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Geomorphology of the Lake Tana basin, Ethiopia

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The geomorphological map of the Lake Tana basin (15,077 km^2, Nile basin, Ethiopia) presented in this paper was prepared from fieldwork data, maps and satellite data that were processed with a geographic information system (GIS). It contains four major components: (i) hydrography, (ii) morphology and morphometry, (iii) materials and (iv) processes at a scale of 1:500,000. The geomorphological setting of the basin consists of lavas that erupted from fissures or (shield) volcanoes during the Tertiary and Quaternary eras, were uplifted and eroded primarily by water. Lake Tana emerged through a combination of a lava barrier blocking the Blue Nile to the south and by epirogenetic subsidence. When the lake reached its maximum extent, extensive lacustrine plain (e.g. Fogera and Dembia plains) were created, river valleys and basins were filled with sediment and higher lying topography was eroded. Today, the lake plays a lesser role in landscape formation because of a decreased extent (3041 km^2) compared to the ancient maximum (6514 km^2). Dominant processes today are fluvial and subaerial. Recent (1886–2010) changes in the lake coastline are small with the exception of the delta formed by Gilgel Abay, which has increased disproportionally over the last 15 years. This indicates a large input of sediment which is mainly due to rivers flowing through Quaternary lavas. The recent sediment input increase is most probably related to human induced land-use changes.

Keywords: Lake Tana; geomorphology; lake level fluctuation; Blue Nile; Ethiopia; Gilgel Abay

1. Introduction

Lake Tana (3041 km^2, 1785 m a.s.l.) is the largest lake in Ethiopia. It is situated in the north-western Ethiopian highlands, and is fed by numerous seasonal rivers and four permanent rivers: Megech, Rib, Gumara and Gilgel Abay (Figure 1). The outlet of the lake at its southern tip yields the Blue Nile. The lake has a high ecological value and its water is used for many purposes, including irrigation, hydropower, fishing, transportation and tourism. Sustainable use of

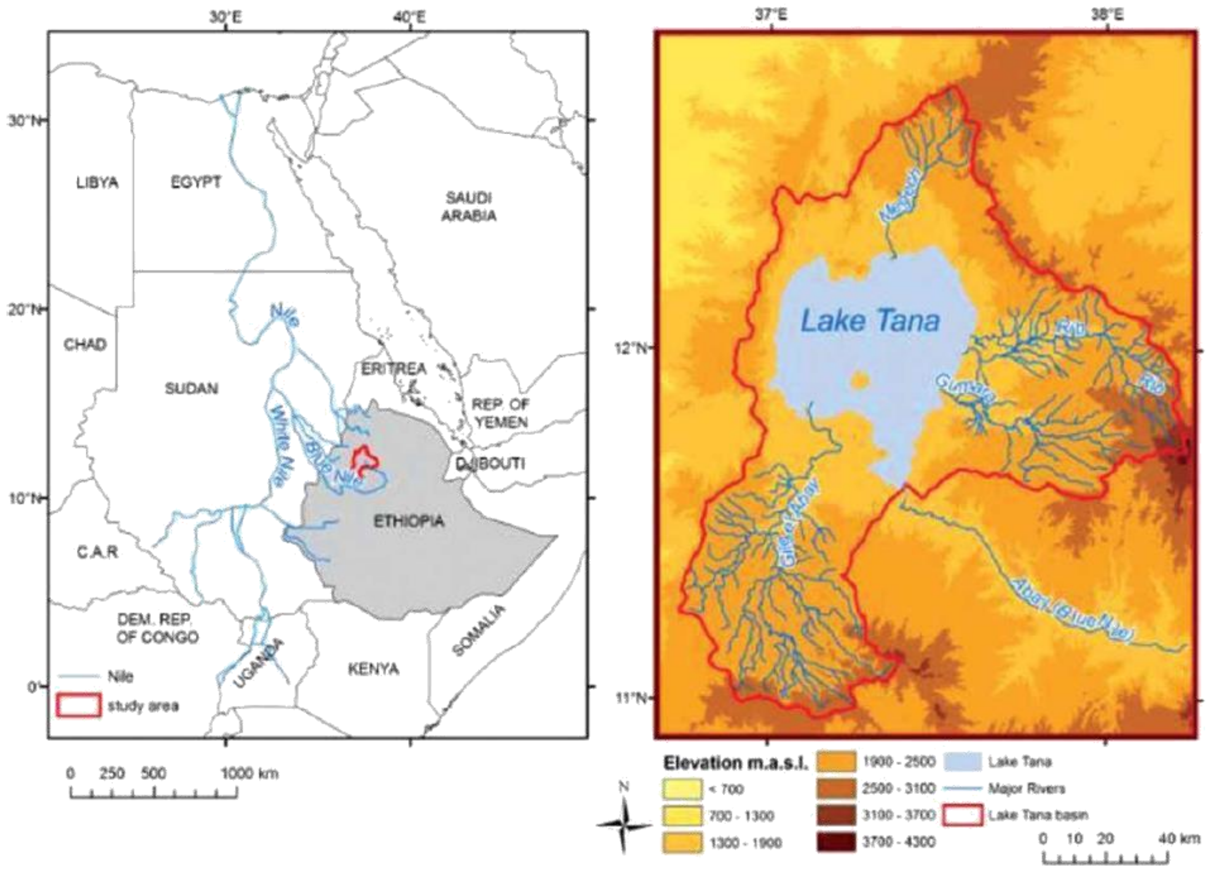

Figure 1. Location of study area a) in Africa and b) on an ASTER DEM (available from http://www.gdem.aster.ersdac.or.jp/).

this water reservoir poses challenges among its users who often have conflicting interests. The most striking example is the conflict between power generation and tourism: hydropower generation sometimes dries out the Blue Nile Falls which draws many tourists. Geopolitical tension between countries depending on Nile water further illustrates this issue.

The Lake Tana basin mainly constitutes lavas that erupted during the Plio-Oligocene through fissures and later through shield volcanoes (Kieffer et al., 2004). During the Pliocene – Holocene, Aden series lavas erupted and formed a volcanic barrier to the south of Lake Tana, which helped to form the present lake (Mohr, 1964). It is, however, argued by Chorowicz et al. (1998) that the Lake Tana basin is formed by a convergence of three grabens, which formed before the mid-Tertiary by deep-slip faults. Chorowicz et al. (1998) also found that fault reactivation occurred in the Late-Miocene-Quaternary period.

The rainy season in the Lake Tana basin occurs from June to September, resulting from the movement of the inter-tropical convergence zone (ITCZ). When the ITCZ is located to the north of the equator, Ethiopia receives moist air masses from the Atlantic and Indian Oceans (Kebede et al., 2006). Mean annual rainfall over the Lake Tana basin is 1421 mm (Conway, 2000), mean annual air temperature is 20°C (Kebede et al., 2006) and mean annual evapotranspiration for the basin is 773 mm (Setegn, 2008).

The importance of Lake Tana for Ethiopia and for downstream countries warrants the production of a geomorphological map. This map (see Online Supplementary Material) will contribute to a better understanding of (a) the formation of the landscape in the Lake Tana basin, (b) the crucial role that lake fluctuations played in determining the geomorphology of the Lake Tana basin, (c) the magnitude of the current erosion processes and (d) the hydrological balance of Lake Tana.

2. Methods

Geomorphological fieldwork was conducted from July to September 2011 to:

- verify and adjust information held on existing geological maps by Kazmin (1972) and BCEOM (1999)
- map distinct geomorphologic features and entities using handheld global positioning system (GPS) receiver
- assess changes in lake extent by investigating ancient lake beaches including those mentioned by Nilsson (1940)
- map inactive volcanic craters, volcanic plugs and faulted blocks. Mapping was augmented using Google Earth (Poppe, 2012).

The hydrology and some geomorphic landforms were mapped using GeoEye, CNES/SPOT and DigitalGlobe imagery available through Google Earth (accessed from http://www.google.com/earth/index.html) and ASTER (accessed from http://www.gdem.aster.ersdac.or.jp/). Isobaths have been defined by digitising the bathymetric map by Pietrangeli (1988) and by applying Natural Neighbour interpolation in Esri ArcGIS 9.3.1.

Lake extent variations were analysed using historical maps from 1868 to 1936 (Table 1) and Landsat imagery from 1973 to 2010 available from the US Geological Survey (USGS) (http://earthexplorer.usgs.gov). The lake was delineated in the Landsat images by using a supervised classification. To test the accuracy of this method, the obtained lake extent was compared to

Table 1. Details about consulted maps.

Holder (H)/Author (A)	Source: Aerial photograph (AP)/Fieldwork (F)/Satellite (S)	Publication	Scale	Area	Series/Sheet
Istituto Geografico Militare	1868–1885 (F)	1901	1:400,000	Gonder region	693
Studio Cartog. G. Giardi – Firenze (H) M. Checchi (A)	1882 (F)	1913	1:600,000	Lake Tana	2114/14 A8
Istituto Geografico Militare (H)	1882 and later (F)	1934	1:400,000	Gonder region	18 A 6/F9
Grabham and Black (A)	1920–1921 (F)	1925	1:500,000	Lake Tana catchment	/
Cheesman	1927 (F)	1936	± 1:500,000	Lake Tana catchment	/
Kazmin	?	1972	1:2,000,000	Ethiopia	
Ethiopian Mapping Agency (H)	1987 (S)	1996	1:500,000	Bahir Dar	EMA 3/ NC- 37-1
Studio Pietrangeli (A)	?	1988	1:200,000	Lake Tana	0801D09A
Ethiopian Mapping Agency (H)	1988 (AP)	1996	1:500,000	Debre Tabor	EMA 3/ NC 37-2
Ethiopian Mapping Agency (H)	1995 (S)	2001	1:500,000	Gondar	EMA 3/ ND 37-13
Ethiopian Mapping Agency (H)	1995 (S)	2001	1:500,000	Yifag	EMA 3/ ND 37-14
BCEOM	1998 (F)	1999	Digital edition	Lake Tana basin	/

lake stage measured at Bahir Dar (south of Lake Tana) lake gauge. A strong correlation was found between the two ($R^2 = 0.86$, $p < 0.0001$).

The accuracy of all these different methods is specified on the geomorphological map. More detailed information about the mapping process and accuracies are given by Poppe (2012).

The geomorphological map was designed using colour for both lithology and chronology following Gustavsson, Kolstrup, and Seijmonsbergen (2006). Colour choice was based on standards of the Alpine Geomorphology Research Group (AGRG) (Degraaff, Dejong, Rupke, & Verhofstad, 1987). The geographic datum used is the WGS 1984 spheroid and the projection is the Universal Transverse Mercator, zone 37N.

3. Geomorphological map of Lake Tana basin and its legend

3.1. *Hydrography*

The hydrogeomorphology of the Lake Tana basin is heterogeneous. The four major rivers are characterised by a succession between bedrock types in their higher reaches, and alluvial types in their lower reaches and floodplains. These alluvial rivers were classified into meandering, anastomosing and braided river types. The river type on the Quaternary Aden series is predominantly braided (see for instance Gumara River between 11.7959°N, 37.6596°E and 11.7909°N, 37.6678°E). This can be linked to the strong sediment input in the lake at the delta of the Gilgel Abay river, whose catchment is mainly occupied by Aden series lavas. Palaeohydrography of the basin was not shown on the geomorphological map, but is reported in Poppe (2012)

3.2. *Geomorphology*

The faulted blocks on the western and eastern margin of Lake Tana support the theory of Chorowicz et al. (1998) that the basin is formed by the convergence of three grabens. During fieldwork it was also clear at the Blue Nile Falls that the Blue Nile plunges over a volcanic barrier that consists of more recent lavas: the Aden series (Mohr, 1964). During geomorphologic mapping, evidence was found reconciling both theories. It is argued here that the basin formed by convergence of three grabens during the mid-Tertiary (Chorowicz et al., 1998) and then extended by lava damming.

The West Tana Escarpment (Chorowicz et al., 1998), which is the water divide for a large part of the west of the basin, is an erosional feature – as suggested by Grabham and Black (1925) – because the escarpment is fringed and not straight like a fault. It was therefore formed by water erosion.

3.3. *Materials*

3.3.1. *Igneous rock*

Igneous rocks comprise the Mio-Pliocene 'Trap Series' and the Quaternary 'Aden Series' (Gani, Gani, & Abdelsalam, 2007; Kazmin, 1972). The Trap series (mainly basalts) extruded from fissures and centres of flood lavas and built up a 500–1500 m thick volcanic pile (Mohr, 1964; Mohr & Zanettin, 1988). Trap series also contain two shield volcanoes from the Miocene which partially form the water divide on the south-eastern margin of the basin: Mount Choke (3504 m a.s.l.) and Mount Guna (4086 m a.s.l.). The entire basin consists of these lavas which are outcropping where they are not overlain by the more recent Aden series or by lacustrine deposits.

The Aden series are characterised by the presence of several strombolian volcanoes that are striking features of the landscape (Figure 2). During the field study, it was observed that parts of the outcropping Quaternary Aden series were more intensively weathered than their surrounding Mio-Pliocene Trap series.

Figure 2. Magma conduit, with lava tube (i.e. a cave, note two persons standing at the entrance) in a strombolian volcano near Merawi. A dyke is also visible within the scoria and the cave is surrounded by volcanic ashes, lapilli and volcanic bombs (in the foreground). Photo taken on 02/08/11 by Ludwin Poppe (11.41559°N 37.13596°E).

3.3.2. *Unconsolidated sediments*

Unconsolidated Quaternary sediments stem from lacustrine, fluvial or hillslope processes. Lacustrine sediments were recognised in the field as black, clearly layered fine sediments which often occur on a large plain or in a drowned valley. These sediments are situated north and east of the lake, where the lake is bordering flat to gently sloping land (Nilsson, 1940). Occurrences of these sediments helped determine the paleoshoreline. Soils formed on these sediments have been analysed by Colot (2012).

Alluvial/colluvial deposits generated from fluvial processes, are locally mixed with slope colluvium. These sediments have a brownish/red colour in the field and are found on slopes and along rivers.

3.4. ***Processes***

Variations in the level and extent of Lake Tana, which interfere with geomorphic processes in the basin, were first studied in detail by Nilsson (1940). An ancient maximum lake level was assumed to exist 120 m above the current lake level. Based on Lamb et al. (2007), we can conclude that such a lake should be at least dated to 15,000 BP. Plotting this assumed level on an ASTER DEM, however, revealed that the present basin cannot support such a high lake level, as the lake would overflow at several locations.

Reinvestigation of ancient lake beaches led to the conclusion that the maximum level of Lake Tana was at 1861 $\pm$ 2.5 m a.s.l., i.e. 76 m higher than the present lake level. This conclusion was

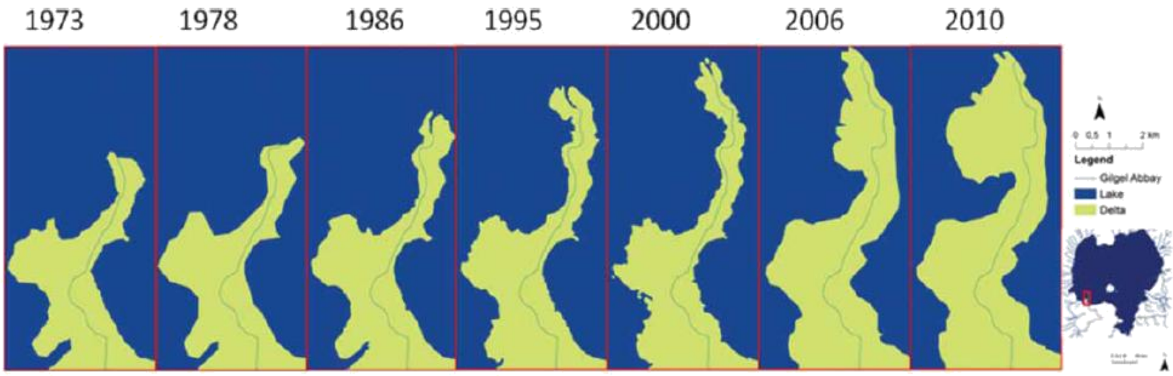

Figure 3. Expansion of Gilgel Abay delta during the period 1973–2010 based on the analysis of Landsat imagery (available from http://earthexplorer.usgs.gov).

drawn based on field evidence of lacustrine deposits at that height. A stage-area curve was calculated for the lake: the equation for lake stage (in m) is: Y = 0.035 X (lake extent in km^2) + 1677. This corresponds to an extent of 6514 km^2 for the ancient maximum lake compared to the present lake extent of 3041 km^2.

Recent (twentieth century) changes in lake extent are small: there is no significant pattern, and there are only small coastal changes. These coastal changes have been linked to dominant wind direction (Gasse, 1987), but no structural link with coastal change was revealed. There is, however, a structural link between rivers flowing through the Aden series and river deltas that have increased significantly during the period (1973–2010). Gilgel Abay's entire catchment is located on the Aden series, and it's delta had the greatest increase (Figure 3). It was also noticed that coasts with small cliffs are often linked with a deep lake bottom and present minor coastal changes.

Tectonic processes are indicated on the map by digitising fault lines from Kazmin (1972), and indicating the three grabens that formed the Lake Tana basin. The edges of the grabens are modified from Chorowicz et al. (1998) based on field observations and Google Earth observations.

4. Conclusions

The geomorphological map, prepared from fieldwork and the analysis of satellite imagery shows that the Lake Tana basin has changed gradually over time. Eruption of the Trap series was followed by formation of shield volcanoes and then eruption of the Aden series. Not only has this basin been formed by lavas, it has also been shaped by tectonic forces: three grabens formed in the lavas during the mid-Tertiary and Lake Tana is located at their convergence.

The importance of lake level and area fluctuations is shown on the map and is crucial for the history of Lake Tana, especially for long-term variations in lake deposits. Lake Tana has an area of 3041 km^2 and is at 1785 m a.s.l., whereas at >15,000 BP it had an area of 6514 km^2, and was located at 1861 m a.s.l.. In the more recent period (1868–2010) the lake level did not show important fluctuations. Coastal erosion and sediment deposition has also been negligible, except at Gilgel Abay delta, which shows considerable change during the last 40 years and particularly in the last 15 years, in response to intense soil erosion in the catchment.

Software

For conducting the supervised classification of the Landsat images, Erdas Image Analyst was used with Esri ArcGIS 9.3.1. The latter was used for the construction of the geomorphological map.

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The water balance of Lake Tana

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Introduction

Lakes are very important components of the earth's hydrological cycle, providing a variety of services for humans and ecosystem functioning. For a sustainable use of lakes, a substantial body of knowledge on their water balance is vital. We present here a daily water balance analysis for Lake Tana, the largest lake in Ethiopia and the source of the Blue Nile.

A review of the previous water balance studies of the lake reveals that most of these studies ignored the extensive floodplain of the Lake Tana basin and its impacts on the water balance of the lake. Significant contribution in this perspective is attributed to Kebede et al. (2011). Floodplains are specific ecosystems, oscillating between terrestrial and aquatic phases (Junk, 1996), having different topography, soils and vegetation patterns. The water balance studies of the lake should address the floodplain hydrology properly and its impacts on the water budgets of the lake. This study analyses the water balance of the lake and the impacts of the extensive floodplain on its water balance.

Methodology

Water balance components of the lake (Fig.1) are quantified simulating two scenarios. Scenario 1 attempts to analyze the water balance of the lake omitting the floodplain. This scenario hypothetically removes the floodplain and its buffering effect from the lake system and estimates the water balance of the lake. Scenario 2 deals with the real field situation (the lake basin and the lake- floodplain system) and the effects of the floodplain are included in the analysis. Based on a comparison of the results of both scenarios, the impacts of the floodplain on the water balance of the lake will be evaluated.

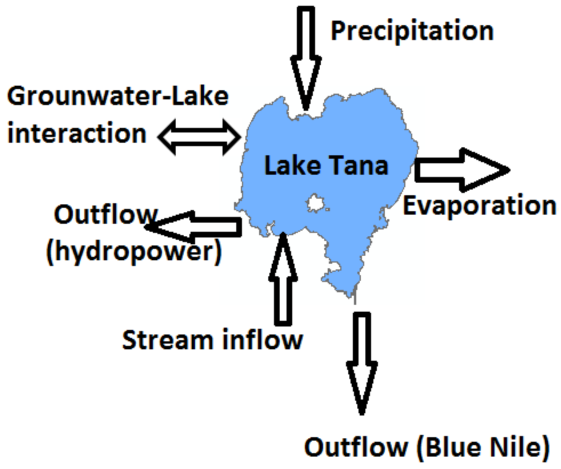

Figure 1. Main components of the water balance terms of Lake Tana

The lake level fluctuations are governed by an Input-Storage-Output process, which can be described by the following water balance model (all terms in $Mm^3\ day^{-1}$):

$$\frac{\Delta S}{\Delta t} = P_{lake} - E_{lake} + Q_{gauged} + Q_{ungauged} - Q_{out} + \varepsilon$$

where $\frac{\Delta S}{\Delta t}$ denotes the change in storage over time, P_{lake} is lake areal rainfall, E_{lake} is the rate of lake evaporation, Q_{gauged} is gauged river inflow, $Q_{ungauged}$ is ungauged river inflow, Q_{out} is the outflow at the Blue Nile River and at the tunnel to the hydropower station, and ε represents the uncertainties in the water balance arising from errors in the data and other terms, such as net groundwater flux or minor abstractions, which usually cannot be accounted for directly.

(1) Estimation of rainfall and evaporation on the lake

Daily measurements from six precipitation stations, located at the lake shore (Bahir Dar, Gorgora, Dengel Ber, and Zegie), at the island of the lake (Dek Estifanos) and close to the lake (Maksegnit), were used to calculate areal rainfall on the lake by the Thiessen Polygon method.

For estimating the lake water evaporation depth, daily maximum and minimum air temperature data from the above 6 stations is used, whilst wind speed, relative air humidity and sunshine hours are collected from Bahir Dar meteorological station. The daily evaporation depth was estimated by the Penman-combination method (Maidment, 1993), which is widely applied as a standard method in water resources engineering.

(2) **Runoff from gauged and ungauged catchments**

The daily runoff flowing into the lake from the gauged catchments (Fig. 2) has been derived for the period 2012 and 2013 using measured water levels of the rivers. The runoff from the ungauged parts of the catchments (Fig. 2) was estimated using a conceptual hydrological model and a runoff coefficient approach.

The conceptual hydrological model of Dessie et al. (2014) was used for ungauged catchment rivers that drain to the lake with no or minimal influence of the floodplain on their way to the lake. The runoff estimation of the ungauged floodplain and the hillslope catchments (Fig. 2) that are affected by the floodplain as the rivers flow across the floodplain are made using the runoff coefficient approach. The runoff coefficients (Table 1) were determined based on discharge measurements from three discharge monitoring stations in the floodplain.

Table 1. Characteristics of the ungauged catchments (including the floodplain), the runoff which are influenced by the floodplain on the way to the lake, and the runoff coefficients used to estimate their corresponding runoff depths.

