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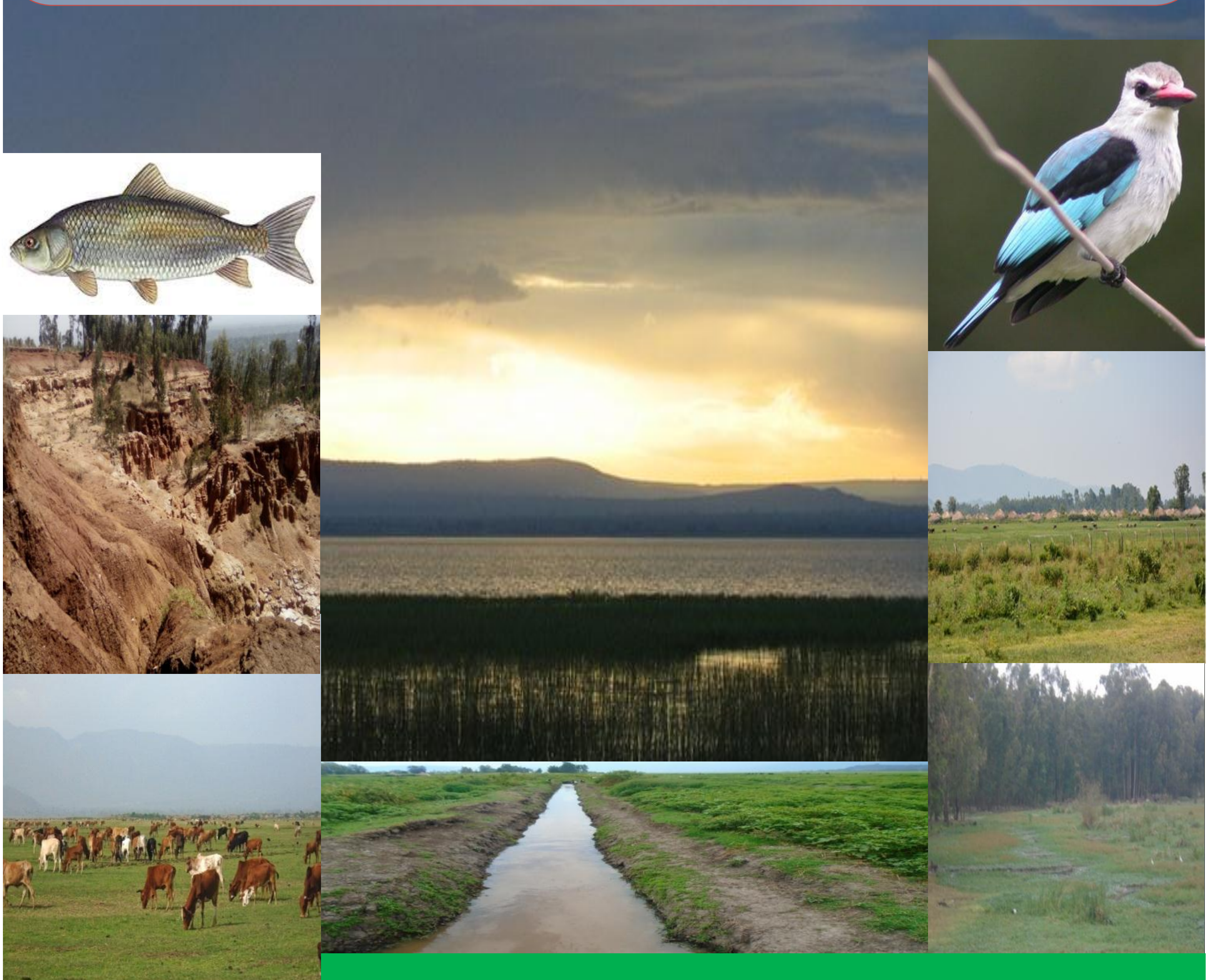

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Analysis of Land Use/Land Cover Change Dynamics and Underlying Driving Forces in the Lake Hawassa Watershed, Ethiopia, Based on Satellite Remote Sensing and GIS Techniques[1]

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ABSTRACT

The rising human population and the increasing demand for more resources such as food, fuel, fresh water, constructional materials etc., resulted in widespread alteration of the earth's biosphere and atmosphere composition. Agricultural activities and settlements have expanded into vegetated areas changing the native ecosystems into barren land and impervious layers. Such changes in land use/land cover are taking place rapidly in developing countries severely affecting the environment and welfare of people. The Lake Hawassa Watershed is one of the most environmentally vulnerable areas in Ethiopia.

This paper is intended to classify multi-temporal image data to produce thematic maps and thereby quantify changes that have occurred in the study area, estimate above ground biomass, quantify land cover conversions, and identify the most prominent underlying driving forces of changes extended over 38 years (1973-2011). Then, inform all stakeholders about the on-going land use/land cover changes in the Lake Hawassa Watershed and its adverse effects on the livelihood of people so that concerted and timely measures can be taken. The results revealed that landscape transformation by humans was extensive. A set of anthropogenic biomes replaced large parts of the more recognized natural biomes offering a new view of the terrestrial biosphere. The dominant land cover was cropland accounting for 56.4% in 2011. The most affected land cover classes over the study period were forest and woody vegetation, which declined by 45.3 and 35.3%, respectively. Lake Chelelleka with an area of 11.3km^2 in 1973 transformed into mudflat and grass dominated swamp. The total mean above ground biomass density estimated for this site was considerably lower than the range of forest above ground biomass reported for the same life zone in other countries. The study indicated that forest cover in Siraro District was found completely depleted in 2011. As the result of conversion, built-up area expanded at a rate of 12.7% annually between 1973 and 2011. On the other hand, cropland lost about 18km^2 of its area to built-up between the same temporal instants indicating that the land cover conversions were multi-directional and significant in magnitude. If the biophysical resources are to regenerate and improve, mitigation strategies should be developed that are geared towards the underlying driving forces.

Key words: Land cover change, Lake Hawassa Watershed, Remote sensing, GIS, Underlying driving force

[1] This paper comprises what has been excerpted from the writer's PhD Thesis and what has been learnt from the field investigation

1. Introduction

1.1. Land use and land cover changes in the Lake Hawassa Watershed

The Lake Hawassa Watershed had undergone profound LULC change. This area and its hinterland are home for a large human population engaged in various activities, which are directly or indirectly related to the well-being of the ecosystem. The Lake Hawassa Watershed has come under unprecedented pressure, ever since the beginning of 1950s (Lemma 2005). The changes coupled with population growth, have occurred mainly due to subsistence agriculture, large-scale state farms, clearing of forests and woodlands for different purposes.

Before the foundation of Hawassa town, the area was covered by forest housing a variety of wild animals (MWUD 2006; Reynolds et al. 2010). The first settlers of the area were the pastoral Sidama people. The settlers gradually became sedentary farmers for which the importance of farming increased and that exerted pressure on the immediate native ecosystem. However, accelerated LULC change began after Hawassa Town was founded in 1960 by the order of Emperor Hailesilassie (Zeleke and serkalem 2006). Commissioned soldiers and their families from various parts of the country were brought to Hawassa and were provided the first plots of land in a newly set-up village to settle on (ibid), which is believed to have given an impetus to the growth and development of the town. The rationale for the settlement of ex-soldiers and their families was to tighten security of the region and supply labor force for the new state farm which replaced the 'Adaare*'* jungle, the native ecosystem. Studies conducted in Lake Hawassa Watershed for 1965 and 1998 indicated that cultivated fields and urban areas have shown a spatial increases of 50.7 and 185.7%, respectively, while dense and open woodlands decreased by 55and 73.8%, respectively (Ayenew and Gebreegziabher 2006).

Under the increasing pressure by human population through intensified cultivation, overgrazing, and deforestation, vegetation cover had declined and indigenous species such as 'Weira' (*Olea spp.*), 'Zigba' (*Podocarpus gracilior*), 'Kerero' (*Anningeria adolfi fredricii*), 'Wanza' (*Cordia africana*), and 'Kawoot' (*Celtis africana*) in the Wondo Genet escarpments are threatened. Deforestation and subsequent land degradation have expedited soil erosion causing siltation, deepening of water level, and desiccation of Lake Chelelleka.

The overstocking of saw mill and joinery enterprises and excessive extraction of timber by illegal loggers coupled with weak law enforcement have aggravated the rate of deforestation and natural resource degradation in the area. A survey result indicated that about 410 formal and 226 informal small and medium forest enterprises exist in Hawassa area (Gebremariam et al. 2009).

The excessive extraction of fuelwood (charcoal and firewood), are the primary drivers of deforestation and subsequent land degradation, which in turn lead to soil erosion and loss of fertility. Ethiopia is one of the world's most fuel wood reliant nations. This is because fuel wood is the dominant household energy source and it accounts for about 92-97% of the total energy consumption (FAO 2003; Sima 2011; Asfaw and Demissie 2012; Brink et al. 2014; She 2014). The consumption of fuel wood for household energy in the study area is estimated at 54, 61, 72, and 96% in Arsi, East Shewa, Bale, and Sidama Zones, respectively, where the eight districts are situated (SNNPRS 2001; ORS 2002). The first three have the lowest proportion of energy deriving from fuel wood, as these are large animal dung and crop residue consuming zones of the Oromiya Region.

The current status of LULC and its change patterns are, in general, the outcome of many highly-interlinked drivers including natural, socio-economic, policy, unsustainable farming practices, among others (Tefera et al. 2002; Meshesha et al. 2010). In many instances, one becomes a cause for the other and vice versa, creating a kind of vicious circle.

2. What is the problem and why bother?

The increase in human and livestock population and their interaction with natural ecosystem have caused landscape changes in the lake Hawassa Watershed. Most changes to the ecosystem have been made to meet a dramatic growth in the demand for food, water, timber, fiber, and fuel (MEA 2005).

Several studies undertaken in the Lake Hawassa Watershed area have indicated that the landscape has undergone significant transformations. For instance, natural resource degradation and decline in agricultural productivity (Gashaw et al. 2014; Ango and Bewket 2007), deforestation and high conversion of vegetation cover to agricultural land (Girma and Mosandl 2012; Rembold et al. 2000), water pollution and wet land destruction (Meshesha et al. 2010; Wondafrash and Tessema 2011), and overgrazing and reduction in grassland cover (DELTA 2005). Though the growth of built-up areas could play an important role in alleviating housing problems for a rapidly growing population, urbanization has stepped-up informal settlements, the extraction of biomass, and destruction of ecological structure.

If all these problems continue unabated, the life of millions of people will be at risk. Therefore, addressing these multi-faceted problems of land cover changes is essential to sustainably manage natural resources and achieve the Growth and Transformation Plan (GTP) of the country.

3. Objectives

The main aim of this study is to analyze and map LULC change dynamics and underlying driving forces in the Lake Hawassa Watershed for the period between 1973 and 2011using RS and GIS techniques. The specific objectives are:

- To explain the spatial and temporal pattern and magnitude of land cover changes that have occurred over the study period (1973-2011),
- To describe the main underlying driving forces of change in the Lake Hawassa Watershed for the time period under investigation,
- To avail the results to all stakeholders and decision makers to take appropriate and timely action.

4. Materials and methods

4.1. Description of the study area

The Lake Hawassa Watershed is located at the border between two regional states, namely Southern Nations, Nationalities and People’s Regional State and Oromiya Regional State. It is situated in the Ethiopian Rift Valley floor on the main highway running from Addis Ababa to Nairobi via Moyale. Its extreme coordinates are $6^{o}49'$ and $7^{o}14'$ N latitude and $38^{o}16'$ and $38^{o}44'$ E longitude (Figure 4), covering about 1435 km^2. The topographical characteristics include *inter alia*, flat plains, gentle slopes to dissected escarpments, mountainous regions, and hilly surfaces with the altitudes ranging from 1678 to 2970 m above sea level. The mean annual rainfall is estimated at 1060 mm (Wondrade et al. 2014), but varies both spatially and temporally, ranging from 821 mm in the low land area to 1307 mm in the highlands (ibid). The climate of the research area is characterized by a high variation in mean minimum and maximum temperature (12.5 to $27.2^{o}C$).

Lake Hawassa is a vital source of livelihood for over five million people (Ayenew and Gebreegziabher 2006) and it is one of the biggest bird sanctuaries in Ethiopia. Lake Hawassa and Senkelle Swayne’s Hartebeest Sanctuary located at the north-western part of the Watershed are major sources of income through tourism both at the local and national level. Agriculture at subsistence level is the main stay of the farming community which dictates the major land use. The western parts of the areas near Lake Hawassa are highly degraded due to repeated cultivation and exposure to gully erosion.

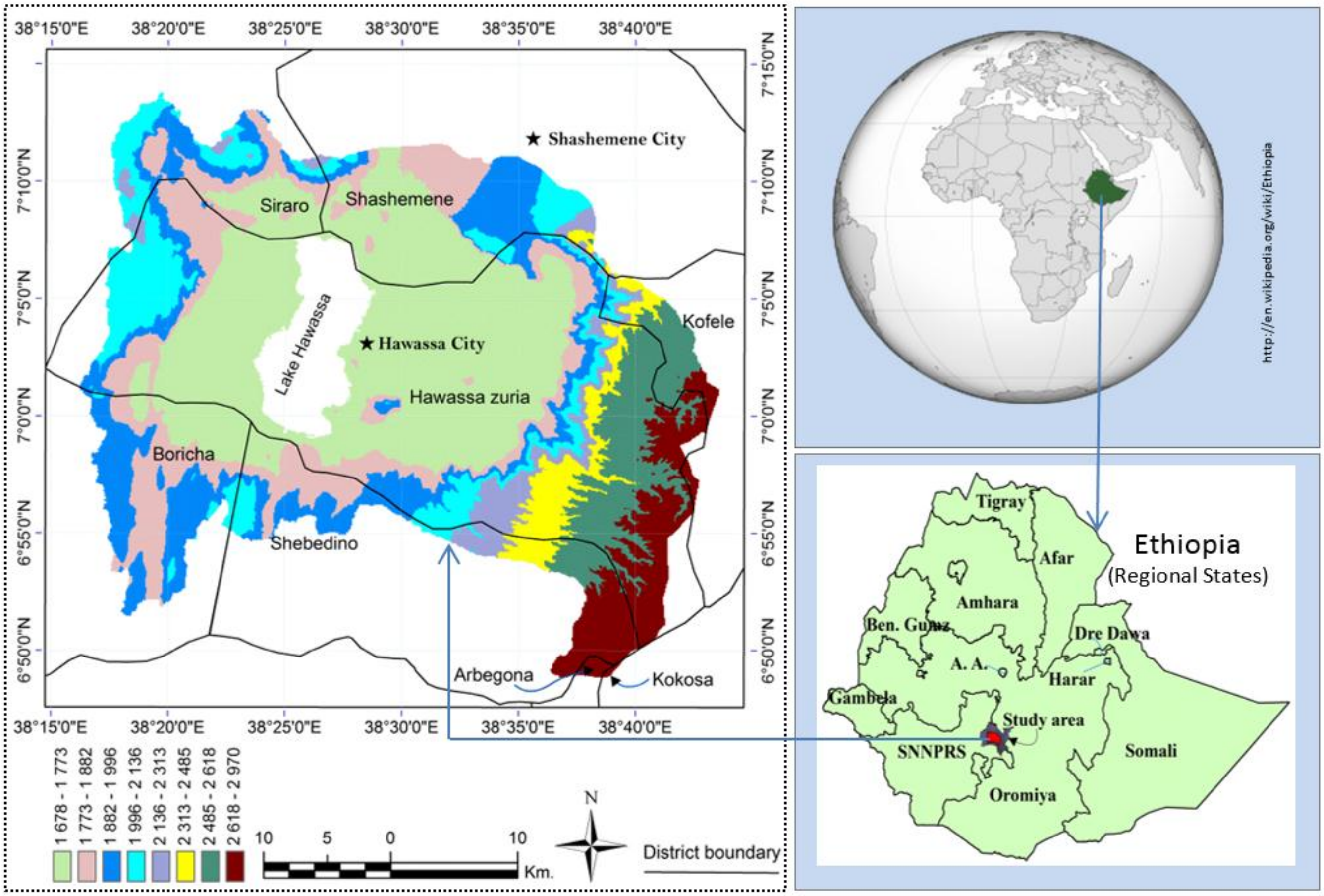


Figure 1. Map of the study area and location of the eight districts. Source (Wondrade, 2015)

The eastern and northeastern parts of the area are more stable and covered with forests and woodlands. The study area is one of the most densely populated regions in the country, ranging from 255.0 in the Kokosa district to 1,330 persons/km^2 in the Shebedino district for the base year 2011 (CSA 2011). The population densities of the Hawassa and Shashemene cities were estimated at 1 994.5 and 11 064.7 persons /km^2, respectively for the same year (ibid). Because of the increasing population and unsustainable resource management practices, the area is experiencing rapid land cover conversion and associated problems.

4.2. Sources of data

Several types of input resources have been used for this research work. The data used can be subdivided into field data, remotely sensed data, and ancillary data.

4.2.1. Field data

Fieldwork was undertaken during the dry months of January and February 2012 to collect field data. The collected data can be grouped into three sections:

i. Data for the classification and accuracy assessment of LULC maps (training areas and reference points),

ii. Data for the estimation of AGB (tree variables such as diameter at breast height and height), and

iii. Key informant interviews were conducted to collect the possible underlying driving forces of land cover changes.

Figure 2. Measurement of tree variables and key informant interviewing (Photo by the author, 2013)

4.2.2. Remote sensing data

Remotely sensed data from Landsat and SPOT operations were used to extract LULC maps for the study area. The Landsat images include: Multispectral Scanner (MSS) and Landsat 5 Thematic Mapper (TM) images acquired in 1973, 1985, 1995, 1999, and 2011, respectively. The Landsat images are downloaded from the Global Visualization Viewer website (http://glovis.usgs.gov/), where image data sets are made available. SPOT1 and SPOT 4 images acquired in 1987 and 2011, respectively were procured from ***e-geos***, an Italian Space Agency, and the Telespazio Company. LULC conversion data were derived from a spatial overlay of successive thematic maps in ERDAS Imagine.

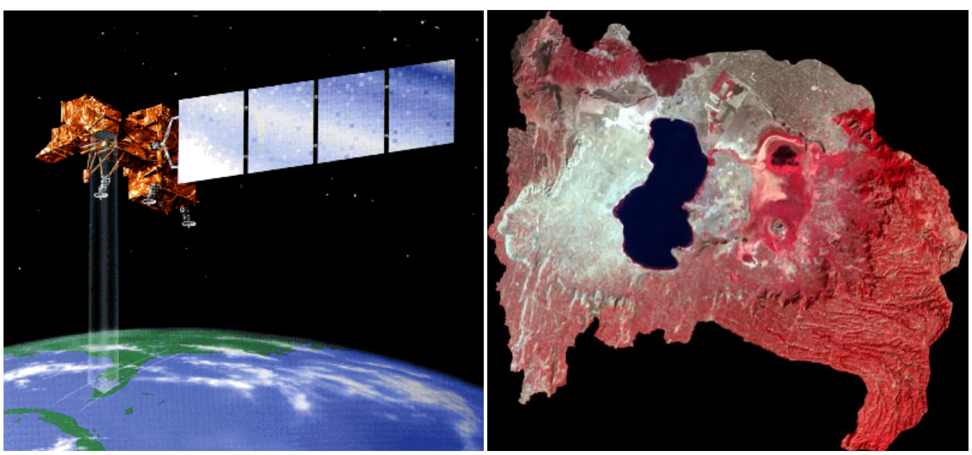


Figure 3. Subset of sample satellite image of Lake Hawassa Watershed

4. 2.3. Ancillary data

Ancillary data both on raster and vector format were used for various purposes. The ancillary data include: topographical maps, aerial photographs, Google Earth imagery (Quick Bird), and digital elevation models (DEM). Topographical maps and aerial photographs covering the study area were procured from the Ethiopian Mapping Agency (EMA). These map sheets were scanned, geo-referenced, mosaicked, and then used to register all remotely sensed data. Both the topographical maps and aerial photographs were used to validate the classified LULC maps. The vector files from the Map Library (2007) were useful to delineate and clip study area and administrative boundaries of regions, zones, districts, city, and other areas of interest.

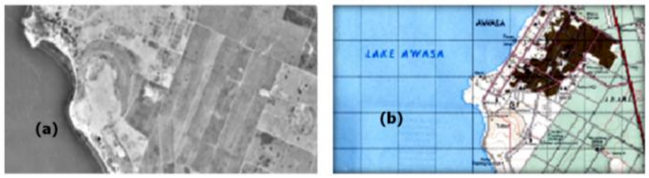


Figure 4. Ancillary data, aerial photograph (a) and topographic map (b)

4. 3. Methods

4.3.1. Classification scheme

Several institutions have developed classification systems for use with remote sensing data. However, there is no one ideal classification scheme that fits the land cover types and their nomenclature everywhere. Thus, the land cover classes in the study area were defined based on the specific nature of the landscape features and partly based on the Level I LULC classification scheme developed by Anderson et al. (1976). The classification scheme used for the study area is given below in Table 1.

