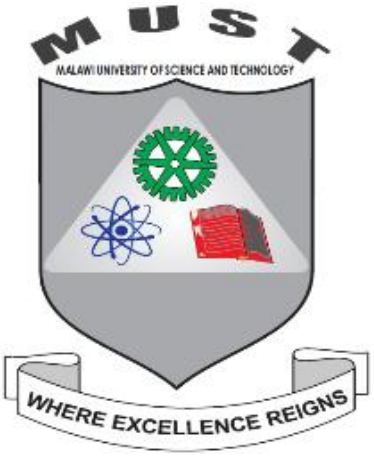


ASSESSMENT OF SEDIMENTATION IN LAKE CHIRWA USING REMOTE SENSING TECHNIQUE

FUNNY MATHINA

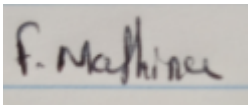
Thyolo, Malawi

Dissertation submitted to Ndata School of Climate and Earth Sciences of the Malawi University of Science and Technology in partial fulfilment of the requirements for the Bachelor of Science degree in Geo information and earth observation science

JULY, 2021

Declaration

I Funny Mathina declare that this research project represents my own work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

Signature 

Date 19/07/2021

DISSERTATION APPROVED BY:

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ASSESSOR:
Title, Initials, Name Signature: _____

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ABSTRACT

Sediment particles originating from erosion processes in the catchment are propagated with the river flow. When the flow of the rivers stores water the sediment settles in the Lake and reduces its capacity. Remote sensing data through its spatial, spectral, and temporal attributes, can provide synoptic repetitive and timely information regarding the revised water spread area in a lake. By using digital image analysis water spread area of the Lake Chilwa was calculated to find how sedimentation in Lake Chilwa has affected the size of the Lake and classification image analysis was used to find how land cover changes around lake Chilwa has affected siltation deposit from 2000 to 2020. The study showed that the water spread area of the lake Chilwa kept on decreasing from 1020726900m^2 to 792852300m^2 for the years 2000 and 2020 respectively due to sediments deposition. The classification results have shown that there is an increase in bare land from 2000 to 2020 around the lake Chilwa which contributed to silt deposition in the Lake.

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ACRONYMS/ABBREVIATIONS

RS : Remote sensing

NDWI : Normalized difference vegetation index

TM : Thematic mapper

USGS : united States Geological survey

QGIS : Quantum GIS

OLI : Operational Land imager

SPC : Sem- Automatic classification plugin

NIR : Near infrared

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1. Introduction

1.1 Background

The erosion of soil results in the transfer of a large number of sediments to watercourses. When this sediment enters a reservoir, the coarser particles begin to deposit in the upper reaches of the reservoir due to a decrease in flow velocity. While the fine materials are deposited further downstream along the reservoir bed (Sharad k and Sanjay k, 2009). The rate and pattern of sediments deposition depend on several factors, including the size and texture of the sediments particles, the characteristics of the reservoir outlets, the size and shape of the reservoir, and its operating schedule (Sharad k and Sanjay k, 2009). In Malawi, Lake Chilwa is one of the lakes experiencing sedimentation problems.

Lake Chilwa is the second largest lake In Malawi. It is a shallow lake, saline and notexceeding 6 m depth at peak water levels. Because of its shallowness, nutrient recyclingis efficient, making Lake Chilwa one of the most productive lakes in Africa (Chiotha1996). The lake is a center of sustenance and commerce, supporting 335 villages with over 60 000 inhabitants who participate in the thriving fishing industry. Additionally, the waters of Lake Chilwa are essential to local agriculture, especially as local farmers adjust to climate change. The lake has no outlet. Within recorded history, Lake Chilwa has dried out on 12 occasions: 1882, 1903, 1913-1916, 1922, 1934, 1948, 1968, 1973, 1995, 2012, and 2018.

One potential method for an operational worldwide capability to identify and monitor suspended sediment concentration in surface waters is satellite remote sensing. Remote sensing techniques, offering data acquisition over a long period and for a broad spectral range, are considered superior to the conventional methods for data acquisition. Spatial, spectral, and temporal attributes of remote sensing data provide invaluable and timely synoptic information regarding (a) changes in the water spread area of the lakes after deposition of sedimentation and (b) sediment distribution patterns in the lakes (Manavalan et al., 1990; Goei & Jain 1996).

1.2 Problem statement

Lake Chilwa contributes very significantly to the availability of water resources for most of the rural communities for the improvement of their livelihood. Lake Chilwa can no longer perform its function because much of its storage has filled up with sediments. The transported silt eventually gets deposited at different levels of a Lake and reduces its capacity. Siltation of the lake is caused by high levels of environmental degradation and deforestation within the lake catchment (Rebelo, 2010).

1.3 Objective of study

The main objective of this study is to assess sedimentation in Lake Malawi using a remote sensing technique.

1.3.1 Specific objective

- To determine the change of size of the lake due to sedimentation using remote sensing technique.
- To evaluate land cover and land-use change detection around the Lake Chilwa that can contribute to massive siltation

1.4 Research questions

- How does sedimentation in Lake Chilwa affect the size of the Lake?
- How does land cover around Lake Chilwa has influenced sedimentation in the Lake?

1.5 significance of study

The process of sedimentation in the reservoirs and the rate of sedimentation are governed by various factors such as land use, topography, lithology, hydrography, and climatic condition of the catchment area of the reservoir. The life span of the lakes, small dams, is governed by the rate of sedimentation, which gradually reduces its storage capacity. The loss in storage capacity affects planning for long-term utilization of water of irrigation, domestic use. To increase the life span of reservoirs

and to use the available storage to optimum is the challenge for the engineers working in the field of water process. However, this study will help people around Lake Chilwa catchment area to take into consideration on harmful activities that lead to siltation of the lake and also it will help the government in giving restriction and rules and regulation on how people can manage the Lake inorder keep its original functionality.

2. Literature review

Many lakes and reservoirs, which are important freshwater resources, are under the threat of sedimentation today which can harm their storage potential and water quality. Today sedimentation in the lakes and reservoirs has become an important issue in sustainable management of water resources as in many areas alarming sedimentation rate has been noticed

2.1 Definition of sedimentation

Different scholars have defined the concept of sedimentation worldwide and in general,sedimentation is defined as the deposition by settling of a suspended material due to gravity. In other words, sedimentation is a result of sediments which are defined as particulate matter that can be transported by fluid flow and eventually are deposited a layer of solid particles on the bed or bottom of water body such as reservoirs (Wikipedia Free Encyclopaedia, 2008).

2.2 Causes of sedimentation

The susceptibility of reservoir sedimentation depends on the sediment delivery of thewatercourses, the retention characteristics of the reservoir, and how the flow is delivered from the natural source to the reservoir (Hal crow, 2001). Hughes and Prosser (2003:12), stating that river erosion is the most uncertain of the sediment sources in terms of river budget modeling. According to the study, it is known that degradation of riparian vegetation and other impacts on the rivers have resulted in greatly increased rates of riverbank erosion, to the extent that this erosion process cannot be ignored as a sediment source in regional assessment

Ainsworth, (2005) states that erosion of the land surface yields sediments that aretransported downstream by rivers and eventually deposited in reservoirs while the rate of erosion depends on a complex interaction of:

- Climate - precipitation and runoff, temperature, wind speed and direction,
- Topography – slope, catchment orientation, drainage basin area, drainage density,
- Vegetation cover, and
- Land use and human impact.

Topsoil and other light surface particles from a catchment are transported by rainwater from land to a reservoir where some of it settles to the floor of the reservoir as a layer of silt. Lindqvist, (2005); observed that a layer of silt that is only a few centimeters thick is good because it reduces seepage, but thicker layers of silt decrease the water storage capacity, reducing the period during which water can be drawn from a reservoir.

2.3 Impact of change of land use on an erosion and reservoir sedimentation

Land use practices have important impacts on both the availability and quality of water resources and the impacts can be both positive and negative. However, it is very difficult to arrive at universally valid statements about land use impacts on water resources because the impacts depend on a host of natural and socio-economic factors.

The natural factors include; climate, topography, and soil structure while the socio-economic factors include economic ability and awareness of the farmers, management practices, and the development of infrastructure such as roads (Kiersch, 2000). For example, a change of land cover from lower to evapotranspiration values will lead to a decrease in annual streamflow and vice versa according to Bosch (1982).

