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## Research

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# Geospatial Analysis of Land Use/Land Cover Dynamics on Lake Abaya-Chamo Wetland in Southern Rift-Valley of Ethiopia

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## Abstract

*Wetlands worldwide and in Ethiopia have long been subject to severe degradation due to anthropogenic factors. This study was aimed at analyzing the impact of land use/cover dynamics on Lake Abaya-Chamo wetland in 1990 – 2019. Data were acquired via Landsat TM of 1990, ETM+ of 2000, and OLI of 2010 and 2019 images plus using interview. Unsupervised and supervised classifications (via ERDAS14 and ArcGIS10.5) were applied to detect land use/cover classes. Normalized difference vegetation index, normalized difference water index, change matrix model and Kappa coefficients were used for analysis of the land use/cover dynamics in the lake-wetland. It was found that forest; water, shrub land, agricultural land, settlement and swamp area were the main land use/cover classes. While ‘settlement’ and ‘water body’ of the lake-wetland increased at progressively increasing magnitudes of changes in three periods within 1990 – 2019, ‘shrub land’ and ‘swamp’ declined at progressively increasing magnitudes of loss in the same periods. The NDWI result revealed that ‘swamp’ area shrank by 48.9% (2,991 ha) due to siltation-led expansion of the lake-water in three decades. Siltation, rapid population growth-led expansion of settlement and irrigation-based farming were the main drivers of the land use/cover dynamics and degradation of the lake-wetland. Thus, consistent mapping and integrated actions should be taken to curb the threats on the sustainability of the lake-wetland in Southern Ethiopia.*

**Keywords:** *land use/land cover, dynamics, magnitude, NDWI, multispectral, Lake Abaya-Chamo wetland.*

## Introduction

Land Use/Land Cover (LULC) changes affect aquatic and inland ecosystems including wetlands across the globe. Technically, the concept of ‘land use’ is different from that of ‘land cover’. ‘*Land use*’ is the purpose for which land is exploited by people; whereas, ‘*land cover*’ is the biophysical or inherent state of land above the lithosphere (Lambin et al., 2003). On the other hand, a ‘*wetland*,’ roughly upon the Ramsar Convention, is a natural or manmade swamp, ‘fen or peatland’ ... having soft, spongy soil/land saturated with draining or stagnant, fresh, brackish or salty water including marine with a depth (at low tide) of less than 6 meter (RCS, 2016). Inland (natural) wetlands are endowed with diverse species of flora usually dominated by

dense growth of annual and perennial grasses, and herbaceous plants (in some cases, mixed with trees of variable densities) as well as with various species of fauna and microorganisms (Schuyt, 2005). Inland wetlands, being formed often on flat to plain landscapes, depressions (surrounded by uplands), banks and deltas of rivers (Ballanti et al., 2017), along margins of lakes, and where clayey/sticky soils are dominant, have vital economic and environmental values (Clarkson et al., 2014; CBD, 2015). Well managed inland wetlands provide myriads of benefits (services) with an estimated value of about US\$ 44,000 per/ha/year (TEEB, 2013).

Wetland ecosystems provide numerous services, which range from provisioning (fish, rice production, animal fodder and fossil fuels) through supportive (e.g. habitat, breeding ground of birds and crop farming) and regulatory (carbon sink, climate control and regulate hydrological cycle) to cultural (e.g. recreation and aesthetic) services (MEA, 2005; Dise, 2009; Erwin, 2009; Davidson, 2014; Clarkson et al., 2014; CBD, 2015). Huge proportion of the wetlands (marine and inland) in the world undergo complete and/or partial degradation or loss in response to the impact of natural and human factors (Schuyt, 2005; Zedler and Kercher, 2005). Climate change, sea-level rise, sediment load into wetlands, volcanism, earthquake and drought are among the main natural causes of degradation of wetlands (Morris et al., 2002; Parry et al., 2007; Ballanti et al., 2017; Galatowitsch, 2018). But the world experienced loss of about 50% (Clarkson et al., 2014) to 64% (CBD, 2015) of the total wetlands due to largely anthropogenic factors-induced LULC dynamics, underlain by rapid population growth (CBD, 2015). Expansion of farming, urban built-up area and infrastructures, air and water pollution, runoff-induced increasing fertilizers, eutrophication, invasive exotic plant species, diversion of wetland tributaries, construction of dams and irrigation canals, and intensive exploitation of resources are among the major manmade driving forces of LULC changes and degradation/loss of wetlands worldwide (Zedler and Kercher, 2005; UNEP, 2012; CBD, 2015; Giweta and Worku, 2018; Galatowitsch, 2018).

Studies reveal that most of the riverine and lacustrine wetlands of Ethiopia have been critically threatened due to the impact of LULC changes (Feoli and Zerihun, 2000; Giweta and Worku, 2018). Numerous studies were made about various issues of wetlands in different parts of Ethiopia. Investigations about the threats and opportunities (Zinabu, 2002; Teklu and Kassahun, 2017) and hydrogeochemical and water level changes (Alemayehu et al., 2006) of Rift-Valley lake-wetlands, sustainable management (Wood and Dixon, 2002) and wetland ecosystem dynamics (Legesse, 2007) in Illubabor Zone, status of natural lakes of Ethiopia (Tenalem, 2009), water level and siltation problem of Abaya lake (Schütt et al., 2002), ecology and wetland vegetation composition (Unbushe, 2013) and limnological changes (Teffera et al., 2017) of lake Abaya-Chamo wetland, ecosystem services of Tana lake-wetland in Northwestern Ethiopia (Wondie, 2018), and reversing wetland degradation in Ethiopia (Giweta and Worku, 2018) were among the main wetland-related studies in Ethiopia.

Most of these studies were conducted not via GIS and remote sensing-based geospatial analyses of the dynamics of the wetlands in the respective areas of Ethiopia overtime largely due to the views and thematic-area interests of the studies. It is ambiguous to understand the accurate spatiotemporal magnitudes of LULC (e.g. forest, water, swamp) changes (gains/losses) of wetlands from results of studies made without the application of GIS and remote sensing (satellite images) techniques (Lillesand et al., 2004; Ballanti et al., 2017).

Several studies have been conducted about the causes of LULC dynamics and degradation of wetlands in Ethiopia (Wood and Dixon, 2002; Tenalem, 2009; Simane et al., 2013; Teklu and Kassahun, 2017; Wondie, 2018; Giweta and Worku, 2018). Persistently high population growth led conversion of wetlands to croplands (Simane et al., 2013) and urban (built-up) areas, open access to and overuse of common (natural) resources (use of wetland trees for timber and fuel, intensive and inefficient water use for irrigation and overgrazing) (Tenalem, 2009; Teklu and Kassahun, 2017), lack of regulations about use and abuse of resources, absence of service costs (i.e. the *free riders/tragedy of the commons' scenario*), draining wetlands, dam construction, intensification of farming, infrastructure expansion and diversion of water flowing to wetlands (Zinabu, 2002; Wood and Dixon, 2002; Wondie, 2018), poor catchment management, sedimentation, eutrophication and pollution by chemical farm-inputs (Giweta and Worku, 2018) were among the major drivers of LULC dynamics and wetland degradation in different parts of Ethiopia. But all the causes (shown above) cannot be equally significant in inducing LULC changes and threatening wetlands everywhere as the drivers and their impacts vary in space and time depending on variations in circumstances across the different specific areas of the country (Giweta and Worku, 2018).

