Ethiop. J. Biol. Sci. 19(1): 1–29, 2020
 ISSN: 1819-8678

RESEARCH ARTICLE

IMPACTS OF ECOSYSTEM DEGRADATION ON LAKE ABIJATA, VEGETATION AND HERBACEOUS BIOMASS IN AND SURROUNDING ABIJATA SHALLA NATIONAL PARK

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ABSTRACT: This study aimed to assess changes in spatial cover of Lake Abijata and impacts of land use/land cover changes on the floristic composition and herbaceous biomass in and surrounding Abijata Shalla National Park. Data were collected using systematic sampling method from 64 quadrats of 400 m^2 established along eight line transects. Land use/land cover changes over time (from 1978 to 2018) were determined from satellite images of the study area using ArcGIS 10.5 and ENVI 5.0 software. Data were analyzed using both descriptive and inferential statistics. A total of 60 plant species belonging to 49 genera and 27 families were documented. Most species had mean Diameter at Breast Height (DBH)/Diameter at Stamp Height (DSH) less than 10 cm, few species (four) were in higher diameter classes (27.6–32.5) and only one species (*Acacia tortilis*) was in the 32.6–37.5 and 37.5–42.5 diameter classes. Most species (77%) had low importance value index which imply the need for conservation attention in the area. Spatial cover of Lake Abijata decreased by 58.6% as its cover decreased from 20,676.51 ha in 1978 to 8,558.1 ha in 2018. Similarly, grassland, wetland and forest/shrub land decreased by 87.6%, 48.9% and 40.9%, respectively. Human settlements, crop land and bare land increased by 517.7%, 105.1% and 81.1%, respectively. Protected area had higher mean biomass (289 g/m^2) than the open access sites (71 g/m^2). Coordinated and multidisciplinary interventions are recommended to restore the degraded terrestrial and aquatic ecosystems and conserve the diverse biodiversity in the study area.

Key words/phrases: Ecosystem restoration, Herbaceous biomass, Land use/land cover change, Species richness.

INTRODUCTION

Dryland ecosystems that are characterized by low, erratic and unevenly distributed rainfall cover about 47% of the global land surface (MacKinnon *et al*., 2000) and 45% of Africa (Kigomo, 2003). These dryland ecosystems are known to be rich in biodiversity and provide important ecosystem services (MA, 2005). According to MA (2005), out of the 25 global

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biodiversity hotspots, eight are located in drylands indicating the fact that drylands are important biodiversity hotspots.

Similarly, drylands ecosystems in sub-Saharan Africa including the Central Rift Valley ecosystems are rich in biodiversity and they have been providing diverse ecosystem services, such as tourism, non-timber forest products, regulation of water flows, water quality, climate and protection of land from soil erosion (Chidumayo and Marunda, 2010). Drylands are also characterized by having diverse ecosystems. For example, according to FAO (2019), global drylands contain 25% grasslands, 18% forest, 10% woodland, 14% croplands, 5% water bodies, built-up areas and other unidentified land and 28% barren land.

Studies show that more than two billion people (about 90 percent of them in developing countries) inhabit dry lands and are dependent on dryland natural resources for their survival (MA, 2005; FAO, 2019). About 50% of African population live in the arid, semi-arid, dry sub-humid and hyper-arid areas (Kigomo, 2003).

The Ethiopian dryland ecosystems constitute a large part of the country and it is known as the cradle of mankind because of the history of human evolution and being the origin of human kind (Wayman, 2012). These ecosystems support diverse biological resources that are of global, regional, national and local importance. Many national parks, wildlife sanctuaries, and controlled hunting areas are established to protect and conserve these resources (UN, 1992).

However, there has been increasing threat to the survival of species and integrity of habitats and ecosystems and therefore, there is a high need to document the biological resources and determine their conservation status. Conservation and sustainable use of biological diversity is fundamental for ensuring sustainable development (SCBD, 2003).

Despite the environmental, biodiversity and socioeconomic significances of Abijata Shalla National Park, it has been under serious environmental degradation of both aquatic and terrestrial ecosystems. According to the IPBES (2018), ecosystem degradation can be defined as a long-term reduction in an ecosystem's structure, functionality, or capacity to provide benefits to people. Studies (e.g. Tafesse Kefyalew, 2008; Hamere Yohannes *et al*., 2017; Eyasu Elias *et al*., 2019) showed that the number of birds has been decreasing because of decreasing fish due to decreasing algae in the lake. The establishment of Soda Ash factory at the shore contributed to decreasing volume of lake water. Because of the continued ecosystem degradation caused by unsustainable utilization of natural resources, both spatial cover and depth of Lake Abijata have decreased over years (Tenalem Ayenew, 2004; Wondwosen Seyoum *et al*., 2015). Some of the anthropogenic factors that contributed to degradation of this aquatic ecosystem include extraction of water for soda and upstream diversion for irrigation (Tenalem Ayenew, 2004).

Furthermore, local poverty, illegal settlements and agriculture practices, lack of law enforcement and unregulated agricultural activities have caused overexploitation of water resources and land degradation. Deforestation of the woodland for charcoal production and market-oriented firewood extraction are also among major threatening factors calling for immediate interventions.

Many studies (e.g., Tenalem Ayenew, 2002; 2004; Wondwosen Seyoum *et al*., 2015; Tadesse Fetahi, 2016; Eyasu Elias *et al*., 2019) showed that spatial cover of Lake Abijata has been decreasing over time calling for immediate restoration interventions. However, degradation of the National Park and its surrounding ecosystems has continued over years and therefore, we aimed at generating more quantitative data and update previous ones with focus on species richness, vegetation structure, comparative data on herbaceous biomass in protected (the Park) and open access (surrounding) sites in the study area. This study documented impacts of land use/land cover changes on floristic composition, vegetation structure, regeneration status of woody species and herbaceous biomass.

Besides, we wanted to determine change in spatial cover of Lake Abijata as some publications contradict existing facts in the area. For example, Hamere Yohannes *et al*. (2017) reported that Abijata lake covered an area of 69,900 hectares in 2000 (with increasing trend of 7.19%), which was greater than its area coverage in 1973 (66,500 ha). The result was contradictory to previous reports (e.g. Eyasu Elias *et al*., 2019) and facts on the ground and therefore, we wanted to generate up-to-date data on the current spatial cover of Abijata lake so that decision makers can take the necessary restoration and conservation measures. Furthermore, we noted that the land use/land cover dynamics study by Hamere Yohannes *et al*. (2017) was based on data with different intervals making comparative study difficult. They used Landsat images of the area for the year 1973, 1986, 1994, 2000 and 2016. As can be seen from these years, the intervals are different (13, 8, 6 and 16 years, respectively) and therefore not comparable. In this study, an interval of twenty years was used to evaluate land use/land cover change over four decades (until 2018) to assess land use/land cover changes in and surrounding Abijata Shalla National Park.

Therefore, this study aimed at evaluating impacts of land use/land cover changes on floristic richness and vegetation structure, determining changes in spatial cover of Lake Abijata and comparing herbaceous biomass production in protected and open access grazing lands in the study area.

MATERIALS AND METHODS

Description of the study area

The research was conducted in and surrounding Abijata Shalla Lakes National Park in the Central Rift Valley, located at about 200 km from Addis Ababa between 7°15′–7°45′N and 38°30′–38°45′E at an elevation of between 1,540 and 2,075 m above sea level (Unpublished Park Office Documents). The study area was in three districts: Nagelle Arsi (north east and in the south), Shalla (in the south west), and Adami Tullu, Jiddo Kombolcha (in the north) of Oromia National Regional State (Fig. 1).