Land use and stream management can also trigger erosion responses and the responses can be complex often resulting in accelerated rates of erosion and sometimes affecting the stability of streams for decades. Queensland Government (2006) observes that the following activities contribute very significantly to soil erosion and consequently reservoir sedimentation:

1) over clearing of catchments and stream bank vegetation
2) poorly managed sand and gravel extraction
3) stream straightening works

According to Queensland Government (2006), the activities listed above are some of the examples of poor land management practices which result in accelerated rates of bank erosion which eventually leads to reservoir sedimentation when the eroded material is deposited in the reservoirs. Further to these poor land management practices, soil erosion is also accelerated by factors such as stream bed lowering or infill, a saturation of banks from off-stream sources, redirection, and acceleration of flow around infrastructure, obstructions, debris or vegetation within the stream channel, removal of disturbance of protective vegetation from stream banks as a result of trees falling from banks or through poorly managed stock grazing, clearing or fire, and excessive or inappropriate sand and gravel extraction.

2.4 Previous study

2.4.1 Other countries

A Geographical Information System (GIS) can be used to model bathymetry and the spatial distribution of sediments (Evans et al., 2002; Heimann, 1995). The use of the Remote Sensing technique to estimate suspended sediment has beenreported by several investigators (Solomonson, 1973; Bartoluci et al., 1977; Holeyer, 1978; Khoram, 1981). Smith et al. (1980) determined siltation in the Aswan High Dam

Reservoir by comparing reflectance values in the green and red portions of the spectrum. Research findings indicate that siltation during the flood period was largely confined to the main river channel of the reservoir and large embayment. Areas of extensive siltation were identified and the amounts of deposition were determined through ground surveys. This information was used to predict the distribution of silt deposits in the reservoir.

The use of Remote Sensing techniques has become very efficient andconvenient to quantify the sedimentation in a reservoir and to assess its distribution and deposition pattern. S.K.Kalvit did a study on monitoring sedimentation in lakes in

MAHARASHTRA using remote sensing. For him to conduct a remote sensing-based sedimentation survey, the cloud-free satellite images of various water levels in decreasing order from F.R.L. to MDDL were analyzed. Normally satellite images from October onwards to the first half of June month of the following year were available. Then he found that Satellite images in the monsoon period were almost full of cloud cover, which were not suitable for the study. In general, 10-12 satellite images of the same reservoir but different water levels were analyzed with digital analysis technique, and actual water spread area at different levels was estimated. Based on the satellite measured water spread areas at different elevations, revised volume i.e. revised storage at different elevations was worked out using the Prismoidal formula. The revised storage was then compared with the original storage and the difference in volume i.e. storage was attributed to siltation in the reservoir. Thereafter he found that the satellite remote sensing technique was useful, for periodic repeat surveys, which provide a faster and cost-effective solution to this problem.

Jonna et al. (1989) carried out digital image processing of remote sensing data for water quality studies. Some of the image processing techniques such as image enhancement, band rationing, principal component analysis, and unsupervised classification were applied using the IMAVISION system for the analysis of digital data of the Jayakwadi reservoir.

Manavalan et al. (1991) evaluated the capacity of the Ghataprapha reservoir using digital analysis of IRS LISS II data. The basic data extracted from satellite data were from the water spread area at different elevation levels. Density slicing on the near-infrared band data was employed to obtain the water spread contours for six different reservoir levels. Water spread estimates were made by converting the water pixels into the corresponding geographical area. The reduction in capacity between consecutive contour levels was computed using the cone formula and integrated to obtain the overall reduction incapacity between the minimum and maximum water levels.

Srivastava et al. (1989) have prepared the sedimentation map in the Panchet reservoir using the Landsat TM visible red band (0.63-0.69 um) picture in B & W and digitally

processed images have been used. Here the clear water with no suspended sediments shows a darker tone compared to the water with suspended sediments of brighter tone.

In 2012 in INDIA, Kamuju Narasayya et al did a study on the assessment of reservoirs sedimentation using remote sensing satellite imageries in the Srisailam reservoir. In this study, the data used were topographical, field data, and satellite multispectral data. The satellite image data were analyzed using digital image processing software. On visual analysis, the pixels representing a water-spread area of the reservoir were quite distinct and clear in the False Colour Composite (FCC) image. The reservoir capacity between two elevations of Srisailam Reservoir was computed by the Prismoidal Formula using water spread areas at corresponding elevations.

2.4.2. Problem of water surface sedimentation in Malawi

2.4.2.1. Small dams

The Malawi National Water Policy (MNWP) of 2006 acknowledges that Malawi as a the country has abundant surface water and groundwater resources but these resources are of variable quality and quantities, unevenly distributed in time and space, and are subjected to poor conservation and management (Malawi Government, 2006).

Some small reservoirs have been subjected to problems of sedimentation, resulting in reservoir failures. For example, Masambanjati Small Earth Dam was built in 2004 in Thyolo District but was silted up in less than two years after its construction. A second reservoir was reported a failure in Chikwawa District after heavy rains resulting in the dam being overtopped and completely washed away (Department of Water Resources, 2007).

Kadewere (2007) states that by 1999 Mudi Dam which is owned by the Blantyre Water Board (BWB) had lost its storage capacity due to sedimentation by 30% of the design the capacity of 1.5 Mm3 in 1955. According to the study, the reservoir was to supply about 8000 m3 per day only by 2007 against the designed capacity

of 45000 m3 per day representing 20% of yield and 10% of total water demand by the Blantyre City residents. Unconfirmed reports show that similar cases are also being experienced by the Lilongwe Water Board (LWB) at the two Kamuzu Dams (I and II) and the Central Region Water Board's (CRWB) Chitete Dam in Kasungu.

2.4.2.2. In Lake Chilwa

Lake Chilwa is a shallow lake that shrinks significantly in the dry season, increasing greatly in the volume during the rainy season. The lake is a center of sustenance and commerce, supporting villagers who participate in the thriving fishing industry. However, A.Morgan and Margarete found that the streams which enter the lake are numerous in the north, west, and south of the lake than from the Portuguese side on the east. Many of the streams become lost in the marshes and since they carry much silt, the marshland is more extensive in these parts. And some of the silts get deposited in the lake.

3.0. Methodology

3.1. Location of study area

Lake Chilwa is situated in the center of the low-lying Chilwa-Phalombe plain in the southern part of Malawi at 35˚15'E and 15˚15'S (Ratcliffe 1971). It is the second-largest lake in Malawi and the twelfth largest natural lake in Africa. It is an enclosed lake with a surrounding reed belt widest on the north and north-east side and a seasonally flooded plain. The water is saline ranging from 1-2% up to 12% during minor recessions. The figure 1 below;