Location	catchment area (km^2)	Runoff coefficients for stations in the floodplain		Average runoff coefficient
		year 2012	year 2013	
Gumara catchment	81.7	0.65	0.53	0.59
Rib Catchment	950.1	0.22	0.2	0.21
North of Lake Tana basin (including Megech, Dirma and adjacent catchments)	1170.3	0.37	0.11	0.24
Gilgel Abay and Adjacent catchments	336.5	0.61	0.5	0.56

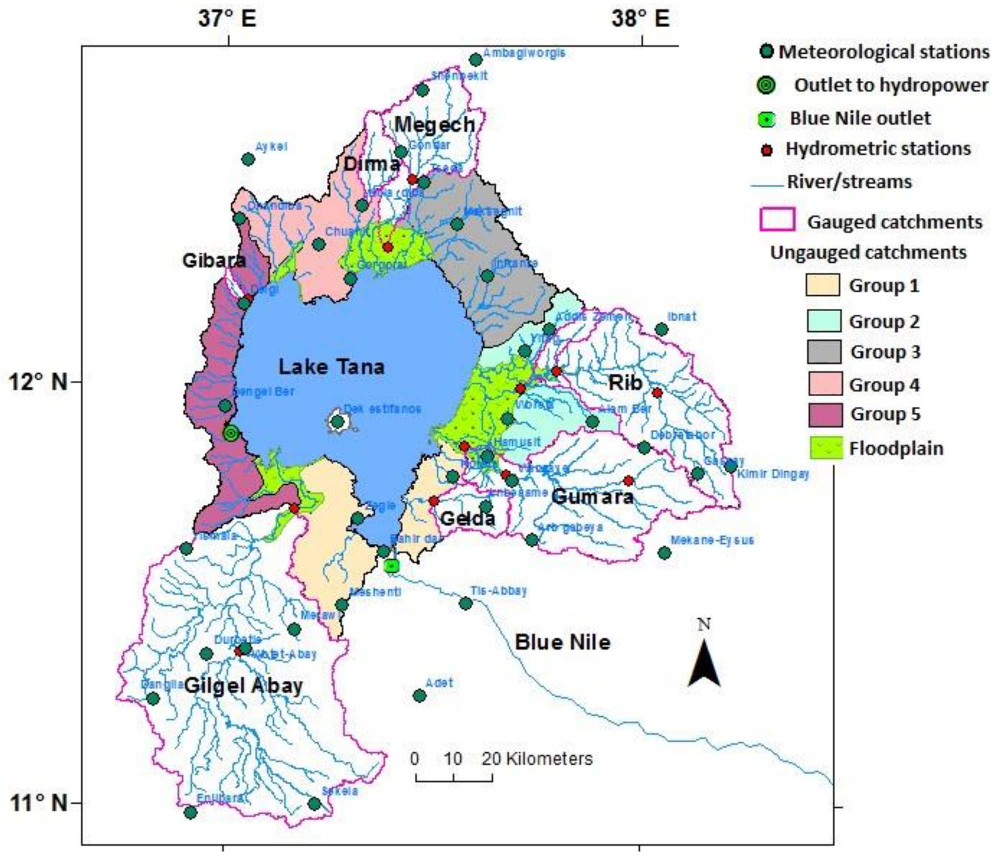

Figure 2. Gauged and ungauged catchments in the Lake Tana basin. Runoff from the groups of ungauged catchments was predicted based on calibrated model parameters of observed runoff data from Gelda for Group 1, from Rib for Group 2, from Megech for Group 3, from Dirma for Group 4, and from Gibara for Group 5.

(3) Outflow, lake levels and water level-area-volume relationships

Daily observation records of discharges are available on both outlets (at Chara Chara weir near the city of Bahir Dar, and a tunnel hydropower outlet for Tana Beles hydropower (from Ministry of Water, Irrigation & Energy and Tana Beles Hydroelectric Power Plant, Ethiopia) and are directly used in the present water balance and lake level simulation studies. We obtained daily lake water level data at Bahir Dar and Kunzila stations (Tana Beles Hydropower outlet) for the years 2012 and 2013.

Results and discussion

(1) River inflows

The analysis of river inflows for the years 2012 and 2013 revealed that Lake Tana received an average yearly runoff of 5.61×10^9 m^3 from gauged and 1.22×10^9 m^3 from ungauged catchments, disregarding the water abstraction by irrigation in the ungauged catchments. More importantly, 0.42×10^9 m^3 of water does not reach the lake. Most of the abstraction (about 50% of the total) takes place by the floodplain (via runoff transmission losses) following the downstream reaches of the Rib River. Floodplains at some reaches of the Gumara River and the southern shore of the lake are exceptions and there is runoff contribution from these floodplains as indicated by the presence of many springs in these areas. Further analysis of the river inflows to the lake shows that 58% of the inflow to the lake is generated from the southern part of the catchment (Table 2), which covers about 38% of the total catchment area of the lake.

Table 2. Runoff inflows to Lake Tana for different sub-catchments

Lake Tana catchment divisions	Major Rivers	Catchment area (km^2)	Average annual rainfall (mm)	Inflow to the lake (mm)	Inflow to the lake ($x10^6$ m^3)	Inflow to the lake from the total (%)
Southern catchment	Gilgel Abay	4507	1660	880	3961.08	58
Eastern catchment	Gelda, Gumara and Rib	4182	1470	490	2044.76	30
Northern catchment	Garno, Arno, Gabi Kura, Megech, Dirma	2651	1140	260	689.24	10
Western catchment	more than 20 smaller streams	660	1035	210	136.41	2

(2) The water balance terms

The results of the annual input and output water fluxes of the lake for both scenarios are indicated in Table 3.

Table 3. Average annual water balance terms of Lake Tana (years 2012 and 2013).

Water balance terms	Scenario 1		Scenario 2	
	mm	10^6 m^3	mm	10^6 m^3
Lake areal rainfall	1330	4129.0	1330	4129.0
Gauged river inflow	1819	5645.5	1807	5608.2
Ungauged river inflow	530	1645.3	394	1223.3
Lake evaporation	-1789	-5547.3	-1789	-5547.3
Outflow from the lake	-1618	-5022.9	-1618	-5022.9
Water abstraction by irrigation	-35	-108	-42	-134
Closure term	238	741.6	82	256.3

(3) Lake level simulations

The results of lake level simulations (Fig. 3) indicate a good match with the observed lake levels for both scenarios, although larger deviations are observed for scenario 1 during the end of the simulation period. The lake level simulations resulted in R^2 values of 0.94 and 0.95 for Scenario 1 and Scenario 2 respectively, which is very similar irrespective of the differences in the closure terms of the water balance terms.

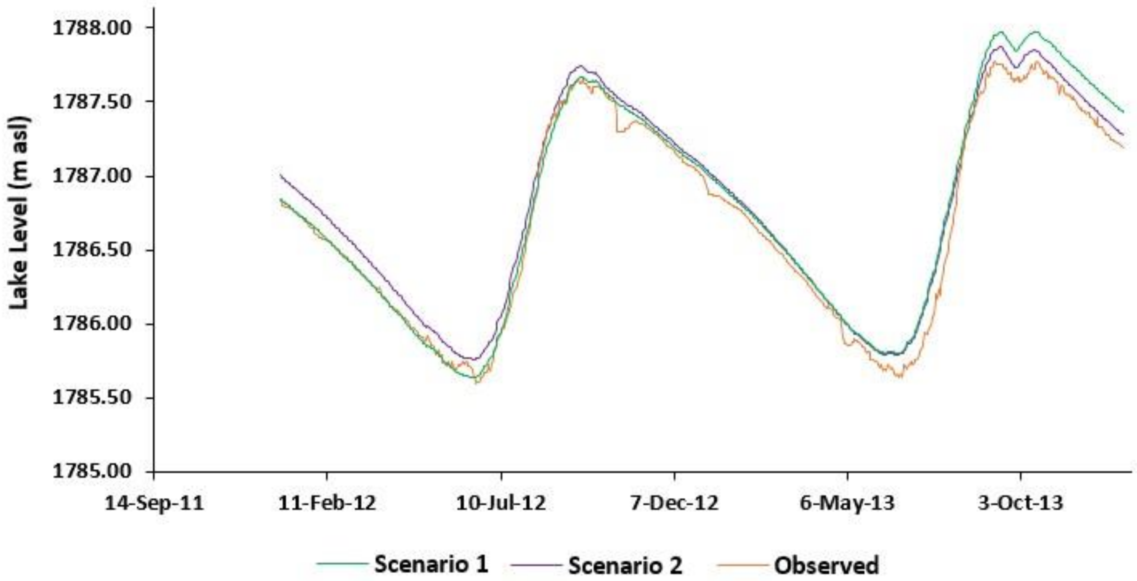

Figure 3. Observed and simulated lake levels for the two Scenarios. Scenario 1 simulates the lake level of Lake Tana omitting the floodplain and its effects. Scenario 2 simulates the real field situation (i.e. the lake basin and the lake-floodplain interactions).

Conclusions

The Lake Tana water balance analysis presented here describes the different water balance components of the lake and provides a meaningful assessment of the components. It demonstrates the importance and the influence of the extensive floodplain on the water balance of the lake. More importantly, 0.42×10^9 m^3 of water does not reach the lake.

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Sediment budget of Lake Tana and the role of lacustrine plains

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1. Introduction

The shallow Lake Tana is at high risk of siltation due to the wide-ranging land degradation in the basin. Research efforts made so far in the basin on its sediment budget are scanty and all attempts are constrained by limited data availability and reliability. Moreover, part of the lacustrine plains is subjected to periodic flooding and sediment deposition (Poppe et al., 2013; SMEC, 2008). Overbank sedimentation on these river floodplains can result in a significant reduction of suspended sediment load transported by a river and thus represents an important component of the sediment budget (Walling et al., 1998). Despite its crucial importance in the sediment budget, floodplain sedimentation is not studied so far in the basin or at country level (Abate et al., 2015; Nyssen et al., 2004). This study attempts to quantify the amount of sediment transported into the lake, stored on the floodplains, delivered out of the lake and stored in the lake annually in order to establish a sediment budget for Lake Tana.

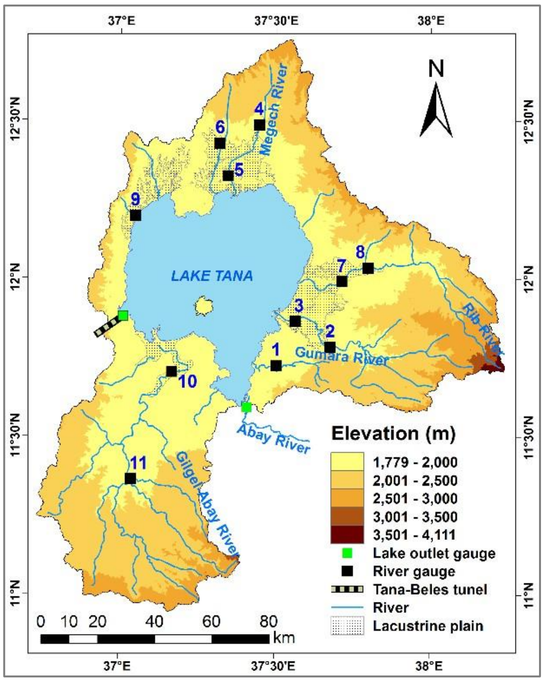


Figure 1. Location of study area

2. Methodology

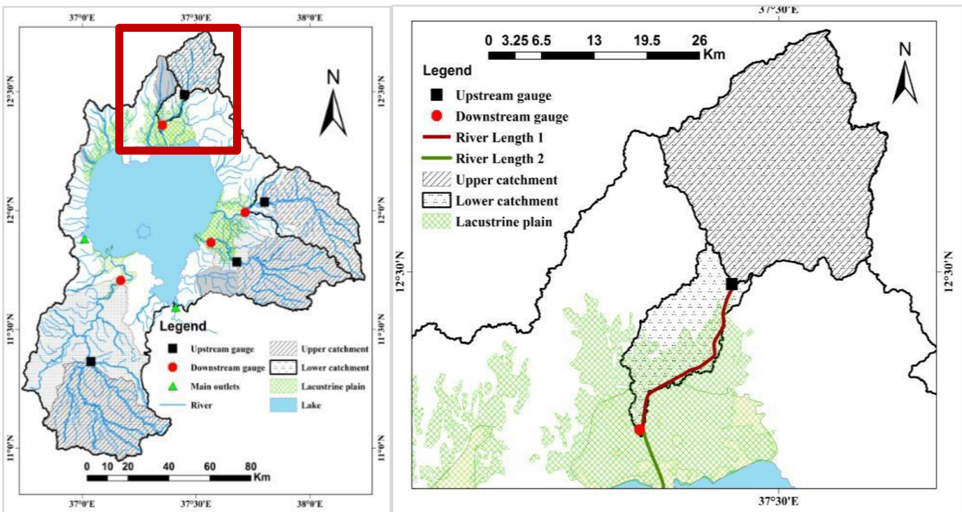
A total of 4635 data on discrete SSC with the corresponding river flow stage have been collected since June 2012, for 13 monitoring stations (Fig. 1; Table 1) by the project called 'Water and sediment budgets of Lake Tana for optimization of land management and water allocation' (WASE-TANA). The flow stage was collected every 10 to 20 minutes for the months of June to October and on daily basis for months of November to May, except the monitoring station at the Tana-Beles tunnel inlet. The river stage (m) was translated to discharge (m^3 s^{-1}) using the rating curves developed by Dessie et al. (2014).

Table 1. Monitoring stations and number of suspended sediment concentration (SSC) samples collected

No.	Station name	Area (km^2)	No. of SSC samples
1	Gelda	190	425
2	Upper Gumara (Wanzaye)	1227	386
3	Lower Gumara	1608	342
4	Upper Megech (Bridge)	514	409
5	Lower Megech (Robit)	652	338
6	Dirma	163	339
7	Lower Rib (Rib Bridge)	1394	485
8	Upper Rib (Abo-Bahir)	1166	394
9	Gibara	23	251
10	Lower Gilgel-Abay (Chimba)	3653	472
11	Upper Gilgel-Abay (Bikolo)	1656	490
12	Abay (Blue Nile) outlet		259
13	Tana-Beles tunnel inlet*		45

Note: * indicates gauge station where only SSC samples are taken, but discharge from EEPCo

To calculate sediment yield (SY) of the 11 gauged rivers, 5 rating curves within a year were developed in order to account for the seasonal effect (Zenebe et al., 2013). SY of ungauged catchments was also determined using an established regression model using catchment area and average annual catchment rainfall. Floodplain deposition rate was calculated from measurements taken at the upstream and downstream monitoring stations of Gilgel-Abay, Gumara, Rib and Megech Rivers (Fig. 2). The selected rivers are crossing large floodplains in their low-lying catchment areas.



$$\text{Load-1} = SY_{US} - SY_{DS}$$

$$D_{rate} = \frac{SY_{US} - SY_{DS}}{L_1}$$

$$\text{Load-2} = L_2 \times D_{rate}$$

Figure 2. Concept for determining floodplain deposition using upstream and downstream river gauge stations and river length

Load-1 and Load-2 were summed and gave total sediment load deposited on floodplains that are bordering that specific river.
Sediment leaving the lake through Abay (Blue Nile) River and Tana-Beles tunnel could be determined as the sum over the year of the product of daily discharge and daily SSC (constant for each month). In this case, we did not try to correlate SSC to Q given that (1) Q is not determined by a natural process but rather by decision of Ethiopian Electric and Power Corporation, and (2) SSC depends on the concentration in the lake, there is no high variability that can be related to discharges such as in river water.
The bed load fraction was estimated using an average measured range of 7% of the total load for for rivers that cross the floodplains (Adeogun et al., 2011) and 11.2% for the hilly catchments without floodplains (NBCBN, 2005). So far, the magnitude of the sediment delivered directly from the shores into the lake is unknown. However, the average erosion rate in LTB is 70 t ha^{-1} yr^{-1} (Kindye, 2013; NBCBN, 2005; Tilahun et al., 2014). Applying the Ethiopian Highlands Reclamation Study 10% estimated sediment delivery ratio to the water body, gives an average specific sediment yield (SSY) of 7 t ha^{-1} yr^{-1} from lake shores and other areas draining directly into the lake (FAO, 1986).
The sediment budget of Lake Tana Basin was then established as:

$$\Delta S_{LT} = SY_g + SY_u + SY_b + SY_s - D_f - SY_{AR} - SY_{TB}$$

where ΔS_{LT} is the net annual sediment deposition in Lake Tana, SYg and SYu are the annual suspended sediment load that are transported to the lake from the gauged and ungauged catchments, SYb is the annual bed load transported to the lake, SYs is the annual sediment load transported directly from the shores into the lake, Df is the sediment deposited annually on floodplains bordering the main rivers, SYAR and SYTB are the sediment load exported from the lake through Abay river and Tana-Beles tunnel.

3. Sediment rating curve and SY from gauged rivers

From the developed sediment rating curves (Figure 3), it is clear that the curves developed for the five periods of the season perform generally much better than a rating curve based on all observations made during the entire measuring campaign: for a given river discharge, SSC values are lower towards the end of the rainy season than at the beginning of the rainy season (Fig. 3). The main reason is that the soil in cultivated lands is bare and loose due to frequent ploughing at the beginning of the rainy season and that there is increased ground cover by crops/vegetation, and decrease in sediment supply towards the end of the rainy season (Asselman, 2000) .

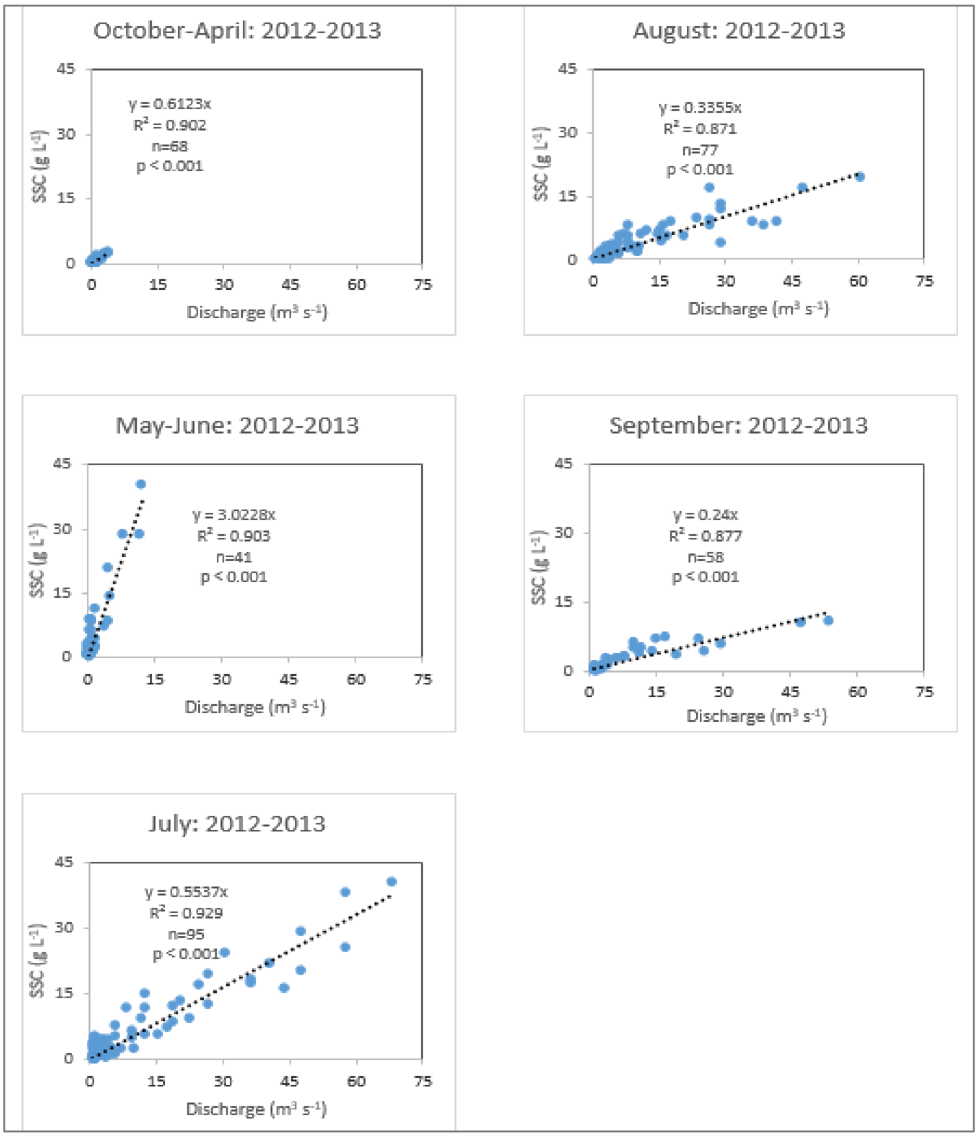


Figure 3. Sediment rating curves of Dirma monitoring station

After evaluating their performance, the rating curve equations were used to calculate the SY and SSY (Table 2). Besides having large catchment areas and higher rainfall, catchments in the south and east are more mountainous with steep slopes. Hence, most suspended sediment is originating from catchments in the South and East of Lake Tana. Regarding the relative order of importance of rivers in transporting suspended sediment load into Lake Tana, Gilgel-Abay (29%) delivers the highest, followed in decreasing order by rivers Gumara (21%), Megech (5%) and Rib (3.5%).

Table 2. Overview of average annual SY (2012-2013) and SSY for different gauged rivers draining into Lake Tana

Main River	**Gauge station**	**Area (km^2)**	**Average SY ($t\ yr^{-1}$)**	**SSY ($t\ km^{-2}\ yr^{-1}$)**
Dirma	Dirma station	163	28,509	175
Gelda	Gelda station	190	70,227	370
Gibara	Gibara station	23	4,733	206
Gilgel-Abay	Upper station (Bikolo)	1656	762,622	461
	Lower station (Chimba)	3653	753,739	206
Gumara	Upper station (Wanzaye)	1227	545,268	444
	Lower station	1608	274,591	171
Megech	Upper station (Megech Bridge)	514	119,325	232
	Lower station (Robit)	652	64,225	99
Rib	Upper station (Abo Bahir)	1166	92,876	80
	Lower station (Rib Bridge)	1394	71,075	51

4. SY from the ungauged rivers

Overall, catchment areas range from 12 to 3808 km^2, whereas the mean annual rainfall ranges from 872 to 1739 mm. After trial of various combinations of explanatory factors, it appeared that the product of catchment area and annual rainfall explained best the annual sediment yield (Fig. 4; Fig. 5).
The use of this equation to calculate SY based on catchment area (A) and annual rainfall (P) gives a total annual sediment yield of 996,968 tons yr^{-1} from all ungauged catchments.