GIS and satellite image-based studies about the dynamics and threats of wetlands in Ethiopia were limited. Dynamics of Dawa Chefa Wetland in North central part (Hussien, 2014), characterizing wetlands and their dynamics in Central Highlands (Dubeau, 2016), and the impact of LULC change on the landscape of Abaya-Chamo basin (Wolde-Yohannes et al., 2018) were among the few GIS and remote sensing-based studies made in Ethiopia in the recent past. Studies made through integrated application of different data acquisitions (GIS and satellite images, ground survey and interview) and analyses (NDVI, NDWI) techniques for addressing the dynamics and threats of wetlands were rare in and around lake Abaya-Chamo wetland (Southern Rift-Valley of Ethiopia) where this study is conducted. Remote sensing-based mapping and analyses of the dynamics of biophysical status of wetland (upon multispectral Landsat images) is useful to develop bases for detecting and monitoring changes (degradation) of the wetland, and to respond for its restoration (Baker et al., 2007; Klemas, 2011; Ballanti et al., 2017). This is so because, GIS and remote sensing techniques, by providing synoptic coverage and repeatability of spatial information, enable to get accurate results about wetland dynamics and are more cost-effective for monitoring the changes overtime (Ballanti et al., 2017). This study was aimed to: (1) quantify the magnitude and rate of LULC dynamics of Lake Abaya-Chamo wetland within

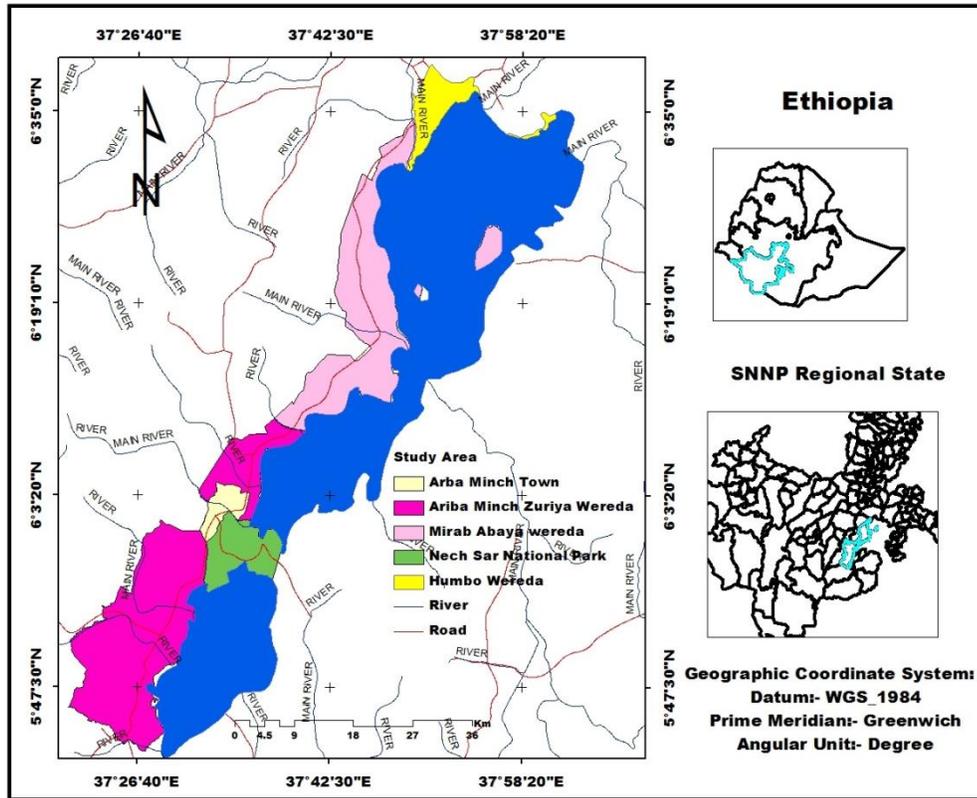
1990 – 2019; (2) explain the trends of LULC changes in three decades; (3) analyze the driving forces and impacts of the LULC dynamics on the degradation/sustenance of the lake-wetland.

## **Research Methods**

### **Study Area**

Abaya-Chamo lake-wetland is located in 5°43'19"N - 6°38'51"N latitude and 37°21'55"E - 38°15'05"E longitude (Figure 2.1). In Figure 2.1, the large Northeastern water body is Abaya Lake and the smaller Southwestern one is Chamo lake. The area of Abaya-Chamo lake-wetland is 242,615 ha (Figure 2.1). Abaya and Chamo lakes, being Rift-Valley lakes in Southern Ethiopia, lie on a graven (depression) created by faulting due to divergent movement along the boundary of the Africa plate (westward) and the Somali plate (eastward). The Western part of the lake-wetland is largely plain, where some dome-shape and conical volcanic hills, and elevated spurs are observed.

Climatically, Abaya-Chamo wetland, based on data of 1987 – 2018 Mean annual temperature, was about 24 °C; and, the mean monthly temperature of the area is the highest in march (26 °C) and the lowest in July (23°C), November (23.1 °C) and December (23.1 °C) (NMA, 2019). The wetland receives a somewhat low rainfall amount where the mean total annual (1982 - 2018) was 870.9 mm. The study area has two rainfall seasons: that is, spring (March, April and May) with total rainfall of 362.9 mm is the main rainy season. In spring, rainfall, averaged for 37 years (1982 - 2018), is the highest in April (153.7 mm). Autumn (September, October and November) with total rainfall amount of 265.6 mm is the second rainy season where it peaks in October (115 mm) (NMA, 2019).



**Figure 2.1** Lake Abaya-Chamo Wetland and Its Surrounding Areas (**Source:** Own Design via ArcGIS, 2021)

Abaya-Chamo lake-wetland provides multiple ecological and economic benefits to people in the surrounding area. The wetland vegetation, being a vital nesting site and feeding source for hundreds of birds and hippopotamus, supports wildlife and serves as a spawning-area for crocodiles (Unbushe, 2013). Rich bird fauna, sport fishing for Tilapia, Nile Perch and Tiger Fish, the ‘Azo-gebeya’/‘Crocodile Market’ (where crocs are not exchanged rather crowds of crocs are visited), the ‘Forty-Springs’ (from which name of ‘Arba-Minch’ Town was coined) provide special attraction to tourists. Crocodile Ranching/Farming is important income source via tourism and the export of skin of crocs (Legesse, 2007). The lakes also harbor large population of common hippopotamus (*Hippopotamus amphibius*) and several rare bird species including migratory ones.

Lake Abaya-Chamo wetland revealed rapid change in land uses/land covers due to fast population growth-induced expansion of cultivated land and settlement at the cost forest and shrub land (Bekele, 2001). Crop farming and livestock rearing are important activities in the area surrounding the lakes. Extensive area to the West of Lake Abaya was cleared in the 1960s and 1970s for expansion of large-scale farms for producing cotton, banana and other crops (Gelaw, 2019). State farms like Bilate, Arba-Minch and Sile (recently given for private investors) are examples of intensive farming in the plain area adjacent to the lakes.

Agroforestry is the main activity in the alluvial plain of the western shores of the lakes, where it is practiced using rain-fed and irrigation. Fruits (e.g. banana, mango, avocado, papaya, tomato,), cereals (e.g. maize), vegetables (e.g. cabbage, pepper), tuber and root crops (casava, onion, carrot) and cotton are cultivated on the fertile soils adjacent to the wetland (Gelaw, 2007; Gelaw, 2019). Wetlands, forest, woodland and bush-lands have changed to settlement and cropland (Kebede, 2012). These wetlands present a rich biodiversity in western shores of the lake Abaya-Chamo wetland even if it has been extremely impacted by anthropogenic pressure.

## **Research Methods**

### **Research Design**

This study, being viewed via the pragmatic lens, was conducted based on the mixed-methods approach. That is, data acquisition and analyses were carried out using a mixture of methods from both the quantitative and qualitative approaches (Creswell, 2009). Kappa coefficient, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were used for statistical based inferences about the LULC dynamics and the degradation of Lake Abaya-Chamo wetland. Methods of the qualitative approaches such as interview and observation were used to check, confirm and strengthen the findings of the quantitative approach. The concurrent embedded model was used to mix the quantitative and qualitative approaches (Creswell, 2009). Cross-sectional survey design was used to acquire and analyze data using both the methods of quantitative and qualitative approaches simultaneously (in parallel).

### **Acquisition and Processing of Satellite Images**

Landsat TM of 1990, ETM+ of 2000, and OLI of 2010 and 2019 of Lake Abaya-Chamo wetland, having spatial resolution of 30 m were downloaded from the website (<https://earthexplorer.usgs.gov/>) of the US Geological Survey (USGS) (Table 1). Landsat images captured during January and February were preferred since these dates enable to acquire satellite images free of the impact of cloud cover and to avoid the effect of seasonal variation on the classification of LULC classes. Digital Elevation Model (DEM) with 30 m resolution (upon Aster imagery) was also used to acquire spatial data. Ancillary data were also utilized during analysis. All data (images) were projected to the Universal Transverse Mercator (UTM) projection system, zone 37N and datum of World Geodetic System-84 (WGS84) to ensure consistency between datasets during analyses.