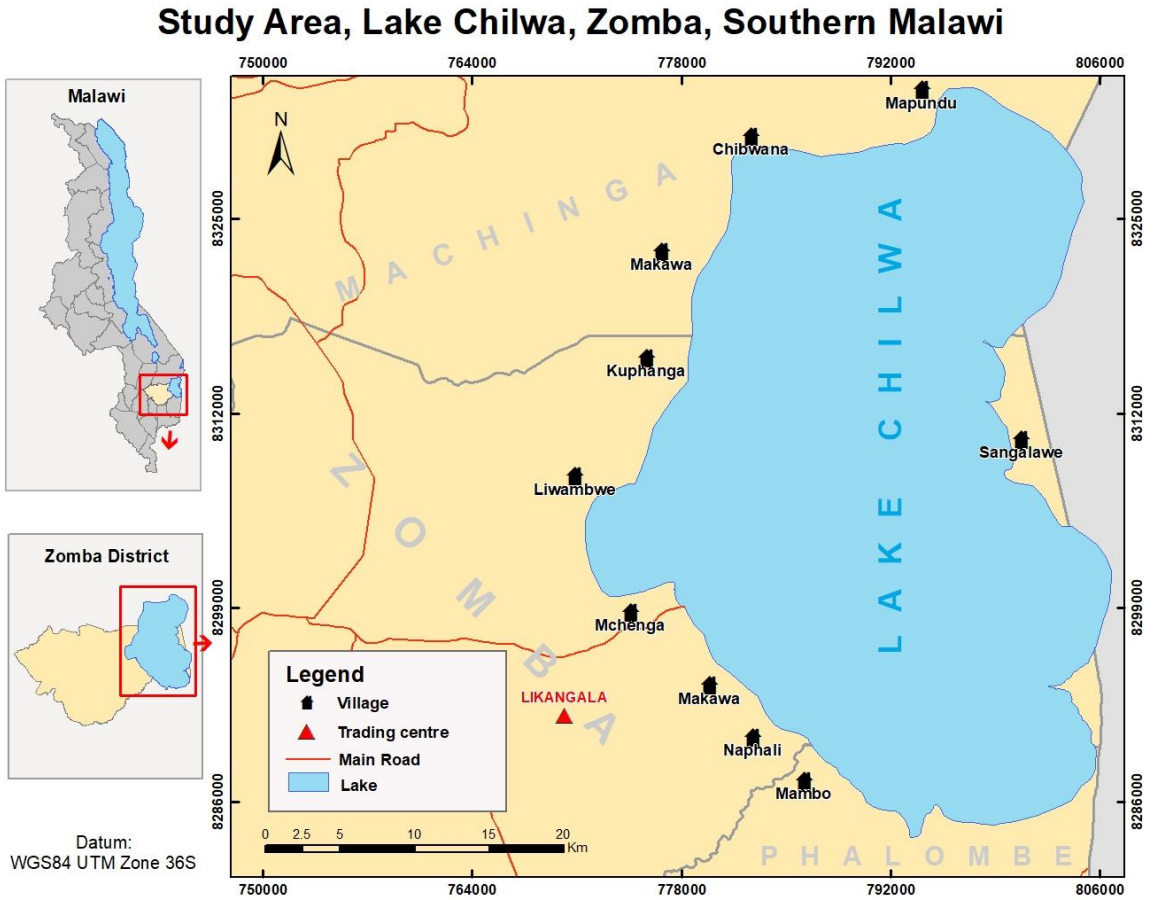


Figure 1: shows the map of Lake Chilwa

3.1.1. Geology

Most of the Chilwa basin is underlain by ancient metamorphic and igneous rocks of the Malawi Basin Complex, which are represented by a group of high-grade metamorphic rocks, mostly charnokitic granulites of quartz and feldspar, and biotite gneisses. Distinctive volcanic events occur to the immediate south of the Lake Chilwa at Tundulu as a complex of alkaline silicate rocks, carbonatites rich in sodium and Calcium Carbonates. Alkaline dykes swarms are widespread, particularly to the Northeast of the Mulanje Massif. Hotsprings at Mpyupyu to the west of Lake Chilwa and off Chisi (Nchisi) island in Lake Chilwa represent the final remnants of the igneous activity and have been postulated to contribute to Lake Chloride and salinity. The soil of the lake bed varies from extremely sandy in the north, to heavy water-sodden clays in the south. A thick layer of fine silt overlies the whole area of the lake (Michael et.al, 2020).

3.1.2. Hydrography and hydrology

Lake Chilwa is endorheic, with water flowing in from six major rivers namely; Domasi, Likangala, Thondwe, Phalombe, Sombani, and Mnembo with maximum discharges that occur during the rainy season from December to April, usually peaking in February. The Mambo River flows from Mozambique into Lake Chilwa and is the lake's largest source of recharge. The level of the lake normally shows seasonal fluctuations the lowest levels occurring in November and December, and the highest, at the end of the rainy season in March and April. When inflow from the rivers exceeds evaporation from the lake and swamp, the lake level rises, and vice versa. The mean amount temperature is 21°C to 24°C, with a climate described as tropical wet and dry. The area is susceptible to climate change impact (Michael et.al, 2020

3.2. Research design

Qualitative research method method was used in this study.

3.2.1. Conceptual frame work

The detailed methodology explained in the form of flow chat, in figure 2 below.

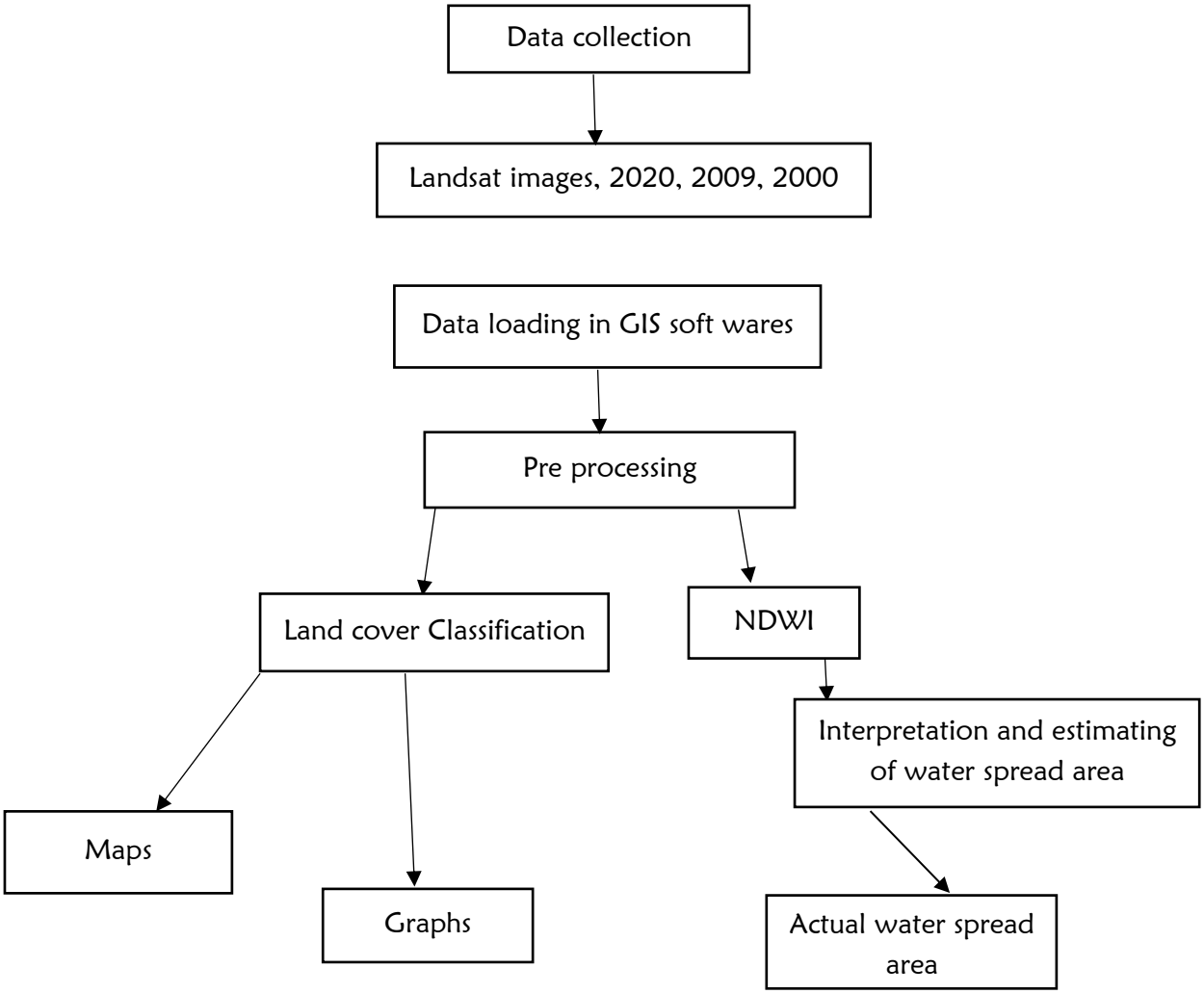


Figure 2: Summary of the methodology conducted in the study

3.2.2. Data collection

The first and foremost task was the selection of satellite sensors and associated images. Based on the purpose of the study, objected to being identified and availability of images, Landsat 4-5 TM and Landsat 8 OLI images were the best option for this study. Landsat images were download from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov) which were manipulated using Quantum GIS. The description of Landsat imagery is given in table 1 below;

Band name	LS 4-5 TM	LS 8 OLI	Pixel size(m)
Blue	B1 (0.42 – 0.52)	2 (0.45 – 0.51)	30
Green	B2 (0. 52 – 0.60)	B3 (0.53 – 0.59)	30
Red	B3 (0.63 – 0.69)	B4 (0.64 – 0.67)	30
NIR	B4 (0.76 – 0.90)	B5 (0.85 – 0.88)	30
SWIR 1	B5 (1.55 – 1.75)	B6 (1.57 – 1.65)	30
SWIR 2	B7 (2.08 – 2.35)	B7 (2.11 – 2.29)	30

Table 1 : Description of Landsat data types used in the project.

