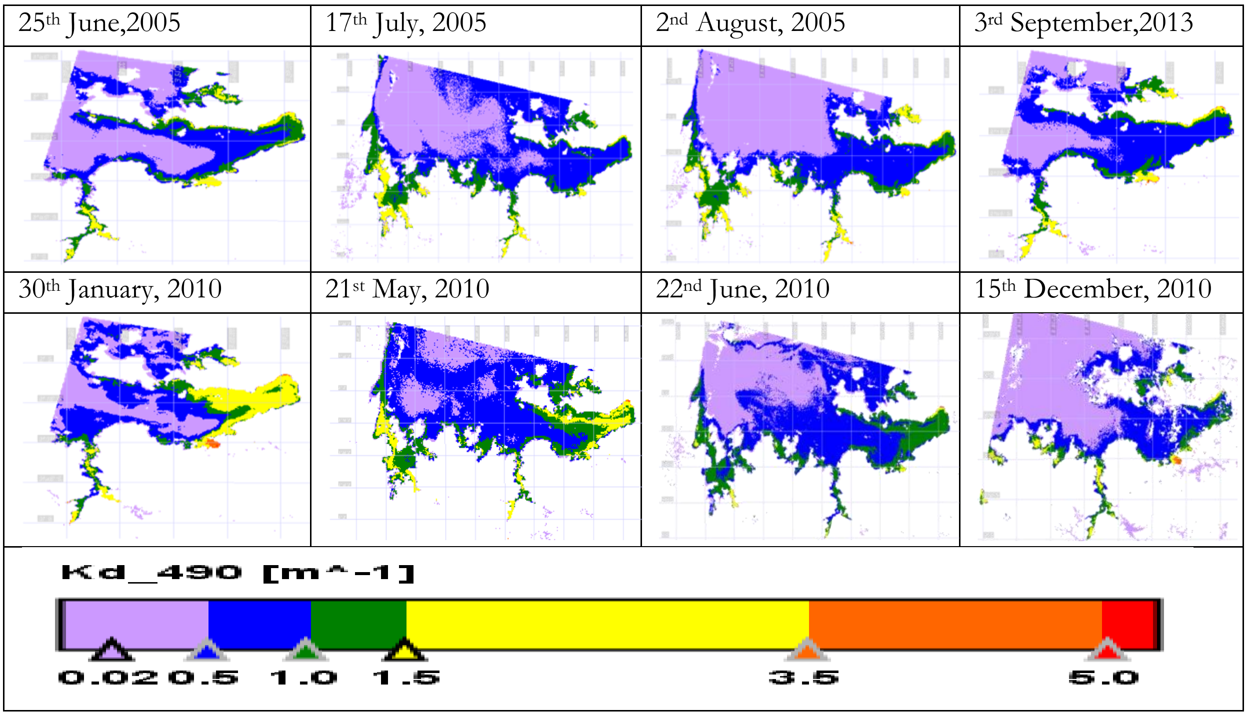


Figure 5.3: Quick looks of spatial-temporal variation of diffuse attenuation coefficients for 2005 and 2010

It has been observed that in the offshore the Kd values were low meaning that there is less suspended solids as compared to the inshore where the values are high. The higher values in the inshore can be due to re-suspension and river discharges. At the littoral zones there is high Kd values and less in offshore/pelagic zones, this implies that the lesser the Kd the lesser the turbidity and vice versa

5.2. Validation of MERIS Variables

A direct/exact match-up of the in-situ and RS variables was found for 14th May, 2011. For validation, 11 pixels were used. *In situ* chlorophyll *a* was used to validate the MERIS chl-*a* although the spatial variability in Figure 5.4 reveals the underestimation of *in situ* chl-*a* by MERIS chl-a. The two has a non-linear relationship. The regression analysis gave a significant logarithmic correlation of about 75% as shown in Figure 5.5; the nature of the graph suggest that there is a decrease in the sensitivity of the sensor especially after 10µg/L to 15µg/L. This might have resulted from sensor saturation. More explanations are given in discussion part in chapter six.

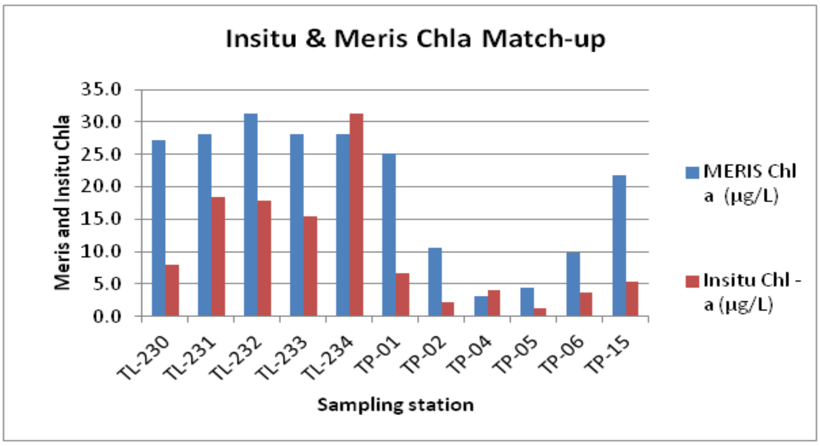


Figure 5.4: The plot of temporal variations of Meris and In situ chl-a concentrations

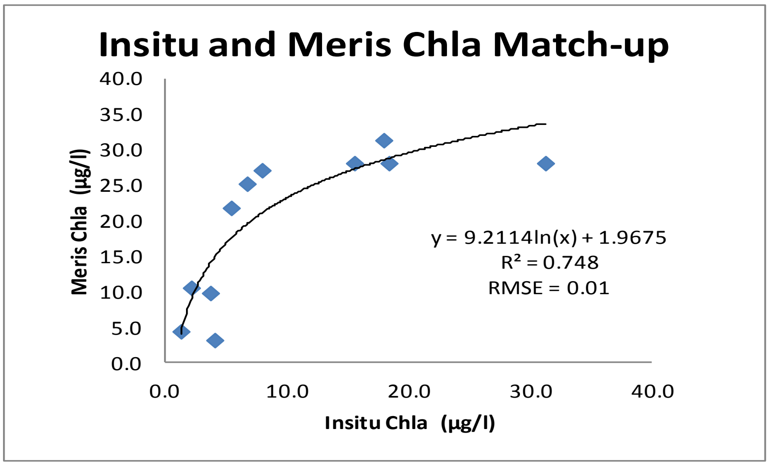


Figure 5.5: The correlation and validation of MERIS Chl-a using in-situ chl-a concentrations

5.3. Time Series Analysis of AATSR Derived Lake surface Water Temperature

The AATSR derived LSWT was used to perform the time series analysis. This was possible due to the wide temporal coverage available. The data from 2003 to 2011 were analysed. Figure 5.6 shows a time series plot of the temporal variations for the study period (2003-2011) whereas Figure 5.7 emphasizes more on the seasonal trend of LSWT. A summary statistics of the LSWT for the specified period is given in Table 5.1 which clearly indicates a very small variation. Although the deviation is small, a substantial seasonal trend is observed.

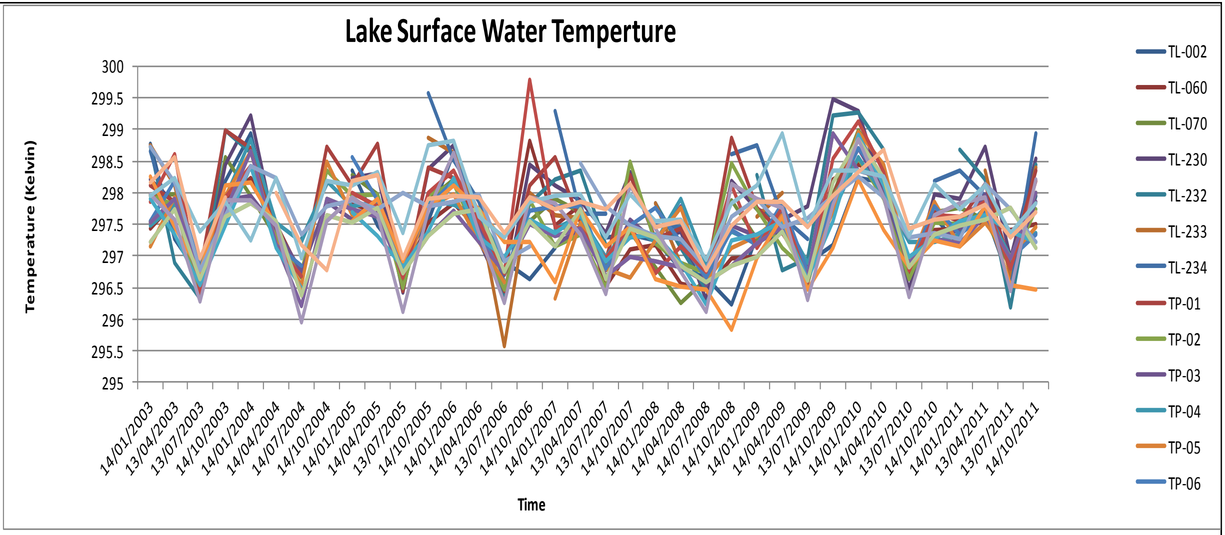


Figure 5.6: Time series plot of LSWT for my study period, 2003-2011

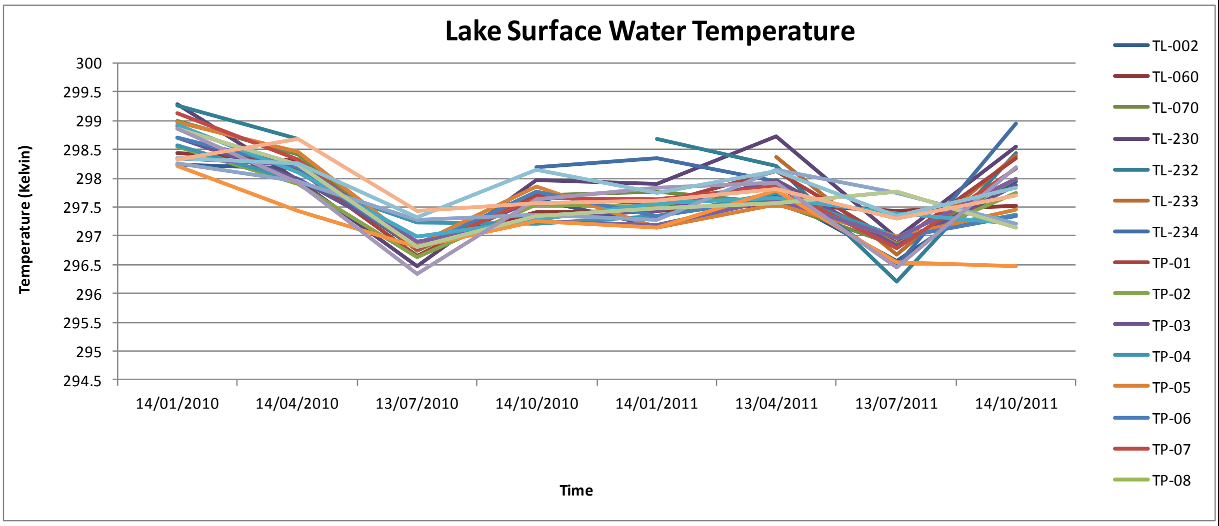


Figure 5.7: The LSWT for 2010/2011 showing the seasonal variation

	Minimum	Maximum	Mean	StDev
Lake Surface Water Temperature (Kelvin)	295.57	299.78	297.50	0.62
Lake Surface Water Temperature (°C)	22.42	26.63	24.35	0.62

