University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

MONITORING THE SPREAD OF WATER HYACINTH USING SATELLITE IMAGERY

A CASE STUDY OF LAKE VICTORIA

A PROJECT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN GEOGRAPHIC INFORMATION SYSTEMS, IN THE DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY OF THE UNIVERSITY OF NAIROBI

BY

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MAY 2019

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Abstract

Water hyacinth is aquatic vegetation that is believed to have been introduced to Lake Victoria in 1988. Using satellite images from 1988 to 2016, this research identifies the trend in the spread and how human activities have contributed to the trend of spread of the water weed.

Landsat satellite images were obtained from internet open sources. Mosaicking and classification were done to the images. During classification, six classes comprising of water, water hyacinth, built up area, bare ground, other vegetation and unclassified were obtained. Built up area is captured in the study because a 10 km buffer along the shores of the lake was included. This was used to monitor the growth of urban centers around the lake. Growth in urban centers is due to population pressure resulting from rural urban migration, and this resulted in increase in pollutants draining into the lake.

From the satellite images used, it is observed that water hyacinth occupied very small area of Lake Victoria in 1988. In this year, the area of the lake covered by water hyacinth was 2,846 m^2, this is approximately 3.4% of the total area of the lake. The weed spread over the years and in the year 2000, it was occupying an area of 19,122 m^2, which is approximately 23% of the whole lake. This shows a tremendous spread of the weed. After the year 2000, the government took some steps to counter the spread. And in the years 2004, 2008, 2012 and 2016, there was a continuous reduction in the spread of the weed, whereby in the year 2016, it occupied an area of 4.9% of the whole lake. The weed is observed to be occupying mostly along the shores of the lake where the water is shallow. This has greatly affected the fishing industry since navigation is not possible in the areas occupied by the water weed. Where the fishermen find small entry or navigation, overfishing is done due to small area available for fishing and the demand is high.

The results show that growth in urban areas is proportional to the amount of spread in water hyacinth. Several efforts to curb the spread have been employed by different countries but none has been totally successful. Human activities have been clearly demonstrated in this study to be the major cause of the spread. NDVI maps were used to demonstrate where the water hyacinths were healthy as compared to other regions.

This study recommends that human activities around the lake should be monitored and controlled so as to reduce the pollutants entering the Lake. The study further recommends on further study to discover other possible propellers of the spread of water hyacinth in the Lake.

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CHAPTER 1: INTRODUCTION

1.1 Background

Lake Victoria is the world's second largest fresh-water lake with an area of 68 000 km^2. Lake Victoria is also the world largest tropical lake found in Eastern Africa. It has a perimeter of 3450 km shoreline and a catchment area of 258,700 km^2. Recently it has been invaded by water hyacinth over the past decades and the tropical aquatic weed presents itself in an enormous challenge for monitoring and controlling it. Less than 0.5 % of the Kenyan portion of Lake Victoria which is about 4200 square kilometers is covered by water hyacinth. The actual area of the whole lake that is now covered is probably more than 5,000 hectares.

Lake Victoria is shared among three countries with Tanzania having the largest portion, followed by Uganda and finally Kenya having the smallest portion. Water hyacinth is believed to have been introduced in Lake Victoria in the 1980s and since then it has been spreading uncontrollably causing various impacts to the surrounding ecosystem and aquatic life present. It has affected various fishing activities and movement by small canoes and boats.

Ever since water hyacinth was introduced the economic development of the lake region has always been on the downfall. This is due to the fact that the weed blocks shipping lanes hence reducing the quantity of cargo transported across the lake. This alone has had negative effects on those who depended on the lake, directly and indirectly, to provide a livelihood. Ship owners have had to either spend more on maintenance and fuel costs or find other sources to meet their financial needs. This then would mean that the hundreds of semi-skilled and non-skilled laborers would lose their sources of income. This led to the rise of social upheavals in the region especially crime rates. The country as a whole also lost a source of revenue thus reducing the gross domestic products. Biologically, the weed provided a conducive breeding ground for various pests e.g. mosquitoes raising mortality rate due to high risk of diseases. The weed has also favored the survival of some fish species while being unfavorable to others. This creates an ecological imbalance in the lake. Various methods have been adopted to regulate its spread but all have been partially successful. These methods can be categorized as mechanical, chemical or biological methods. Mechanical methods involve the weed being dragged to the shore by boats (boat-ferried) or being loaded into boats (boat-loaded). Both of these methods are not as effective as the rate of removal is way lower than the rate at which the weeds reproduces asexually especially after the uprooting/cutting process. This is because every cut branch, either still rooted or floating, forms a whole new plant.

Biologically water hyacinth weevils were introduced by the Kenya Agricultural Research Institute (KARI) but then an ecological imbalance was established.

1.2 Problem Statement

Water hyacinth has brought with it more negative effects than positive effects so far. The negative effects can either be totally eliminated or minimised.so far water hyacinth has proved impossible to eliminate and is proving difficult to control. This can be done by either majoring on minimizing the negative effects or maximizing on the positive effects which in theory wasmaking the rate of harvesting the weed higher than the reproduction rate.

Water hyacinth is also an indirect cause of unemployment as it makes it difficult for ships to operate in the lake thus those depending on the operation of shipping lanes for employment both, directly and indirectly, suffer the most by receiving low pay or losing their jobs since their employer can no longer sustain their presence in the organization. This, in turn, leads to low living standards and a general drop in the economy

Because of lack of employment, most opt for the easiest source of employment which in this case is fishing. The effect of this is overfishing and depletion of some fish species.

1.3 Objectives

1.3.1 Main objective

To monitor trends in the spread of water hyacinth in Lake Victoria

1.3.2 Specific objectives

1. To characterize past trends of water hyacinth
2. To quantify and predict future spread
3. To relate the population settlement around the lake to the spread in water hyacinth

1.4 Justification for the Study

Various technologies have been used in the past to manage water hyacinth in Lake Victoria but none has succeeded so far. This is because these methods are time-consuming considering the geographical extent of the lake.

Studies done outside remote sensing would mean that sampling of the study area is to be conducted. This procedure was based on speculation or depending on another person's knowledge, especially the locals, to collect the different samples from relevant sites. This can be done in remote sensing quite faster and efficiently as remote sensing helps a researcher familiarize with the area of study before the actual visit.

The lake is also shared by three countries and boundary issues always rise due to uncontrollable political reasons. This makes remote sensing suitable for this study as it is able to obtain information over a large area with minimal time consumption as compared to other existing methods. The lake is also sometimes dangerous as it gets stormy thus endangering the lives of those conducting the study. Remote sensing can be used to conduct studies in such dangerous areas as it is the only option in such places which are dangerous. Remote sensing provides an aerial view which makes it easier to identify trends of spreading phenomena such as water hyacinth.

Remote sensing can provide data for previous occurrences of phenomena thatwere not presumed to be of importance then but have a significant impact on the present situation.

This applies to this situation as no or little data was collected in the past about water hyacinth and thus are of little or no use at all on any study on water hyacinth.

With remote sensing images, various analyses can be done especially the band derived indices that monitor vegetation and other phenomena related to vegetation.

1.5 Scope of work

This study majored on monitoring spread of water hyacinth in Lake Victoria by employing Remote Sensing technology. Successful management of the weed will result in various advantages especially in the security of aquatic food. Previous studies have majored on political definition of Lake Victoria mostly Kenya. This study seeks to expand the general understanding of the entire lake (Lake Victoria).

Generally, the study looked at past trends, present situation and tried to predict the future spread of water hyacinth. It also looked at ways on how the weed can be controlled by maximizing on the benefits.

The study further looked into human activities which could be related either directly or indirectly to the spread water hyacinth. Figure 1 shows the extents of the area of study.

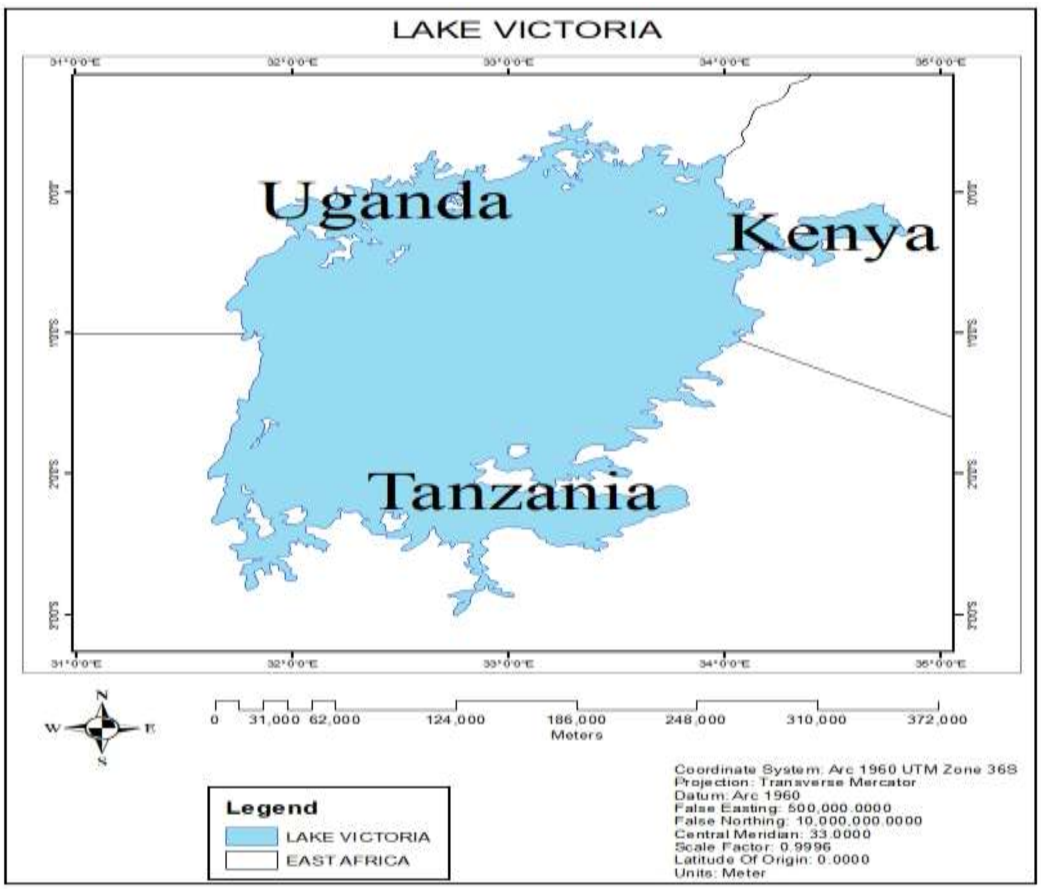

Figure 1. Study area map

CHAPTER 2: LITERATURE REVIEW

Some of the published literature on recent advances that tried the use of biological control of the water hyacinth is documented in countries such as South Africa by (Cilliers 1991), Benin by (Van Thielen*et al.* 1994) and Zimbabwe by (Chikwenhere 1994). The introduction of *Neochetina*spp. into Lake Kyoga, Uganda in 1993 led to their rapid establishment and spread in Sigiriver in Tanzania, Lake Malawi and Shire River in Malawi, riverine systems and lagoons in Ghana and Côte d'Ivoire.

The World Bank has supported efforts to control the water hyacinth in East Africa through the Lake Victoria Environmental Management Programme. The three riparian states of Kenya, Uganda and Tanzania are its joint administrators. The Kenya Agricultural Research Institute (KARI) has initiated a 5-year programme, Water Hyacinth Control and Monitoring, whose main thrust was be biological control. However, herbicide and physical control components was remaining as an integral part of a community-based, multi-sectoral water hyacinth management programme. However, throughout the years other methods of monitoring the water hyacinth menace have come up and they include use of GIS and remote sensing technologies. This paper presents recent results from a biological control programme initiated by KARI and other methods specially tailored for water hyacinth control on Lake Victoria.

The first major water hyacinth control program was initiated by the Kenya agricultural research institute back in 1993. They mainly targeted to weaken the weed by introducing water hyacinth weevil that found an ecological balance with the weed and thus stopped being efficient.

Water hyacinth reduction in Lake Victoria between 1997 and 1998 was related to biological control (weevils) of water hyacinth introduced in December 1995. They also attribute the rise of water hyacinth in Winam Gulf to the EL Niño rains experienced in eastern Africa in the late 1997 and early 1998. During this period, it is recorded that the level of water in the lake rose by about 1.7 meters.This is to say that the reduction of the photosynthesis process reduced the rate of multiplication of water hyacinth. This would have slowed down the rate of multiplication and not the reduction as suggested in their study. Because of the changing characteristics of water hyacinth,the weevils introduced in 1995 were slowly decreasing in population and eventually came to a point where almost none were present. This led to an increase in water hyacinth in the Lake. (Wasiams et al, 2007), Water hyacinth decline across Lake Victoria was caused by climatic perturbation or biological control. The study did not look at the human factors but they acknowledged that water hyacinth spread is related to more than one factor (Wasiams et al., 2007).

(Wilson et al., 2007), The Rise and Fall of Water Hyacinth in Lake Victoria and the Kagera River Basin, 1989-2001.Responding to an earlier article conducted by (Wasiams et al., 2007) Water hyacinth in Lake Victoria : Why did it vanish so quickly and did it return back in 2005? They insisted that water hyacinth reduction was not because of the reduced photosynthetic activity but rather as a result of weevils. This paper refers to an earlier study conducted by (Albright et al.,2004) who used remote sensing between the years 1995 and 2002,showed a drastic decrease from 1999 to 2002 .they attribute this reduction to weevils four years after their introduction to the lake. (Wilson et al., 2007) does not look at other factors that might influence water hyacinth spread such as human-related factors.

(Guerena et al,2015) Looked at how water hyacinth is affecting those around the lake and the activities around the lake as well. They give a brief overview of how water hyacinth found its way to Lake Victoria. Their study also referenced other studies from which they identified that water hyacinth is able to double its biomass through asexual reproduction in approximately two weeks.