**Table 1. Sensor Type, Resolution, Acquisition Date and Source of Satellite Images used for the Study**

Sensor Type	Resolution	Path/Row	Acquisition Date	Source
Landsat-5 TM	30 m	169/56, 169/55	Jan 12, 1990	<a href="http://earthexplore.usgs.gov">http://earthexplore.usgs.gov</a>
Landsat-7 ETM+	30 m	169/56, 169/55	Jan 27, 2000	<a href="http://earthexplore.usgs.gov">http://earthexplore.usgs.gov</a>
Landsat-8 OLI	30 m	169/56, 169/55	Mar 05, 2010	<a href="http://earthexplore.usgs.gov">http://earthexplore.usgs.gov</a>
Landsat-8 OLI	30 m	169/56, 169/55	Mar 10, 2019	<a href="http://earthexplore.usgs.gov">http://earthexplore.usgs.gov</a>

**Source:** Own Summary, 2020

The imageries were checked against any defects such as striping. All image scenes were subjected to image processing using ENVI software (version 5.3), and each was clipped using the base-map of lake Abaya-Chamo wetland. Geometric and radiometric corrections were made for the images of the four periods (Table 1). The two scenes (i.e. the one that fall within path 169 and row 56, and the other that fall in path 169 and row 55) of each data set were mosaicked using linear contrast stretching and histogram equalization technique to create a single image covering the whole study area for each period.

### **Image Classification and Accuracy Assessment**

Unsupervised and supervised classification techniques were used to identify about six LULC classes of Lake Abaya-Chamo wetland. Unsupervised procedure was used to classify the LULC classes of the lake-wetland in 1990, 2000, 2010 and 2019. Unsupervised classification technique is the Iterative Self-Organizing Data Analysis Technique Algorithm (ISODATA) that depends upon the natural groupings of the spectral properties of the pixels, which are usually selected by the remote sensing software without any influence from the user (Lellisand et al., 2004; Govender et al., 2007). About six LULC classes were produced (via unsupervised classification) by merging unknown distribution of pixel values in the image data using ERDAS IMAGINE 2014 before the field work. The six LULC classes are agricultural land, forest, settlement, shrubland, water-body and swamp.

Landsat TM of 1990, ETM+ of 2000, and OLI of 2010 and 2019 were also classified using supervised classification (*maximum likelihood technique*) separately to identify LULC classes of the study area. This method assumes the normal distribution of DN values, allowing the function to determine the probability of a pixel belonging to a specific feature class and assign each pixel to the highest probability class (Lillesand et al., 2004). The classifications were repeated numerous times by adding more training sites so as to come up with satisfactory results. Supervised classification was chosen to compare the outputs with results of the unsupervised classification; this was particularly vital for this study because it identifies and locates LULC types, which are known priori through a combination of interpretation of aerial photography, survey analysis and fieldwork.

In the accuracy assessment, confusion matrices and Kappa coefficient of agreement were calculated for each classification map. Estimation of Kappa coefficients yields statistics, which are measures of agreement or accuracy between the remote sensing–derived classification map and reference data (as shown by the major diagonal) and the chance agreement, which is indicated by the row and column totals (referred to as marginal) (Jensen, 2009). The classification results were compared with the ground truth (data) to confirm accuracy of the classification process. It is a way of assuring how many ground truth pixels were classified correctly, and how much errors were propagated during data acquisition, analysis and conversion (Edwards et al., 1998). In this study, the accuracy assessment was done for the recent satellite image (2019) for which the ground truth data were likely to correspond. An error matrix is square array of numbers set out in rows and columns which express the number of sample units (i.e. pixels, cluster of pixels or polygons) assigned to a particular category relative to the actual category as verified on grounds. The  $\check{K}$  ("KHAT") statistic is a measure of the difference between the actual agreement between reference data and an automated classifier and the chance agreement between the reference data and a random classifier (Jensen, 1996). Conceptually,  $\check{K}$  can be defined as:

$$\check{K} = \frac{\text{observed accuracy} - \text{chance agreement}}{1 - \text{Chance agreement}} \dots\dots\dots (\text{Eq.1})$$

In reality, the value of  $\check{K}$  usually ranges between 0 and 1. Kappa coefficient of is calculated as follows:

$$\hat{K} = \frac{N \sum_1^k x_{ii} - \sum_1^k (x_{i+} \times x_{+i})}{N^2 - \sum_1^k (x_{i+} \times x_{+i})} \dots\dots\dots (\text{Eq.2})$$

Where:  $N$  is the total number of observations in the entire error matrix,  $k$  is the total number of classes or categories,  $x_{ii}$  refers to the number of observations correctly classified for a particular category, and  $x_{i+}$  and  $x_{+i}$  refer to the marginal totals for row  $i$  and column  $i$  associated with the category.

**Collection of Field Data and Verification**

Reference data were collected for training and validation of each LULC type of Abaya-Chamo lake-wetland for each satellite image in each period. Geographic locations of ground truth LULC classes, used to calibrate the classification procedure, were identified using high spatial resolution imagery made freely available through Google Earth Pro. About 120 reference samples were derived from the LULC of the lake-wetland in 2019 and via the support of Spot map of 2019. Reference data for 2019 were collected directly from the field between September 2018 to February 2019 using handheld GPS. About 80, 86, 100 and 100 GCP samples were collected for 1990, 2000, 2010 and 2019, respectively, which were used for accuracy assessment.

Verification of the mapped lake-wetland was done through field visits, comparison with features on Google Earth and the DEM, and the use of prior knowledge of features present in the study area. The ground-truth

points were randomly chosen. Ground-truthiness of the mapped features was necessary for the verification and accuracy assessment of the features.

**Techniques of Data Analysis**

LULC changes of Lake Abaya-Chamo wetland were analyzed using GIS and remote sensing techniques. Determination of appropriate classes was done based on level ‘I’ of the LULC classification and six classes were identified (Table 2). Computer aided interpretation of images was conducted using environmental resources data analysis system (ERDAS) Imagine 2014, ArcGIS 10.5, GPS (Garmin 5.1)-based data and environment for visualizing images (ENVI) 5.0 software, which were used for satellite image processing, classification of LULC, accuracy assessment and analysis of the wetland dynamics. Microsoft excel was also used for analysis.

Arc Map GIS 10.5 raster calculator was used to perform the change detection analysis. Change detection analysis was applied on results of the unsupervised and supervised classification about the six LULC classes of Abaya-Chamo lake-wetland for periods 1990 -2000, 2000 -2010, 2010 - 2019 and 1990 - 2019. The magnitude of area change of each LULC class in each period was calculated as follow:

$$M = (A_2 - A_1)/A_1 * 100 \dots\dots\dots (Eq.3)$$

Where: *M* is magnitude of area change of a LULC class in a period, *A<sub>1</sub>* is area (ha) of the LULC class in the initial or earlier year, and *A<sub>2</sub>* is area (ha) of the same LULC class in the recent year. The annual rate of change of each LULC class for each period was computed as:

$$R = (A_2 - A_1)/t * 100 \dots\dots\dots (Eq.4)$$

Where: *R* is annual ‘Rate’ of area change (in ha and %), *A<sub>1</sub>* is area (ha) of a LULC class in the initial year, *A<sub>2</sub>* is area (ha) of the LULC class in the recent year, and ‘*t*’ is the time-interval between the initial and recent years.

Change matrix model (the raster calculator) was used to compute the area change from one LULC class to another type between the periods accounted in the study. The magnitude of change for each period was statistically tested using the Wilcoxon Signed-ranks test. The Wilcoxon Signed-ranks test is a non-parametric statistical test used to assess the difference between two conditions where the samples, in this case change of LULC class, are correlated. The data sets can be compared repeatedly over consistent periods (between initial and recent years).

**Normalized Difference Water Index (NDWI):** was used to extract water (wet) area of the study site. Combination of band 2 (green) and band 4 (near-infrared) was used for Landsat 5 TM and Landsat 7 ETM+

images. Band 3 (green) and band 5 (near-infrared) were combined for Landsat 8 OLI imageries. Thus, the NDWI, useful to identify open-water features (wet-area), was computed as (McFeeters, 1996):

$$NDWI = \frac{Green\ band - NIR\ band}{Green\ band + NIR\ band} \dots\dots\dots (Eq.5)$$

The NDWI ranges between -1 and +1, where increasing positive values indicate increasing water presence and negative values indicate dry surface (decreasing wet/water). The NDWI indices, which indicate moisture content, are used as wet-land/swamp area proxies. Where a wetland is covered by hydric-soils or is dry the NDWI values are expected to be low (lower than -0.3) due to the absence of moisture. Fluctuations in the NDWI values of a wetland indicate variable frequency of occurrence of its water. NDWI values above 0 represent water presence.