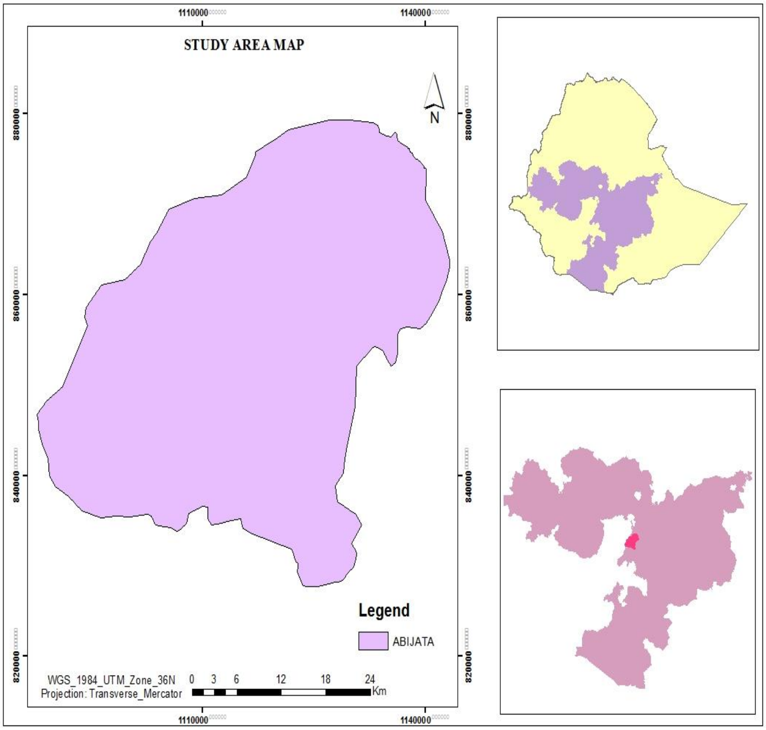

Fig. 1. Map of study area in Oromia Regional State, Ethiopia.

Abijata Shalla National Park is one of the protected areas located in dryland ecosystems of the Central Rift Valley of Ethiopia. This Park was established mainly for conservation of spectacular number of water birds, which use Lake Abijata for feeding and Lake Shalla as nesting site (Tadesse Fetahi, 2016). Review of different studies showed that the Park has a total of 457 bird species (out of which about 144 species are water-associated and 292 terrestrial) and 76 mammals (Reaugh-Flower, 2011). In addition to varieties of mammals, the Hot Springs and beautiful scenery of the lakes have been part of the Park (Tafesse Kefyalew, 2008). Large numbers of Flamingos gather in the Park, together with Great White Pelicans and a wide variety of other water birds. Because of the high diversity of water birds and diverse ecosystems, Abijata Shalla Lakes National Park is one of the most well-known tourist attraction sites. The Park has unique ecosystems such as Acacia Woodland, the two Lakes (Abijata and Shalla), Shalla hot springs, grazing land, wetlands and Shalla Islands.

Temperature and rainfall

The temperature and rainfall data from 1981 to 2017 was obtained from National Meteorological Agency of Ethiopia. Average monthly temperature was 21.4°C and maximum monthly temperature 30.6°C and minimum monthly temperature is 12.0°C. Mean annual rainfall was 806 mm and maximum rain fall was recorded during the months July, August and September (Fig. 2).

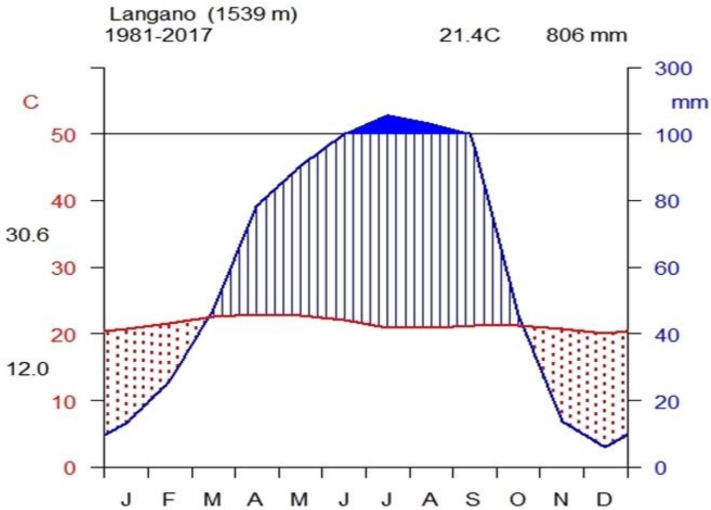

Fig. 2. Climate diagram for Abijata Shalla (Langano), showing rainfall distribution and temperature variation from 1981 to 2017 (Data source: National Meteorological Agency).

Soil

Soil of the study area was reported to be alluvial and very fine in nature that is very susceptible to both wind and water erosion (Tolcha Regassa, 2005).

Vegetation

Vegetation of the study area belongs to the *Acacia-Commiphora* (small-leaved) deciduous woodland vegetation type. Acacia woodland, shrublands, grasslands, bushland and shrubland cover the area around the Lake Abijata (Tolcha Regassa, 2005). *Acacia tortilis*, *A. seyal*, *A. senegal* and *A. etbaica* are dominant species in the study area (Mekuria Argaw *et al*., 1999; Feoli and Zerihun Woldu, 2000; Tolcha Regassa, 2005).

Land use/land cover

The major land cover types of the area were open woodland (at all parts of the study area), wooded grassland and bush land. Woodlands, grasslands, crop fields and settlements are major land use types.

Data collection

Land use/land cover change data collection

Time series satellite data were collected using remote sensing. Data on the land use/land cover change mapping and detection were collected using time-series satellite images. The land use/land cover change classes were mapped for each year by using ArcGIS 10.5 and ENVI 5.0. ArcGIS software was used to map and determine the coordinates and geographical location of the study area. ENVI software was used to identify changes between different years of land use and land cover change (LULCC) from 1978 to 2018.

Image selection from the Cloud free Land sat images were downloaded for the years (1978, 1998 and 2018) and layer stacking and band selection for Landsat 5 (1, 2, 3, 4) and Landsat 8 (1, 2, 3, 4, 5, 6, 7, 8) bands were used for data collection (Table 1).

Table 1. Summary of the image's acquisition date, path, senor and resolutions.

Acquisition date (Year/mm/DD)	Path/row	Sensor	Resolution
1978/1/28	168/054	Landsat5 TM	30 m
1998/2/16	168/054	Landsat5 TM	30 m
2018/2/25	168/054	Landsat8 OLI	15 m

Vegetation data collection

Vegetation data was collected using combinations of stratification and systematic random sampling techniques. Stratification was used to collect data from protected and open access woodlands/grazing lands. Data was collected along the eight transect lines established in both protected and open access sites. The quadrates were established at regular interval of 200 m from each other along the line transects. A total of 64 sample plots (32 plots each in both protected and open access sites) of 20 m x 20 m (400 m^2) were used for sampling trees/shrubs. Five subplots of 1 m x 1 m (1 m^2) were established at the four corners and the center of each main plot to document list of herbaceous species and determine regeneration status of woody species.

All plant species in each plot and subplot were recorded using their local names. Plant specimens were collected, pressed, dried and identified at the National Herbarium of Ethiopia using the published volumes of the Flora of Ethiopia and Eritrea (Hedberg and Edwards, 1989; 1995; Edwards *et al*., 1995; 2000; Hedberg *et al*., 2004).