Water hyacinth can also be used as a source of energy. Water hyacinth can produce enough energy to drive steam boilers to create electricity (Guerena, et al, 2015). The by-products of water hyacinth combustion is an ash content which is reported to comprise of 0.53% phosphorus and 2.44% K.This means that the ash by-product can be used to manufacture fertilizers thus decreasing the cost of fertilizes in Kenya, providing jobs, and cheaper farming. (Guerena et al, 2015 also concluded that biomass of water hyacinth can be subjected to anaerobic digestion. This is the fermentation of organic materials biologically in the absence of oxygen.one of the output products is biogas rich methane that can be used as a source of energy or used to generate electricity.

Economically the port of Kisumu has experienced a drop in ship traffic since only vessels weighing more than 700 tonnes can navigate through the water hyacinth. This achievement comes with an increased fuel consumption. This led to decreased outgoing traffic from 97000 tones to 37000 tonnes (Mailu,2001).

(Guerena et al, 2015) suggested that if total eradication of the weed is impossible then the focus should be turned to how the weed can be converted to an energy source. Cheaper biological methods and chemical methods to control the weeds spread were realized but were harmful to the environment. Physical methods used to remove the weed could cause the weed to rapidly multiply asexually by splitting at the rhizomes

(Robles et al, 2015) Conducted a study on lake Columbus and lake Aberdeen both located in northern Mississippi. They estimated the biomass of water hyacinth present in the lake through the application of NDVI. NDVI can be used to find the rough estimates of biomasses of both terrestrial and aquatic plants. The result is an estimate of the live biomass present on the area of interest. The level of precision depends on the resolution of the satellite or aerial image used.

In the 1990s, water hyacinth had a coverage of 4000 ha in Uganda's shoreline 2000 ha in Tanzania's shoreline and 6000 ha in Kenya's shoreline. The total coverage of water hyacinth in the lake was approximately 17000 ha. (Albreight et al 2004), Microwave remote sensing: Active and passive. Volume 1 - Microwave remote sensing fundamentals and radiometry.

(Gunnarsson & Petersen, 2007) They majored on agricultural use as well as energy systems related to water hyacinth. Approximation of biomass of water hyacinth to be harvested determines how much of water hyacinth product is capable of being produced. Water hyacinth also poses a biohazard risk as they act as breeding grounds for vectors e.g. mosquitoes. Water hyacinth also provide habitat for other water animals such as snakes, hippos, crocodiles among others. Working with water hyacinth requires intense labour and pose health risks as well. This is because waterborne diseases can infect the workers much faster since most of them do not use protective gears.

Mechanical harvesting of water hyacinth seems to be the only remaining way to control the spread of water hyacinth. This is because the chemical and biological methods adopted are either illegal or have been unsuccessful in the past.

(Gunnarsson & Petersen, 2007) Also identified that water hyacinth can be used as roughage and thus can reduce animal feed shortage. Water hyacinth is also capable of being used to produce silage. Water hyacinth can also be used to produce biogas through anaerobic respiration. Spreading water hyacinth on the crop fields is also a usage for water hyacinth as it can act as green manure.

(Lalah et al, 2008) conducted a study that analyzed the heavy metals that are carried into Lake Victoria through rivers. The study focused on rivers Kuja, Kisat, Sondu-Miriu, Nyamasaria, Yala, AwachNzoiza and Nyando. Their findings were that almost all the rivers were of low sediments load except river Kisat which had elevated levels of lead, magnesium, copper and zinc. Higher lead, copper and zinc levels were also found in rivers Nyando and Nyamasaria In their study (Lalah et al., 2008) discuss the various sources of heavy metals into Lake Victoria. These sources fall into two main categories. One, those introduced as a result of weathering of soil and rocks from volcanic eruptions. Two, those introduced as a result of anthropogenic activities. Those from anthropogenic activities are directly introduced by human activities especially the jua kali industry and other industries along the rivers. Their study reveals that the high levels of heavy metals into river Kisat is mainly due to industrial discharge and sewerage effluence into the river.

(Juma et al, 2014) conducted a water quality study between the period 1990 and 2012 and found that population and economic drivers were the key drivers on water quality degradation. The main activity that reduces water quality is unplanned development near the lake region. Their findings were that nitrate-nitrogen, soluble phosphorous and chlorophyll, both indicators of water quality, increased. The study used moderate resolution imaging spectroradiometer (MODIS) to study the aquatic vegetation for the years 2000 and 2012 of Kenyan waters. Their study concludes that the increase in population increases pollution discharge thus polluting water bodies.

(Ongulu & Kituyi, 2015) Their study identified that the main cause of reducing water quality in Lake Victoria is pollution. This pollution results from industrial expansion, population increase and poor sewerage systems.

In conclusion many studies have been done but each focus on a certain aspect only as discussed above. As clearly stated in the objectives this research is different from the others and mainly seeks to predict future trends and spread, the fuelling causes of spread and mitigation measures towards controlling the water hyacinth menace.

CHAPTER 3: MATERIALS AND METHODS

3.1 Satellite images

This study was conducted using Landsat images from 1988 to 2016 with an interval of four years. This is aimed at providing a clear picture of how water hyacinth has been spreading and by how much. After obtaining the images, geometric correction won't be required since it is one of the pre-processing processes carried out by the distributor hence no need to carry out geometric corrections and correct for satellite imagery since they are georeferenced already.

3.2 Radiometric correction.

Radiometric correction is acomputer-based technique for reducing noise in imagery.It is necessary to remove the atmospheric noises e.g. the clouds and haze. Radiometric correction wasthe first form of image correction specifically to eliminate or reduce cloud cover which would corrupt the classification output.

3.3 Resampling

Since this study uses satellite images of different resolutions, the satellite images were resampled to the lowest resolution of the images which is Landsat 4 and 5 which has a resolution of 30m.

3.4 Classification

This study employed unsupervised classification since it has been proven to be more accurate than supervised classification and also prevents a lot of classes during classification.

3.5 Accuracy Assessment

This can be described as the process of relating the classified image and what is in existence or what existed when the image was captured. This is usually done through ground truthing or by the use of high-resolution satellite imagery.

Ground truthing was done after performing classification of the Landsat images. This givesthe accuracies of the classified classes as to what was on the ground when the imagery was taken. The expected accuracies are user's accuracy, producer's accuracies, kappa, errors of omission and commission

3.6 Change detection

Change detection was done on the mosaiced classified images to determine how water hyacinth has spread over time since it was believed to have been introduced in Lake Victoria. This is aimed at identifying the spread vector which was be of use in identifying the human factors involves in the spread or reduce.

3.7 NDVI

NDVI is a vegetation index that can be used to estimate the biomass of plant and their condition. Here the NDVI was used to estimate the biomass of water hyacinth over the years in Lake Victoria. This was achieved through conducting a combined analysis on the near-infrared band and the red band. The output ranges from -1 and 1.the output of NDVI is an image showing the presence of vegetation with -1 representing water bodies,0 bare ground and 1 healthy vegetation. The values in-between describe the condition of the vegetation present (0 to 1).

3.8 Prediction of future spread

One of the objectives is to predict the future spread of water hyacinth in Lake Victoria and quantify its rate of change. This was carried out using a prediction model that considers the environmental factors and history on how it has been spreading depending on these factors. Markov prediction model was employed for this.

3.9 Data sources

Table 1. Data sources

Data	Source
Landsat images	USGS
Lake Victoria shape file	Kenya open data
East Africa shapefile	Kenya open data

3.10 Softwares used

The soft wares used in this study are:

1. Envi
2. QQIS
3. ERDAS Imagine

Figure 2 shows the methodology flowchart used in the project.

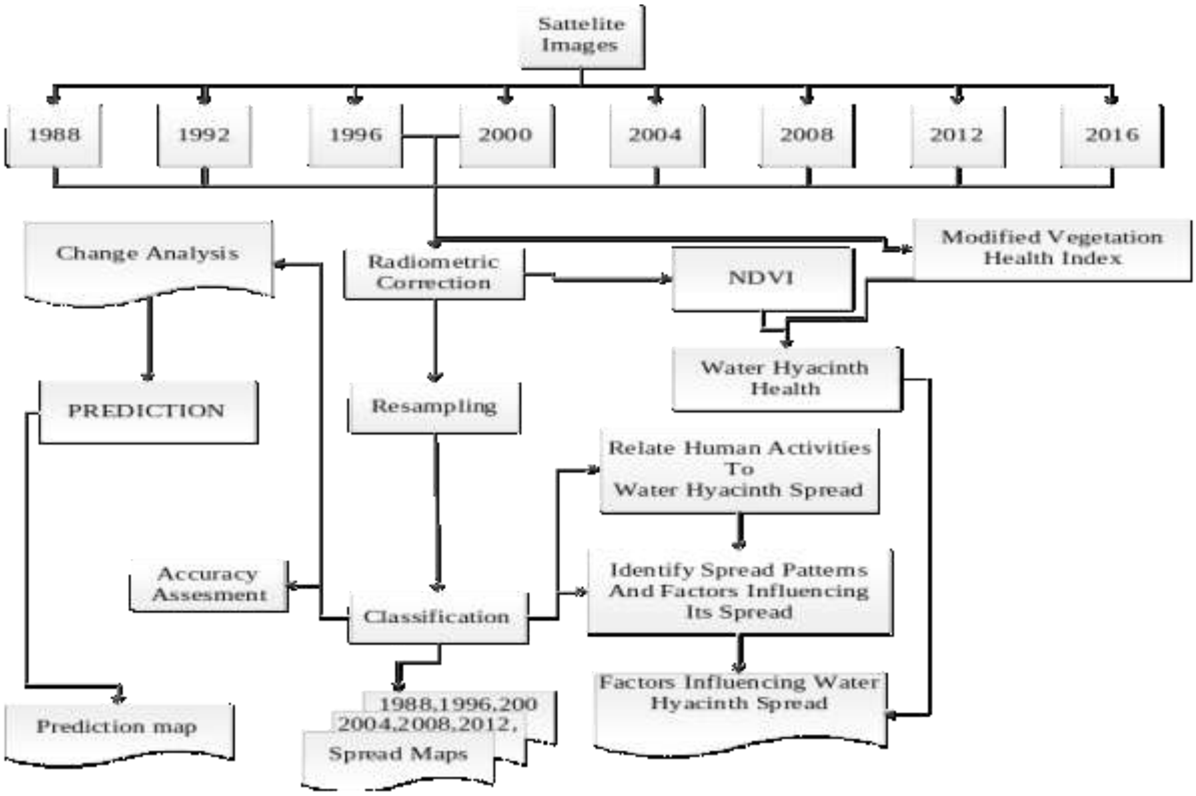

Figure 2. Methodology Flowchart

CHAPTER 4: RESULTS AND DISCUSSION`

4.1 Image classification

Image classification is the process of assigning image pixels into different groups or classes depending on their properties. Pixels with similar properties are grouped together while those which do not have similar properties are put into a different group or class. This study generally adopted supervised classification since there was a need to generalise some of the classes that are of less interest.

Since the study is also interested in the human activity around the lake region, the study area was extended to include a ten-kilometer buffer from the lake shores.

This made possible to perform analysesof human-related activities that might have an influence on water hyacinth.

Below are the classes identified during classification.These classes are

1. Water
2. Water hyacinth
3. Bare ground
4. forest
5. Other vegetation
6. Built-up areas

Different vegetation classes were merged into one single class (other vegetation) as they are of less interest to the study. This study has not yet identified if there is any relationship whatsoever between the type of vegetation on the mainland and how it affects the spread and behavior of water hyacinth in the lake.

The classification was conducted to include the mainland in order to identify specifically how urban areas have changed over the years. This is because pollution is proven in this study to be the driving factor behind water hyacinth spread and flourishment.

The classification summary of each year is provided for and finally an overall summary of how water hyacinth and urban areas have changed throughout the study years.

4.1.1 Classification map 1988

Water hyacinth is believed to have been introduced into Lake Victoria around this time. For this reason, this study focused on looking at 1988.The classification method adopted is supervised classification utilizing maximum likelihood algorithm. The classes identified were water, water hyacinth, built-up areas, forest, other vegetation and bare ground. This is because there are various types of vegetation on the grounds which are not of interest to this study and therefore identifying these types of vegetation in the classification would add little or no knowledge to the study while consuming valuable time and reducing the overall classification accuracy.

The images used for classification were obtained from a dry season to minimize on the classification errors usually caused by clouds. The classification produced results displayed belowin Figure *3* and its confusion matrix is as shown in table 2(a). A summary of the respective areas of every class is shown in table 2(b).