4.3.2. Image classification and accuracy assessment

Image classification was performed using a hybrid method, where spectral signatures for specific land cover classes were created using unsupervised method followed by supervised method to further discern the land cover types. Hybrid classification techniques offer more reliable and accurate results to assess land cover changes (Bakr et al. 2010).

Accuracy assessment was performed using independent reference data created from aerial photographs, topographical maps, field data, and visual interpretation. One of the most common ways of representing accuracy assessment information is in the form of an error matrix or contingency table (Congalton 1991; Binaghi et al. 1999; Foody 2002).

Table 1. Land cover classes considered and their description. Source (Wondrade et al., 2014).

No.	LC Class	Description
1	Water	All areas of open water, including lakes, rivers, and ponds
2	Built-up	Included are residential, commercial, and industrial buildings, transportation infrastructures, and play grounds.
3	Cropland	Mechanized and smallholder’s farms, tilled and planted, bare crop fields, and limited areas temporarily left as fallow.
4	Woody Vegetation	Land covered by bushes and shrubs, in some cases mixed with grasses. Ground cover often composed of patches of woodland, scattered trees and perennial crops, such as Khat (*Catha edulis*) and Coffee (*Coffea arabica)*.
5	Forest	Natural and plantation forest with trees forming open to closed canopies, 30 - 70% and more than 70% respectively.
6	Grassland	Areas dominated by herbaceous vegetation with low occurrence of shrubs.
7	Swamp	Area with topographic low where water table is near, or above the land surface. The occurrence of herbaceous vegetation is also obvious.
8	Bare land	Land surface devoid of vegetation, sand along lake side, exposed rocks, and quarries.
9	Scrub	Specific area characterized by scattered bushes to closed canopy vegetation dominated by shrubs, grasses, and small trees usually less than 5m tall, and occasionally with few scattered trees.

The tables produce many statistical measures of thematic accuracy including an overall accuracy, producer’s accuracy, and user’s accuracy. The kappa statistic, a metric that compares chance agreement between the remotely sensed classification and reference data, was also computed as a measure of thematic map accuracy. ERDAS Imagine software was used to accomplish both classification and accuracy assessment. This study applied a post-classification comparison method to perform pixel based land cover change detection analysis. Image pairs of consecutive dates were compared by overlaying thematic maps, for instance images from 1973-1985, 1985-1995, 1995-2011 etc. The overlay procedure in ERDAS Imagine produced cross-tabulation matrices, which permitted to quantify changed and not changed land cover types between temporal instants over the study period.

4.3.3. Estimating above ground biomass

This study characterizes the LULC, above ground biomass (AGB), and carbon status of the forest in the Lake Hawassa Watershed, using remote sensing data and allometric equations for the base year 2011. Remote sensing is an effective and efficient tool in forestry studies (Roy and Ravan 1996; Kale et al. 2009), so analysis of the vegetation status and delineation of forest land cover was performed using a Landsat 5 TM image in ERDAS/ArcGIS. The equations constructed by Chave et al. (2005) and Brown (1997) for mixed species were found to be more appropriate for describing the relationship between biomass and tree variables for natural and plantation forests, respectively.

4.3.4. Analysis of LULC conversions and underlying driving forces

This analysis focuses on the determination of magnitude and rates of land cover conversions and its causative agents. The temporal and spatial analysis of LULC conversions relied on classified Landsat images extending over 38 years. To detect and quantify LULC conversions, thematic maps of successive dates were overlaid in a matrix function using ERDAS Imagine, which generates cross-tabulation matrices with systematic arrays of numbers. Each cell in the matrix contains the surface area converted from one land cover class to another and the surface area remained unchanged. Key informants interviews were conducted to identify the underlying driving forces of the LULC conversions that had been quantified using remote sensing methods. The key informants included both men (92.6%) and women (7.4%). The respondents were selected based on purposive sampling because of their specific knowledge on the topic of interest. The interviewees responded to the semi-structured list of questions, drawing on their own individual experience about the development and status of the natural resources in the Lake Hawassa Watershed ecosystem.

5. Main findings/results

5.1. Classification results and associated field observation

The analysis of multi-temporal remotely sensed image data extracted nine distinct land cover themes in the Lake Hawassa Watershed. These were water, built-up area, cropland, woody vegetation, forest, grassland, swamp, bare land, and scrub (Figure 5). The overall classification accuracy of the produced thematic maps for 1973, 1985, 1995, and 2011 ranged from 82.5 to 85.0%.

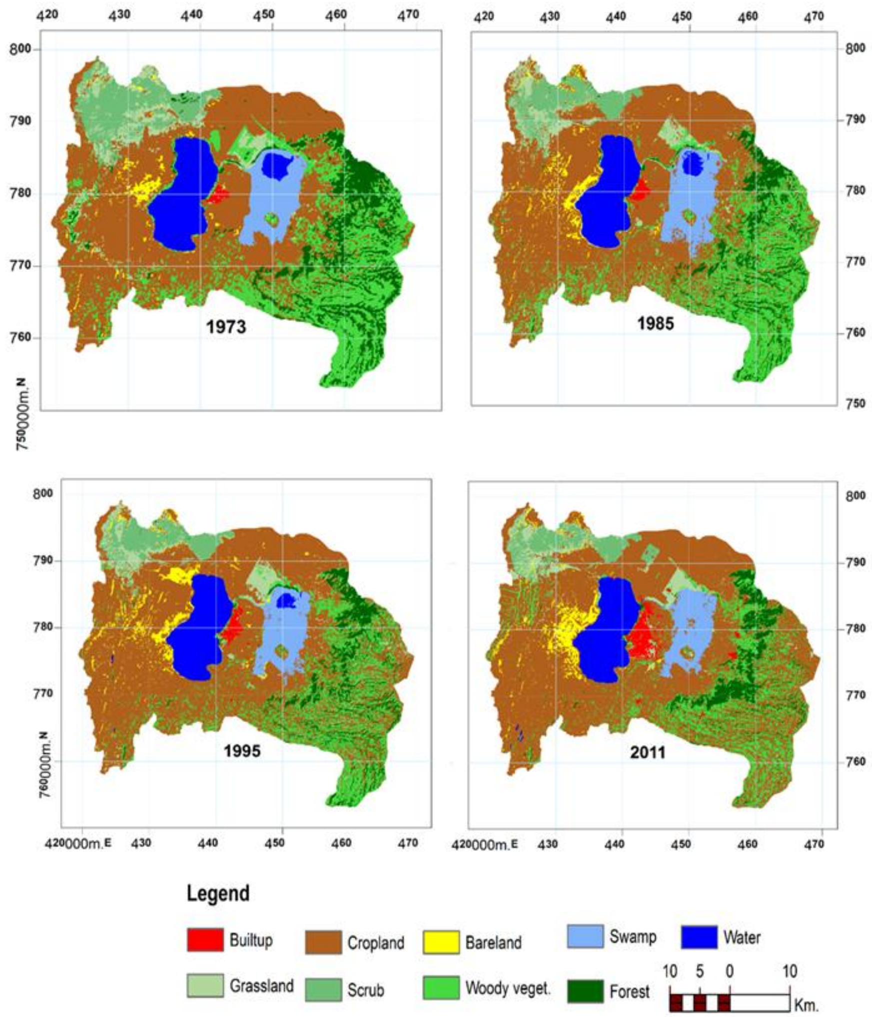


Figure 5. Land cover maps of the Lake Hawassa Watershed at four temporal instants. Source (Wondrade et al., 2014)

The results revealed that cropland, woody vegetation, and forest had the highest magnitudes of change over the entire study period (Table 2). The results in Table 2 reveal a clear picture of LULC changes in space and time. The built-up area expanded more than fivefold compared to the original surface area coverage. The expansion of cropland and built-up area, and the rapid decline of the native ecosystem (woodland and forest cover) highlight the impact of anthropogenic activities.

Table 2. *Spatial coverage and proportion of land cover classes resulted from classified images*

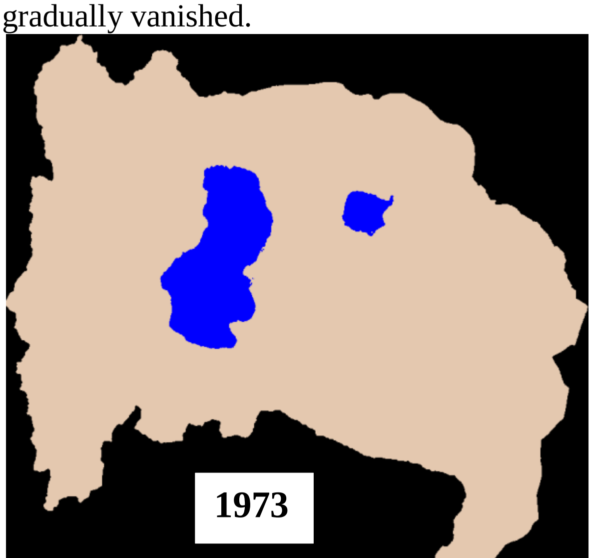
Land cover (LC) classes	1973 Area of LC (km²)	1973 (%)	1985 Area of LC (km²)	1985 (%)	1995 Area of LC (km²)	1995 (%)	2011 Area of LC (km²)	2011 (%)
Water	103.3	7.2	101.5	7.1	100.3	7.0	95.8	6.7
Built-up	4.2	0.3	5.8	0.4	8.6	0.6	24.6	1.7
Cropland	625.3	43.6	699.7	48.7	766.7	53.4	809.1	56.4
Woody veget.	301.1	21.0	275.8	19.2	218.7	15.2	194.9	13.6
Forest	148.0	10.3	102.5	7.1	93.2	6.5	81.0	5.6
Grassland	71.8	5.0	78.2	5.5	73.8	5.1	65.8	4.6
Swamp	67.8	4.7	77.3	5.4	70.7	4.9	64.2	4.5
Bare land	18.1	1.3	28.4	2.0	42.1	2.9	39.9	2.8
Scrub	95.2	6.6	66.5	4.6	61.7	4.3	60.5	4.2
Total	1434.9	100.0	1435.7	100.0	1435.8	100.0	1435.9	100.0

Source (Wondrade et al., 2014)

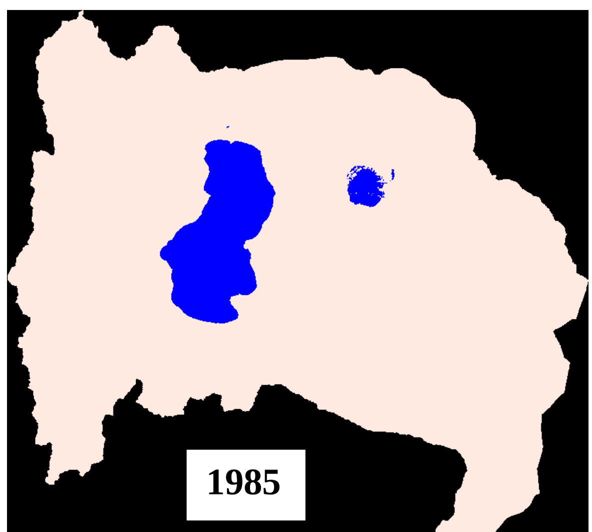
The spatial pattern and change trends of each LULC type are described hereunder:

i. Water body

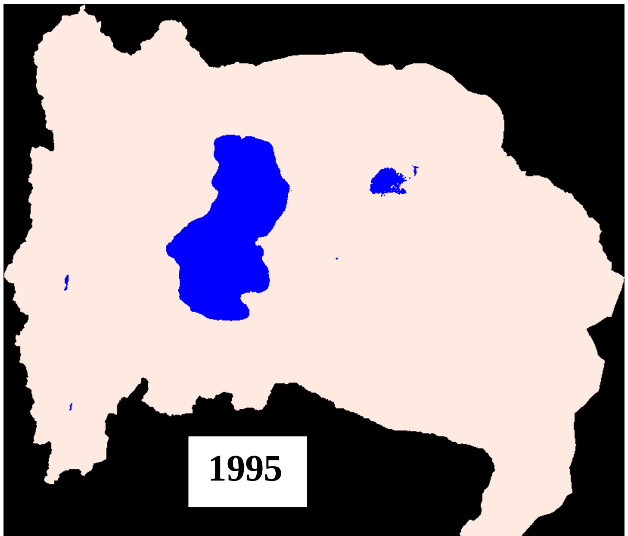
The analysis revealed that the surface area of Lake Hawassa has increased by about 3.5km^2 between 1973 and 2011 while Lake Chelelleka has gradually vanished.



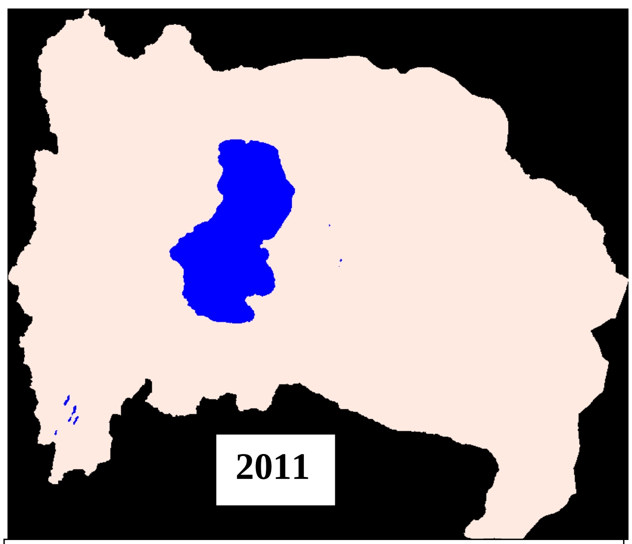
- Area of Lake Hawassa=92.0km^2
- Area of Lake Cheleleka=11.3km^2
- Total area of water body=103.3km^2
- No visible ponds in 1973



- Area of Lake Hawassa=93.2km^2
- Area of Lake Cheleleka=8.3km^2
- Area of total water body=101.5km^2



- Area of Lake Hawassa=95.1km^2
- Area of Lake Cheleleka=5.1km^2
- Total area of water body=100.5km^2
- 0.3km^2 is pond water



- Area of Lake Hawassa=95.2km^2
- Area of Lake Cheleleka=0.0km^2
- Pond water area=0.65km^2
- Total area of water body=95.8km^2

Figure 6. Trends of change in water body. Source (Wondrade et al., 2014)

Lake Hawassa, the smallest and located at the highest altitude in the Central Main Ethiopian Rift Valley, is one of the tourist attractions of Hawassa City. It is one source of livelihood for millions and shelter for different species.

The area of Lake Chelelleka was 12km^2 in 1972 (Ayenew, 2004) and 11.34km^2 in 1973 (Wondrade et al., 2014) in 1972 and 1973, respectively. The average depth was 5m having a total volume 60x10^6 m^3 in 1972. However, Lake Chelelleka is today a mud flat and grass dominated swamp (see Figure 7).

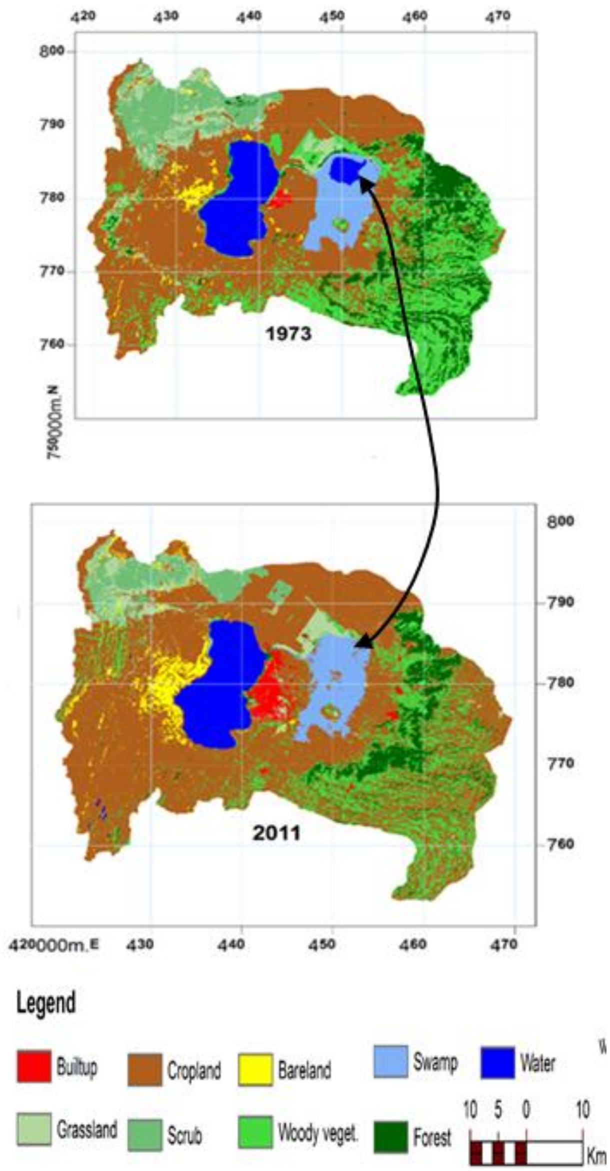
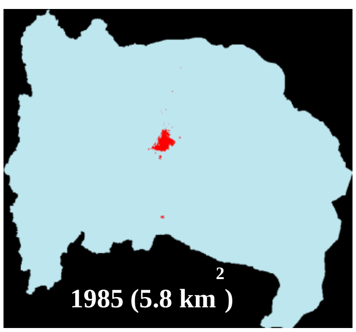
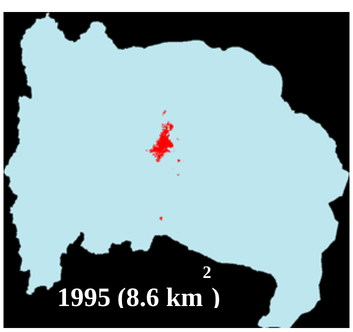


Figure 7. The conversion of Lake Chelelleka into swamp between 1973 and 2011. Source (Wondrade et al., 2014)

ii. Built-up area

Though small in absolute terms, built-up area has increased by 480% between 1973 & 2011. Particularly, the expansion was significant since 1995. Urbanization is one of the most dynamic processes in the context of global and local land cover transformations. In 2025, Africa is expected to be urban by ≈54% and Ethiopia by 30% (World Resource, 1996).





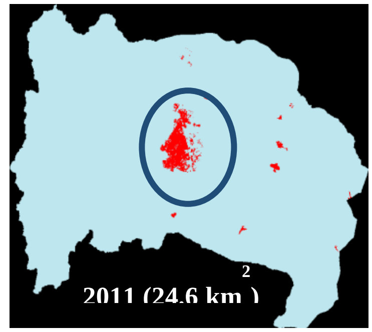


Figure 8. The trends of change in built-up area. Source (Wondrade et al., 2014)

Where no proper planning, urbanization leads to squatting of public lands. Such squatting of public land occurred in 2011 as shown on the classified image above. 19.8 & 14.5% of N & NE part of Hawassa city was illegally occupied public land. Manhattan City is usually considered as a good example of the expansion in built-up areas and its consequence on natural resources, which is tremendous.

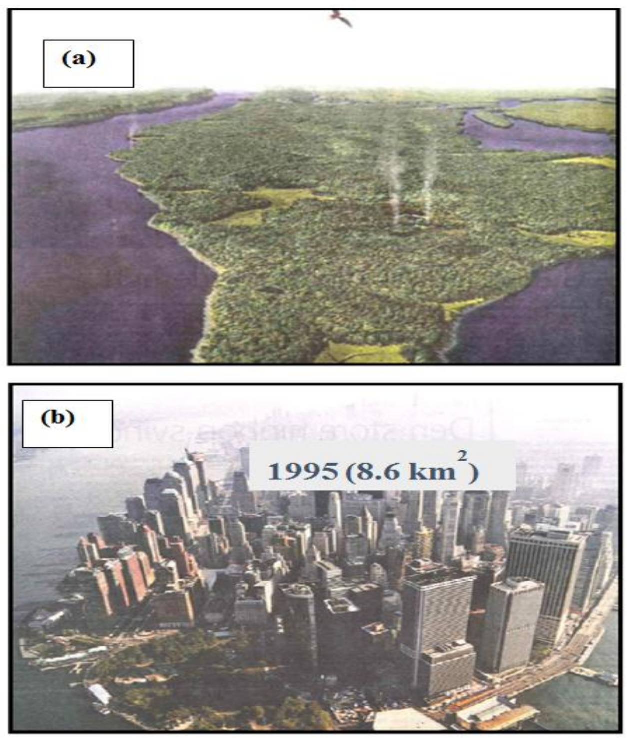


Figure 9. Manhattan City before (a) and after (b) 400 years

iii. Crop land

Cropland is the most predominant land cover in the Lake Hawassa Watershed covering about 56.4% in the year 2011. This expansion is supposed to be due to population pressure, parallel growth in livestock, lack of intensification etc. Population of the watershed is estimated to be ≈ 1, 103, 507 for the year 2014, while the livestock under private holdings reached 1, 136, 670 in 2014 (CSA, 1973 & BoFED, 2014).