Table 5.1: Summary statistics of the LSWT in Kelvin and Degree Celsius

5.4. In situ Data Analysis

The results of the biochemical analysis together with the Secchi depth for the data collected during the field work in September 2013 are illustrated in a plot below (Figure 5.8). The observations reveal unexpectedly low concentrations of nitrates and high ammonia concentrations (see also appendix B). The possible explanations for this behaviour can the presence of denitrifying bacteria and the increased anoxic condition in the lake as described in chapter six.

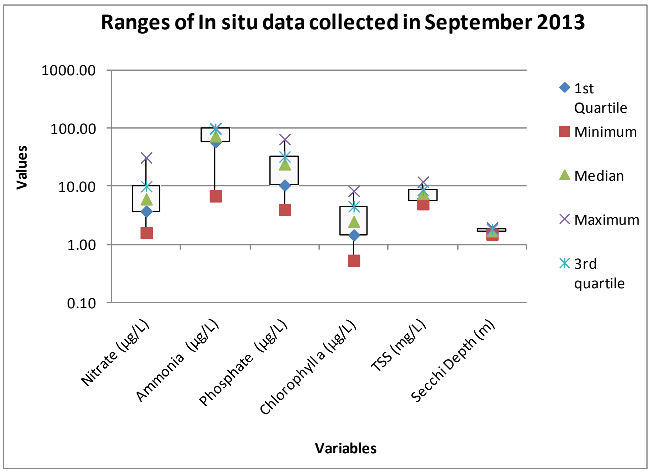


Figure 5.8: A plot showing the ranges of the biochemical analysis collected during the fieldwork in 2013

5.5. Comparison between Nutrients and In-situ Chlorophyll-*a*

5.5.1. Analysis of spatial –Temporal Variability of *In situ* Variables

The *in situ* water quality variables were collected from different sampling station within Lake Victoria. The distribution of sampling station is as shown in Figure 5.9 below.

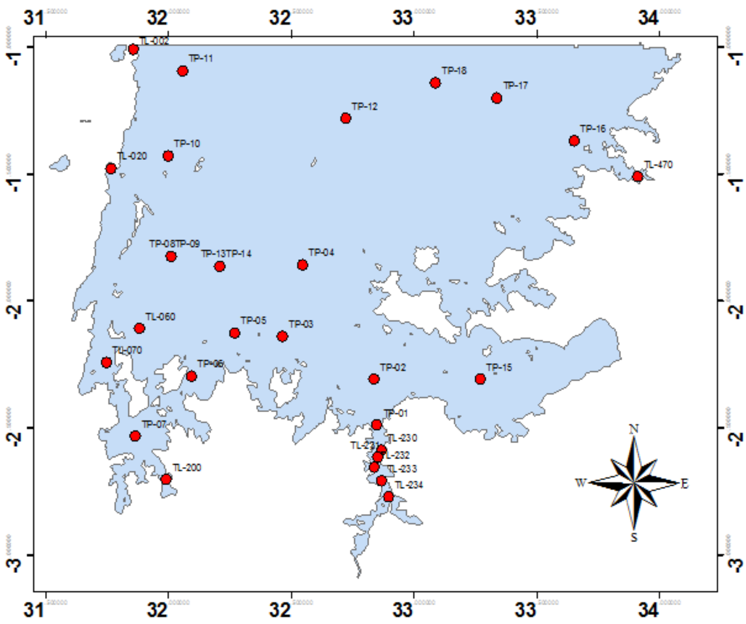
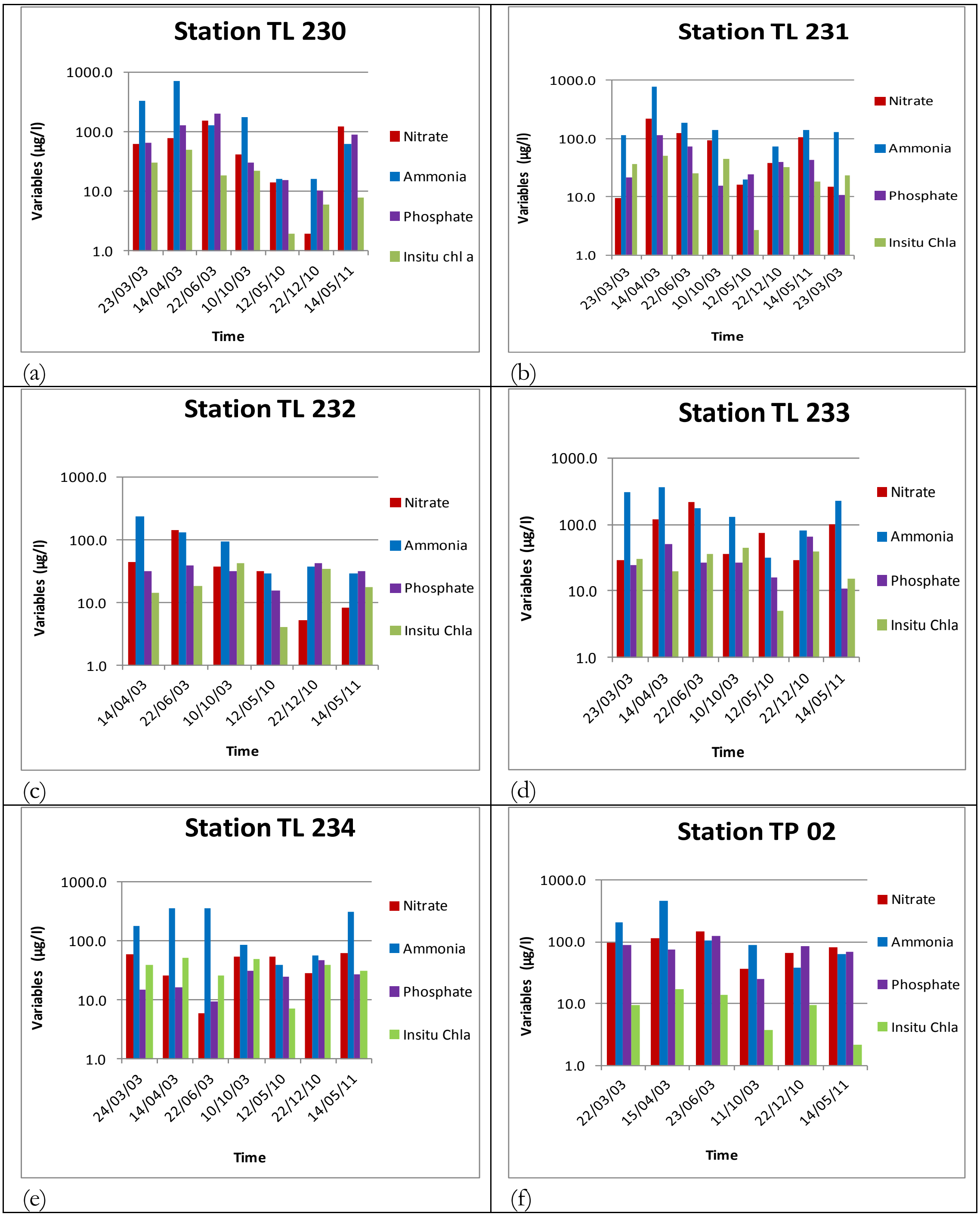


Figure 5.9: Distribution of sampling points in Lake Victoria

5.5.2. Temporal and spatial Variations

The concentrations of *in situ* water quality data from ten different sampling stations were properly arranged and then used in the analysis of temporal variation. The histograms in Figure 5.9 (a-j) of the obtained WQ variables concentrations were plotted per sampling station as shown in Figure 5.8; the histograms shows the quantitative contribution of each variable and temporal fluctuations (variability). In almost all the sampling station, ammonia gave the highest concentrations and the lowest were given by chlorophyll- a. These observations are well explained in chapter six.