Table 2(a):Confusion matrix for classified 1988 image

Table

conf_1988

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
1	C_1	9	1	0	0	0	0	10	0.9	0
2	C_2	1	9	0	0	0	0	10	0.9	0
3	C_3	0	0	9	0	0	1	10	0.9	0
4	C_4	0	0	0	8	0	2	10	0.8	0
5	C_5	1	0	2	0	7	0	10	0.7	0
6	C_6	0	0	1	0	0	9	10	0.9	0
7	Total	11	10	12	8	7	12	60	0	0
8	P_Accuracy	0.818182	0.9	0.75	1	1	0.75	0	0.85	0
9	Kappa	0	0	0	0	0	0	0	0	0.82

Table 2(b): Summary of areas for classes of 1988 image

Class name	Area in km^2
Water	63935
Water hyacinth	2846
Built-up areas	1507
Bare ground	11604
Other vegetation	4253

Total	841455

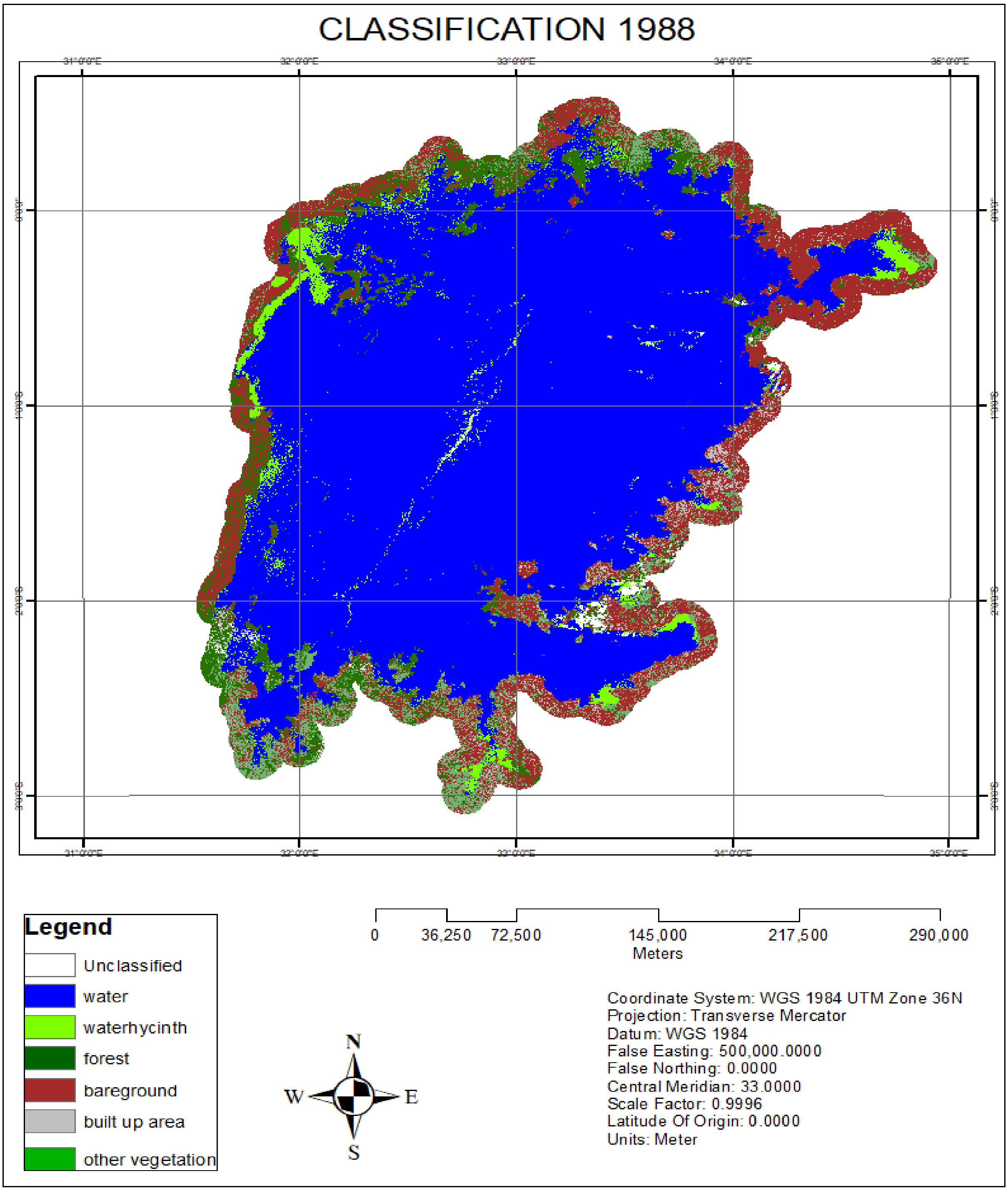

Figure 3. Classification map 1988

4.1.2 Classification map of 1996 image

Image classification of the year 1996 reveals an increase in water hyacinth as well as built-up areas. The increase in water hyacinth can partly be attributed to the increase in pollutants into Lake Victoria. Increase in urbanization comes with various environmental challenges and pollution is one of these challenges. The increase in vegetation on the areas adjacent to the lake is probably because of the high volumes of rains experienced in the previous years, EL NINO included.

Figure 4 shows the classification map for the image of the year 1996.A summary of classes and their respective areas obtained from the 1996 image are shown in table 3(a), and table 3(b) shows the confusion matrix of the classification results.

Table 3(a) *Summary of areas for classes of 1996 image*

Class name	Area in km^2
Water	59047
Water hyacinth	7713
Built-up areas	2755
Bare ground	3977
Other vegetation	10653
Total	84145

Table 3(b): Confusion matrix for classified 1996 image

Table

conf_1996

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	Total	U_Accuracy	Kappa
1	C_1	97	3	0	0	0	100	0.97	0
2	C_2	8	92	0	0	0	100	0.92	0
3	C_3	4	5	66	18	7	100	0.66	0
4	C_4	0	0	6	88	6	100	0.88	0
5	C_5	0	1	15	14	70	100	0.7	0
6	Total	109	101	87	120	83	500	0	0
7	P_Accuracy	0.889908	0.910891	0.758621	0.733333	0.843373	0	0.826	0
8	Kappa	0	0	0	0	0	0	0	0.7825

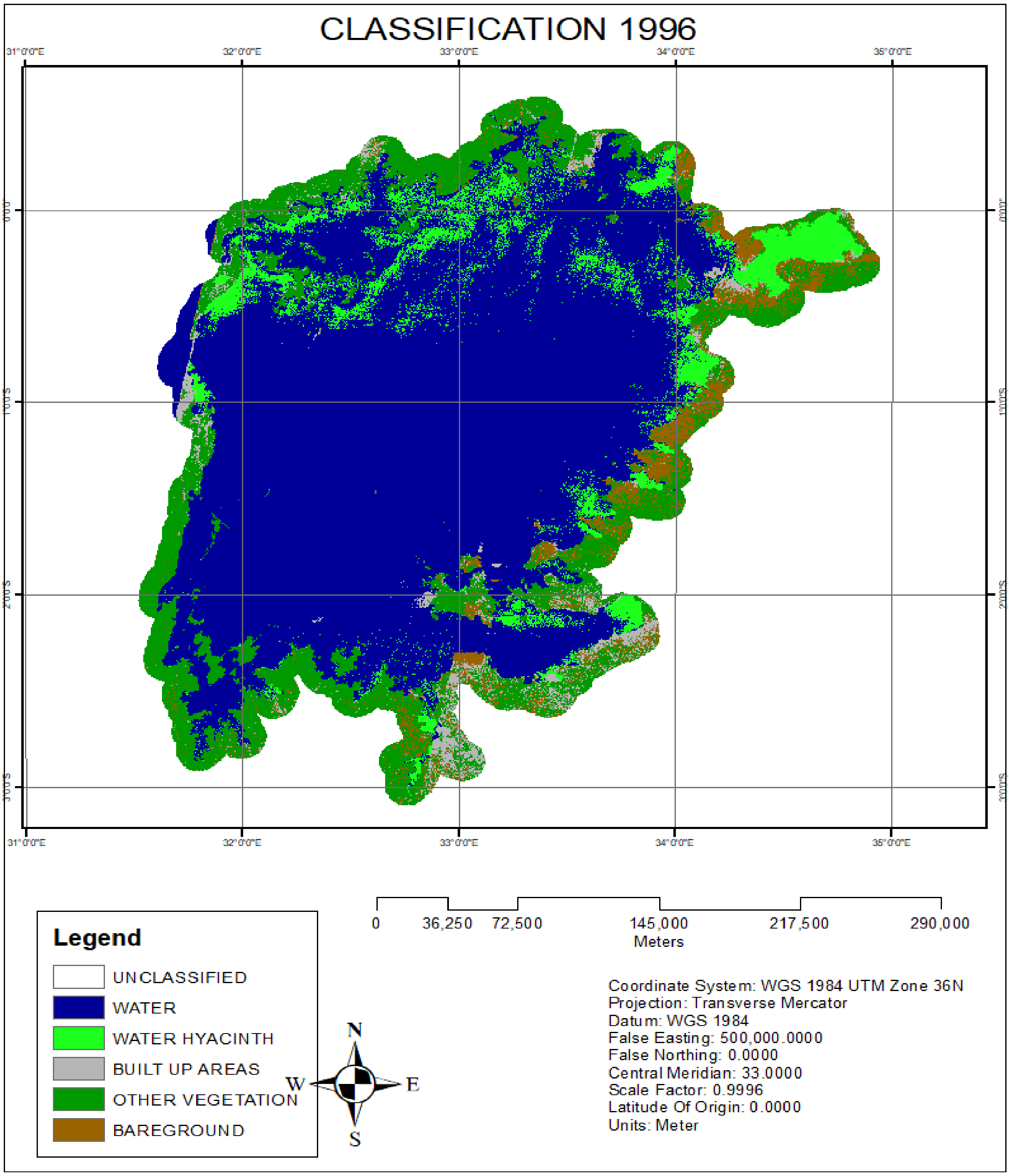

Figure 4 Classification map of 1996 image

4.1.3 Classification map of 2000 image

Classification of images obtained for the year 2000 shows an increase in water hyacinth and built up areas as well. Since urban areas contribute to polluting the lake, the high increase in water hyacinth can be attributed to an increase in built-up areas near the lake. From this classification, there is an increase of water hyacinth in the Winam Gulf and generally in the northern region of Lake Victoria. This would mean that the pollution is high in the north (Kenya and Uganda) than in the south (Tanzania).Water hyacinth also increased significantly in the south. It is during this period that there was a massive migration to urban areas in Kenya in search of jobs, better lively hood and business opportunities.

Figure 5 shows the classification map of the image for the year 2000. Table 4(a) shows the confusion matrix of the classification results and a summary of classes and their respective areas obtained from the 2000 image are shown in table 4(b).

Table 4(a): Confusion matrix for classified 2000 image

Table

conf_2000

OBJECTID *	ClassValue	C_1	C_3	C_4	C_5	C_6	C_7	Total	U_Accuracy	Kappa
1	C_1	47	0	0	0	5	7	59	0.79661	0
2	C_3	0	46	0	0	4	9	59	0.779661	0
3	C_4	0	0	57	2	0	0	59	0.966102	0
4	C_5	0	0	6	53	0	0	59	0.898305	0
5	C_6	2	2	0	0	51	4	59	0.864407	0
6	C_7	1	8	0	0	8	42	59	0.711864	0
7	Total	50	56	63	55	68	62	354	0	0
8	P_Accuracy	0.94	0.821429	0.904762	0.963636	0.75	0.677419	0	0.836158	0
9	Kappa	0	0	0	0	0	0	0	0	0.80339

Table 4(b) summary of classification of 2000 image

Class name	Area in km^2
Water	47246
Water hyacinth	19122
Built-up areas	4295
Bare ground	8508

Other vegetation	4974
Total	84145

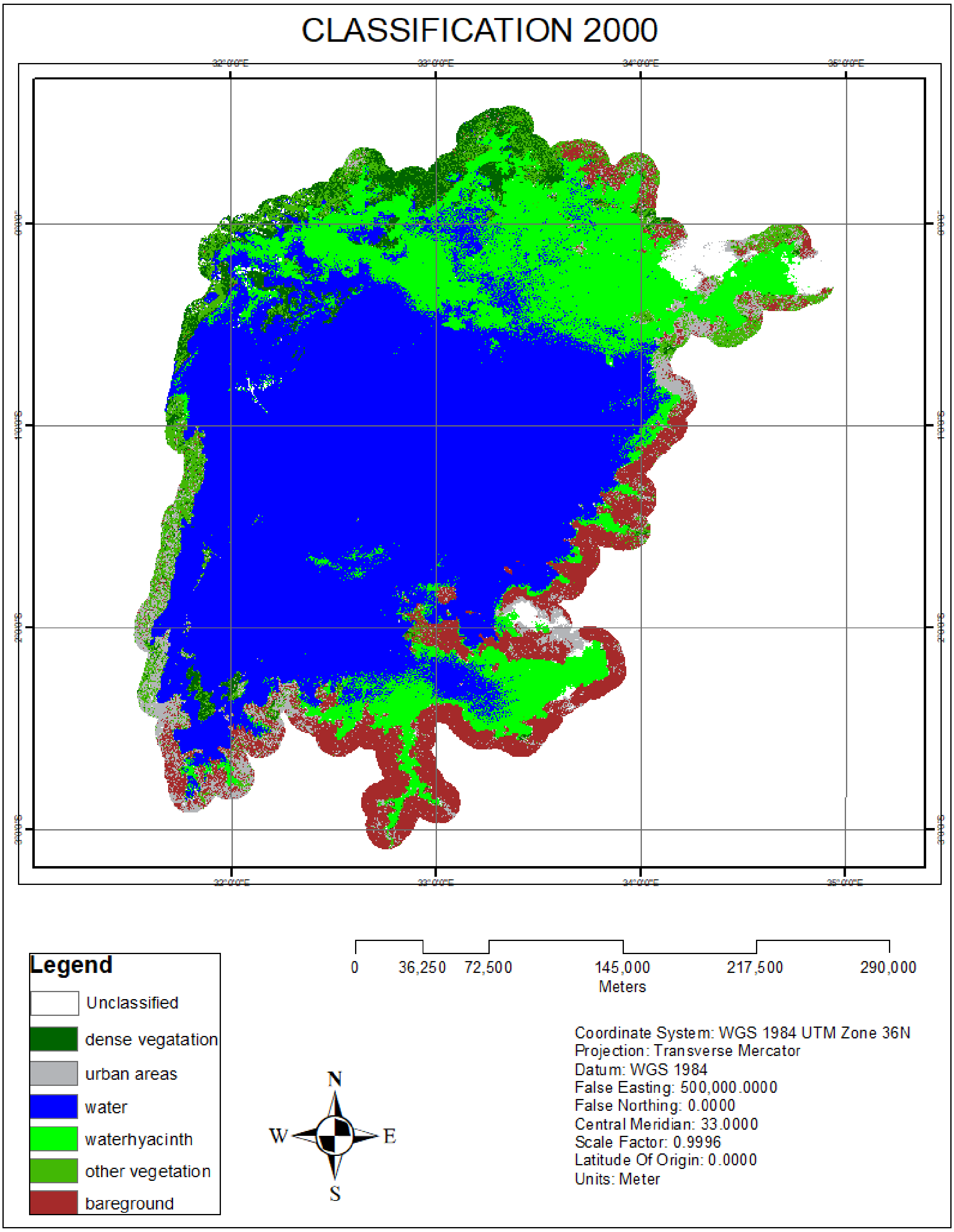

Figure 5 Classification map of 2000 image

4.1.4 Classification Map of 2004 image

The year 2004 saw a drop-in water hyacinth levels as compared to the year 2000 but these levels were still high as water hyacinth still occupied a larger portion of the shores of Lake Victoria in the north as shown in Figure *6*.