From each main plot, the circumferences of all woody plants having Diameter at Breast Height (DBH) or Diameter at Stamp Height (DSH) ≥2.5 cm were measured using the graduated Caliper. DBH was measured at 1.3 m above ground. Height was measured using Hypsometer. Furthermore, growth habit and number of stems of each species existing in the plots were recorded. On the other hand, the data of the saplings and seedlings of woody plant species were collected from the subplots. Both seedlings and saplings were categorized as young plants with DBH<2.5 cm but the two were differentiated by their height (seedlings <1 m and saplings <3 m above ground). Voucher specimens were deposited in the National Herbarium of Ethiopia.

Herbaceous biomass determination

Data for herbaceous biomass was collected from a total of 63 (32 from protected and 31 from open access areas) sample plots of 1 m x 1 m (1 m^2) size located at the centre of the main plot. Harvesting was done at the ground level. After cutting, the samples were transferred into airtight plastic bags. The samples were transported to Addis Ababa and then each sample was wrapped with aluminum foil and put inside oven and dried at 60°C for 72 hours in the laboratory of Centre for Environmental Science, Addis Ababa University.

Data analysis

Descriptive statistics was used for data analysis.

Land use/land cover change detection analysis

The land use land cover change classification was done for the years 1978, 1998 and 2018; after having the classification, the change detection statistics were calculated by ENVI 5.0 (Table 1). Image classification and Change Detection was done by undertaking supervised classification to identify the overall land use land cover type and post classification comparison change detection technique was used for detection of land cover change following Yenenesh Hailu *et al.* (2018). For satellite images data analysis, geometric correction plus image enhancement were carried out and post-classification comparison was conducted. Then, percentage of cover change and rate of change was calculated as follows (Berhanu Keno and Suryabhagavan, 2014):

$$\%CC = \%LcYrb - \%LcYra$$

$$\text{RC} = \frac{\%LcYrb - \%LcYra}{\text{Yr. interval}}$$

Where $\%CC$ = Percent of cover change between each period in percent; $\%LcYrb$ = Land cover of recent year in percent; and $\%LcYra$ = Land cover of previous year in percent.

Vegetation structure

Density, frequency, dominance and importance value index (IVI) were calculated to describe the vegetation structure following Kent and Coker (1992).

Basal area (BA)

Basal area (BA) is the area outline of a plant near ground surface. It is the cross-sectional area of tree stems at DBH. It is measure of dominance (degree of coverage) of species as an expression of the space it occupies at ground level (Mueller-Dombois and Ellenberg, 1974). Its area is also used to calculate the dominance of species.

Basal area $=\sum(D/2)^2$, where D is diameter at breast height.

Woody species density

Density is defined as the number of plants of a certain species per unit area.

Frequency

Frequency is defined as the probability or chance of finding a plant species in a given sample area or quadrat.

Importance value index

Importance value index (IVI) is the most important characteristic used to determine the environmental significance of species (Curtis and McIntosh, 1951; Lamprecht, 1989). The index indicates how the species is dominant in a certain area and hence helps to compare ecological importance of the species in vegetation (Curtis and McIntosh, 1951). Therefore, IVI of species in the study area was determined using the following formula (Kent and Coker (1992):

IVI = Relative Density + Relative Dominance + Relative Frequency (Kent and Coker, 1992) which were calculated using the following formulae:

$$Relative\ density = \frac{Number\ of\ individuals\ of\ species}{Number\ of\ individuals\ of\ all\ species} * 100$$

$$Relative\ frequency = \frac{Number\ of\ occurrence\ of\ species}{Number\ of\ occurrence\ of\ all\ species} * 100$$

$$Relative\ dominance = \frac{Total\ basal\ area\ of\ species}{Total\ basal\ area\ of\ all\ species} * 100$$

Herbaceous biomass

Herbaceous data was analyzed using both descriptive and inferential statistics. The mean and standard deviation of herbaceous biomass across sites were calculated. Furthermore, one-way analysis of variance (ANOVA) was employed to determine whether the biomasses between study sites were significantly differed or not. The result was displayed using box plot graph because it gives a good indication of how the values in the data were spread out.

RESULTS AND DISCUSSION

Land use land cover change

The main land use land cover change classes in the study area were open woodland, water body and crop land (Fig. 3 and Table 2). Table 2 summarizes area coverage of each land use/land cover change classes and their percentage for different years.