**Normalized Difference Vegetation Index (NDVI):** NDVI was used to assess the presence of live green vegetation in Abaya-Chamo lake-wetland. The NDVI was computed as follow:

$$NDVI = \frac{NIR - RED}{NIR + RED} \dots\dots\dots (Eq.6)$$

NDVI values range from -1 to 1. The higher the NDVI, the higher the fraction of live green vegetation present in the scene. Landsat band 4 (0.76 - 0.90 mm) measures the reflectance in NIR region and band 3 (0.63 - 0.69 mm) measures the reflectance in Red region. NDVI for the Landsat 8 image was computed using bands 4 and 5 for Red and NIR, respectively.

**Table 2. Contextual Description of the LULC Categories/Classes of Abaya-Chamo Lake-Wetland**

<b>Category</b>	<b>Description/Definition</b>
Agriculture	Farmland used for growing cereals, tuber and root crops, agroforestry practice and horticulture including currently uncultivated (arable) land and fallowed plots.
Shrubland	Area covered with more of short, hard woody stem trees (bushes), limited herbaceous plants (shrubs) and isolated trees which often are mixed with undergrowth of grasses.
Forest	Area of dense, tall trees having interlocked canopies, including woodland and riverine forests
Swamp/wetland	Is spongy, soft, wet/marshy land saturated with water, adjacent to Abaya and Chamo lakes, and on the banks of tributary-rivers (of the lakes) having permanent and seasonal grasses.
Water body	Area with temporary and permanent water cover which includes lakes, intermittent ponds and other areas with shallow water cover.
Settlement	Consists of homesteads of rural villages and buildings of urban areas (with commercial and residential purposes), camps, warehouses, roads and other infrastructures.

**Source:** Own Summary, 2020

## Results and Discussion

### Assessment of Accuracy of LULC Classification and Change Detection:

Accuracy assessment was run in order to measure (statistically) the level of accuracy and degree of acceptance of analysis results of the GIS and remote sensing-based LULC classification and change detection of Abaya-Chamo lake-wetland, Southern Ethiopia (Table 4). Accuracy levels of all the six LULC classes upon values of both the Producer's Accuracy (PA) and User's Accuracy (UA) were approximately 80 % and above except the PA of 'forest' for the period 1990 (79.03 %), 2010 (79.02 % and 2019 (78.79 %) (Table 4). The low accuracy level of forest in the three periods under study could be perhaps due to proximity in the spectral/reflectance value of 'forest' to that of 'agroforestry' (agriculture) of mango trees, which creates ambiguity during image classification. Anyway, results of the PA and UA indicate that all the classified LULC classes of 1990, 2000, 2010 and 2019 satisfy the recommended accuracy level (above 80 %); that is, there are strong agreements between the classified LULC classes and the GCP data.

**Table4. Producer's Accuracy (PA) and User's Accuracy (UA) of LULC Maps of 1990, 2000, 2010 and 2019**

LULC Class	1990		2000		2010		2019	
	PA (%)	UA (%)						
Forest	79.03	82.22	88.64	92.12	79.02	84.00	78.79	92.86
Water	90.00	82.93	91.60	88.00	86.40	86.00	96.80	93.75
Settlement	91.06	80.00	92.80	86.01	86.02	84.05	92.50	88.72
Shrub-land	79.60	81.90	81.02	87.07	82.01	88.04	83.33	83.33
Agriculture	84.05	91.07	89.07	79.80	86.60	85.01	86.05	88.10
Swamp	86.03	87.50	87.40	88.05	89.03	86.00	92.10	100.00
Kappa statistics	88.90		90.21		91.20		97.92	
Kappa coefficient	0.887		0.890		0.884		0.968	

**Source:** Own Summary upon Result of the GIS Analysis, 2020

The Kappa statistics for periods 1990, 2000, 2010 and 2019 were 88.9 %, 90.2 %, 91.2 % and 97.9 %, respectively, and Kappa coefficients of the respective periods were 0.887, 0.890, 0.884 and 0.968 (Table 4). Kappa coefficient is a measure of agreement/accuracy between the reference data and the values of LULC classes in the classified image; its coefficients range from +1 to -1. Kappa coefficient of 0.0 – 0.20, 0.21 – 0.40, 0.41 – 0.60, 0.61 – 0.80 and 0.81 – 1.0, respectively, indicate slight, fair, moderate, substantial and strong/perfect agreement; and a coefficient of < 0 reflect no agreement (Manonmani & Suganya, 2010). The

high Kappa coefficients reveal that the GIS-based classifications of the 1990, 2000, 2010 and 2019 LULC classes were accurate as they showed strong agreement with the GCP data. This level of agreement/accuracy is acceptable for classification, detection and prediction of LULC changes.

### Magnitude, Rate and Trend of LULC Dynamics in Abaya-Chamo Lake-Wetland

Abaya-Chamo lake-wetland experienced dynamics among the different LULC classes within 1990 – 2019. Forest, water-body, settlement, shrub-land, agricultural land and wetland are the main LULC classes of the lake-wetland based on the GIS-based image classification. As is illustrated in Table 3, settlement area in the Western coast of Abaya-Chamo lake-wetland revealed a continuously increasing trend in the three periods accounted in by the study, that is, where it has expanded by 47.1 % (5,147 ha), 27.2 % (4,373 ha) and 55.3 % (11,298 ha) in the periods 1990 – 2000, 2000 – 2010 and 2010 – 2019, respectively. Similarly, ‘water body’ with magnitude of expansion of 0.4 % (599 ha), 0.7 % (967 ha) and 1.1 % (1,443 ha) in the periods 1990 – 2000, 2000 – 2010 and 2010 – 2019, respectively, exhibited a consistently increasing trend in the three decades studied. However, the increasing trend of ‘water body’ was different from that of ‘settlement’ in that ‘water body’ of the lake-wetland had been increasing with consistently increasing magnitude of change as one moves from the earliest period (1990-2000) through the next (2000 -2010) to the latest period (2010- 2019) accounted in by the study (Table 3).

**Table3. Area and percentage Change (ha) between LULC Classes of Lake Abaya-Chamo Wetland between 1990- 2019**

LULC Class	1990 (ha)	2000 (ha)	2010 (ha)	2019 (ha)	1990 – 2000		2000 – 2010		2010 – 2019		1990 – 2019	
					A (ha)	%						
Forest	9719	6301	12511	10585	-3418	-35.2	6210	98.6	-1926	-15.4	866	8.9
Water	134708	135307	136274	137717	599	0.4	967	0.7	1443	1.1	3009	2.2
Settle.	10921	16068	20441	31739	5147	47.1	4373	27.2	11298	55.3	20818	190.6
Shrubland	50636	49424	38983	25869	-1212	-2.4	-10441	-21.1	-13114	-33.6	-24767	-48.9
Agri	30515	30099	29857	33580	-416	-1.4	-242	-0.8	3723	12.5	3065	10.0
wetland	6116	5416	4549	3125	-700	-11.4	-867	-16.0	-1424	-31.3	-2991	-48.9
<b>Total</b>	<b>242615</b>	<b>242615</b>	<b>242615</b>	<b>242615</b>	<b>0</b>	<b>0.0</b>	<b>0</b>	<b>0.0</b>	<b>0</b>	<b>0.0</b>	<b>0</b>	<b>0.0</b>

**Source:** Own Analysis via ArcGIS, 2021 (**Note:** Settle = Settlement. Agri = Agriculture land)

Contrary to the reality about ‘settlement’ and ‘water’ body, ‘shrubland’ and ‘swamp’ area revealed consistently declining trends in the three periods within 1990 – 2019. For instance, ‘shrubland’ cover with magnitude of change of 2.4 % (1,212 ha), 21.1 % (10,441 ha) and 33.6 % (13,114 ha) in the period 1990 – 2000, 2000 – 2010 and 2010 – 2019, respectively, exhibited continuous decline in three decades. In the same way, ‘swamp’ area

has continuously declined throughout 1990 – 2000, 2000 – 2010 and 2010 – 2019 where its magnitude of shrinkage in the respective periods was 11.4 % (700 ha), 16 % (867 ha) and 31.3 % (1,424 ha) (see Table 3).