Water hyacinth tends to be more in the Winam Gulf. This trend is observed from the year 1996. This could be possible because most pollution occurs in this part of the lake or the winds could have blown the floating plant to this side of the lake.

The urban areas were almost at the same level to the previous year (2000).

Figure 6 shows the classification mapfor the image of the year 2004.A summary of classes and their respective areas obtained from the 2004 image are shown in table 5(a) and table 5(b) shows the confusion matrix of the classification results.

Table 5(a) summary of classification of 2004 image

Class name	Area in km^2
Water	51100
water hyacinth	11192
Built-up areas	3608
Bare ground	6694
Other vegetation	11551
Total	84145

Table 5(b) Confusion matrix for classified 2004 image

Table

conf_2004_new2

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
1	C_1	156	7	0	0	0	0	163	0.957055	0
2	C_2	8	28	0	0	0	0	36	0.777778	0
3	C_3	0	1	6	0	0	3	10	0.6	0
4	C_4	1	0	0	7	2	2	12	0.583333	0
5	C_5	0	0	1	3	13	5	22	0.590909	0
6	C_6	0	0	1	3	3	30	37	0.810811	0
7	Total	165	36	8	13	18	40	280	0	0
8	P_Accuracy	0.945455	0.777778	0.75	0.538462	0.722222	0.75	0	0.857143	0
9	Kappa	0	0	0	0	0	0	0	0	0.767137

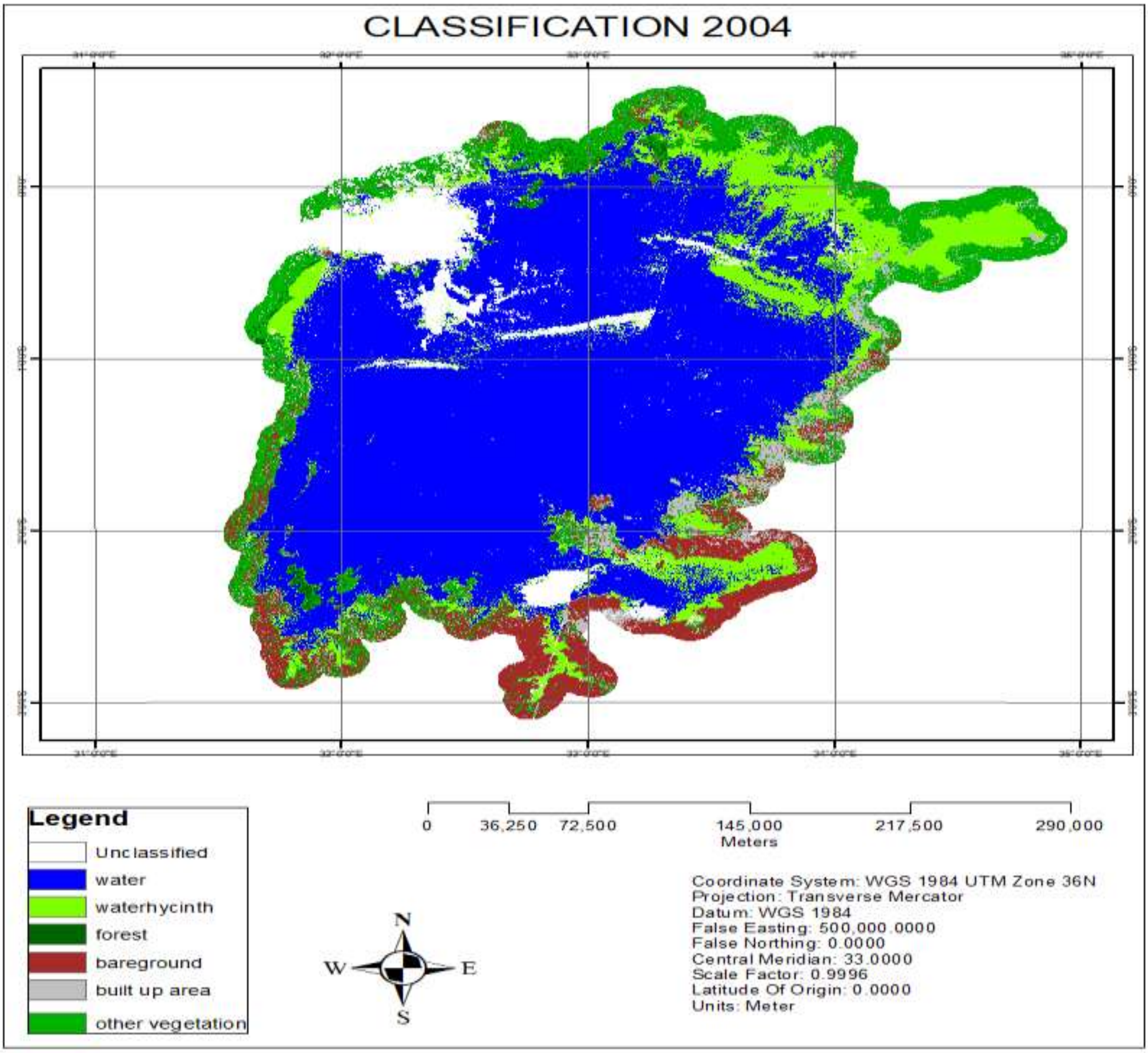

Figure 6 Classification map of 2004 image

4.1.5 Classification map of 2008 image

This year also saw a drop-in water hyacinth especially in the northern part of Lake Victoria. Winam gulf was still covered with water hyacinth. Parts of southern Lake Victoria were also still covered by water hyacinth. This is the period where technology was revolutionizing the world and probably had an influence in the reduction of water hyacinth in Lake Victoria possibly through the adoption of environment-friendly technology by people around the lake.

Figure 7 shows the classification map of 2008 image. A summary of classes and their respective areas obtained from the 2008 image are shown in table 6(a) and table 6(b) shows the confusion matrix of the classification results.

Table 6(a)summary of classification of 2008 image

Class name	Area in km^2
Water	56680
Water hyacinth	8878
Built-up areas	4335
Bare ground	4044
Other vegetation	10208
Total	84145

Table 6(b) Confusion matrix for classified 2008 image

Table

conf_2008

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_7	Total	U_Accuracy	Kappa
1	C_1	173	14	0	0	0	0	187	0.925134	
2	C_2	1	21	0	0	0	0	22	0.954545	
3	C_3	0	0	10	0	0	0	10	1	
4	C_4	0	0	0	7	3	0	10	0.7	
5	C_5	2	1	0	1	7	3	14	0.5	
6	C_7	0	1	2	9	9	29	50	0.58	
7	Total	176	37	12	17	19	32	293	0	
8	P_Accuracy	0.982955	0.567568	0.833333	0.411765	0.368421	0.90625	0	0.843003	
9	Kappa	0	0	0	0	0	0	0	0	0.73026

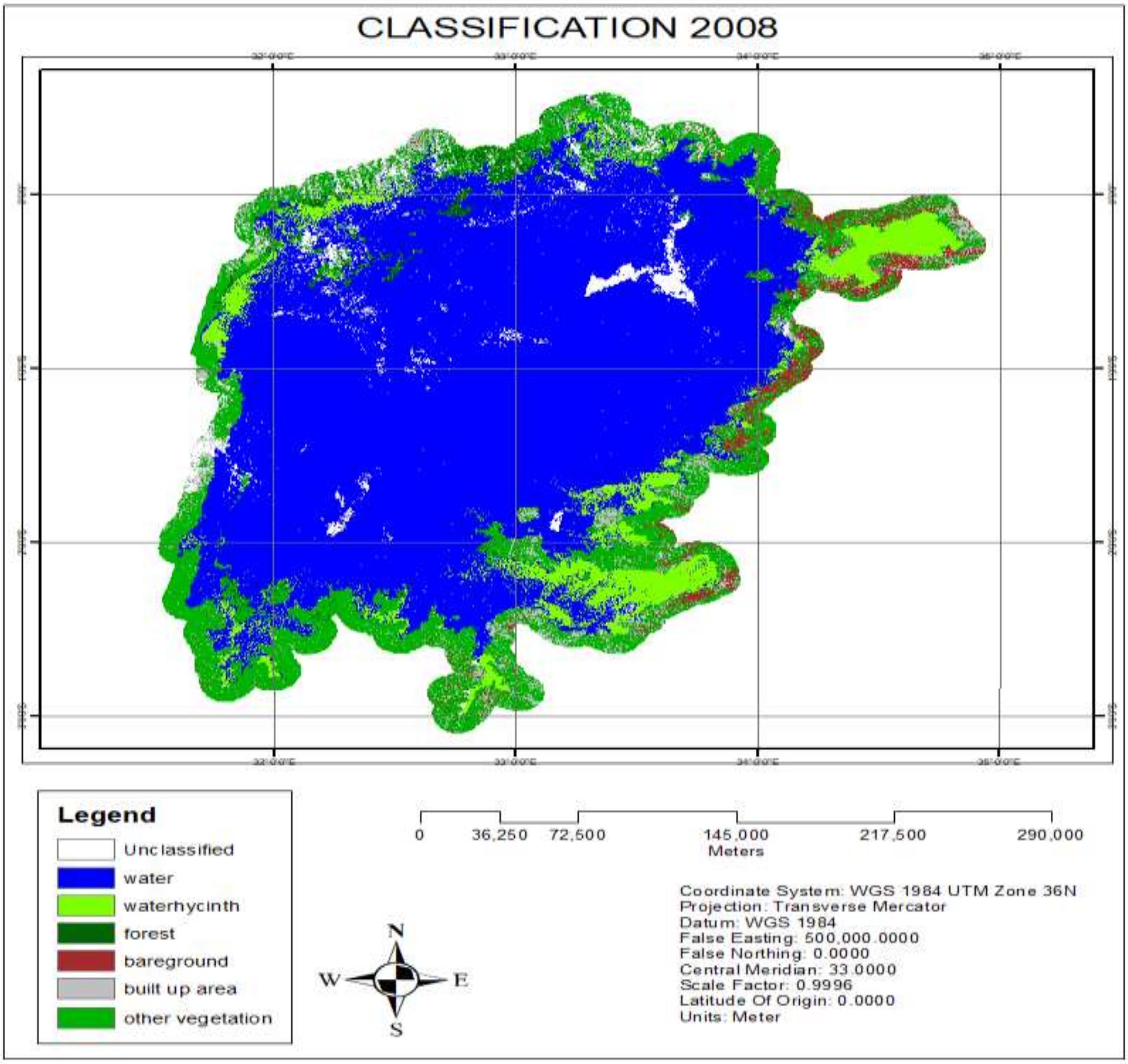

Figure 7 Classification map of 2008 image

4.1.6 Classification map of 2012 image

Classification from 2012 shows the same trend identified earlier of water hyacinth covering most part of the Winam Gulf. Water hyacinth is also seen to have covered most of the eastern shores of Lake Victoria as well as parts of the western shoreline of Lake Victoria.

The area covered by built-up areas was almost the same as the area covered by the same in 2008.This is probably because urban areas were developing outside the 10 kilometres radius from the shores of Lake Victoria.

Figure 8 shows the classification map of 2012 image. A summary of classes and their respective areas obtained from the 2012 image are shown in table 7(a) and table 7(b) shows the confusion matrix of the classification results.

Table 7(a)summary of classification of 2012 image

Class name	Area in km^2
Water	57277
water hyacinth	7602
Built-up areas	4064
Bare ground	6032
Other vegetation	9170
Total	84145

Table 7(b)Confusion matrix for classified 2012 image

Table

conf_2012

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
1	C_1	175	0	0	0	13	0	188	0.930851	0
2	C_2	0	6	0	4	0	0	10	0.6	0
3	C_3	0	0	19	2	0	5	26	0.730769	0
4	C_4	0	0	4	22	0	4	30	0.733333	0
5	C_5	1	0	0	0	24	0	25	0.96	0
6	C_6	0	0	0	2	0	11	13	0.846154	0
7	Total	176	6	23	30	37	20	292	0	0
8	P_Accuracy	0.994318	1	0.826087	0.733333	0.648649	0.55	0	0.880137	0
9	Kappa	0	0	0	0	0	0	0	0	0.793256

