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Anthropogenic threats to wetland resources and its implication on carbon sequestration in Southwestern Ethiopia

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Abstract

Even though wetlands have been valued for their numerous ecosystem services and hydrological, ecological and habitat functions, its services have been threatened by its sudden losses. Nevertheless, the losses along its driving factors and the effects brought due to the loss have not been scientifically investigated. The study is geared to scrutinize anthropogenic threats to wetland resorces and its implication on carbon sequestration in southwestern Ethiopia. A combination of geospatial and socioeconomic data were utilized to attain the intended objectives. A total of 384 households were selected using simple random sampling technique from sample kebeles to assess the drivers of wetland degradations. Besides, to address the experimental work, the wetland was stratified, and soil samples were taken from three classes of wetlands viz., permanent wetlands (intact wetlands), semi disturbed wetlands and wetlands converted to agricultural land. From the total category of wetlands, 24 composite soil samples in five replications at a depth of 0-20 cm were collected. The result of Landsat imageries revealed that Wichi wetland area has been shrinking. It was 17.4% of the area in 2001, while it declined to 3.1% in 2021. The results of One-Way ANOVA indicated that there is a significant mean difference in soil organic carbon and sequestration capacities between different classes of wetlands at $p<0.01$ significance level.The organic carbon content of soils converted to agricultural land is very low. In intact/undisturbed wetlands, there is better carbon content than other states of wetlands. This triggers the wetlands to lack their pristine nature. To reverse these problems, integrated problem-solving approach through collaboration of stakeholdfrom policy level down to grassroots community is found to be essential for sustainable wetland management in the area.

Keywords *Wetland degradation, land use/cover, carbon sequestration*

Introduction

Wetlands are ecosystems found at interface between land and water or land and water together at the same time and place (Hailu, 2009). As noted by Hu et al. (2017), globally wetlands cover a total of about 29.83 million km^2 of the total land surface area. The largest wetlands of Sub-Saharan Africa (SSA) covers 2,072,775 km^2 (9.01 %) of the landmass (Mitchell, 2013). According to Dixon et al. (2021), wetland resources of Ethiopia are distributed mainly in the southwest parts of the country and from the existing wetlands coverage, wetlands comprised 1.4 % of Ilu Aba Bor Zone's total land area. Although wetlands have been valued for their numerous ecosystem services and hydrological, ecological and habitat functions, its services have been been threatened by its its sudden losses. In southwest Ethiopia, where many and extended wetlands are found there was no

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act of cultivation around the periphery of the wetlands before the entrance of 20 century (Dixon & Wood, 2007).

But, in the years 1911-1918, wetland cultivation has extended beyond the use of wetland margins to include much larger areas. Due to their inherent diversity, wetlands are highly productive ecosystems that play a fundamental and disproportionate role in providing a multitude of ecosystem services that sustain all life on the planet, regardless of the landscape in which they are found (Seid, 2017). Wetland resources contribute for environmental wellbeing through recharging and discharging underground water, hosting biological diversity, sequestering carbon and mitigating flood hazards (Gebresllassie et al., 2014). Despite the services it has been providing, wetlands were still being lost at a rate faster than that of any other ecosystem which perhaps result in huge carbon losses.

The world's wetlands continue to be lost and degraded at an alarming rate because of human activities (Seid, 2017). Hence, Scientific estimates show that 64% of the world's wetlands have disappeared since 1900 (Xing et al., 2018). Most wetlands already have been destroyed or severely degraded, largely due to human activities such as road construction, agriculture, non-point pollution sources (including highway and pesticide run-off), land development.Therefore, identifying the stressors or pressures on the ecological character of wetlands is the best practice for preventing further loss and degradation for which wetlands loss can vary widely from country to country. In Ethiopia, wetlands are under severe pressure and degradation due to improper uses and misconceptions forwarded to wetlands. According to Hailu et al. (2000), complete drainage and cultivation of wetlands, double cropping in wetland which extends the period of drainage, plantation of destructive crops, e.g., sugar cane, Chat and eucalyptus trees, grazing pressures, are also identified as major driving forces of wetlands degradation. When wetlands are degraded, the broad range of benefits they produce begins to deteriorate and eventually vanish (Sasha et al., 2012). In investigating about this, only limited studies have been conducted to assess the roles and potentials of wetlands in Carbon sequestration (Hari et al., 2015). Hence, the value of wetlands in capturing and storing carbon has generally been underestimated. The role of Ethiopian wetlands in carbon sequestration has not been well studied except the exemplary work previously done by Afework (2013) on Tekuma wetlands and Gebrekidan (2014) on the Fogera wetlands of Lake Tana basin, and Tesfau et al. (2020) on Lake Ziway. Same is true for Wichi watershed where the wetlands capacities have been not well investigated and its services from carbon sequestration dimensions have been unquantified. This pronounces that wetland degradation, causes, consequences and its implications for carbon sequestration as well as their value remain little understood for the study site. Therefore, this study aimed to fill emperical evidence gaps on the potential contributions of wetlands in carbon sequestration, identify the driving factors of wetlands degradation and quantify the existing wetlands losses in Wichi watershed of Ilu Aba Bor Zone, southwest Ethiopia.