The analysis of cropland revealed a slight deceleration in cropland expansion both at annual and temporal rates. This slight deceleration in the expansion of cropland could be attributed either to shortage of suitable land for further conversion or that the remaining area cannot be used for cropping due to policy restrictions or natural barriers.

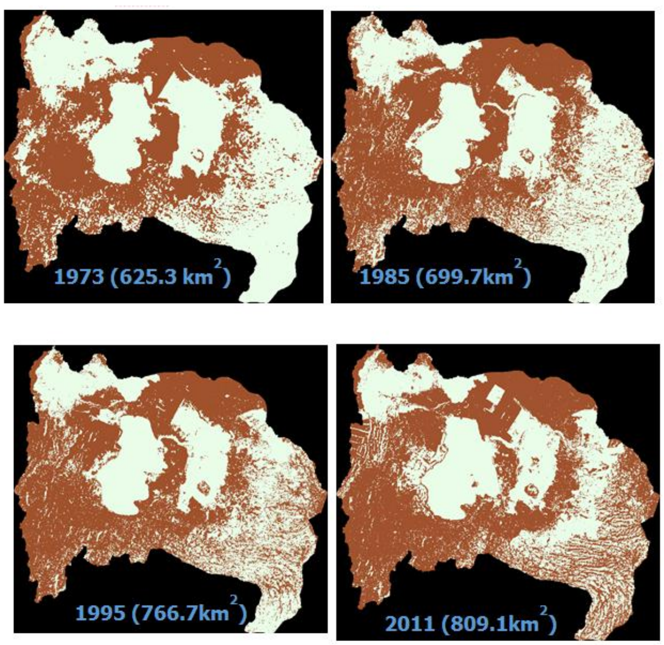


Figure 10. Trends of cropland expansion. Source (Wondrade et al., 2014)

iv. Woody vegetation

Woody vegetation constantly declined throughout the study period and the highest was -20.7% that occurred between 1985 & 1995. This time coincides with the regime change in Ethiopia where control over resource was loose. Western part of the watershed is found to be the most degraded area.

The loss of woody vegetation is caused by high demand for fuel wood & construction materials, cropland expansion, weak law enforcement, power vacuums during regime changes, urbanization, freely roaming livestock etc.

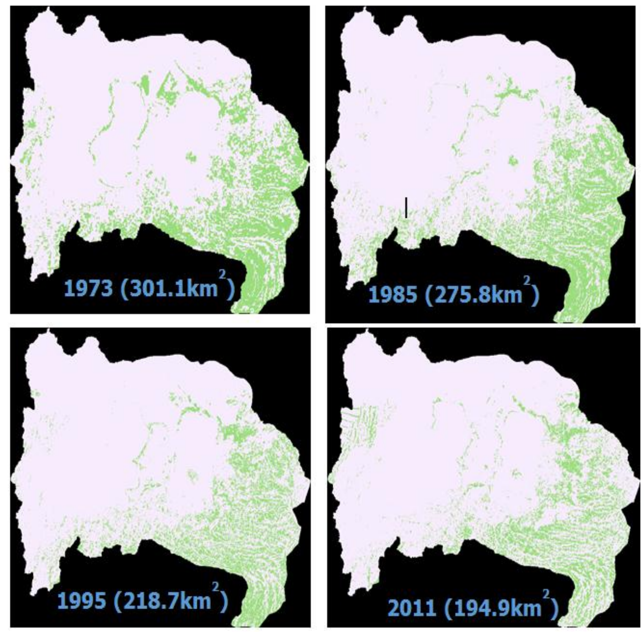


Figure 11. Trends of change in woody vegetation. Source (Wondrade et al., 2014)

v. Forest

Forest experienced continuous decline, -30.8% from 1973 to 1985 and -13.1% from 1995 to 2011 period with a -1.2% annual rate of change during the whole study time. Causes of decline in forest cover are more attributed to human induced factors, such as illegal logging & selected felling of trees, extraction of fuelwood and construction materials, loose law enforcement, forest fire & soaring prices of timber products, expansion of rain fed agriculture, urbanization, proximity to big cities & road networks, overstocking of saw mills & joinery enterprises, etc.

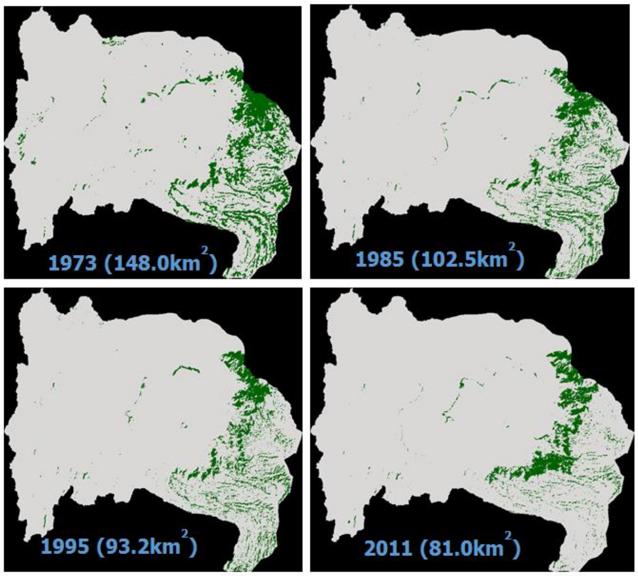
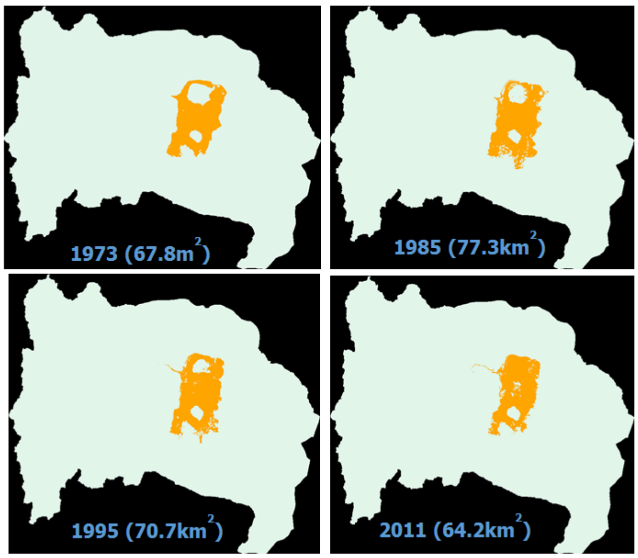


Figure12. Trends of change in forest cover. Source (Wondrade et al., 2014)

vi. Wetland or swamp area

The wetland in 1985 was greater than that of in 1973, because of the continuous evacuation of water from Lake Chelelleka. As the Lake Chelelleka recedes, the area has been converted into mud flat & grass dominated swamp indicating the transported sediments have gradually filled the lakebed. Thus, the unprotected swampy area had continuously decreased as the result of cropland expansion.



The on-going and unplanned settlement in the wetland also draws particular attention. According information derived from satellite acquired in 2016, there exists more than 1564 cone-shaped mud huts, with a thatched roof and handful of CIS roofed houses. The following Figure depicts the illegal settlement in the wetland within the jurisdiction of Hawassa City administration. The total settlement in the wetland across the watershed is much larger than this. We are not able to count the number of houses in the entire wetland due to lack of high-resolution imagery.

Figure 13. Trends of change in wetland. Source (Wondrade et al., 2014)

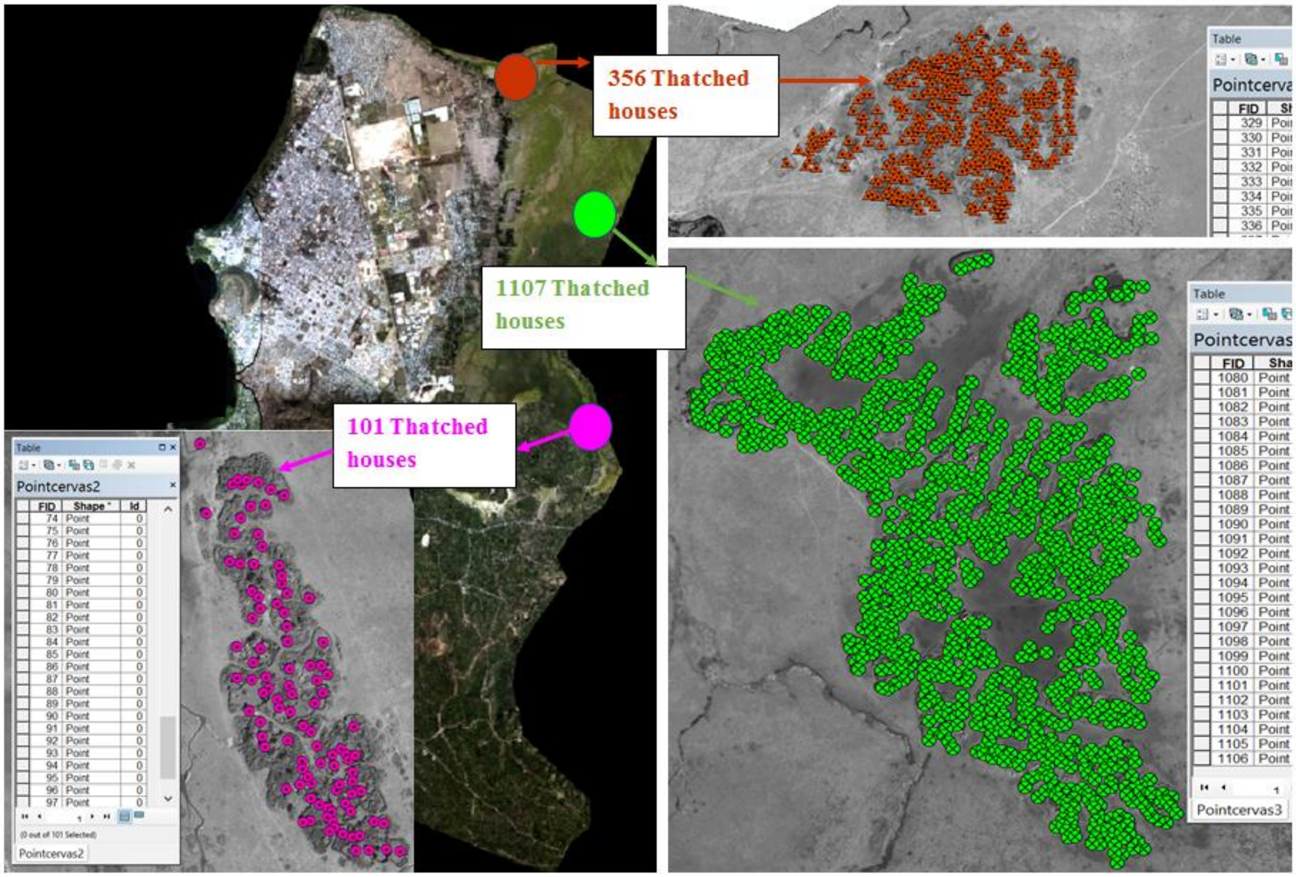


Figure 14. Illegal settlement in the wetland within the boundary of Hawassa City administration (Year, 2016)

vii. Scrubland

Scrub is limited to the northwestern part of the watershed. This LULC was conserved as Swayne's Hartebeest Sanctuary, however, it has frequently been disturbed and still clearing for farming land, construction materials, and firewood has continued by encroaching settlers. Consequently, its area has declined from 95 km^2 in 1973 to 61 km^2 in 2011.

From a socioeconomic perspective, altering the natural setting of this area may result not only in degradation of the ecosystem, but also a decline in the number of visitors and subsequent reduction of income from tourism both at national and local level.

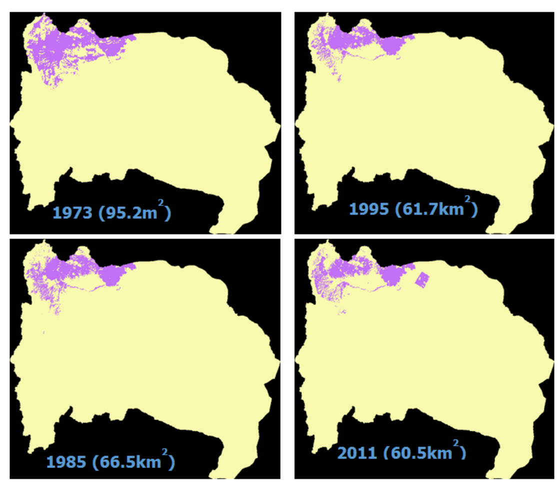


Figure 15. Trends of change in scrubland. Source (Wondrade et al., 2014)

viii. Grassland and bare land

Significant changes have also been observed in grassland and bare land LULC types. The result of analysis revealed an interchange between cropland, grassland, and bare land with other land cover classes. Owing to management practices, some areas that once covered by grassland were converted to cropland and then back to grassland through time. Bare land increased with the highest rate between 1973 and 1985, but declined by 5.2% during 1995-2011 as farmers started to cultivate more marginalized lands.

5.2. Above ground biomass estimation

The available above ground tree biomass (AGB) was estimated by applying allometric equations to the inventoried individual tree and extrapolated to the entire area. The mean AGB density was computed for each forest type and these were then averaged to obtain the total mean AGB density for the entire sample plots. This total mean expressed in t/ha was later multiplied by the total forest cover (ha) in each district to obtain the AGB in tons, the summation of which gives the AGB of the forests in the entire study area (Table 3).

Table 3. The estimated mean AGB of forest in the Watershed (2011). Source (Wondrade, 2015)

District	Geographic area (ha)	Forest cover (ha)	Total AGB[3] (ton)
Hawassa Zuria	84512.2	6550.6	1390683.9
Boricha	14286.3	72.7	15438.5
Shebedino	12116.3	236.7	50251.4
Arbegona	306.1	14.8	3133.5
Siraro	**11518.0**	0.0	0.0
Shashemene	17124.2	521.4	110686.9
Kofele	4038.2	733.7	155760.3
Kokosa	72.1	0.7	152.9
-	**143973.4**	**8130.5**	**1726107.3**
			1.726 Mt

The absence of forest cover in Siraro district indicated the presence of heavy anthropogenic activities and active LULC changes on the border between the two regional states. Besides, Siraro district is found near two big cities (Shashemene and Hawassa) and accessible to road network.

Thus, establishing inter-regional (SNNPR and Oromiya) collaboration is indispensable to thwart further threats to ecosystems.

5.3. LULC conversions

Empirical evidence of LULC conversions obtained from multi-temporal image analysis can greatly contribute to a better understanding and management of available resources, especially in developing countries where other kinds of background data are limited. A cross-tabulation matrix showing the pathways of LULC conversions between successive dates is depicted below (Table 4).

Table 4. Cross-tabulation matrix showing **pathways** of LC conversion (in km^2). Source (Wondrade et al., 2016)

	Year 2011									Total (1973)
Year 1973	WR	BP	CL	WV	FT	GL	SP	BL	SB	-
Water (WR)	**91.5**	0.0	0.3	0.1	0.1	0.0	11.4	0.0	0.0	103.3
Built-up (BP)	0.0	**4.0**	0.0	0.2	0.0	0.0	0.0	0.0	0.0	4.2
Cropland (CL)	1.2	17.8	**506.4**	44.0	9.7	13.1	0.5	27.1	5.6	625.3
Woody veg. (WV)	2.4	2.0	168.6	**103.2**	16.1	8.3	0.1	0.6	0.0	301.2
Forest (FT)	0.3	0.1	46.6	42.6	**54.5**	2.5	0.1	0.1	1.4	148.1
Grassland (GL)	0.3	0.4	44.7	2.6	0.4	**17.0**	0.3	3.2	2.9	71.8
Swamp (SP)	0.0	0.0	12.9	1.3	0.1	1.5	**52.0**	0.0	0.0	67.8
Bare land (BL)	0.0	0.4	9.4	0.1	0.0	0.5	0.0	**7.7**	0.1	18.1
Scrub (SB)	0.0	0.0	19.6	0.9	0.0	22.9	0.0	1.2	**50.7**	95.2
Total (2011)	95.8	24.6	808.4	194.7	81.0	65.8	64.2	39.9	60.5	1434.9

In some cases, conversions are two directional, particularly in cropland. Limited area conversions from cropland to forest and woody vegetation were observed as the result of farmers' initiative to grow Eucalyptus trees on their farmstead to partially fulfill their wood demands for fuel wood and construction materials.

5.4. Underlying driving forces

To answer the question of what forces have driven the LULC changes in the study area, it was necessary to conduct purposive selection of key informant interviewees who have the knowledge about the watershed's resource usage to pinpoint the possible causes of changes.

Though it is difficult to analyze and represent all driving forces adequately due to their complexity, the assessment result indicated that the LULC conversions in the Lake Hawassa Watershed are mainly driven by a combination of demographic, low agricultural technology, institutional, economic, and biophysical factors. Figure 16 illustrates the conceptualization of the links between LULC change and the identified driving forces.

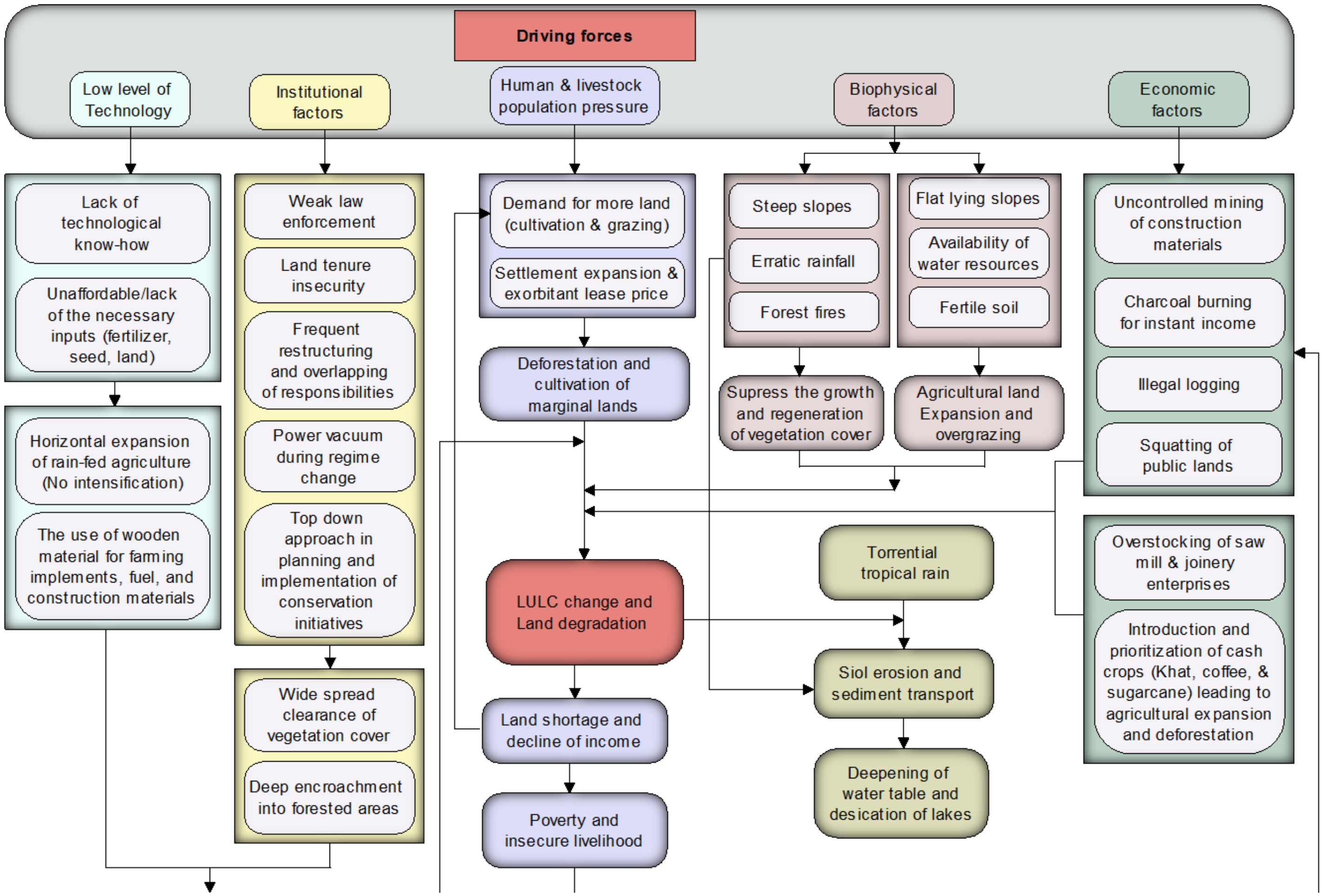


Figure 16. Simplified representation of interaction between LULC change and the major driving forces. Source (Wondrade, 2015)

6. General conclusion

The Lake Hawassa Watershed and its hinterlands have undergone landscape transformation, mainly due to anthropogenic activities over the study period (1973-2011).

