ORIGINAL ARITICLE

Temporal Trajectory Analysis of Lake Surface Area: Case study on Lake Tana, Ethiopia

Abrham Zelalem[1], Eyaya Belay[2] and Abel Markos[3]

Abstract

Lakes are facing challenges due to climatic and anthropogenic activities with slow changes causing unnoticed damages over a long time. The long term historic data provides concrete evidence of change. The earth observation satellites which include both geostationary and polar orbiting satellite provide different types of environmental data. The main aim of this paper is to evaluate the temporal trajectory change of the lake surface area of LakeTana from 1985 – 2015 using geospatial technologies. The study uses seven Landsat TM and ETM+ images to detect the lake surface area change. The change was examined using modified normalized difference of Water index (MNDWI) method. This was attained by making use of ERDAS Imagine 2014 and ArcGIS10.1 software. The results of this study indicate that within the past three decades, the lake area has shown a significant decrease–about 362.74 sq.km. The area calculated from bathymetric surveys and the ccorresponding results from other alternative methods were gathered and computed with the findings of this study. The results portray that there is strong relationship between the estimates of lake surface area results of MNDWI with NDVI alongside the bathymetry results. Hence, lake surface area quantification and characterization using remote sensing and GIS techniques enables resource managers to project realistic change scenarios helpful for lake surface area management.

Keywords: *lake surface area, change detection, Normalized Difference of Water Index, Normalized Differential Vegetation Index*

Introduction

Background of the Study

Water availability at a given site determines the vegetation structure, wildlife habitat, microbial activities, and organic matter concentrations and, therefore, strongly influences the interactions of nutrients, pesticides, and other contaminants between lake sediments and its water column (Lane and Amico, 2010). Water flow in stream channels is seldom constant, with high flows during periods of rainfall and low flows in dry seasons. Stream channels develop their characteristic form or morphology because of stream gradient, geologic and soil materials through which the channel flows, and the historic streamflow patterns. Water moves slowly in flat meandering streams and quickly in steep mountainous channels (Baulies and Szejwach, 1998).

All lakes have great significance to the riparian inhabitants; providing freshwater for drinking, preserving ecosystems and biodiversity, as well as maintaining important recreational values. Changes in lake water quality and quantity may affect sustainability of aquatic and terrestrial ecosystems (Covich et al., 1997). Coastal Wetlands are also

1 (MA Student, Department of Geography and Environmental studies, University of Gondar,Ethiopia)

2 (Assistant professor in Remote sensing and GIS, Department of Geography and Environmental studies, University of Gondar,Ethiopia)

3 (Assi. Prof), Department of Geography and Environmental studies, University of Gondar. Email:abelmarkos2@gmail.com, Gondar, Ethiopia. Telephone: 0920253472

depending on the inflow of freshwater from the water bodies and adjusting to their local circumstances with periodical floods and droughts. Fluctuations in the water regime could change the timing and duration of droughts and floods, consequently affecting the environment (Quentin et al., 2006).

Environment, however, has an important role in hydrological cycle, as it has natural cleaning capacity which reduces the concentration of many pollutants in water. It also helps to reduce extremes in runoff through their capacity to store water and thereby, plays an important role in supplying food, fiber, wood, medicine, and, of course, supports the existence of many species (Gilbert and Janssen, 1998). For centuries, humans have affected natural conditions in rivers and other water bodies by reducing the capacity of water resources to support ecosystems and biodiversity (Covich et al., 1997).

In a broader context, land use and land cover change has a strong impact on the water budget of lakes and their watersheds. Changes in land use and land cover, driven by a range of socio-economic and biophysical factors, affect biodiversity, water and radiation budgets, trace-gas emissions and other elements that cumulatively can alter the hydrological system of the environment (Riebsame et al., 1994). There are varieties of driving forces, like hydrological cycle variation that can influence land use and land cover, and they interact dynamically to produce different sequences and trajectories of change, depending on the specific environmental, social and economic contexts in which they arise (Riebsame et al., 1994).

On the other hand, various methods of lake surface change detection have been developed to track the temporal trajectory of Lake Surface. Conducting a trajectory analysis of lake surface area, from a spatio–temporal perspective provides the basis for sustainable resources management, especially in delicate environment, where any subtle change in the environmental configuration will trigger changes in the system at a micro scale (Anderson et al., 2004). Lake surface area change has been recognized as an important driver of environmental change at all spatial and temporal scales (Tansey et al., 2006),and it has been emerging as a key environmental issue both at global and regional levels (Rai et al., 2006). In general, pattern of lake surface area change are complex, particularly it alters the hydrological cycle of a given area, and their environmental impacts affect a variety of resources simultaneously. Thus, understanding lake surface area change is essential for proper water resource management and decision-making (Prakasam et al., 2010).