Material and Methods

Study site

Ilu Aba Bor zone is found in Oromia regional state which is situated in the south-western part of Ethiopia. The geographic location of the zone lies between 7°36'00"−8°37'00"N latitude and 35°1'30"−36°2'30"E longitude. In terms of relative location, the zone is situated at about 600 km Southwest of Addis Ababa, the capital of Ethiopia. According to Dixon et al. (2003), approximately 40% of the zone is covered with forest and different landforms such as rugged mountains, deep gorges and extensive dissected plateaus are the main topographic features of the study area. Based on the FAO soil classification system (FAO-Unesco, 1977), the study area is dominated Dystric Nitisols (red-basaltic soil), Dystric Gleysols, Orthic Solonchaks, Calcic Xerosols and Orthic Acrisols soil types. As per the traditional agro-ecological zone classification of Ethiopia, the study area is predominantly characterized by midland agro-ecology. The study area climate is moderately hot and humid type. The altitude varies from 559 - 2531 meters above sea level. The annual average temperature in the zone varies between 16^0c and 24^0c and the climax vegetation is tropical montane rainforest with an average annual rainfall of approximately 2000 mm.

Mettu is one of the district in this zone that has several macro and micro watersheds. From these, Wichi is among the watersheds found within Mettu District, Ilu Abba Bora Zone of Oromia regional state (Fig. 1). The watershed is located at 8^015'- 8^019' N and 35^040' – 35^045' E stretching across five kebeles namely Ale Buya, Tulube, Boto, Burusa, and Adele Bise, covering a

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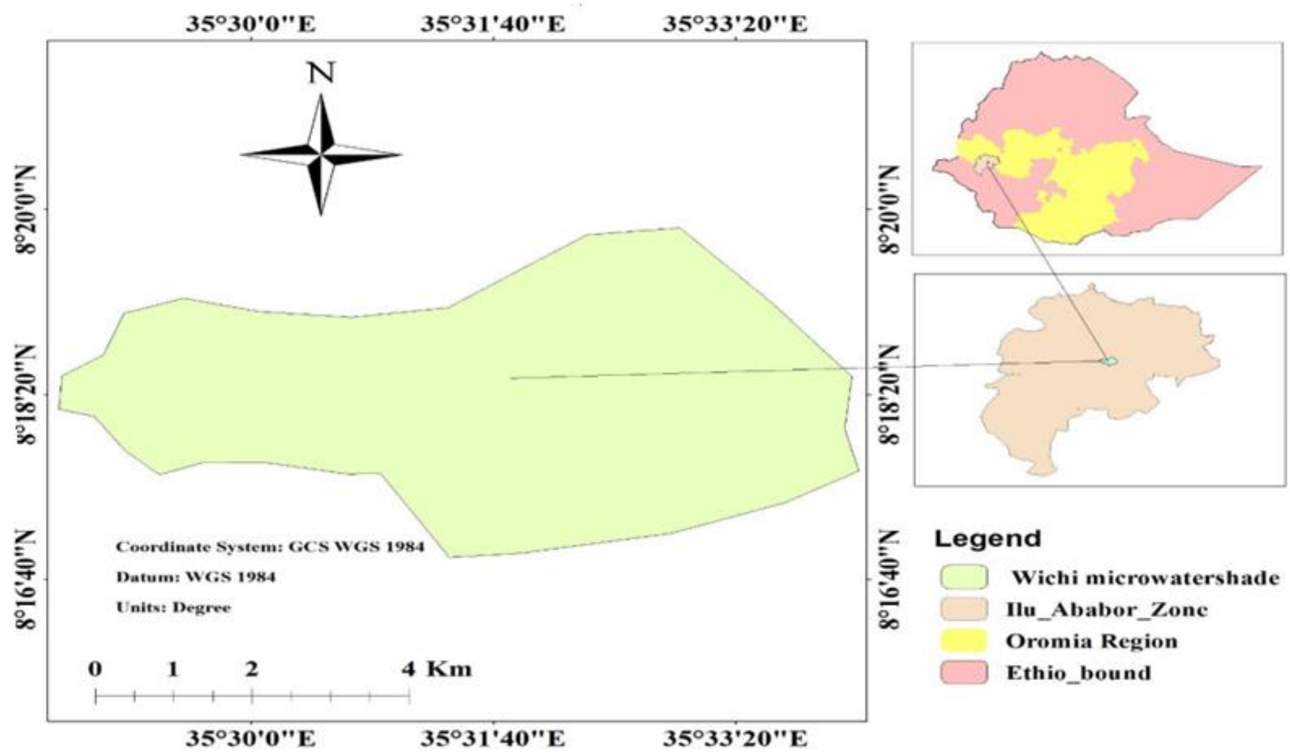
total area of 8149 hectares. The Wichi watershed is in the central part of Metu district. Wichi wetland with a total area of 364 hectares is located at the middle of the watershed, stretching from Tulube and Boto kebeles in the southeast to Adele Bise in the northwest.