Three images were downloaded for 2000, 2009, and 2020. The following are the advantage of Landsat images on water sediments assessment;

- Although several satellite systems have been used for water quality and sediments assessment, the combination of temporal coverage, relatively low-cost spatial resolution, and data availability systems are particularly useful for the assessment of inland lakes (Kloiber et al. 2002, Leif 2002). And 30 m resolution Landsat multispectral imagery is suitable for lakes and provides information on in lake availability.
- Another important benefit of a Landsat water sediments assessment is the ability to use this technique in a retrospective analysis (Kloiber et al. 2002). Landsat data have been collected since the early 1970s, allowing the possibility to extracting historical water information from Landsat images.

3.2.3. Data Preprocessing

First and foremost, QGIS semi-Automic Classification plugin (SPC) was installed before the dataset was explored in QGIS. SPC was developed by Luca Congedo, it allows for the classification of remote sensing images, the pre-processing and post-processing of images. Then, the downloaded level 1 Landsat images are explored in QGIS and undergo several preprocessing steps. The first step was to convert Landsat images from digital numbers to the top of atmosphere reflectance using the Dark object subtraction 1 (DOS1) method in QGIS. Thereafter, to identify the location that is near Lake Chilwa, a distance of 2cm was measured from the Lake to the surrounding area on the images to clip up the study area from the image. Then color composite was created on clipped images which is useful for photo interpretation. Thereafter, two analyses were done. The first phase of analysis involved was classifying the downloaded satellite Landsat images to detect the changes in land cover on the area around the lake that contribute to massive siltation. Three classified maps were produced to show changes detected on land cover for 3 years. And the possible change in the size of the lake was analyzed and related to sedimentation.

3.3. Material and methods

The material used in this study was GIS software i.e. ArcGIS 10.5, QGIS, ENV, Landsat images and google earth images. The 2000 and 2009 satellite images were downloaded from USGS and these are examples of Landsat 4-5 thematic mapper (TM) mission images. The 2020 images were examples of images from Landsat 8 operation land image (oli) and Thermal infrared sensor.

3.3.1. Identification of water pixels

The methodology adopted for this study involved pre-processing of satellite data, identifying the water pixels, and computation of the water spread area of the Lake. In this study, Landsat satellite data were processed and analyzed using Qgis software for determining the water-spread area of Lake Chilwa. Then Normalized difference water index (NDWI) an algorithm was used for identifying the water pixels using

data of different bands, which is created as separate images. The NDWI can be represented as:

NDWI= (Green-NIR)/ (Green+NIR) or

= (band 2- band 3)/ (band 2+band 3) for Landsat 4-5 thematic mapper or

= (band 3- band 5)/ (band 3 + band 5) for Landsat OLI

In all three images, it is found that the NDWI for water is greater than 0.43. The algorithm checks for the following conditions of each pixel, if the condition is satisfied, then it is recorded as water, otherwise not;

"If the DN value of Near-IR band of a pixel is less than the DN value of red band and green band and the NDWI is >0.43, then it is classified as water, otherwise not."

This condition differentiates water pixels from other pixels. Then isolated water pixels within and near the periphery of the lake Chilwa were removed by mask. After applying corrections, the actual water spread was obtained.

Since the absorptance of electromagnetic radiation by water is the maximum in the near-infrared spectral region, the DN value of water is appreciably less than those other land uses. Even if the water depth is very shallow, the increased absorptance in band 3 will cause the DN value to be less than band 2 and band 1. This condition differentiates water pixels from other pixels.

3.3.2. Image Classification analysis

The images were classified based on physiographical knowledge of the study area and visual interpretation of each land cover class supported with the use of the historical function of Google Earth. Using Qgis, 4 classes of vegetation, water bodies (Lake), mud soil, and bare land were trained. However, mud soil and bare land were separated due to their difference in spectral reflectance that is influenced by the following factors; moisture content, organic matter content, and soil texture. Mud soil contains moisture and some organic matter which increases absorption of EMR and decomposition of organic matter influences mud soil to appear black in an image. While bare land appeared bright white in an image because visible wavelengths are more or less equally reflected due to its texture. Supervised classification was performed for each of the years using the Maximum likelihood (MAXLIKEHOOD) algorithm. In the MAXLIKEHOOD process, pixels are assigned to the most likely class based on a comparison of the subsequent probability that it belongs to each of the signatures being considered. After that, the area for every feature was calculated. LCLU maps were created and the percentages counts of bare land were used to determine the sedimentation effects.

4.0. Results and discussion

The results of this study fall in the three categories depending on the specific objectives of the study because each objective uses different ways of analyzing the data.

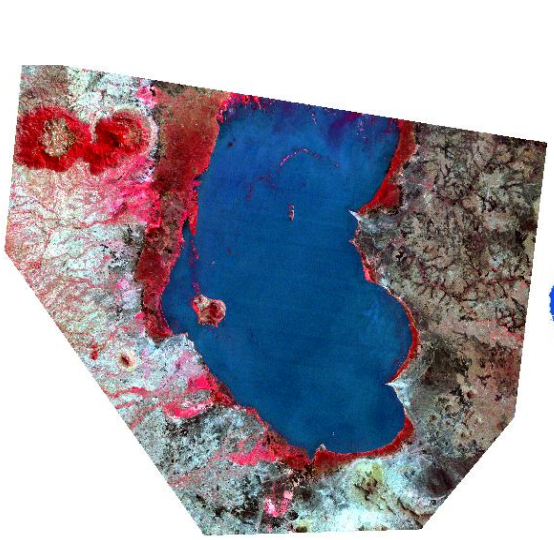
4.1. Results of water spread area analysis

The basic information extracted from satellite data in this scope was the water spread area of the Lake Chilwa at the different water elevations. The revised area at different elevations in Lake Chilwa (obtained from the remote sensing analysis) was calculated by multiplying the number of pixels in the water spread area by the size of one pixel (30m ×30m). The revised area are presented in table 1 below,

Revised area using R.S(m^2)	Date of satellite pass	Number of water pixels
1020726900	August - 01 – 2000	1134141
1042939800	July - 11 – 2009	1158822
792852300	July - 07 – 2020	880947

Table 2 : Lake Chilwa revised area on the date of satellite pass

The NDWI operation images from imageries of 2000, 2009, and 2020 have been carried out to extract the water spread area of Lake Chilwa at a different elevation. Figure 3 below displays the output generated from the analysis of the 2000 imagery. Figure 3 shows two images, image A and image B. image A false-color image of Lake Chilwa and its surroundings and image B extended image on how Lake Chilwa water spread was at the time of satellite pass. The image B was extracted after applying some isolated water pixels within and near the Lake. Therefore image B helped to calculate the actual water spread area of Lake Chilwa at the date of the satellite pass. The analysis shows that the water spread of Lake Chilwa was 1,020,726,900 m^2.



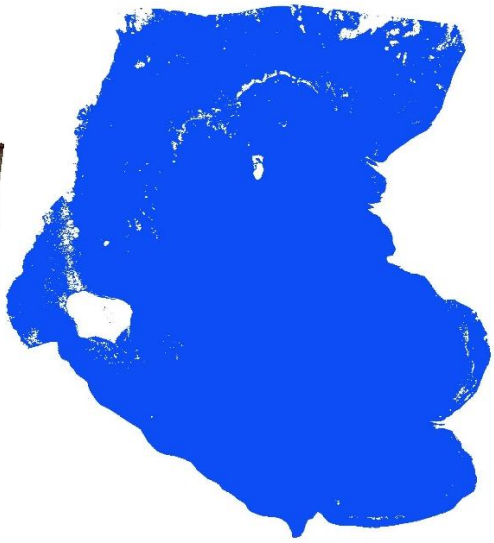


Image A **image B**

Date of pass: August 01 2000 water spread area : 1,020,726,900 m^2

Figure 4: shows false color image and water spread of the Lake Chilwa at the satellite pass 2000.