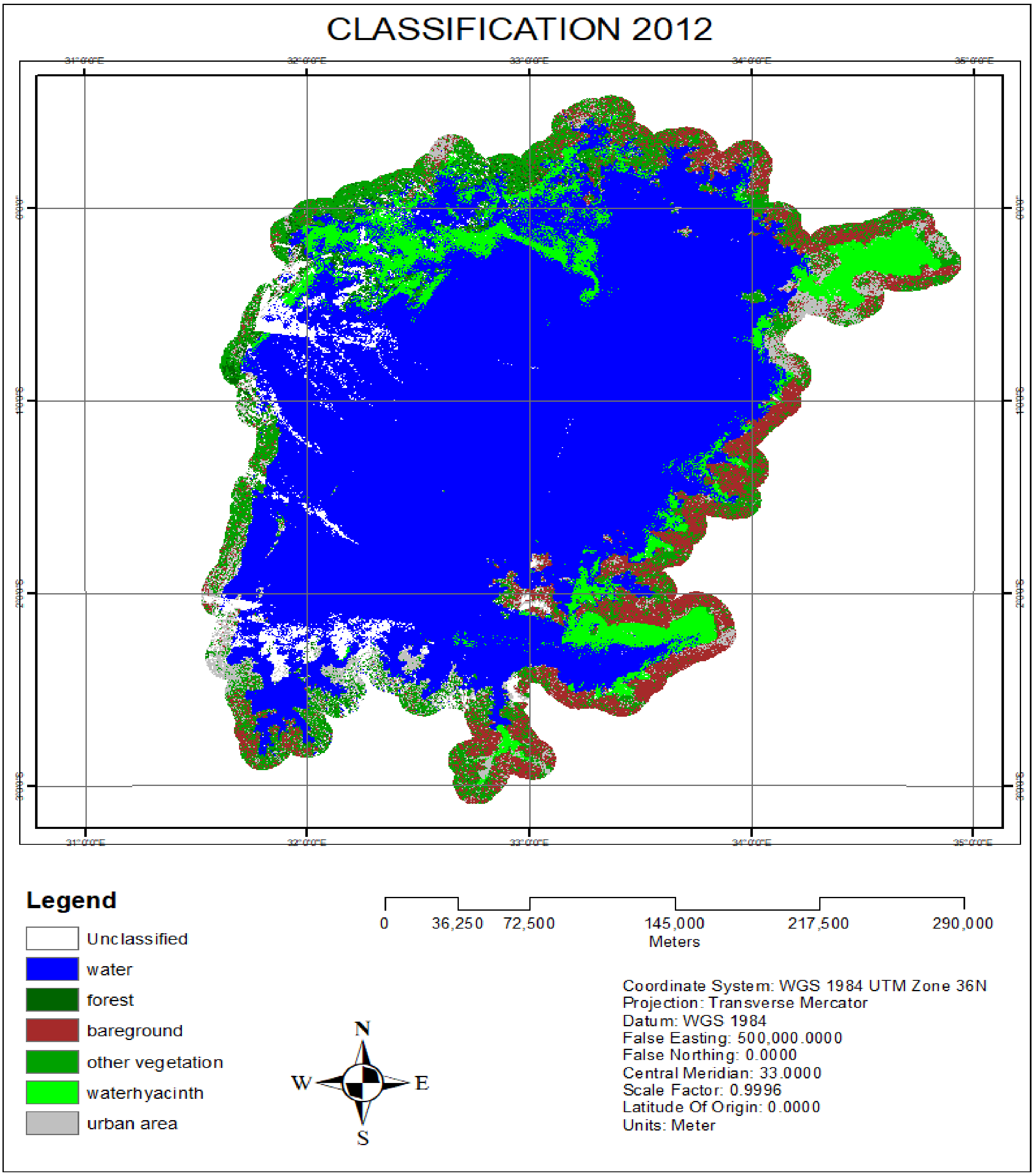

Figure 8 classification map of 2012

4.1.7 Classification map of 2016 image

2016 shows a slight decrease in water hyacinth coverage on the shores of Lake Victoria but still covers almost the whole of Winam Gulf.

The area covered by built-up areas was almost the same to the previous year. This is probably the expansion of urban areas was away from the lakeside.

Figure 9 shows the classification map of 2016 image. A summary of classes and their respective areas obtained from the 2016 image are shown in table 8(a) and table 8(b) shows the confusion matrix of the classification results.

Table 8(a) summary of classification of 2016 image

Class name	Area in km^2
Water	60762
water hyacinth	4153
Built-up areas	5828
Bare ground	3213
Other vegetation	10189
Total	84145

Table 8(b) Confusion matrix for classified 2016 image

OBJECTID *	ClassValue	C_1	C_2	C_3	C_4	C_5	C_6	Total	U_Accuracy	Kappa
1	C_1	183	13	0	0	0	0	196	0.933673	0
2	C_2	2	11	0	0	0	0	13	0.846154	0
3	C_3	0	0	18	1	0	0	19	0.947368	0
4	C_4	0	2	1	8	0	2	13	0.615385	0
5	C_5	0	0	0	1	9	0	10	0.9	0
6	C_6	1	1	5	2	4	20	33	0.606061	0
7	Total	186	27	24	12	13	22	284	0	0
8	P_Accuracy	0.983871	0.407407	0.75	0.666667	0.692308	0.909091	0	0.876761	0
9	Kappa	0	0	0	0	0	0	0	0	0.765461

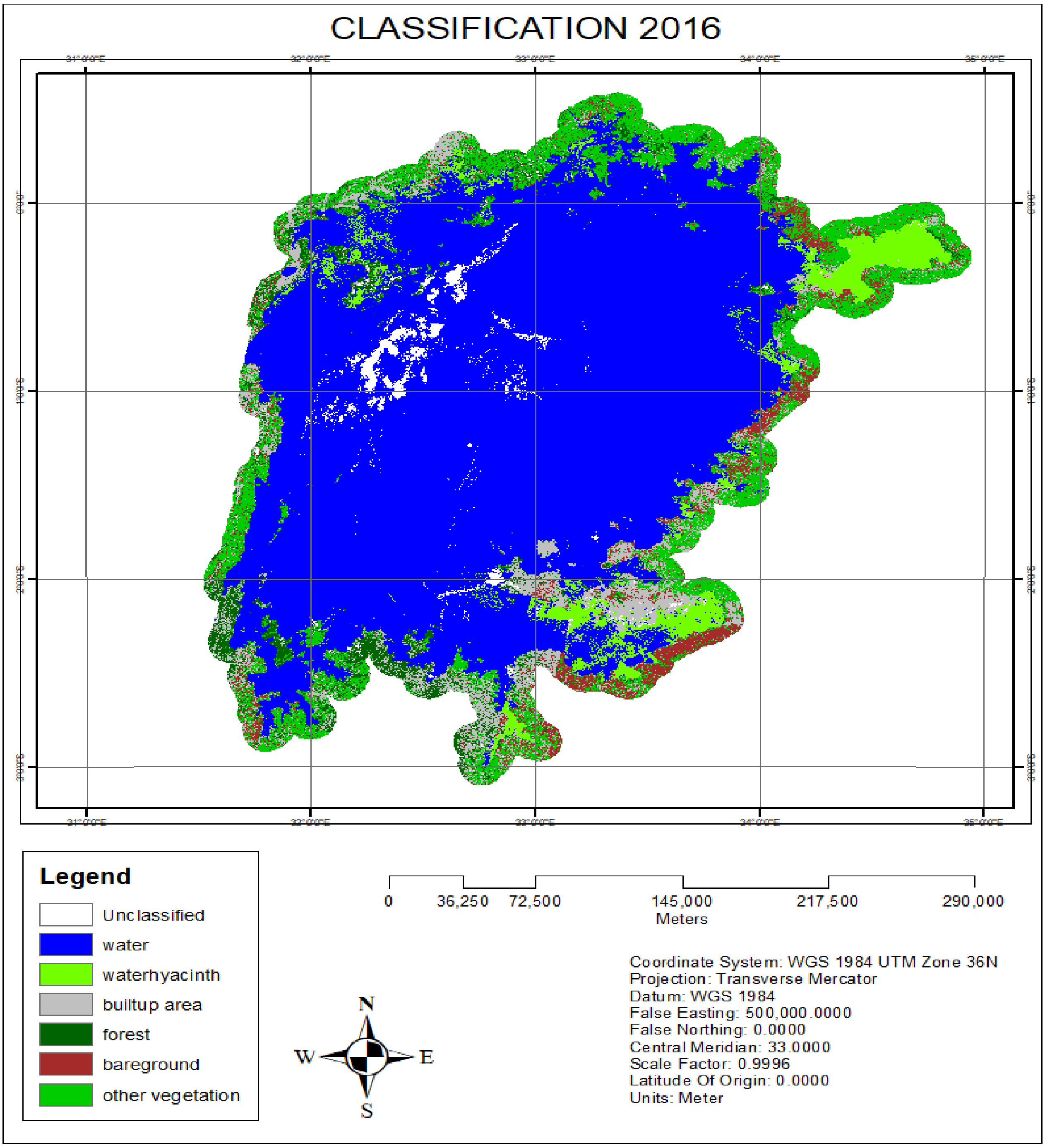

Figure 9 Classification map of 2016 image

A summary of how water hyacinth and urban areas have changed from 1988 to 2016 is shown in table 9, and the graphical representation is shown in figure 10.

Table 9: Comparison of areas covered by water hyacinth and built up area in different years

(Area in km^2)

	Water hyacinth	Built up Area
1988	2846	1507
1996	7713	2755
2000	19122	4295
2004	11192	3608
2008	8878	4335
2012	7602	4064
2016	4153	5828

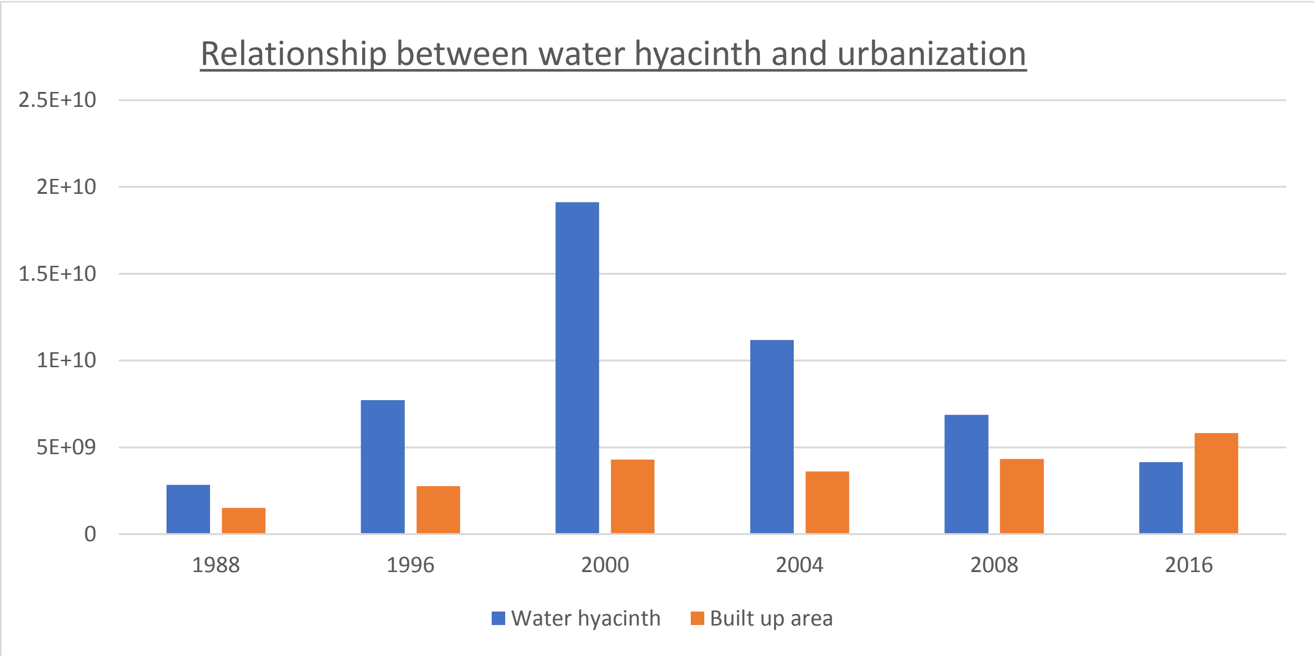

Figure10 Water hyacinth, urban areas graph (Area in m^2)

4.2 NORMALIZED DIFFERENCE VEGETATION INDEX

In this study, NDVI has been employed to help determine where water hyacinth flourishes more. NDVI ranges from -1 to 1 with -1 being pure water pixel ,0 being bare ground and dry vegetation and 1 being healthy vegetation on the ground. Water hyacinth lies somewhere in between -1 and 0 because it is on water and therefore would cause NDVI on water to tend towards 0.

For this reason, reclassification was necessary to be able to clearly visualize water hyacinth on water since the NDVI values are so closely spaced making difficult to visualize water hyacinth on maps using small scales maps covering large areas.

The method used to reclassify the NDVI to highlight water hyacinth was to identify the highest value of water hyacinth and the lowest value of water hyacinth, below the lowest value, was classified as water and above the highest value was classified as terrestrial vegetation (bare ground and other vegetation)

Below are the NDVI maps of Lake Victoria for the years 1988,1996, 2000,2004,2008,2012 and 2016.