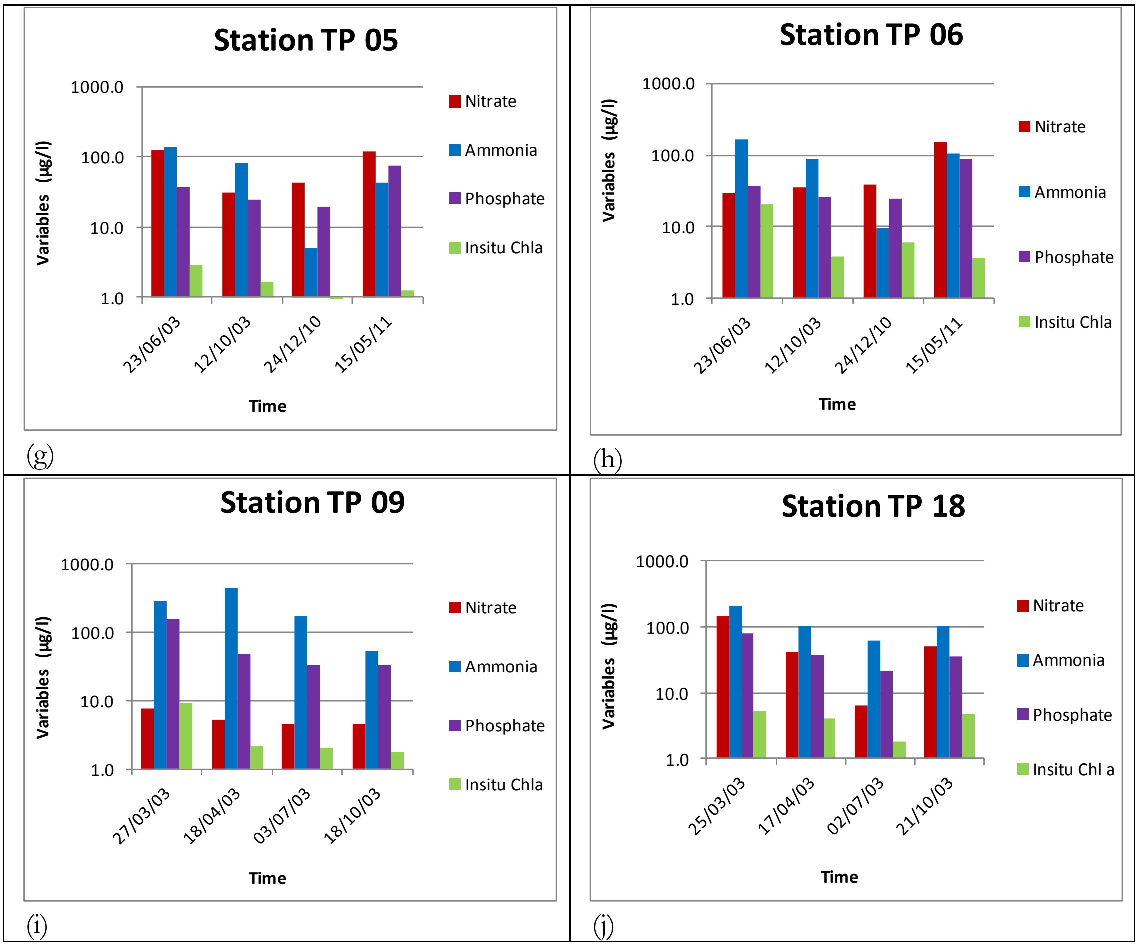


Figure 5.10: Histograms (a-j) showing quantitative temporal fluctuations per sampling station

5.5.3. Spatial Variations of In-situ data Collected during 2013 Fieldwork

Even the data collected during field work in on 13th and 14th of September 2013 reveal the spatially low concentration of Chl-a and higher phosphate concentrations for the majority of the stations sampled as illustrated in figure 5.11 below. The very high concentrations of phosphates and low nitrate concentrations during that period can be translated to have resulted from not only the increase of sediments and total suspended solids but also due to thermal stratification.

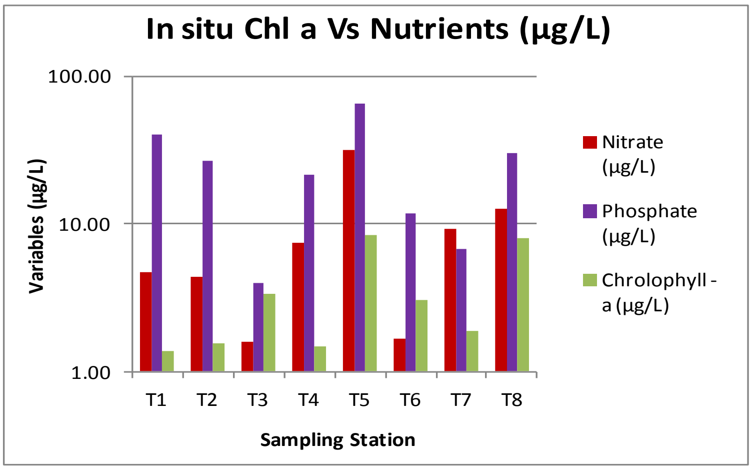


Figure 5.11: Spatial distribution for the chlorophyll-a and nitrate concentration for the in-situ data collected during the fieldwork in September, 2013

5.5.4. Correlation of In situ Chlorophyll-*a* Concentrations with Nitrate and Phosphate Concentrations

The realization of the characteristics and the role played by nutrients in Lake Victoria was made possible through comparing the *in situ* chlorophyll-*a* concentrations and the nutrients (P and N). The observations in Figures 5.10, 5.11 and 5.12 suggest that the nutrients concentrations in nearly all the sampled stations were higher than the chl *a* concentrations. These observations are supported by the results of the linear regression analysis in Table 5.2 which gave a very low and negligible correlation between chl-*a* and nutrient concentrations. Nutrient out-competition and phytoplankton light shading (by macrophytes and self-shading) are among the probable reasons for this behaviour, a concise elaboration is given in chapter six.

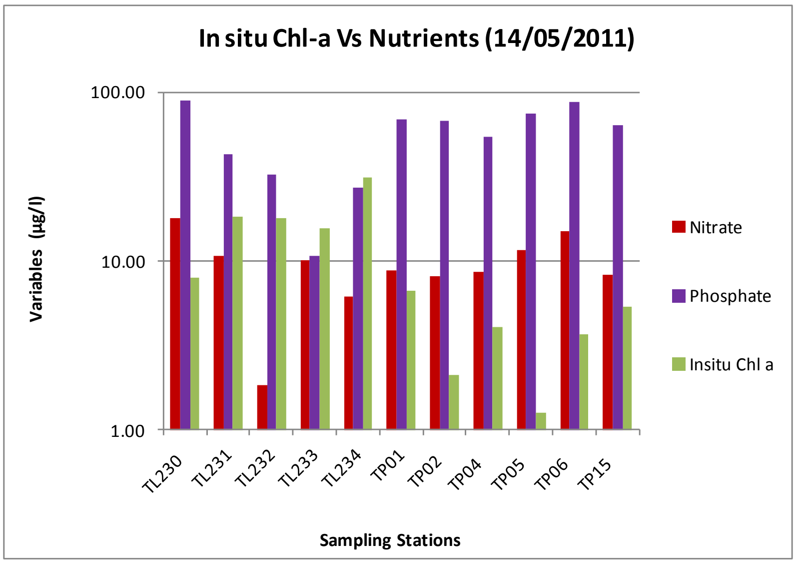


Figure 5.12: Spatial Distribution of in situ water quality variables as per 14/05/2011

	R2	INTERCEPT	SLOPE
In-situ Chl a & Nitrate Concentration	1.30E-03	17.091	-0.0065
In-situ Chl a & Ortho-Phosphate Concentration	0.0002	16.938	-0.0066

Table 5.2: The correlation of in-situ chlorophyll-a with nitrate and phosphate concentrations

5.6. Determination of In situ and Remote Sensing Eutrophication Indices

5.6.1. In-situ Eutrophication Index

Eutrophication Index was obtained after running the principal component analysis (PCA) for the selected physical-chemical and biological indicators (Zeu, phosphate and chl a concentration respectively) as shown in Appendix F. Only the near match-up data were involved in this exercise. Through this, the correlation matrix in Table 5.3 was obtained. Phosphate concentrations gave an insignificant correlation with chl-*a*. The highest correlation with chlorophyll-*a* was however given by the euphotic depth (Zeu). The first of the five principal coefficients were used to calculate the eutrophication indices. Table 5.4 and 5.5 below shows the coefficients of first principal of the five variables of the in-situ WQ variables and the Eutrophication index respectively.

Variables	Phosphate (µg/L)	Insitu Chl - a (µg/L)	Zeu(m)
Phosphate (µg/L)	**1**		
In-situ Chl - a (µg/L)	0.186	**1**	
Zeu (m)	-0.140	0.769	**1**

Table 5.3: Correlation matrix at 5% significance level with p-value <0.0001

WQ Variables	Coefficient of First Principal
Ortho-Phosphate (µg/L)	0.045
Zeu (m)	0.702
Insitu Chl - a (µg/L)	0.711

Table 5.4: Coefficient of first principal for in-situ WQ variables

The calculation of the E.I was done by substitution of the unknown coefficients in equation 4.5 by the known ones in equation 5.1. The values were obtained from Table 5.4 above. The EI summary statistics is given in Table 5.5 below.

$$E.I = 0.045C_{PO_4} + 0.702C_{Z_{eu}} + 0.711C_{chl-a}$$

Equation 5.1

Year	Maximum	Minimum	Mean	StDev
2003	32.56	4.13	19.01	10.200
2010	33.98	4.31	18.45	11.79

Table 5.5: E.I summary statistics

5.6.2. Remote Sensing Eutrophication Index

Remote sensing eutrophication index (RSEI) was calculated by involving the MERIS derived chlorophyll-*a* concentrations, diffuse attenuation coefficient (Kd) and the lake surface water temperature (LSWT) for the near match-up data (appendix G) as per Equation 5.2. On the other hand, Table 5.6 shows the correlation matrix for the variables used; Kd is significantly correlated to the derived MERIS chl-*a* whereas the correlation between MERIS chl-a and LSWT is very low. The tables 5.7 and 5.8 below show the variables' principal component coefficients and the summary statistics of the RSEI respectively.

Variables	MERIS Chl_a (µg/L)	Kd 490 (1/m)	LSWT (°C)
MERIS Chl_*a* (µg/L)	**1**		
Kd 490	0.958	**1**	
LSWT (°C)	0.157	0.155	**1**

Table 5.6: Correlation matrix for the remotely sensed variables at 5% significance level with p-value <0.0001

WQ Variables	Coefficient of first Principal
MERIS Chl_a (µg/L)	0.691
Kd 490 (1/m)	0.691
LSWT (°C)	0.214

Table 5.7: Coefficients of first principal for RS WQ variables

$$R.S.E.I = 0.691C_{Chl-a} + 0.691C_{Kd} + 0.214C_{LSWT}$$

Equation 5.2

Year	Maximum	Minimum	Mean	StDev
2003	22.13	9.34	16.66	5.9
2010	31.21	6.93	19.68	9.31

Table 5.8: R.S.E.I summary statistics

5.7. Assessment of Eutrophication Status Based on Carlson and OECD Classification

For remote sensed variables, only chlorophyll-*a* was used for trophic status characterization of L. Victoria. Both OECD and Carlson types of classification did not define the categorization criteria for other RS derived variables. The results of the annual mean concentration of chl-*a* and TSI calculations presented in Table 5.9 are the basis for determination of trophic status of Lake Victoria. The criteria used in these classifications are given in Table 2.1 and Figure 2.1. Based on the outcome of both types of classification; L. Victoria falls under the category of eutrophic lakes for all the three years assessed (Table 5.10).
Although the target for status assessment in this study is RS variables; the in-situ variables obtained during field work in 2013 were also assessed to see the current status. Appendix K, show lake trophic state categories which were derived from the *in situ* chlorophyll-*a* and secchi depth transparency.