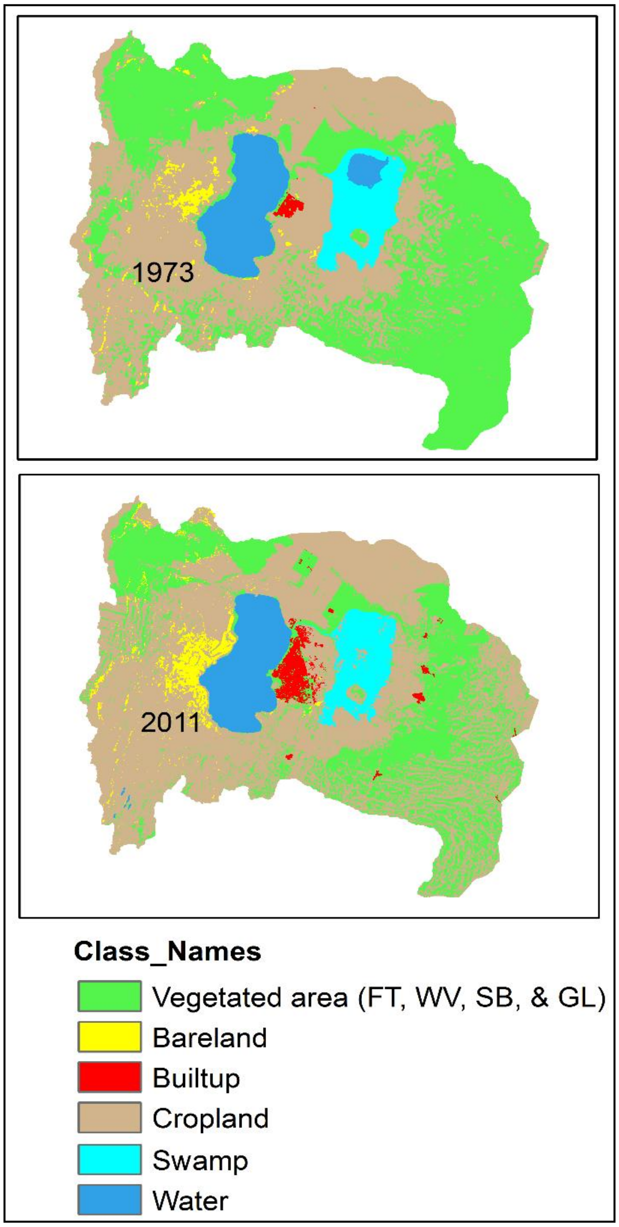


Figure 17. Thematic map showing the decline in vegetation cover

- The combined estimates of forest, woody vegetation, grassland, and scrub, which accounted for 42.9% in 1973, have been reduced to 28% in 2011. Look at the greenish color coded area on the thematic map illustrated on left side.
- Cropland, woody vegetation and forest were the land cover types with higher magnitudes of change than others, while built-up area experienced the highest annual rate of change over the study period.
- Woody vegetation was the biggest loser followed by forest, while cropland was the biggest gainer followed by built-up area.
- The proximity to big cities (Hawassa and Shashemene), road networks, and overstocking of saw mills & joinery enterprises have contributed to the widespread clearance of vegetation cover and biomass depletion.
- This was demonstrated by the absence of forest cover (biomass depletion) in Siraro district at the end of the study period.
- As a result of deforestation, the area has become vulnerable to erosion. The Shallo wetlands has attenuated surface runoff and stored sediment loads leading to the desiccation of Lake Chelelleka.

7. Possible interventions

- ❑ Carry out regular evaluation of the LULC conversions, land degradation, and sediment transport to the wetlands and Lake Hawassa using high spatial resolution imagery by giving more attention to erosion prone areas.
- ❑ Create increased awareness and understanding of environmental and resource issues among the local community so that they:
  - ➢ learn to value an ecosystem more than the odd commodity that it produces for daily subsistence,
  - ➢ plant trees in their farmyards to overcome the shortage of fuel wood and housing materials and thereby reduce biomass depletion,

- follow appropriate tillage practices that will reduce land degradation,

Figure 18. Cutting a tree without planting its replacement is severly affecting the life of people

- ❑ Establish inter-regional (SNNPR and Oromiya) collaboration to thwart further threats to ecosystems,
- ❑ Upgrade institutional capacity at the district level to be able to implement policies and enforce law, devise clear mechanisms to facilitate community participation in forest management (rights, duties and benefit sharing), and
- ❑ Coordinate efforts in the management and conservation of the available natural resources and rehabilitation of the affected areas,
- ❑ Develop alternative energy sources (such as rural electrification, biogas, solar and wind power, and energy saving stoves) to wood fuel and charcoal in order to reduce destruction of the remaining forest resources,
- ❑ Establish an appropriate institution with a mandate to identify actions that cause wetland degradation and support the protection and wise use of wetland ecosystems,
- ❑ If the biophysical resources are to regenerate and improve, mitigation strategies should be developed that are geared towards the underlying driving forces. These may include:
    - strengthening of family planning to control population growth,
    - transforming low agricultural technology and organizing farmers who are able to adopt intensification measures to improve agricultural productivity and reduce widespread expansion of croplands,
    - enabling local users to influence resource management institutions through policies, and introducing secure land tenure system,
- ❑ Any assistance to the rural community should focus on a continuous transfer of adaptable technologies, ensured land tenure security, and development of human capacity that will enhance sustainable use of natural resources and ensure food security.

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Current Status of Chelelleka Wetland and Proposed Actions to Improve its Purification and Replenishment Functions

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ABSTRACT

The current status of Chelelleka Wetland was surveyed by a multidisciplinary team of researchers. The initial objective of this study was to assess the current ecological status of the wetland and, based on the findings, develop research proposal that will outline what needs to be studied about the wetland. The imperative purpose of the ecological study was to contribute to the overall initiative that is designed to ultimately protect Lake Hawassa from pollution. The methods used in the study included desk work, in which a through literature search was made and the findings were compiled before field visits were carried out. Field visits to the wetland were carried out along the shorelines to assess the present status of the wetland. Casual discussions were made with residents near the wetland to sound out the progress of the changes in the wetland. The survey revealed that the wetland is going through critical environmental problems that include habitat loss and fragmentations due to human settlement, agriculture, forestry, and pollution from industrial effluents – all of which call for immediate actions. It is concluded that unless immediate actions are taken to halt these threats, Chelelleka Wetland will soon be converted to residential, agricultural and industrial area, and the ultimate impacts of this will be detrimental to Lake Hawassa ecosystem. At this initial stage of the study we proposed an immediate stake holder consultation where the findings of the study would be presented and possible solutions be sought. Moreover, based on the findings of the survey and information from the literature, it was proposed to put in place actions which can improve the purification and replenishment functions of the wetland. To that effect, ecohydrological approaches - which include construction of a series of wastewater treatment ponds within the wetland, modified riverine treatment and constructed (engineered) wetland - were recommend as complementary mitigation measures.

Key words: Chelelleka Wetland; ecohydrological approach; riverine treatment; stabilization pond, Constructed wetland.

1. Introduction

Wetlands are among the world's most productive environments and cradles of biological diversity. They are ideal habitats for many different species of animals - mammals, birds, reptiles, fish, amphibians, and invertebrate species. Intact wetlands provide breeding and feeding sites as well as hiding places to threatened and endangered species of wildlife. They are also important storehouses for plant genetic material.

Among other important functions and values of wetlands, their roles in water purification (water quality), storm water control, sediment and nutrient trapping, ecosystem productivity, regulating climate change, etc. come to the forefront. The hydrologic functions of wetlands relate to the quantity of water that enters, is stored in, or leaves a wetland. These functions include such factors as the reduction of flow velocity, which enable wetlands to serve as temporary reservoir - slowly releasing water to rivers and streams, recharge/discharge groundwater, and influence atmospheric processes of evaporation and precipitation. Water quality functions include the trapping of sediments, pollution control, and the biochemical processes that take place as water enters, is stored in, or leaves a wetland. Wetlands also regulate climate change because they serve as sink of greenhouse gases, particularly carbon dioxide, through carbon sequestration and cause microclimatic change by evaporative cooling (Abebe & Geheb, 2003).

The wide range of values and benefits obtained from wetlands to humanity have been increasingly understood and well documented in recent years (Mengesha, 2017 and references cited therein). These are mainly social and economic values derived from wetland ecosystems. The social benefits have spiritual, cultural, recreational, educational and aesthetic values. The economic benefits embrace provision of food (fisheries and agriculture), timber for construction, and fuel wood for cooking, thatch for roofing, fibers for textiles and medicinal plants for treating ailments, transport and tourism opportunities, etc. The economic worth of the ecosystem services provided by intact, naturally functioning wetlands are beyond monetary value. They are valuable heritage and home for diversified flora and fauna that have the right to exist (Abebe & Geheb, 2003).

While wetland functions are natural processes of wetlands that continue regardless of their perceived value to humans, the values people place on those functions in many cases is the primary factor determining whether a wetland remains intact or is converted for some other uses. The functions, values and benefits of wetlands can only be maintained if their ecological processes are allowed to continue functioning. In spite of the growing recognition given to wetlands over recent years, they still continue to be among the world's most threatened ecosystems, owing mainly to draining activities, conversion to farmlands and residential areas, over-exploitation of their resources, etc.

Although wetlands of Ethiopia are roughly estimated to cover only 2% of the total surface area (18,580 Km^2) of the country (Abebe & Geheb, 2003), they provide valuable ecological and socio- economic services. The ecological diversity of the country enables it to have all types of inland wetlands including riverine (wetlands along rivers and streams) , lacustrine (wetlands associated with lakes), palustrine (marshes, swamps and bogs) and flood plains. Unfortunately, these wetlands are concentrated in areas where industrial, urban and agricultural development pressures are comparatively high.

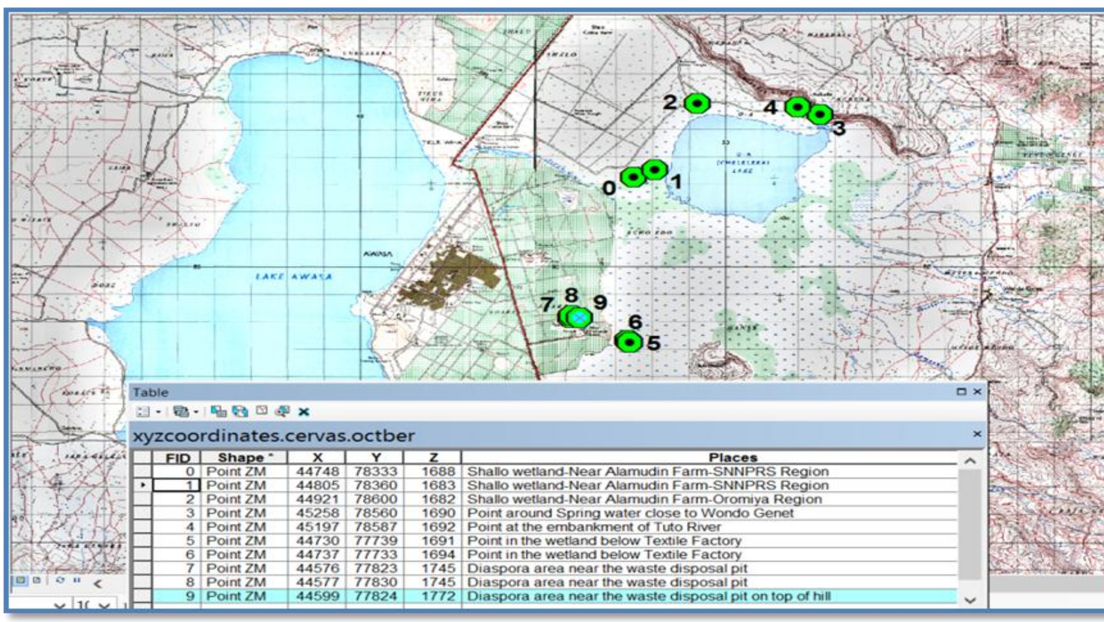
Chelelleka is among such wetlands in close proximity to Hawassa City where human activity is a serious environmental threat to water resources. Although there is a general supposition that Chelelleka Wetland is probably degraded as a result of anthropogenic influences, there has not been a study that would validate the assumptions.

The main reason for this study is to fill this information gap.

The initial objective of this study was to assess the current ecological status of the Chelelleka Wetland and based on the findings; develop research proposals that will outline what needs to be studied about the wetland. The imperative purpose of this ecological study was to contribute to the overall initiative that is designed to ultimately protect Lake Hawassa from pollution. However, the observations during the initial survey showed that the current environmental situations of the wetland are so acute that immediate actions have to be taken. Therefore, a change in the objective of the study was required. As a result, the objective of the study turned out to be to survey the current status of Chelelleka Wetland and propose actions that will improve its purification and replenishment functions.

2. **Methodology**

The methods used in the study included desk work, in which a through literature search was made and the findings were compiled before the field visits were carried out. Existing literature on the Chelelleka Wetland was reviewed to examine past records (historical background) and identify possible changes in the last few decades. Three round field visits were carried out (in 2017 and 2018) along the edges of the wetland to assess the present status of the wetland. Nine points of observation (Figure 1) were purposely selected and marked, using GPS. The observation points were selected with the intent of having full view (observations) of the wetland as close and as far-reaching as possible. During the field visits, informal discussions were made with some people, who live near the wetland - to sound out the progress of the threats on the wetland.



FID	Shape *	X	Y	Z	Places
0	Point ZM	44748	78333	1688	Shallo wetland-Near Alamudin Farm-SNNPRS Region
1	Point ZM	44805	78360	1683	Shallo wetland-Near Alamudin Farm-SNNPRS Region
2	Point ZM	44921	78600	1682	Shallo wetland-Near Alamudin Farm-Oromiya Region
3	Point ZM	45258	78560	1690	Point around Spring water close to Wondo Genet
4	Point ZM	45197	78587	1692	Point at the embankment of Tuto River
5	Point ZM	44730	77739	1691	Point in the wetland below Textile Factory
6	Point ZM	44737	77733	1694	Point in the wetland below Textile Factory
7	Point ZM	44576	77823	1745	Diaspora area near the waste disposal pit
8	Point ZM	44577	77830	1745	Diaspora area near the waste disposal pit
9	Point ZM	44599	77824	1772	Diaspora area near the waste disposal pit on top of hill

Figure 1. Locations of nine points of observation.

3. Results and Discussion

The field survey revealed that there are some acute circumstances which need to be dealt with before any research is intended to be carried out. The study team observed that the current environmental situations are so severe that immediate actions have to be taken. Although the initial intent of the survey was to gather information that will help in developing research proposal on the wetland, after the survey, it was decided that no time should be spent on planning research on Chelelleka Wetland - given the current situation of the wetland ecosystem.

It was agreed that long-term research should be planned after the current conditions of the wetland are rectified. It was also believed that if some of the situations are allowed to continue, it may be too late to curb the problems. The environmental issues that call immediate action include habitat loss and fragmentations due to human settlement, agriculture, forestry, and pollution from industrial effluents.

3.1. Human settlements: The study team observed that there are at least two major locations (*Datto* and *Honse*) where there have been growing settlements of people that have come from different corners of the region (see Figure 12 under The Socio-Economic Aspects of Chelelleka Wetland article). Local sources indicated that the population of the settlers is not only growing from the newborns in the community but also from the continuous influx of people that is not being controlled. These communities, unless their growth is controlled, will grow to the extent of occupying a large proportion of the wetland area. Such human impacts on the environment, which of course needs a full-fledged study, will be very significant. The social aspect of the settlements is treated in detail another paper of this publication. At this juncture, it suffices to point out that such settlements will modify the wetland ecosystem and lead to permanent habitat loss. The consequences of such modifications like fragmentation (due to roads for pedestrian access) and increased soil erosion - will ultimately lead to siltation and nutrient deposition in Lake Hawassa. Moreover, wildlife like bird populations will continue to diminish through time.

3.2. Agriculture and Forestry*:* the Chelelleka Wetland is being seriously encroached by large scale agricultural activities designed to increase economic development (mainly by ELFORA) and other adjacent property owners that have been expanding into the wetland. Farmers in Cheffe Kote Jabessa, Datto and Gara Riketta kebeles have expanded their subsistence holdings and are advancing into the wetland causing degradation of the wetland (refer The Socio-Economic Aspects of Chelelleka Wetland article). Eucalyptus trees are being planted on many new plots in the wetland (under The Socio-Economic Aspects of Chelelleka Wetland article). Such activities will certainly compromise the ecosystem services that can be obtained from the wetland as well as threaten its existence.

3.3. Grazing: Almost all of the wetland is being used as grazing land which removes the land-cover and exposes the soil to erosion and reduced water retention capacity. Again, the effects of such human interventions which are detrimental to the existence of the wetland are unquestionably enormous. (see Figure 13 under The Socio-Economic Aspects of Chelelleka Wetland article)

3.4. Effluents from factories: At least three major factories (Hawassa Textile Factory, Hawassa St. George Brewery, and MOHA Soft Drink Factory) discharge their effluents into the wetland and/or streams that flow through the wetland into River Tikur-Wuha (Figure 7). Although some of the factories are known to treat their effluents before the discharges are released into the wetland, there is no evidence that the discharges are clean enough to comply with the requirements to release them directly into the wetland. The study team strongly believes that these effluents should not be allowed to continue polluting the wetland - and eventually the Lake Hawassa. At this juncture, it is important to mention that non-point pollution from agricultural runoff cannot be discounted given the intensive land use and modification in the watershed.

As mentioned earlier in this paper, the environmental issues we identified include habitat loss and fragmentations due to human settlement, agriculture, forestry, and pollution from industrial effluents. The actions that need to be taken in order to alleviate the problems related to human settlement, agriculture and forestry are discussed elsewhere in this publication (see Dagne & Alemante). In this part of the study we dwell only on the problems related to pollution from industrial effluents. Accordingly, the following ecohydrological mitigation actions are proposed:

4. Proposed Mitigation Actions

Preservation of Chelelleka Wetland is vital for protecting the Lake Hawassa ecosystem. It is a known fact that huge amount of money is invested worldwide on conventional water purification structures to purify water which is tainted because of human activity. There are also many local and international laws, with strict regulations on draining of wetlands, established to prevent wetland destruction. Multiple projects are also developed all over the world to restore and protect wetlands. In a nutshell, wetland management activities, which include any activity that preserves, restores, or protects the wetlands in any way, are being practiced with a lot of success stories from many parts of the world. Most of these activities are positive mitigation actions such as protecting the wetlands from any human interference. However, as it was mentioned in the previous section, Chelelleka Wetland is facing a big threat from encroachments dominated by human settlements, farming activities, industrial pollution, etc. in all directions (Figures 2), and yet with little intervention efforts. Therefore, the present effort is an urgent call for immediate mitigation actions.

Figure 2. Farming practice inside the wetland downstream of Burkito Hot spring, north east of the wetland

When mitigation actions are thought of, the technologies to be used become the primary concern. Different technologies are implemented worldwide to mitigate such detrimental environmental problems and protect the environment from excessive overloading from different kinds of pollutants. These technologies are verified with their capacity to treat wastewater to meet the appropriate effluent standards. Numerous technological options exist for treatment of sanitary and storm wastewater. Those options can be implemented based on various properties of treatment systems. Treatment options may be classified into primary, secondary and tertiary treatment methods according to the process of wastewater treatment. They can also be classified into decentralized and centralized treatment systems based on their location of application. Table 1 below summarizes attributes of different treatment systems that are of relevance to this study.

Table 1*.Overview of natural wastewater treatment systems*

Treatment system	Description	Advantage	Disadvantage
Waste-stabilization ponds (WSP)	- A series of large surface area ponds connecting each other. - Ponds have different depths for different purposes.	- High reduction in pathogens - Can be built and repaired with locally available materials - Low operating cost - No electrical energy required - No real problems with flies or odors if designed correctly - Providing treated water of sufficient quality for irrigation - Satisfactory resistance to load variations	- Requires large flat areas - Dependent on climate conditions - Possibility of odors with anaerobic and facultative ponds - Fair pollutant removal efficiency in a single facultative pond. - Inflexible in accommodating population growth
Ecohydrological Approach (constructed wetlands)	- Artificial treatment system designed and constructed to replicate the biological processes found in natural wetland ecosystems. - It simulates the ecosystem's	- No oxygenation requirement - Low-cost treatment systems - Requiring minimum levels of Operation and Maintenance Robust on shock loadings	- Dependence on climate conditions, i.e. cold climate negatively impacts system efficiency

	biochemical functions such as filtration and cleansing.	- Equally pathogen removal efficiency as WSP with more flexible design criteria - Using harvested reeds as a good source for composing	
Land treatment (soil aquifer treatment)	- Sewage is supplied in controlled conditions to a soil media.	- High capacity soil matrix required - High efficiency in BOD and coliform removal - Simple construction and O&M - Low construction and O&M costs - Resistance to variations in effluent quality - No sludge production - Providing soil fertilizers - Groundwater recharge	- Low removal efficiency for some pollutants, such as phosphorus - Requires large area - Possibility of odors, insects, and worms - Application interrupted in rainy periods - Dependence on soil characteristics - Risk of contamination to the soil and plants - Possibility of nitrate groundwater contamination - An overland flow system: greater dependence on ground slope

Ecohydrology is concerned with the effects of hydrological processes on the distribution, structure, and function of an aquatic ecosystem, and with the effects of biotic processes on elements of the water cycle (Moore & Gafford,, 2015). Ecohydrology is an integrative science that focuses on the interaction between hydrology and biota. The concept emerged as a transdisciplinary approach to finding solution-oriented methods for reducing anthropogenic impacts on ecosystems. Indeed, the transformation of landscapes in recent decades, from pristine ecosystems to novel or highly-impacted systems has entailed negative effects on their natural processes. It is with the aim of reversing these that ecohydrology seeks to reinforce ecosystem services in these modified landscapes.