Materials and Methods

Description of the study area

Lake Tana is the source of the Blue Nile River and has a total drainage area of approximately 15 000 km2, of which the lake covers around 3000 km2. The Lake is located in the northwestern highlands of Ethiopia at 110 37’ 00” to 12o 18’ 00” N and 370 00’ 00” to 37o 37’ 00” receives runoff from more than 40 rivers. Major rivers feeding the lake are Gilgel Abbay from the south, Ribb and Gumara from the east and Megech River from the north. From the western side of the Lake, only small river systems drain to the Lake. Of all the 40 rivers, Gilgel Abbay, Ribb, Gumera and Magetch contribute more than 93% of the inflow to the lake (Kebede et al., 2006).

Figure 1:-Location map of the Study area

Climatic condition

The climate of the region is 'tropical highland monsoon' with one rainy season between June and September. The air temperature shows large diurnal but small seasonal changes with an annual average of 20. 80C (Menale and Rao, 2011). The northward and southward movement of the inter-tropical convergence zone (ITCZ) controls the seasonal distribution of rainfall. During the rest of the year, the ITCZ shifts southwards and dry conditions persists in the region between October and May.

Topography of the study area

The eastern part of the basin is located in an area where water resources development is identified for achieving local and national development goals (Menale, 2013). Most of the downstream part of the study area is flat or rendering a large tract of floodplain around Lake Tana. The middle part of the basin has mainly rolling or hilly relief. The upper part is dominantly hilly with limited mountainous and dissected land close to the watershed divide (Engida, 2010). Mount Guna, one of the highest mountains in Ethiopia, is located at the study area. The topographic map presented in Figure 3 is developed from a 30 m x 30 m digital elevation model (DEM) obtained from USGS.

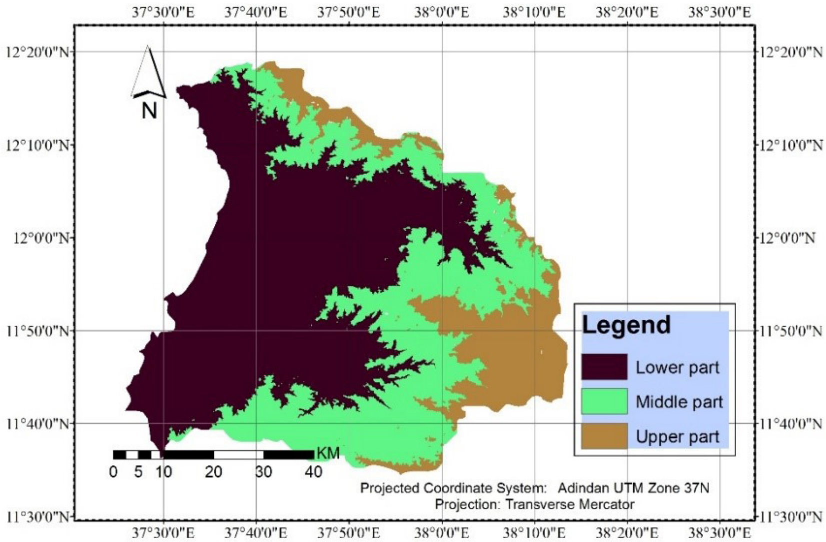

Figure 3:- Broad categories of topographic feature

The topographic factors in the study area can be the major reasons for the lake water resource desiccation. Among the factors that contribute to the accelerated soil erosion evident in the study area include extensive cultivation (even on steep slopes), overgrazing, scarce vegetation cover on hillslopes, and high rainfall intensity (Menale, 2013).

Land use and land cover

Soil erosion and sedimentation could be a major threat in the Lake Tana basin. Agriculture is the mainstay for most of the population in the basin and, hence, land degradation by soil erosion would directly affect the lives of millions. A significant part of the basin is designated for crop production using rain-fed agriculture which makes it vulnerable to drought and flooding. Because of the growing population pressure, cultivation is also practiced on marginal lands with a resulting increase in upstream soil erosion and sedimentation in downstream areas (SMEC, 2008). The low-lying parts of the basin bordering Lake Tana has extensive floodplains where cultivation is practiced. Valuable wetlands are also found around Lake Tana but they have been drained for agricultural purposes (Kindie, 2001). Two major urban centers which are found in the study area, Addis Zemen and Woreta, comprise of more than 100, 000 inhabitants each. Other land cover types include grasslands, open shrub lands and plantations, mainlyof eucalyptus. A major road network traverses the study area from south to north.

The socio-economic condition

The total population in the lake basin was estimated to be more than 3 million in 2007, and in 2014 the number of populations in the study area is projected to be approximately 1.5million (CSA, 2013). The majority of the population mostly depends on rain fed agriculture. Cultivation practices are primitive and crop production and livestock raising are closely integrated. Despite significant potential, there is currently very little irrigated agriculture in the basin. In some places, farmers pump water from the rivers that flow into Lake Tana, but the current areal extent of this is unknown.

Data types and sources

The study integrates data from different sources and uses different methods and approaches to analyze the long-term surface area changes and trends during the last three decades on the Lake Tana. Both primary and secondary sources of data were used in the study. Generally, variolous types of data including Satellite images were gathered.