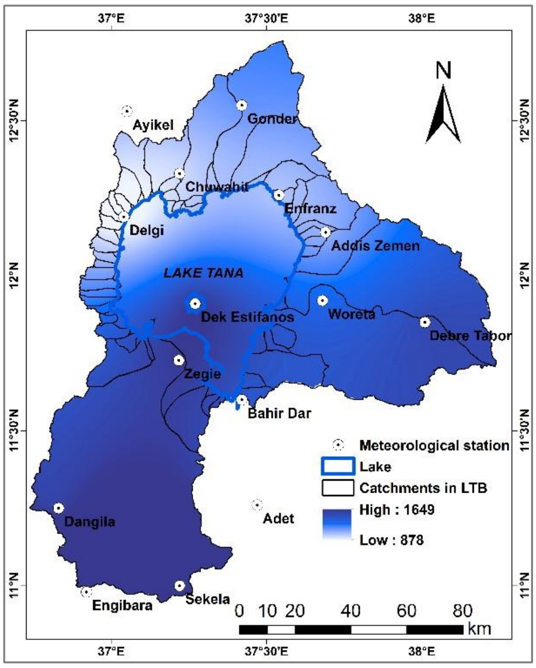


Figure 4. Average annual rainfall in LTB

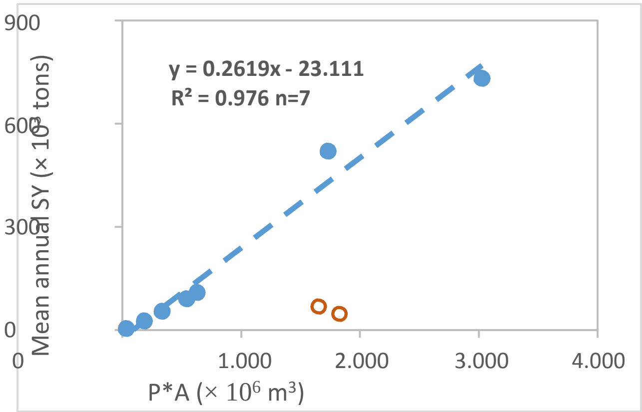


Figure 5. Relationship of mean annual SY of hilly catchments with the product of annual rainfall (P) and area (A). Rib data (open circles) were not taken into account

5. Sediment deposited in lacustrine plains

On average 482,364 tons yr^{-1} or 32% (ranging from 2% for Gilgel-Abay to 63% for Gumara) of sediment load from hilly catchments is deposited in the floodplains (Table 3). In terms of deposited mass, the lion share is taken by Gumara River followed by Megech and Rib rivers, while Gilgel-Abay contribution is the least. This seems logical as Gumara River has to cross an extensive floodplain bordering its meandering river in the downstream low-lying areas. In spite of mobilizing huge sediment by Gilgel-Abay River, floodplain deposition is minimum as its catchment has relatively smallest floodplain areas. As a result, Gilgel-Abay deposited its significant amount sediment at the lake shore that leads to visible delta development (Poppe et al., 2013).

Table 3. Sediment deposited on lacustrine plans and the net SY delivered to the lake in 2012-2013

River	Monitoring station		SY (t yr^{-1})		Floodplain deposition		Net SY into lake (t yr^{-1})
	Upper	Lower	Upper	Lower	(t yr^{-1})	% of upper station SY	
Gilgel-Abay	Bikolo	Chimba	762,622	753,739	12,831	2	749,791
Gumara	Wanzaye	Lower Gumara	545,268	274,591	342,106	63	203,163
Megech	Megech Bridge	Robit	119,325	64,225	73,322	61	46,003
Rib	Abo-Bahir	Rib Bridge	92,876	71,075	54,105	58	38,771
Total			1,520,091		482,364	32	1,141,197

6. Sediment exported out of Lake Tana

The mean annual sediment exported out of the lake was estimated to be 1,094,276 tons, of which Abay (Blue Nile) River and Tana-Beles tunnel shared 65% and 35% (Fig. 6). As the two outlets are positioned at different water depths, they get lake water with different SSC.

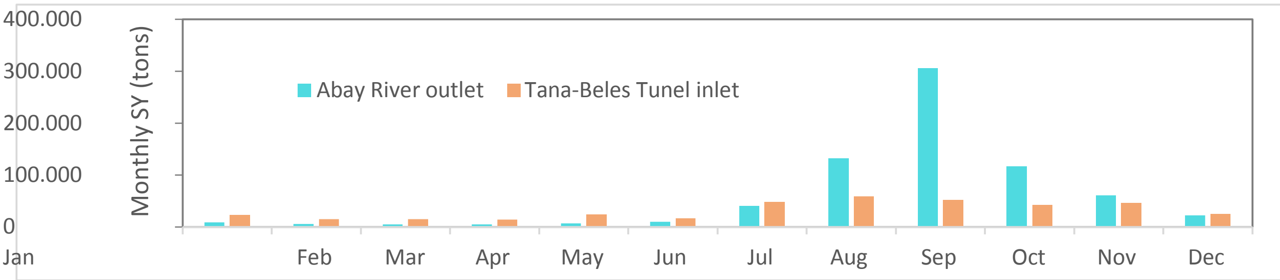


Figure 6. Monthly exported sediment load (tons) through Abay (Blue Nile) River and Tana-Beles tunnel

7. Annual sediment deposited in Lake Tana, its volume and trap efficiency of the lake

A net annual suspended sediment lake deposition of 1,043,888 tons yr^{-1} could be calculated with a trap efficiency of 49%. Dividing this mass by bulk density of 1.2 tons m^{-3} (SMEC, 2008) resulted in a total sediment deposition rate of 869,907 m^3 yr^{-1} in the lake, corresponding to an average deposition rate of 0.28 mm yr^{-1}. Incorporating the estimated bed load and SY from lake shores increased the total sediment entering the lake by 24% and the lake deposition by 50%. Moreover, the trap efficiency increased to 59% with a uniform sediment deposition rate of 0.42 mm yr^{-1}.

8. Sediment budget of LTB

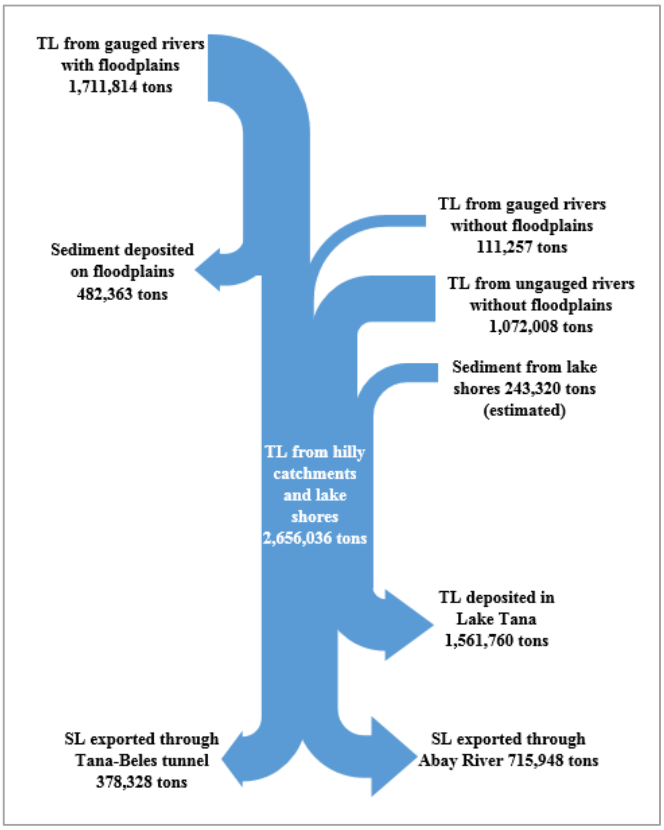


Figure 7. Average annual sediment budget in 2012-2013 for Lake Tana. All values are taken as average annual sediment load. Suspended load based on measurements; total load (TL) as suspended plus calculated bed load; SY of ungauged rivers, SY from shores and lake deposition were calculated

9. Major sediment deposition areas

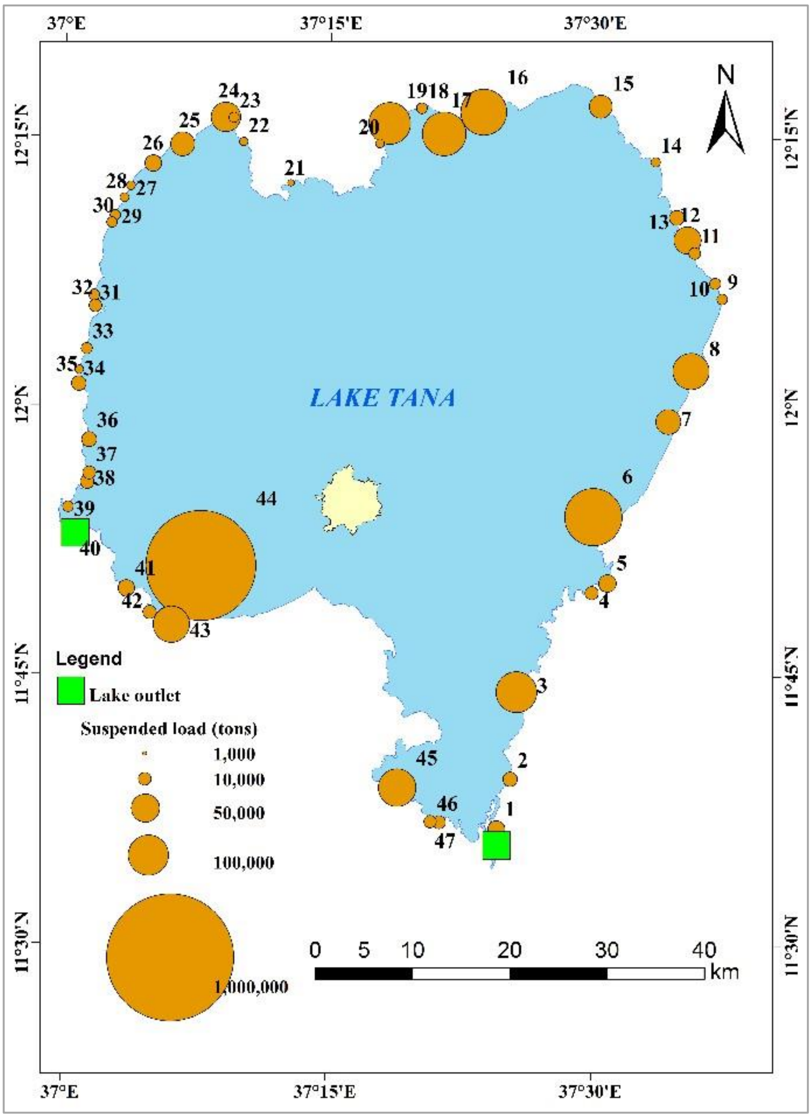


Figure 8. Major sediment depositional areas in Lake Tana

The highest sediment load from Gilgel-Abay River not only leads to visible delta development, it may also send sediment laden water to the Tana-Beles hydropower station of which the intake is located nearby.

10. Conclusion

The results obtained in this study are based on a large number of observations (about 4,327 sampled SSC and even much more river discharge, the largest set of observations in the area) with optimal spatial coverage and representativeness. Consequently, the estimated result in this study is assumed to be the most reliable so far. The trapping efficiency (T_e) of Lake Tana is estimated as 49%. In case bed load is also taken into account, T_e is even more, the lake is expected to fill up earlier, and the sediment budget is quite different.

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Fish and Fisheries in Lake Tana

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Fig. 1. Reed boat (Amharic: '*Tankua'*) fishing in Lake Tana

1. INTRODUCTION

Lake Tana, the source of the Blue Nile River, has a surface area of about 3200 km^2 and it is largest lake in Ethiopia. It is situated in the north-western highlands at an altitude of approximately 1,800m. The wetlands and floodplains that surround most of the lake form the largest wetland area in Ethiopia and are an integral part of the complex Tana ecosystem. These wetlands serve as breeding and nursery habitats for catfish and Nile Tilapia (Fig. 2)

Fig. 2. Catfish and Nile Tilapia in Shesher Wetlnad, eastern part of Lake Tana

From the twenty eight species described in Lake Tana, nearly 70% of the fish species are endemic (Getahun and Dejen, 2012) and eighteen of the endemic species are cyprinids. The evolution of high degree of endemism is probably because the incipient lake offered new habitats which promote adaptive radiation (Sibbing *et al*., 1998; de Graaf *et al*., 2008). The 40 m high Tissisat Falls, located 30 km downstream from the Blue Nile outflow, effectively isolated the gene pool from the lower Blue Nile basin (Nagelkerke, 1997). Four fish families occur in Lake Tana (Getahun and Dejen, 2012). The Balitoridae, Cichlidae and Clariidae are represented by only one species each, *Afronemacheilus abyssinicus*, *Oreochromis niloticus* and *Clarias gariepinus*. The fish fauna of Lake Tana is dominated by the family Cyprinidae, represented by four genera, *i.e. Varicorhinus* (one species, *Varicorhinus beso*), *Labeobarbus* (15 species, Nagelkerke and Sibbing, 2000), barbs (three species, Dejen, 2003) and *Garra* (4 species, Abebe Getahun, 2000). Each of the last three genera developed new endemic species in Lake Tana (Nagelkerke, 1997; Nagelkerke and Sibbing, 2000).

Since the large cyprinid species flock in Philippines, Lake Lanao, has been decimated by human influences (Kornfield and Carpenter, 1984), the genus 'large' *Barbus* (barbs), currently renamed as *Labeobarbus* (labeobarbs) (Skelton, 2002) in Lake Tana represents the only extended cyprinid species flock left in the world (Nagelkerke, 1997; Sibbing *et al*., 1998; Nagelkerke and Sibbing, 2000). The species flock is apparently young (less advanced) in its evolution compared to the Lake Lanao's cyprinid flock (Mina et *al*., 1996). It is most likely that the Lake Tana

Labeobarbus species evolved from one ancestral species that probably resembled *Labeobarbus intermedius* (Nagelkerke, 1997) through adaptive radiations (de Graaf *et al*., 2008), the process of evolution whereby species of common ancestry multiply and diverge by exploiting new habitats and food sources.

Two exotic species, *Gambusia holbrooki* and *Esox lucius,* were reported to have been brought from Italy during the late 1930s and introduced into the lake (Nagelkerke, 1997); there is, however, no trace of these fishes from the lake in recent times.

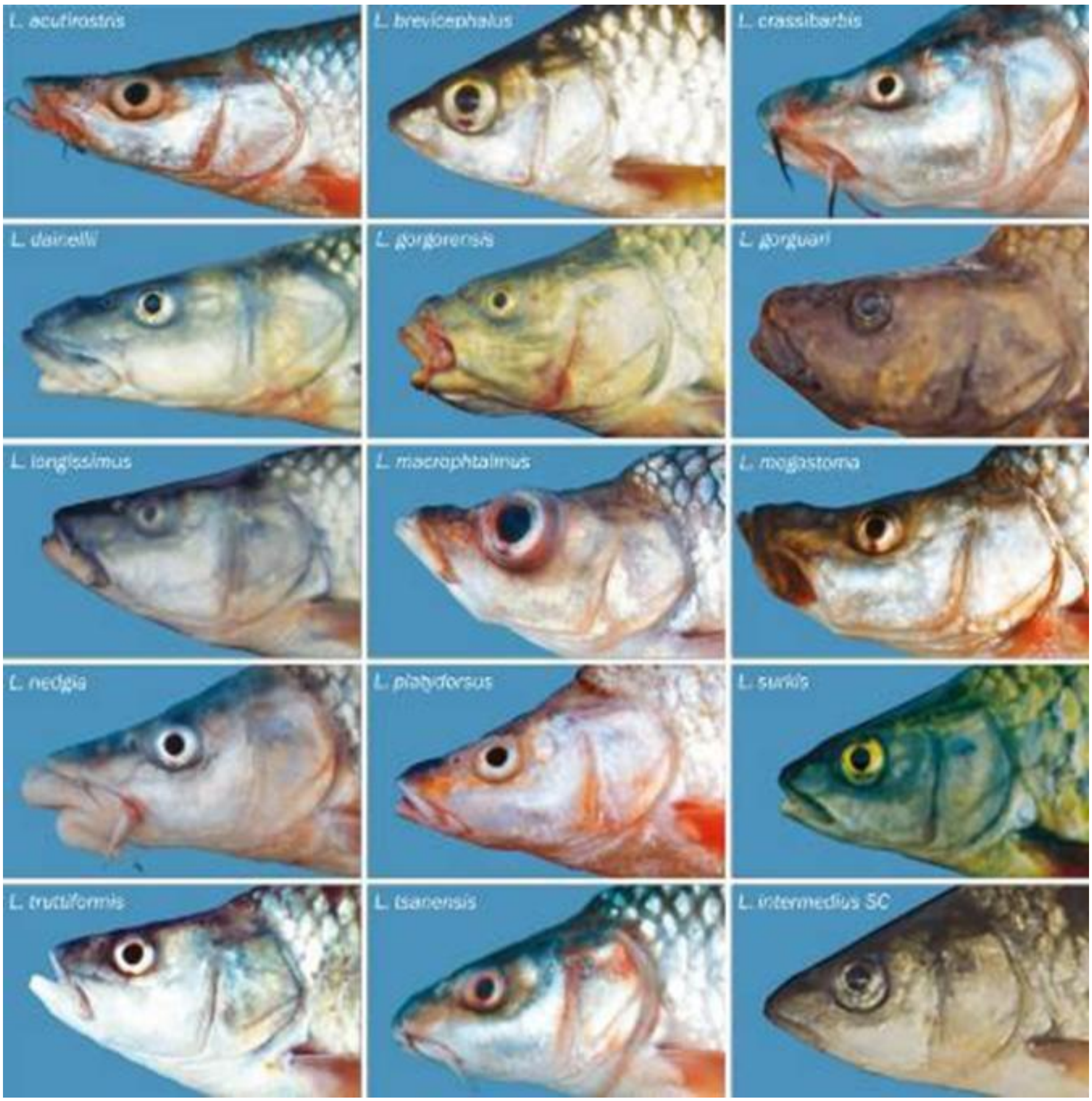

Fig. 3. Heads of the 15 endemic *Labeobarbus* species flock in Lake Tana (© Martin de Graaf)

2. METHODOLOGY

This excursion guide is compiled using published and unpublished literature collected after 1980s. Most of the research works have been done by the joint efforts of Ethiopians and The Netherlands. All the data were collected using extensive field sampling of the fish populations, using gillnets, seining (Fig. 4), cast nets, scoop nets, fykes, local traps and trawling in Lake Tana and its tributary rivers. Taxonomy, fisheries, spawning behavior, feeding habits and habitat changes of fishes were the focuses of study in Lake Tana in the Last three and half decades.

Fig. 4. Fish collection by using seining method in Gelda River (a tributary of Lake Tana)

Most fish species in Lake Tana reproduce in the shallow shore areas and some migrate to adjacent wetlands (e.g. *C. gariepinus*) (Wudneh, 1998; Anteneh *et al*., 2012) and others migrate more than 50 km up tributary rivers (e.g. some *Labeobarbus* species) (Nagelkerke and Sibbing, 1996; Palstra *et al*., 2004; Anteneh *et al*., 2008). Most juvenile fishes also stay long in the breeding area. For instance, the juveniles of the migratory riverine spawning *Labeobarbus* species stay nearly one year in the pools of rivers (Anteneh, 2013).

Fig. 5. Reproductively mature Labeobarbus spp. of Lake Tana (left Female, right male) collected upper (50 km from the lake) Ribb River, tributary of Lake Tana.

The spawning behavior of the endemic *Labeobarbus* species flock has be studied relatively in detail. According to Anteneh (2005), three categories of spawning behavior has been hypothesized by the endemic Labeobarbus species of Lake Tana: obligate river spawners, lake spawners and generalists (spawning both in the lake and its tributary rivers).

At least seven species of *Labeobarbus* spawn in the headwaters of the main rivers draining to the lake. As yet, there is no evidence of river-specificity, but this cannot be discounted. After a brief pre-spawning aggregation at the river mouths, the adults migrate upstream in July and August, at the onset of the rainy season. Final maturation and spawning occur in the tributaries of the major rivers, or possibly in gravel reaches in the main channels. After spawning, the adults return to the lake for feeding until the next cycle of breeding. Highly oxygenated water and gravel beds are important for development of the eggs and larvae. Deposition of eggs in gravel beds prevents them from being washed away, and clear water is required to ensure they are free of sediments that might obstruct the diffusion of oxygen. The juveniles remain in the pools and fringes (Fig. 6) of the main river segments for an extended period, until the next rainy season, at which time they will be carried into the lake (Anteneh, 2013).

Fig. 6 Fish collection using gillnet (left) and seine net (right)

3. RESULTS AND DISCUSSION

Lake Tana Fisheries

The lake fisheries in Lake Tana is clearly very important to the local population, employing more than 6,000 people in fishing, marketing, and processing. Traditionally, the main fishery has been a subsistence reed boat fishery targeting three groups of fish: Nile Tilapia, catfish and *Labeobarbus* spp. Modernisation of Lake Tana's fishery did not occur until the end of the 1980s. Traditionally, the fisheries in Lake Tana consisted of a subsistence papyrus reed boat fishery. The fishers, limited in their mobility, only had access to the shore areas, using locally made fish traps, hooks and small gillnets (15–20 m).

In 1986 motorised boats and modern, nylon gillnets were introduced as part of the Lake Tana Fisheries Resources Development Program (LFDP) which was initiated by the Ethiopian Ministry of Agriculture, the Ethiopian Orthodox Church and two Dutch NGOs (ISE-Urk and ICCO-Zeist). This created new opportunities for the fishermen, extending their fishing area from the shore to deeper, offshore waters and, more importantly, to distant river mouths. The commercial gillnet fishery of Lake Tana developed rapidly, total catches increasing from 39 MT in 1987 to 360 MT in 1997 (Wudneh, 1998). According to the 2006 survey data 14 000 tone of fish was collected from Lake Tana.

However, the catch per unit effort for the commercial gill net fishery dropped by more than 10% for Nile Tilapia, 88% for catfish over the period 1991 to 2011 (de Graff *et al.* 2004; Mohammed *et al*., 2012). Unraveling the major causes for the decline of the commercially important fishes seems difficult. Combination of overfishing and habitat disturbances is thought to be the major drivers for the decline of the commercial fish stocks in Lake Tana.

Overfishing

Although a fishery policy has been developed both at federal and regional levels, it is not effectively implemented. Lakes and rivers are, unofficially, considered to be resources that are freely available to everyone. There are still many illegal, unregistered fishermen exploiting the fish resources, and there is little regulation of fishing gears. As reported above, this has led to overfishing of *Labeobarbus* in some parts of the lake, especially in the south around the town of Bahir Dar. Especially, recruitment overfishing (the commercial gillnet fishery targeting the spawning aggregations at the river mouths) is a serious factor for the decline of *Labeobarbus* species (de Graaf *et al*., 2004).