Year	Annual Mean Chlorophyll-a (mcg/L)	Carlson TSI
2003	16.07	57.84
2010	30.47	64.11
2011	19.83	59.89

Table 5.9: Summarized calculation results of annual mean values and Carlson TSI

	OECD Classification		Carlson Classification	
Year	Annual Mean Chlorophyll-a (mcg/L)	Trophic Category	Carlson TSI	Trophic Category
2003	16.07	Eutrophic	57.84	Eutrophic
2010	30.47	Eutrophic	64.11	Eutrophic
2011	19.83	Eutrophic	59.89	Eutrophic

Table 5.10: Summary of OECD and Carlson Trophic Categories for L. Victoria

6. DISCUSSION

6.1. Spatial Temporal Variability of MERIS derived Variables

The MERIS derived variables in this context refer to chlorophyll-*a* concentrations and diffuse attenuation coefficient. Figures 5.1 and 5.2 display the chl-*a* concentration quick looks derived from cloud free images of 2010 and 2011 respectively. The results suggest presence of variations in space and time of chlorophyll-*a* concentration. The spatial variation is mainly due to the interaction of the surrounding environment and the effects of depth. The littoral zones/areas are found to have higher chl-*a* concentrations than the pelagic zones. A good explanation for littoral zones can be the presence of many river inflows and runoff from different places, its shallowness and the low mixing depth are also important contributing factors; the opposite of these explains the pelagic zones (Bootsma, 1993). Apart from being rich in nutrients from external sources, the littoral zones are said to be harbouring the nitrogen fixing cyanobacteria (Mwirigi et al., 2005). Further, Abuodha (2006) found out that the algal community in Lake Victoria are light limited; therefore not many algae can survive in the deep pelagic zones where the depth is high resulting in to strong wind-induced mixing and low optical depth.

However, the spatial categorization of the lake trophic status following the OECD classification indicates that the littoral zones ranged from eutrophic to hypereutrophic while the open pelagic zones ranged from Mesotrophic to eutrophic although oligotrophic and ultra oligotrophic was also observed. These results coincides with the previous observations made by Gikuma-Njuru et al. (2005).

Furthermore, the temporal variations were found to be so irregular due to climate forcing factors. The irregularity posed difficulties to account for the observed variations. Some results are in good agreement with the physical regimes such as rainfall, temperature and wind pattern. Okonga (2005) portrayed that, the months of January–February and June-September are normally dry, on the other hand October-December and March-May are wet periods. The 2010 results reveal that, the chlorophyll-*a* concentrations were a bit low during the dry period and low temperature with weak thermal stratification which were January, June, July and August. May had high chlorophyll-a concentration and denotes the high temperature and wet period.
It is not easy to account for the variations of chl-*a* concentrations for 2011, but the possible explanation for the observed fluctuations can be the interference exerted towards the South-easterly wind by the windblown from the Ethiopian Highlands in February or sometimes the Monsoon winds from the Indian Ocean in July (Okonga, 2005).

On the other hand, the diffuse attenuation coefficient has shown a remarkable spatial variation and a slight low temporal variation. The littoral zones/inshore are found to have high Kd values as compared to pelagic zone/offshore. The explanations of this rely on the increasingly high suspended particulate matter in littoral zones resulting from re-suspension and the inflow by the rivers. High levels of Kd translate to high levels of suspended particulate matter. Temporally, only January 2010 and May 2010 have shown a bit high values, the remaining others did not show significant variation. The lack of a remarkable temporal variation may be due to the very minimal deviations of the physical parameters.

6.2. Comparison of MERIS Derived Variables and In-situ Chlorophyll-a Concentration

In Figure 5.4, results reveal that the remotely sensed chlorophyll-*a* varies considerably from *in situ* derived chlorophyll-*a* at almost all points. MERIS derived Chl-*a* concentrations were higher (ranging from 0.03-41.88 μg/L) as compared to *in situ* ones (ranging from 0.85-39.29μg/L). Despite the stated observations the logarithmic regression analysis for the direct match-up gave a significant 75% correlation as shown in figure 5.5. Although the correlation is high the graph suggests the possibility of sensor saturation, the sensor reduced its sensitivity especially after 10μg/L to 15μg/L. The saturation of the satellite sensor can be used to account for over estimations of MERIS Chl-*a* concentration. On the other hand, poor measurements can be a reason for underestimation of the actual *in situ* chl-*a* concentration values. Even so, it is the fact that the *in situ* measurements are point specific whilst the RS counterpart are more heterogeneous as they based on the average of a large area.

Being very close to the equator, Lake Victoria experiences a cloud cover almost throughout the year. Clouds might cause interference to the signals sent to the sensor. (Ambarwulan et al., 2010), pointed out that the atmosphere in the equatorial regions is highly variable spatially due to the presence of clouds and haze; the clouds affect the atmospheric correction by altering the reflectance received by the sensor. However, inaccurate parameterization of MERIS Chl-*a* algorithms is another possible factor to consider (Shen et al., 2010).

Also, there it is possible that the lake condition is covered by turbidity which can lead to inaccurate results. Turbidity is the result of eutrophication and it has great negative impacts to the aquatic ecosystem and the lake condition at large by reducing the water transparency and productivity to mention few (Ndungu et al., 2013; Portielje & Van der Molen, 1999).

The presence of much non-algal suspended particulate matter can hinder the proper recording of chlorophyll-a concentration because in such environment, even the depth at which light can penetrate will be reduced by the attenuating components. For this case, there is a possibility that the phytoplankton underneath will not be recorded (Liew et al., 1999).

In some instances dissolved organic detritus can also be a hindrance as it can result in to over estimation of Chlorophyll-*a* concentration. At the surface or near surface, the suspended coloured matter can reflect at the same wavelength as the Chl-*a*.

Further, the presence of diverse species of phytoplankton in the lake can also play a big role in altering the estimation of chlorophyll-*a* concentrations; this can only occur if there are some species which have the same spectral characteristics as the chlorophyll-*a*.

6.3. Time series Analysis of Lake surface Water Temperatures

The time series analysis of LSWT from 2003 – 2011 indicated a substantial seasonal trend. It ranged from 22°C to 26°C. LSWT data were corrected on the quarterly basis in a year. The results in Figure 5.6 and a more clear one in Figure 5.7 reveals that there is a tremendous temperature rise and drop in April and July respectively. A small drop was observed in January and a rise in October. The maximum LSWT so indicated on Table 5.2 are usually reached in April and the minimum in July. These observations coincide with what Muhindo (2011) observed and the best explanation for this lie on the apparent movement of the sun over equator. It is logical for the LSWT to reach its maximum in April because this is just after the sun is overhead the equator (March equinox) and the October rise is after the September equinox. Also Okonga (2005) revealed that the LSWT fall in July is the result of the effect of June Solstice when the sun overheads the tropic of Cancer; the solar movement to the tropic of Capricorn in December explains the LSWT drop in January.
Moreover, the variations of LSWT in most instances were concurrent with the variations of chlorophyll-a concentration for the year 2010. This suggests that LSWT can be used as the eutrophication indicator.

6.4. An account for Low Concentrations of Nitrate and High Concentrations of Ammonia

The results of the *in situ* data analysis in Figure 5.9 and in Appendix B for the observations made during the 2013 fieldwork revealed very low concentrations of nitrates and higher concentrations of ammonia. The nitrate concentrations range from 1.59-31.47 μg/L (same as 0.0016-0.031 mg/L) and ammonia range from 6.84-100.50 μg/L (same as 0.068-0.1 mg/L). The observed low nitrate concentrations for the present study are supported by the previous studies which were conducted in Lake Victoria. The nitrate concentrations as per Mavuti and Litterick (1991) ranged from 0.056-0.106 mg/L whereas Njuru (2001) reported the range between 0.005-0.037 mg/L.

However, high ammonia and low nitrate concentrations indicate the possibility of increased rate of organic matter decomposition which leads to reduced levels of dissolved oxygen (anoxia). Anoxic condition subsequently lowers the rate of ammonia oxidation to nitrites and then nitrates (USEPA, 2000).
Another possibility is the presence of many denitrifying bacteria which converts nitrates to other forms of nitrogen.

6.5. Comparison of In-situ Chlorophyll-a with Nutrients

The results in Table 5.3 above indicate a very low correlation between the *in situ* chl-*a* concentration and the nutrients (P and N) concentrations, the lowest having shown by Nitrates. Also in Figures 5.10 and 5.11 it was observed that there is a tremendous increase of nutrients although the Chlorophyll-*a* levels are very low. The low chl-a concentrations can be due to the reduced transparency which consequently led to the reduced primary production as the primary production takes place in the euphotic zone where light is sufficient (Mugidde et al., 2003). The fact that in the water bodies/lakes, it is not only phytoplankton which consumes nutrients can better explain the observed variation. Normally the external nutrient loading positively affects the concentration of the nutrients in the lake. Depending on the nature of the lake, the possible competitors of the so increased nutrient concentration are grazing zooplankton, macrophytes and phytoplankton (based on their species composition) (Portielje & Van der Molen, 1999). When dealing with a specific case of Lake Victoria, this unexpected nutrient to chlorophyll-a relationship can be due to the presence of water hyacinth (WH) and other aquatic macrophytes. According to Okungu (2005), there might be a considerable nutrient out-competition between the phytoplankton and the water hyacinth. The water hyacinths are known by its abundant bio-productivity through high consumption of solar radiation and nutrients(Service, 2013).

Gichuki (2012) pointed out the possibility of light shading by WH to phytoplankton community; due to its widespread, floating nature and extensive growth, the WH deters the growth of phytoplankton under its mats. The water hyacinths were somehow controlled by the beginning of 2000 (Kateregga & Sterner, 2007), re-invasion appeared in 2005 (Service, 2013; Thomas et al.).

However, according to Gikuma-Njuru and Hecky (2005) self shading of phytoplankton in shallow depth is also possible and it limits the light hence prevent phytoplankton growth. It is also mentioned by Mwirigi et al. (2005) that phytoplankton in Lake Victoria are light limited, this will consequently affects their growth regardless of how much the nutrients' concentrations are available.