Satellite images

By considering the scale and characteristics of the study area, availability of various image data and their characteristics (Lu et al., 2007), the researchers decided to use Landsat image for Lake surface area change mapping.The study utilized 14 Landsat images dated from 1985 to 2015 to map the lake surface area. Dry season images of each year were acquired. Scenes were required to be of the same phonological cycle (dry) and have little (less than 10%) or no cloud cover as shown in table 1.

The satellite image used for both lake surface area, land use and land cover change detection are imageries of Landsat (which are Landsat 5 TM 1985, 1990, 1995, 2000 and Landsat 7 ETM+, 2005, 2010 and 2015).These data sets were freely downloaded from the www.earthexplorer.gov. The approximate scene size is 185 x 185 kilometers. The spatial resolution of each band is 30 x 30 meters, except for the thermal band, which is 120 x 120 meters, which, of course, were not used for this study. Landsat instruments provide a 16-day temporal resolution. The data received to this site were geo-referenced (Michael, 2014; Chander, 2007).

Table1:-Satellite images, properties and acquisition date

Satellite images used for water feature change mapping		
Years	*Sensor type*	*date acquired*
1985	*Landsat 5 TM*	*5/29/1985*
1990	*Landsat 5 TM*	*4/12/1991*
1995	*Landsat 5 TM*	*5/20/1995*
2000	*Landsat 5 TM*	*4/11/2000*
2005	*Landsat ETM+ 7*	*4/28/2005*
2010	*Landsat ETM+ 7*	*5/12/2010*
2015	*Landsat ETM+ 7*	*2/12/2015*

Source: - Meta data file of Landsat image

Moreover, additional secondary data such as Lake water level from bathymetry surveys were used to compute and to support the findings in the surface area of Lake Tana. Other published and unpublished papers, articles and magazines were also used.

Methods of Data Collection

The suitable data period for interpretation of most of the lake surface area in the study area is the dry season when the minimum lake level is attained and the minimum temperature is highest in the basin i.e. in the month of May. This month is selected in order to minimize the impacts of weather in the inflow because of precipitation. Also, this month is useful in minimizing some difficulties to find cloud free data.
Methods of Data Processing

Image pre-processing

To prepare the input satellite images for further processing, absolute radiometric calibration, atmospheric correction and layer stacking, mosaicking, subseting and extraction of area of interest and image-to-image registration pre-processing steps were performed. All these preprocessing methods were performed by using ERDAS imagine 2014.

Lake surface area change detection

The study used a multi band change detection method rather than a single band method. This helps to cancel out a large portion of the noise components that are common in different wavelength regions (i.e., sensor calibration and changing radiation conditions caused by illumination, soil, topography, and atmospheric conditions, etc.) and subjective selection of the threshold (Lei et al., 2009). In this study, one simple metrics (or index) was used to detect lake surface area changes. Thus, Modified Normalized Difference Water Index (MNDWI) was used to map the surface area of Lake Tana. The major reason to use MNDWI is due to the fact that it can overcome the shortcoming of NDWI. In case of NDWI the reflectance pattern of built-up land in the green band (TM 2) and NIR band (TM 4) is similar with that of water i.e. they both reflect green light more than they reflect near infrared light (Xu, 2006). As a result, the computation of the MNDWI will be vital and, hence, water will have greater positive values than in the NDWI as it absorbs more MIR light than NIR light. Built-up land will have negative values, alongside soil and vegetation that still have negative values as soil reflects MIR light more than NIR light (Jensen, 2004) while the vegetation reflects MIR light than green light.

As (Xu 2006) modifies, the calculating formulae is -

$$MNDWI = (\rho Green - \rho MIR)/(\rho Green + \rho MIR)$$

Equation 1: - water feature mapping

Both ρ green and ρ MIR are the reflectance of green and mid infrared bands, respectively. The MNDWI value ranges from -1 to 1 with a set zero as the threshold. That is, the cover type is "water" if MNDWI > 0 and it is" non-water" if MNDWI is < 0. After the processes of MNDWI, the lake area was extracted from its attribute and the results were summed up to get the entire lake area by using Microsoft excel 2013. The loss rate of the lake area was calculated to serve as an input for impact analysis.

Thus, the loss rate of the lake area was calculated using the following formulae:

$$\text{The loss rate of the lake area} = (\text{lake area in } t_1 - \text{lake area in } t_2)/(\text{lake area of } t_1)$$

Equation 2:- loss rate of the lake area

Where

Lake area t_1 is the area of the lake from MNDWI of the previous year
Lake area t_2 is the area of the lake from MNDWI of the coming year

Based on the above equation (equation 1), images for the respective years were processed and the MNDWI maps of each year were prepared by ERDAS Imagine 2014 and the results of lake surface area were calculated by using Microsoft Excel 2015. Besides, the MNDWI lake surface area maps of 1985 and 2015 were also processed by ERDAS imagine 2014 with the additive and the subtractive change images were produced and stacked to produce the Lake surface area changes map in the period 1985–2015.