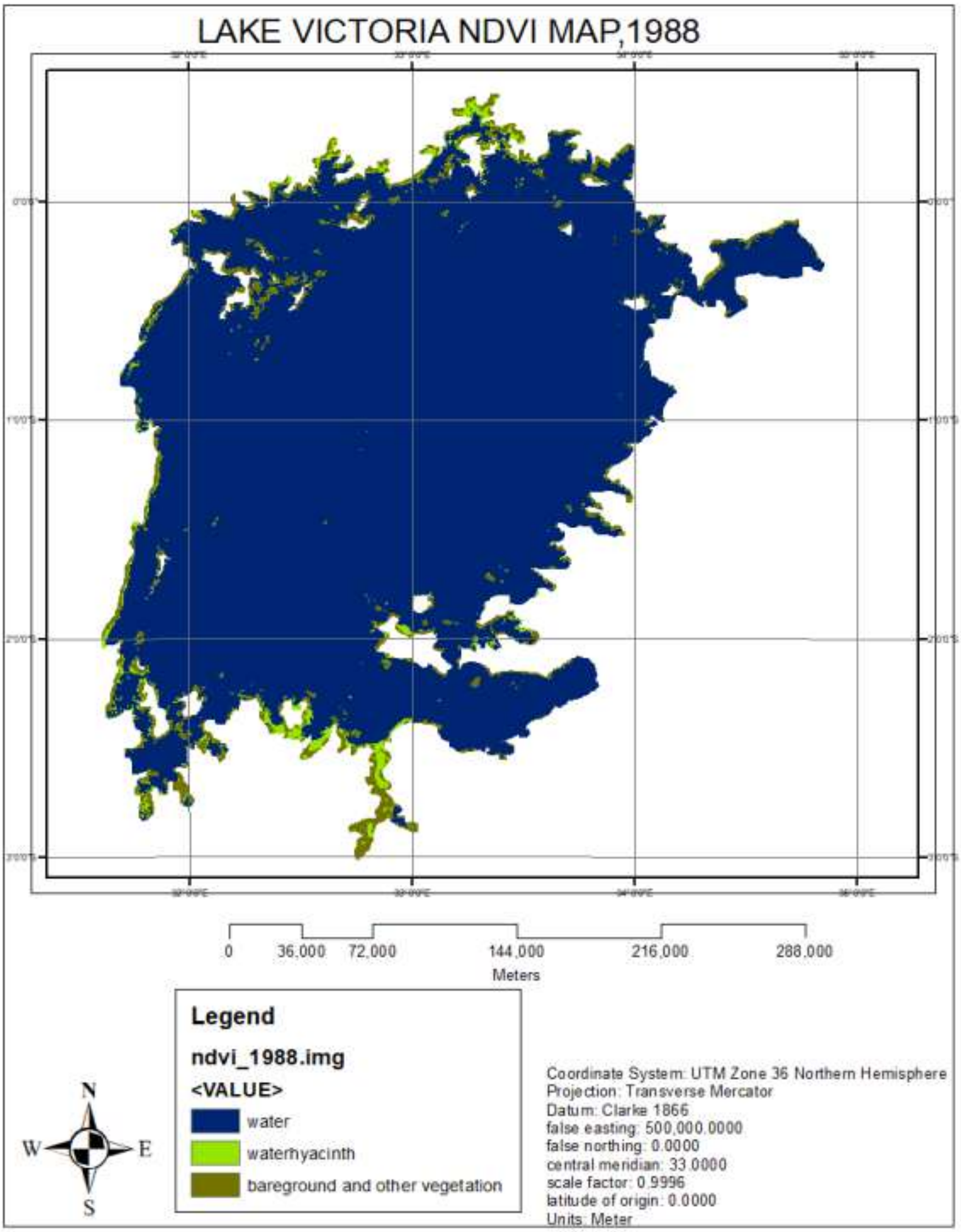

Figure 11 NDVI 1988

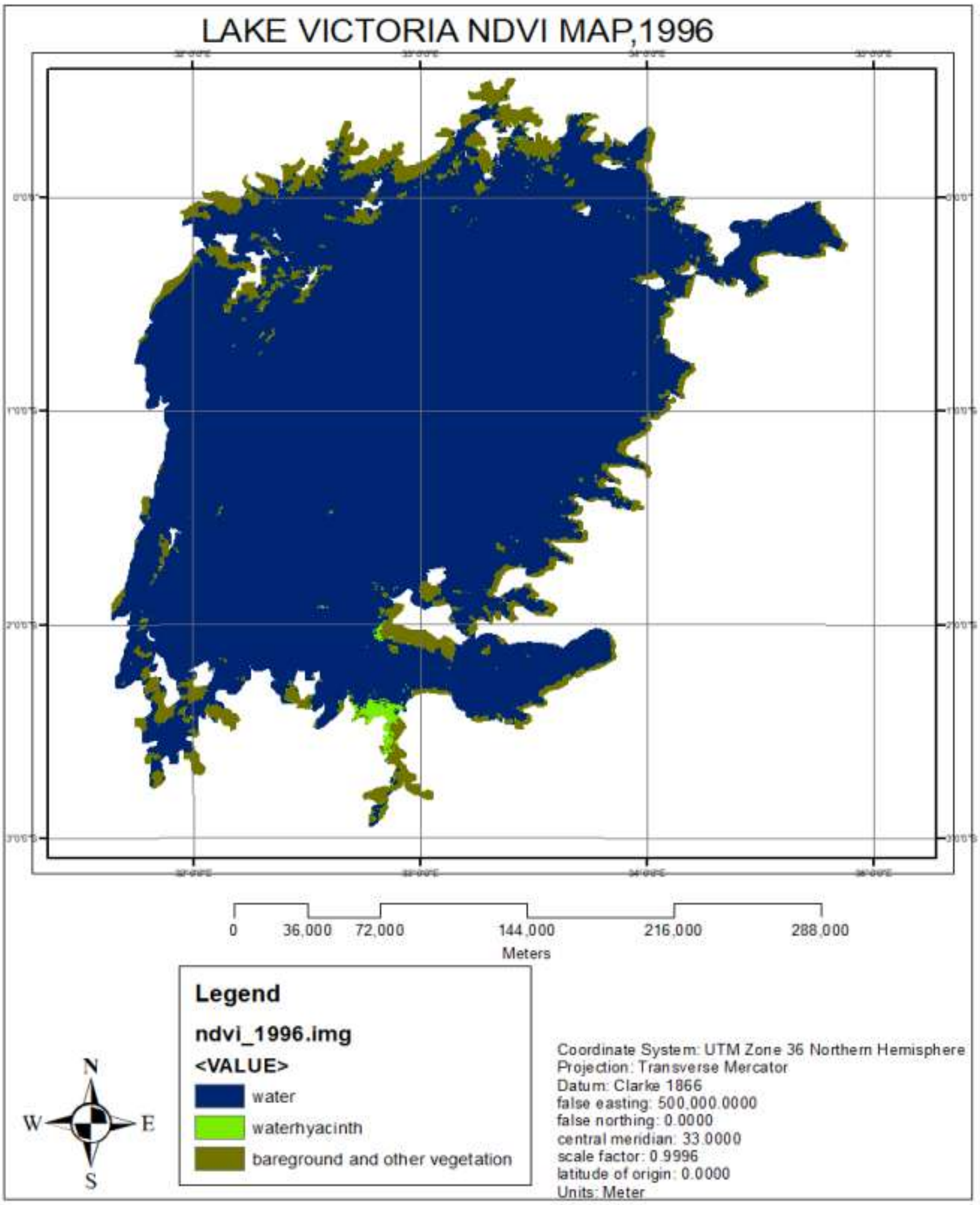

Figure 12 NDVI 1988

4.2.1 NDVI ,1988

In 988, NDVI analysis shows that water hyacinth flourished mostly on the southern and northern areas of the lake. This trend can be explained possibly because water hyacinth was introduced into Lake Victoria through river Kagera from Rwanda. River Kagera flows into Lake Victoria from the south. This way the water hyacinth was more concentrated in the southern area at this period.

During this period, the level of pollution was relatively low as the level of urbanization was relatively low, since urbanization is the common source of various causes of pollution, especially water and soil pollution which eventually enters the lake. Figure 11 shows NDVI map for 1988.

4.2.2 NDVI, 1996

During this period, water hyacinth nourished in the southern part and not in the northern part as observed earlier in 1988. This may be possibly explained by the EL NINO rains experienced by countries along the equator around this period. Figure 12 shows NDVI map for 1996.

EL NINO rains must have increased inflow volumes of rivers feeding the lake, river Kagera included. With increase in the amount of water flowing into the lake through the rivers, much volume must have as well been realized in the outflow. This must have caused the southern part of the lake to contain favorable conditions for water hyacinth flourishing than the northern part.For this reason, water hyacinth seems not to thrive in the northern part of Lake Victoria.During this period, the level of pollution was on the rise as urbanization was also on the rise as well.

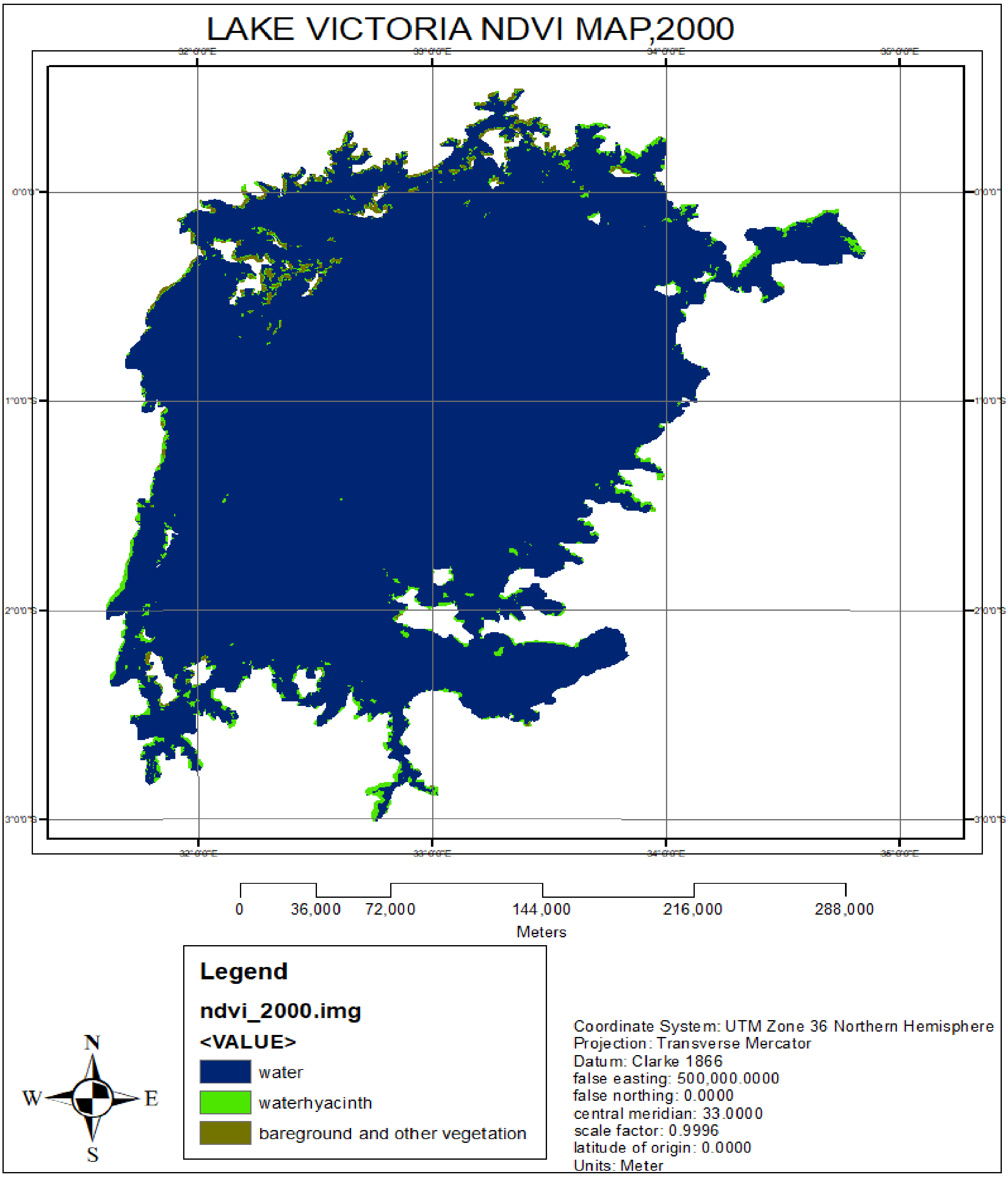

Figure 13. NDVI 2000

4.2.3 NDVI ,2000

By the year 2000, urban towns had already developed thus attracting migration from rural areas as people search for employment and business opportunities. This led to an increase in population in the urban area. With the increase in population, there came an increase in pollution which eventually ended up in the lake through rivers and other channels. This explains why the NDVI of water hyacinth is high near the shores of Winam Gulf, the northern part of Lake Victoria, and parts of Tanzanian shoreline. Figure 13 shows NDVI map for 2000.

4.2.4 NDVI, 2004

Since the population was still in the increase during this period, industries, businesses and other money generated activities were on the increase. This also led to an increase in pollution especially in areas near Winam gulf as shown by high NDVI near and in Winam Gulf. Figure14 shows NDVI map for 2004.