6.6. Eutrophication Index and State

The Eutrophication indices for *in situ* and remote sensed measurements was performed by applying a principal component analysis in accordance to Primpas et al. (2010). The results of the two indices are found to be in good agreement to each other although the eutrophication indicators used for the two scenarios were different. The deviations between 2003 RSEI and EI for the maximum and minimum values were 10.43 and 5.21 respectively; while in 2010 the deviations were 2.77 and 2.62 for maximum and minimum respectively. The differences in mean values were 2.35 and 1.23 for 2003 and 2010 respectively. Table 5.5 and 5.8 gives a summary statistics of the outcome.

Moreover, when comparing the correlation between variables and chlorophyll-a, the euphotic depth gave a very significant correlation of 77% for *in situ* data whereas the diffuse attenuation coefficient for MERIS data scored 96%. The relationship between diffuse attenuation coefficient and chlorophyll-*a* is not 100% due to the fact that the attenuation encountered in the water bodies is not only caused by algal biomass, in case 2 waters there are other non-algal suspended solids and organic detritus which cause the attenuation. However, a poor correlation of about 19% and 16% for phosphates and lake surface water temperature respectively with in situ chl-*a* can best be explained by an un-usual behaviour of L. Victoria's phytoplankton light limitation (Mugidde et al., 2003).

The assessment of eutrophication status based on Carlson and OECD classification gave out similar results. Both classifications categorized Lake Victoria as being a eutrophic lake as it is shown in Table 5.10. For this research, only chlorophyll-*a* concentrations were used in determination of trophic level. Although the annual mean chlorophyll-*a* concentrations for all three years were different, they fit under one category in accordance with OECD (1982). Nevertheless, with Carlson's trophic state indexing, the year 2010 had the highest TSI (64.11) and 2003 had the lowest which is 57.84 TSI but they are all under one class, eutrophic as per Carlson (1977). The previous studies by Gikuma-Njuru et al. (2005) and Hecky (1993) also regarded Lake Victoria as eutrophic lake, thus supports the current findings.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The use of remote sensing techniques in analysing the spatial and temporal variations of water quality variables and the determination of eutrophication state of Lake Victoria was the main objective of this research. Remote Sensing has its own challenges especially in obtaining cloud free images from the tropical regions. The difficulties of getting cloud free satellite images that coincide with the *in situ* measurements for the study area was encountered. However, it was possible to derive the results and come to the following conclusion:

- The estimation of chlorophyll-*a* and diffuse attenuation coefficient for Lake Victoria from MERIS satellite was possible.
- There was a significant spatial-temporal variability of chlorophyll-*a* which coincides with seasonal variability of physical parameters as a result of equatorial solar movement. Apparently, the diffuse attenuation coefficient has shown spatial variation but did not show a remarkable temporal variation.
- However, the time series analysis and the retrieval of lake surface water temperature from (A)ATSR were possible. This is actually the first research to explore a large dataset of LSWT derived from remote sensing. The LSWT had its maximum in April and minimum in July which is described as being the effect of the March and June overhead sun over the Equator and Tropic of Cancer respectively.
- It is the fact that nutrients and chlorophyll-*a* have a cause and effect relationship, but for Lake Victoria the situation is somehow different. The phytoplankton community in the lake are light limited. This is the result of high turbidity, light shading by water hyacinth/macrophytes and self shading (Mugidde et al., 2003; Mwirigi et al., 2005).
- Although there are some statistical variations observed between the *in situ* eutrophication index and the remote sensing derived eutrophication index; those variations are minimal and not significant. This suggests that in Lake Victoria, the remote sensing eutrophication index can substitute the *in situ* eutrophication index.
- The assessment of the trophic state classified Lake Victoria as eutrophic lake for the assessed years. Despite the over estimation of chl-*a* concentration, the two types of classification gave the results which are similar to other scholars. This suggests the applicability of the method to other lakes.

7.2. Recommendations

- There should be advancement in RS algorithms for retrieval of water quality variable to avoid overestimation or underestimation of variables and to improve the accuracy; hence, replace *in situ* with RS measurements.
- In determination of eutrophication state of the lake, there is a need of developing criteria for other remotely observable variables such as Kd and TSM so as to increase the reliability and accuracy of the results.
- There should be a remote sensing based study to understand the effects of turbidity, water hyacinth and light to the phytoplankton abundance in Lake Victoria.
- In order to be able to assess and evaluate the accuracy of the atmospheric and adjacency effects corrections, there should be established an *in situ* spectrometric measurements.

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APPENDICES

Appendix A: In situ water quality measurements for the year 2003 and 2010-2011

St. No.	Date	ActualE	ActualN	Nitrate Nitrogen (µg/L)	Ammonia Nitrogen (µg/L)	Ortho-Phosphate (µg/L)	In situ Chl - a (µg/L)
TL230	23/03/03	32.8684	-2.5908	62.275	330.714	63.899	29.949
TL231	23/03/03	32.8535	-2.6178	9.581	112.641	21.166	36.130
TL232	23/03/03	32.8393	-2.6574	14.907	128.582	10.542	23.345
TL233	23/03/03	32.8683	-2.7119	29.317	305.313	24.553	30.776
TL234	24/03/03	32.8975	-2.7741	58.870	182.893	15.040	38.627
TL470	07/03/03	33.9120	-1.5120	96.105	44.303	23.535	4.910
TP02	22/03/03	32.8381	-2.3105	96.430	208.133	89.234	9.321
TP04	24/03/03	32.5464	-1.8608	235.672	320.548	118.492	8.662
TP09	27/03/03	32.0120	-1.8267	7.740	285.342	160.097	9.485
TP12	26/03/03	32.7234	-1.2823	212.859	224.596	99.655	7.499
TP18	25/03/03	33.0883	-1.1433	143.237	214.067	80.121	5.203
TL230	14/04/03	32.8684	-2.5908	78.792	696.727	125.994	49.180
TL231	14/04/03	32.8535	-2.6178	223.345	794.799	113.493	51.150
TL232	14/04/03	32.8393	-2.6574	44.194	235.859	31.646	14.435
TL233	14/04/03	32.8683	-2.7119	117.163	359.025	50.855	20.047
TL234	14/04/03	32.8975	-2.7741	25.865	354.233	16.426	51.572
TP02	15/04/03	32.8381	-2.3105	112.212	463.685	75.667	16.720
TP04	16/04/03	32.5464	-1.8608	54.031	438.621	74.920	13.856
TP09	18/04/03	32.0120	-1.8267	5.401	435.281	48.303	2.149
TP12	18/04/03	32.7234	-1.2823	98.270	317.199	36.075	4.141
TP18	17/04/03	33.0883	-1.1433	42.356	102.826	38.349	4.066
TL230	22/06/03	32.8684	-2.5908	149.647	126.489	202.525	18.736
TL231	22/06/03	32.8535	-2.6178	125.164	188.102	73.798	25.283
TL232	22/06/03	32.8393	-2.6574	140.969	133.746	38.666	18.186
TL233	22/06/03	32.8683	-2.7119	213.989	174.273	26.231	36.003
TL234	22/06/03	32.8975	-2.7741	5.934	362.835	9.516	25.650
TP02	23/06/03	32.8381	-2.3105	145.543	106.097	123.431	13.566
TP03	23/06/03	32.4650	-2.1411	56.363	176.112	35.300	13.230
TP05	23/06/03	32.2700	-2.1290	122.857	138.533	37.453	2.857
TP06	23/06/03	32.0953	-2.2997	29.784	165.182	37.485	20.779
TP08	28/06/03	32.0120	-1.8267	51.065	128.236	20.762	31.792
TP09	03/07/03	32.0120	-1.8267	4.672	170.853	33.831	2.018
TP10	28/06/03	31.9995	-1.4308	30.624	133.533	25.821	34.326
TP11	28/06/03	32.0587	-1.0961	17.902	180.517	33.570	26.013
TP14	06/07/03	32.2095	-1.8659	60.650	100.443	51.869	20.819
TP16	06/07/03	33.6535	-1.3715	36.380	54.222	28.566	5.677
TP17	02/07/03	33.3378	-1.2031	30.656	115.134	29.989	3.118
TP18	02/07/03	33.0883	-1.1433	6.350	61.957	21.269	1.790
TL200	30/06/03	31.9915	-2.7052	163.153	155.137	20.563	19.449
TL230	10/10/03	32.8684	-2.5908	41.576	171.794	29.831	21.701
TL231	10/10/03	32.8535	-2.6178	95.251	142.096	15.397	44.491
TL232	10/10/03	32.8393	-2.6574	38.138	95.519	32.233	42.939
TL233	10/10/03	32.8683	-2.7119	36.047	128.800	26.608	43.812
TL234	10/10/03	32.8975	-2.7741	53.097	85.418	31.908	50.584
TL470	22/10/03	33.9120	-1.5120	6.150	67.800	9.643	19.400