Habitat disturbance

The root cause for the existing threats for the ecological damages in the Lake Tana's watershed is shortage of agricultural land derived from increased human and livestock populations (Sewnet and Rao, 2011; Heide, 2012). This has lead to unsustainable agriculture over the receding shore, wetlands, riparian zones of rivers (Fig. 7) and steep high lands (Gebriye, 2010; Atnafu *et al*.,2011). Deforestation and recession agriculture coupled with high erosion from the high landsresulted in high sediment deposition (average annual sediment yield of 30-65 tons/hectare; (Gebriye *et al*., 2009). As seasonal flooding recedes, many people use the shores of the lake for 'floodplain recession agriculture'. Human encroachment on the wetlands increases every year, with the subsequent depletion of emergent macrophytes through harvesting and burning, while there is an expansion of submerged macrophyte stands in other areas. Sand mining in the spawning rivers has become a common practice in the Lake Tana watershed, which alters the natural flow of the river significantly and consequently damages the fish breeding areas (Fig. 7). As Lake Tana is considered as growth corridor by the government, a number of irrigation and hydro-dams are under construction on the tributaries of Lake Tana. This will affect the migratory riverine spawning *Labeobarbus* spp.

Fig. 7 Farming in the riparian areas of Gelda River (tributary of Lake Tana) and sand mining activities in Labeobarbus spawning rivers (Arno-Garno River, a tributary of Lake Tana)

A final blow to the Lake Tana ecosystem could be the recent infestation of the most ecologically dangerous weed, water hyacinth. It starts to invade not only the lake but the Fogera and Dembiya floodplains (Anteneh et al., 2015). If water hyacinth expansion continues towards the southern tip of Lake Tana, then it will invade the Blue Nile River starting from its source, and consequently the Great Ethiopian Renaissance Dam (GERD) reservoir. It out competes the indigenous macrophytes and form dense thick mat on the shore of the lake. This completely damages the fish breeding and nursery areas (Fig. 8). According to the current estimate more than 30 thousand hectare of the shore area and about 128 km length of the shoreline in the northeastern part of the lake is invaded in Lake Tana (Anteneh, 2015).

Fig. 8. Water hyacinth infestation on the shore of Lake Tana

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Birds of Lake Tana area, Ethiopia

Shimelis Aynalem[1]

Introduction

Ethiopia provides habitats for more than 800 species of birds (Urban and Brown, 1971). Of these 16 are wholly restricted to the political boundaries of the country and thus are endemic (Ethiopian Wildlife and Natural History Society 1996). However a large proportion of bird species are still located in the Upper Blue Nile Basin area. Lake Tana area is one of the places where resident and migratory birds are found.

Lake Tana sub-basin qualifies as an Important Bird Area (IBA) (Tilahun *et al.*, 1996). It possesses the globally threatened species such as wattled crane, pallid harrier, greater spotted eagle, Egyptian vulture, lesser kestrel, and sociable lapwing. It is estimated that the population of water birds around Lake Tana is likely to exceed 150,000 seasonally (Shimelis *et al.*, 2011). Previously the Lake Tana area was considered to hold 19 highland biome species (Ethiopian Wildlife and Natural History Society, 1996). However, the Lake Tana sub-basin has 35 highland biome species, out of 56 in the country as a whole (Ash and Atkins 2009). These species are: blue-winged goose, Erckel's francolin, wattled ibis, spot-breasted lapwing, black-winged lovebird, yellow-fronted parrot, white-cheeked turaco, Abyssinian (African long-eared) owl, Nyanza swift, banded barbet, Abyssinian woodpecker, Abyssinian oriole, thick-billed raven, white-backed black-tit, brown woodland-warbler, Abyssinian catbird, parisoma (brown warbler), montane (broad-ringed) white-eye, Abyssinian slaty-flycatcher, Rueppell's robin-chat, little rock-thrush, Rueppell's chat, white-winged cliff-chat, moorland chat, slender-billed starling, white-billed starling, Tacazze sunbird, Abyssinian longclaw, African citril, yellow-rumped serin, streaky seedeater, brown-rumped seedeater, Swainson's sparrow, Baglafecht weaver, and yellow-bellied waxbill (Ash and Atkins, 2009; Shimelis, 2013)
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Black Crowned-Crane (*Balearica pavonina*)

African Darter (*Anhinga rufa*)

Double-toothed Barbet (*Lybius bidentatus*)

Goliath Heron (*Ardea goliath*)

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In addition, four Sudan–Guinea Savanna biome species are found: green-backed eremomela, white-fronted black-chat, red-billed pytilia and bar-breasted firefinch. Other species of interest include bronze sunbird, which has been reported on a number of occasions, and bar-breasted firefinch, which is fairly common in Gorgora area. Silvery-cheeked hornbill nests in the large figs around the lake, including in hotels along lake shore in Bahir Dar, and both brown-backed woodpecker and black-backed cisticola are known from the area to the west of Lake Tana (Shimelis, 2013).

Hadada Ibis (*Bostrychia hagedash*)

The sub-basin area particularly is important for wetland and water birds. Some of which occur in large numbers. For example, the total population of birds counted during the winter season exceeds 150,000 seasonally (Shimelis, 2013) and more than 100,000 bird were counted in *Shesher-wallala* alone in 2009 (Shimelis et al., 2011). Any ways the area is known to hold the largest population of migratory birds. With regard to other wildlife, Lake Tana harbours different varieties of wild animals such as Hippos, Crocodiles, and some primate species as well. The population of water birds around Lake Tana is likely to exceed 100000 individuals seasonally, with 83 wetland species (Francis and Shimelis Aynalem, 2007; Shimelis Aynalem, et al., 2011).

Malachite Kingfisher (*Corythornis cristatus*)

However, the primary aim of this paper is just to give highlight on some birding routes of Lake Tana area. Lake Tana is largest lake in the country, which approximately 84 k.ms long and 66 k.ms wide with a maximum depth of 15 meters, and an elevation of 1,800 meters. The distribution and the occurrence of birds in the area are variable that some prefer the wetland, and others the agricultural field and forest areas. Most of the birding sites are situated along the shore of the lake and in isolated/patchy wetlands. Though there are different birding routes, for our purpose, we only focus only one route that is Bair Dar-Zegie Peninsula to Daga Estifanos Islands.

Glossy Blue-eared Starling (*Lamprotornis chalybaeus*)

Trip Itinerary: Zegie Peninsula –Deq & Daga Estifanos birding route

7:00 a.m. -8:00 a. m. - breakfast then move to Zegie Peninsula by boat. Once you are in the boat make sure there are lifesaver jacket for all. On the way, you will see the old and ancient monasteries- Kibran Gabriel and Entos-Iyesus. Make sure and inform your guide you want to visit these monasteries, then he will tell you a few do's and don'ts when you are there. If you are really lucky, you will see the rare birds the African Fin-foot particularly at Kibran Gabriel Island northwest direction where there is fringed habitat, but should not be disappointed if you don't see because they are very rare to find. However,

Blue-headed Coucal (*Centropus monachus*)

September-October sometimes December, you will see the nesting sites of Cormorants (both reed and white breasted Cormorant), and the African Darter nesting sites. You will see white pastes on the tree near the shore of the Lake. If you come to the breeding time you can have a look the enormous number of brood patch or nests. Special bird here is – the Lemon Dove – focus in the understory of the trees both in Kibran Gabriel and Entos-Iyesus.

By the time you are on Azwa-port –you go to Azwa Mariam Church compound to see some birds, the fee will be covered by tour operator or organizer. Keep silent and make your line of profile while you are inside the Peninsula (forest). The area is intact with indigenous trees with a canopy cover less than 40%. If you just keep on standing for some minutes you will hear the knocking sound of Woodpeckers- please focus on dead branches of trees. The special birds of the Peninsula are: Yellow-fronted Parrot (E), Banded Barbet, Bearded Woodpecker, Gray Woodpecker (E), Red-winged Starling, if you are lucky- the Narina Trogon (rare), Blue- Spotted wood-Dove .

Explore the forest birds in the peninsula; visiting Ura-Kidane-Miheret church (should be informed first to the guide and as wish by the clients).

Here you will see many of the earliest manuscripts & precious examples of ecclesiastical art as well as royal objects were safely stored in their treasuries. At the same time, new religious arts were developed and displayed in the churches. Seven of the most accessible and representative of these churches, still serving their original function, have been selected for the international campaign.

At Zegie peninsula you will see the indigenous trees older than 100 years with large canopy, which shade the peninsula. The endemic plant species are also found here, some of the trees are very important for food and nesting of the Endemic bird of Ethiopia- Yellow Fronted Parrot. By the time you are in the forest, you can hear the unique call of Parrot, and others. The old and organic coffee tree is also preserved here under the canopy of dense trees.

African Jacana (*Actophilornis africanus*)

African Spoonbill (*Platalea alba*)

White-faced Whistling-Duck (*Dendrocygna viduata*)

Keep on walking and birding in the Peninsula-it is common to hear the beautiful voice of the African Fish Eagle. Of course you can see it if you manage to look through the lit of the forest to the shore of the Lake where there are big trees. You find it sitting on the top-with white neck and rufous head.
Once you arrived at Zegie town (Affaf), people may wander you, don't frustrate because you are a stranger for them. Keep on walking on the way to Bahir Dar then turn right (near Tele office) to get the Yiganda wetland. It is located adjacent to Zegie Peninsula to the southeast. The wetland is bordered by Lake Tana. It is one of Important Bird Area (IBA) for several birds. Though the area is still under human pressure you can see different wetland bird species. The presence of papyrus plant makes the area unique as compared to the northern, western and eastern part of Lake Tana. Special bird of the area: Black-Crowned Crane, Purple Heron, Harlequin Quail (Rare to see).
Back to the jetty at Zegie peninsula (Ura port) keep on going to Daga Estifanos and Deg Island. To see birds and hippos you should take the Lake Shore to the west up until you arrive Ambo-Bahir where a huge wetland is located. On the way you can have a look several birds. The most commons are water and wetland birds; but it is less to see migratory birds as the most winter birds come lately in September. White-faced Whistling-Duck, Fulvous Whistling-Duck, White-backed Duck, Egyptian Goose, Spur-winged Goose, African Pygmy-Goose, African Black Duck, Yellow-billed Duck are some of the Anatidae family.
By the time when you are in Daga-Estifanos and Deq Island specially around the shore of the lake in general the following birds can be seen: Little Grebe, Greater Flamingo, African Openbill, Black Stork, Woolly-necked Stork, Saddle-billed Stork, Yellow-billed Stork, Great Cormorant, Long-tailed Cormorant, African Darter, Great White Pelican, Pink-backed Pelican, Hamerkop, Gray Heron, Black-headed Heron, Goliath Heron, Purple Heron, Great Egret, Intermediate Egret, Little Egret, Cattle Egret, Squacco Heron, Striated Heron, Black-crowned Night-Heron
he eastern part of Lake Tana is better one for birders who come to Lake Tana area during winter time since it supports enormous number of Eurasian birds; however, still the area is known for many resident birds breeding place. As you see breeding birds you are advised to stay in the boat not to disturb the breeding colony of many birds. Iit is strictly forbidden from ethical and breeding behaviour point of view to walk inside the nesting area. However, you can use your binocular to spot and look by moving the Island in all direction specially at Mitsili Fasiledes Island near Tana Kirkos Monastry. At least you should away from the harbour by 50 meter.By special order you can visit the Monasteries in Tana Kirkos, where the sacrifice in the Old Testament was practiced before 2000 years ago.
It will be of course difficult to stay until late afternoon because of high wave/tide usually occur starting 1:00 pm. For safety reason it is better to be back before the wave comes. Besides to common birds large number of Pelicans (great White Pelican) and Greater Flamingo can be found there.

Conclusion

Lake Tana area is rich in terms of fauna and flora. When we take the issue of avi-tourism it can be categorized as one of best birding site in Ethiopia. The variety of species residing including the migratory, endemic and highland biome species, the area can be selected as anyone love to come and do birding. To enjoy the multitude species and high number of birds at least one should spend a minimum of five days. The northern, southwestern, and the riverrine habitat of the Blue Nile (Abay River) and the town (Bahir Dar) itself harbors many species of birds.

As birds are concentrated where food resources are abundant especially in wetlands, fruit trees and Lake Shore areas, might be difficult to find birds if you are in the middle of the Lake or while crossing from Deq Island to eastern shore of the Lake. We hope that you enjoy the birdlife of the area.

Photo Credit: ©Shimelis A.

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Regional geography of Dek Island, Lake Tana, Ethiopia

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Introduction

Located in the middle of Lake Tana, Dek Island is endowed with unique geographical, environmental and socioeconomic features. Dek is the largest island in Lake Tana covering about 28 km^2. The topography, soil and geology of the island are the result of quaternary volcanic activity. Nearly 75% of the island has a plain topography gradually rising from the lake shore to the central part of the island. This eases cultivation and movement of people across the island.

Dek is inhabited by more than 6000 people settled mostly at the shore of the island. The quest for improving livelihood for the growing population is becoming the fundamental source of socio-environmental problems of the island. Subsistence agriculture and fruit plantation are the main means of livelihood. Maize and millet are the major crops produced for household consumption; coffee and mango are the primary source of income. Small scale fishing and trade are also means of additional income for few inhabitants.

Being located in the middle of Lake Tana, water transportation is sole means to access the terrestrial villages and towns for trade and social activities. Lake Tana Transport Enterprise is the only enterprise providing limited transportation services for the Dek community on its way from Bahir Dar to Gorgora and Delgi. Owing to its irregular trip and high price, the villagers are owning private boat in small groups. However the absence of permanent port both in Dek and Bahir Dar are still the major obstacle to transport goods and services in and out of the island.

In a semi-closed society like Dek, social systems and their activities have a strong relationship with the biophysical environment. The inhabitants of Dek are strongly dependent on natural resource, and at the same time the biophysical change is attributed to expansion of economic activities. Thus the coexistence of social system and natural environment is crucial for the island surroundings. Therefore this study aimed at investigating the persistent biophysical and socioeconomic characteristics of Dek Island and their nexus. The objective is to present an integrated synthesis of the main biophysical- and socioeconomic characteristics of Dek Island and in turn show the nexus between the two in shaping environmental and livelihood conditions of the island.

The study is based on descriptive analysis of the general socio-economic and geographic characteristics of the island using primary and secondary data analysis. The primary data was collected using field observation and key informant interviews with elderly and religious leaders, with experts and with Woreda (district) and Kebele (municipal) Administrators. The key informant interviews were conducted in Amharic with a written checklist of open-ended questions. Topics discussed included:

natural, cultural, historical and accounts of the island. How things have changed; ecological histories; changes in land use patterns; changes and trends in resource use patterns; and, causes of changes and trends.

Field observation about land use, vegetation, topography, geology and soil, livelihood, economic activity cultural organization were also conducted though transects walk using Garmin 46s hand held GPS and observation checklist. NDVI was also calculated using GIS analysis techniques to investigate the mid-term environmental change induced by anthropogenic and natural factors.

1. Physical geography of Dek Island

1.1. Geographic location

There are 37 islands on Lake Tana and Dek Island is the largest with an area of 2800 ha of land. It is located almost at the center of the lake. Administratively it is part of Bahir Dar Zuria Wereda of the West Gojam Zone. It is located between *11^0 53'N to 11^0 56' N and 37^0 14' E to 37^0 17' E. To* the southeast of Dek is the much smaller Daga Island at a distance of 1 km. Dek Island is found at a distance of 20 km from Bahir Dar.

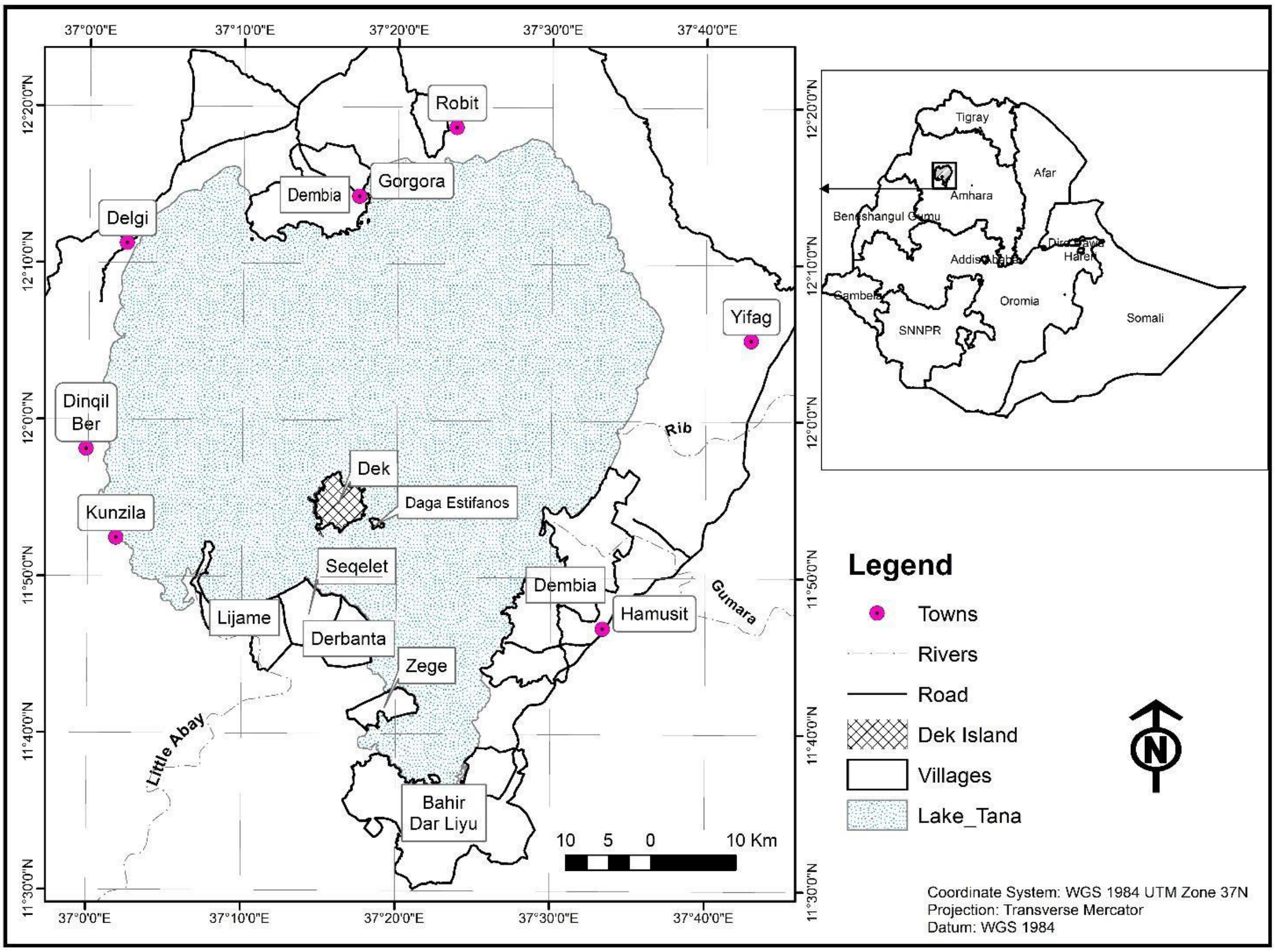

Figure 9: Location of Dek Island in Lake Tana

2.2. Topography of Dek Island

The topography of the island plays significant role for cultivation as well as for the low level of land degradation. Cheesman (1935) described the terrain as an island gradually rising above the lake and almost with no serious topographic difference. The topography of the island was analyzed using 30m SRTM DEM downloaded from http://earthexplorer.usgs.gov. After removing irregularities of the DEM using fill function of ArcGIS; elevation, slope, and relief difference was derived to characterize the general topography of the island.

Elevation gradually increases from 1785 m a.s.l. at lake shore to 1829 m a.s.l. at Zibid Village, with an average elevation of 1807 m a.s.l. The slope of the island varies from 0% (flat) to 19.5% (moderately steep) south of Zibed Medhanyalem Church. Nearly 70% of the topography is flat area, 26% undulating, and the remaining 4% is hilly with moderate slope. Due to the gradual rise of altitude there is no serious case of flooding and erosion and the general topography make the island suitable for cultivation and internal movement of people.

2.3. Geology and soils of Dek Island

The topography, geology and soil of Dek Island are explained by geological history of Lake Tana. Lake Tana is formed by structural deformation, erosion and extrusions of volcanic rocks (Poppe et al., 2013). It is considered to owe its present form to damming by a 50 km-long Quaternary basalt flow (Chorowiz et al. 1998). Volcanic lava extrusion in the middle of the depression perhaps created Dek Island in Lake Tana.

The rocks of Dek Island have been identified as vesicular olivine basalt and nepheline normative (Begosew Abate et al, 1998; Cheesman, 1935). The chemical nature of this rock is an alkaline basalt, where its alkalinity ranges between *mg* values of 50 and 60 (Begosew Abate et al. 1998; Girum Admasu 2010). As observed during field observation dark fine grained basalt rock outcrops at most shores of the island as well as in the form of minor ridges on the island, which bound farm plots.

The soil of the island is derived from weathered basalts through long pedogenetic process. Although it needs further investigation the soil map compiled by the Ministry of Agriculture in 2008 shows that island is dominated by Dystric Gleysol. It is characterized by reddish fine grain soil, cracks when dry and is muddy when wet. The stable porous soil structure permits deep rooting of plant and makes it generally less prone to erosion. (see next section in the excursion guide, specifically on soils).

1.4. Climate of Dek Island

According to Alebachew (2009) the climate of Lake Tana region is 'tropical highland monsoon' with a single main rainy season between June and September. Based on the agro-climatic zoning of Ethiopia, Dek Island belongs to Weyna Dega zone (1500 to 2300 m a.s.l.).

The rainfall records obtained from Dek Estifanos from 2000 to 2011 show that the mean annual rainfall is 1448 mm. It receives 88.6% of its rainfall in main rainy season (June to September), where August is the peak. The rainfall in these seasons are brought about by wind system from Atlantic Ocean (Kebede et al. 2005). It also receives light rainfall from March to June, from a wind system in the Indian Ocean. In general, Dek Island has a unimodal rainfall pattern.

The average annual temperature is 19.6 ^{0}C with a maximum temperature 27.4 ^{0}C and minimum 14 ^{0}C. The highest maximal temperatures are recorded in March and April (around 30 °C), whereas the lowest minima are in December and January (around 15.3 ^{0}C).