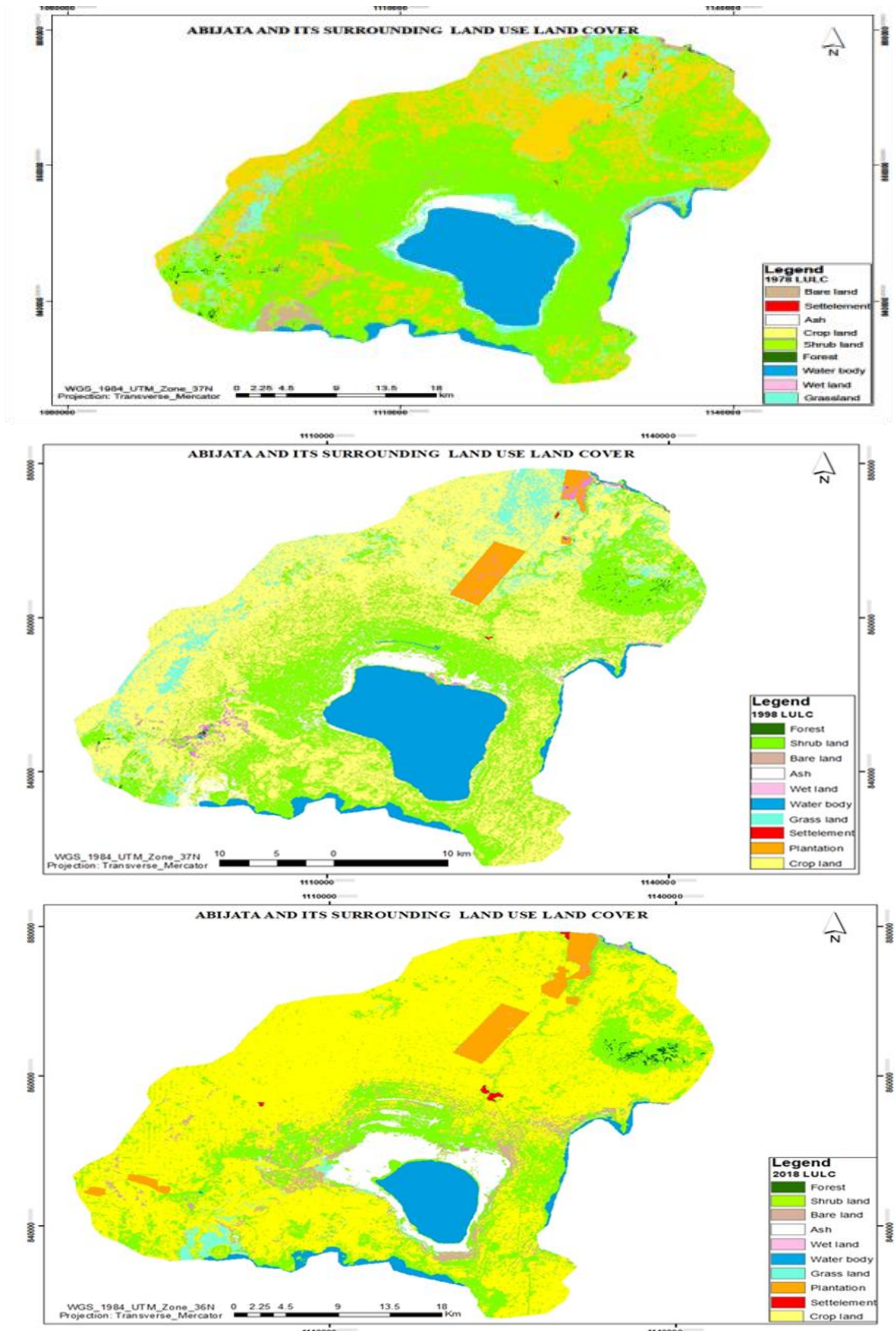

Fig. 3. Changes in spatial cover of Lake Abijata and land use/land cover change in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Table 2. Land use/land cover change class of the years 1978, 1998 and 2018 in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Year	**1978**		**1998**		**2018**	
Class name	**Area/ha**	**Area/%**	**Area/ha**	**Area/%**	**Area/ha**	**Area/%**
Bare land	1084.14	0.584795	1895.48	1.022438	5746.68	3.099802
Ash	6654.42	3.589455	4861.19	2.622168	8087.1	4.362243
Grassland	15015.15	8.099309	10667.5	5.754142	1865.29	1.006151
Forest land shrublands	91593.63	49.40644	52220.73	28.16831	54125.2	29.19554
Settlement	33.57	0.018108	35.01	0.018885	207.36	0.111852
Wetland	617.85	0.333274	2140.74	1.154734	315.9	0.170399
Soda Ash Factory	0	0	3312	1.786522	4504.86	2.429955
Water body	20676.51	11.1531	20913.12	11.28072	8558.1	4.616304
Cropland	49712.76	26.81552	89342.42	48.19208	101978.1	55.00775
TOTAL	185388	100	185388.2	100	185388.6	100

Status and trend of Lake Abijata

Spatial cover of Lake Abijata decreased from the cover in 1978 to 2018 by 58.6%. In 1978 the water body of Lake Abijata was 11.15% land cover with an area coverage of 20,676.51 ha but in the year 2018 it decreased to 4.61% with area coverage of 8,558.1 ha. This result was in agreement with many previous reports (e.g., Reaugh-Flower, 2011; Tadesse Fetahi, 2016; Hamere Yohannes *et al*., 2017; Eyasu Elias *et al*., 2019). However, the total area coverages in different years and trends in decrease that was reported by Hamere Yohannes *et al*. (2017) disagree with our study. They reported that highest water cover in 2000 which was not supported by this study and previous report. For example, Eyasu Elias *et al*. (2019) reported a continuous decreasing trend of Lake Abijata from 1985 to 2015 in agreement of our result. According to Eyasu Elias *et al*. (2019), Lake Abijata showed a progressive decline by 25.9% resulting in severe degradation of the fragile ecosystem that have sustained the rich biodiversity of both plants and animals.

Therefore, it was established beyond any doubt that Lake Abijata has been drastically decreasing over time not only in terms of spatial coverage but also in its depth. The lake has lost about 6.5 m in total lake depth between 1985 and 2006 out of which 70% (~4.5 m) of the loss was attributed to anthropogenic or human-induced causes, whereas the remaining 30% was related to natural climate variability (Wondwosen Seyoum *et al*., 2015). Human activities such as unsustainable developmental activities, unplanned urbanization, aggressive agricultural expansion, climate change, and the associated changes in land use and land cover practices and unregulated water abstraction have significantly contributed to the changes in the hydrology of the Central Rift Valley lakes including Lake Abijata (Wondwosen Seyoum *et al*., 2015; Eyasu Elias *et al*., 2019).

Settlements, bare land and crop cultivation

Human settlements in the area increased by 517.7%. It was 0.01% of the total area with aerial coverage of 33.57 ha in 1978 and 0.111% with areal coverage of 207.36 ha in 2018. Similarly, crop land increased from 26.8% with area coverage of 49,712.76 ha in 1978 to 55% with area coverage of 101,978.1. This increase was 105.1% of the proportion of cropland in 1978. These findings concur with previous studies (Hamere Yohannes *et al*., 2017; Eyasu Elias *et al*., 2019).

Rapid expansion of croplands has been identified as the most extensive direct driver of land degradation (IPBES, 2018) and this unsustainable and unregulated agricultural practices have negative impacts on a wide range of ecosystem services (e.g. Davari *et al*., 2010). The increased crop cultivation and associated practices in the study area were noted contributing to habitat destruction thereby negatively affecting local biodiversity and ecosystem services. The negative impacts of crop cultivation have been already well documented. For example, it was reported that transformation of rangelands and other silvo-pastoral systems to cultivated croplands is leading to significant, persistent decrease in overall dryland plant productivity (MA, 2005). Furthermore, the unregulated agricultural expansion in the Central Rift Valley ecosystems has been using irrigation water in an unsustainable manner as all agricultural practices have not been climate smart. Such inappropriate dryland irrigation and cultivation practices has led to soil salinization and erosion in many dryland ecosystems (MA, 2005).

Bare land also increased from 0.5% with areal coverage of 1,084.14 ha to 3.099% with areal coverage of 5,746.68 ha. In other words, bare land increased by 81.1% in 2018 when compared with the proportion in 1978. This result disagrees with that of Hamere Yohannes *et al*. (2017) who reported that bare land decreased by 1.02% in the first period (1973 to 1994), increased by 0.56% in second period (1994 to 2000) and decreased by 4.17% in the third period (2000 to 2016). According to our result, bare land increased consistently over the years with clear increasing trend from 1978 to 2018 confirming the continued land degradation in the study area.

Grassland, wetland and woodland

Grassland decreased by 87.6% (1,865.29 ha) compared to the 1,5015.15 ha area coverage in 1978. Similarly, wetland and forest/shrub land decreased over time by 48.9% and 40.9%, respectively. These results were in agreement with previous reports (Hamere Yohannes *et al*., 2017; Eyasu Elias *et al*., 2019). Decrease in grassland results in decreased forage availability and livestock productivity in the area negatively contributing to livelihoods of local pastoral/agropastoral communities. Besides, local biodiversity in and surrounding the park will be under threat as a result of disturbance of this ecosystem, which might have caused loss of food and habitat.

Status of floristic composition

From the studied Abijata Shalla National Park woodland, a total of 60 plant species belonging to 49 genera and 27 families were documented (Appendix 1). Despite the high land degradation and land cover/land use changes, the area was found to be still home for many plant species in agreement of previous assessment report about dryland biodiversity (MA, 2005). However, our result showed that there was local loss of some species and decreasing trend in species richness in the study area. For example, Tolcha Regassa (2005) reported a total of 97 plant species belonging to 28 families from the same area. We noted that the two studies did not use exactly the same methodology both in sampling and land area coverage. However, as to the listing of species in the area, we believe, the continued degradation has contributed to local loss of species. Some of the species that were not encountered during this study but documented by Tolcha Regassa (2005) were *Acacia albida* Del., *Acacia oerfota* (Forsake.) Schweinf., *Andropogon schirensis* Hochst. ex A. Rich, *Aristida adoensis* Hochst., *Aristida kenyensis* Henr., *Asparagus africanus* Lam., *Berchemia discolor* (Klotzsch.) Hemsl, *Bidens pilosa* L., *Cenchrus ciliaris* L., *Cynodon dactylon* (L.) Pers., *Digitaria milanjiana* (Rendel) Stapf, *Ehretia cymosa* Thonn., *Panicum maximum* Jacq, and *Themeda triandra* Forssk. This may be caused by continued land degradation and uncontrolled agricultural expansion surrounding Abijata Shalla National Park. It is worth noting that highly desirable forage species such as *Cenchrus ciliaris, Cynodon dactylon* and *Digitaria milanjiana* (Gemedo Dalle *et al*., 2006) were not encountered during this study which could be due to overgrazing in the study area.