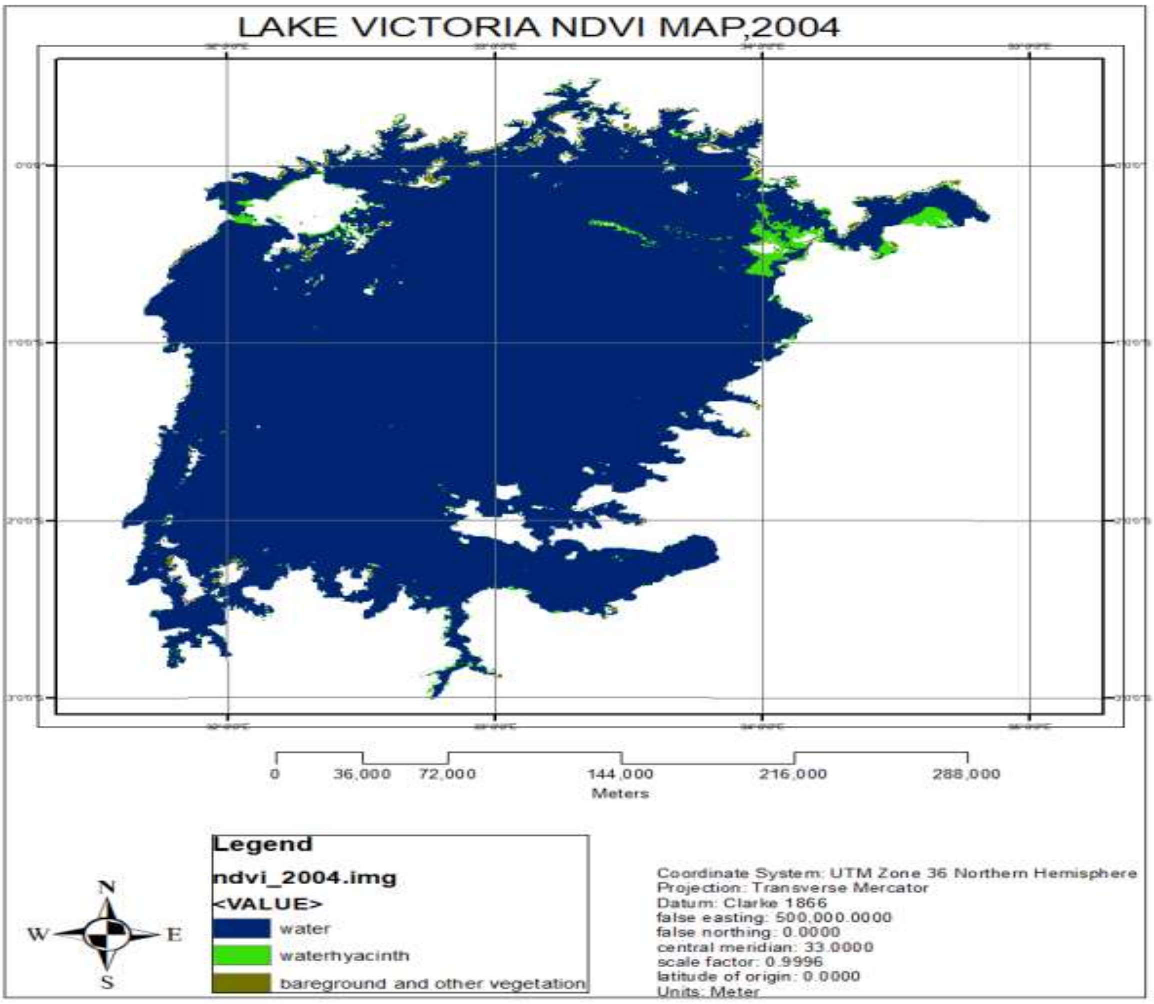

Figure 14 NDVI 2004

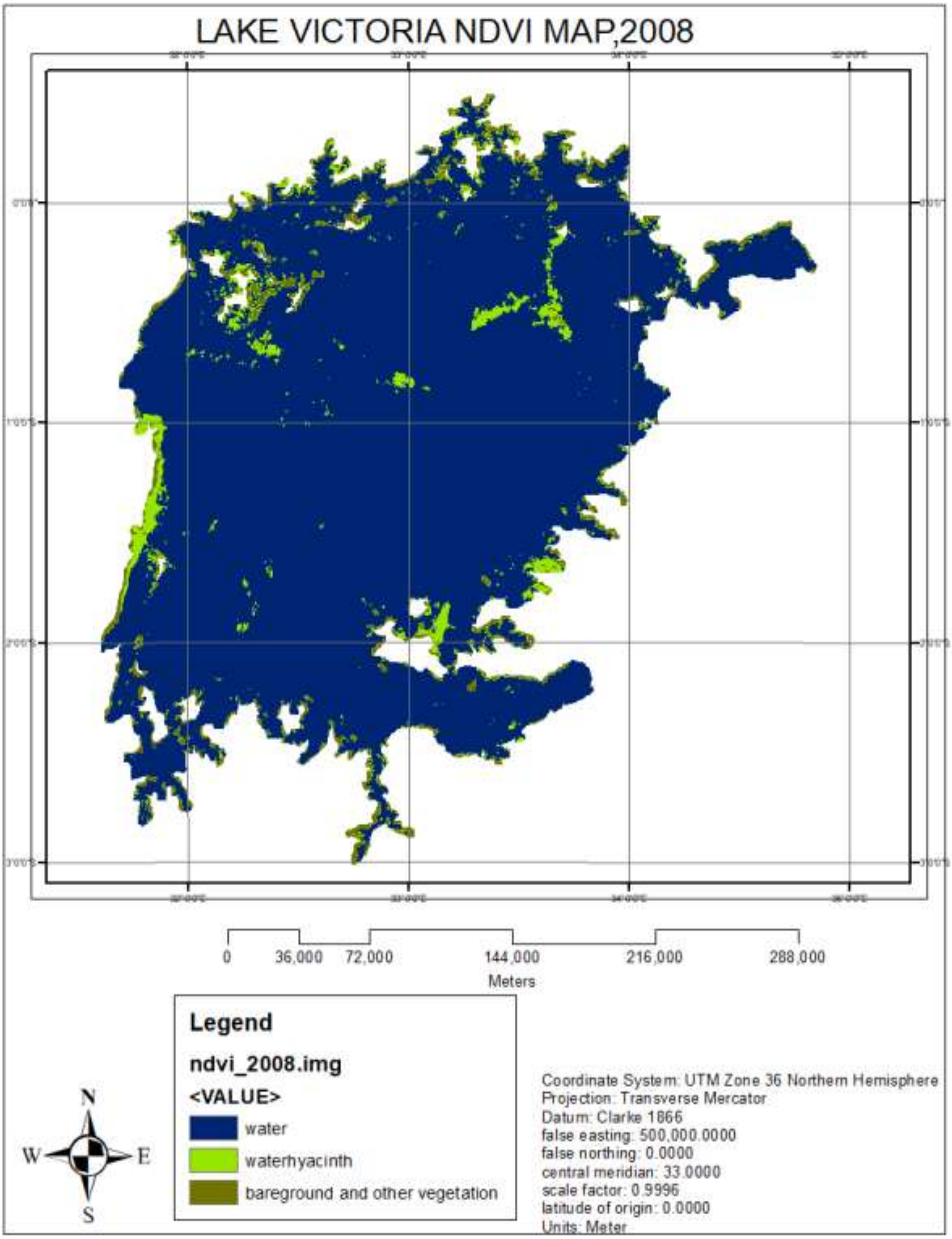

Figure 15 NDVI 2008

4.2.5 NDVI 2008

The NDVI map for the year 2008, as shown in figure 15, shows a larger area covered by healthy water hyacinth. This trend might be attributed to an increase in water pollution especially since within this period is when agriculture (irrigation) was at its peak in areas surrounding the lake. High levels of pollution might have been caused by use of fertilizers during the rainy season or increased in other pollutants in the due to otherhuman activities from the human settlements (urban areas) around the lake. Figure 15 shows NDVI map for 2008.

4.2.6 NDVI 2012

The NDVI map for 2012 shows reduced area covered by healthy water hyacinth plant. This does not mean that there was reduced coverage by the weed in Lake Victoria. The NDVI shows that water hyacinth thrived more in areas adjacent to the shores of Lake Victoria. This is most likely because pollution has a high impact on water hyacinth on the shores than those far away from the shores. Figure 16 shows NDVI map for 2012.

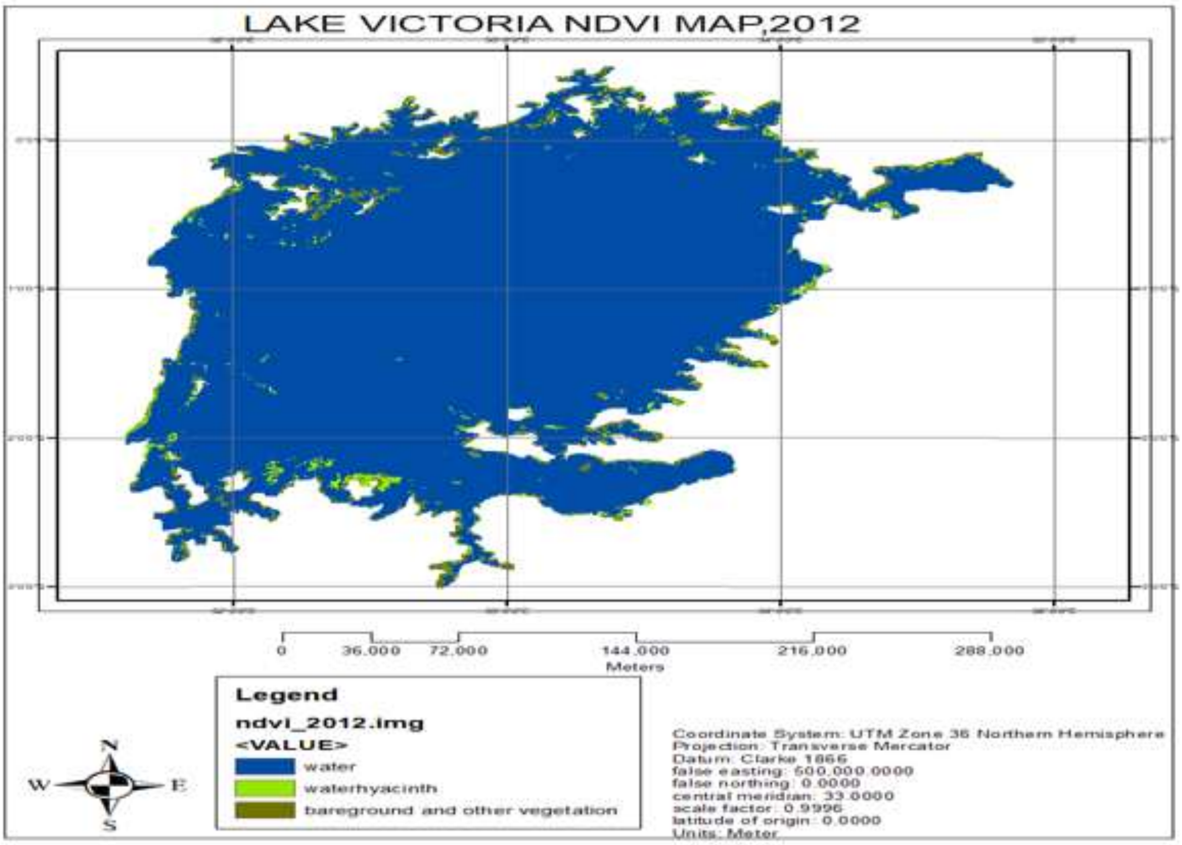

Figure 16: NDVI 2012

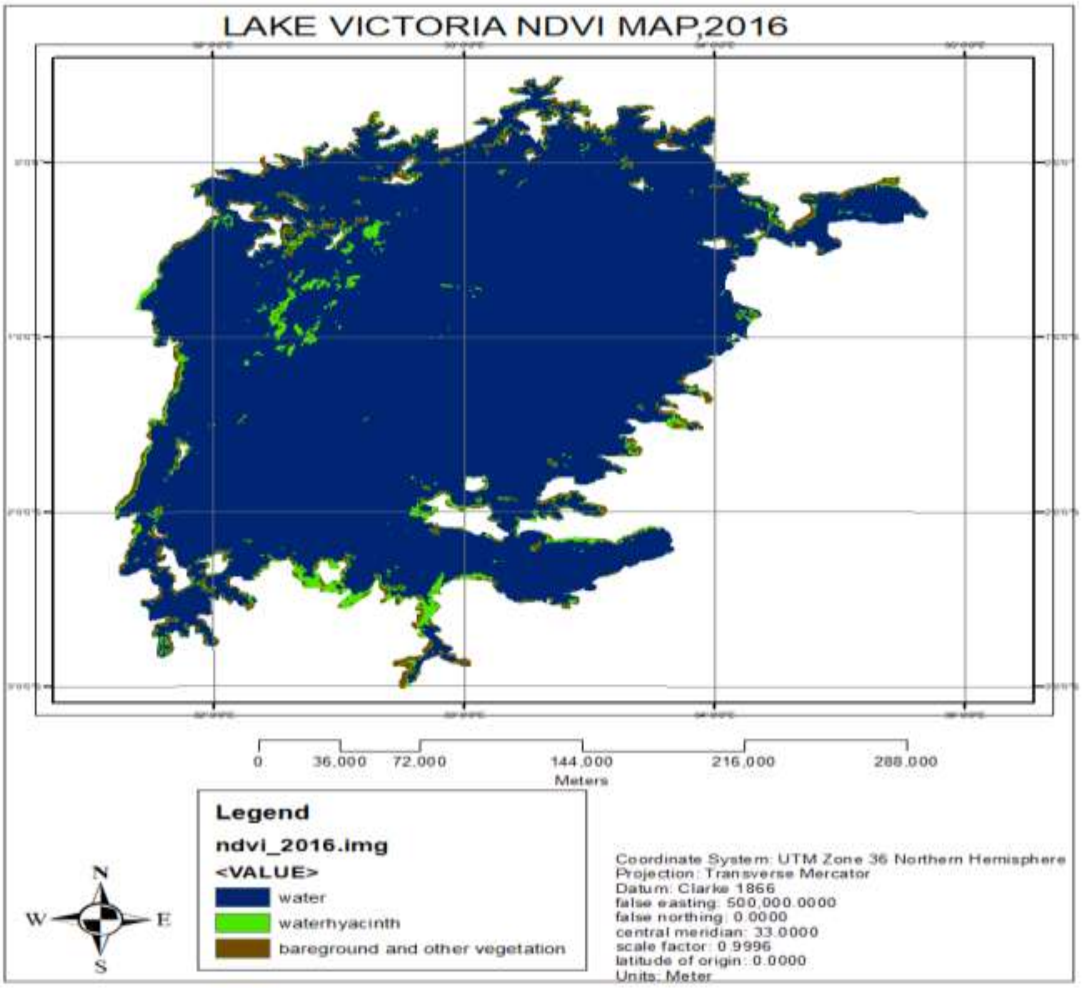

Figure 17. NDVI 2016

4.2.7 NDVI 2016

The NDVI still shows a consistent trend of identifying healthy water hyacinth near the shores of Lake Victoria.2016 was a year that saw the development of technology, especially in the manufacturing industry. This led to an increase in pollutants related to technology. The affected areas include Winam gulf, shores of Tanzania and Ugandan shoreline as well. Figure 17 show NDVI map for 2016.

4.4 POLLUTION FLOW INTO LAKE VICTORIA

Lake Victoria mostly receives pollution from the adjacent areas both in solid waste form disposed of in rivers, disposed directly in the lake and those carried into the lake by other channels and surface runoff or liquid waste dissolved in rivers and surface runoff. Solid pollutants are the most common in urban areas and some contain chemicals which dissolve in water and thus might have a direct influence on the growth and flourishing of water hyacinth.

There are also other sources of pollution that cannot be clearly visualized and analyzed by remote sensing. These include the introduction of car washes at the lake's shores. An example is car washes in Kisumu at the shores of Lake Victoria near the famous "Lwang'ni Hotel" and Dunga beach. This activity introduces foreign materials which are contents of petroleum into the lake.

Figure 1*8* shows possible pollution flow channels into Lake Victoria.