Results and Discussion

Lake surface area change

The lake surface area result that is extracted from the MNDWI metrics portrays that the lake area has shown a significant decrease within these three decades. The results have shown that the lake areas decreased significantly in the entire five years interval, and the entire area has been reduced by 10.82%. The 30 years' time series analysis shows that the lake area has shrunk with a mean of 60.46Km^2 per 5 years. Table 2 shows the surface area of the lake and lost and transformed areas in five years interval.

Table 2: The calculated lake surface area and the loss rate

Years	**Area**	**loss of lake area in sq.km**					
		1985-1990	**1990-1995**	**1995-2000**	**2000-2005**	**2005-2010**	**2010-2015**
1985	*3353.74*						
1990	*3239.03*	*114.71*					
1995	*3110.26*		*128.78*				
2000	*3058.79*			*51.46*			
2005	*3001.06*				*57.73*		
2010	*2946.97*					*55*	
2015	*2991.00*						*-44.03*
lost and transformed lake area					**362.74 sq.km**		

The results summarized in the above table reveals that the lake surface area during the dry months were about 3353.74 sq. km, 3239.03km^2, 3110.26 km2, 3058.79 km^2, 3001.06 km^2, 2946.97 sq.km and 2991.69 km^2 in 1985,1990,1995,2000,2005,2010 and 2015 respectively.

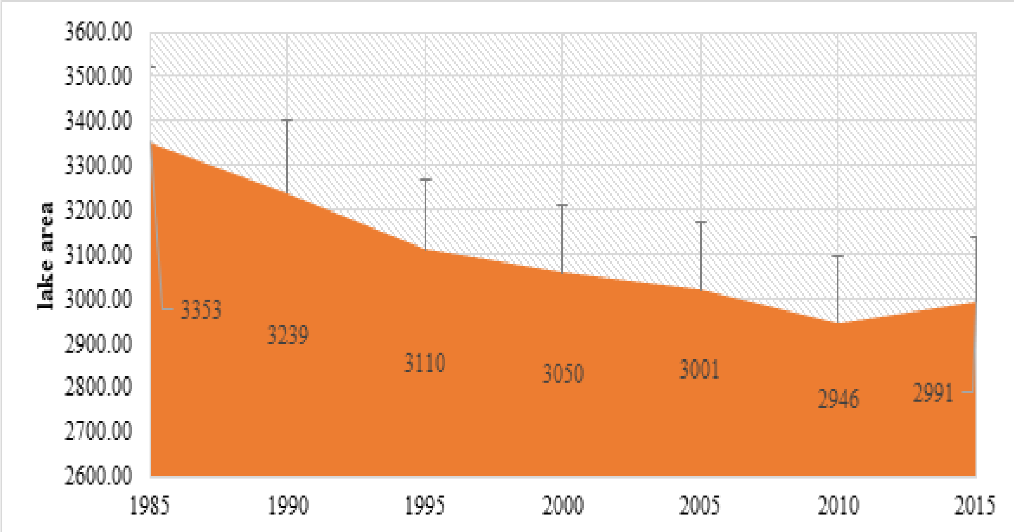

Figure 2:- Changes in lake surface area

The results further show that the lake surface area changes were about 114.71 sq. km between 1985 and 1990, and the surface area continually decreased between the years 1990 to 2010 by 361 sq. km. However, by the proceeding windows period, the lake area has shown an increasing trend by 44.03 sq.km from 2010 to 2015.

The satellite image used to calculate the lake area of 2015 was acquired on 2/12/2015. It has approximately 3 month difference to the other images. This is due to the absence of cloud free images in March, April and May. Thus, the study was forced to conduct the water feature mapping of 2015 with this image of previous years. However, for impact analysis purpose, the missing data were filled by using a Markovian transition probability matrix. Based on the result of the probability matrix, the calculated lake area was 2949.12 sq.km. This also shows 2.15-sq.km increase compared to the area of 2010.

Nevertheless, the area calculation of MNDWI indicates, the total surface area changes of the lake between 1985 and 2015 were about 362.74 sq.km. This indicated that the lake has lost 10.82 percent of the total surface area in the last 30 years. The results indicate a considerable decreasing trend in Lake Tana's surface area in the period 1985–2000. The most significant changes were occurred between 1985–1995 and 2000–2010, and within these periods, the lake has lost about 67.41 percent out of the total loss and transformed area. The decreasing trend of the Lake area shown in this study also is supported by other researchers; attributed the trend to human activity and catchment mismanagement. Out of the lost and the transformed area, the loss of the lake was 294.95 sq. km between the year 1985–2000, nearly 82 percent of the total loss and transformed surface area within the past three decades.

Figure 3, below indicates the huge lake area reduction. For the period after the CharaChara weir became operational, the surface area estimated by the index shows great variability within the study time intervals.