The distribution of plant species in terms of the growth forms or habits was eight trees, nine shrubs, three climber or lianas and 41 herbaceous species (grass and forbs) (Appendix 1). Forbs (non-graminoid herbaceous vascular plants) were the most dominant growth forms (45%) followed by grasses (21.7%). Shrubs, trees and lianas comprised 15%, 13.3% and 5%, respectively (Appendix 1). This result concurs with previous studies. For example, Zaloumis and Bond (2016) reported that forbs were most abundant in the eastern South Africa followed by graminoids. It has been well established that forbs constitute the largest component of herbaceous species richness in grasslands (Siebert and Dreber, 2019). However, it is worth mentioning that this dominance of forbs in the Central Rift Valley could be one indicator of the fact that the rangeland has been degraded as higher proportion of forbs and annual grasses were reported from degraded area than in rehabilitated areas (e.g. Ombega *et al*., 2017).

The result showed that out of the 27 families, 48.15% and 37.04% were represented by one and two species, respectively which adds up to be 85.19% (Table 3). It was noted that species diversity in most families was low which may indicate high degree of land degradation and local species loss. There was decreasing species richness of the families over time as previous study from the area reported that families represented with one and two species were 50% of the total families documented (Tolcha Regassa, 2005). Poaceae was the most dominant family with 13 species (contributing 21.67%) followed by Fabaceae which was represented by eight species (13.33%) and five genera (10.20%) in agreement with previous study in the area (Tolcha Regassa, 2005). In the *Combretum-Terminalia* and *Acacia-Commiphora* dry woodland in Hirmi, Tigray, Fabaceae had the highest number of species followed by Poaceae and Asteraceae (Mehari Girmay *et al*. (2020). Similarly, Motuma Didita *et al*. (2010) reported that Fabaceae was the most dominant family followed by Asteraceae, Lamiaceae and Anacardiaceae in the woodland vegetation around Dello Menna in Bale, southeast Ethiopia. Therefore, it can be concluded that Fabaceae and Asteraceae are the two most important families in most dry woodlands in Ethiopia.

Table 3. List of families with their representative genera, species and percentage contribution, Abijata Shalla National Park, Oromia, Ethiopia.

Family	**Number of genera**	**%**	**Number of species**	**%**
Acanthaceae	2	4.08	2	3.33
Amaranthaceae	2	4.08	2	3.33
Anacardiaceae	1	2.04	2	3.33
Anthericaceae	1	2.04	1	1.67
Asteraceae	3	6.12	3	5.00
Balanitaceae	1	2.04	1	1.67
Boraginaceae	2	4.08	2	3.33
Brassicaceae	2	4.08	2	3.33
Burseraceae	1	2.04	1	1.67
Cactaceae	1	2.04	1	1.67
Capparidaceae	1	2.04	1	1.67

Family	Number of genera	%	Number of species	%
Caryophyllaceae	1	2.04	1	1.67
Celasteraceae	1	2.04	1	1.67
Chenopodiaceae	1	2.04	1	1.67
Combertaceae	1	2.04	1	1.67
Commelinaceae	1	2.04	1	1.67
Cyperaceae	1	2.04	1	1.67
Euphorbiaceae	2	4.08	2	3.33
Fabaceae	5	10.20	8	13.33
Gentianaceae	2	4.08	2	3.33
Lamiaceae	2	4.08	2	3.33
Malvaceae	1	2.04	2	3.33
Poaceae	9	18.37	13	21.67
Rubiaceae	1	2.04	1	1.67
Santalaceae	1	2.04	1	1.67
Solanaceae	2	4.08	3	5.00
Tiliaceae	1	2.04	2	3.33
	49		60	

Review of the environmental situations in and surrounding Abijata Park showed that biodiversity in the park has diminished and savanna, riparian, and dry forest ecosystems have been converted to farms and grazing lands (Reaugh-Flower, 2011). There is high need to restore, conserve and promote sustainable use of biodiversity in and surrounding Abijata Shalla National Park. Many studies confirm the fact that biodiversity is critical for stability and healthy functioning of ecosystems (Blench and Sommer, 1999; Griffin *et al.*, 2009). According to SCBD (2009), promoting conservation of intact and functioning ecosystems is the most fundamental strategy for biodiversity conservation that can be achieved through different approaches including reducing other stresses on species and ecosystems (such as habitat loss and fragmentation, invasive alien species, pollution, and overharvesting) and increasing protected area systems and improving the connectivity of protected areas and natural landscapes to provide opportunities for species to adapt to climate change.

The diverse ecosystems in and surrounding Abijata Shalla Lakes National Park have been providing many ecosystem services at local, national and global levels (Tafesse Kefyalew, 2008).

Due to the many degrading factors (for example, establishment of Soda Ash factory at the shore of Lake Abijata, illegal settlements in the Park, deforestation, unregulated and unsustainable agriculture practices, lack of law enforcement, etc.), the ecosystem services are under threat calling for immediate interventions that would restore ecosystems and promote ecosystem services.

Vegetation structure

Species dimensions

The measurements of woody plant species that include maximum DBH/DSH, mean DBH/DSH, maximum total height, mean total height and number of stems per species are presented in Table 4. The maximum height attained in the woodland was 8.5 m while the maximum DBH/DSH was 41 cm represented by *Acacia tortilis*. This species had also the highest mean height (8.5 m) and mean DBH/DSH (19.97 cm).

Table 4. Mean species dimensions of some woody plants in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Scientific name	Max DBH/DSH	Mean DBH/DSH	Max height	Mean height	Stems sampled
Acacia etbaica	18.2	8.3	6.0	4.2	37.0
Acacia senegal	28.2	9.0	8.5	4.1	301.0
Acacia seyal	32.0	7.9	8.0	4.3	180.0
Acacia tortilis	41.0	20.0	8.5	6.2	107.0
Balanites aegyptiaca	28.6	12.6	7.5	4.8	64.0
Croton dichogamus	5.2	4.0	4.5	3.7	24.0
Cordia monica	18.5	8.6	6.0	4.8	13.0
Dichrostachys cinerea	5.2	5.2	4.0	4.0	7.0
Grewia bicolor	6.8	5.5	5.0	4.3	3.0
Grewia villosa	2.8	2.8	3.0	3.0	5.0
Opuntia ficus-indica	15.5	12.4	3.0	3.0	37.0
Osyris quadripartita	10.6	9.5	6.0	5.3	4.0
Rhus longipes	11.6	11.6	7.0	7.0	4.0

As presented in Table 4, most species (69.23%) had mean DBH/DSH less than 10 cm and only one species had mean DBH/DSH of 20 cm clearly showing impacts of selective cutting on mature trees/shrubs. On the other hand, the least size of DBH/DSH and total height recorded was 2.5 cm and 2.5 m, respectively.

Stand diameter and height profile

Stand diameter profile

For ease of the comparison and interpretation and also following Abreham Assefa *et al*. (2013), the diameter class was formed in to eight groups as: **A** (2.6–7.5 cm); **B** (7.6–12.5 cm); **C** (12.6–17.5 cm); **D** (17.6–22.5 cm); **E** (22.6–27.5); **F** (27.6–32.5 cm); **G** (32.6–37.5 cm) and **H** (37.5–42.5 cm). The species density distribution by diameter class is shown in Table 5.