Aiming to achieve sustainability in both ecosystems and human populations, as well as to improve Integrated Water Resources Management (IWRM), ecohydrology leads the way for the accomplishment of the Sustainable Development Goal on Water. Through managing dual regulation of hydrology and biota, ecohydrology seeks to take into consideration four multi-dimensional parameters within river basins: water, biodiversity, ecosystem services for society and resilience to climatic changes.

Water quality in freshwater ecosystems is dependent, to a great extent, on biological processes (Figure 3). This is because freshwater ecosystems are situated in landscape depressions and, thus, are permanently supplied by organic matter from terrestrial ecosystems which is decomposed by aquatic biota — invertebrate grazing and microbial enzymatic processes. The pattern and intensity of hydrological variability significantly moderate biotic structure and activity. On the other hand, biotic structures regulate abiotic ones: wetland and flood-plain plant-cover significantly determine the extent of river self-purification capability (Zalewski, 2002).

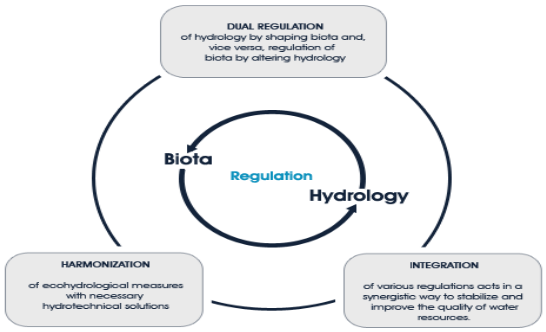


Figure 3. Integration of biological process and hydrology

Thus, management of hydrological processes which include precipitation, evaporation, average air temperature, mean water level and flow control biological processes that are vital for a living organisms. On the other hand, shaping of biological structures of an ecosystem in a catchment regulates hydrological processes.

In light of the theoretical background elaborated above, three work-packages are proposed as mitigation actions using ecohydrological approach. We have arbitrarily named them as work-packages 1, 2, & 3 with locations indicated in Figures 4 & 5.

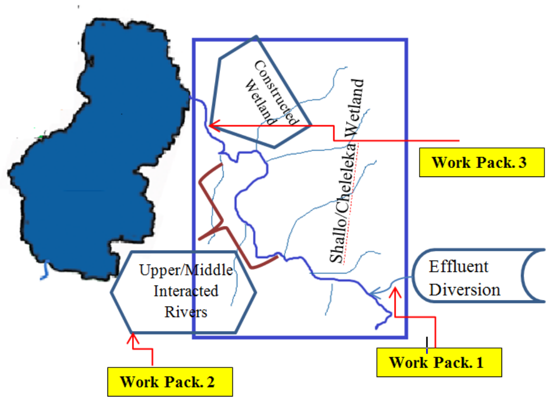


Figure 4. Schematic representation of three work-packages (Work Pack.) suggested being in place for an Ecohydrological intervention in Chelelleka Wetland

Figure 5. Satellite images depicting the suggested cites of the three work-packages for an ecohydrological intervention

Detailed descriptions of the three work packages proposed for mitigation actions are presented hereunder.

4.1. Work Package-1: Waste stabilization ponds

Treatment ponds that are proposed in this work-package include anaerobic, facultative and aerobic types which can be used individually or in combination. They need to be organized in series with a flow from anaerobic to facultative and then to aerobic ponds to obtain satisfactory treatment results. These three pond types are elaborated in detail hereunder.

i. Anaerobic Treatment Ponds

The main objective of this treatment stage is to break and dissolve organic solids by letting the non-degradable solids form the deposited mud. It can also reduce the BOD in the range of 40 to 85%. The method used for removing the BOD is almost the same for all anaerobic ponds that do not depend on the presence of algae and uses sedimentation of solids and anaerobic digestion of the remaining mud. The main resultant from the anaerobic treatment is biogas that is collected after coating the pond with plastic membrane during digestion. This gas is very beneficial and can be used in different domains and for different purposes such as heating or lightening.

ii. Facultative Treatment Ponds

The facultative treatment ponds (FTPs) have the same purpose as the anaerobic ponds as they both work on reducing the BOD. For FTPs, the removal range of BOD is between 80 to 95%. They are the easiest one to design compared to other treatment ponds and contain two main zones, one anaerobic and another aerobic. This difference is due to the usage of algae, that perform the photosynthesis using the atmospheric oxygen and sun light, in aerobic zone, unlike what is used in the anaerobic zone. The ponds can use algae but only in the aerobic zone with the existence of oxygen at the surface. In addition to BOD removal, facultative ponds have also other purposes - decreasing odor and removing pathogenic microorganisms, by solid sedimentation and deposition of the remaining sludge at the bottom resulting in the reduction of phosphorous and nitrogen (80% removal) as well as ammonia released to the air (about 95%) (Sitwala, 2017).

iii. Aerobic Treatment Pond

BOD is reduced to the possible minimum as a result of decomposition of organic matter in the anaerobic and facultative ponds. Thus the purpose of aerobic ponds is mainly removing pathogens and filtering/blocking solids. This purpose can also be extended to the removal of nitrogen and phosphorus (major nutrients responsible for eutrophication) when combined with harvesting of fish and/or algae. The amount of aerobic ponds required and their size rely on the desired final quality that depends on pH, temperature and light.

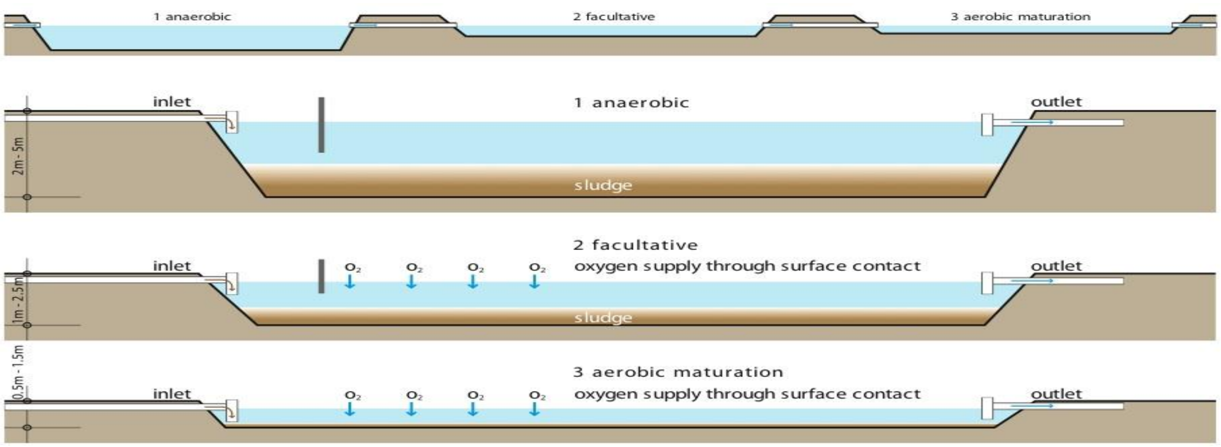


Figure 6. Details and arrangements of Anaerobic-Facultative - Aerobic ponds in series

4.2. Work Package-2: Modified Riverine Treatment

Tikur Wuha River, the only perennial river that flows into Lake Hawassa, is the final recipient of the discharge from the wetland and the effluents from the industries upstream. It is loaded with inorganic and organic impurities consisting of bicarbonates, total suspended and dissolved solids, and other contaminants, which influence the BOD and turbidity of the water, among other variables, etc. These need to be removed before the River joins Lake Hawassa. Thus the purpose of package-2 is to remove the contaminants from the river at different reaches using natural treatment techniques with the provision of ample hydrologic retention time (HRT) for the flow with enhanced microbiological activities and for better phytoremediation actions. During a preliminary reconnaissance study conducted in November, 2018; three places were identified for possible modification along the main stream and its tributaries (Figures 7, 10 & 11) using the existing endemic macrophytes while shaping the river/stream bank for better HRT.

Figure 7. *Location 1 (just downstream of Cheffe Kote-Jebesaa Kebele) selected for modified riverine treatment.*

Phytoremediation ("phyto" meaning plant, and the Latin suffix "remedium" meaning to clean or restore) is a relatively new field of science and technology that uses plants to clean-up polluted soil, water, or air (Lamoureux, 2005).Phytoremediation can be applied to both organic and inorganic pollutants present in soil, water and air. It consists of mainly four different plant-based technologies each having a different mechanism of action for the remediation of polluted soil, sediment, or water (Cunningham, 1995).

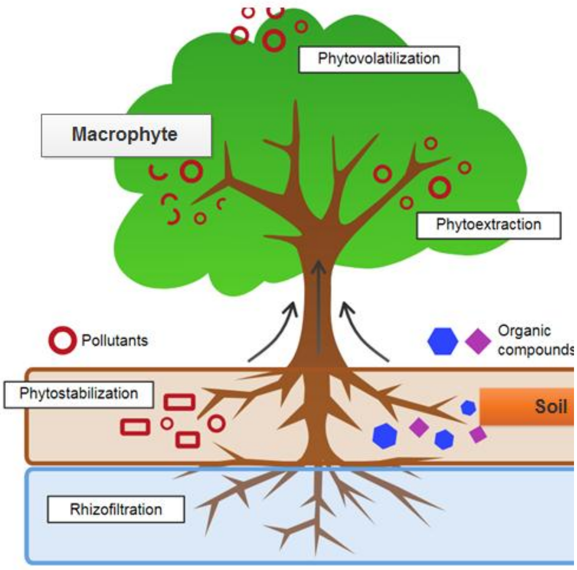


Figure 8. Phytoremediation techniques (https://en.wikipedia.org/wiki/Phytoremediation)

These technologies include: ***rhizofiltration,*** which involves the use of plants to clean various aquatic environments; ***phytostabilization,*** where plants are used to stabilize rather than clean contaminated soil; ***phytovolatilization,*** which involves the use of plants to extract certain heavy metals and nutrients from soil and then release them into the atmosphere through volatilization; and ***phytoextraction***, where plants absorb heavy metals and nutrients from soil and translocate them to the harvestable shoots where they accumulate (Figure 9). Although plants show some ability to reduce organic pollutants (Torricelli, 2009) the greatest progress in phytoremediation has been made with metals (SALT, et al., 1995; Torricelli, 2009).

Figure 9. Location 2 (just downstream of Burkito Spring) selected for modified riverine treatment.

Phytoremediation should be viewed as a long-term remediation solution because many cropping cycles may be needed over several years to reduce contaminants to acceptable regulatory levels. This new remediation technology is competitive, and may be superior to existing conventional technologies at sites where phytoremediation is applicable.

4.2. Work Package-3: Constructed / Engineered Wetland

The third package proposed for mitigation action is a constructed wetland artificially designed to filter and treat waterborne pollutants found in sewage, industrial effluent or storm water that ultimately reach *Tikur Wuha*, which in turn joins Lake Hawassa. Building constructed wetlands has mainly one purpose of treating wastewater coming from different sources such as agricultural, domestic, food processing, etc. Moreover, constructed wetlands can serve other functions such as augmenting the landscape existence value, fish farming and enhancing aesthetic values of the landscape. For some cases like the case of *Tikur Wuha* River; constructed wetlands are the main and only prevailing wastewater treatment options, for others they are only a step within a bigger treatment process. The use of Plants in constructed wetlands helps filtrating wastewater and absorbing solids in addition to transferring oxygen (Mghaoui, 2014).

Based on either volume or area, there are a variety of different wetland design methods. Each method carries its own set of assumptions, and different sets of equation having their own strength and weaknesses. Volume-based methods use HRT for pollutant reduction (Reed et al., 1995) whereas areal-based methods assess pollutant reduction using the overall wetland area (Kadlec and Knight, 1996). Basically there are two designs of constructed wetlands, viz. surface flow and sub-surface constructed wetlands. In our case, we have opted to use the surface flow constructed wetland for the very reason that the technology has been tested under tropical conditions and is found to be cost effective, operation and maintenance friendly, and less demanding to modify the landscape (Mihret Dinanto, 2014 and references cited therein). To that effect, a three-zone Free Water Surface Flow (FWSF) constructed wetland model (adopted from USEPA, 2000) is suggested here for the proposed constructed wetland (Figure 10).

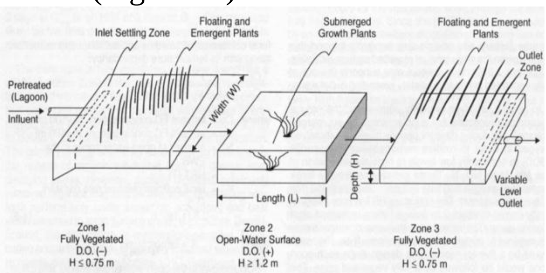


Figure 10. Typical Elements of FWSF Wetland, A 3-zone FWSF Wetland Model (adopted and modified from USEPA, 2000). **Zone- 1** is a densely vegetated region designed for flocculation and sedimentation of influent suspended solids and BOD. **Zone -2** is an open water region designed to increase the dissolved oxygen content of the water, allowing for aerobic degradation of soluble BOD and nitrification. **Zone -3** is a densely vegetated region similar to Zone 1, which is designed to reduce suspended solids reaching the outlet and provide for denitrification.

Free Surface Flow Constructed Wetland is composed of plants (Figure 14) in series (Figure 12) inside basins to reproduce water flowing through natural wetlands (Figure 13).

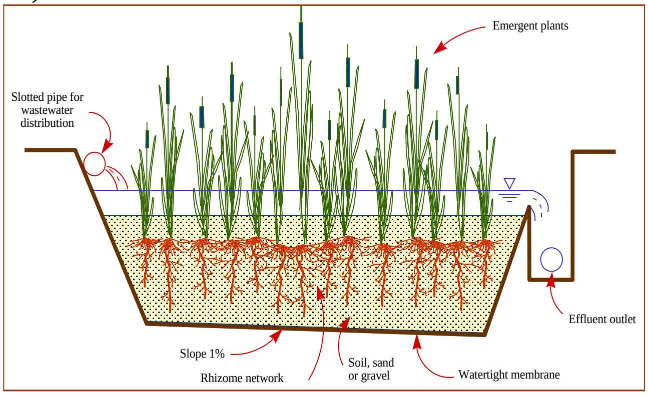


Figure 11. Free Water Surface Flow Constructed Wetland

The function of such wetland is mainly accomplished as the water goes through it where pathogens are eliminated, big particles stabilize and the rest of the contaminants are consumed by plants as food.

Figure 12. Typical FWSF macrophyte native to Chelelleka Wetland near Monopol Quarry site.

This process is very advanced and can be used after Work Package 1&2 are completed. The actual system design depends on many factors such as temperature, availability of space, and hydraulic and organic loading rates (EPA, 2011).

5. Conclusions and Recommendations

Results of the survey have revealed that Chelelleka Wetland is facing growing threats from habitat loss and fragmentation due to human settlement and associated rapid population growth, increased economic development - mainly large scale agricultural practices and related water extraction, overgrazing, expansion of farmlands and forestry in the wetland, and pollution from industrial effluents . These situations may disrupt the natural functions of the wetland – particularly its purification and replenishment capacities. Unless immediate actions are taken to halt these threats, the wetland will soon be converted to residential, agricultural and industrial area. The ultimate impacts of such human activities are immeasurable - especially on the ecosystem of Lake Hawassa.

On the basis of the actualities outlined above, the following recommendations have been put forward:

a. Immediate interventions by local authorities and other stakeholders need to be taken to at least halt the ongoing human activities in and around the wetland. We suggest that a discussion forum among stakeholders and local government authorities be initiated whereby these issues can be discussed and immediate actions are started. Issues that need to be studied can further be discussed in such a forum and research priorities can be set.

b. At this initial phase of the study we recommend that the **intervention/mitigation measures** proposed in section 4 of this paper be undertaken as immediate actions to improve the purification and replenishment functions of the wetland and to ultimately protect Lake Hawassa from pollution.

c. It is necessary to take the appropriate actions to restore the wetland. We, therefore, recommend that establishment of a "Chelelleka Wetland Restoration Initiative - **CheWRI**" should be considered after the necessary studies are made. Notwithstanding this recommendation, protection of existing functions of wetlands is much easier and preferable to restoration of degraded functions, and hence we suggest that all efforts must be made to protect the wetland from the current threats.

Finally, Chelelleka Wetland is vanishing in the presence of institutions and individuals who can take actions and make a difference. However, "inaction" seems to have prevailed over "action" in the last many years. The costs of such indifference are incalculable. Needless to say, it is the responsibility of all environmentalists and those in political leadership to end the inaction that has sustained for so long. In this connection, we would like to quote Emperor Haile Selassie of Ethiopia who said *"Throughout history, it has been the INACTION of those who could have acted; the INDIFFERENCE of those who should have known better; the SILENCE of the voice of justice when it mattered most; that has made it possible for THE EVIL TO TRIUMPH"* as a closing remark.

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The Socio-Economic Aspects of Chelelleka Wetland: Current Status and Future Prospects

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ABSTRACT

The purpose of this study is to explore the socio-economic activities which are affecting Chelelleka Wetland resources and bring them to the attention of policy makers so that measures relevant to combat the problem may be taken. The research uses qualitative methods such as interview, group discussion and observation with community members living in and around the wetland. The findings showed that complex socio-economic activities which have long been undergoing in and around the wetland have affected the size and the functions. Farm land expansion, deforestation, agro-forestry, irrigation, industrial effluents, mining and irregular settlements were found to be the major socio-economic factors that dwindled the wetland resources. The findings made clear that urgent and concerted actions are required of the stakeholders to halt the progressive decline of Chelelleka Wetland resource. They also suggest that upper catchment watershed management, introducing appropriate irrigation technologies, delineating boundaries and treating effluents require short term interventions; whereas controlling open grazing, planning resettlement, providing alternative livelihood sources, introducing environmentally friendly energy sources and engaging stakeholders in meeting their corporate social responsibilities need to be carried out in the long term. Since identified socio-economic activities that are affecting the wetland have broad nature, each of them demands very detail study to find sustainable solutions.

Keywords: socio-economic, activities; Chelelleka wetland; interventions.

1. *Background of the study*

Wetlands occupy about 6% (890 million ha) of the land surface of the world, but an estimate of 50% of world's wetlands may have been already altered or lost in the last 50 years (Finlayson and Moser, 1991 in Gemechu , 2010). Ethiopia has diverse wetlands of various origins that distributed in many parts of the country, and a large number of Ethiopians depend on its resources for their survival (Wood and Dixon, 2002). As to the estimates of EPA (2004), wetlands account for 2% of the land mass of Ethiopia. With the exception of coastal and marine related wetlands and extensive swamp forest complexes, all forms of wetlands at present, together with their associated wetlands, are fundamental parts of life interwoven into the structure and welfare of societies and natural ecosystems.

Wetlands have considerable socioeconomic and ecological values. Wetlands support crop production and fishing and are sources of medical plants among others. Ecologically, wetlands are instrumental in water storage, filtration and supply; they control flood; perform sediment, nutrient and toxin retention functions and are habitats for biodiversity of both flora and fauna (Abebe and Geheb, 2003). Ethiopian wetlands are increasingly being lost or altered by unregulated over utilization, including water diversion for agricultural intensification, urbanization, dam construction, pollution and other anthropogenic intervention (Abebe and Geheb, 2003).

Lake Hawassa, which is one of the Ethiopian Rift Valley Lakes, is located at the western edge of Hawassa City The lake has a surface area of 90 km^2. The community of Hawassa and its environs has been utilizing the resources of the lake as a livelihood source for a very long time.

The water of the lake is used for bathing, recreation, domestic use, and as habitat for different wild lives. The fishery of the lake supplies protein and generate incomes for the local people and beyond.

The wetland yields grasses and other vegetation on which cattles graze. It is also used for the the construction of boats (‘tankua’), mattresses, mats and agricultural implements and houses. The Lake also supports different species of birds some of which are believed to be endemic.

Chelelleka Wetland, which is located at the eastern part of Hawassa City, is the major source of water that drains into Lake Hawassa through *Tikur Wuha River.*Nowadays, this wetland and Lake Hawassa are facing serious ecological problems due to deleterious anthropogenic activities in the catchment.