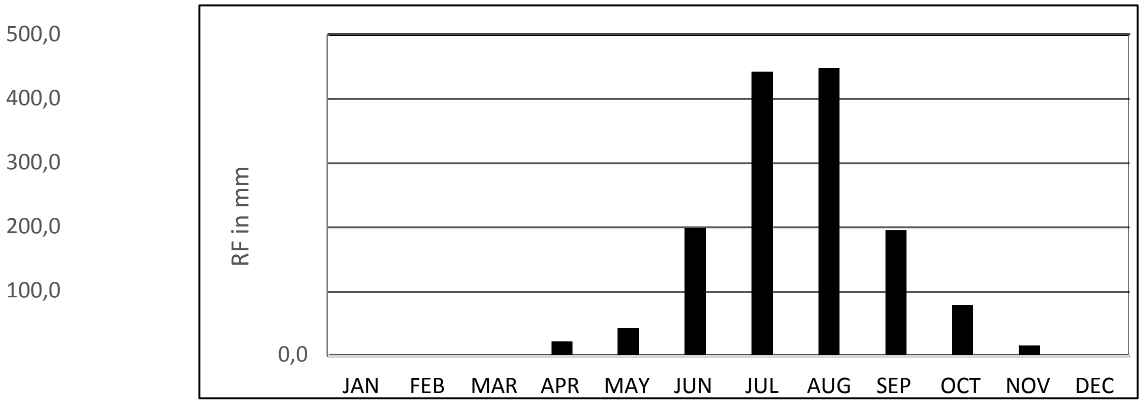

Figure 10: Mean monthly rainfall at Daga Estifanos (2000-2011)

Over the years under investigation the temperature shows little variation but rainfall has considerable trend of variation. The annual rainfall varied between 1620 mm (in 2001) to 890 mm (in 2009).

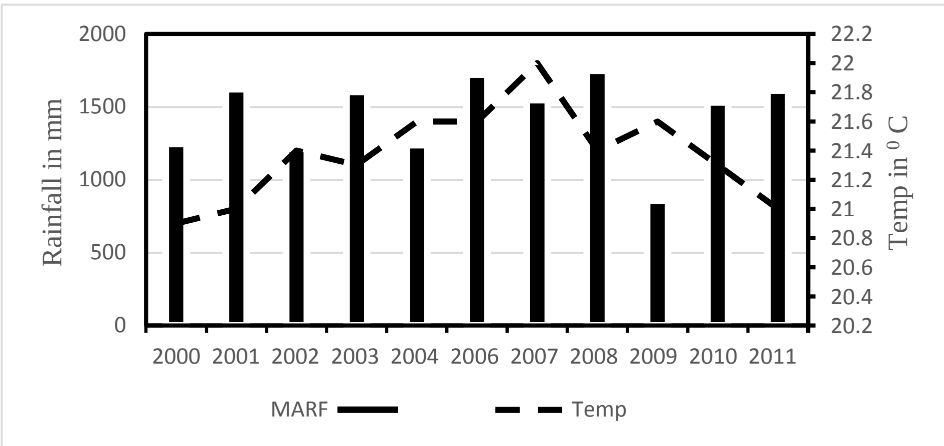

Figure 11: Mean annual rainfall and temperature at Daga Estifanos (2000-2011)

1.5. Land use and vegetation types of Dek

1.5.1. Land use

Visual analysis of satellite image and field observations indicate that the major land use types of the island are cultivated land, grassland, natural forest and wetlands. The cultivated land covers 2085 ha which is 75% of the total land. According to the Kebele Agriculture Office, 1279 ha is used for permanent cereal cropping mainly millet and maize, the remaining land is allotted for fruits and vegetables. Mango and coffee are the permanent fruits commonly grown around the homesteads of every farmer.

Grasslands account for nearly 87 ha or 3% of the total land. It is communal holding in the transition zone between the cultivated land and the lakeshore or wetlands. It is dominated by outcropped basaltic lava. The grasslands nowadays are changed into cultivated land especially for small scale irrigation.

The wetlands consists of 230 ha or 8% of the land. It is characterized by marsh or swampy area which are at the transition between the grasslands and the lakeshore. Short and long grass such as papyrus and rich fish resource as well as a variety of organisms are found within it. The tall grasses are used by the community for local boat (*tankwa*) and house equipment making. According to key informants, the wetlands and its ecosystems are shrinking year after year due to grazing and small scale recession irrigation.

Nearly 397 ha (14%) of the land is covered by forest. Isolated patches of forest are found around the seven churches. The largest natural forest is located at Kota Kidanemhret, in the north east followed by Woba Kidanmhret and Narga Selase at the east and west of the island.

The vegetation in the forest areas forms different structural levels i.e. trees (high canopy), shrubs (short trees and bushes) and ground cover of (grasses and herbs), boarding the forest and cultivated land. However, wetlands and lakeshore are dominated with short and long grasses such as papyrus and other grasses.

1.5.2. Flora and fauna

Around Lake Tana ever-green forest are said to have covered a large portion of islands and peninsulas in the past centuries (Woldegabriel and Selemon, 2005). The vegetation of Dek is a montane broad leaf forest type.

The most common species of trees are warka (*Ficus vasta*), birbira (*Millettia ferruginea*), wanza (*Cordia africana*), zana (*Stereospermum kunthianum*), bamba (*Ficus sycomorus*) and bisana (*Croton macrostachyus*). The fig tree *Ficus vasta* is found almost everywhere reaching high above all other trees. *Croton macrostachyus* is dominantly used as main source of improving soil fertility as it drops its leaves on the plots. It is also one of the dominant tree used by the community as coffee shade. Dokma (*Sizygium guineense*), eshe (*Chionanthus mildbraedii*), and agam (*Carissa edulis*) are among the common species of shrubs and herbs on the island.

In general the presence of large and old trees is a peculiar characteristics of Dek in terms of vegetation. Very tall and old *Ficus vasta* trees are found almost everywhere in the island, which looks evergreen and which is considered as a symbol for firm standing and solidarity. It is also appreciated by the islanders because it gives shadow for coffee plantation, crops and even the people moving around the island. On the other hand, *Millettia ferruginea* is a lakeshore tree. The people believe that, it is native from the island and a gift from to the island to protect it from lake waves, gully and rill erosion. The presence of diverse plant species can provide suitable ground for ecological studies; in an ethnobotanical study of medicinal plants on the island, Tilahun reported 60 medicinal plant species, distributed across 40 families and 58 genera. In terms of number of medicinal plant species, Asteraceae are the dominant family (4 genera, 5 species) followed by Euphorbiaceae, Malvaceae and Poaceae (3 genera, 3 species), Amaryllidaceace, Brassicaceae, Cucurbitaceae, Lamiaceae, Olacaceae, Sapindaceae, Solanaceae and Verbenaceae (2 genera and 2 species). All medicinal plants have local Amharic names. The reported medicinal plants species are used to treat 45 diseases (Tilahun, 2009).

As expected, the island has not many vertebrate fauna. Besides domestic animals, rats are probably the only wild mammal in the island. According to residents, pythons are seen around the lake shore, but rarely.

1.6. Biophysical change in Dek Island

Triggered by anthropogenic factors, landuse changes rapidly across the island. Even though it needs further investigation, the increasing demands for arable land, overgrazing and lake level rise due to Chara Chara weir at Lake Tana outlet may create high pressure on the environment and lead to ecological degradation. One way to assess the presence of environmental changes is to assess the change in biomass productivity (Fox et al, 2004). Biomass productivity can be assessed by the Normalized Difference Vegetation Index (NDVI) using remote sensing imagery. This index takes advantage of the contrast of the characteristics of two bands from a multispectral raster dataset—the chlorophyll pigment absorptions in the red band and the high reflectivity of plant materials in the near-infrared (NIR) band (Fox et al, 2004; Sader and Winne, 1992).

The NDVI of Dek Island was mapped for the years 2001 and 2015. LandSat 5 was used for the former and LandSat 8 OLI imagery for the latter. For Landsat TM+ 5 band 4 is IR and band 3 is red band, whereas, for Landsat 8 OLI sensor the red is band 4 and the NIR is band 5 (http://landsat.gsfc.nasa.gov/). The equation used to generate the output in ArcGIS software is:

$$NDVI = \frac{Near\ IR\ band - Red\ band}{Near\ IR\ band + Red\ band}$$

The NDVI result of 2001 ranges from -1 to 1 and 2015 ranges from -1 to 0.8. High NDVI is an indicatorof vegetation abundance while negative and low NDVI values indicate the absence of vegetation(http://landsat.gsfc.nasa.gov/).

The NDVI value of was reclassified at equal interval. Negative values were classified as wetland and water body, while low values (0-0.2) were assigned as built-up areas, bare land and cultivated land. Moderate to high NDVI values (0.2 to 0.67) represented vegetated areas (grassland, shrub and forest). The reclassification and comparison of the 2001 and 2015 Landsat imagery indicates an increase in woody vegetation cover especially on the cultivated land (Figure 4). This increase in vegetation cover is because of plantation of coffee and mango fruits. Reversely, the larger forests have become more fragmented, indicating encroachment.

The overall vegetation cover of the island also increases, but it shows decline around the lakeshore wetlands which is now covered by water. This is most probably an indicator for the rise of the water level. Papyrus and other tall and small grasses are affected by this change.

The other aspect of biophysical change in the island is the disturbance of wetlands ecosystem. Visual analysis of multi temporal satellite image and key informant interview confirms that wetlands that were once found almost everywhere around the coast are now limited to a few places. Its disturbance is attributed to overgrazing and recession irrigation farming. The decline of papyrus and other grasses leads to reduction of spawning areas and a decline in fish production.

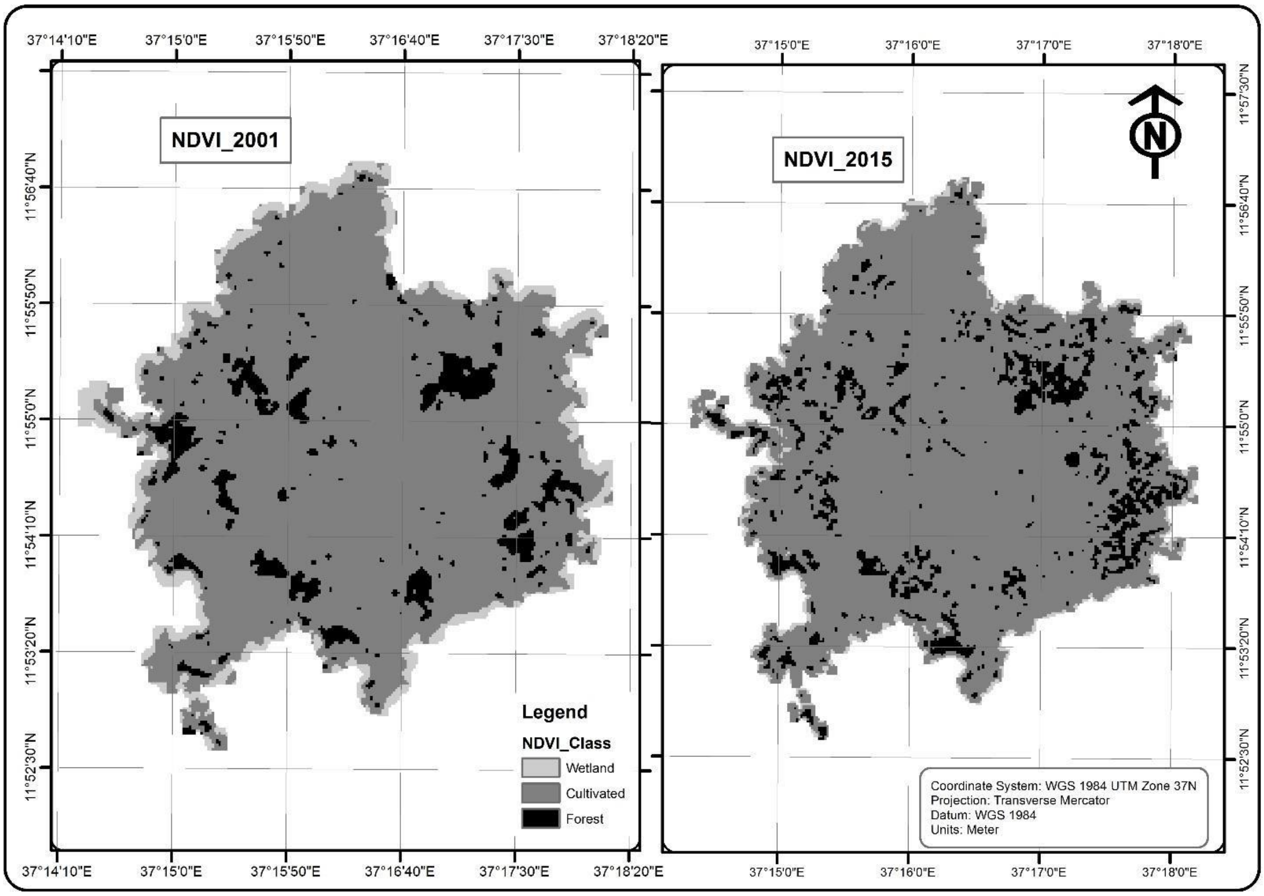

Figure 12: Land cover map of Dek Island derived from NDVI interpretation for 2001(left) and 2015 (right)

2. Social system of Dek Island

2.1. Demography and settlement

The origin of the people of Dek is believed to be from the surrounding South Gonder and West Gojam Zones. They came to the island through church activities, marriage, and fishing. Most of the elders claims family attachment with the people in Fogera (South Gonder Zone), Gorgora and Dembia (North Gonder Zone). At present however, the people have more social attachment with the people in Bahir Dar Zuria wereda, through marriage, especially with the nearby village Sekelet, through trade, education and employment (Figure 1).

Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA), the total population of Dek Island is 4816, of whom 2503 are men and 2313 women; a total of 1218 households were counted in the island (CSA, 2007). Revised statistics by 2012 obtained from the

Bahirdar Zuria Wereda Agriculture Office show a total population of 6023 people. Average family size is 4.9 persons per household and population density is about 215 persons per km².

The island is divided into eight small villages namely Gurer, Narga Silasie, Korebet, Kota, Woba, Gadena, Kola and Zibed (Figure 5). All the villages are situated along the lake shore and their agricultural land is mainly towards the middle of the island. Gurer is the main village where most of the public institutions, market and the main port are located. These main public institutions include Kebele (municipal) administration, primary schools, health station, churches, rural agricultural development station, animal health station, agricultural cooperative office, police station and Lake Tana Transport Enterprise branch office (Gurer Transport).

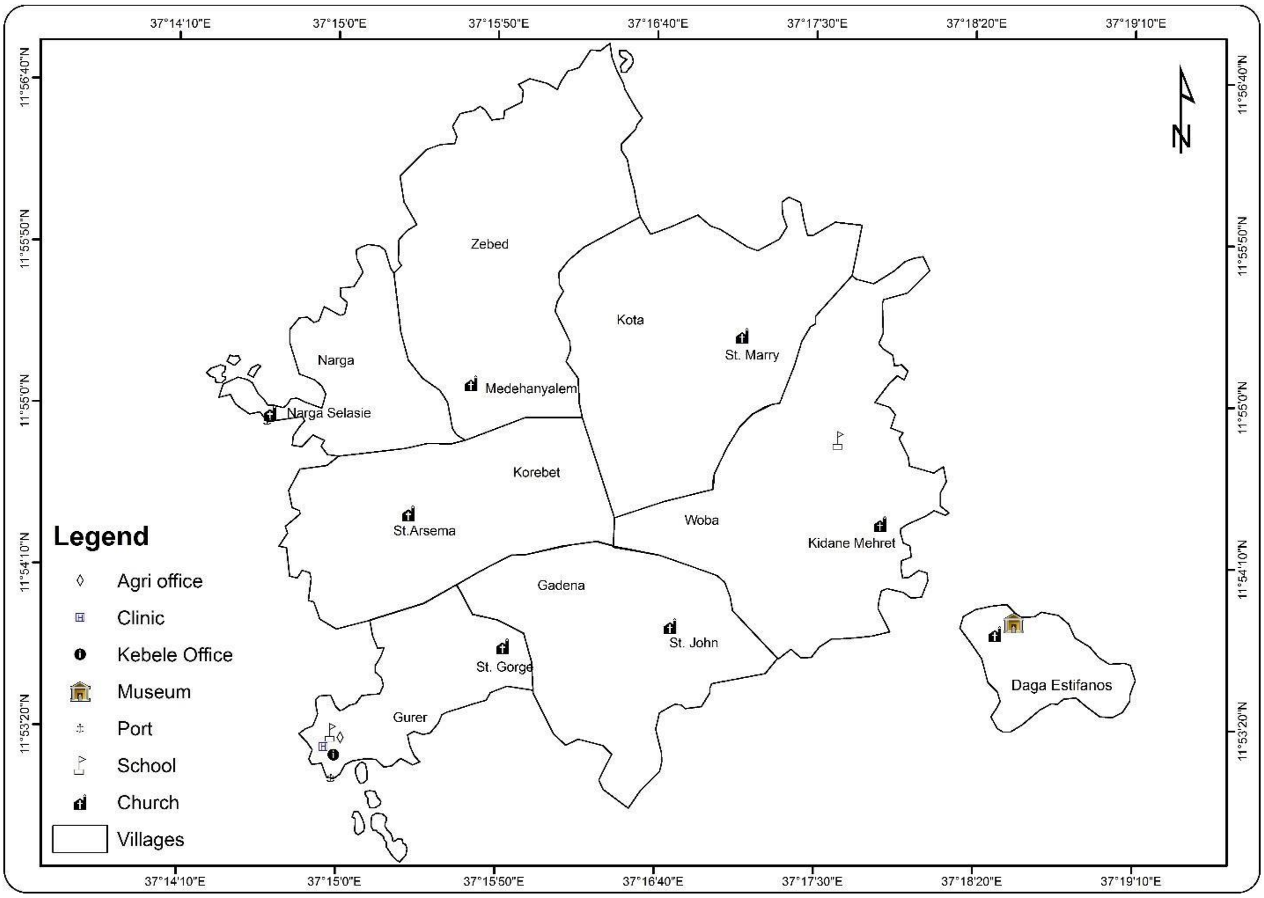

Figure 13: Villages of Dek Island

2.2. Social relations and organizations on Dek Island

The inhabitants of Dek have a strong social relationship, expressed through marriage, kinship, working group, worship and other cultural and economic organization.

Marriage in the island mainly takes place among themselves, through the consent of the brides, parents and religious leaders. The criteria is that the brides must be separated by at least seven steps in the family tree. However, due to limited population size, marriage relation with the adjacent villages is frequent, mainly with the people of Sekelet, and sometimes Derbanta, Delgi and Zege (Figure 1). If the marriage is from these villages, mostly the bride comes from outside.

There are cultural organizations such as Mahiber or Adbarats (church group). They are means of gathering and discussion of the problems of the island and working together for crop cultivation and harvesting, peace and security, and experience sharing.

The main economic organizations are the Fruit Association and small scale saving groups. The former is aimed at collecting and trading fruit production (mainly mango); it has more than 2000 members. Saving groups provide saving and credit service for its members.

There are many peculiar features that characterize the inhabitants of Dek. Above all they are known by having very strong social bonding, sense of unity and cooperation, expressed through working together, protecting each other's resource, solidarity at the time of happiness and grief, etc. The people are also very peaceful and friendly. There is no theft, crime or violence. They have strong adherence to their local values, customs and religion. During field observation, we learned that the people have strong awareness about their environment, protection of their scarce resource and maintain the security of their island together.

There are seven churches on the island. Almost all the inhabitants on Dek Island are Ethiopian Orthodox Church followers. Because of the community's long tradition of attachment to the church, the church leaders are playing a great role in coordination and awareness creation related to the different development activities on the island.

2.3. Livelihood

The livelihood of the local farmers mainly depends on subsistence agriculture and fruit production. Some portion of the villagers also involves in off-farm activities such as fishing and other small business activities like trade, handicrafts, small restaurant and kiosk.

Agriculture is the central means of living in Dek Island. They practice crop farming and to some extent livestock production. Farmland is divided into plots of about 0.5 ha, separated from each other by outcropped basaltic rock, narrow hedges of scrub and trees. According to Dek Agricultural office, the average farmland size is about 1.2 ha per household. However, unlike other parts of Amhara region, land redistribution has not been done on the island, they still implement the previous government's (Derg) land allocation.

Crop production on the island is mainly rainfed. The main crop growing season is June to September. Maize covers 333 ha and millet 576 ha of arable land; they are the two major cereal crops produced in the island that are used for household consumption. There is a recent attempt to introduce teff, though farmers are resistant to adopt it as it requires more effort to cultivate and has lower productivity compared to the other crops grown in the island. Vegetable crops such as sweet potato and hot pepper constitute a considerable proportion of the total production of the farmers. Other crops produced on the island at a very small quantity are teff, peas and beans (Figure 6).

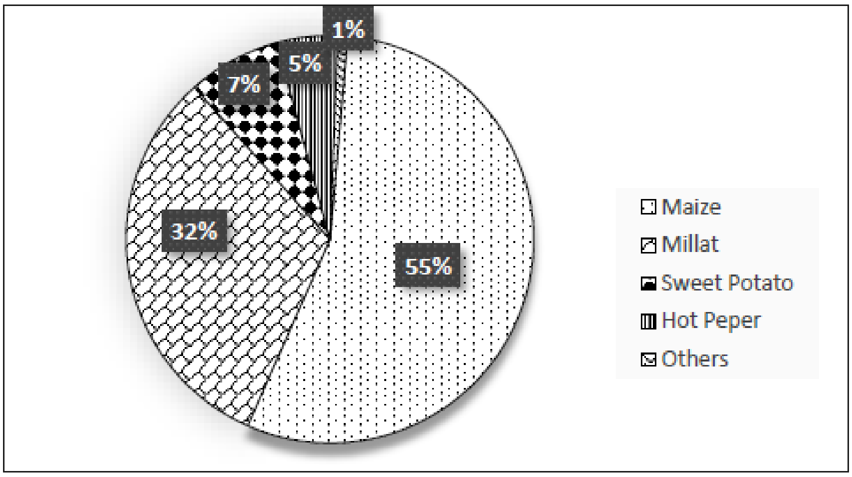

Figure 14: Production of major annual crops on Dek (2013-2014)

Coffee and mango are the main cash crops for the villagers. It is common to find them in every farmer's homestead. According to key informants coffee is their leading cash crop. It contributes the largest share of the households' income. To protect the effect of sunshine, farmers use *Millettia ferruginea*, *Croton macrostachyus*, and recently mango as shade trees. However, the productivity of coffee in the village is declining owing to the traditional method of cultivation, coffee diseases and termites. On the other, hand mango plantations are becoming dominant, contributing a significant environmental and financial benefit to the islanders. It provides an evergreen look and a main source income for the villagers.

Even though, the island is suitable for agriculture, crop failure and termite hampers farmers' productivity. According to the information from the farmers, the crop damage caused by the termite is very serious especially during years with low rainfall. It affects coffee and mango plantations as well as vegetable production. Termites have also effects on the main crops during harvest. The farmers have mentioned that the post-harvest damage is much more severe than the pre-harvest damage by termite. It is totally impossible to leave harvested crops in the field for more than two days without piling it on the stone or wood branches.

Due to its agro-ecology and soil type and fertility, non-cereal crops particularly pulses such as beans, pea and vetch are not cultivated. This leads to the loss of large quantities of their product (maize and millet) for non-cereal crops through barter exchange as pulses have higher market price.