Table 5. Stand diameter profile and species density distribution of some woody species in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Scientific name	Diameter class (diameter in centimetre)								
	2.6–7.5	**7.6–12.5**	**12.6–17.5**	**17.6–22.5**	**22.6–27.5**	**27.6–32.5**	**32.6–37.5**	**37.6–42.5**	**Total**
Acacia etbaica	11.5	3	3.5	0.5					18.5
Acacia senegal	90.5	29.5	18.5	5.5	1.5	5			150.5
Acacia seyal	53.5	24.5	9	1.5	1	0.5			90
Acacia tortilis	2.5	9	8.5	13	12	4.5	0.5	3.5	53.5
Balanites aegyptiaca	10.5	5.5	10.5	1.5	1.5	2.5			32
Capparis tomentosa	3.5								3.5
Croton dichoamus	12								12
Combretum hartmannianum	0.5								0.5
Cordia monica	5.5			1					6.5
Dichrostachys cinerea	3.5								3.5
Grewia bicolor	1.5								1.5
Grewia villosa	2.5								2.5
Opuntia ficus-indica		17.5	1						18.5
Osyris quadripartita		2							2
Rhus longipes		2							2

The result of the analysis of the diameter profile data indicated that about 28.6% (N=12) of the tree/shrub species were those species which were in diameter class A; 19% (N=8) in diameter class B; 14.3% (N=6) in diameter class C and D; 9.5% (N=6) in diameter class E and F; 2.4% (N=1) in G and H, respectively (Fig. 4).

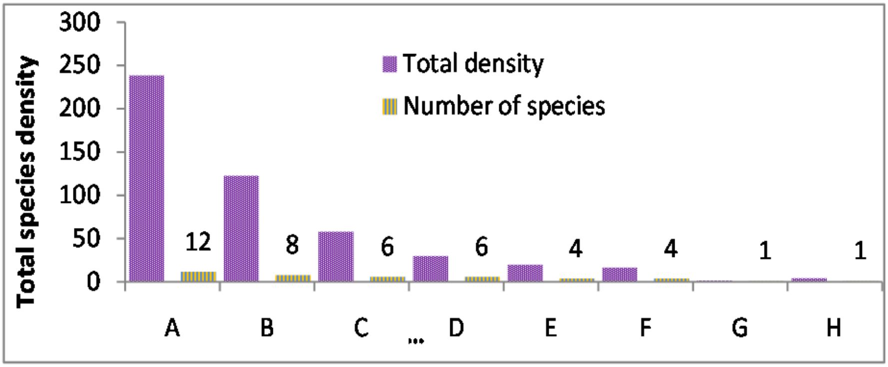

Fig. 4. Number and total species density by diameter class in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Most plants belonged to the lower DBH class in agreement with previous reports from dry woodlands (Mehari Girmay *et al.*, 2020). The low amount of the tree species in high diameter classes G and H might indicate that mature trees that attained the higher diameter size would have been selectively exploited by the local communities for different purposes such as firewood, construction and charcoal making.

Stand height profile

In determining the stand height profile, the height class was formed in to three groups as: **A** (≤5 m); **B** (5.1–10 m) and **C** (>10 m). Table 6 summarizes the species density distribution by height class.

Table 6. Stand height profile and species density distribution of some woody species in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Scientific name	**Height in metre**			
	<5	**5.1–10**	**>10**	**Total**
Acacia etbaica	16	2.5		18.5
Acacia senegal	133	17.5		150.5
Acacia seyal	75	15		90.0
Acacia tortilis	6	47.5		53.5
Balanites aegyptiaca	18	14		32
Capparis tomentosa	3.5			3.5
Croton dichogamus	12			12.0
Combretum hartmannianum	0.5			0.5
Cordia monica	5.5	1		6.5
Dichrostachys cinerea	3.5			3.5
Grewia bicolor	1.5			1.5
Grewia villosa	2.5			2.5
Opuntia ficus-indica	18.5			18.5
Osyris quadripartita	1	1		2.0
Rhus longipes	2			2.0

The result of the analysis of the height profile data indicated that about 75.2% (N=15) of the tree/shrub species were those species which had fallen in height class A; 24.8% (N=7) in height class B and no species recorded in C diameter class (Fig. 5). This depicts that the majority of the species belonged to the lower height class in similar trend as diameter distribution in agreement with reports from dry woodlands (e.g. Mehari Girmay *et al*., 2020). The possible reason could be selective cutting of matured trees/shrubs, intensive browsing and moisture deficit or recurrent droughts in the study area. Similar results were also reported from other parts of Ethiopia (Mehari Girmay *et al*., 2020).

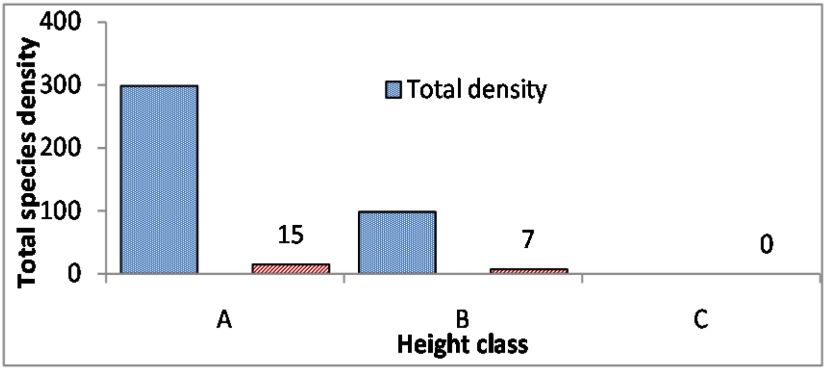

Fig. 5. Number and total species density by height class of woody species in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Important value index (IVI)

Table 7 summarizes importance value index of woody species measured during the study. The species IVI values varied between 1.49–87.66 (Table 7). It was lowest for *Grewia villosa* and *Osyris quadripartita*; whereas it was the highest for *Acacia senegal*. The study revealed that *Acacia senegal*, *Acacia tortilis*, *Acacia seyal*, *Balanites aegyptiaca* and *Acacia etbaica* were woody species with highest IVI (Table 7) in agreement with previous studies in dry woodland ecosystems (e.g. Tefera *et al*., 2015; Gadisa Demie, 2019).

This reveals that in this woodland the species relative frequency, density and dominance differ accordingly. This in turn implies the importance of developing the threat level for the existing species in the woodland.

Table 7. Overall mean importance value index (IVI) of woody species in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

No.	Scientific name	RD	RDO	RF	IVI	Rank
1	*Acacia etbaica*	4.66	2.44	7.44	14.54	5
2	*Acacia senegal*	37.91	26.61	23.14	87.66	1
3	*Acacia seyal*	22.67	12.31	19.83	54.81	3
4	*Acacia tortilis*	13.48	40.95	20.66	75.08	2
5	*Balanites aegyptiaca*	8.06	10.83	18.18	37.07	4
6	*Croton dichogamus*	3.02	0.32	0.83	4.17	7
7	*Cordia monica*	1.64	0.97	0.83	3.43	8
8	*Dichrostachys cinerea*	0.88	0.15	0.83	1.86	10
9	*Grewia bicolor*	0.38	0.08	1.65	2.11	9
10	*Grewia villosa*	0.63	0.03	0.83	1.49	13
11	*Opuntia ficus-indica*	4.66	4.58	1.65	10.89	6
12	*Osyris quadripartita*	0.5	0.29	0.83	1.62	12
13	*Rhus longipes*	0.5	0.43	0.83	1.76	11

According to Curtis (1952) cited in Greig-Smith (1983), species with the greatest importance value are the leading dominants of the vegetation. Accordingly, *Acacia senegal*, *Acacia tortilis* and *Acacia seyal* were most important and leading dominants in the woodland ecosystem in the study area. In other words, these species had important ecological significance in the study area (Lamprecht, 1989). On the other hand, most species (77%) had importance value index less than 50.0 and 54% of the species had IVI < 10. Similar results were reported from dry woodlands in Ethiopia and Botswana (Motuma Didita *et al*., 2010; Neelo *et al*., 2013; Ajayi and Obi, 2016). For example, the majority of woody species (90.4%) in the woodland vegetation around Dello Menna district of Bale, southeast Ethiopia had an important value index of less than ten (Motuma Didita *et al*., 2010). That means, most species in the study area need immediate conservation attention. As a result of this study, *Grewia villosa*, *Osyris quadripartita*, *Rhus longipes*, *Dichrostachys cinerea* and *Grewia bicolor* were identified as priority species for conservation.