Clearing of forest and eucalyptus tree expansion, new human settlement, building of factories that dischareg toxic materials, and use of fertilizers, herbicides and pesticides all damage these indispensable but fragile ecosystems.

This socioeconomic study attempts to assess the past and present status of the wetland and its future prospects, and how human interventions are affecting it so as to propose a working action plan to safeguard the wetland as well as the lake from the hazards they are facing. "Although the effects of pollution on wetlands may not be noticeable at the moment, the long term effects are inevitable unless mitigation measures are taken as early as possible" (Girma et al, 2014:36).

If the present trend of human impacts, especially those related to the industrial effluents and domestic discharges as well as agricultural activities and deforestation in the catchment continue, the lake will unquestionably go through irreversible pollution and permanent loss of suitable habitats and biodiversity in the ecosystem (Girma et al, 2014).

2. *Problem statement*

While wetlands are the most productive ecosystems on earth, they are also the most threatened ones. Wetland destruction and alteration has been and is still seen as an advanced mode of development, even at the government level. Wetlands and their value remain little understood and their loss is increasingly becoming an environmental disaster. While rates of wetland loss are documented for the developed world, the limited study of these ecosystems in countries like Ethiopia leaves us with little to say (Yilma, 2003).

In Ethiopia, no or little study has been done as to how socio-economic factors hinder and /or promote wetlands in general and Chelelleka Wetland in particular. People’s knowledge, attitude and practices towards protecting and sustaining wetland ecosystems are important issues that need to get due concern of communities.

Therefore, studying socio-economic conditions of the people who are living in and around the wetland becomes an entry point to suggest sustainable wetland conservation measures and bring about lasting positive impacts on the functions of Lake Hawassa.

3 *Objectives of the study*

The overall objective of this study is to assess the opportunities and challenges, and future prospects of Chelelleka Wetland thereby to protect Lake Hawassa.

The specific objectives of the study are:

1. To identify the major economic activities in the wetland
2. To point out the formal and informal institutions existing in the wetland
3. To describe the livelihood activities that are undertaken in the wetland
4. To reveal the socioeconomic problems encountered in the wetland
5. To describe the major functions of the wetland
6. To uncover the socio-economic conditions of the people living around and in the wetland

4. *Methods*

This study mainly relied on qualitative approaches of data collection methods. Accidental sampling was used to draw informants from the general population. Structured observation, interview and group discussions were used as instrument of data collection. The Interviews and FGDs were conducted with Kebele officials, residents in and around the wetland. Secondary sources (books, journals, articles, internet sources) were also referred to consolidate the information we got through primary data sources.

5. Findings

5.1 *Major functions of the wetland*

Chelelleka Wetland is the major source of water that drains into Lake Hawassa through *Tikur Wuha River*. The community of Hawassa and its environs has been utilizing the resources of this wetland as a livelihood source since long. The wetland provides natural resources and services for the community around it. It serves as source of food, controls flood and improves water quality. It is also important to biodiversity and wildlife conservation. The wetland yields grasses and other vegetation on which cattles graze. These resources are also used for the construction of boats, mattresses, mats and agricultural implements and houses, among others.

Different writers listed out the multifaceted functions of the Chelellka Wetlands. Among these Zerihun (2003) in his study on the *challenges and opportunities of Ethiopian wetlands* illustrated the following major functions of the wetlands: the water is used by local people for irrigation, sanitation and domestic animals. Much of the runoff from Lake Hawassa catchment area drains first into the swamp and then gradually flows into the lake via *Tikur Wuha River*. The system also plays a vital role in controlling flooding that particularly originates from Wondo Genet highland areas. Besides, diverse species of water fowl, weed bed fauna, zooplankton, phytoplankton, fungi, bacteria, amphibians, reptiles and macrophytes inhabit the wetland, and this makes it an important regional biodiversity domain. ;

Furthermore, it stabilizes the microclimate and serves as a buffer against harmful human activities in the catchment.

5.2. Major socio-economic activities around the wetland

5.2.1. Agricultural activities

Intensive agricultural and deforestation activities in the catchments are serious environmental problems of the wetland. Our visit to the catchment area of the lake revealed that agricultural production is a major activity of the local farmers residing in the northern and north-western part of the wetland. There are also state and private farms which include *Shallo Basic seed farm* and the *ELFORA farm*. Shallo Seed Farm covers 1321 hectares of land. Maize, sunflower, soya bean and Haricot bean are the major seed types grown in the farm. The farm multiplies and distributes these high quality improved seed varieties to farmers of the region and the nation at large at fair prices. Inorganic fertilizers such as DAP and UREA, and different types of pesticides and herbicides are applied in the farm. Close to the farm, there are also individual small holdings, estimated to be about 10 hectare which also uses the aforementioned types of pesticides, herbicides and fertilizers. During the rainy season, the flood from this farm flows to the lake which in turn has impact on all living bodies in the lake.

Elffora mechanized Farm (Figure 1) is located in the north and north east part of the wetland. The total area of the farm is over 3000ha, out of which 2600ha is used for growing different types of crops. Maize, Alpha-alpha grass, and vegetables such as green pepper and tomato are grown by the farm. Chemical fertilizers (UREA, and DAP), herbicides and insecticides are used to boost production and productivity of the farm. The farm provides employment for 400-600 seasonal and 55 permanent workers. The farm allows free access to the local farmers to use the crop aftermath for their livestock feed.

In sum, though the amount and types of agro chemicals used in these farms is not easily determined, undoubtedly leached chemicals from the farms and other small holder farms reach the lake via the drainage system.

Figure. 1 ELFORA Mechanized Farm partial view, April 2017**.**

We verified that in this part of the catchment where there is agricultural activity, there is very little plant cover becuase of the increased tilling of the land and overgrazing of vegetation. Therefore, the soil is exposed to erosion. This has been the trend since long. Such land use and degradation of the catchment led to the runoff with increased input of sediments (soil and nutrients) that have negative impacts on the lake.

5.3. Irregular settlement/ house construction

In the north and north west part of Chelelleka Wetland, there is land grabbing (Figure 2). and irregular house construction (Figure 3). Currently we have observed that there are over 500 housing units in the area. The settlers are mainly from Shire Borera and Woransa Kebeles of Wendo Genet Woreda. With estimated average family size of 5, the total human population currently residing in the area is estimated to be about 2500. So many new huts are still under construction in the area.

Figure. 2. Land grabbing and irregular house construction, December 2017

As the researchers observed, in the northern part of the sub-watershed where there is agricultural activities and new settlements, there is very little plant cover due to the increased tilling of the land and overgrazing of vegetation. This in turn leads to run off with increased input of sediments and agrochemicals that end up in the lake.

Intensive crop production and deforestation is the prominent feature of the area, and is among the major problems of the wetland. Irregular house construction and opening new crop land is common phenomena in the upper/north and north west parts of the sub-watershed of Shallo Swamp, which drains into *Tikur Wuha* River and then to the lake.

Figure 3. Irregular settlement on northern part of wetland in November 2018.

Figure 4- girl's Horticultural activities on formally distributed wetland, December 2017.

Every year, particularly during dry seasons (end of December and early February) so many farmers (500-600), and their livestocks come to this area from Gojelle (Aje Woreda), Koffole, Kokosa, Arsi Negelle, Bisan Guracha, Daleti and Wondo Genet, and settle temporarily in tents. They return to their origin when the heavy dry season leaves its turn to wet / rainy season.

Box 1- Bushure Jibo (Figure 4) is a young girl of 26. She is single and lives in Shire Borera kebele. Her origin is Shashemene town. Bushure is graduated with BA degree in Accounting from Shashemene US college. She could not get job after graduation and decided to come to this area. Bushure has built her dwelling in 2008EC and now she is growing cabbage and selata on her farm plot of 1000m^2 which she got some 5 years ago when shire Borera kebele had been mating out land for the land less and newly married couples in the kebele.

Bushure says nowadays no any land to be distributed by the kebele. But still some individuals come from different nearby Woredas of west Arsi zone, and from wondo genet areas. They irregularly construct huts during the nights and start tilling crop land.

The average number of livestock coming to this area with the new comers are estimated to be over 2000. These people come to the area primarily in search of water and pasture to their livestock. They feed their cattle on the stalk of maize from ELFORA farm and water their cattle on the Chelelleka Wetland. Every year, considerable number of people remain in Shire Borera and Woransa Kebeles after having clandestine purchase of land. Then, step by step, they till the land, plant crops and plant eucalyptus tree as a wind break.

6.1.3.Emergence of social institutions

Institutions governing human relations can be categorized as formal and informal ones. The formal instructions govern people's interactions on the basis of written rules and regulations, whereas the informal institutions oversee relations through implicit ways. In the Chelelleka Wetland, both the formal and informal institutions are working simultaneously, although the formal relations are dominating the informal ones.

Several formal institutions are flourishing around the wetland. Water, road, education and religious institutions are providing services for the people living around the wetland. These institutions will be described turn by turn below.

6.1.3.1. Development of spring water

Tutu spring is the major water source for the people who settled around in the northern part of the wetland. It comes out of the foot of a big mountain in the upland. It has been built and developed to supply water to the community living in the area. This spring is serving as a major source of drinking water for human and domestic animals and for washing clothes. Some people come to fetch water from distant place such as Toga village. These activities affect the volume of water that drains into the wetland and later into Lake Hawassa.

Figure 6- a.) Tulu spring for washing cloth and domestic items; b) Hot spring for washing purposes, December 2017.

Tulu spring is also being used to irrigate farmlands for the cultivation of vegetables. Farmers usually grow potato, onion, tomato and cabbage. Vegetable production has been important economic activities to get income though supplying them for markets in Hawassa and Shashemene cities. According to the local people, farm expansion into the wetland has become a common phenomenon. The size of Shallo Swamp is consequently declining and may eventually dry totally. The overall effect of this in turn would be detrimental to the size of Tikur Wuha River and that of the lake .

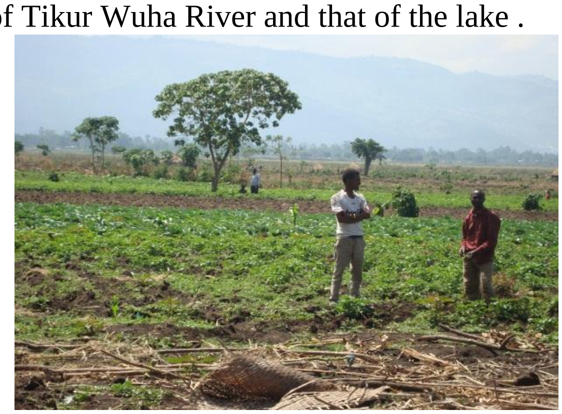

Figure 7. Tulu spring is used for vegetable irrigation at the northern part of the wetland, December 2017.

6.1.3.2. Building of educational institution

Since the settlement is a newly established one, we find elementary school called Shallo Elementary School that teaches from grade

1to 3. The school director stated that the school has been opened in 2015. Currently, more than 120 pupils are attending their education at this school. There are four diploma graduate teachers serving the school.

Figure 8. Shallo Elementary Schoo, December 2017

6.1.3.3 Construction of religious institutions

Spiritual life has been an integral part of any community. So, people are motivated to establish their religious institutions. Currently, a mosque and a protestant church have been built to provide spiritual services in the area. This indicates that the people have permanently settled in the area.

Figure 9- Formal institutions: (a) Mosque; (b) Protestant church, November 2017.

6.1.3.4. Construction of All weather Road

Road construction is crucial social and economic institution for people. Services and goods are transported with the help of road infrastructure. The road joins the new settlement with Hawassa-Shashemene asphalt highway. Cars, donkey carts and motor cycles are transporting goods and facilitating service provisions to and from the settlement. Road accesse has strong power in transforming temporary settlements into permanent ones.

a b

Figure 10- (a) fetching water using both donkey and carts; (b) Narrowing gender roles in fetching water, October 2017.

6.1.3.5. Kebele Administration

The lowest government structure in the control and management of natural resources is given to Kebele administration. Kebele oversees /administer, control and distributes land in and around the wetland. It has also dominant roles in controlling the exercise power of local institutions working in the wetland. There are several Kebele administrations bordering the wetland from the Oromia and SSNPR States. However, Cheffie Kotie Jebessa Kebele is the one which has strong influence on socio-economic life of people in the wetland. This Kebele is playing crucial role in mitigating irregular activities in and around the wetland, although little outcome is achieved.

Figure 11. Cheffie Kotie Jebessa Kebele Adminstration Office, December 2017.

6.2. Socio-economic activities in the wetland

There are different socio-economic activities being carried out in the wetland. Permanent settlements, animal husbandry, grass cutting and mining have been the major types of socio-economic activities practiced in the wetland by people living either in and/or out of the wetland.

6.2.1 Permanent settlements

Chelelleka Wetland has long been an important dry season grazing area for agro-pastoral systems of the Oromo and Sidama peoples. According to key informants, several people came from the aforementioned areas with their livestock and settled temporarily in and around the wetland during the Imperial and Derge regimes. However, these short-term settlements had been gradually changed into permanent ones. Biru Edo and Honsie villages are cases in point.

Figure 12 -(a) villegers in Birue Edo settlement; (b) Honsie village, September 2017.

Biru Edo village is part of Chaffee Kote Jebessa *Kebele* administration, Tula sub-city. It is located at about 1 to 1.5 km south of ELFORA Farm. As to the local people, the village was established during Emperor Haile-Silassie-I regime (about 50 years ago). It is also reported by the local people that the number of housing units / Tukuls/ during the imperial regime were estimated to be about 40. This number has raised to 100 - 140 during the Derg regime. Nowadays, in this settlement, the number of residential units would be about 1,000-1,500. It has been also estimated by the villagers that human and animal populations count about 5,000-7,500 and 8,000-10,000 respectively.

Honsie village is the oldest settlement in the wetland. According to the informants, it began during Emperor Haile-Silassie-I regime, 50years ago. It is found about 2-3km South of Biru Edo village. This village is currently administered under Chaffee Kote Jebessa *Kebele*, Tula sub-city. The total human population in this village is estimated to be about 12 - 15000. The number of dwelling units (huts) are about 3000.

In the dry season of the year, people come with their animals from Shebedino, Boricha, Melete, Gorche, Wegigra, Wondo-Genet, Tula, Korke, Melga, Dato, Dore-Bafana, Shamana Kedida, Jara damoa, Yanase, Rukesa and Guguma areas. These Woredas are reported as drought prone areas. Leaving elders, women, children and some important animals, most men return to their original places during rainy seasons to engage in crop farming.

6.2.2 Sources of livelihood

Regardless of these permanent settlements, people usually get their livelihood from animal husbandry. People rear different species of animals such as cattle, sheep, goats, donkey, horse and mules.. These people sell the livestocks, milk and milk products in Hawassa and Shashemene markets, and buy crops and other basic necessities. Besides, there are some arrangements among people living in the wetland and outside. Some individuals from Wendo Genet and Hawassa towns purchase livestock and give to residents of these villages to keep them for fattening and reproduction in the wetland so as to share the benefit. In addition, settlers supplement their livelihood by engaging in daily labours at ELFORA Farm and Industrial Park, which are found in nearby areas. Apart from other socio-economic pressures around the wetland, animal husbandry in the wetland aggravated overgrazing. Accordingly, it is very common to observe overgrazing throughout the wetland.

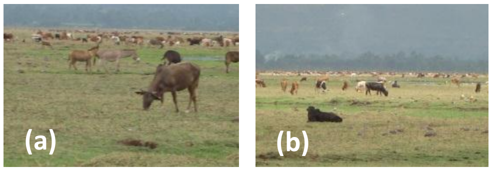

Figure 13- (a)Diffrent species of animals in the wetland; (b) Over grazed wetland, December 2017.

Since, animal husbandry is the dominant source subsistence in the area, local institutions manage the use of resources in the wetland. One of the most important intuitions is Teda (elders shengo). This institution serves the local people to settle dispute arising among settlers in the wetland, oversees/prohibits any cultivation activities in the wetland, and involve in mutual aid principles such as house construction. Moreover, protestant and Hawariat churches are there to provide religious services for Biru Edo and Honse villagers. But the villagers get health and education services from institutions outside of the wetland, at Cheffie Kotie Jebessa Kebele.

6.3 Socio-economic activities in the eastern, southern and western part of the wetland

The wetland gets much of its water from Wendo Genet catchment. The catchment has been covered with natural forest. The forest has been protected and watered the wetland for several years. However, different socio-economic activities are limiting the potential of irrigating the wetland. Farmland expansion, logging, irrigation, agro-forestry, house construction and factory construction are some of the activities which are extensively practiced in the upper catchments.

6.3.1 Farmland expansion

The expansion of farm land for the cultivation of crops coupled with a rise in demand of its products in nearby urban centres such as Hawassa and Shashemene are the causes for the continuous decline in forest cover in the upper catchments. These activities, in turn, have affected the quantity and quality of water flow towards the wetland because the natural forests which have the potential for discharging water are declining. In similar ways, the land which has been used to cultivate crops is exposed to water erosion and closed springs with sediments. According to some of the informants, rivers that come from Wendo Genet area and enter into the wetland have declined.

6.3.2 Irrigation activities

Another important activity in the sub-watershed is irrigation. It has also been reported that people in Wendo Genet area (particularly those in Edo, Basha, Busa, and Elala and other Kebeles) are engaging in intensive irrigation farm for their khat, sugarcane and vegetables which seriously affects the amount of inflow of water into the wetland. Moreover, during field visits, we observed several parts of the wetland are under irrigation for vegetable production. Unlike the vegetable production activities in the northern side of the wetland, the western part is irrigated with polluted water coming from factories. This polluted water could have damage on plants and the consumers as well. Cultivators noticed the effect of waste on their farming activities. One farmer commented:

> *"I did not have a problem growing good quality vegetables, enset, and a coffee plant before this factory was here. Over the last three or four years, however, the size of my fruit and the taste of my vegetables have changed. Leaves turn white, dry and ultimately fall off. It has brought economic setbacks for my family and for other people here. I think the waste from the textile factory is destroying our life and future and the life of our children."*

Figure 14 -(a) Vegetable production on encroched prart of the wetland; (b) Industrial effluant used for vegetable production, December 2017.

6.3.3 Agro-forestry

Agro-forestry has been an important socio-economic activity in the area. Eucalyptus tree has been strategic plant in the area. People in the surrounding area use this tree to encroach into the wetland. It is because of high potential of eucalyptus trees to absorb water from the ground, and make the land suitable for cultivation of different crops. Eucalyptus tree is also used as construction material and source of firewood in the nearby urban areas. Hence, it generates substantial amount of income for the people in a very short period of time. However, eucalyptus tree negatively affects the ecology of the wetland by making the land dry.

Figure 15- (a) Encroachment Mechanisms into the wetland ;(b) Eucalyptus tree plantation after encroachment, November 2017.

6.3.4 House construction

The expansion of Hawassa city has seriously impacted the wetland. Most people have strong belief that the wetland is a land that is open to access for housing and farming activities, although the Kebele administrations have some control over the land. According to the information from Chaffee Koti jebessa kebele administration, recently about 400 persons were accused for irregular house construction and farming activities around/ in the wetland. The kebele chairperson disclosed that the kebele with Tula sub city and police force made a survey around the wetland and found the aforementioned number of individuals for the irregular acts. Besides, the kebele detains individuals who carry/transport eucalyptus tree into the middle of wetland for house construction. It was also evident during field visits that the wetland has been under pressure from the periphery and inside due to house construction and farming activities.

Figure 16- Irregular housing in the wetland with vegetable farming, December 2017.

6.3.5 Factory/Industrial production

The western part of the wetland has a direct contact with discharges from factories operating in the area. These industries have been releasing effluent since the 1980s, the time they were established.

"People in the neighborhoods of factories complain about water quality problems , human and domestic animal health issues, setback in agricultural production, etc due to the discharge of effluent from various sources to the environment" (Girma etal, 2014:21).

During our field observation also we saw industrial affluents flowing into the wetland.

Although several industries such as beverage, soap, textile, plastic, meat processing and many others are operating in the area, it was evident that the brewery factory, is the prominent in discharging its waste. The nature and amount of waste discharged are not studied well. The impacts of wastes could be many. Solids that settle on wetland beds can cover flora and fauna resulting in an anaerobic layer (Taylor, 1984). Still we are lacking scientific information on the type, magnitude and degree of ecological damage caused by theses industrial effluents to the Chelelleka Wetland and Hawassa Lake ecosystems.

The industrial effluents have brought about several socio-economic problems on people living around the wetland. Human and domestic animals drink the waste water, and they get sick, lose weight and abort (Desta, 1997). According to the informants living adjacent to the waste drainage system, the industrial effluent have caused several health and economic problems on humans and their animals. People who have a direct contact with the waste are suffering from skin irritation and respiratory diseases due to bad smell. Children who often use the waste for swimming to spare their time in the rainy season have been affected by the smell of alcohol.

Figure- 17 -(a) Children after swimming; (b) Children fetching the waste for domestic use, December 2017.