St. No.	Date	ActualE	ActualN	Nitrate Nitrogen (µg/L)	Ammonia Nitrogen (µg/L)	Ortho-Phosphate (µg/L)	In situ Chl - a (µg/L)
TP02	11/10/03	32.8381	-2.3105	36.304	87.987	24.984	3.738
TP03	12/10/03	32.4650	-2.1411	32.288	73.268	24.073	1.479
TP05	12/10/03	32.2700	-2.1290	31.549	81.153	24.996	1.627
TP06	12/10/03	32.0953	-2.2997	35.913	86.692	25.429	3.814
TP08	14/10/03	32.0120	-1.8267	65.071	73.655	21.709	2.628
TP09	18/10/03	32.0120	-1.8267	4.677	53.314	32.973	1.780
TP10	14/10/03	31.9995	-1.4308	42.099	111.048	31.098	5.551
TP11	16/10/03	32.0587	-1.0961	57.389	133.706	36.097	28.005
TP12	21/10/03	32.7234	-1.2823	21.768	96.377	34.651	2.008
TP14	22/10/03	32.2095	-1.8659	120.136	255.443	55.431	8.041
TP16	22/10/03	33.6535	-1.3715	69.885	173.044	56.178	16.878
TP17	21/10/03	33.3378	-1.2031	144.737	155.773	45.021	5.842
TP18	21/10/03	33.0883	-1.1433	51.213	103.417	35.311	4.695
TL200	13/10/03	31.9915	-2.7052	36.760	129.322	20.56	58.549
TL 230	12/05/10	32.8684	-2.5908	13.958	16.094	15.252	1.918
TL 231	12/05/10	32.8535	-2.6178	16.333	19.500	24.333	2.656
TL 232	12/05/10	32.8393	-2.6574	31.867	29.400	15.640	4.131
TL 233	12/05/10	32.8683	-2.7119	73.067	31.267	16.204	5.037
TL 234	12/05/10	32.8975	-2.7741	53.333	39.867	24.677	7.069
TP 01	11/05/10	32.8495	-2.4907	42.815	84.896	87.288	4.384
TL 230	22/12/10	32.8684	-2.5908	1.938	15.708	10.107	5.949
TL 231	22/12/10	32.8535	-2.6178	38.500	73.167	39.020	32.818
TL 232	22/12/10	32.8393	-2.6574	5.189	37.176	43.088	35.205
TL 233	22/12/10	32.8683	-2.7119	28.600	79.500	64.785	38.338
TL 234	22/12/10	32.8975	-2.7741	28.500	57.250	47.648	39.285
TP 01	22/12/10	32.8495	-2.4907	13.300	2.186	19.472	2.471
TP 02	22/12/10	32.8381	-2.3105	64.336	38.104	82.979	9.227
TP 03	24/12/10	32.4650	-2.1411	42.584	3.092	26.463	1.018
TP 05	24/12/10	32.2700	-2.1290	43.612	5.037	18.969	0.854
TP 06	24/12/10	32.0953	-2.2997	37.852	9.460	24.782	5.927
TP 07	24/12/10	31.8660	-2.5349	16.820	37.180	12.847	9.963
TP 15	22/12/10	33.2712	-2.3102	41.700	36.075	121.733	17.724
TL 200	24/12/10	31.9915	-2.7052	11.737	168.605	36.919	23.984
TL 230	14/05/11	32.8684	-2.5908	679.804	62.577	88.467	7.920
TL 231	14/05/11	32.8535	-2.6178	107.702	142.702	42.680	18.359
TL 232	14/05/11	32.8393	-2.6574	8.400	29.600	32.425	17.926
TL 233	14/05/11	32.8683	-2.7119	100.667	227.000	10.628	15.520
TL 234	14/05/11	32.8975	-2.7741	61.667	311.333	27.320	31.230
TP 01	13/05/11	32.8495	-2.4907	87.600	70.250	68.592	6.694
TP 02	14/05/11	32.8381	-2.3105	81.100	61.843	67.833	2.103
TP04	15/05/11	32.5464	-1.8608	85.858	59.604	54.444	4.026
TP05	15/05/11	32.2700	-2.1290	116.625	43.713	73.968	1.249
TP06	15/05/11	32.0953	-2.2997	150.732	106.635	87.679	3.671
TP15	15/05/11	33.2712	-2.3102	82.728	63.269	63.150	5.384

Appendix B: The Integrated In situ Water Quality Measurements for September 2013

Sample ID	Date of Sampling	Actual E	Actual N	Nitrate Nitrogen (µg/L)	Ammonia Nitrogen (µg/L)	Ortho-Phosphate (µg/L)	Chrolophyll - a (µg/L)	TSS (mg/L)	Totoal Depth (m)	Secchi Depth (m)
T1	13.09.13	32.89960	-2.46615	4.67	73.68	39.91	1.36	8.00	5.00	1.62
T2	13.09.13	32.83839	-2.31022	4.42	66.17	26.93	0.53	5.00	9.00	1.95
T3	13.09.13	32.84953	-2.49068	1.59	6.84	4.00	3.37	7.20	14.00	1.83
T4	13.09.13	32.86887	-2.48110	7.48	35.31	21.73	1.48	10.60	17.00	1.83
T5	14.09.13	32.86835	-2.59080	31.47	100.50	65.00	8.38	5.40	9.00	1.68
T6	14.09.13	32.86825	-2.71188	1.67	74.64	11.77	3.05	7.80	7.00	1.74
T7	14.09.13	32.86798	-2.66342	9.25	98.85	6.76	1.89	12.00	4.50	1.50
T8	14.09.13	32.88663	-2.71255	12.58	98.85	30.30	8.00	5.90	5.00	1.68

Appendix C: In situ Water Quality Measurements for September 2013

Sample ID	Sample Location	Date of Sampling	Actual E	Actual N	Depth (m)	Lab. No.	Nitrate Nitrogen (µg/L)	Ammonia Nitrogen (µg/L)	Ortho-Phosphate (µg/L)	Chrolophyll - a (µg/L)	TSS (µg/L)	Totoal Depth (m)	Secchi Depth (m)
T1	Ilemela at Neck	13.09.13	32.899599	-2.466153	0.50	MZ.1009	0.00	62.06	37.23	0.16	8.00	5.00	1.62
	Ilemela at Neck	13.09.13	32.899599	-2.466153	2.00	MZ.1010	8.00	64.25	30.46	1.75	4.50		
	Ilemela at Neck	13.09.13	32.899599	-2.466153	4.00	MZ.1011	0.00	62.06	38.92	1.16	5.70		
T2	Ilemela 1000m	13.09.13	32.900679	-2.460806	0.50	MZ.1012	7.00	60.96	33.84	0.58	5.00	9.00	1.95
	Ilemela 1000m	13.09.13	32.900679	-2.460806	2.00	MZ.1013	5.00	97.20	30.46	0.58	3.40		
	Ilemela 1000m	13.09.13	32.900679	-2.460806	8.00	MZ.1014	0.00	64.25	35.53	1.16	0.50		
T3	TP 01	13.09.13	32.849533	-2.490683	0.50	MZ.1015	3.00	59.86	28.76	1.16	7.20	14.00	1.83
	TP 01	13.09.13	32.849533	-2.490683	2.00	MZ.1016	5.00	45.58	42.30	1.16	3.00		
	TP 01	13.09.13	32.849533	-2.490683	13.00	MZ.1017	8.00	104.89	45.69	1.16	3.00		
T4	Mwanza Gulf	13.09.13	32.868872	-2.481098	0.50	MZ.1018	18.00	48.88	30.46	1.75	10.60	17.00	1.83
	Mwanza Gulf	13.09.13	32.868872	-2.481098	2.00	MZ.1019	4.00	46.68	28.76	2.33	4.00		
	Mwanza Gulf	13.09.13	32.868872	-2.481098	16.00	MZ.1020	0.00	49.97	27.07	1.16	0.00		
T5	TL 230	14.09.13	32.868350	-2.590800	0.50	MZ.1021	6.00	78.53	8.46	2.33	5.40	9.00	1.68
	TL 230	14.09.13	32.868350	-2.590800	2.00	MZ.1022	17.00	114.78	11.84	0.58	3,2		
	TL 230	14.09.13	32.868350	-2.590800	8.00	MZ.1023	4.00	56.56	16.92	1.16	3.30		
T6	TL 233	14.09.13	32.868250	-2.711883	0.50	MZ.1024	5.00	105.99	28.76	2.91	7.80	7.00	1.74
	TL 233	14.09.13	32.868250	-2.711883	2.00	MZ.1025	0.00	73.04	3.38	4.07	4.00		
	TL 233	14.09.13	32.868250	-2.711883	6.00	MZ.1026	0.00	46.68	5.08	1.75	4.00		
T7	Nyashishi	14.09.13	32.867980	-2.663423	0.50	MZ.1027	11.00	96.10	3.38	1.16	12.00	4.50	1.50
	Nyashishi	14.09.13	32.867980	-2.663423	1.50	MZ.1028	0.00	53.27	3.38	1.16	6.50		
	Nyashishi	14.09.13	32.867980	-2.663423	3.50	MZ.1029	15.00	43.38	10.15	1.75	4.00		
T8	Busisi Fery	14.09.13	32.886634	-2.712555	2.00	MZ.1030	17.00	51.07	25.38	2.91	5.90	5.00	1.68
	Busisi Fery	14.09.13	32.886634	-2.712555	4.00	MZ.1031	17.00	56.56	22.00	1.16	1.00		

Appendix D: MERIS Derived water Quality Variables for 2003, 2010 and 2011

St. No.	Date	ActualE	ActualN	MERIS Chl_a (µg/L)	Kd 490 (1/M)
TL-230	26/07/2003	32.86789	-2.590979	23.45	1.06
TL-231	26/07/2003	32.852886	-2.6179764	23.45	1.07
TL-232	26/07/2003	32.8389	-2.656971	21.03	1.04
TL-233	26/07/2003	32.86791	-2.7119858	23.45	1.35
TL-234	26/07/2003	32.89691	-2.773994	22.61	1.30
TP-02	26/07/2003	32.837852	-2.3099585	10.56	0.43
TP-16	26/07/2003	33.652897	-1.3711438	7.62	0.21
TP-17	26/07/2003	33.337933	-1.2030447	6.36	0.24
TP-18	26/07/2003	33.087948	-1.1429387	6.13	0.22
TL-230	15/12/2010	32.86784	-2.5913866	35.82	1.67
TL-231	15/12/2010	32.85285	-2.6183984	35.49	1.86
TL-232	15/12/2010	32.83886	-2.6574092	29.62	1.60
TL-233	15/12/2010	32.867874	-2.7124178	25.64	1.41
TL-234	15/12/2010	32.896896	-2.7744164	24.09	1.45
TP-01	15/12/2010	32.849815	-2.491364	26.48	1.04
TP-02	15/12/2010	32.83779	-2.3103147	8.13	0.33
TP-03	15/12/2010	32.464878	-2.1410704	2.21	0.13
TP-04	15/12/2010	32.545895	-1.8609649	5.55	0.25
TP-05	15/12/2010	32.269913	-2.1289124	2.12	0.13
TP-06	15/12/2010	32.09491	-2.2998495	11.05	0.47
TP-07	15/12/2010	31.86581	-2.53516	34.94	1.25
TP-15	15/12/2010	33.270733	-2.3102663	15.82	0.70
TL-230	May, 2011	32.867825	-2.591151	27.11	
TL-231	May, 2011	32.85282	-2.6181533	28.11	
TL-232	May, 2011	32.838818	-2.6571522	31.34	
TL-233	May, 2011	32.86781	-2.7121627	28.11	
TL-234	May, 2011	32.89681	-2.7741668	28.11	
TP-01	May, 2011	32.849823	-2.4911418	25.21	
TP-02	May, 2011	32.83785	-2.3101287	10.56	
TP-04	May, 2011	32.545937	-1.8609782	3.19	
TP-05	May, 2011	32.26989	-2.1288822	4.42	
TP-06	May, 2011	32.094883	-2.2997985	9.82	
TP-15	May, 2011	33.270844	-2.310195	21.81	