Figure 4 below shows 2 images for the output generated from the analysis of the 2009 imagery. Image A shows Lake Chilwa and its surrounding on satellite image while image B shows an extended image of the water spread area of the Lake Chilwa. Analysis shows that the water spread of Lake Chilwa was 1,042,939, 800m^2.

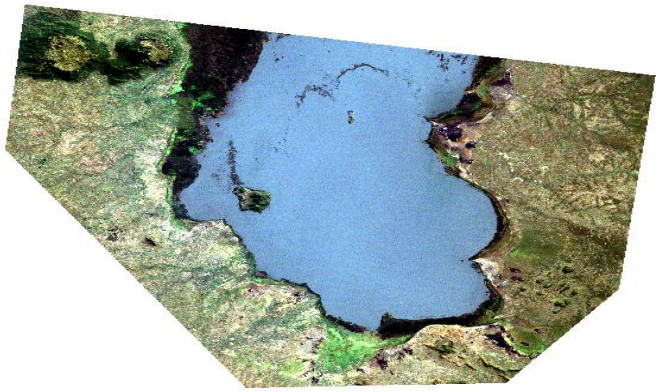




Image A

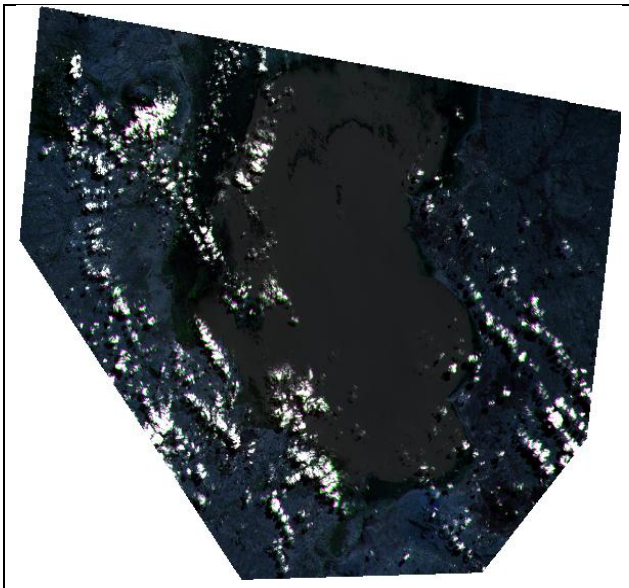
Date of pass: July 11 2009

image B

water spread area: 1,042,939,800 m^2

Figure 5: Shows false color image and water spread of the Lake Chilwa at the satellite pass 2009.

Figure 5 below 2 images. Image A shows a false-color image of Lake Chilwa and its surroundings and image B shows the extended image of how the Lake Chilwa water spread area was at the date of the satellite pass. The image B was extracted after applying corrections i.e. removing some isolated water pixels within and near the Lake. Therefore image B helped to calculate the actual water spread area of Lake Chilwa at the date of the satellite pass. For the current year of 2020, the analysis shows that the water spread area of Lake Chilwa was 792,852,300 m^2.



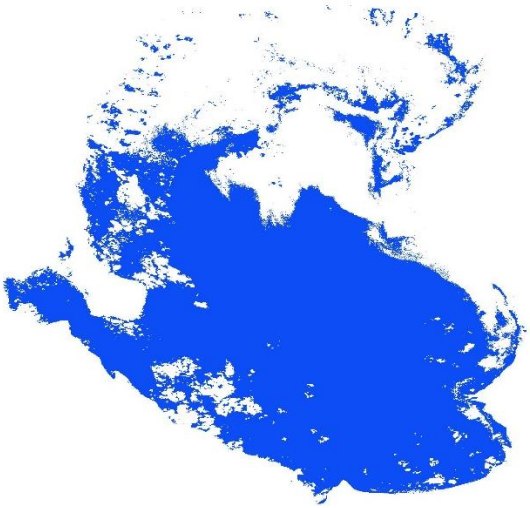


Image A **image B**

Date of pass: July 07 2020 water spread area: 792,852,300 m^2

Figure 6: Shows false color image and water spread of the Lake Chilwa at the satellite pass 2020.

The remote sensing technique does not directly measure the silt in the Lake. The RS method for assessment of lakes sedimentation uses the fact that the water spread area of the lake at various elevations keeps on decreasing due to sedimentation. Based on the satellite remote sensing studies concerned with Lake Chilwa, the following results have been concluded. From the above-said results, the following inference can be made;

The water spread of Lake Chilwa has reduced from 1,020,726,900 m^2 to 792,852,300m^2 till 2020. Lake Chilwa has lost its area by 227,874,600m^2 in the year 2020 since 2000. The graph below shows the water spread of Lake Chilwa in different satellite passes, 2000, 2009, and 2020.

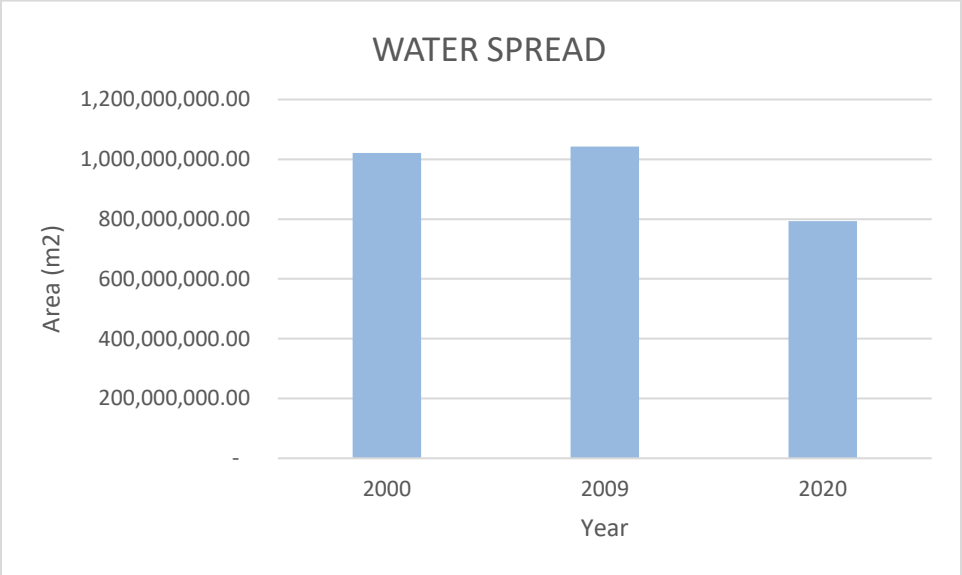


Figure 7 : Shows water spread of the Lake Chilwa in different satellite pass, 2000, 2009 and 2020.

The net water spread on Lake Chilwa from the year 2000 to 2020 is 227,874,600m^2. However, according to the histogram in figure 6 above which shows the changes in the water spread area of the Lake Chilwa for different years (2000, 2009, and 2009), it is clear that for various elevations, and there is a change in water spread for different years. There is a gradual decrease in the water spread area of Lake Chilwa as time passes i.e. for a period of 20 years which is from 2000 to 2020 water spread area of Lake Chilwa has decreased by 227,874,600 m^2 uncovered from the study. This shows that sedimentation in Lake Chilwa has reduced Lake Chilwa's water spread area. However, this study has uncovered that Lake Chilwa's size has decreased due to sedimentation. Therefore it is understood that a definite relationship exists between Lake Chilwa size and the sediments accumulation since 2000. However, the increase in the water spread area of the Lake in 2009 was due to misclassification of mixed pixels which seemly looked like part of the Lake. And the high decrease in water spread was observed in 2020 where there is more poor vegetation cover and steep slope, which indicates that sedimentation rate is highly dependent on slope factor and vegetative cover. If it gives on increasing, it reduces the useful life of the Lake. According to (Madalitso Kafumbata, 2021) says that Lake Chilwa supports the livelihood of over a 1.5million people in the basin through agriculture and natural resource goods and services. Low water levels have

negative implications on people's livelihoods through loss of income and employment, reduced fish supply, increased conflicts from competition for resources, and increased exploitation of birds.