Regeneration status of woody species

Total density of seedlings and saplings recorded from the study area was 606.25 per ha with 318.75 and 287.5 seedlings and saplings per ha, respectively (Table 8). On the other hand, total density of mature woody species was 397 per ha. *Acacia senegal*, *Acacia tortilis* and *Acacia seyal* had the highest seedlings density in the woodland and it was the least for *Acacia etbaica*, *Rhus longipes*, *Dichrostachys cinerea*, *Maytenus arbutifolia* and *Balanites aegyptiaca*. Furthermore, many of the woody species recorded during this study did not have seedlings and saplings.

Table 8. Density (per ha) of mature woody plants, seedlings and saplings in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Scientific name	Mature	Seedlings	Saplings	Total density of seedlings and saplings	Rank
Acacia etbaica	18.50	0.00	6.25	6.25	7
Acacia senegal	150.50	143.75	68.75	212.50	1
Acacia seyal	90.00	62.50	93.75	156.25	2
Acacia tortilis	53.50	75.00	62.50	137.50	3
Balanites aegyptiaca	32.00	18.75	18.75	37.50	4
Capparis tomentosa	3.50	0.00	0.00	0.00	
Combretum hartmannianum	0.50	0.00	0.00	0.00	
Cordia monica	6.50	0.00	0.00	0.00	
Croton dichogamus	12.00	0.00	0.00	0.00	
Dichrostachys cinerea	3.50	0.00	18.75	18.75	6
Grewia bicolor	1.50	0.00	0.00	0.00	
Grewia villosa	2.50	0.00	0.00	0.00	

Scientific name	Mature	Seedlings	Saplings	Total density of seedlings and saplings	Rank
Maytenus arbutifolia	0.00	18.75	12.50	31.25	5
Opuntia ficus-indica	18.50	0.00	0.00	0.00	
Osyris quadripartita	2.00	0.00	0.00	0.00	
Rhus longipes	2.00	0.00	6.25	6.25	7
	397.00	318.75	287.50	606.25	

The result showed that the regeneration status of woody species in the study area was low. According to Khumbongmayum *et al*. (2006), when proportion of seedlings > saplings > adults, regeneration is considered to be good. Based on this, regeneration status in the study area was poor and many species had no seedlings and saplings (Table 8). The major reasons for poor regeneration could be the intensive trampling by livestock while browsing and grazing in the woodland that compact the soil thereby reducing germination of seeds from the soil seed bank. Besides, livestock might have caused physical damage on the seedlings by peeling during grazing and browsing. This finding was in agreement with previous studies (e.g. Reaugh-Flower, 2011) who reported that grazing, cultivation and timber harvesting had negatively affected trees in the Rift Valley; humans cut trees for a variety of uses such as fuel and building materials; and cultivation and grazing/browsing by livestock prevented regeneration of trees/shrubs. Furthermore, Neelo *et al*. (2013) reported that crop cultivation, fuel wood, overgrazing, cutting of stems and lopping of branches of woody species for fencing of farms, kraals and house compound were some of the factors that hampered regeneration of woody species. Cutting of mature woody species does decrease regeneration because under such dry and fragile ecosystems, when woody species are cut for different purposes, they may not bear sufficient seeds.

Herbaceous biomass comparison

The result of herbaceous biomass showed that protected areas had higher mean biomass (289 g/m^2) than the open access sites (71 g/m^2). See Appendix 2 for details on overall herbaceous biomass of both protected and open access sites. There was high variation of the herbaceous biomass (Table 9).

The result showed that herbaceous biomass recorded in protected and open access (unprotected) areas were significantly different at $p<0.001$ (Fig. 6). The result showed that protected area had more herbaceous biomass than the open access grazing lands, in agreement with previous studies (Ayana Angassa and Oba, 2010; Al-Rowaily *et al*., 2015; Mengistu Asrat *et al*., 2015). The open access grazing lands were highly exposed to disturbance such as overgrazing, browsing, agricultural expansion leading to decreased primary productivity of the herbaceous species. This in turn results in low biomass in the open access grazing land. Grazing affects herbaceous production because of defoliation, treading and fouling (Jones, 2000).

Table 9. Comparison of herbaceous biomass in protected and open access woodland in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Plot No.	Protected (n=32)	Open access (n=31)	Plot No.	Protected	Open access
1	294	0	17	225	0
2	146	0	18	198	100
3	77	0	19	156	58
4	370	72	20	204	90
5	785	0	21	110	61
6	286	138	22	279	40
7	325	91	23	184	113
8	970	174	24	293	127
9	393	51	25	176	106
10	160	48	26	172	65
11	425	362	27	449	0
12	346	0	28	114	0
13	200	72	29	295	78
14	140	93	30	77	0
15	229	132	31	700	142
16	147	0	32	320	
			Mean	289	71
			STDEV	202	75

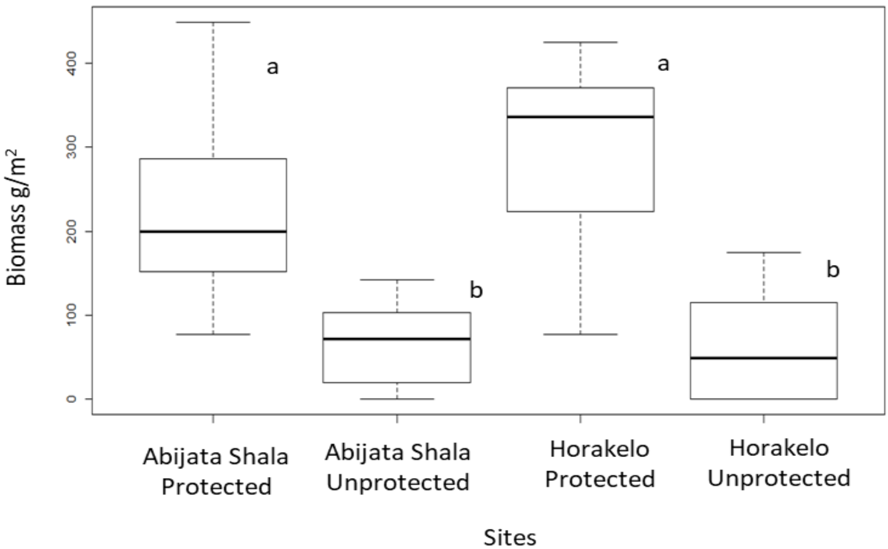

Fig. 6. Biomass records of herbaceous species in protected and unprotected sites in and surrounding Abijata Shalla National Park. N.B. Similar and different letters on the boxplots per each site show significant differences in biomass at p≤0.001.