Moreover, when animals move for grazing into and from the wetland, they drink and contaminate it with the waste. Fetal abortion, reduction in milk production and discoloration of milk and body emaciation have been prevalent effects observed on livestock. Under worst scenarios, these occasionally result in the death of animals.

Figure 18- Industrial effluents are drunk by livestock, December 2017.

Even though there is a lack of extensive study about the impacts of the industrial effluents on the people and their ecosystems, field visits and observational studies in and around the wetland have shown pollutants causing social and economic problems for the local community.

If the present trend of human impacts, especially those related to the industrial effluents and domestic sewerage as well as the agricultural activities and deforestation in the sub-watershed continue unhalted, the lake will unquestionably go through eutrohpication that will eventually lead to irreversible pollution and permanent loss of suitable habitats and the biodiversity (Girma et al, 2014:36).

7. Conclusion

Chelelleka Wetland has been significantly undergoing changes. The size and the nature of swamp have been declining across times. Different Socio-economic activities, irregular settlements, irrigation, deforestation, agro-forestation (eucalyptus tree) industrial productions, overstocking, mining and grass cutting are prominent undertakings, among others. The wetland is losing its important functions. because it has been subjected to expansion of new agricultural lands, increased irrigation activities (of seasonal and perennial crops) using industrial waste, stream waters and wells; overgrazing and land cracking; industrial effluents, decline in land size; animal population increase, building houses (in and around the wetland), agro-chemical hazards, decline in local institutions capacity in the management and sustained use of the wetland. Moreover, multiple and complex social, economic and political interests are taking place in and around the wetland. The breadth and depth of the problems of the wetland require urgent, but sustainable policy interventions to conserve indispensible functions of the wetland and ecosystem of the lake.

8. Policy implications

Chelelleka Wetland is a natural resource useful for the two regional states. The Efforts to restore the wetland requires the commitment and dedication of the leadership of the regions. To curb the problem, the socio-economic team suggests the interventions at two levels. These are: short term and long term ones.

8.1 Short term interventions

Catchment treatment/carrying out soil and water conservation activities

- Involve private sector to discharge social corporate responsibilities
- Use of appropriate irrigation technology (drip irrigation),
- Delineate boundaries around the wetland, and create buffer-zone that can help prevent siltation and retaining sediments, that otherwise negatively affect the quality/quantity of the lake water as well as living organisms in the wetland/the lake
- Conduct census and restrict new settlers in the wetland
- Introduce appropriate waste treatment plant.

8.2 Long term interventions

-Recycling industrial solid and liquid waste

-Relocating settlers in the wetland to their original rural places

-Controlling open grazing, grass cutting and mining activities in the wetland

-Developing alternative sources livelihood for the people

-Introducing renewable energy sources to the communities in and around the wetland

-Strengthening local institution so as to regulate / manage/ control the use of resources in the wetland thereby that in the lake

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Rehabilitating Extremely Gullied Landscape of Boricha Sub-Catchment of Lake Hawassa: Putting Principles of Eco-Engineering and Ecohydrology into Practice

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A B S T R A C T

Soil erosion has been recognized as one of the most serious environmental problems in Ethiopia. In Boricha sub-watershed of Lake Hawassa, the agricultural lands are eroded and most are exposed to erosion hazards due to improper land use, farming practice and over grazing. Gullies which are a symptom of severe soil erosion are commonly observed. In the classical approach to control gully erosion, the solution mainly focuses on hydro-technical design and construction of permanent and temporary erosion control measures that reduce soil erosion threats. While elements of this approach remain valid and viable, a hydro-technical solution alone is clearly insufficient for the sustainable use of the water resources in general and for controlling soil erosion in particular. To guarantee sustainability of freshwater resource use, it is necessary not only to reduce or eliminate sedimentation threats, but also to extend the number of potential tools to manage the degradation of ecological processes at landscape scale. This brings us the development of integrated thinking concurrently with the recognition of the importance of the meaning of ‘sustainability’. Such situation gives rise to the birth of eco-engineering (nature-sensitive engineering)/ ecohydrology that provides the chance to benefit from the opportunities that nature provides to us. This action research has been implemented using the above concept with the aim of supporting the move from the conventional “soil and water conservation” into “landscape restoration”. It is hypothesized that with the application of low-cost innovative technologies, it is possible to rehabilitate the extremely degraded landscape into the level of sustainable land use.

Keywords: Gully erosion; landscape restoration; eco-engineering; ecohydrology

I. Introduction

Background

At the beginning of the 21st century, increase in human population became a major factor in progressive environmental degradation on the global scale. Although the traditional perception of freshwater degradation has been usually linked to pollution, increasing human activities in a catchment has more profound effects on environmental quality. Most river basins in the world have been dramatically modified due to unsustainable development of agriculture, grazing, deforestation, and urbanization. These disturbances have been changing local and regional climates, hydrological cycles as well as evolutionary-established biogeochemical cycles in a catchment. Therefore, it became evident that degradation of river ecosystems has two-dimensional nature:

first - pollution, which can be eliminated to a large extent by technologies;

second - and much more complex, degradation of evolutionary-established water and nutrient cycling.

Soil erosion has been recognized as one of the most serious environmental problems in Ethiopia. It generates strong environmental impacts and major economic losses from decreased agricultural production and from off-site effects on infrastructure and water quality by sedimentation processes (Daba, 2003; Amsalu et al., 2007). In Boricha-Shebedino sub-watershed of Lake Hawassa (figure 1), the agricultural lands are eroded and most are exposed to erosion hazards due to improper land use, farming practice and over grazing. Gullies which are a symptom of severe soil erosion are commonly observed. Due to the presence of active large gullies, sizeable amount of land has already been lost, and this is a major threat to agricultural production and a source of high load of sediment to Lake Hawassa ecosystem.

In recognition of the severity of the problem, several efforts have been made by various organizations to manage runoff, conserve soil and water and reclaim gullies. In the classical approach to control gully erosion, the solution majorly focuses on hydrotechnical design and construction of permanent and temporary erosion control measures that reduce soil erosion threats. As an approach, the physical soil erosion control measures are said to be integrated with the biological ones for more efficiency. While elements of this approach remain valid and viable, a hydrotechnical solution alone is clearly insufficient for the sustainable use of the water resources in general and soil erosion control in particular.

To guarantee the sustainability of freshwater resource use, it is necessary not only to reduce or eliminate sedimentation threats, but also to extend the number of potential tools to manage the degradation of ecological processes at landscape scale. Implicitly, the existing gully control approach in the catchment is no longer appropriate or effective for these mega-gullies, and new approach and reinterpretation of existing concepts for practical use is needed. Rehabilitation of such mega-gullies is urgently needed. This brings us to the development of integrated thinking and the recognition of the importance of the meaning of 'sustainability'.

Such situation gives rise to the birth of eco-engineering (nature-sensitive engineering)/ ecohydrology that provides the chance to benefit from the opportunities that nature provides to us. It should be stressed that, according to the ecoengineering/ecohydrology concept, the overall goal defined in the hypotheses of ecohydrology is the sustainable management of water resources. This should focus on the enhancement of ecosystem carrying capacity against anthropogenic stresses.

In this situation, development of an integrated approach to environmental management that is based on the harmonization of technical and ecological measures is necessary to achieve sustainable use of natural resources. Integrating different branches of environmental science such as ecology and engineering can help provide an understanding of environmental changes as well the knowledge necessary for applying efficient measures that improve the quality of practices and increase the ability of environment to withstand/absorb disturbances resulting from environmental and social changes.

Therefore, this study applies the ecoengineering /ecohydrological approach that extends the conventional soil and water conservation activities into "landscape restoration" concept. Gully treatment is the stabilization of active gullies by vegetative or structural measures or a combination thereof. Gullies can be prevented by such measures as increasing the absorptive capacity of the soil (increasing surface roughness thereby reducing runoff volume and velocity and improve infiltration), protecting the land surface and natural drainage ways from erosion, and by conveying excess surface runoff from fields at a non-erosive velocity through properly prepared and maintained waterways. Besides ruining fertile land, gullies interfere with farm operations, undermine farm improvements, encroach on public highways, endanger livestock, and often mar the beauty and lower the market value of a farm. Materials eroded from gullies reduce the capacity of reservoirs, natural streams, and drainage channels, and cover bottom lands with deposits of soil. Preventing gully formation or taking action at the early stages of newly formed gullies is easier and more economical than letting the problem go unchecked for too long. Large gullies are difficult and costly to repair. After a certain period of gully development, it is apparently not possible to stabilize some gullies once they become longer, larger and deeper.

Preliminary findings on the current status of soil erosion in the Boricha sub-catchment

The gully network under consideration can be categorized as large gully systems in deep sandy soil (Figure 1) lateral or side headcuts or overfalls that frequently develop where small side drainages flow over the rim of the main gully. Unfortunately, the Boricha gully has passed the labeling of 'early-stage' treatment. However, it must be treated as soon as possible to avoid further expansion. This demo site is dedicated to search for best-fit gully treatment options by respecting the design and construction principles formulated to this specific demo project as shown in the upcoming sections.

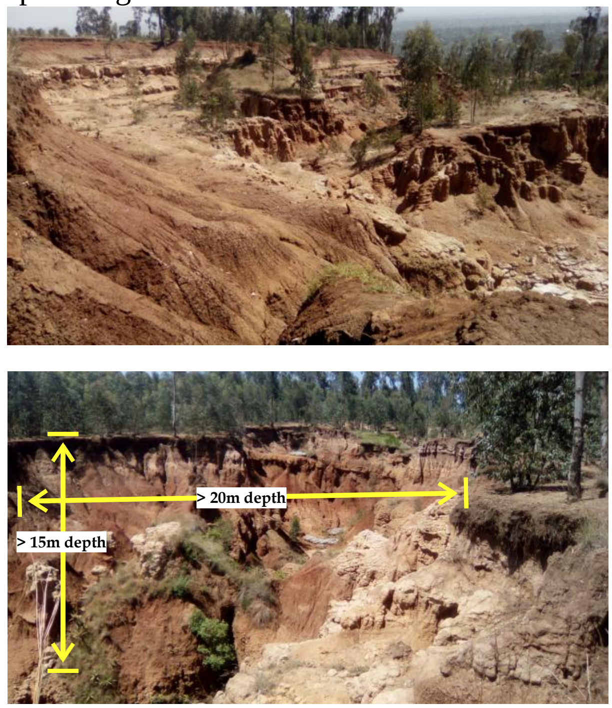


Figure 1. Partial view of gully head at Yirbadubancho Kebele (Borcha wereda)

Objectives

The objective of the action research is to establish landscape restoration demonstration site that combines best-fit eco-hydrology and water infiltration methods, nature-based gully treatment measures, sediment and, nutrient trapping methods, and constructed wetlands.

II. Material and methods

The study area

The intervention area (Borcha-Shebedino project) is found within lake Hawassa watershed and geographically located within coordinates of 38^0 23' to 38^0 26'E and $6^0$55' to $6^0$59'N. . The study area is located in the southern direction of Lake Hawassa, and has an area of 2776 ha. The bigger gully which runs from Bonoya Miride kebele to Lake Hawassa has a length of about 7Kms.

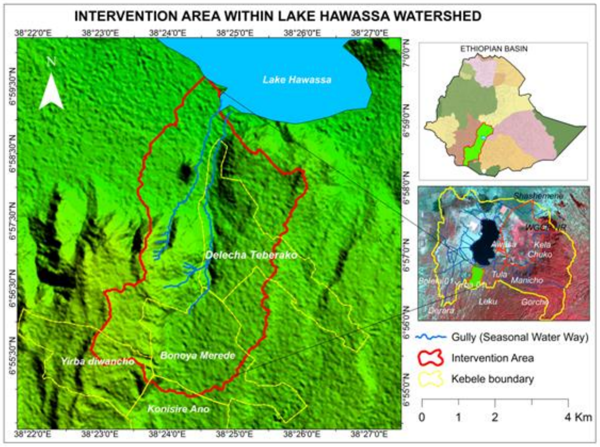


Figure 2. Location map of the intervention area

The generic approach to control gully erosion

Generally, the following three methods will be applied as depicted in figure 3. When the first and/or second methods are applied in some regions or countries with temperate climates, small or incipient gullies may be stabilized without having to use the third method. On the other hand, in tropical and subtropical countries which have heavy rains (monsoons, typhoons, tropical cyclones, etc.), the three methods must be carried out for successful gully control. (Source ?????? ?)

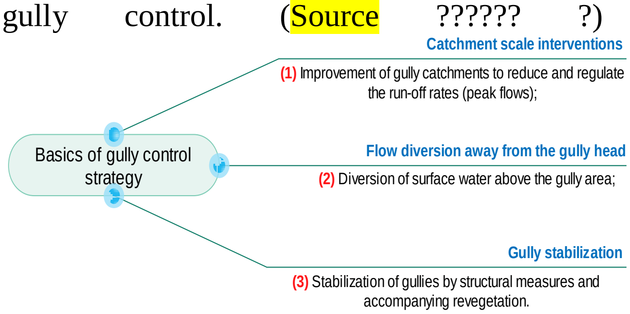


Figure 3. Basics of gully control strategy

Design and construction principles

This demonstration technology transfer project is based on the following key underlying design principles that govern its design and construction aspects (Source ???? ?):

1) Low-cost options
2) Minimum earth work
3) Avoidance of mechanistic approach as much as possible
4) Avoidance of over-engineering of the environment
5) Maximizing the use of local materials
6) Respecting and considering local knowledge (consulting life experience of the community)
7) Rely on local technical capacity or building the know-how locally
8) Multiple goal
9) Based on community consensus
10) Maximizing community ownership
11) Maximizing women participation
12) Empowering the community

Technical options to be considered

The technical approach segmented the gully network into three parts: (1) Gully head; (2) Gully bed; (3) Gully side. Each of them requires different approaches as shown in figure 4.

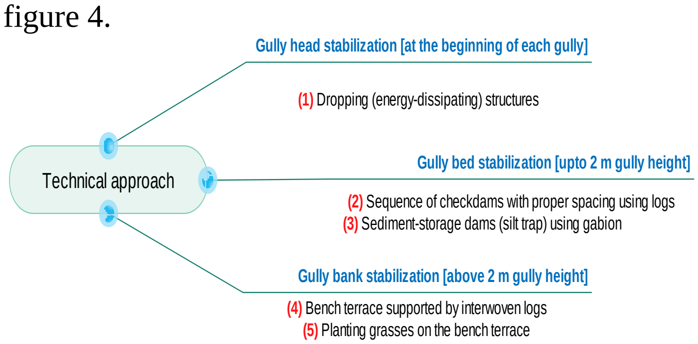


Figure 4. Segmentation of gully treatment activities

Conceptual diagram for eco-engineering system

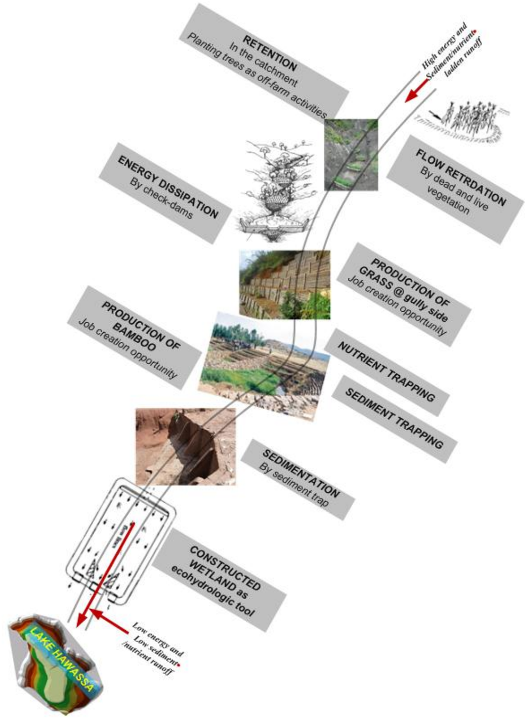


Figure 5. Anticipated ecohydrological processes and physical-biological-social benefits

Conceived eco-engineering gully control measures

The likely intervention gully control measures comprise the combinations of structural and vegetative measures which will be designed to reclaim gullies. Vegetation provides protection against scouring and minimizes the erosion risk by reducing flow velocity. In addition to protective role, the biomass produced in the gully area can be used for different purposes such as cattle fodder. The following pictures reflect the likely structures in the demonstration site.

[Box 1] Gully head treatment

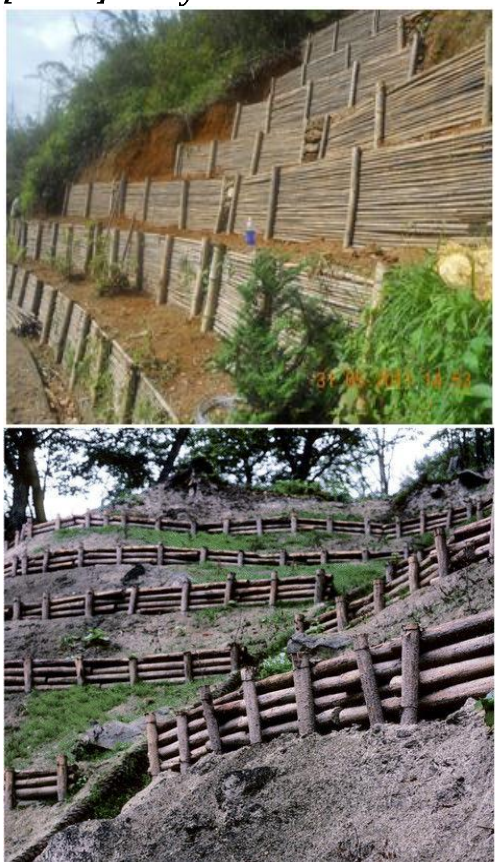
- Divert excess runoff into another drainage line (stable) or treat the catchment area.
- Control the gully head and the side banks by cutting & filling (see figure above in Box 1)
- Gully heads can be stabilized by the means of stepped stone carpets, brushwood layering or a combination of both.
- Using stepped stone carpet is more appropriate for dry areas because of intensity of rainfall.

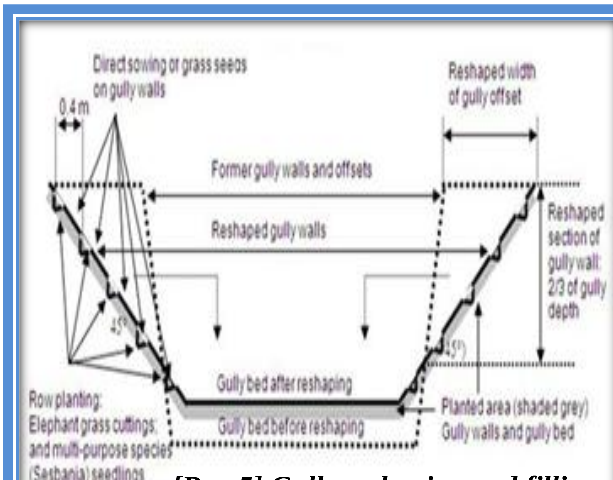
The stepped stone carpet occurs following the semi-circular shape of the gully head, moving backwards and filling empty space with soil and small stones until it reaches the gully edge.

[Box 2] Small wooden checkdams

[Box 3] Silt trap (basin)

[Box 4] Gully side bench terrace





[Box 5] Gully reshaping and filling

The Landscape Function Analysis (LFA) methodology

The LFA is used to develop an understanding of the functionality of the landscape to help the management of the resources available in the landscape used for different purposes. The LFA helps to analyze the factors which maintain the functionality of a landscape.

At the pre-rehabilitation stage, LFA allows the specific processes that need improvement to be identified (Randall, 2004). The LFA can be applied to sites of all sizes, from an individual patch to a hillside and all ecosystems types (Tongway and Hindley, 2004). LFA also offers insights into how the landscape function at the rehabilitation site changes overtime, and facilitates numerical comparison of restored sites against reference sites (Haagner, 2008; Randall, 2004).

The LFA methodology is composed of three components which include the conceptual frame work, indicators of landscape function and field procedures for monitoring of the indicators (field data acquisition) and an interpretational framework.

The conceptual framework of an LFA – A Theoretical Basis

The conceptual framework is used to collect data to determine the landscape organisation (LO) in the study area as well as to show how scarce resources are moving through a landscape in space and time.

With the conceptual framework, the functioning of the landscape will be examined. The landscape can be categorised into two classes: functional or dysfunctional. When a landscape is categorised as functional it means the applied ecohydrological technologies cause the overflow of water to take a longer path to flow out of a landscape.

The vegetation and the structures obstruct water flow and sieves out material like litter and seed. A landscape which is dysfunctional does not have a great effect on the water flow. In a dysfunctional landscape, scarce resources are not trapped but rather allowed to flow out of the landscape.

Preliminary findings

The preparation stage

In the project document, it was emphasized that the community and other stakeholders shall involve in all stages of the planned activities essential for design, implementation, and sustainability of interventions. Since the eco-hydrology approach for gully restoration is different from the conventional approach, the team members of the project carried out continuous and intensive discussion with Woreda experts and administrative bodies to better understand eco-hydrology principles and approaches as well as the purpose of the project.