On the other hand, as one moves from the period 1990 – 2000 to 2000 – 2010 and then to 2010 – 2019, forest cover and agricultural land of Abaya-Chamo lake-wetland revealed no clear trends in their patterns of change across the three decades. In fact, both ‘forest’ cover and ‘agricultural’ land experienced similar (declining) trend in the initial period (1990 – 2000) studied, where the magnitude of change (decline) of the respective LULC classes was 35.2 % (3,418 ha) and 1.4 % (416 ha). However, forest area of the lake-wetland revealed an increase by 98.6 % (6,210 ha) while ‘agricultural’ land continued to decline by 0.8 % (242 ha) in the next/second period (2000 – 2010) under study (Table 3). In the last period (2010 – 2019) accounted in by the study, the trend of forest cover of Lake Abaya-Chamo wetland was reversed to decline by 15.4 % (1,926 ha); whereas, the agricultural land of the study site increased by 12.2 % (3,723 ha) (see Table 3).

In the last two columns of Table 3, the overall magnitudes of change of the six LULC classes of Lake Abaya-Chamo wetland have been computed and displayed. Settlement, agriculture, water body and forest cover of lake Abaya-Chamo wetland with magnitudes of changes of 190 % (20,818 ha), 10 % (3,065 ha), 2.2 % (3,009 ha) and 8.9 % (866 ha), respectively, revealed net increases in three decades (1990 – 2019). Settlement and agricultural areas of the study site have been expanding at 6.4 % (693.9 ha) and 0.3 % (102.2 ha) per annum, respectively, in the last three decades (1990 – 2019). Similarly, the annual rates of increase of forest cover and water surface of lake Abaya-Chamo wetland in the 30-years’ period were 0.3 % (28.9 ha) and 0.07 % (100.3 ha), respectively. On the contrary, shrubland cover of the study area experienced significant net decline by 48.9 % (24,767 ha) in the same period; this implies that shrubland cover of the lake-wetland has been declining at a rate of 1.6 % (825.6 ha) per/year in the three decades studied. The area extent of wetland/‘swamp’ cover also showed a net decline by 48.9 % (2,991 ha) in 1990 – 2019, where the wetland/swamp area of the study site has been shrinking at 1.6 % (99.7 ha) each year in the three decades’ period (Table 3).

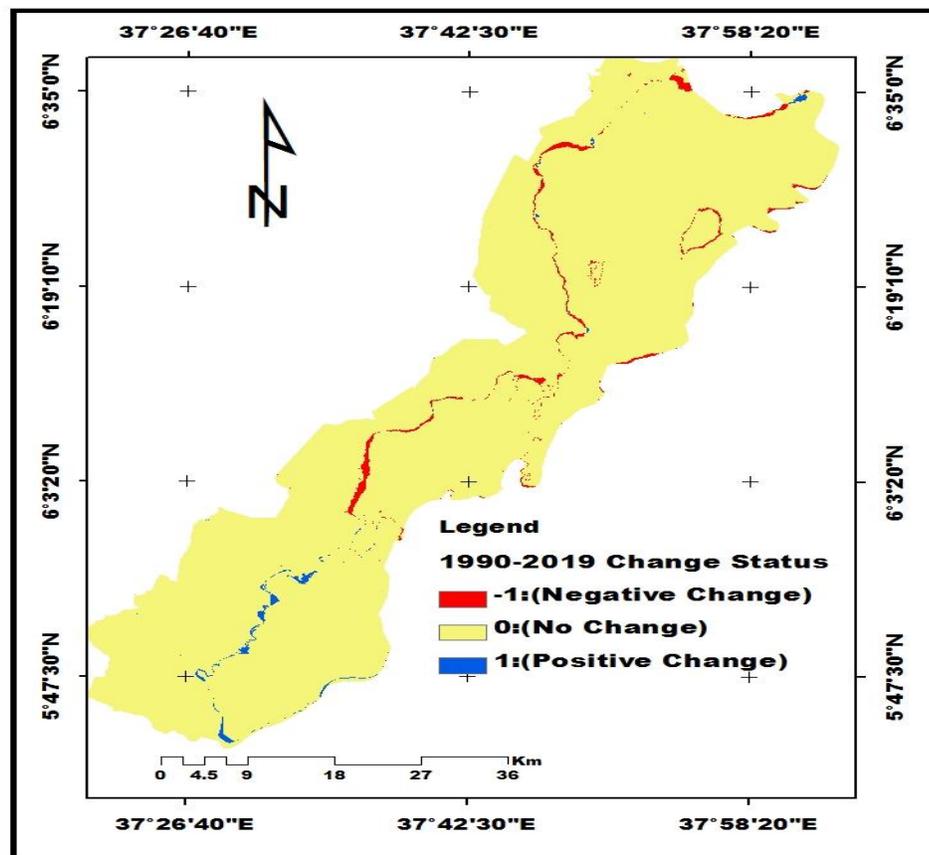
Indices such as NDVI and NDWI were also computed for 1990, 2000, 2010 and 2019 so as to detect the ‘water’ and ‘non-water’ area dynamics of lake Abaya-Chamo wetland (Table 5 and Figure 4).

**Table 5. NDVI and NDWI Thresholds of Area Classes of the Lake-Wetland for 1990, 2000, 2010 and 2019**

Class	1990		2000		2010		2019	
	NDVI	NDWI	NDVI	NDWI	NDVI	NDWI	NDVI	NDWI
Water	-0.50	-0.75	-0.65	0.88	-0.57	0.92	-0.20	0.16
Non-water	0.70	0.91	0.51	-0.44	0.70	-0.63	0.99	-0.40

**Source:** Own Analysis via ArcGIS, 2021

Results of both the NDVI and NDWI (in each period) were opposite/contradicting between ‘water’ and ‘non-water’ covers of the maps illustrating Abaya-Chamo lake-wetland. The NDVI and NDWI results revealed that there were significant changes in the ‘non-water’ (vegetation) and ‘water’ area of the study site in 1990 – 2019 (Table 5 and Figure 3). The water surface area of Abaya-Chamo lake-wetland showed an increasing trend in the three decades studied. Contrary to this, the ‘non-water’ (including wet/swamp) area exhibited continuous decline in the same period (1990 – 2019). Moreover, while the NDVI change revealed maximum pixels under increasing change category of the study site, the same category of change exhibited minimum pixels in the NDWI results of the change detection. In other words, results (indices) of both the NDVI and NDWI change detection analyses were accurate, and the entire study made using remote sensing technology-based analysis was also effective.



**Figure 3.** Map of the Dynamics of the Lake-Wetland in 1990 – 2019 (Source: Own Analysis via ArcGIS, 2021)

### **Driving Forces and Impacts of the LULC Dynamics in Lake Abaya-Chamo Wetland**

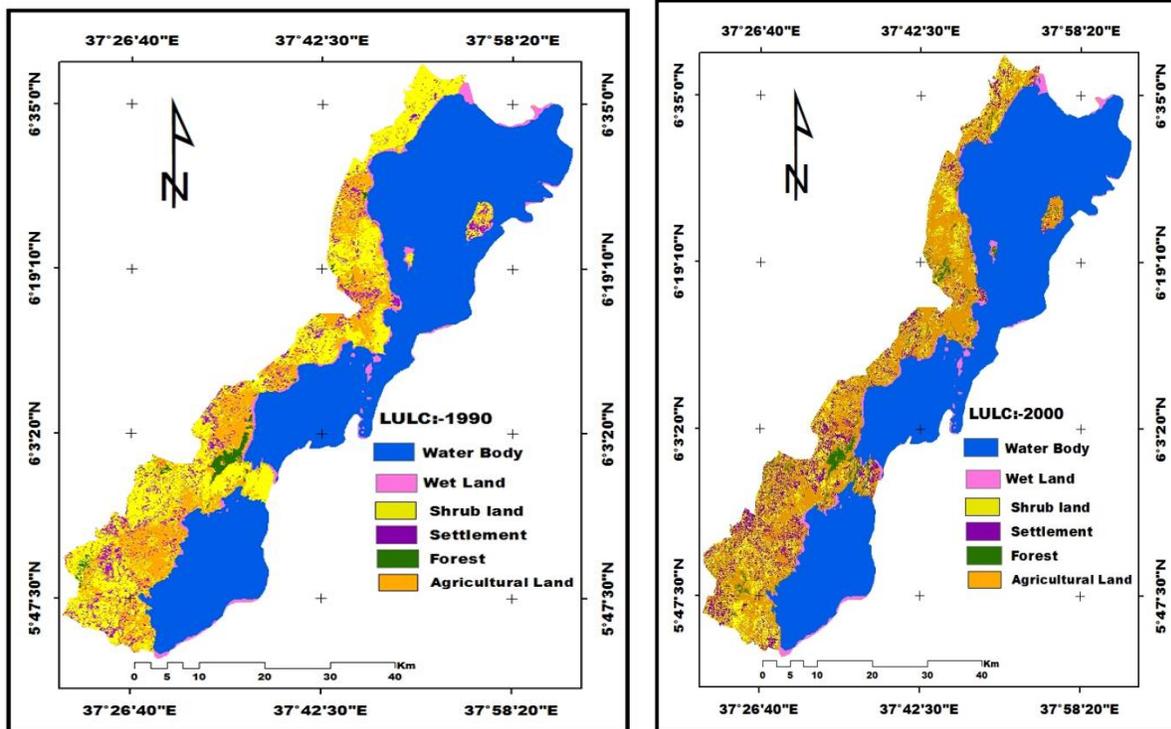
The net increase in forest cover of lake Abaya-Chamo wetland (by 8.9 % or 866 ha) in the period 1990 – 2019, most likely, was a result of the expansion of agroforestry (e.g. banana, mango, avocado and papaya) practice at