Appendix E: The AATSR Derived Lake Surface Temperature (2003-2011)

DATE	TL-002	TL-060	TL-070	TL-230	TL-232	TL-233	TL-234	TP-01	TP-02	TP-03	TP-04	TP-05	TP-06	TP-07	TP-08	TP-09	TP-10	TP-11	TP-12	TP-13	TP-14	TP-15	TP-16	TP-17
14/01/2003	298.79	297.45	297.97	298.22	298.74	298.75	298.66	298.13	297.95	297.56	297.49	297.16	297.56	297.86	297.54	297.54	297.90	298.27	298.73	297.21	297.21	297.98	297.96	298.17
13/04/2003	297.26	297.85	297.98	297.83	296.88	298.11	297.32	297.86	297.80	297.75	297.82	297.93	298.19	298.61	297.91	297.91	297.34	297.45	298.16	297.73	297.73	297.57	298.24	298.57
13/07/2003	296.69	296.66	296.45	296.42	296.33	296.49		296.76	296.42	296.62	296.81	296.74	296.83	296.43	296.69	296.69	296.54	296.74	296.78	296.63	296.63	296.28	297.39	296.96
14/10/2003	298.20	297.88	298.57	298.46	298.98		299.36	298.98	297.74	297.87	297.92	297.95	297.64	297.93	297.72	297.72	297.47	298.11	297.66	297.62	297.62	297.88	297.87	297.92
14/01/2004	298.95	298.23	297.96	299.22	298.63	299.61		298.70	298.43	297.96	298.85	298.65	298.43	298.42	298.66	298.66	298.42	298.16	298.43	297.84	297.84	297.88	297.25	
14/04/2004	297.25	297.51	297.30	297.35			296.97	297.43	297.30	297.43	297.53	297.21	297.19	297.17	297.20	297.20	297.12	297.49	298.25	297.54	297.54	297.48	298.23	297.99
14/07/2004	296.76	296.70	296.65	296.77	297.28	297.18		296.69	296.74	296.75	297.23	296.54	296.84	296.67	296.22	296.22	296.48	296.42	297.34	296.39	296.39	295.94	296.97	297.16
14/10/2004					298.14			298.74	298.35	297.86	298.18	298.49			297.91	297.91			297.79	297.65	297.65	297.55	298.19	296.77
14/01/2005	298.36	297.85	298.29	298.23				298.12	297.95	297.58	297.78	297.64	298.57	298.00	297.75	297.75	297.69	297.56	297.89	297.53	297.53	297.92	298.13	298.19
14/04/2005	297.49	297.66	297.98	298.30	298.34	297.96		298.77	297.99	297.73	297.86	297.76	297.89	297.78	297.63	297.63	297.32	297.91	297.74	297.76	297.76	297.65	298.33	298.28
13/07/2005	296.97	296.67	296.64	296.43				296.46	296.50	296.76	296.88	296.68	296.85	296.65	296.74	296.74	296.83	296.92	298.00	296.73	296.73	296.12	297.35	296.95
14/10/2005	297.55	297.52	297.88	298.38	298.52	298.87	299.59	298.40	297.97	297.80	297.89	297.78	297.79	297.99	297.32	297.32	297.39	297.77	297.80	297.32	297.32	297.73	298.75	297.90
14/01/2006	298.64	297.84	298.22	298.76		298.63	298.51	298.24	298.15	297.87	297.81	297.98	298.18	298.35	297.71	297.71	298.23	298.13	297.85	297.66	297.66	298.64	298.81	297.95
14/04/2006	297.45	297.42	297.32	297.24	297.53	297.67	297.85	297.48	297.29	297.46	297.64	297.22	297.37	297.55	297.23	297.23	297.28	297.75	297.97	297.73	297.73	297.37	297.63	297.93
13/07/2006	296.91	296.71	296.70	296.35	296.32	295.57	296.59	296.45	296.46	296.71	296.94	296.59	296.72	296.73	296.75	296.75	296.98	297.22	296.92	296.74	296.74	296.25	297.30	297.36
14/10/2006	296.63	298.82	297.55	298.44	297.84	297.99		298.12	297.88				297.71	299.78	297.50	297.50	297.58	297.22	297.15	297.56	297.56	297.93	297.87	297.92
14/01/2007	297.12	297.49	297.90	298.13	298.21	297.65	299.30	298.56	297.16	297.18	297.43	296.32	297.78	297.45	297.32	297.32	297.37	296.59		297.16	297.16	297.84	297.95	297.73
13/04/2007		297.82	297.70	297.87	298.35	297.60	297.67	297.54	297.35	297.43	297.63	297.54	297.78	297.44	297.44	297.44	297.64	297.73	298.47	297.73	297.73	297.35	297.98	297.85
13/07/2007	297.28	296.52	296.86	297.35	297.18		297.67	296.94	296.50	296.78	296.98	296.79	296.79	296.96	296.67	296.67	296.93	297.14	297.79	296.64	296.64	296.39	297.29	297.74
14/10/2007	297.34	297.11	297.39	298.33				298.29	298.50	297.57	297.47	296.67	297.47	297.49	296.99	296.99	297.29	297.46	297.49	297.44	297.44	298.12	297.98	298.14
14/01/2008	297.26	297.17	296.83	297.24	297.84	297.83	297.49	297.27	297.20	297.23	297.23	297.24	297.77	296.72	296.92	296.92	297.35	296.63	297.31	297.30	297.30	297.42	297.56	297.47
14/04/2008	296.79	296.56	296.26	297.39	297.12	296.87	297.47	297.45	296.90	297.78	297.89	297.76	297.22	297.16	296.82	296.82	296.90	296.53	297.27	296.84	296.84	296.76	297.58	297.54
14/07/2008	296.65	296.46	296.64	296.31	296.46			296.66	296.72	296.55	296.86	296.61	296.67	296.75	296.59	296.59	296.23	296.48	296.80	296.60	296.60	296.13	296.93	296.78
14/10/2008	296.23	296.97	297.88	298.20			298.61	298.87	298.46	297.48	297.39	297.12	297.41	298.11	296.85	296.85	297.25	295.84	297.62	296.85	296.85	298.15	297.84	297.48
14/01/2009	297.31	297.00	297.27	297.74	298.29	297.62	298.75	297.77	297.73	297.32	297.19	297.32	297.17	297.12	297.20	297.20	297.35	296.95	297.91	296.99	296.99	297.91	298.11	297.85
14/04/2009	297.37	297.52	297.59	297.57	296.78	297.99	297.61	297.36	297.13	297.43	297.63	297.64	297.84	297.76	297.46	297.46	297.55	297.61	297.46	297.39	297.39	297.75	298.93	297.86
13/07/2009	296.89	296.62	296.56	297.79	296.96		297.28	296.76	296.75	296.85	296.89	296.69	296.76	296.58	296.69	296.69	296.63	296.46	297.60	296.62	296.62	296.30	297.47	297.45
14/10/2009	297.17	298.21	297.98	299.47	299.23			297.95	297.95	297.83	297.69	297.72	297.89	298.54	298.95	298.95	297.56	297.13	297.94	298.16	298.16	297.82	298.35	297.96
14/01/2010	298.23	298.44	299.00	299.29	299.26			298.91	298.54	298.69	298.56	298.96	298.71	299.13	298.36	298.36	298.93	298.21	298.26	298.85	298.85	298.86	298.35	298.32
14/04/2010	298.16	298.30	298.42	297.96	298.69	298.58	298.59	298.15	297.91	298.00	297.95	298.45	298.19	298.32	298.24	298.24	298.11	297.42	297.94	298.23	298.23	297.93	298.25	298.69
13/07/2010	296.76	296.84	296.73	296.46				296.65	296.63	296.84	297.22	296.85	296.79	296.77	296.90	296.90	296.98	296.82	297.29	296.82	296.82	296.35	297.31	297.43
14/10/2010	297.63	297.41	297.69	297.97			298.18	297.70	297.54	297.32	297.22	297.86	297.78	297.65	297.26	297.26	297.27	297.25	297.37	297.33	297.33	297.64	298.14	297.57
14/01/2011	297.16	297.44	297.76	297.90	298.68		298.34	297.54	297.50	297.42	297.34	297.15	297.35	297.63	297.19	297.19	297.56	297.15	297.27	297.48	297.48	297.83	297.75	297.62
13/04/2011	297.69	297.55	297.57	298.74	298.21	298.36	297.95	298.13	297.91	297.98	297.75	297.54	297.67	297.85	297.64	297.64	297.65	297.79	298.15	297.57	297.57	297.93	298.12	297.82
13/07/2011	296.56	297.42	296.83	296.97	296.20	296.68	296.47	296.88	296.85	296.83	296.98	296.99	296.97	296.79	296.97	296.97	297.38	296.55	297.75	297.78	297.78	296.46	297.35	297.30
14/10/2011	297.94	297.51	297.99	298.55	298.44	298.39	298.95	298.36	297.75	297.87	297.37	297.45	297.34	298.18	298.00	298.00	297.21	296.48	297.22	297.14	297.14	298.20	297.83	297.69

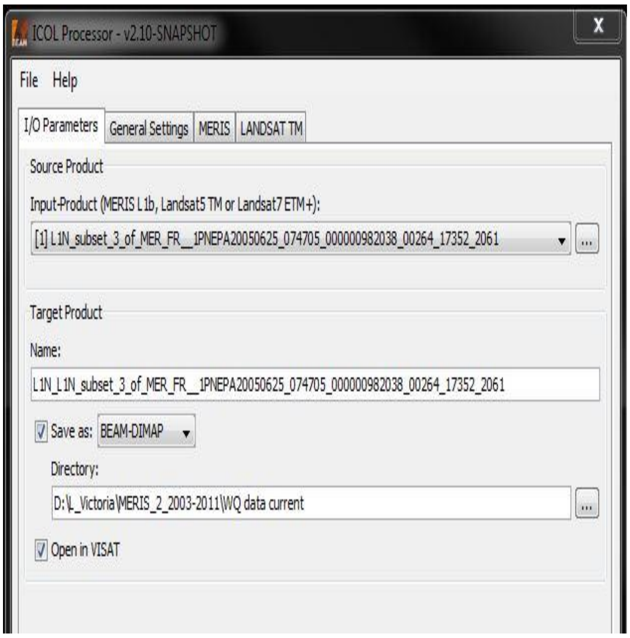
Appendix F: The Eutrophication Index Derived from In situ Measurements