Figure 6. Discussion with woreda experts and development agents

Awareness creation, training and capacity building to framers (masons and carpenters) and development agents were among the key components that were implemented before the actual restoration activity started.

Figure 7. Hands-on training for carpenters and mason

Regular discussions were carried out with community representatives of the area throughout the implementation stage in order to monitor the progress and get feedback to adjust activities to maintain the needs of the community as well as the spirit of the project objectives. The project site was selected in consultation with Woreda experts and community representatives.

Figure 7 Discussion with community representatives & kebele leaders

The implementation stage

In gully treatment the first step is diverting of runoff which will stop headward erosion by waterfalls. The basic aim of diversions is to reduce the surface water entering into the gully through gully head. However, safe disposal points of the diverted water are not available in the study area. Therefore, at the beginning, discussion was made with the communities to manage the excess runoff so as to reduce the speed of flow. To this effect, farmers who live just above the head of the gully were made to construct various water retention structures.

Figure 8. Checkdams above the gully head

A combination of simple and low cost structural and biological conservation measures were implemented using locally available materials such, wood and grass. The major cost was payments for wood, grass seedlings and daily labour. The gully areas were not in good condition for vegetative growth since the slopes are steep and the fertile topsoil had been washed away. It was hence difficult to establish vegetation and provide quick cover. Therefore, reshaping the steep walls was necessary. To reshape the steep slope, retaining wall is also required to stabilize and hold back the soil, and to reduce the risk of wall collapse. To construct the retaining wall, the first step was to mark out the contour line across the slope from the beginning to the end of the gully area. After marking the contour line, the wooden posts were anchored in to the ground at specified distance along the contour and across the slope at various spacing depending on the slope gradient.

Figure 10 Partial views of gully head at Yirbaduwancho Kebele

Figure 11 Design improvements as suggested by the community

Figure 12 After 25 days of the project start

To keep the wooden posts firmly at their position, back stays were fitted at regular intervals. After completing the retaining wall construction, the slope that was in vertical position was reshaped to gentle slope by cutting and filling to the lower area to create a levelled bed. This bank slopping was necessary for establishing vegetation. What if you explain about the use of plastering of the walls inside and the wooden posts? They are visible from the pictures

Figure 13 One day of planting

Figure 14 Current statuses (after one rainy season)

Then *Pennisetum pedicellatum* (locally known as *desho*) and *Chrysopogon zizanioides (Vetiver)* grasses were planted on the reshaped slope and the bed with clump spacing of 15 cm within a row and 30 cm between rows. The *Pennisetum pedicellatum* was established by *planting* tillered cuttings while Vetiver was planted by splitting the culm. Vetiver was selected due to its ability to grow under dry and unfavourable conditions and control erosion with its dense root system binding the soil together. *Pennisetum pedicellatum* provides massive fibrous root system to stabilize the wall of the gully, vigorous

vegetative growth and a high biomass with great nutritive value for livestock.
What if you indicate that the areas the two grasses were planted differed in slope and the nature of the soil?

Remaining activities

The rehabilitation measures implemented so far cover smaller and the upper part of the gully area. The results are encouraging and brought some change in farmer's attitude on the possibility of gully rehabilitation and ecosystems restoration with low cost and with materials and manpower locally available.

Figure 15. Micro-basin

The activities will continue to the downslope direction of the gully using the existing approach and by developing new and innovative measures that rely on biological methods which are effective, economical and long lasting. In order to create sense of ownership over the process and to ensure provision of goods and services, inclusive and effective community involvement is vital. This should be taken as a continuous process rather than a one-time exercise.
Once the soils are regenerated and its fertility is improved, trees and shrubs will be planted to provide sufficient cover and provide quick benefit to the community. Tree and shrub species will be selected based on Ecological range, root system characteristics (creeping and drought resistant grasses and tree & shrubs), socioeconomic and cultural functions, environmental services and general plant performance. After sufficient rehabilitation is achieved, a management plan should be prepared for harvesting resources and maintaining structures.

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Socio-Economic Dynamics and Gully Expansion: Current Status and Future Prospects

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A B S T R A C T

Gully erosion in the Hawassa Lake sub-watershed, southern Ethiopia, is affecting the livelihoods of communities since early 1970s. Understanding its socio-economic effects on the communities is important for any remedial measures that need to be taken for the sustainable development of the communities and effective management of soil and water resources in the watershed. Qualitative data were collected from participants drawn from the communities in the sub-watershed mainly affected by gullies using interview and focus groups . The findings showed that the areas which had dense forest cover and no gullies in the long past developed gullies due to human actions like deforestation, settlement and overgrazing that were practices for decades. The socio-economic conditions and environmental degradation in the last fifty or so years has made the communities change their livelihood strategies. The government and communities tried to deal with the problem of environment degradation, and gullies, employing biological and physical interventions on both private and communal lands. The communities are aware of most of the factors that drive environmental degradation including gullies, and are willing to contribute their share if concerted effort and commitment is gained from the government.

Keywords: Communities' perception, gully, Lake Hawassa, socio-economic dynamics

1. Introduction

Most of the ecosystem services on which human well-being depend are being degraded and lost.(Hiwasaki and Arico, 2007; Millennium Ecosystem Assessment, 2005). Gully erosion is one of the causes for environment degradation. In gullies the runoff water accumulates and often recurs in narrow channels and, over short periods, removes the soil from this narrow area to considerable depths (Poesen et al. 2003). The runoff in a gully transports sediment from upland to the valley into permanent channels and increases the effects of water erosion. One of such effects is the silting of storage lakes and water courses (Iacob, Nemes and Laura, 2011:622). According to Valentin (2005), nowadays there is a growing interest in gully erosion and its off-site impacts. Gully erosion that is observed in Lake Hawassa sub-watershed, is affecting the livelihoods of communities in different ways. Understanding its effects on the socio-economic life of communities is important for any remedial measures that need to be taken for the sustainable development of the communities and for effective management of soil and water resources in the watershed.

In recent years, there has been a shift from top down approaches towards bottom up approaches with full participation of the community to development. It is recognized that the management and conservation of natural resources can be more successful with a proactive participation of the different actors. This requires an approach towards genuine partnership and contractual agreements among the different stakeholders. Particularly, sociological approach to watershed management involves several important components (Bonnal, 2005). One of them is raising awareness of *the people's role* in the watershed approaches. The concerned communities in the watershed areas must be fully aware and convinced of the principles, methods and the advantage of their participation in the development of programs or projects. The second one is *strengthening the capabilities* of local organizations. Enhancing informal community associations, groups, and cooperatives is essential so as to make them capacitated to play important role in watershed management. This may involve training the leaders of such organizations, and ensuring the involvement of deprived groups, such as women and youth, in local decision-making process. The capacity of local organization should be strengthened in order that they become self-sufficient. The third component is *decentralizing decision-making* by all players concerned, including those outside of watershed areas. This is because a decentralized system tends to promote local level initiatives and participation. It is well recognized that local communities support projects that reflect their views and priorities. The forth component is *promoting dialogue, partnership and alliances* among players. This involves sharing of information and dialogue and promoting cooperation among the parties. From this perspective, it is important to understand how the earlier intervention efforts were conducted, and how the communities were involved in the development of the sub-watershed so as to revise the approaches for the future endeavors. It is equally important to understand the socio-economic factors that either facilitated or hindered the efforts made and communities' interests concerning future actions. The attempt made in this regard was checking how far the components we saw above were considered in the intervention actions that have been undertaken up to now.

The study was conducted in *Boricha and Shebedino Woredas (districts) of Sidama Zone, southern Ethiopia.* In these areas, gully formation began during Emperor Haileselassie I regime due to natural resource degradation, and it continued to expand gradually. However, until the last decades of the Imperial regime no biological and structural conservation measures were taken to halt the expansion of gully in the catchment.

1.2 Statement of the problem

Over the last 3 - 4 decades, human interventions coupled with natural factors caused severe environmental degradation in south west sub-watershed of Lake Hawassa. Several gullies were formed due to deforestation, overgrazing, expansion of agriculture, and settlement. These gullies are affecting the livelihoods of the communities, and are threatening the existence of Lake Hawassa through sedimentation. The problems that gullies caused made thousands of people vulnerable to the adverse impacts of natural resource depletion.

In response to this, governmental and non-governmental organizations introduced biological intervention works to address the problem. Hence, the degraded mountainous areas of Boricha and Shebedino Woredas were covered by eucalyptus trees. Although eucalyptus tree covered the area, through time run off kept increasing from time to time and made the smaller gullies grow bigger. Later, in the 1990s, structural measures were also installed in the watershed to minimize the problem. Efforts that were made to protect the natural environment through soil and water conservation activities made some changes but the problem was not overcome fully. Moreover, compared to the biological and physical intervention works, little attention was given to understand the socio-economic dynamics, and to empower the community regarding the management of the problem of natural environment degradation.. As a result, people's activities, needs and priorities were not well understood. This led to the neglect of genuine participation and contribution the local people could make in the designing, planning and implementation of the interventions (Achouri, 2005) despite the growing importance of people centred development (Bonnal, 2005). It was partly due to the absence of genuine partnership between experts and the people. The experts did not change their way of working which was "a management-based and top-down approaches" to understand the realities on the ground and to engage the people. On the other hand, the local communities did not appreciate the potential contribution of experts. Consequently, communities regarded themselves as recipients of development outcomes.

In the study, effort was made to look into how communities perceive the problem of gully erosion and its socio-economic impact in their livelihoods, and the role they think they can play in the watershed management in two woredas (districts) of Sidama Zone from which the gullies originate - Boricha and Shebedino and discharge to Lake Hawassa. It was also tried to understand the measures that have been taken so far to tackle the problem, and what the communities suggest for the future to curb the problem.

1.3 Objectives

The study was intended to explore the history of gullies in the area and the socio-economic aspects of gully erosion in the sub-watershed. It mainly tried to find out the socio-economic dynamics in relation to the formation and the expansion of gullies in the study area, to identify the roles communities can play in reducing the formation of gullies and in rehabilitating gully affected areas, and to identify possible interventions to curb the problems for the future.

2. Methods

Using a qualitative approach, data were collected from local communities and agriculture experts. Two Kebeles which are among the most seriously affected by gullies (Yirba Dubancho from Boricha Woreda and Boniya Miride from Shebedino Woreda) were purposively sampled. FGDs and key informant interviews were conducted with knowledgeable community members that consisted elders, adults, and youth of both sexes who were selected based on their knowledge about the Kebeles and the gullies. Observations were also made on sites that were affected by gullies. There were also some kebele leaders, religious leaders and development agents (DAs). Secondary data sources were also consulted concerning the socio-economic conditions of the two Kebeles. The issues discussed are related to people and economy, the history of gullies in the area, causes and impacts of gullies, and community institutions that contribute to the management of watershed.

3. Major findings

The study attempted to shed some light on the history of gully formation in the sub-watershed. The place from which the major gullies in the south west of Lake Hawassa sub-watershed originate is the uplands located in Boricha and Shebedino Woredas of Sidama Zone. These gullies (referred to as "ho*shoshame"* in Sidama language) cross about six kebeles before they drain to Lake Hawassa. Communities who participated in the study (fig 1) indicated that, in the long past, the areas from which the gullies originate were covered by forest, bushes and vegetations, and there was no gully.

Figure. 1: FGD at Yiba Dubancho

However, as the human and animal population increased and farming and settlement expanded over decades, land cover continued to decrease. The forests were affected because they were the sources of construction materials, household furniture, farm implements and fuel wood. In addition, in the early 1970s, high scale damage was done to the forests as it was a transition period from the imperial regime to Derg. As a result, the vegetation cover along with most of the local trees disappeared. Rain water (it was heavy at that time) which used to be absorbed by soil, began to run away causing erosion. Through time the erosion became intense and gave rise to gully formation which. was first noticed towards the end of Emperor Haileselasie I regime, and continued to expand and to grow wider and deeper, as can be seen from figure 1below.

Figure.2: Partial view of gullies in Yiba Dubancho

The first intervention effort to conserve soil and water in the area was made during Derg period by planting eucalyptus trees in the upstream and enclosing it. This measure brought about some changes on land cover, but the problem of gullies persisted. Constructing physical structures began only during EPRDF period. These structures contributed in terms of conserving soil and water. It was also indicated that in recent years the building of gabion in the gullies has also brought some changes in raising the level of the bed of gullies. The communities expressed that if such intervention works had not been done, it could have gotten worse.

3.1 Perception about causes of gullies

The responses of FGD participants indicated many factors for the formation of gullies in the area. The major ones include deforestation for different purposes like the need for fuel wood, expansion of farms, settlement, grazing, and the hilly topography of the area. In addition to this, ignorance of the people as to the consequence of all their actions on the environment was also found to contribute to the problem negatively. It was indicated that different measures were taken to manage erosion and gully formation on individual farmlands and communal lands. But the measures that were implemented on individual plots varied from those that were implemented on communal lands. Planting banana and elephant grass surrounding their plots was reported to have produced better results. Likewise, building terraces and planting inset was also found to be helpful. On the communal lands, however, the conservation measures that were applied were stone bunds and terraces (locally known as Kitir). This is because the magnitude of the problem on communal lands is high, and some of the measures that were used on individual plots like planting inset and elephant grass are not feasible to the communal lands. The findings revealed that the watershed management works are bringing about positive changes on the environment. Although the technical and professional supports that are given by agriculture professionals at woreda and kebele levels were appreciated, at the same time communities expressed their worries regarding two things: 1) Since the attention for physical structures as soil and water conservation measures is decreasing in the area, the structures are being destroyed and there are no maintenance schemes. 2) Compared to the magnitude of gullies in the area, the efforts being made are minimal.

3.2 Socio-economic Dynamics

The response of the FGD participants revealed that the area which used to be more of agro-pastoral has now shifted to complete subsistence farming system. Various socio-economic factors contributed to this change. Owing to the increase in population size and decrease in land size, the communities which used to plant mainly enset and maize have now diversified the crops. With the minimum land size the household own, 0.25 hectare (according to kebele managers) or one '*timad'* on average, they try to cultivate varieties of crops, either using inter-cropping or rotation. Now-a-days, most households practice planting khat and sugarcane in addition to enset and maize as major crops (fig 3 & 4). There are different crops that are produced at secondary level as well, for example, *teff*, coffee, haricot bean, and pepper. They also produce fruits like mango, banana and avocado. Common live stocks the pocess include cow, ox, donkey, sheep and goat. There are also households who engage in petty trading and handicrafts. Some even seasonally migrate to adjacent kebeles and woredas in off farm seasons. The FGD participants estimated that, about 10% of households migrate in search of employment. These households use this as a coping mechanism in their livelihoods. Some farmers either engage in share-cropping or they rent in land and cultivate, while others engage in labour work in urban areas.

Figure 3. Enset, sugercane and khat on a single farm land

Figure 4. Enset, banana and khat on a single farm land

3.3 Impacts of land degradation and gullies in the study area

The major impacts of gullies on the communities' life include reduction of farm lands, reduction of soil fertility, shortage of animal feed, reduction in grazing land and loss of farm plots. Besides these, the communities expressed that they have been facing death of livestock and humans (by falling into the gullies while grazing in the banks of gullies, and while moving during the night or while crossing gullies or floods). The participants of the FGD also indicated that in the past they were able to move freely from one place to another, but now they are forced to move around to get to a place they want because of gullies.

As the FGD participants reported, a lot of indigenous tree species were lost due to land degradation and the gullies that are formed. Many water sources failed in different places that the areas are currently facing severe shortage of water. Communities in the study area also disclosed that they travel for 1 - 3 hours to get water. It was indicated that in Yirba Dubancho Kebele, the residents go to Yirba Town, the capital of the woreda, to get water, where as in Boniya Miride, they go to the few water points in the kebele. In these kebeles, fetching water is the sole duty of women and to some extent children. Shortage of fuel wood and construction materials is also acute problem for the majority of households. It is only households that have eucalyptus trees who do not experience this problem. However, the communities also expressed their concern about the expansion of eucalyptus trees in every household's farmland. Another impact of land degradation on the communities was found to be the hot temperature in the area which is increasing from time to time.

3.4 Factors for gully formation

The area that has been affected by gullies in the study area did not have gullies in the long past. It was due to many driving factors that gully formation began in the area and grew to large gullies we see in the study area today. The primary factor was mentioned to be the cutting of trees and clearing forest for different purposes. The communities cut trees and cleared forests for the production of different household materials, construction of houses, settlement and expansion of land holding. Open grazing that was practiced for years and intensive farming as well as the cultivation hillsides also contributed to the formation and expansion of gullies. Participants of the study indicated that lack of awareness about the long-term consequences of human actions also played a role to the problem. Particularly in Boricha Kebele, the participants emphasized the role topography has for the formation and expansion of gullies. This is a kebele situated in the upstream most part of which is hilly.

3.5 Actions of communities and institutions to deal with the problem

Environment conservation effort cannot be successful without active involvement of communities and institutions. In this regard, the FGD participants revealed that the communities in the study areas have made different efforts to curb the problem of soil and water erosion both on private farms and communal lands. The measures included those taken to treat gullies at their early stage as well as the formation of new ones. These techniques which were applied on private plots are planting sugarcane, enset, banana, khat, some trees and some types of forage, e.g., Desho Grass. However, on communal land the technique applied was only planting trees, mainly imported species including eucalyptus. A rather new technique which is being applied to mitigate the problem of gullies is building gabion in the beds of big gullies (fig 5). It was indicated that this is mainly carried out by the financial support Rift Valley Basins Authority and labor contribution of the community. The other measure the communities took in this connection is protecting the area closures from human and livestock intervention. Institutions like *'Sera'* and '*Idir'* played positive role in reinforcing the instructions by government structures. Sera is a traditional local institution in which respected local elders are the leaders, whereas Idir is a sort of cooperative mechanism to deal with different hardships. These institutions influence the practices of communities by imposing sanction (social and economic) against those who violet the accepted norms of the society.

Figure 5. Gabions constructed in the gully beds

3.6 Major challenges

In the study attempt was made to identify major challenges to livelihoods in the area. Agriculture is the main source of livelihood in the area. But there are many challenges to this livelihood strategy. One of the major challenges was found to be drought that occurs recurrently in the area. It is characterized by short and low rainfall, irregular onset and leaving, long dry season and sometimes flooding. Another challenge is population growth. It was indicated by the participants that the growth of human and livestock population is making the land size for agriculture shrink from year to year. As a result, households are forced to redistribute their landholdings among the grown up male children, and this caused land fragmentation in the area to be severe. Consequent, the size of land holding is always diminishing. Some of them have only 1/4th of a 't'imad' (which is about 0.0625 hectare). Gullies are also contributing to the reduction of farm lands because it is encroaching to the backyards of many households.

Currently, gabions which were constructed in the deep gully beds and plain areas in the lower stream are contributing in reducing the degradation, but at different points some of the gabions were broken/washed away by heavy gullies, or the erosion is expanding sideways destroying the gully banks (fig .6 & 7). Despite this fact, the participants expressed their worries relating to the absence of maintenance scheme to the gabions. Moreover, since gabion work was begun in the lower stream, the magnitude of erosion from the upper steam has not reduced much, and this is making the effort less effective than it would do in the lower stream. Thus, still more and more sediment is discharged and is entering Lake Hawassa thereby threatening its existence. In the face of this problem, the communities expressed that their financial and technological capacities are limited to tackle the problem since the gullies are very huge.

Figure 6. A broken gabion in the gully bed

Figure 7: Gully eroding the bank on the sides *of gabion*

The local institutions like *sera* and *Idir* should be empowered more to own the local environmental resources and to take responsibility of protecting and managing them if the resources are to be developed and used sustainably. Strengthening the local capacity in terms of technical skills and knowledge will have significant contribution to achieve the goals. In Yirba Dubancho, the researchers observed how a traditional pond was protected by the local institutions and the communities (fig 8). Although it is a pond that collects water from flood, the community fenced it around so that animals may not access it. It is serving as the only source of water for the community. They use it for various purposes including washing clothes (fig 9)..

Figure 8. A traditional pond at Yirba Dubancho

Figure 9. One of the services of a tradional pond at Yirba Dubancho

4. Conclusions

The emergence and development of the gullies in the southwest of Lake Hawassa sub-watershed evolved over long period of time. The huge deforestation in the study area, led to the environmental degradation with serious consequences. The siltation from the gullies in this watershed affected the socioeconomic life of the communities and the environment both in the upper and lower streams. There are institutions, for instance, ***Sera***, ***limat budin*** and ***Idir*** that can facilitate the efforts made to ensure sustainable development of the environment. The readiness of the Kebele administrations and the existence of adequate labor force in the study areas are resources that can make the intervention works. Planting sugarcane, enset, khat and forage were effective techniques communities used for treating gullies at early stage on private landholdings. Apart from treating mature gullies, it is very important to pay equal attention to prevent the creation of new ones. Besides, the communities must be empowered on matters of the environment so that they can reduce the impact of gullies on livelihoods and the ecosystem as a whole.

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