4.2. Land cover classification results

The land cover maps produced by incorporation of remotely sensed image classification and have provided important Land cover information around Lake Chilwa. Classification analysis of 2000 imagery has been summarized in figure 7 which is showing the histogram of classification based on a percentage of the class covered around the Lake Chilwa area and figure 8 is showing the land cover map. The analysis has shown that the major share of the Land around Lake Chilwa is covered by different feature types mainly Lake Chilwa 22.9% followed by grassland 6.1% then mud soil 23.9% and bare land 20.1%.

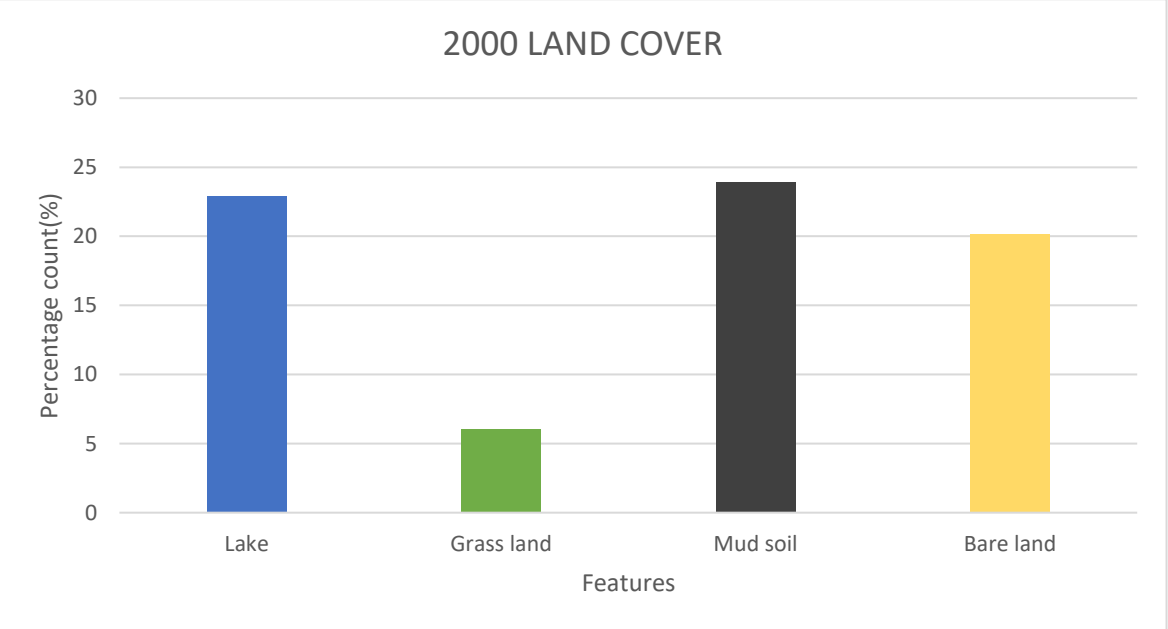


Figure 8 : Shows percentage count for each feature in 2000

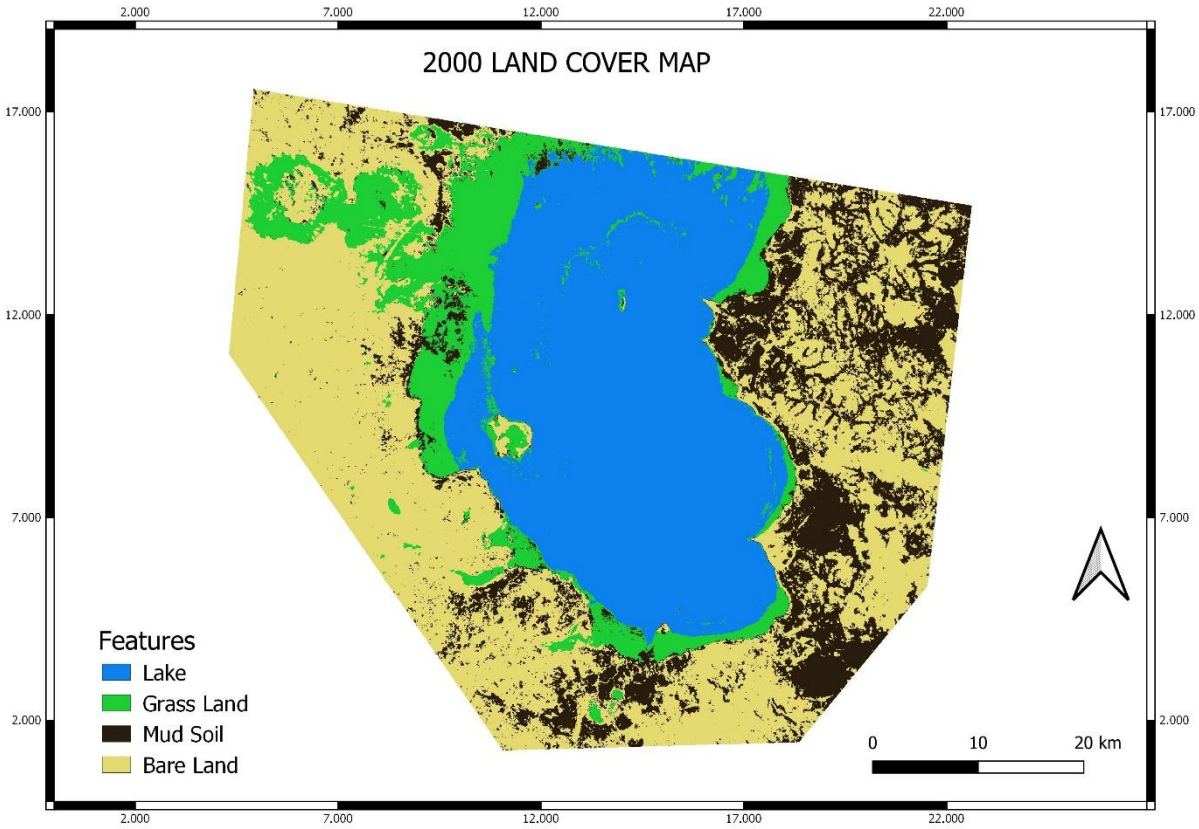


Figure 9 : Shows 2000 land cover classified map of area around Lake Chilwa

Figure 9 and figure 10 below display the output generated from the analysis of 2009 imagery. The analysis shows that Lake Chilwa was covered by 23.5%, grassland 3.0%, mud soil 6.1%, and bare land 37.1%.