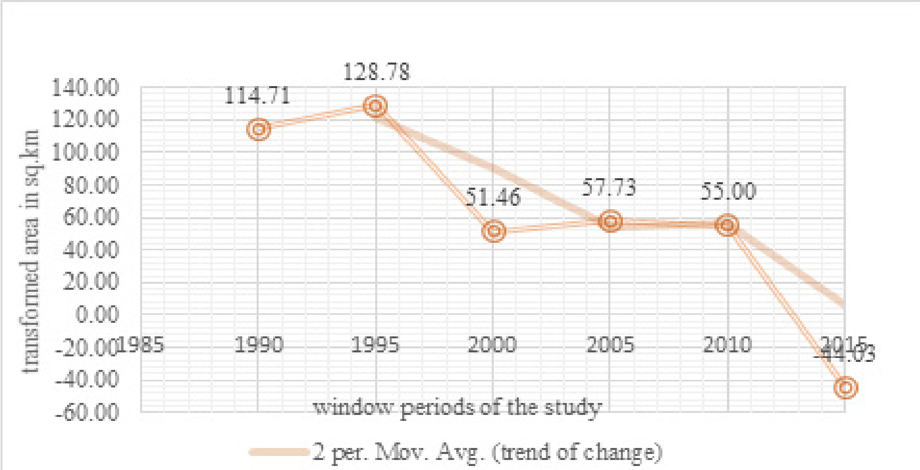

Figure 3:The lost and transformed lake area in km²

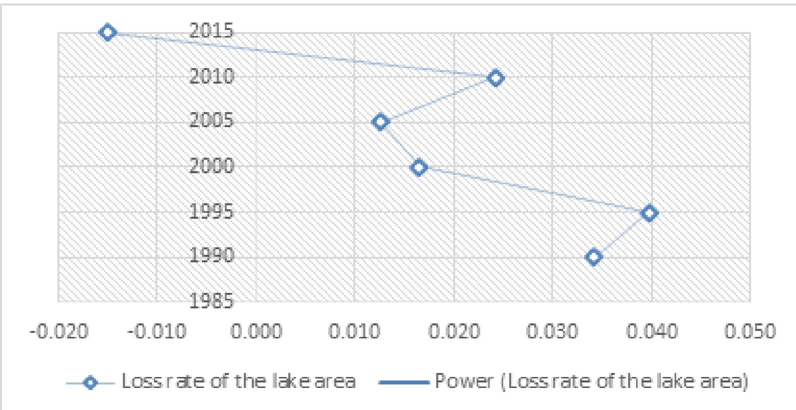

Figure 4: Loss rate of the lake areafrom 1985 – 2015.

As shown in Figure 4, the loss rate of the lake area in the late 1980's, 2000's and in early 1990's was very pronounced. Apparently, the pattern of the loss rate in lake surface area from 2000 onwards is characterized by extreme variability.

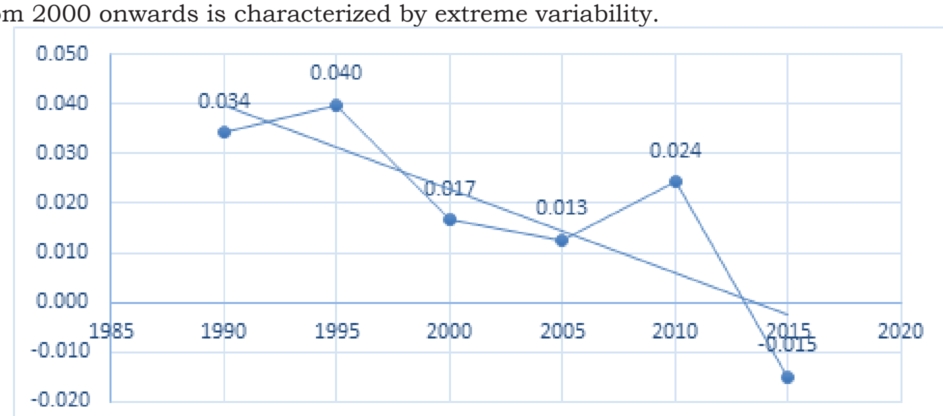

Figure 5: The linear trend of the loss rate of the lake area

The largest variation in surface area change was not in all cases related to Charachera weir. It is also associated with the variability in rainfall, land use and land cover change. The following maps depict the surface area of Lake Tana in 1985, 1990,1995,2000,2005, 2010, and 2015. The lake surface area was extracted by adopting MNDWI.