As the island is completely surrounded by the lake, there is a potential for irrigated crop production. However, it is not possible to irrigate the agricultural fields by natural gravity because of the relatively higher altitude of the island as compared to the lake. Currently, some farmers are acquiring motor pumps on credit basis in collaboration with Bahir Dar Zuria Agricultural Office and as a result irrigated agriculture is practiced by a small number of farmers especially by those who have plots near the coast. Moreover, the farmers in the village have little knowledge of modern irrigated agriculture. The presence of free grazing is also one of the factors that impedes irrigation practice in the village.

The main types of livestock on the island are cattle, goats, sheep and donkeys. Although the average livestock holding in the area is very low, livestock plays a great role in the farming system of the villagers. Oxen are the only source of traction power for farming; donkeys a means of transporting harvest from farm to home and home to local market. Almost all of the households keep poultry. Some of the households are also involved in beekeeping activities.

Fishing is another economically important activity on Dek Island. The major and economically important fish species of the Lake are tilapia (*Oreochromis niloticus*), cat fish (*Clarias gariepinus*), the endemic beso (*Varicorhinus beso*) (Getahun, 2010) and barbs (*Barbus intermedius*). Farmers go to fishing as off-farm activity and most of it is used for household consumption. According to key informants although there is one individual at Gurer who collects and trades fish outside the island, it is almost a dying sector in the island. Burglary by fishers coming from Gorgora, Delgi and the nearby shore villages, and the decline in fish productivity are the main hindrances.

2.4. Trade

Trading is an inevitable practice as the people are not able to produce all the goods and services they need for their consumption. This is true for Dek community too. They have two types of market; local market and outside market.

There are less than 10 small shops, all located in Gurer village, that sell commodities for daily consumption such as sugar, soap, oil, pens, razor blades and the like. There is also an open-air market held in Gurer every Friday morning. People from the seven villages and from Sekelet take part in the market.

Quite unique in the marketing system of the island is that the islanders are still using bartering systems for the exchange of some commodities. The villagers from Sekelet area mainly produce beans which are used for making stew. Sekelet village is located between Lake Tana shore and the lower Gilgel Abay River (Figure 1). As a result, this village is at the end of a peninsula, without roads, hence difficult access to the market in Bahir Dar, thus mainly marketing their product with Dek people.
The small traders both from Dek and Sekelet take millet and maize from Dek to Sekelet, and beans to the Gurer market on the Island. The small traders from these places also bring products that are not sufficiently produced on the island such as barley, wheat, teff, beans, onions, or tomatoes to the Gurer market. In addition the people buy most of their consumer commodities, agricultural inputs, tools and instruments mainly from Bahir Dar.

While the majority of Dek farmers retail their products on the island at Gurer market because of absence of regular transportation system, a small number of farmers and traders from Dek Island use different market places outside the island. Mango, coffee and maize are the three main crops sold on these markets. As the profit it generated became low due to crop diseases and failure, the contribution of hot pepper as one of the main cash crops declined. Some households that have a relatively large land holding size can also sell some portion of their maize and millet yield that is in excess of household needs. The market places for these crops are mainly Bahir Dar, Gorgora, Delgi and Sekelet (Figure 1). Compared to the other crops, coffee is the main crop sold at Bahir Dar market by the households due to its relatively higher market value.

Fish is another product that is marketed on the island. It is a secondary activity for the majority of the islanders. Only few traders (those who have their own boat) are involved in the marketing of fresh fish products. Two types of fish products are produced and marketed on the island: fresh and dried fish. The majority of the fishermen have indicated that it is more profitable to sell fresh fish instead of drying it. However, the absence of a regular transportation system forces them to dry the collected fish and sell it at cheap price to traders in Dek. Fresh fish will be sold in Bahir Dar by the owners of motorized boats or dried to sell to other places. The majority of the fish product is traded in dried form. The dried fish has a relatively long market chain as compared to the other products. The majority of it is marketed to Sudan through the Matema route.

In spite of the fact that there is high production of mainly mango, maize and coffee, the people are not getting their best share out of it due to lack of market and regular transportation services. There is no organization that is assisting farmers with the provision of up to date market information and in identifying the potential buyers of their products.

Although there is a Fruit Association, it is not effective to collect fruit production of members and sell their product before it perishes. Some farmers who are able to take their product to Bahir Dar also do not have specific customers and sell their product on the open market at cheap price. The problem is most serious for mango as it perishes rapidly.

One key informant described the severity of the problem as: *Mango is very productive in the island and has a great potential to provide as a worthwhile amount income for our community. It is very good for our environment. However, as we produce more, we have nowhere to sell it especially during the rainy season. As a result it perishes here and creates even bad smell. If the trend continues like this we have no choice but to cut it and use our land for other crop production.*

2.5. Social services

As the island is isolated from the mainland, the supply of social services is quoted as the fundamental problem by the people. Existing services and their problems comprise the following.

School: There are two primary schools on the island. Gurer primary school and Dek Primary School (located in Woba Village), both teach from 1st up to 8th grade. The total number of students in Gurer School is 107 male and 73 female students while there are 477 male and 485 female students in Dek School. According to the schools' principals and field observation, there is lack of classrooms and the existing ones are uncomfortable. Class rooms made of timber and daub (mud mixture plastering) are affected by termites and are getting ruined. Once the students have completed the primary school they have to go to Bahir Dar to attend secondary school. As mentioned by key informants sending their children to Bahir Dar is becoming unaffordable, due to high cost of living in Bahir Dar and transportation problem. As a result many parents are forced not to send their children to secondary school.

Health service: There was one rural human health and one animal health station on the island. The human health center is currently upgraded to clinic. But the infrastructure is not contented and it is not yet providing the service required. There are professionals employed but mostly they are idle as the services provided both by the human and animal health stations are very limited. According to the interviews with both the nurses and animal health development agent, there is a great need for both human and animal health services on the island but due of shortage of facilities and medicines the service provided to the society is very limited.

Government service: There is Kebele level administration, agricultural Development Office and police station, all located at Gurer village (Figure 5). These offices are accountable to Bahir Dar Zura Wereda. According to the office heads, the villages of the island are forgotten by the higher administrative levels; this hinders the development effort of the inhabitants.

2.6. Transportation

Dek Island is surrounded by Lake Tana and water transportation is the only means of transportation to access villages and towns on the nearby lake shores.

For ages, the Dek community has used *tankwa*, bundles of papyrus bound together and streamed in to boat-like shape. On his voyage, Cheesman observed in 1932/33 that *tankwas* were the only craft used for transportation on Lake Tana and Dek. Lake Lake Tana Transport Enterprise (LTTE) was established in 1942 to provide shipping from Bahir Dar to Gorgora via Dek. Although it does not replace *tankwas*, it has become one valuable means of transportation for the people ever since.

Since then, LTTE is the only enterprise or organization providing limited transportation services for the Dek community. The enterprise provides only a single trip per week for the Dek community on its way to Bahirdar or Gorgora. Thus, the people who travel to Bahir Dar on Friday have to wait until Sunday morning to get back to Dek because of absence of transportation services.

Consequently, the community now owns small private boats, almost in every village on the island there is at least one private boat, owned by a group of farmers. In addition to the private boats there is also one ambulance boat provided by a Netherlands-based NGO called Interchurch Foundation for Ethiopia and Eritrea (ISEE), which services for emergency purpose only. Hence, the role of *tankwa* is left only for short distance travel around the island and fishing.

Lake Tana Transport Enterprise (government owned) is the chief provider of transportation for the people and their commodities. The privately owned boats are not providing sufficient services to the local community. According to the information from the owners of the boats, the main constraint is that they are required to pay high landing tax to the ports constructed by the LTTE either in Bahir Dar or on Dek Island. And, if they agree to pay, the enterprise does not provide storage service until they take their products to the market.

Even though they have requested since a long time to build their own port especially at Bahir Dar, their main market destination, the response is negative. In this respect, a Kebele administrator described the problem as:

We have no port in Dek, Bahir Dar and Gorgora to land our products. We urged the Woreda, Zone and Regional office several times. But we got only promise response, we are forgotten people. The Transport service by LTTE is not regular and we are charged high price compared to others, and in addition we don't have place to store our product. As a result merchants and brokers are able to bargain the price of our products down. All these affects the motivation of farmers to increase productivity.

2.7. Social Problems and Changes in Dek Island

Dek community does not have problems of food security. It has enormous potential in agriculture, fishing and tourism. However, different factors constrain their effective utilization. The following were identified as major constraints hindering the improvement of people's livelihood.

Rapid population growth: Since the island is completely surrounded by the Lake, agricultural land expansion is impossible. On the other hand, the size of the population is increasing which further decreases the households' land holding size and aggravates shortage of agricultural land in the island.

Dependence on rain fed agriculture, inadequate agriculture extension service, low agriculture input supply, and traditional methods of cultivation and farmers resistance to adopt new techniques are also prevalent problems affecting the major means of livelihood (agriculture) in the island. Besides, crop disease and termites are also major constraint for crop production and construction in the island

Lack of market access: the very location of Dek Island, combined with ineffective economic organization, limited transportation and communication, creates a lack of up to date market information and lack of buyers of their products.

Absence of port and regular transportation: transportation by LTTE is not regular and at high price. Lack of regular transportation services has forced the farmers to mainly depend on the low productive cereal crops because of the post-harvest loss associated with the other market-oriented types of crops.

Unemployment: according to the villagers, the number of jobless young people is increasing. When the students finish their secondary school and do not succeed the national examination to enter college or university, they have to go back to the island and depend on their family's resource or migrate to Bahir Dar or other towns in search of a job. Since there are very limited job opportunities on the island, most of these young people migrate to urban areas.

Public service: the community is not adequately beneficiary to different public services such as secondary school, appropriate health service, communication or electricity.

3. Socioeconomic and biophysical nexus

Recognizing the socio-economic and physical geographic attributes provides a good understanding of the mutual interdependence between human activity and environment. To this end, the existing biophysical condition and socioeconomic activities of Dek Island display complex changes and challenges.

Due to its location, the livelihood of Dek communities is strongly related to biophysical attributes. Land remains at the center of rural livelihoods, yet population growth becomes a persistent problem which increased livelihood vulnerability. Population dynamics are often recognized as a prime underlying cause of land degradation or improvement (Müller and Zeller, 2002; Fischer, 2001). According to Malthusian and Boserup's school of thought in a closed society, an increase in population density would increase the demand for food (Fischer. 2001; Quyet et al. 2014). In this regard, to meet the growing demand, agricultural activity is expanding in Dek Island. The expansion of agricultural land is often associated with the conversion of wetlands and uncultivated land to mango and coffee plantation that cause a general increase in biomass. But, the coverage of natural forest is decreasing due to increased human intervention. These coupled with environmental variables such as the fact that the soils are easily affected by termites, unprecedented crop production failure and rainfall variability are becoming a major challenge to improve the livelihood of the inhabitants. On the other hand, increasing intensity of cultivation, free grazing and frequent overgrazing, fragmentation of land holdings are main sources of the biophysical degradation.

The increase in annual mean NDVI over the last 14 years (2001–2015) concerned the persistent increase of the biomass productivity of the island, owing to plantation of mango and coffee as a means of adaptation to improve livelihood for the growing population. The wetlands and its ecosystem and the density of the natural forest are the two affected land-uses. However, mango plantation is threatened by lack of market, transportation, and telecommunication and electricity services. On the other hand the expansion of agriculture and mango plantation is often associated with the conversion of natural forest that causes the loss of natural biomes.

In addition the livelihood vulnerability of the community is aggravated by social problems such as effective economic organization, absence of social services such as health, electricity and communication, transport and market opportunity. These aggravate the proper use of the island's resources and productions. This entrapment limits the expansion of the non-farm sector and constrains agriculture, contributing to slow improvements of livelihood. Consequently, households tend to engage in many diversified livelihood activities of which seasonal migration is a typical example.

Changes to annual water level fluctuation are an externally generated problem, due to control of the lake level at Chara Chara weir that results in a biophysical change on the lake shore wetland ecosystem of Dek Island. In line with McCartney (2010), and Pfeifer et al. (2012), our NDVI result shows that the size of wetlands around the lakeshore changed since the construction of

Chara Chara weir. Ayalew et al. (2008) in their stakeholder analysis of the Chara Chara weir point out that it has posed environmental and livelihood problems.

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Are there Gleysols on Dek Island?

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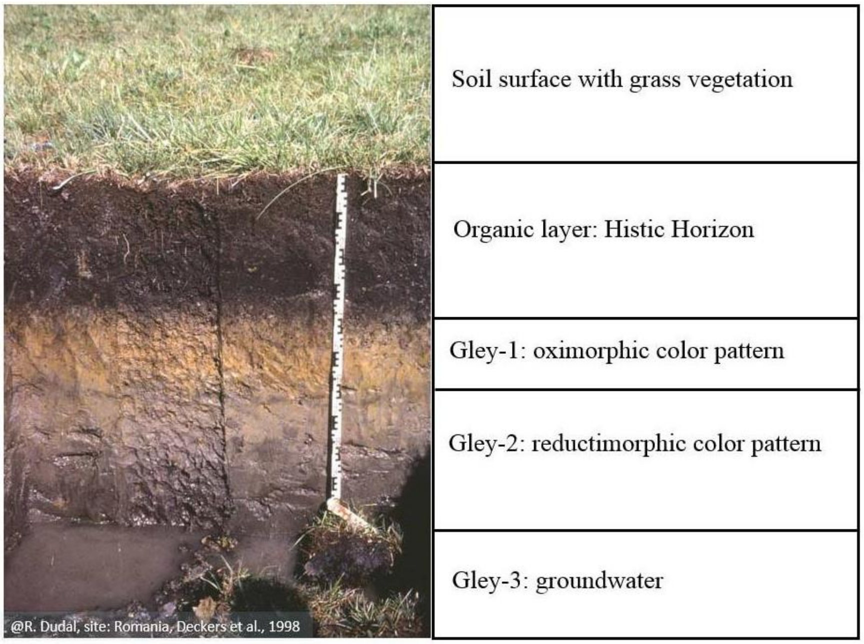
Gleysols are swampy soils affected by groundwater gley. This means that groundwater is occurring at shallow depth, sufficiently long for a gleyic color pattern to develop. Gley colors typically are blue, grey or sometimes whitish. They are a token for prolonged absence of oxygen. In such conditions iron in the soil is reduced and the soil color goes from reddish-brown to blue or colorless.

As the islands of Lake Tana are surrounded by lake water, it is expected to find indeed Gleysols. However, for soils to key out as **Gleysols**, the gleyic color pattern has to start within 40 cm from the surface. That means that the permanent groundwater table should be at very shallow depth, which is only the case along the fringes of the islands closest to the lake (Fig. 1). The Gleysol areas are readily recognized as flat swampy areas covered by papyrus vegetation or by grass sedges. They seasonally flood starting from the second part of the rainy season, when there are high water conditions in Lake Tana. Due to the permanent poor drainage conditions, abundant organic matter from the papyrus is accumulating and remains as peat in the topsoil. As soon as the peat layer reaches a thickness of 40 cm, the soil becomes a **Histosol**.

Fig. 1. Tankwas made from papyrus, resting on Gleysols on the shore line of Dek Island in Lake Tana

One may also wonder: ‘are there **Fluvisols** on Dek Island’? Fluvisols are by definition soils of alluvial origin. In the flood plain, also on the islands, Fluvisols are indeed bound to occur. They get flooded by the lake during the rainy season, but during the dry season their water table typically is dropping so that they gleyic color pattern occurs between 40 and 100 cm from the soil surface.

In summary, it is anticipated that Gleysols are occurring in lower topographical positions on Dek island of Lake Tana, along with Histosols and Fluvisols. Field verification will be done on the island.



Histic Gleysol with gleyic color patterns at shallow depth and a Histic horizon at the surface

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Ethiopian Highlands, Home of Arabica Coffee (*Coffea arabica* L.)

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Introduction

Ethiopia, located between 3 30' and 14 55' North and 33 to 48 East at the Horn of Africa. Ethiopia is one of the largest countries in Africa, with an area of over 1.13 million Km^2. It has a rugged topography with altitudes ranging from around 100 meters below sea level in the Danakil depression to 4600 meters above sea level in the Semien Mountains.

Coffee is the most important agricultural commodity in the world, and it worth up to $14 billion annually. More than 121 countries including Ethiopia export and/or re-export coffee to more than 165 countries worldwide. More than 50 developing countries, 25 of them in Africa, depend on coffee as an export commodity (http://www.ecea.org.et/uk/). The agriculture-based Ethiopian economy is also highly dependent on coffee as it contributes more than 41% of the country's foreign exchange earnings. Moreover the sector provides income for approximately eight million smallholder households which are participating in the various activities in the value chain of coffee (Samuel Gebreselassie and Lud, E., 2013).

Coffee plays a vital role in both cultural and social life of Ethiopian community. Among coffee producing countries in the world, Ethiopia is the first country in consumption of coffee. From the 200,000-250,000 tons of average annual production, about 50% is consumed in the country. Preparation and drinking of coffee is a unique culture in Ethiopia; coffee ceremony. Coffee is not drunk alone. It is a social activity to be shared with others. Sharing coffee with others means you are 'at peace' with them and cultivates community and friendship. Coffee is typically made by roasting and brewing on a small charcoal burner. Cups (cinis) are usually laid out in a square on a tray dressed with fresh grass and served with a snack such as fresh popcorn.

History of Coffee Consumption

The history of coffee consumption is associated with most widely cited legend of the goat-herd Kaldi. Kaldi was herding his goats in the mountain forests of what is now called Ethiopia. One day, his goats were very active and dancing on their hind-legs. Kaldi was surprised with unusual activity of the animals and investigated and found that they had eaten the red cherries of the strange coffee tree. Kaldi was worried and afraid since his goats might get sick. In the next day when he took his goats out, they immediately went back to the same bush and started eating again. Therefore, he was aware of that the cherries didn't seem to harm his goats and took some cherries as well. He noticed the effect immediately and felt energetic and very awake (Lokker, 2013).

Kaldi took the cherries home and gave to some monks in a nearby monastery. They were very happy with the strange cherries, because chewing them kept them awake during long praying sessions. So coffee was then accepted as stimulant drink. Still today, the offspring of these trees can be admired in south west, and other parts of the country including Zege (an island on Lake Tana, the source of the Blue Nile River), where thousands of these trees are being used for crossbreed purposes by the Ethiopian Coffee Research Center (www.ethiopianspecialtycoffee.com).

Origin and Distribution of Coffee

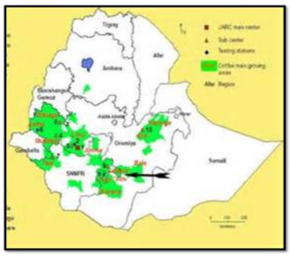
There are two main species of commercial coffee, Arabica coffee (*Coffea arabica*) and Robusta coffee (*C. caneophora*) and two minor commercial species, Liberica coffee (*Coffea liberica*) and Excelsa coffee (*Coffea excelsa*) (Mangal, 2007). The Arabica coffee is originated in the highland forests of south-western Ethiopia whereas that of Robusta coffee in the wild forest of humid hot lowland areas of Middle East, Central, and West Africa. In south-western part of Ethiopia about 400,000 ha of an ancient forest where coffee occurs as understory shrubs still remain (Ervine, 1969). Moreover, there are also high genetic diversities of coffee in the region that are used as source of plant stock for the selection of disease resistance, high yields and top quality in terms of aroma as well as flavor (www.ethiopianspecialtycoffee.com/).

The distribution of Arabica coffee from its center of origin to Yemen (secondary origin) is probably through Persian invaders in 575 and Arab traders in 13th century. From Yemen, it spread to Middle Eastern countries and India in the 14th century from where European traders subsequently took coffee seeds to other parts of Asia, Africa, eventually to South America (Ervine, 1969).

Coffee Production Systems in Ethiopia

Settled agriculture began in Ethiopia some 2000 years ago. Since time immemorial, Arabica coffee has been growing in the wild forests of the South-western highlands of Kaffa and Buno districts of Ethiopia and other parts of the country (www.ethiopianspecialtycoffee.com).

Ethiopian coffee is rightly known as highland coffee by consumers. The diversified types of *Coffea arabica* in the country, growing in an ideal environment has allowed Ethiopia to be attractive to the world coffee market. Ethiopian coffee is rich in acidity and body. It possesses an aromatic and sweet flavor and is characterized by winey, spicy notes and the world famous mocha tastes so highly prized by connoisseurs. Arabica coffee can be enjoyed as specialty coffee and it can also be blended with coffees from other origins to upgrade them.



The main coffee producing areas in Ethiopia are west & south west, southern, eastern, and central regions. Generally four production systems are distinguished in Ethiopia; forest coffee, semi-forest coffee, garden coffee and plantation coffee. About 95% of the coffee produced from these systems can be considered as organic, although not yet officially certified.

Forest coffee

This system is found in South and South-Western Ethiopia (Bale, West Wolega, Bench- Maji, Keficho-Shekicho, Metu and Jimma). These areas are the centers of origin of Arabica coffee (*Coffea arabica* L.). Forest coffee is self-sown and grown under the canopy of natural forest trees. Forest coffee has a wide genetic diversity and accounts for about 10% of the total coffee production in the country.

Semi-Forest coffee

This production system is also found in the South and South-West parts of the Country. Farmers acquires forest land for coffee farms, and then thin and select the forest trees to ensure both adequate sunlight and proper shade for the coffee trees. Farmers slash the weeds once a year to facilitate harvesting. This system accounts for about 35% of the total coffee production of the country.

Garden coffee

Garden coffee is grown in the vicinity of farmer`s residences, mainly in the Southern, Eastern parts of the country (Sidamo, Gedeo, South and North Omo Hararghe, Wolega and Gurage Zones, East and West). The coffee is planted at low densities (1000 -1800 trees/ha), mostly fertilized with organic material and inter- cropped. It accounts about 35% of the total production in the country.

Plantation coffee

Plantation coffee is grown on plantations owned by the state and on some well managed smallholders coffee farms. In this system, recommended agronomic practices like improved seedlings, spacing, proper mulching, manuring, weeding, shade regulation and pruning are practiced. Only state owned plantations (5%) are known to use chemical fertilizers and herbicides. In the remaining 15% of the plantation coffee owned by smallholder farmers such chemicals are not applied (**http://www.ecea.org.et/uk/**).

The potential for coffee production in Ethiopia is generally very high, thanks to the country's suitable altitude, ample rainfall, optimum temperatures, appropriate planting materials and fertile soil. Thus, Arabica coffee can be grown in various parts of the country.

Ecology of Arabica Coffee

In Ethiopia, coffee grows at various altitudes, ranging from 550-2,750m above sea level. However, the bulk of Arabica coffee is produced in the altitudes ranging from 1,300 - 1,800 m.a.s.l.

Annual rainfall in the coffee-growing regions of the country varies from 1,500-2,500mm. Where precipitation is less, as in the eastern part of the country (about 1,000 mm), coffee is supplemented with irrigation. It is not only the total rainfall which is important for good production of coffee but also its eight-month distribution.