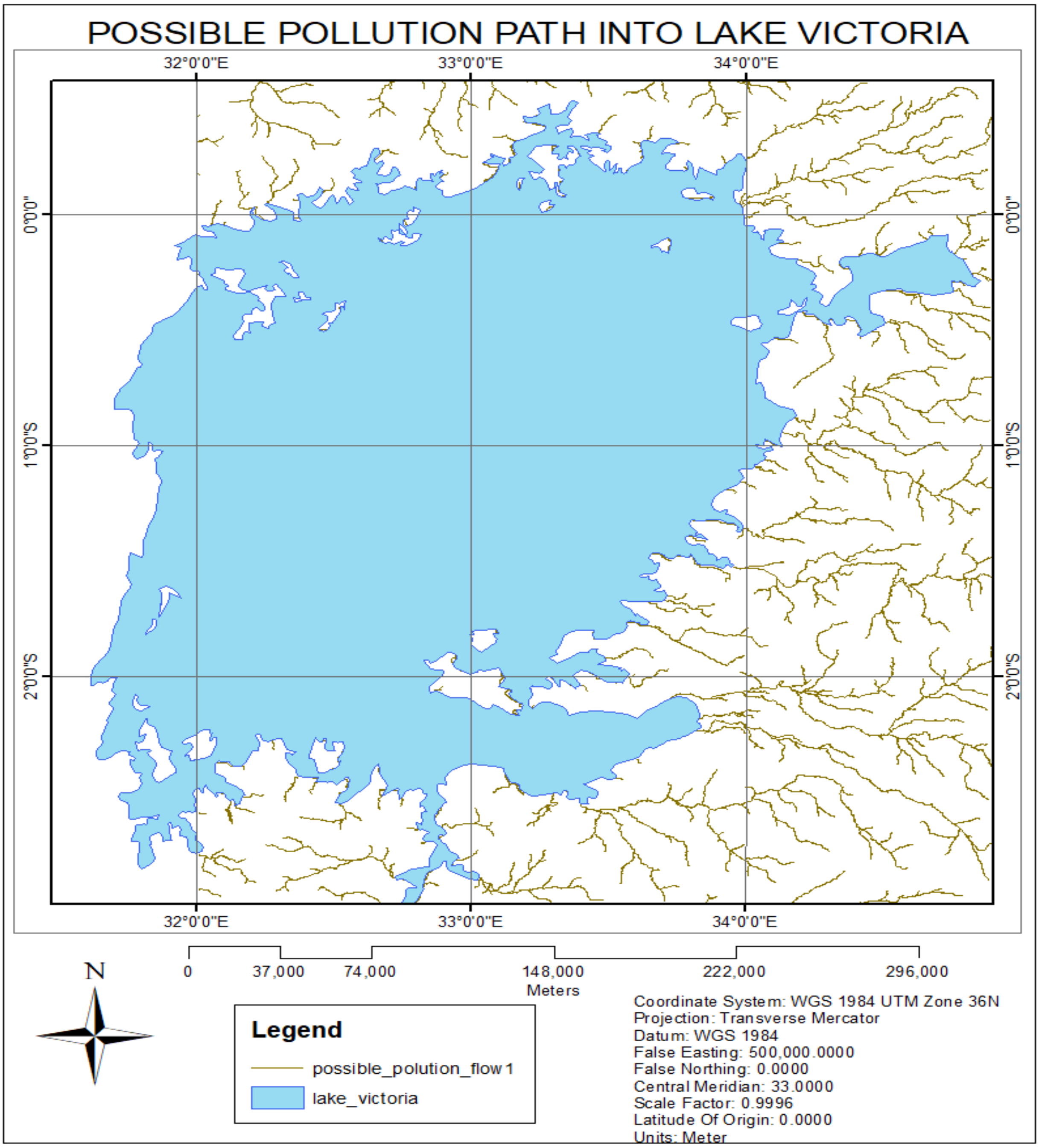

Figure 18 Possible pollution flow channels into Lake Victoria

4.4 Prediction map

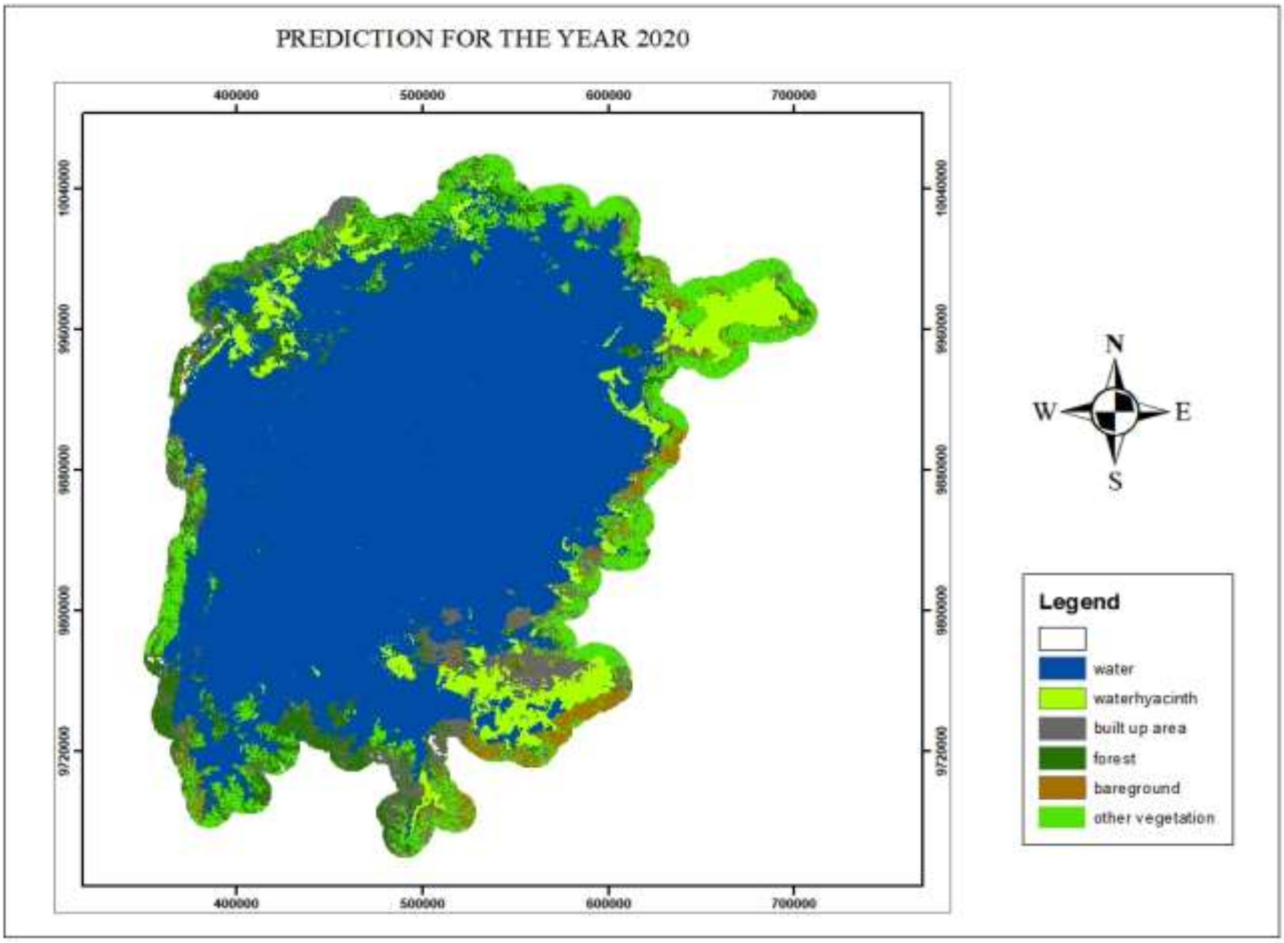

Figure 19. Prediction map for 2020

Using TerrsetIdrisiselva remote sensing software, it is possible to predict future trends using this tool. The Marcov predictor indicates that water hyacinth will remain in the Winam Gulf, and parts of Ugandan shoreline. This is most likely because these areas will experience increase in population which will increase population density. Since planning was not included in the previous years, there is a low probability that it will be included in the upcoming developments and even if included, its effect will be minimal if not negligible.

Predicting water hyacinth for long periods tend to be inaccurate as water hyacinth is affected by human factors, environmental and climatic factors. Human factors are usually from within the lake region and can be controlled whereas climatic factors cannot be easily controlled even at the small region level as it takes a long time for the climate to change and by then it is almost irreversible.

Figure 19 shows prediction map of water hyacinth coverage in the year 2020.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Research finding summary

The classification of Lake Victoria and the surrounding mainland reveal that water hyacinth mainly occupies the shores of Lake Victoria. The most affected part is the Winam Gulf. The Winam Gulf has been occupied by water hyacinth since the year 1996 to date. The most closest town to Winam Gulf is Kisumu town whose population has been on the rise.

The Winam also serves as an inlet channel to the lake for rivers Kisat, Nyamasaria, Nyando, Sondu-Miriu, Kuja, Awach, Yala, and Nzoia. These rivers have been introducing foreign materialscollectivelytermedaspollutants mostofwhichhaveadirectinfluenceofthegrowth and flourishing of waterhyacinth.

These rivers bring with them both solid, dissolved minerals and other occasional wastes introducedintotheriverchannelswhenitrains.Occasionalpollutionintroducedintotherivers is mainly due to poor or insufficient drainage systems, poor planning and poor waste management by towns and centers where these riverspass.

Classification of remote sensing images from 1988 to 2016 shows that urban areas have been increasing steadily until it reached a point where there is almost zero change in urban areas. This is probably because of the need for space for expansion not provided for by thelake.

Water hyacinth has been increasing from1988 to around the year 2000. There was a significant reduction in 2004 because of the introduction of mechanical harvester in the year 2002.The NDVI trends for water hyacinth show that water hyacinth is healthier near the shores of Lake Victoria and also at the point of contact with the pollution paths in Victoria. This trendshows how the spread of water hyacinth has been propelled by pollutants draining into Lake Victoria.

5.2 Conclusions

From the classification results and NDVI results it can beconcludedthatgrowth of urban centers aroundthelakehassomelevelofinfluenceonthegrowthandspreadof water hyacinth. This is because the most affected areas by water hyacinth are close to major towns.

The pollution is mostly from the towns as indicated by the decrease in water qualityidentified by previous studies. In Kenya and Uganda, urban centers are found surrounding the Lake within a buffer of 15 km.Since these towns are densely populated, poor planningandpoormanagementofbothsolidwasteandseweragewaste,variouspollutantsfind their way into thelake.

Pollution from areas far from the lake but close to the rivers also contributes to pollution. An exampleisriversKisatandNyamasariawhicharepollutedalongtheircourseandthispollution finally ends up into thelake.

It is clearly shown in the NDVI values that the water hyacinth is healthier near the inlets and shores of major towns. This must have been contributed to by water carrying pollutants from the urban areas into the lake.

5.3 Recommendations

Since pollution is the identified factor that facilitates water hyacinth growth, therefore towns which are near the lake should improve on their waste management so as to reduce pollutants entering the lake. Industries should also adopt green technology to do away with industrial effluence that introduces chemical pollutants into the lake. It is also recommended that industries adopt rehabilitation measures on used water before releasing back into the river channels. This is aimed at reducing the heavy metals in the lake and rivers as well. This study recommends that further studies should be conducted to identify ways of rehabilitating the lake and rivers from the already presentpollutants.

The weevils that were introduced into Lake Victoria in the 1990's worked for some time until it attained ecological equilibrium. It is recommended that a combination of both biological and mechanical method is carried out for the whole lake. This together with rehabilitating both the lake and the inflowing rivers, managing the solid waste and improving on the sewerage systems to minimize the leaks of pollutants into the lake, could help reduce the spread of water hyacinth in LakeVictoria.

The mechanical removal method should also be further looked into to see if a mechanical designcanbeachievedtoremovethewaterhyacinthfromsomedepthandatthesametimebe able to collect the cut water hyacinth to minimize the chances of water hyacinth multiply asexually.

REFERENCES

Albreight, T. P., Moorhouse, T. G., & McNabb, T. J. (2004). The Rise and Fall of Water Hyacinth in Lake Victoria and the Kagera River Basin, 1989-2001. *Waterhyacint in lakevictoriaJAPM4220004*, 73-84.

Guerena, D., Neufeldt, H., Berazneva, J., & Duby, S. (2015). Water hyacinth control in Lake Victoria: Transforming an ecological catastrophe into economic, social, and environmental benefits. *gerea2015*, 1-11. doi:http://dx.doi.org/10.1016/j.spc.2015.06.003

Gunnarsson, C. C., & Petersen, C. M. (2007). Water hyacinths as a resource in agriculture and energy production:A literature review. *gurnasson2007*, 117-129.

Juma, D. W., Wang, H., & Li, F. (2014). Impacts of population growth and economic development on water quality of a lake: Case study of Lake Victoria Kenya water. *Environmental Science and Pollution Research*, *21*(8), 5737–5746. https://doi.org/10.1007/s11356-014-2524-5

Lalah, J. O., Ochieng, E. Z., & Wandiga, S. O. (2008). Sources of heavy metal input into Winam Gulf, Kenya. *Bulletin of Environmental Contamination and Toxicology*, *81*(3), 277–284. https://doi.org/10.1007/s00128-008-9452-3

Malik, A. (2007). Environmental challenge vis a vis opportunity: The case of water hyacinth. *malik2007*, 122-138. doi:10.1016/j.envint.2006.08.004

Mailu, A.M (2001). Preliminary Assessment of the Social, Economic and Environmental Impacts of Water Hyacinth in the Lake Victoria Basin and the Status of Control. *mailu2001Eischhornia*, 130-139.

Ongulu Roselyn and Kituyi John, G. Z. (2015). Assessment of the pollution impact in the Winam Gulf. *ongulu2015*, 1374-1386.

Robles, W., Madsen, J. D., & Wersal, R. M. (2015). Estimating the Biomass of Waterhyacinth (Eichhornia crassipes) Using the Normalized Difference Vegetation Index Derived from Simulated Landsat 5 TM. *robles2015*, 203-209. doi:http://dx.doi.org/10.1614/IPSM-D-14-00033.1

Wasiams, A. E., Hecky, R. E., & Duthie, H. C. (2007). Water hyacinth decline across Lake Victoria—Was it caused by climatic perturbation or biological control? A reply. *Aquatic*

Botany, *87*(1), 94–96. https://doi.org/https://doi.org/10.1016/j.aquabot.2007.03.009

Wilson, J. R. U., Ajuonu, O., Center, T. D., Hill, M. P., Julien, M. H., Katagira, F. F., … Van, T. (2007). The decline of water hyacinth on Lake Victoria was due to biological control by Neochetina spp. *Aquatic Botany*, *87*(1), 90–93. https://doi.org/https://doi.org/10.1016/j.aquabot.2006.06.006