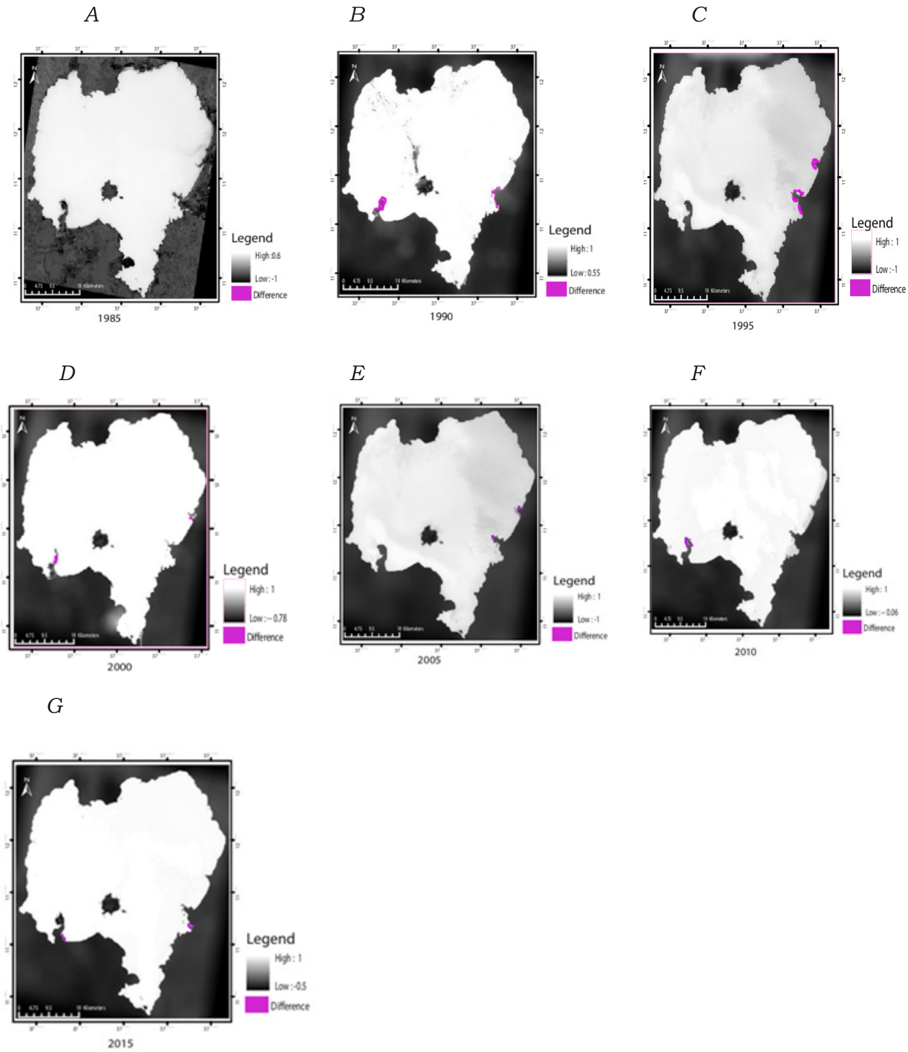

Figure 6: Lake surface area maps developed using MNDWI metrics of 1985, 1991, 1995,2000,2005,2010 and 2015 years respectively.

Accuracy, Errors and Uncertainties

Surface Area Relationship

The area calculated from bathymetric surveys and the calculated corresponding results from other alternative methods were gathered and computed with the findings of this study. Particularly, this is useful to understand the lake surface area changes and to support the findings of the study conducted using MNDWI and Landsat imageries. However, it is more feasible to determine relative bathymetry survey and NDVI results in computing changes in Lake surface area for the definite period. Lake bathymetry survey and NDVI results of the lake surface area were taken from different published research works/bathymetry surveys/ and satellite driven products, respectively. Firstly, the lake areas from bathymetry survey were computed and the results were presented as follows:

Lake surface area and the bathymetry survey results

There is a difference in the findings about the surface area of Lake Tana from studies to studies. In 2006 a bathymetry survey was conducted by Kaba, 2007 and updated later by Wale et al., 2008. Both estimate the lake surface area from the bathymetry survey using ground truth data and satellite images. The results of these studies show that the lake surface area varies between 3024 to 3150 sq.km. Despite the differences in seasons/months and the models used, as well as the number of ground control points, the lake surface area obtained from the bathymetric survey of these three distinct studies has shown a significant difference in estimating the size of the lake area.

Similarly, the bathymetry survey conducted by the Italian researcher in 1940 estimated the lake surface area to be 3156 sq.km. Comparing the lake surface area that was estimated by the Italian researcher with the results of both Kaba (2007) and Wale et al., (2008), it is hardly possible to conclude that the lake area has no change /6sq.km/wit in these 68 years.

Despite all the above conflicting lake area estimates, it is vital to crosscheck the results of this study with the available bathymetric surveys during the respective periods of the study years. The available lake surface area bathymetric surveys (1985–2015) were collected from different published research works and presented as follows:

Table 3:-Bathymetric survey results from different literature

Date	**Lake surface area from bathymetry**	**Lake surface area estimate from MNDWI**	**Difference in square Km**
Pietrangli1990	*3,225*	*3239.03*	*-14*
(Esayaset.al., 2007) 16-Sep-00	*3,091*	*3,058.79*	*32*
(Esayaset.al., 2007) 10-Oct-05	*3,012*	*3,001.30*	*11*

Based on these surveys, the surface area of the Lake Tana was 3225 in 1990, 3087 sq.km in the year 2000, and it was 3011 sq. Km by the year 2005. On the other hand, the lake surface area estimated by MNDWI matrix of this study were 3239 in 1990, 3058 in 2000 and 3001 in 2005.