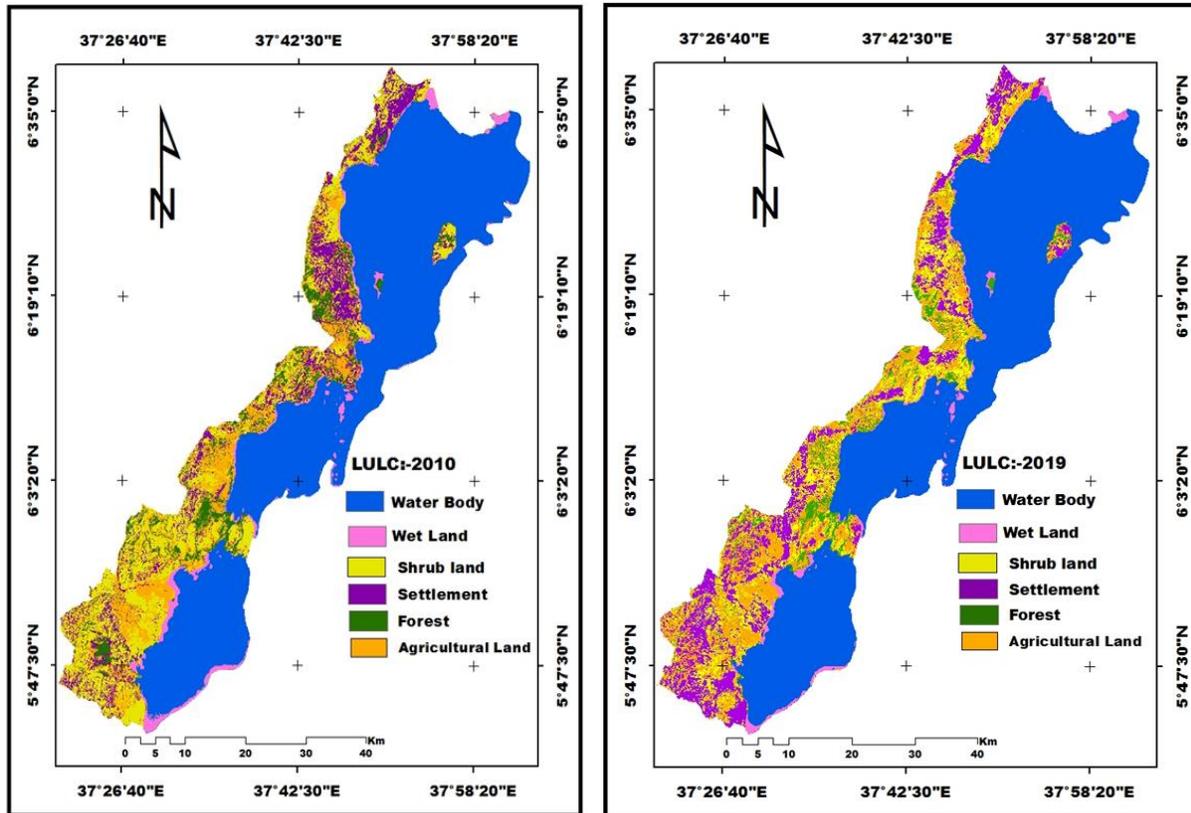
the expense of shrubland in the Western cost of the lake-wetland. In other words, the categorization of, especially, mango-forest during image classification, to a little extent, is thought to have contributed to the increase in forest cover in 1990 – 2019; that is why the accuracy level of forest cover (upon the producer's index) was the lowest for 1990 (79%), 2010 (79%) and 2019 (78.8%) (See Table 4 below). The expansion of agroforestry practice is also assumed to have been among the reasons for the low magnitude of increase (by 10 % or 3,065 ha only) of agricultural land in the three decades studied; this is so because, smallholder farmers in the Western coast of the lake-wetland were indicated to have been replacing the maize-dominated cereal croplands with banana and mango-dominated agroforestry (Gelaw, 2007); that is why (despite the increasing human population in Abaya-Chamo depression/basin) agricultural land of the study site had exhibited decreasing trend by 1.4 % (416 ha) in 1990 – 2000 and by 0.8 % (242 ha) in 2000 – 2010 (Table 3). In fact, the lateral expansion of Abaya and Chamo lakes' water was also the other driving force for the decline of agricultural land; the siltation-led expansion of the lake water, according to a priest (age 58) having farmland in *Lante Kebele* (administrative unit) (Western cost of lake Abaya), has invaded significant share of his farmland and the landholdings of other smallholder farmers who have farm-plots proximate to the lake.

Population growth-induced expansion of settlement (by 190 % or 20,818 ha) in the study area (in 1990 - 2019) has also contributed for the significant decline in shrubland cover (Table 3). An informant (age 47) also added that migrants played significant role in the reduction of shrubland area surrounding Abaya and Chamo lakes. Result of the GIS-based change detection revealed that 'shrubland' of the study site has been declining at progressively increasing magnitudes of changes in 1990 – 2019; that is, where its magnitude of decline was small (2.4 % or 1,212 ha) in 1990 – 2000, medium (21.1 % or 10,441 ha) in 2000 – 2010 and the largest (33.6 % or 13,114 ha) in the latest period (2010 – 2019) studied (Table 3). This happened largely due to increasing conversion of 'shrubland' to cropland (since the turn of the 21<sup>st</sup> C) by local farmers and small-scale investors who began extensive use of the salty-water of Abaya and Chamo lakes for irrigation-based cash crop production (e.g. banana, mango, papaya, tomato, cabbage, onion,) in the Western coast and adjacent areas of the lake-wetland, according an expert (age 54) in Natural Resource Management and own field observation.

The high annual rate of expansion of settlement (by 6.4 % or 693.9 ha) in 1990 – 2019 was a consequence of various factors such as rural to rural migration (in-migration) to the plain Western coasts of the wetland, natural increase-induced expansion of rural villages, and development and expansion of infrastructures (Arba-Minch University, Arba-Minch Airport Terminal, modern irrigation structures, concrete and asphalted roads, and the Arba-Minch Crocodile Ranch) surrounding the lake-wetland. Expansion of urban centers like Birbir (Mirab-Abaya) town and Arba-Minch city was also a vital cause for the high rate of settlement expansion in the study site, which was underlain by natural increase and rural to urban migration-led rapid population growth. Studies also revealed that the degradation of forest, woodland and shrubland covers in the Western coast of the Abaya-

Chamo depression was caused by fast population growth-led expansion of settlement and agriculture, which was rooted by high magnitude of in-migration from Gamo-highlands and Wolaiyta areas since the 1960s (Kebede, 2012; Assefa and Bork, 2016; Gelaw, 2019). Lake Abaya-Chamo wetland ecosystems are under considerable stress due to unsustainable rates of resource exploitation, inadequate and inappropriate management regimes, degradation of lake catchments and high demand for water, fish and agriculture products.