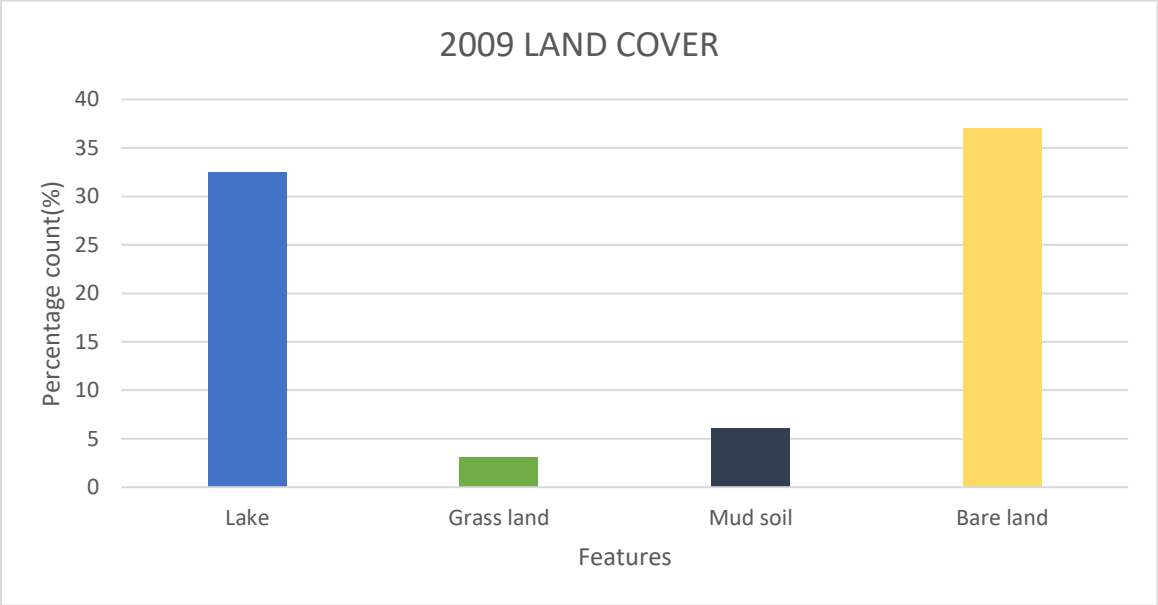


Figure 10 : Shows percentage count for each feature in 2000

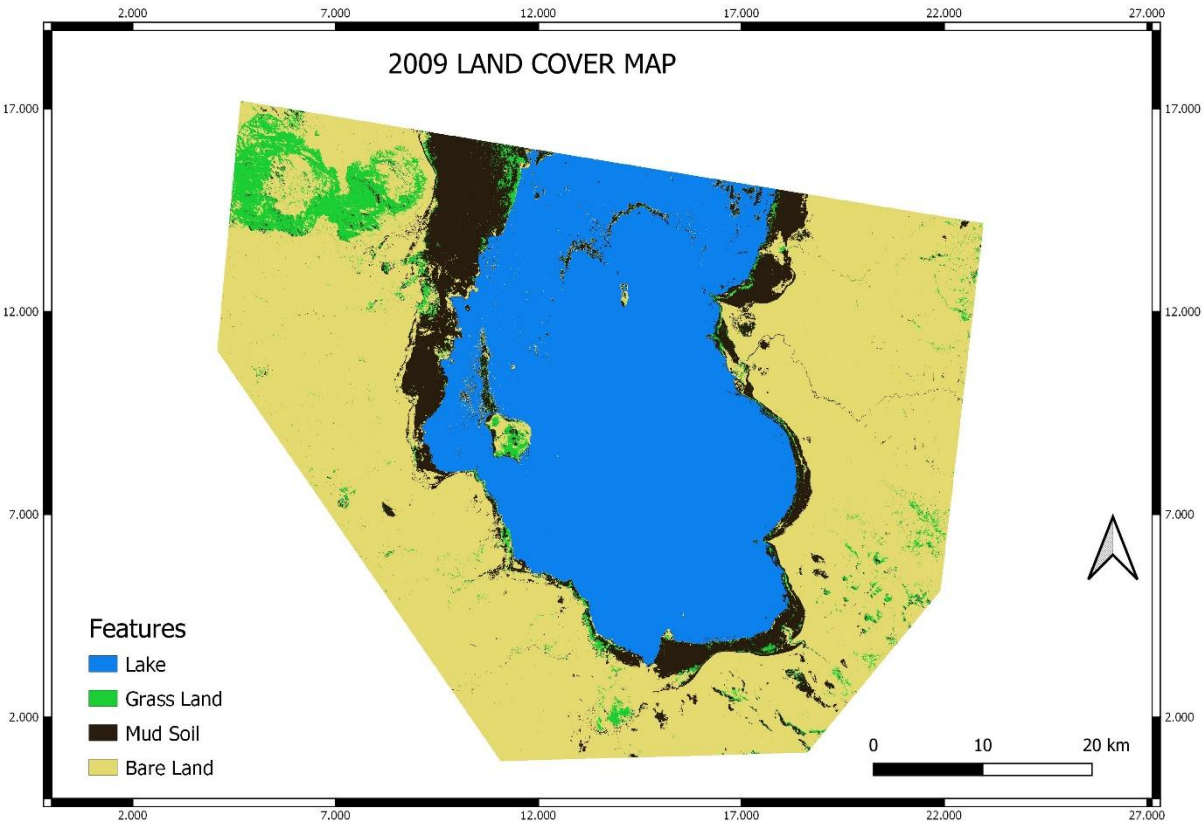


Figure 11 : Shows 2009 land cover classified map of area around Lake Chilwa

The current year 2020 analysis shows that Lake Chilwa was covered by 17.7%, grassland 16.4%, mud soil 1.2%, and bare land 38.5%. Figure 11 below shows the histogram of classification based on a percentage of the class covered around the Lake Chilwa area and figure 12 is showing a land cover map of 2020.