When compute, the observed the difference with the bathymetry survey results of 1990s, the MNDWI result surpasses the bathymetry survey result by 14 km2. Nonetheless, both in the year 2000 and 2005, the surface area estimate from bathymetry survey exceeds the MNDWI estimate of this study by 32 and 11 km2 respectively. This is an acceptable difference because the lake surface area from bathymetry surveys were calculated based on the data collected in September and October months when the volume of the lake is at its maximum level. The MNDWI results of this study were estimated from images acquired in April and May months which have a difference of 6 and 7 months, respectively.

Computation of results from MNDWI and NDVI

Lake surface areas estimated from Normalized Difference of Vegetation Index/NDVI/ of Landsat images and the corresponding lake areas obtained from the Modified Normalized Difference of water index are shown in the table below. Areas mapped from MNDWI were compared with surface areas estimated from NDVI metrics. The lake surface area from both indexes with their respective time periods are also presented in the following table:

Table 4: Results of lake surface area from MNDWI and NDVI

Year		**Lake surface area estimate from metric**	
		MNDWI	**NDVI**
Year	*1985*	*3353.74*	*3255.98*
	1990	*3239.03*	*3199.89*
	1995	*3110.26*	*3096.70*
	2000	*3058.79*	*3097.30*
	2005	*3001.06*	*2992.40*
	2010	*2946.97*	*2930.16*
	2015	*2991.01*	*2994.37*

The lake surface area from both metrics were estimated and used for further analysis. In the second column, the study years, and in the third and fourth columns the areas estimated using MNDWI and NDVI, respectively are shown in table 4 above. The result shows that the MNDWI metrics performed differently on image 1985 but in the remaining years both MNDWI and NDVI metrics resulted with acceptable differences. Based on the result changes of 1985, 1990, 1995, 2005 and 2010, the NDVI approach underestimated the lake surface area change by about 97.75km^2, 39 km^2, 13km2, 16km^2 and 8km^2 respectively. In the year 2000 and 2015, the change is overestimated by about 38 km^2, and 3km^2 respectively. This seems to happen because of the prevalence of algae, grass and papyrus plants as well as some invasive species like water hyacinth in the reservoir, which could be mapped as vegetation.

Statistical goodness of fit tests

Precision of lake surface area estimates were examined in this paper. The examinations were conducted to assess the agreement between the values of measurements. The coefficient of determination (R^2) between the area from the MNDWI and the NDVI metrics were used to evaluate the accuracy of the area estimated. The results of the goodness of fit between these surface area estimates were calculated and the coefficient of determination results were presented as follows:

Table 5:- analysis of coefficient of determination; source own compile

Correlations			
		MNDWI	*NDVI*
MNDWI	*Pearson Correlation*	*1*	*.975***
	R Square		*.950*
	N	*7*	*7*
NDVI	*Pearson Correlation*	*.975***	*1*
	R Square	*.950*	
	N	*7*	*7*

Table 5 shows that the areas mapped from MNDWI were compared with surface areas determined from NDVI method for further statistical significant tests. The results are suggestive of a high association between the areas estimated using the MNDWI and a multi-temporal NDVI metric. The lake area estimated using MNDWI correlates strongly with the area estimated from NDVI metric with the result R2 of 0.950. The depicting surface area (MNDWI) and its counterpart, which was estimated from NDVI of this study, are plotted in Figure 8.