CONCLUSION

Abijata Shalla National Park has been providing various economic, sociocultural and ecological benefits to the community and the country. However, the current status and future trend in and surrounding this park was noted to be worrisome unless immediate and coordinated restoration measures are taken. The result of this study and others showed that the ecosystems in the Central Rift Valley in general and Abijata Shalla Lakes National Park in particular have been degraded and unsustainable utilization of natural resources has continued to be a practical challenge. The vegetation of the study area was dominated by small sized trees/shrubs due to selective cutting of matured trees/shrubs. Spatial cover of Lake Abijata, grasslands, wetland, and forest/shrub land has decreased by 58.6%, 87.6%, 48.9% and 40.9%, respectively. Human settlements, crop land and bare land have increased by 517.7%, 105.1% and 81.1%, respectively. The significant increase in bare land and crop field indicate increased land degradation. Major factors for the degradation of both terrestrial and aquatic ecosystems include unregulated agricultural land expansion, overgrazing, deforestation and woodland degradation for charcoal and firewood, and establishment of human settlements in and surrounding the Park. Degradation of the different ecosystems has threatened survival of unique and diverse biodiversity (fauna and flora). Targeted actions should be taken to conserve the unique biodiversity and enhance ecosystem services of both the terrestrial and aquatic ecosystems. Environmental law enforcement measures should be implemented to regulate agricultural expansion, stop illegal human practices and over exploitation of the park's vegetation. There is a need to coordinate interventions for restoring the degraded terrestrial and aquatic ecosystems, conserving unique biodiversity and enhancing ecosystem services of the park and its surrounding ecosystems.

RECOMMENDATIONS

As a result of this study and review of different documents, the following recommendations are made for immediate and sustainable solutions:

- Strengthen integrated ecosystem restoration/rehabilitation initiatives with special focus on Lake Abijata and surrounding Arsi and Gurage highland mountains.
- Put in place an effective and functional system on the use and regulation of water resources in the area.
- Ensure environment law enforcement including effective

implementation of Environmental Impact Assessment (EIA) before and during implementation of any development project in the area.

- Diversify livelihood options for local communities including ecotourism and other environment friendly activities.

ACKNOWLEDGEMENTS

We would like to thank the Ethiopian Wildlife Conservation Authority and Abijata Shalla National Park Management for their support and facilitation of this study. The support and guidance of Centre for Environmental Science is highly acknowledged. The critical comments and inputs of the three anonymous reviewers have improved the quality of this manuscript and therefore, we highly appreciate and thank them for their professional contributions.

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Appendix 1. List of plant species documented from in and surrounding Abijata Shalla National Park, Oromia, Ethiopia.

Species name	Local name (Afan Oromo)	Family	Growth habit
Acacia etbaica Schweinf.	Dodota	Fabaceae	Tree
Acacia senegal (L.) Wild.	Qarxafaa	Fabaceae	Tree
Acacia seyal Del.	Waacuu	Fabaceae	Tree
Acacia tortilis (Forssk.) Hayne	Ajoo	Fabaceae	Tree
Achyranthes aspera L.	DarguuDaalatii	Amaranthaceae	Forb
Amaranthus spinosus L.	Dallo	Amaranthaceae	Forb
Anthericum corymbosum Baker	Burii	Anthericaceae	Forb
Balanites aegyptica (L.) Del.	Badana	Balanitaceae	Tree
Brassica rapa (L.)	Shalali	Brassicaceae	Forb
Capparis tomentosa Lam.	Huntuti	Capparidaceae	Liana
Capsella bursa-pastoris (L.) Medic	Aananoo	Brassicaceae	Forb
Chenopodium ambrosiphdes L.	Urgoo saree	Chenopodiaceae	Forb
Chloris gayana Kunth	Lelago	Poaceae	Grass
Croton dichogamus Pax	Uleefoonii	Euphorbiaceae	Shrub
Combretum aculeatum Vent.	Gaalee korma	Combertaceae	Liana
Commelina erecta L.	Dallansiisaa	Commelinaceae	Forb
Commiphora schimperi (Berg) engl.	Hammaressa	Burseraceae	Tree
Cordia monoica Roxb.	Mandheera	Boraginaceae	Tree
Cyperus rotundus L.	Qunii	Cyperaceae	Forb
Dactyloctenium aegyptium (L.) Willd	Margahillo	Poaceae	Grass
Datura stramonium L.	Banjii	Solanaceae	Forb
Dichrostachys cinrea (L.) wight & Am.	Gaato	Fabaceae	Tree
Dicliptera verticillata (Forssk.) Blatter	Daraartuu	Acanthaceae	Forb
Digitaria ternata (A. Rich.) Stapf		Poaceae	Grass
Digitaria velutina (Forssk.) P. Beauv.	Lelago	Poaceae	Grass
Echinochloa colona (L.)	Sardoo	Poaceae	Grass
Enicostema axillare (Lam.) Raynal	Qarxaaxummee	Gentianaceae	Forb
Eragrostis aspera (jacq.) Nees	Sardoo	Poaceae	Grass
Eragrostis paposa (Roem. & Schult.) Steud.	Sardoo	Poacaeae	Grass
Euphorbia depauperata A. Rich	Guurii	Euphorbiaceae	Forb
Galinsoga parviflora Cav.	Camarii	Asteraceae	Forb
Gentiana cruciata L.	Qorichaloonii	Gentianaceae	Forb
Gnaphalium unionis Sch. Bip. Ex Oliv. & Hiern	Biletuu	Asteraceae	Forb
Grewia bicolor Juss.	Harooressa	Tiliacae	Shrub
Grewia villosa Willd.	Ogomdii	Tiliacae	Shrub
Heliotropium longiflorum (A.DC in DC.) Jaub. &Spach	Bocha	Boraginacaeae	Forb
Heteropogon contortus (L.) Roem & Schult.	Woraantuu	Poaceae	Grass
Hyparrhenia filipenduls (Hochst.) Stapf	Huffee	Poaceae	Grass
Hypoestes forskaolii (Vahl) R.Br.	Darguu	Acanthaceae	Forb
Indigofera spicata Forssk.	Tephrosia	Fabaceae	Forb

Species name	**Local name (Afan Oromo)**	**Family**	**Growth habit**
Leucas martinicensis (Jacq.) R. Br.	Darguu	Lamiacecae	Forb
Maytenus arbutifolia (A. Rich.) Wilczek	Kombolcha	Celasteraceae	Shrub
Medicago sativa L.	Robaanjiregna	Fabacece	Forb
Olderlandia corymbosa L.	Ababoo	Rubiaceae	Forb
Opuntia ficus-indica (L.) Miller	Adaamii	Cactaceae	Shrub
Orthosiphon pallidus Royle ex. Benth.	Urgoo	Lamiacaeae	Forb
Osyris quadripartita Decn.	Waatoo	Santalaceae	Shrub
Rhus glutinosa A. Rich	Xaaxessaa	Anacardiaceae	Shrub
Rhus longipes Engl.	Qalqalcha	Anacardiaceae	Shrub
Rostraria cristata (L.) Tzvelev	Ganaboontuu	Poaceae	Grass
Saponaria officinalis L.	Muja	Caryophyllaceae	Forb
Setaria incrassata (Hochst.) Hack.	Daraaraa	Poaceae	Grass
Setaria pumila (Poir.) Roem & Schuit	Changulfa	Poaceae	Grass
Setaria sp.	Maxxanee	Poaceae	Grass
Sida ovata Forssk.	Borera	Malvaceae	Forb
Sida schimperiana Hochst. ex A. Rich	Qeensajabeesa	Malvaceae	Forb
Solanum incanum L.	Hiddii	Solanaceae	Shrub
Solanum nigrum L.	Mugelo	Solanaceae	Forb
Tagetes minuta L.	Ajaa'aa	Asteraceae	Forb
Vigna oblongifolia A. Rich.	Gadisso	Fabaceae	Liana