Arabica coffee grows best in the cool, shady environment of Ethiopian highland forests. The ideal temperatures for coffee production are considered to be 15-25ºC. These temperatures prevail in most of the country's coffee-growing areas.

Arabica coffee requires fertile, friable, loamy soils, with a depth of at least 1.5m and relatively high water holding capacity. The fertility of coffee soils is naturally maintained through organic recycling of litters fall from coffee, and shade trees. Relatively acidic soil is suitable for Arabica coffee (5-6.8). The soil of most coffee growing regions in Ethiopia satisfies these characteristics of coffee soil.

Husbandry of Arabica Coffee

Seed preparation

Arabica coffee in Ethiopia is commonly propagated by seeds. For this purpose mature-red and healthy cherries are collected from vigorous and healthy mother trees and prepared carefully for sowing in nursery. Coffee nursery sites should be selected by considering various aspects such as availability of water, topography (gentle slope), accessibility of the site, etc.

To prepare the seeds, handpicked red cherries should be washed in clean water to remove any surface dirt or spray residue. During washing, floaters should be discarded and only heavy cherries will be used for further preparation. Heavy cherries will be then hand pulped to avoid parchment cracking which will increase incidence in the formation of twisted-taproot in coffee seedlings (undesirable characteristic).

After pulping the skins should be discarded with the washing water. Parchment coffee in the container will be put under shade for up to 10 hours for fermentation. Coffee seeds are then thoroughly washed in clean water for twenty minutes to remove the mucilage attached with.

Seed draying

Cleaned parchment seeds should be dried on mesh trays or open woven mats in a layer of one bean thick in well ventilated and shady place protected from rain and strong wind. Drying will continue until the seeds have a moisture content of 15-18%, i.e. until the seeds just crack when bitten. So prepared seeds can be used immediately or can be put in fiber sack and stored in clean, cool, dark and ventilated areas. However, seeds should not be stored for more than five months; beyond that they lose their viability and thus reduced germination rate.

Seed sowing and seedling management

Coffee seedlings can be raised in ground soil as well as in poly-tube. In the first case, seeds are sown in well prepared seedbed. Seeds in poly tubes are sown in a medium containing a mixture of top soil (forest soil), compost and sand at the ratio of 4:2:1, respectively. In both cases seeds should be sown the flat side down to avoid the formation of twisted taproot and mulched and watered immediately. Seed beds/media should be inspected regularly for its moisture content and emergence of seedlings. As soon as seedlings start to emerge, mulches should be removed carefully to avoid damages of seedlings and shades should be constructed at desirable distance from the ground level (1-1.5 m). Fertilizer application, weed, insect pest and disease control should be carried out in nursery as required.

Seedling transplanting and management of coffee plantation

The seedlings will be ready to be transplanted when they have 5-7 pairs of leaves. That is likely to be when the seedlings are 8 - 9 months old. Seedlings should be acclimatized to the harsh environment that will be occurred in the production field before transplanting. Therefore, 4-5 months after sowing, hardening of seedlings should be started by thinning the shade cover and reducing the amount and frequency of watering. Four weeks before transplanting, coffee seedlings should be completely exposed to the full sun (CTAE, 1996).

Strong and healthy seedlings which fulfill the quality requirements will be then transplanted into holes (50x50x50cm) prepared 2-3 months before in coffee plantation field (Kuit *et al.,* 2004). During transport seedlings should be well protected from direct sunlight to reduce water loss; especially the roots of ground bed seedlings (bare rooted transplants).

In the first year of transplanting and other subsequent years of coffee growth, management activities like mulching, loosening of the soil after heavy rainfall, growing intercrops, fertilizer application and disease and insect pest control should be carried out in coffee plantation farm.

Pruning is an essential task in coffee plantation. The goal of pruning is to create strong, well-structured and healthy coffee tree that give good yields over a long period of time and to rejuvenate old trees by stumping. Thus removing of weak and diseased branches and unproductive woods as well as improving air circulation in the canopy are the most important management practices performed during pruning activities. For detailed information, please refer Kuit *et al*., 2004.

Harvesting and Processing

Coffee fruits require 6-9 months for maturity after blooming depending on the variety and the environment. In most coffee-growing areas, coffee flowers from December to April and being harvested from August to January. During harvesting it is important to pick only red cherries. Green, dried and overripe cherries lead to different quality defects. Coffee harvesting is done in Ethiopia mostly by family labor, as the size of the average coffee farm is as small as 0.5ha (http://www.ecea.org.et/uk/).

Coffee is processed by two widely-known methods, dry and wet methods. The proportion of dry- and wet-processed coffee in Ethiopian coffee export is about 15-20 and 80-85%, respectively. In dry processing, the harvested whole red cherries are subjected to sun drying on clean mat, screen bed or cemented floor and allowed to dry to about 11.5% moisture content. The process may take up to four weeks depending on the weather conditions. After drying the outer layers of dried cherries are removed together through the process called husking.

In wet-processed coffee, harvested cherries will be pulped using pulping machines. The pulped wet parchment coffee goes to the different fermentation tanks to ferment naturally. The fermented coffee is finally washed with clean running water and to degrade and remove the remaining mucilage and acids and to improve the color of the beans. The wet parchment coffee is dried on raised drying tables to 11.5% moisture content by continuous stirring for uniform drying. Dried parchment coffee will be then hulled and polished to remove the parchment and silver-skin from beans, respectively.

Coffee Quality Control in Ethiopia

Ethiopian coffee is top in both green (color, appearance) and cup-quality (cleanliness and taste) parameters. To maintain these qualities, there is a well-established and linked structure that connects coffee farmers, processing-plant owners, governmental organizations and coffee-purchasing. Quality control is done by professional at producers, regional, central, and export levels with the aim to keep the country's export reputation and protect the overseas client`s interest. European Countries such as Germany, France, Italy, Belgium, Sweden, Norway, Finland, Denmark, UK, Switzerland, USA, Japan, Saudi Arabia, Canada, Taiwan, South Korea, Australia and South Africa are traditional buyers of Ethiopian Coffee.

Coffee Production in Lake Tana Islands

Lake Tana is the biggest lake in Ethiopia. On Lake Tana, there are about 31 islands. They are the home for the most interesting island churches such as Debre Maryam, Dega Estefanos, Narga Selassie, Tana Cherkos, Kebran Gabriel and monasteries on the Zege Peninsula including the monasteries of Bete Maryam, Azuwa Maryam , Ura Kidane Mehret, Bete Selassie and Tekla Haimanot, Kibran Gebriel, Ura Kidane Mihret, Azwa Mariam, Dega Estifanose, Tana Cherkos, and Narga Sellasie (www.**laketana-**biosphere.com/visit/**monasteries/**).

The Zege peninsula is about 17.5 km^2 with approximately 9,500 inhabitants. Monks and farmers living in the islands and Zege peninsula are producing coffee, vegetables, fruits and spices for their livelihood. Coffee is produced in Lake Tana islands and Zege peninsula since 830 A.C. and it is a major income source of monks and farmers. Coffee is occurring naturally and indigenously in forest.

Coffee is currently produced as semi-forest, and garden coffee in islands of Tana including Zege peninsula. Monks cultivate coffee using relatively proper cultural practices including application of organic matter to improve the fertility of the soil. Moreover, monks and farmers in the area are receiving training and machineries to modernize the processing of their coffee through extension workers and NGOs which are working to ensure supreme coffee quality, and thus to improve the livelihood of monks and farmers (http://blacksmithcoffee.com/products/). No chemicals such as mineral fertilizers and pesticides are used in the production of coffee in the area.

In Lake Tana islands, coffee flowers from April to June triggered by rainfall and harvesting time is in February and March. The coffee is well-balanced and round with full body has distinct mocha flavor with nuances of chocolate and malt in both aroma and flavor (http://blacksmithcoffee.com/products/).

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Human impacts on the hydrogeomorphology of Gumara River, Upper Blue Nile basin, Ethiopia

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1. Introduction

The processes of erosion, transport and deposition of sediments has modified the landscape of the upper Blue Nile basin, Ethiopia (Conway, 1997) indicates that alluvial and lacustrine plains may get huge sediment depositions. As a result of sediment deposition in the alluvial plain, the flood carrying capacity of the stream channel is reducing in recent times. This might be due to changes of river morphology (geometry) or as a result of land use and land cover changes (Poppe et al. 2013). Alluvial rivers change their shapes in reaction to humans influence on the natural system. Since long time, the human-induced factors have disturbed the alluvial river channels of the upper Blue Nile. This paper highlights the results of the recent study by Abate et al. (2015) on planform change along a 38-km stretch and the vertical adjustment of the Gumara River which drains towards Lake Tana and then to the Blue Nile. Over a 50 years period, agriculture developed rapidly in the catchment and flooding of the alluvial plain has become more frequent in recent times.

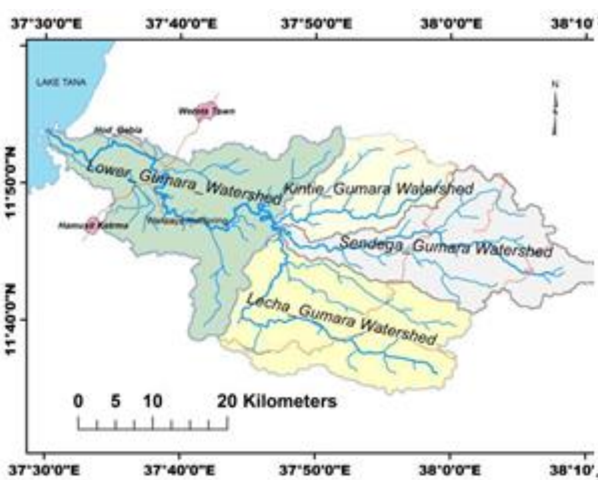

Fig. 1: The Gumara catchment and its sub catchments (modified after Abate et al., 2015).

Fig. 2: The study reach (Kizin to Lake Tana) of Gumara River and the excursion location (modified after Abate et al., 2015).

2. Materials and Methods

2.1 Description of the study area

The study area is the Gumara River with a total catchment area of about 1496 km2. The studied reach starts at the confluence of Kizin and Gumara Rivers, at the edge of the hills bordering the lacustrine plain, and ends at Lake Tana (Fig. 2). The whole reach is of the meandering type.

2.2 Preparation of data

Aerial photographs (1957, 1980 and 1984), SPOT image of 2006, Google Earth and field observations were the data which have been used for the understanding and analysis of the planform changes of the study reach of Gumara river.

3. Results

3.1 Planform change

The results indicated that the lower reach of Gumara has undergone major planform changes (Fig. 3 and 4)

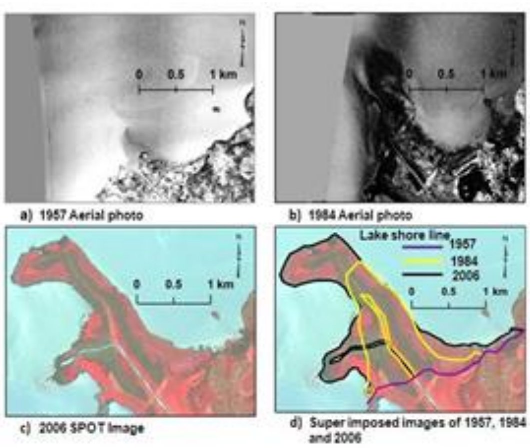

Figure 3. The Gumara River outlet at Lake Tana for the three periods (a, b and c). At the mouth of the river (d), a 1.12 km² delta has been created over 27 years (1957-1984) and an additional 1 km² area has been added in the 22 years spanning 1984-2006 (after Abate et al. (2015)*).*

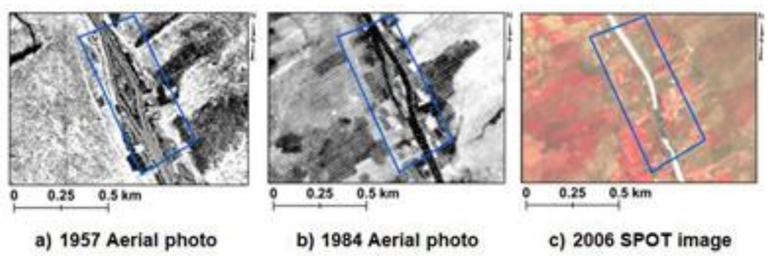

Figure 4. Example of in stream sediment deposition. A 1.74 ha island was observed on the 1957 aerial photograph (a), and after 27 years its area increased by 0.43 ha (b). The extent of the island expanded further and in recent years it became part of the left floodplain (c) (after Abate et al. (2015)*).*

3.2 Cross-sectional changes

At Gumara bridge, the deepest riverbed aggraded in the order of 2.91m for the period 1963-2009 (Fig. 5) and the banks undergone erosion and deposition (Table 1). As it is shown on Table 1, the channel cross sectional area at the bridge is reduced in its size for the reported period indicates that the flood carrying capacity of the channel is decreasing over time.

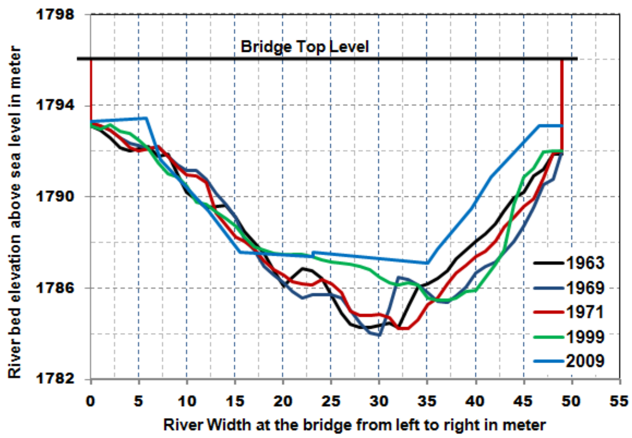

Figure 5. Changes to Gumara River cross-section at the Gumara bridge (source: MoWIE) (after Abate et al. (2015)).

3.3 Aggradation of natural levee induced by river bank overtopping

Although it is very difficult to quantify the depth of deposition in the floodplain, some structures, for instance automatic water level recorder (Fig. 6) which is installed in the river bank showed that the natural levee of the river is aggraded by about 1.4m.

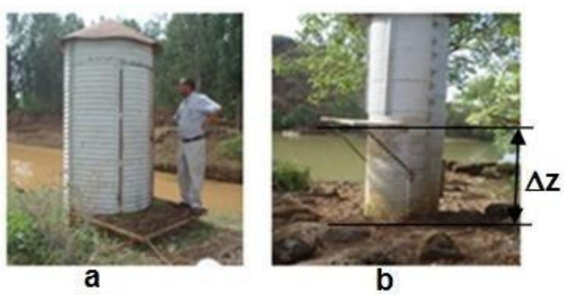

Figure 6. Automatic water level recorders installed by USBR in 1959, and photographed in June 2012 along the alluvial Gumara River (a; at 11.838408°N, 37.637086°E) and the bedrock Abay River 4 km downstream from Chara-Chara weir at the outlet from Lake Tana (b; at 11.567543°N, 37.403952°E). Δz indicates the depth of sediment that was accumulated in Gumara's natural levee over the intermittent 53 years, i.e. 140 cm (after Abate et al. (2015)).

4. Discussion

The position or geometry of streams may suddenly change due to human pressure on the catchment. (Heede, 1980; Surian, 1999; Urban and Rhoads, 2003; Surian and Cisotto, 2007). The notable development that occurred in the planform of Gumara River is the delta (Fig.3) creation at the mouth of the river within 50 years and the eliminated mid channel bar or island (Fig.4) in the channel located at a distance of about 8 km from Lake Tana indicating that the effects of the upper catchment erosion and the sediment input into the stream is increased and this is most probably related to human induced land-use changes in the catchment. Direct anthropogenic impacts; irrigation activities (Fig. 7), building of dykes along the river banks and artificial rising of Lake Tana level have contributed to the huge deposition (Fig. 8) in the river bed. Since there is no buffer area between the irrigation areas and the river banks, there is high hydraulic gradient and seepage is observed along the river banks which makes them to collapse into the river channel. Upstream of the Gumara Bridge, water pumping is intensively done, more than 6.52 km2 area is irrigated in the study reach since 2006 (Fig.7); to the extent that the whole base flow is exhausted before it arrives at Gumara Bridge (Fig.9). This study showed that changes to the riverbed level are substantial and its implication that the flood carrying capacity of the Gumara river channel has diminished.

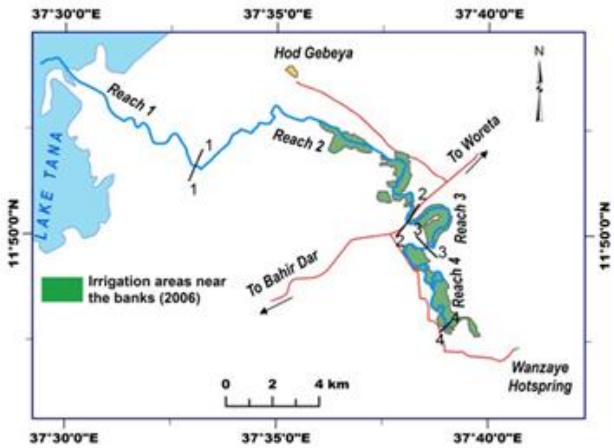

Figure 7. Extent of pump irrigation activities along the Gumara River banks (after Abate et al. (2015)).

Figure 8. Thickness of deposits in the river bed in the sand mining area (after Abate et al. (2015)).

Figure 9 Gumara River at the Gumara Bridge location showing that there is no base flow in the dry season. (Photo by Mengiste A. March 2015)

5. Conclusion

The changes in Gumara River channel are attributed to human induced factors (Fig.10). The overall analysis shows that the changes in the channel characteristics in the alluvial plain are linked to human- induced modifications in the upper catchment, in the river corridor, and on lake levels. The planform changes are very slow but the vertical morphological changing process is very active: in-channel deposition (2.91 m), development of natural levees and streambank erosion. The anthropogenic activities along the banks of the river have facilitated bed deposition. The raise of the river bed level results in more frequent high floods and sediment deposition. This will further increase the river bed level and this further reduces the flood carrying capacity of the channel

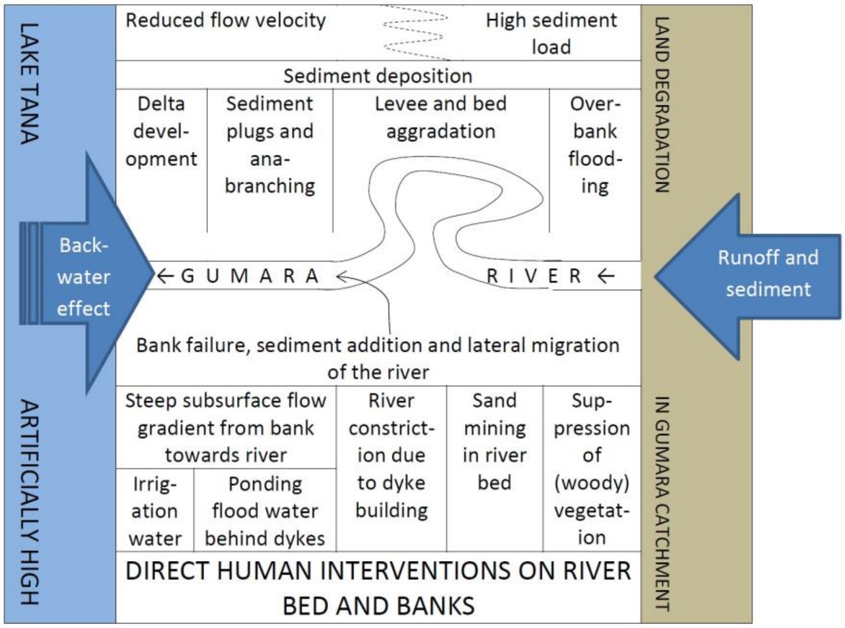

Figure 10. Conceptual model of hydrogeomorphic dynamics of Gumara River in the Lake Tana lacustrine plain. Major human impacts that influence the system are written in block letters at the lower, left and right sides of the diagram. Sequence of processes is both from top and bottom of the diagram towards the middle (after Abate et al. (2015)).

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Habitat Suitability Analysis of Hippopotamus *(H. amphibius)* using GIS and Remote Sensing: The Case of Lake Tana and its Environs, Ethiopia

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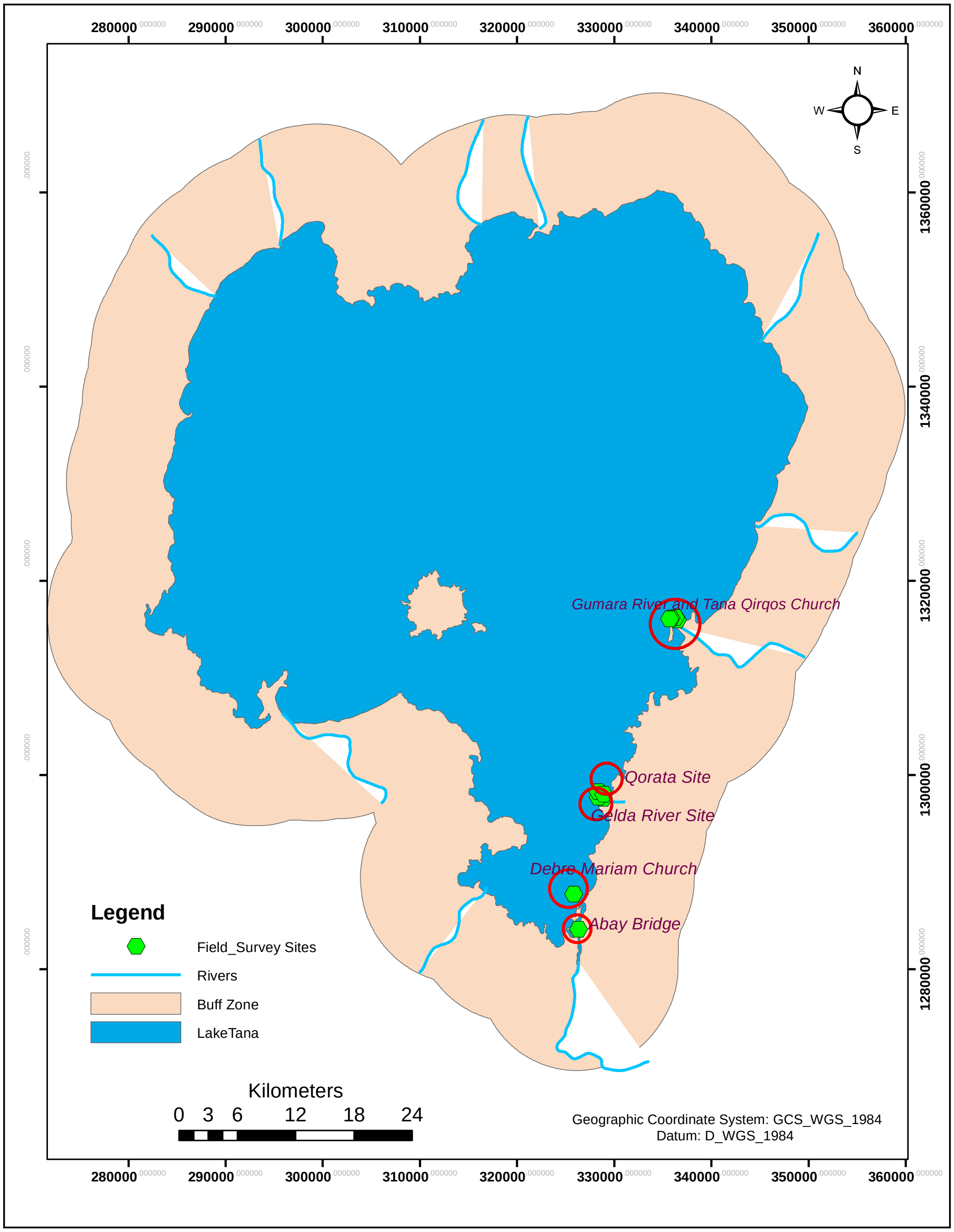


Figure 1. The study area Map

1. Introduction

Hippopotamus (*H. amphibius*) or hippo is a mammalian species distributed in different lakes and rivers where ecological requirements are fulfilled for its survival. Hippopotamus specialist group evaluated its status to vulnerable category on the International Red List of threatened species in 2006 (Lewison, 2007; Lewison & Oliver, 2008) due to habitat destruction and population decline in recent years. The study UNEP- WCMC (2010) indicated that there is no adequate country wide information on population size of hippopotamus in Ethiopia. However, the study confirms the presence of some populations of this species in Lake Tana, and other Rivers and Lakes of the country. The absence of previous study coupled with its' ecological and economic importance requires mapping suitable habitat site in Lake Tana and its environs using GIS and Remote sensing techniques.