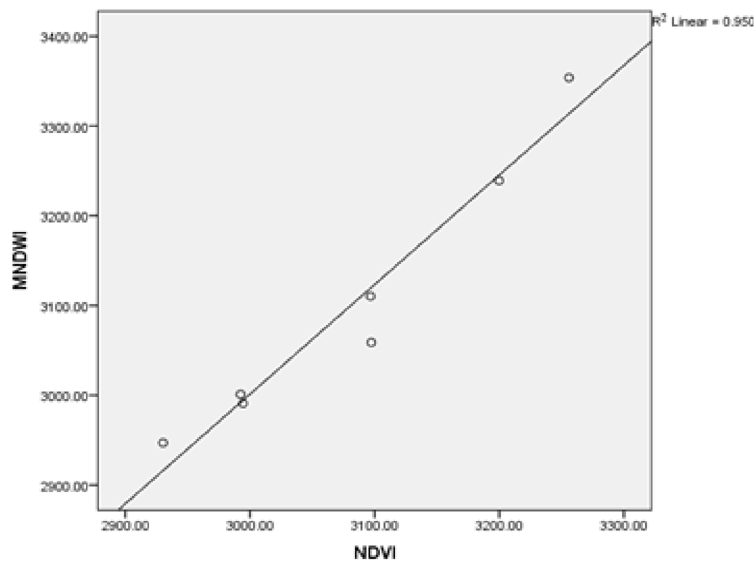

Figure 8: the scatter plot diagram

Results portray that there is a strong relationship (Pearson correlation: r= 0.975) between the estimates of lake surface area results of MNDWI and NDVI metric. The correlation coefficient (R2) of 0.950 shows a good agreement between lake surface area results estimated from both indexes. The coefficient of determination was able to reveal that the surface area estimates from both methods were very strong with the p-value of < .001 as the error of which was accounted by the remaining 1 %. The agreement between these two indexes in estimating the lake surface area was very strong showing that the results calculated by both indexes are significant even at 0.001.

Conclusion

In this work, it was proven that the use of multi temporal satellite images is an effective tool to quantify current lake surface as well as to detect changes in a changing lake. LandstaTM and ETM+ satellite images of the year 1985, 1990, 1995, 2000, 2005 and 2015 were used. After preprocessing, unsupervised MNDWI and NDVI index methods, it is revealed that within these three decades, the lake area has shown a significant decrease. The total surface area changes of the lake between 1985 and 2015 were about 362.74 sq.km; i.e. the lake has lost 10.82 percent of the total surface area in the past 30 years. The area calculated from bathymetric surveys and the calculated corresponding results from other alternative methods were gathered and computed with the findings of this study. The results indicate that there is a strong relationship between the estimates of lake surface area results of MNDWI with NDVI and bathymetry results. For larger lakes like Lake Tana, mid resolution landsat image pixels were able to detect the changes on lake surface area. Similar methodology can be adapted to other specific interest based on the suitable detection indices.

References

Baulies, X., and Szejwach, G., (1998). *LUCC data requirements workshop survey of needs, gaps and priorities on data for land-use/land-cover change research* or ganized by IGBP/IHDP-LUCC AND IGBP-DIS, Barcelona, Spain, 11-14 November 1997 LUCC report series no.

Covich, A.P., Fritz, S.C., Lamb, P.J.., Marzolf, R.D., Matthews, W.J., Poiani, K.A., Prepas, E.E., Richman, M.B. and Winter, T.C., (1997). Potential effects of climate change on aquatic ecosystems of the great plains of North America. *Hydrological Processes*,11(8),993–1021.

Gilbert, A.J. and Janssen, R., (1998). Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. *Ecological Economics*, 25, 323–346.

Kaba E, Philpot W, Steenhuis T. 2007. Evaluating suitability of MODIS-Terra images for reproducing historic sediment concentrations in water bodies: Lake Tana, Ethiopia. *International Journal of Applied Earth Observation and Geo-information*, 26,286-297.

Kebede S, Travi Y, Alemayehu T, Marc V., (2006). Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, *Ethiopia Journal of hydrology*, 316(1), 233–247

Kindie, Abye, (2001). *Wetlands distribution in Amhara Region, their importance and current threats.* In Dixon, A.B., A. Hailu and A.P. Wood (eds.),

Kindie, Abye, (2001). *Wetlands distribution in Amhara Region, their importance and current threats.* In Dixon, A.B., A. Hailu and A.P. Wood (eds.),

Lane, C. R., and E. D'Amico., (2010). *Calculating the Ecosystem Service of Water Storage in Isolated Wetlands Using LiDAR in North Central Florida,* USA. *Wet lands*, 30: 967–977

Lei Ji, Li Zhang, and Bruce Wylie (2009). Analysis of dynamic thresholds for the nomalized difference water index.*Photogrammetric Engineering & Remote Sensing*, 75(11), 1307–1317.

Menale, (2013). *Retrospective Analysis of Land Cover and Use Dynamics inGilgelAbbay Watershed by Using GIS and Remote SensingTechniques*, Northwestern Ethiopia

Prakasam, P. B. and Rose, C. W. (2010). Modeling water erosion due to overland flow using physical principles 1. Sheet flow. *Water Resources Research*, 28(1), 237-

243.
Quentin F. B., Jim, C., Julia, C., Carole, H., and Andrew, S., (2006). *Drivers of land use change Final report: Matching opportunities to motivations,* ESAI project 05116, Department of Sustainability and Environment and primary industries, Royal Melbourne Institute of Technology,Australia.

Rai Bento H. Adrriano. M, (2006). Review article digital change detection techniques using remotely sensed data,International Journal of Remote Sensing, 10(6), 98-110

Tansey, hulla, Emanda (2006). *Biology and management of fish stocks in Bahir Dar Gulf, Lake Tana, Ethiopia.(PhD thesis).*Wageningen Institute of Animal Science, Wagnen Agricultural University, the Netherlands.

Wale, A., Rientjes, T. H. M., Dost, R. J. J., & Gieske, A. (2008, April). *Hydrological Bal ance of Lake Tana Upper Blue Nile Basin, Ethiopia.* The Netherlands: ITC.