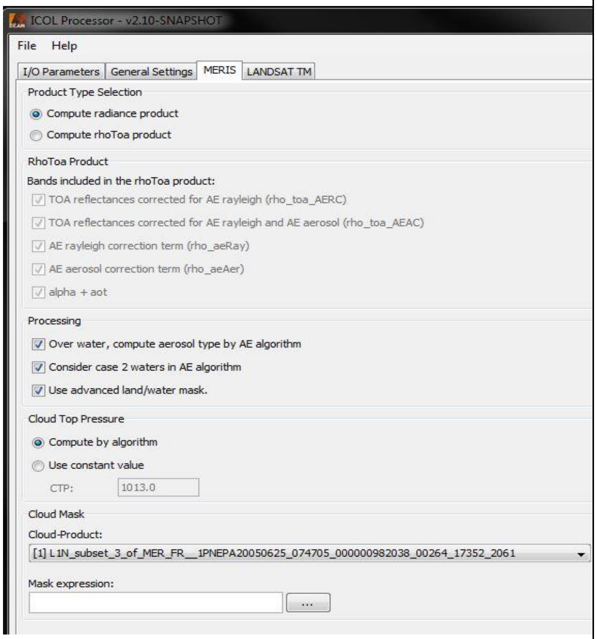
St. No.	Date	ActualE	ActualN	Ortho-Phosphate (µg/L)	In situ Chl - a (µg/L)	Zeu (m)	E.I
TL230	22/06/2003	32.8684	-2.5908	202.525	18.736	5.42	26.24
TL231	22/06/2003	32.8535	-2.6178	73.798	25.283	7.04	26.24
TL232	22/06/2003	32.8393	-2.6574	38.666	18.186	8.84	20.87
TL233	22/06/2003	32.8683	-2.7119	26.231	36.003	8.24	32.56
TL234	22/06/2003	32.8975	-2.7741	9.516	25.65	9.48	25.32
TP02	22/06/2003	32.8381	-2.3105	123.431	13.566	8.13	20.90
TP16	22/06/2003	33.6535	-1.3715	28.566	5.677	5.42	9.13
TP17	22/06/2003	33.3378	-1.2031	29.989	3.118	2.98	5.66
TP18	22/06/2003	33.0883	-1.1433	21.269	1.79	2.71	4.13
TL 230	22/12/2010	32.8684	-2.5908	10.107	5.949	10.02	11.72
TL 231	22/12/2010	32.8535	-2.6178	39.02	32.818	9.48	31.75
TL 232	22/12/2010	32.8393	-2.6574	43.088	35.205	8.13	32.67
TL 233	22/12/2010	32.8683	-2.7119	64.785	38.338	5.42	33.98
TL 234	22/12/2010	32.8975	-2.7741	47.648	39.285	4.06	32.93
TP 01	22/12/2010	32.8495	-2.4907	19.472	2.471	5.42	6.44
TP 02	22/12/2010	32.8381	-2.3105	82.979	9.227	6.77	15.05
TP 03	22/12/2010	32.465	-2.1411	26.463	1.018	4.06	4.77
TP 05	22/12/2010	32.27	-2.129	18.969	0.854	4.06	4.31
TP 06	22/12/2010	32.0953	-2.2997	24.782	5.927	9.48	11.98
TP 07	22/12/2010	31.866	-2.5349	12.847	9.963	6.23	12.04
TP 15	22/12/2010	33.2712	-2.3102	121.733	17.724	8.13	23.78

Appendix G: The Remote Sensing Derived Eutrophication Index

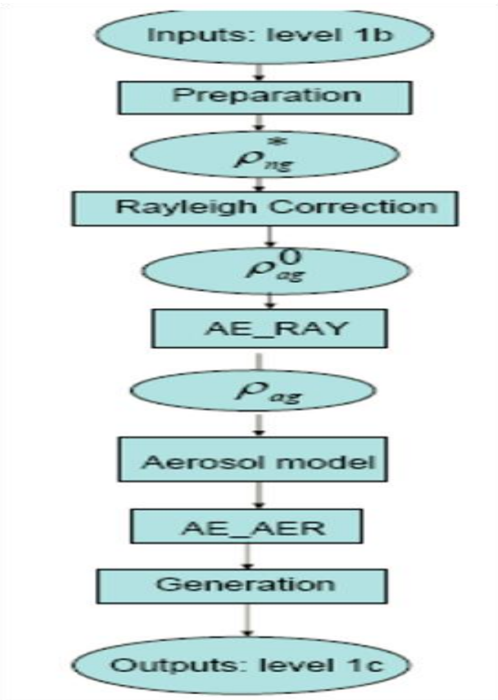
St. No.	Date	ActualE	ActualN	MERIS Chl_a (µg/L)	Kd 490 (1/M)	LSWT (°C)	RSEI (°C)
TL-230	26/07/2003	32.86789	-2.590979	23.45	1.06	23.27	21.92
TL-231	26/07/2003	32.852886	-2.6179764	23.45	1.07	23.47	21.96
TL-232	26/07/2003	32.8389	-2.656971	21.03	1.04	23.18	20.21
TL-233	26/07/2003	32.86791	-2.7119858	23.45	1.35	23.34	22.13
TL-234	26/07/2003	32.89691	-2.773994	22.61	1.30	23.54	21.56
TP-02	26/07/2003	32.837852	-2.3099585	10.56	0.43	23.27	12.57
TP-16	26/07/2003	33.652897	-1.3711438	7.62	0.21	24.24	10.60
TP-17	26/07/2003	33.337933	-1.2030447	6.36	0.24	23.81	9.66
TP-18	26/07/2003	33.087948	-1.1429387	6.13	0.22	23.13	9.34
TL-230	15/12/2010	32.86784	-2.5913866	35.82	1.67	24.81	31.21
TL-231	15/12/2010	32.85285	-2.6183984	35.49	1.86	24.82	31.12
TL-232	15/12/2010	32.83886	-2.6574092	29.62	1.60	25.54	27.04
TL-233	15/12/2010	32.867874	-2.7124178	25.64	1.41	25.43	24.14
TL-234	15/12/2010	32.896896	-2.7744164	24.09	1.45	25.44	23.09
TP-01	15/12/2010	32.849815	-2.491364	26.48	1.04	25.00	24.36
TP-02	15/12/2010	32.83779	-2.3103147	8.13	0.33	24.76	11.15
TP-03	15/12/2010	32.464878	-2.1410704	2.21	0.13	24.85	6.93
TP-04	15/12/2010	32.545895	-1.8609649	5.55	0.25	24.80	9.31
TP-05	15/12/2010	32.269913	-2.1289124	2.12	0.13	25.30	6.97
TP-06	15/12/2010	32.09491	-2.2998495	11.05	0.47	25.04	13.32
TP-07	15/12/2010	31.86581	-2.53516	34.94	1.25	25.17	30.39
TP-15	15/12/2010	33.270733	-2.3102663	15.82	0.70	25.09	16.79

Appendix H: Settings for ICOL processor

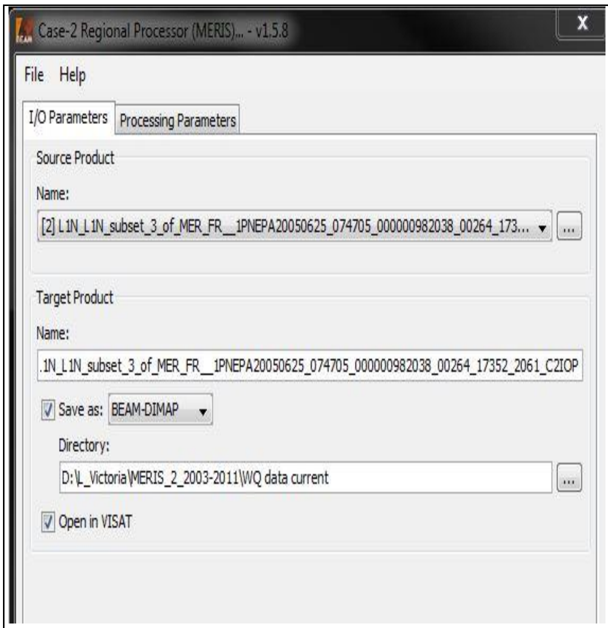


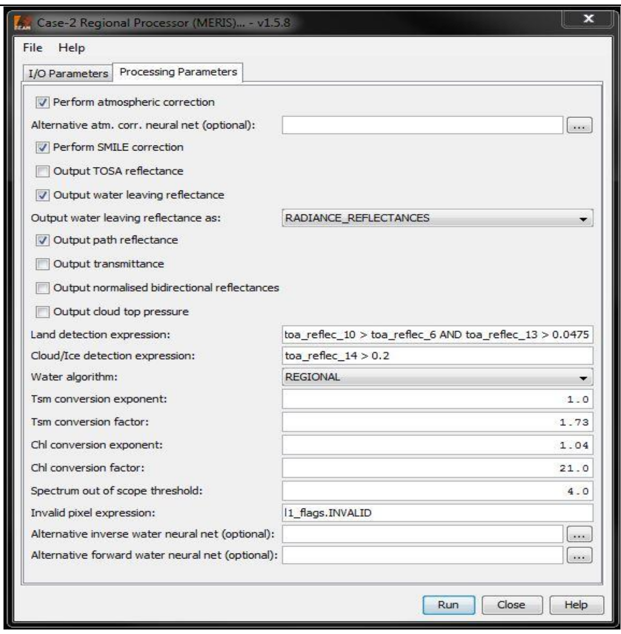


Appendix I: General Flowchart for ICOL processor adopted from (Santer & Zagolski, 2009)



Appendix J: Settings for Case 2 Regional Processor





Appendix K: Summary of Classification for September 2013 in-situ WQ data

	OECD Classification		Carlson Classification	
Variables	**Annual Mean Values**	**Trophic Category**	**TSI**	**Trophic Category**
Chlorophyll-a (mcg/L)	3.51	Mesotrophic	35.97	Oligotrophic
SD Transparency (m)	1.73	Eutrophic	52.11	Mesotrophic - Eutrophic