2.Objectives

The objectives of this study were to carry out habitat suitability analysis and find out suitable sites for hippopotamus in Lake Tana and its environs using the integration of GIS and remote sensing techniques with MCDM.

3.Materials and Methods

The data used were GPS readings, SPOT image of 2012, DEM (Digital Elevation Model), Google Earth images and pictures. In addition bathymetric data of the Lake and thorough filed observation were very helpful for the completion of the work. The sample sites for field survey were the outlet of Nile River (at Debere Mariam), Gelda site, Tana Chirkos (at the confluence of Gumara River to the Lake Tana), Korata and Robit. **Microsoft Virtual Earth Satellite Downloader,** was used to generate settlement maps. The major Softwares used were ERDAS IMAGIN2010 to classify land use/ land cover and Arc GIS 10.2 to produce thematic maps based on their particular criteria.

3.1. Data Analysis Methods

Based on literatures slope (Holmes, 1996 cited in Dietz, et al., 2000), elevation (Eltringham, 2003, cited in UNEP- WCMC, 2010), Land Use and Land Cover (Mackie, 1976; Lock, 1972 cited in Erastus, *et al.* 2011; IUCN, 1993; Eltringham ,1999), forage proximity to the Lake (Tracy, 1996), distance from settlement (Wengström, 2009) and water depth (Tracy, 1996) were identified variables. In order to map suitable habitat site for hippopotamus in Lake Tana and its environs thematic map was produced for each variable. The thematic layers have varied (qualitative and quantitative) values. Thus the data classes need conversion into uniform suitability measures to make the combination compatible. Each layer was reclassified into three suitability classes: Highly suitable (3), moderately suitable (2), Not suitable (1) based on the literature evidences and field observation.

3.2 Multi Criteria Decision Making

Before the layers were merged into the weighted overlay analysis, the inputs were first converted into a raster data model and segregated into common scale to make combination possible. Multi criteria Decision Making (MCDM) problems typically involve criteria of varying importance to decision makers (Eastma *et al.* (1995). Accordingly, 1 to 3 class scales were assigned for each criteria/ factor.

4.Results and Discussion

4.1 Elevation Suitability

The DEM shows an elevation ranging from very low altitude of 1646 meter to 2394 meter above sea level. The study conducted by Eltringham (2003) show this species is abundant between altitudes of 200 and 2,000 m in Ethiopia. The other literature evidence and the researcher's field observation confirmed the upper altitude limit to be approximately 2000m (Rebecca, 2008). So that based on these evidences the altitude suitability classes between 1,646m and 1,900m, 1900.1m and 2000m and more than 2000m above mean sea level were identified as more suitable, moderately suitable and not suitable respectively. Thus by using raster reclass tool, the reclassification analysis was computed for elevation suitability classes.

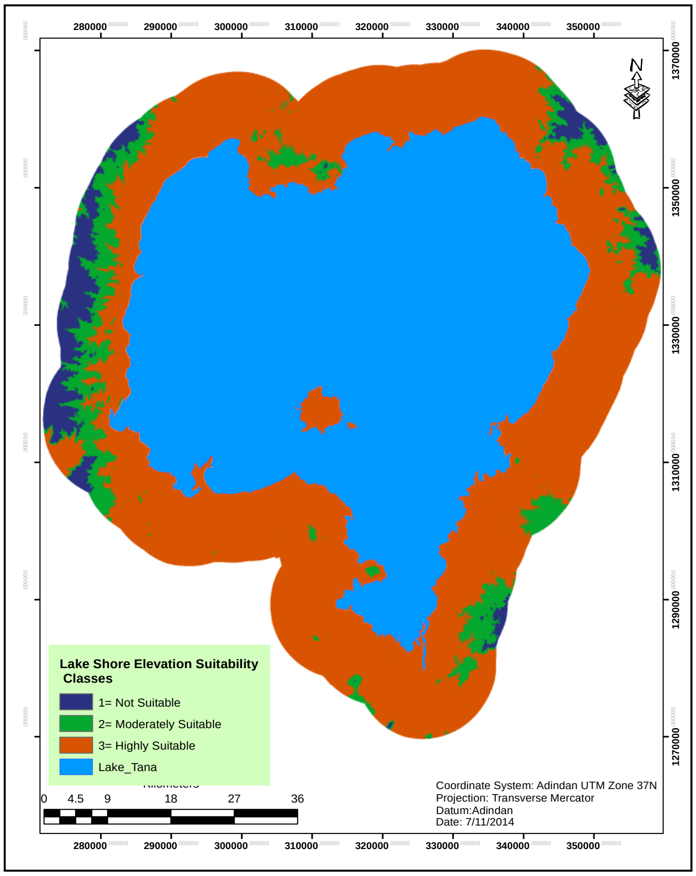


Figure 2 Elevations suitability classes

The GIS analysis result shows that, most of the study area's elevation was fall under the suitable class for the species understudy. As can be seen from figure (2) the greatest share of the lakeshore is under suitable elevation classes which cover an area of 81.85% of estimated hippopotamus habitat in the study area. Moderately suitable elevation covers only 11.9% of the area and the unsuitable elevation class covers the least (6.2%).

4.2 Lake Shore Slope Suitability

The slope class which helps hippopotamus movement to the land was identified based on literature and field observation. As a result the lakeshore less than 7^0 was identified suitable grazing ground for this species. According to Holmes (1996) cited in Dietz, et al., (2000) sites with a high slope can cause inaccessibility problems due to morphology and body size and structure of the specious. The suitable slope values were those that represent conducive travel for the species, since it could not raise high gradients.

Figure (3) depicted the slope suitability classes of the study area. Thus the figure shows from the Lake shore only 6.97% as highly suitable, 47.2% moderately suitable while the remaining 45.83% is not suitable (the slope classes that could not be climbed by the hippopotamus).

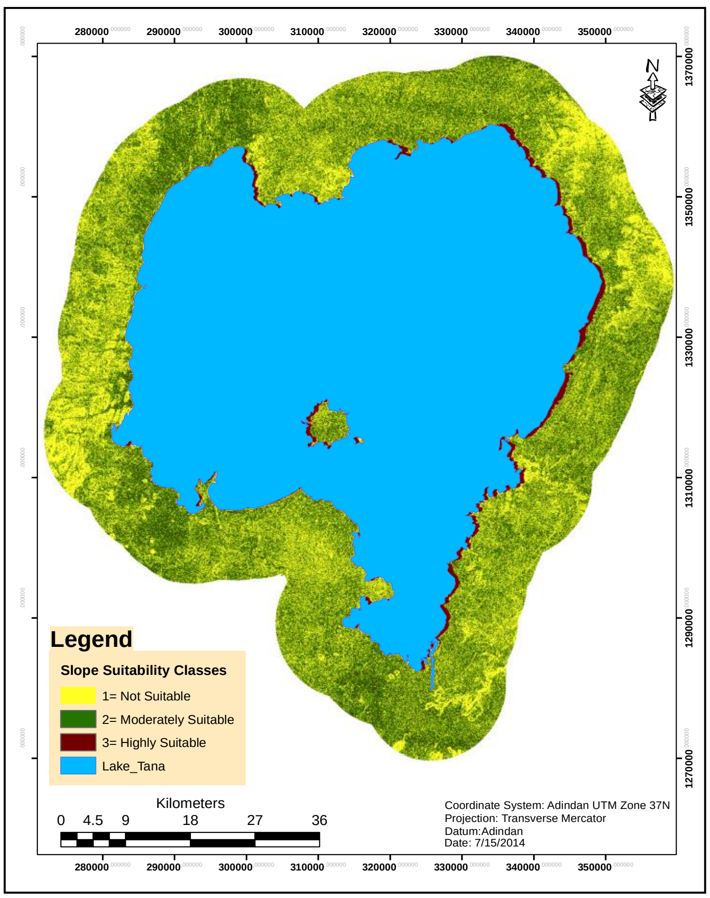


Figure: 3 Slopes suitability classes

4.3 Land Use /Land Cover Suitability

In order to know Land Use/Land Covers status, SPOT image with spatial resolution of 5 m pixel size was processed using ERDAS Imagine version 2010 software. By using ground control points (GCP) collected in the field, Land Use/Land Covers classification was performed. The Land Use/Land Covers map of the Lakeshore was reclassified on the basis of suitability/ compatibility to hippopotamus living and feeding. Accordingly, human activities (cultivated and settlement) and forested banks were identified to be unsuitable (IUCN, 1993), while wetlands and grasslands were classed as suitable. The classification for Land Use/Land Covers indicated that the area occupied with human action accounts about 45.26% of the total area within the study area. And is followed by bushland (27.42%) which is unsuitable for hippopotamus grazing. The remaining land use/ land covers (grassland, wetland and forests) account about 20.77%, 3.73% and 2.84% respectively. Most of grasslands near the Lake were dominantly communal (domestic animal grazing) which were frequently grazed and highly disturbed due to compitetion over limited resources. From the total estimated area of hippopotamus habitat including the Lake Tana, only 21.23% was identified as highly suitable. Most of the suitable areas from figure (4) were located behind settlements. On the other hand 78.77% of the lakeshore was not suitable for hippopotamus grazing due to either human interferences or natural barriers.

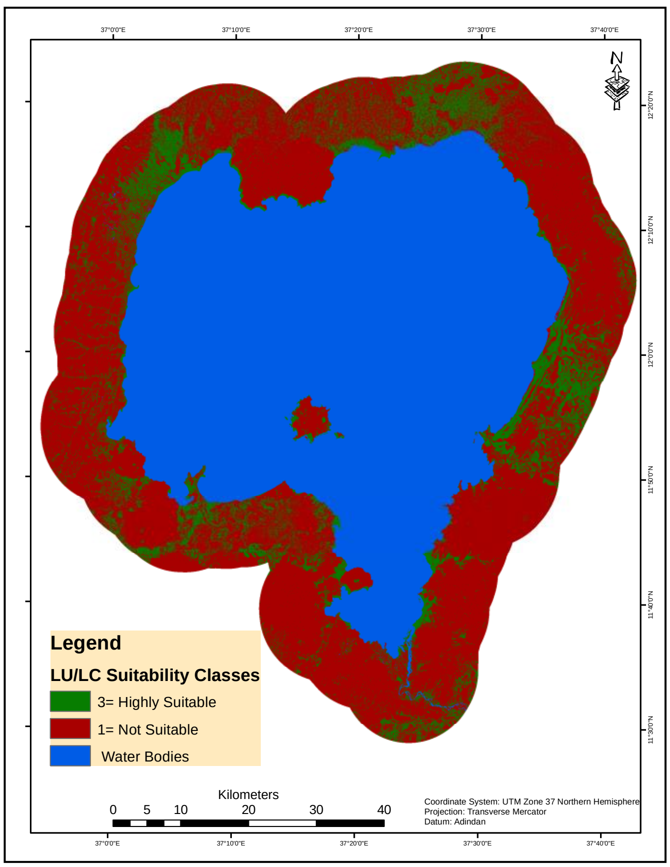
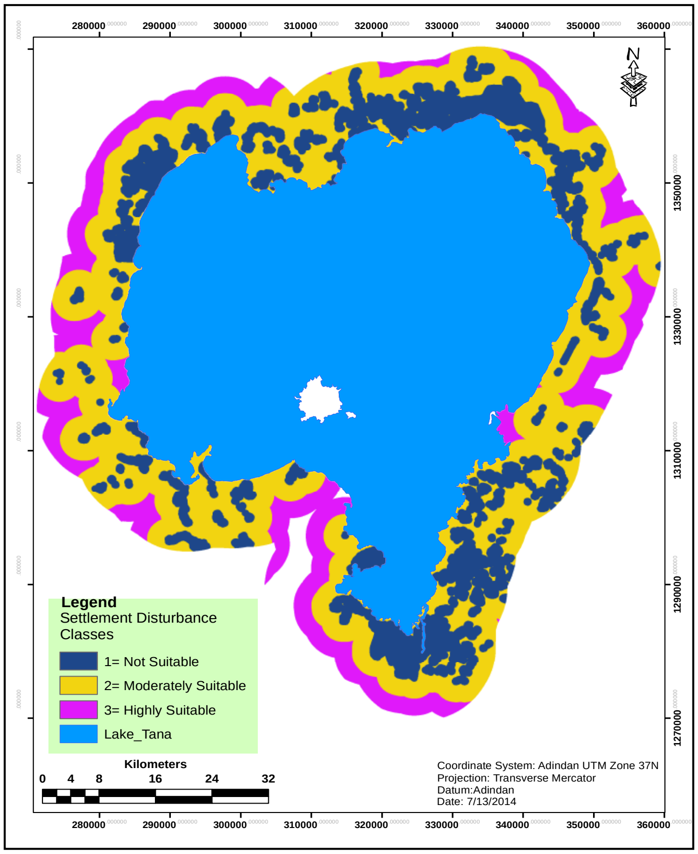


Figure 4. Land Use/ Land Cover Suitability Classes

4.4. Settlements Proximity to Hippopotamus Resting and Grazing Area



In addition to cultivation of hippo grazing land and competition with domestic animals on the same area, permanent settlements have a great disturbance on hippopotamus habitat. As the field visit confirms that people living very close to the Lake made different types of barriers to prevent the passing of these animals to their vegetable ground. Manmade obstacles that threaten this animal's life were the holes dug for this purpose and stone hedge. People knew that due to its body size and short leg it could not pass such barriers. From settlements multiple rings buffering at specified distance around the input feature was computed as shown from the figure.

Figure5. Settlements Disturbance on hippopotamus

The figure depicted the presence of high human disturbance on hippopotamus habitat in Lake Tana Environs. From the estimated terrestrial habitat, only 1.81% of the land area was safe from human interference whereas 50.88% of the land was highly disturbed for its survival in the study area. On the other hand 47.29% of the area was moderately disturbed.

4.5. Hippopotamus Grazing Ground Proximity to the Lake

In search of food individual hippopotamus is estimated to commute every night up 2 to 7 km from the river or lake in which they spent the day, but during condition when food is not easily obtained the distance they move may increase up to 10km (Eltringham, 1999; Tracy, 1996).

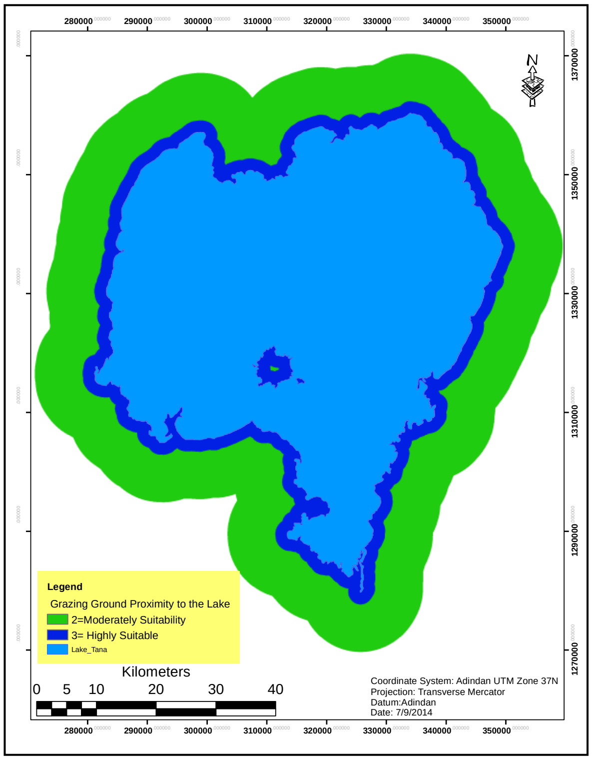


Figure 6. Grazing Ground Proximity Classes to the Lake.

As the multiple rings buffer analysis depicted that, the most suitable area for nocturnal grazing by hippopotamus is preferred to be close to resting water. Therefore, taking the capability of hippopotamus to move and forage only, 22% of estimated area was classed as highly suitable and 78% area was moderately suitable.

4.6 Weight Assignment for Thematic Maps

In multi criteria evaluation of various factors for habitat suitability, estimating weights by ranking method was taken into consideration to find optimal location for hippopotamus in Lake Tana and its environs. The criterion was first ranked based on the influence of each factor relative to other factors.

Table 3. Weight Assignments For Thematic Maps

Thematic Maps/ criteria	Measure	Straight Rank	Weight (n-rj+1)	Normalized Weight	Percentage Influence %
Land Use/ Land cove	Types of LU/LC	1	5	0.333	33.3
slope	Degree of slope	2	4	0.266	26.7
Settlement disturbance	Proximity in Km	3	3	0.20	20
Grazing distance from resting water	Proximity to the lake in Km	4	2	0.133	13.3
Elevation	From mean sea level (m)	5	1	0.067	6.7

Source: Expert's and Researcher judgment (2014)

4.7 Weighted Overlay Analysis

By running the overlay weighted overlay analysis, suitable sites for hippopotamus were identified in Lake Tana and its environs. On the other hand the aquatic habitat was analyzed separately because of the terrestrial and aquatic environments are adjacent each other than overlaying. As we can see from the figure below, it seems there is large area for hippopotamus habitat. For instance 22.54% of the study area is suitable based on used variables analyses. However, the animals could not cross settlement areas. As a result much of the areas are inaccessible. Whereas 40.5% of the study area is moderately suitable that can made more suitable if conservation strategy is designed by the government and the community. On the other hand 36.96% of the Lake Tana environs were not suitable for hippopotamus habitat.

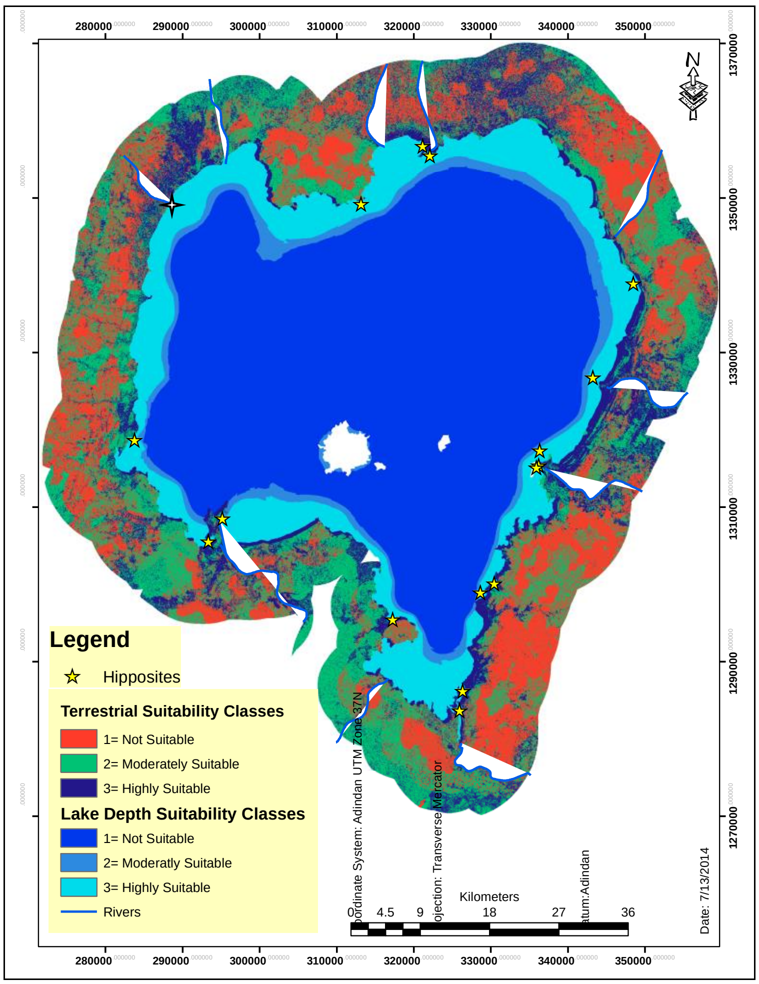


Figure 7. Model result for hippopotamus habitat around and in Lake Tana

5. Conclusion

In the study area high interferences of man in hippopotamus habitats takes the lion’s share in making the areas unsuitable. To this end the Land Use/ Land Cover classification indicated that the area occupied with human action (settlement, cultivation) accounts about 45.26% of the total area within the study area. however, as the analysis output ilustrated the sphere of influence of settlement was beyond the area occupied by it and is followed by bushland (27.42%) which is unsuitable for hippopotamus grazing. Due to too much proximity these animals may begin to make threats on human life and crops as its territories are disturbed continually. Therefore, such mammal's habitat has to be protected by local planning and rational management of the population is desirable. So that the Environmental Protections Authority of the Regional State has to be concerned on the conservation issue of this vulnerable species in the study area. Moreover, there should be legal enforcements to protect hippopotamus habitats in the study area to insure its sustainable conservation

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Appendix

The map below is to show hippo sites(GPS readings) identified by the researcher in 2014 and Amhara National Regional State, Bureau of Industry and Urban Development (BoIUD), 2012. From the sites Qorata (local name) and Abay Bridge were accessed by road transports. The remaining Gelda site, Tana Qirqos Church and Gumara River were visited by boat trips. The appropriate time to see the population of these animals at their grazing place is in the early morning and in the night.

Figure 1. *H. amphibius* sites in Lake Tana