**Figure 4.** LULC of Lake Abaya-Chamo Wetland in 1990, 2000, 2010 and 2019 (Source: Own Design via ArcGIS, 2021)

‘Swamp’ area of the lake-wetland, like shrubland cover, has been decreasing at progressively increasing magnitudes of changes in the four decades’ period (1990 – 2019); that is, where the magnitude of decline of the swamp cover was smaller (11.4 % or 700 ha) in the initial period (1990 -2000), moderate (16 % or 867 ha) in 2000 – 2010 and the largest (31.3 % or 1,424 ha) in the latest period (2010 – 2019) accounted in by the study (Table 3). This is mainly a result of the progressively increasing sediment load into Abaya and Chamo lakes (Schütt et al., 2002). Meaning, land degradation in the Western Escarpment of the Southern Rift-Valley of Ethiopia [due to exploitation of fuel-wood and construction materials, overgrazing, over-browsing, and conversion of forest and woodland to cropland and settlement (Kebede, 2012; Assefa and Bork, 2016; Gelaw, 2019)] has resulted in increasing siltation in the floors of Abaya and Chamo lakes; the increasing siltation, in turn, led to the decline depth of the lakes (Schütt et al., 2002), and the displacement and lateral expansion of the lakes’ water, and the subsequent shrinkage of the ‘swamp’ area of the lake-wetland by 48.9 % (2,991 ha) within 1990 – 2019 (Table 3). That is, the progressively increasing siltation-led expansion of ‘water’ body was the main cause of decline of the ‘swamp’ area of Abaya-Chamo lake-wetland; this is so because, the progressively increasing magnitude of increasing trend of ‘water’ body had been accompanied by progressively increasing magnitude of decline trend of ‘swamp’ area in the three decades’ period as these LULC classes are configured inherently adjacent to each other (Table 3 and Figure 4). Analysis results of the NDVI and NDWI also confirm

the contradicting trends of ‘wet/swamp’ area and ‘water’ cover of the lake-wetland (Table 5 and Figure 3). Anyway, siltation problem of Abaya and Chamo lakes is the main cause of swamp area loss, a consequence of LULC dynamics and a vital degradation indicator of the lake-wetland.

Population increase-led expansion of settlement (infrastructures), agroforestry practice and drought might have been the other driving forces of the decline of ‘swamp’ area, especially, in 1990 – 2000 since the magnitude of decline of ‘swamp’ area had exceeded the magnitude of expansion of ‘water’ body by 101 ha in the same period (Table 3). Overgrazing and intensive livestock grazing induced compaction of the spongy soil/land might also have a slight contribution to the shrinkage of the ‘swamp’ area of Lake Abaya-Chamo wetland.

## **Conclusion**

Lake Abaya-Chamo wetland is getting threatened overtime due to largely anthropogenic factors-induced LULC dynamics in the period 1990 – 2019. Settlement, agriculture, water body and forest cover of the lake-wetland showed net increases in three decades. Whereas, shrubland and ‘swamp’ area experienced significant net decline (by almost half of each) in 30 years. While settlement and water body increased at progressively increasing magnitudes of changes in three decades, shrubland and swamp cover declined at progressively increasing magnitudes of loss in the same periods. Increasing agroforestry practice by smallholder farmers and small-scale investors overtime contributed to the net increase in forest cover, and for the huge magnitude of shrinkage of shrubland (by 48.9 %) in lake Abaya-Chamo wetland. Decline of shrubland and natural forest was also driven by settlement and farm expansion. Generally, the LULC dynamics led to depletion of natural forest and shrubland in the coasts and uplands of the lake-basin, increasing runoff erosion and sediment load into plus pollution of the lake-wetland, invasion of the lakes by a strange plant water hyacinth(‘*emboch*’), siltation-led displacement of the lakes’ water, area shrinkage and loss of biodiversity of the swamp, and to the overall degradation of lake Abaya-Chamo -wetland and its ecological services in the Southern Rift-Valley of Ethiopia.

To curb the impact of LULC dynamics on wetlands, the government should: (i) formulate clear policy, institutional and legal framework on the management of wetlands; (ii) revise the investment policy and enforcement of impact assessment; (iii) enforce ‘*user tax*’ (on users of land, water) and/or ‘*pollution charge*’ (on polluters of land, water) on investors in agriculture and other sectors in risky areas, adjacent to wetlands; (iv) reforest and afforest the uplands surrounding wetlands; and (v) revise the policy on the allocation of land uses.

## **Availability of data and materials**

All data generated or analyzed during this study are included within the article

## **Competing interests**

The authors declare that they have no competing interests.

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### **Contributions**

TZ has made a substantial contribution to the conception and designing of the study, data collection, data analysis, interpretation of the results, and prepared the manuscript. VG, YK and AG have contributed to planning the study, supervising the study, editing, commenting, and suggesting ideas in the manuscript preparation process. Finally, all authors read and approved the final manuscript for publication.

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### **Ethics Declarations**

#### **Ethics approval and consent to participate**

An effort was made to conduct the research in an ethical manner. A research area permission letter was obtained from the concerned institutions and the participants' consent was asked before commencing the interviews, discussions and taking photographs.

### **Additional information**

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# Figures

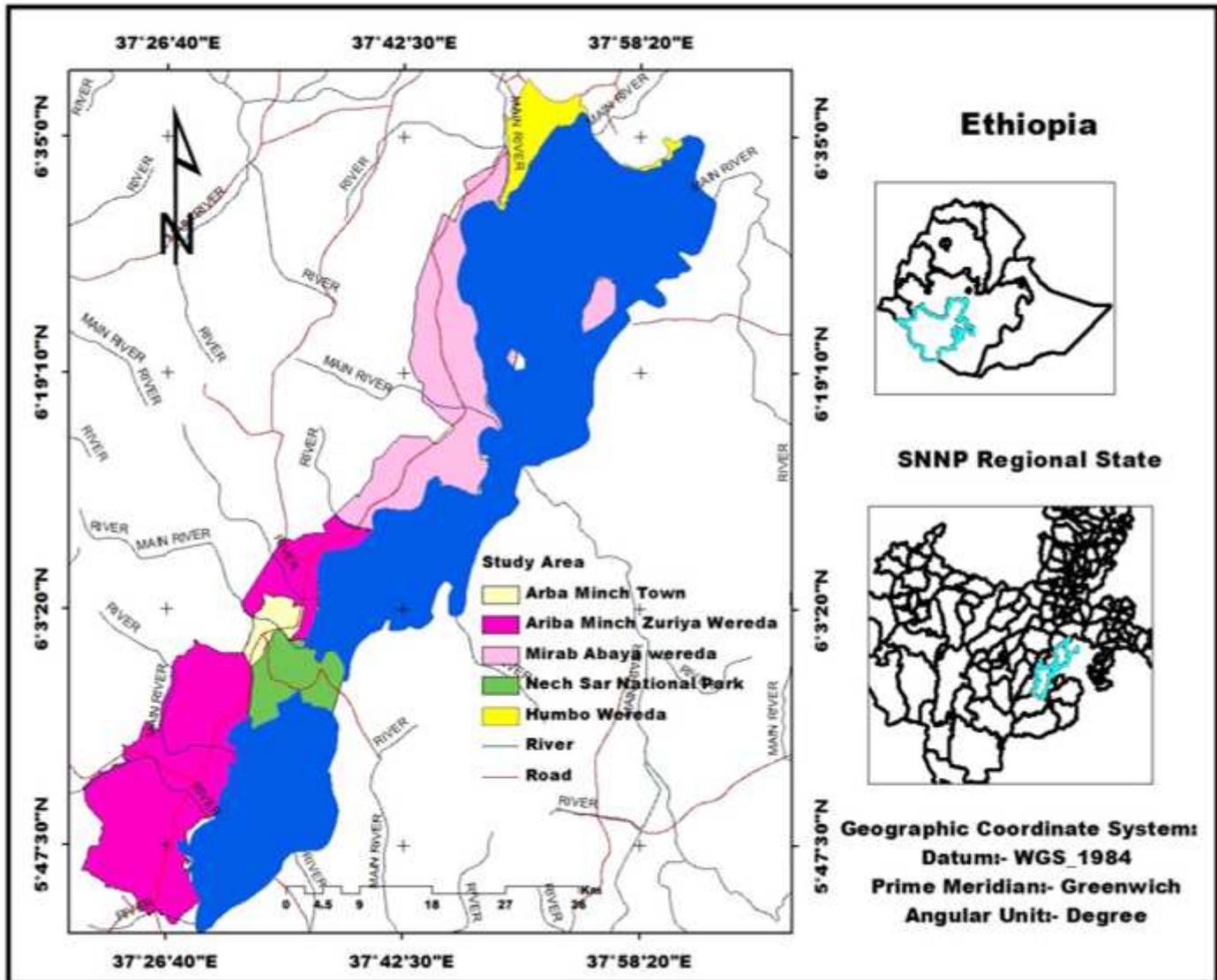


Figure 1

Lake Abaya-Chamo Wetland and Its Surrounding Areas (Source: Own Design via ArcGIS, 2021) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