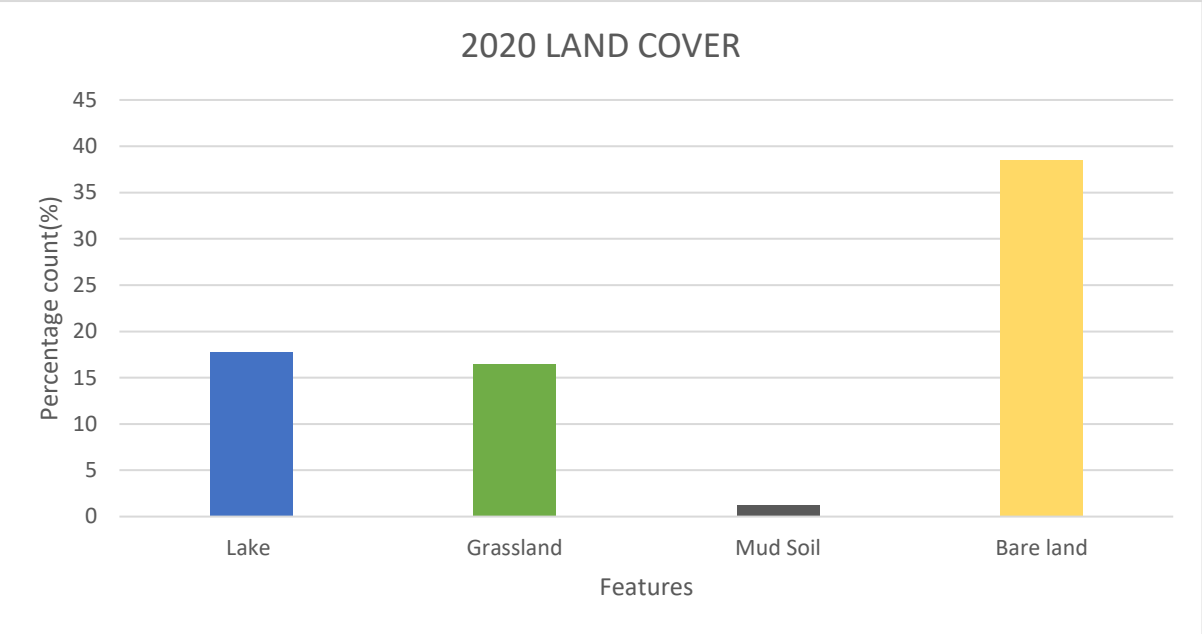


Figure 12 : Shows percentage count for each feature in 2020

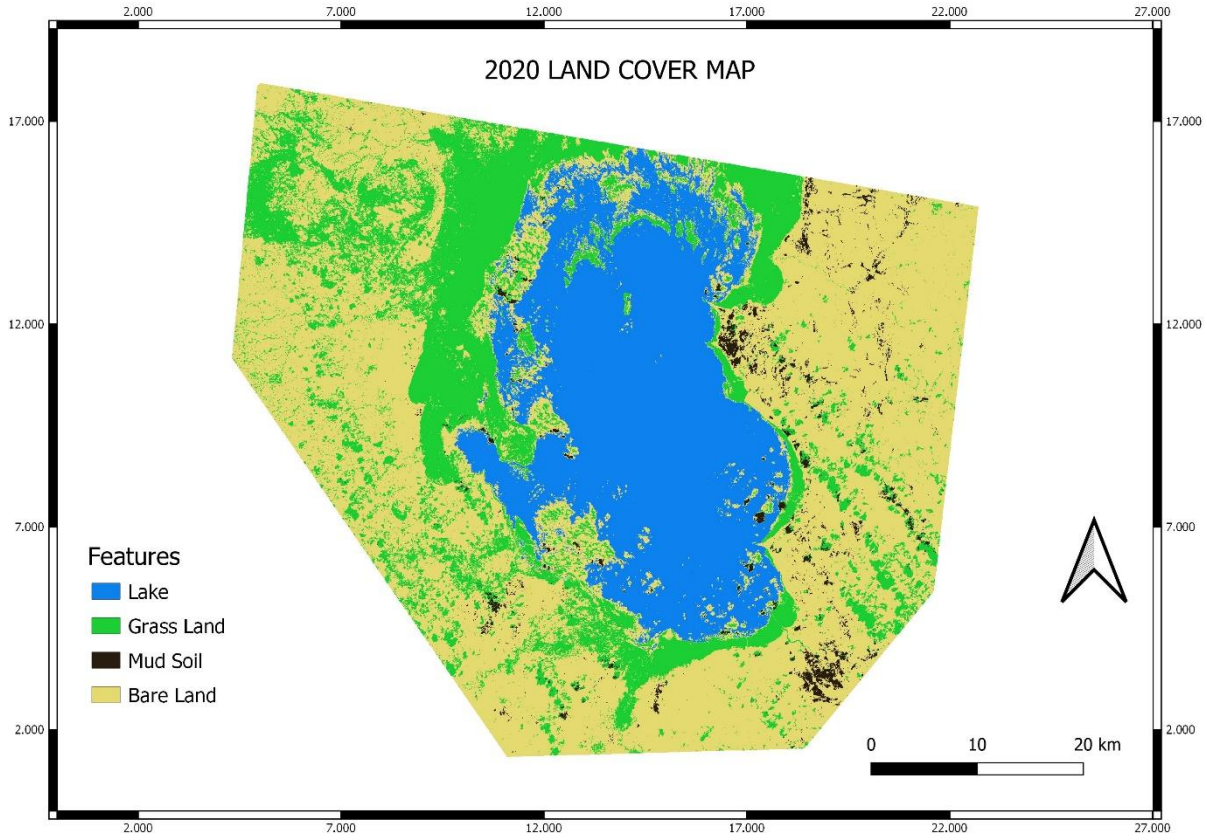


Figure 13 : Shows 2020 land cover classified map of area around Lake Chilwa

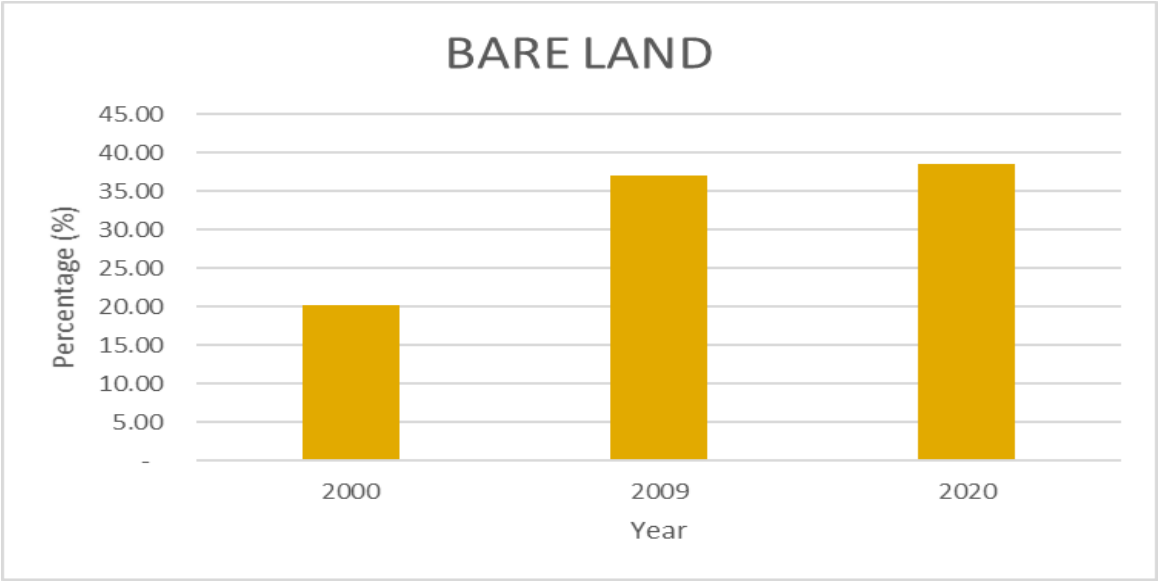


Figure 14 : shows the percentage of bare land from 2000 to 2020

From land cover maps shown in Figures (6, 8, and 10), the bare land class was used to assess how it affects sedimentation in Lake Chilwa. Figure 13, shows that trend in bare land has gone through at three years period of the study (2000, 2009, and 2020). In 2000 there was about 20.1% of the bare land area around Lake Chilwa, in 2009 there was 37.0%. There was an increase in bare land area from 2000 to 2009. And finally, there was 38.5% of bare land area in 2020. The classification maps show that there was a logical increase in the percentage of the bare land area around Lake Chilwa that shows that there was an increased rate of soil erosion which affect sedimentation in Lake Chilwa. concerning the bare land cover percentage, the water spread area of the Lake shows that there is a decrease within the same period uncovered through the study.in 2000 water spread area was 1,020,726,900m^2, in 2009 1,042,939,800m^2, and in 2020 the water spread area was 792,852,300m^2 thus a recognizable decrease of water spread area in the Lake Chilwa within a range of 20 years. This shows that bare land cover around Lake Chilwa has an impact on sedimentation in the Lake. Daniel Jamu in 2003 studies land use and cover changes in the Likangala river catchment of the Lake Chilwa. Land use analysis indicated there was increasing deforestation and conversion of agricultural land to homeland development and there was the high loss of soil that contributed to silt deposit in the Lake due to poor vegetation cover (Jamu et al, 2003). And another previous study says that siltation caused by high levels of environmental degradation and deforestation within the lake catchment threatened the lake ecosystem (Rebelo et al., 2011)

The classification results further show that there were changes in the percentage count of the Lake Chilwa concerning bare land. In 2000 and 2009 there was an increase in percentage count of the Lake (22.9% and 23.4%) respectively. while in 2020 there was a dramatic decrease in the percentage count area of the Lake which is evident that an increase in bare land, decreases the percentage count of the Lake. As shown in the 2000 and 2009 maps, Chisi island was seen as an island since there was enough water between the island and the boundary of the Lake on the west side of the Lake.

In 2020 the gap between the Chisi Island and the Lake boundary was not seen as a result of being filled with vegetation and bare land. The results show that Lake Chilwa is being filled with sediments.

5.0. Study Limitation

In this study, the application of RS in sedimentation assessment has proven to be effective means for calculating a change in water spread area by using digital analysis techniques and produced some meaningful information about the overall land cover system of the area around Lake Chilwa. However, it has some limitations, such as;

1. Inability to find data of Lake Chilwa water level at the time of satellite pass
2. Challenges in acquiring cloud imagery
3. With spatial resolution (30 m) of the Landsat satellite data, it was hard to differentiate the signature of some land cover features.

6.0. Conclusion and recommendation

6.1. Conclusion

Remote sensing and GIS techniques were employed in this research to study the land cover dynamics in the Lake Chilwa area and evaluating the effects of land cover on Lake Chilwa sedimentation. The study provided a path for comprehensive land cover change analysis in the area around Lake Chilwa. Land cover maps were created to understanding the characteristics of land cover changes and their effect on Lake Chilwa sedimentation. And water pixels were identified using digital image processing techniques to calculate changes in the water spread area of Lake Chilwa due to sedimentation.

The study shows that there is a decrease in the water spread area of Lake Chilwa as the year's pass. i.e. In 2000 water spread area was 1,020,726,900m^2, in 2009 1,042,939,800m^2, and in 2020 the area was 792,852,300m^2 thus a recognizable decrease of water spread area in the Lake within the range of 20 years. Therefore there is a decrease in Lake Chilwa size due to sedimentation.

In conclusion, the study shows that there is an increase in bare land percentage cover as the year pass. I.e. in 2000 bare land cover was about 20.1%, 37.0% in 2009 and 38.5% in 2020. Concerning the bare land cover percentage increase, the water spread area shows that there is a decrease within the same period uncovered through the study. This shows that bare land cover affects Lake Chilwa sedimentation. (Assuming 100% of water spread area in 2000 to 77% water spread area in 2020, a decrease of 23% of water spread area. Therefore Lake Chilwa's water spread area is decreasing gradually as the year's pass, if the activities around the Lake is maintained, the spread area of the water will continue to decrease i.e. for the next 20years (2040) the area could decrease up to 54% due to siltation deposit.

6.2. Recommendations

For the analysis which has been carried out on Lake Chilwa sedimentation, it is recommended that people should plant trees around the lake Chilwa. And the government should introduce adaption programs of awareness especially on that people should avoid clearing the land around the lake Chilwa and should teach people on good farming practice methods because cultivation leaves the land bare therefore being prone to erosion which will contribute to silt deposit in the Lake.

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