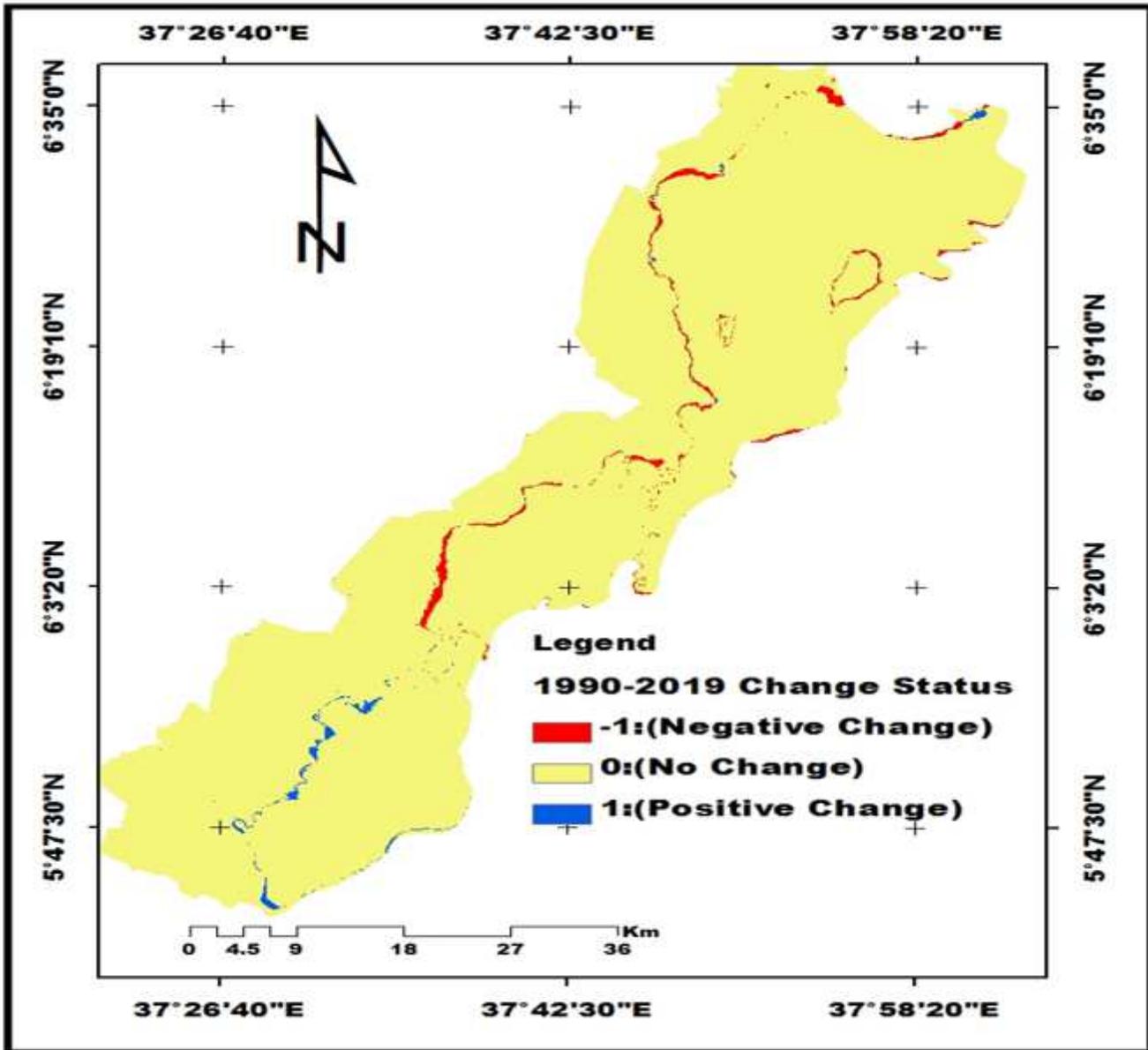
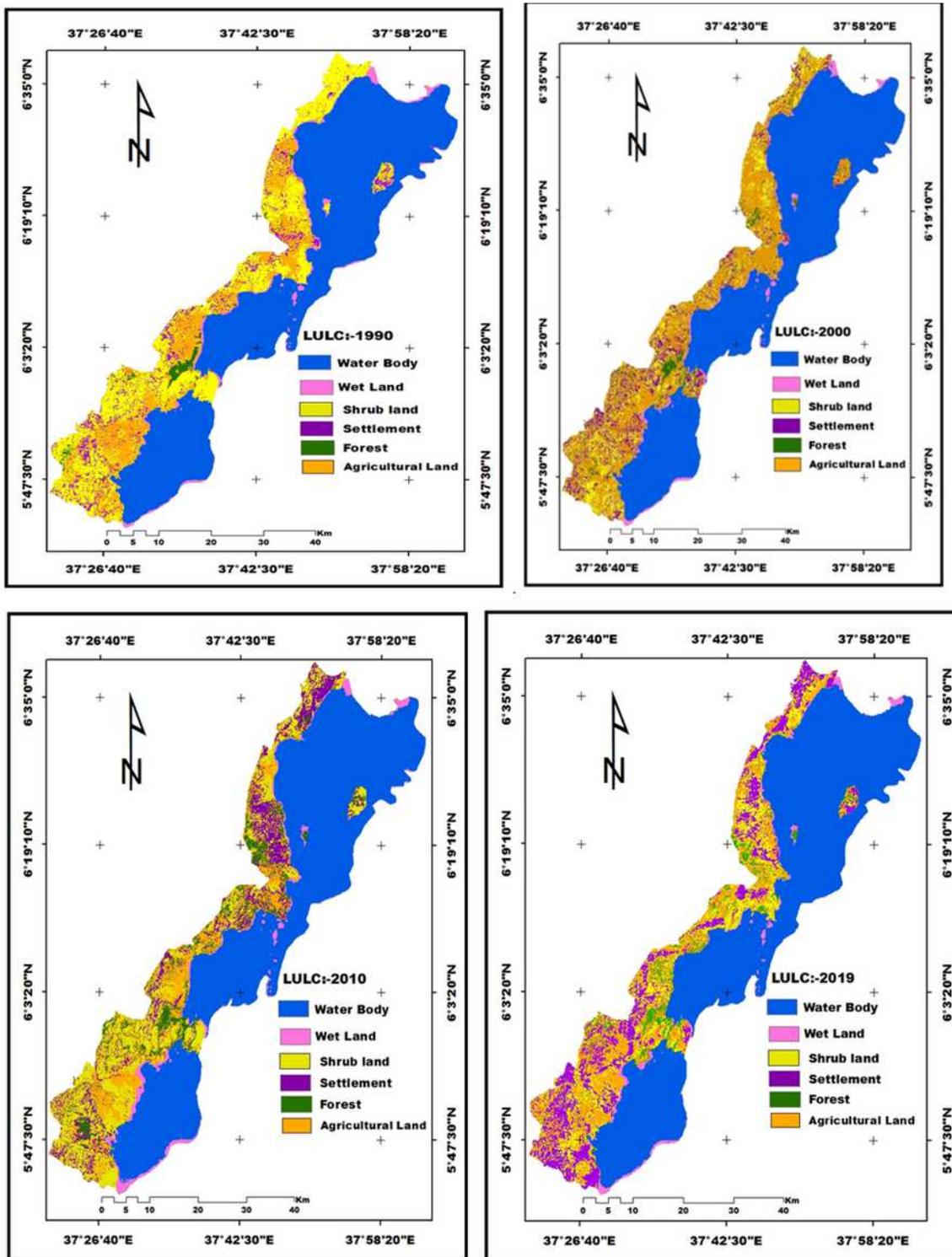


Figure 2

Map of the Dynamics of the Lake-Wetland in 1990 – 2019 (Source: Own Analysis via ArcGIS, 2021) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.



**Figure 3**

LULC of Lake Abaya-Chamo Wetland in 1990, 2000, 2010 and 2019 (Source: Own Design via ArcGIS, 2021) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.