Research design and approach

The study employed a cross-sectional survey design to attain the intended objectives. In addition, a mixed research methods which involves both qualitative and quantitative methods were used. The researchers collected both qualitative and quantitative data concurrently to have the necessary data concerning the research problem under inquiry. This is due to the fact that using mixed approaches enables the researchers to overcome the weakness of one method with the strength of the other and provide a better solution to the problem and the research questions.

Data sources and collection tools

The required data were collected both from primary and secondary sources. Questionnaires, in-depth interviews, focus group discussions (FGDs) and field observations were the main means of generating data from primary sources. Household survey questionnaires were composed of both open and close -ended types to collect reliable data required for the study. In-depth interview was conducted with agricultural extension workers, kebele managers, woreda and zonal level officials from agricultural and rural development offices of the area to get detail information about the issue understudy. Field observation was also carried out to crosscheck data collected via other data collection instruments. Besides, secondary data were obtained from published and unpublished sources.

Sample size and sampling technique

Wichi watershed was purposely selected considering that it is the watershed sharing boundaries with the five selected kebeles and owning the largest wetland that meet the required three statuses of wetlands (Undisturbed, minimally disturbed, and completely converted wetlands). For this study, the researcher used satellite images to understand the loss of wetland considering Wichi watershed during 2001, 2011 and 2021. Wichi wetlands are divided into three strata based on its status (Undisturbed, minimally disturbed,

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and completely converted wetlands). For the study purpose, 24 plots (10m*10m) were randomly established. Hence, six (6) plots belong to undisturbed wetlands, semi disturbed wetlands accompany eight (8) plots, and wetlands completely converted to agricultural land were tested with ten (10) sample plots. The plots are representative enough relative with studies conducted by other authors who took only nine (9) plots for the three wetlands features in homogeneous situations (Tesfau et al., 2020). Distance between each 10*10m plots was 10m apart for the next plot which is applied in reference to studies conducted by Villa and Mitsch (2014). Soil samples collected from undisturbed wetlands (sample site 1), minimally disturbed (sample site 2) and from completely converted wetlands (Sample 3) using standard soil sampling auger. Generally, twenty-four (24) soil samples were collected from all wetland's features. The total household heads of the sample kebeles are 3,340 and the sample size was determined by using the formula given by Kothari (2004). Accordingly, a total of 384 households were selected proportionally from sample kebeles to analyze the anthropogenic related drivers of wetland cover change in the area.

Method of data analysis

The collected data for the study were analyzed using descriptive and inferential statistical techniques.

To quantify the wetlands loss in the study site, Landsat satellite imageries of the Wichi watershed for the year. 2001, 2011 and 2021 each with 30 m spatial resolution were downloaded free of charge from United States Geological Survey (USGS) websites (*https://earth explorer.usgs.gov/*). In order to understand the impact of wetlands degradation on carbon sequestration, soil samples were collected from the field After collection of soil samples, recognizable plant litters, coarse root materials, and stones were removed from the air-dried soils.

The soil samples were placed in a plastic zip-lock bag and placed where it can be dried. After laboratory analysis of carbon content of wetlands, statistical analyses such as One-Way ANOVA test was used to compare the mean difference in soil organic carbon and sequestration capacities between different classes of wetlands. Soil organic carbon was determined using loss on ignition method. Ground Soil samples (<2mm) were placed in a muffle furnace at 550 ^{0}C for four hours to determine organic matter content of the samples and the organic carbon content (g C kg^{-1}) was calculated as the organic matter content divided by 1.86 (Kuffman & Donato, 2012). For this study, Bulk density is determined by dividing the oven-dry soil sample by the volume of the sample.

The bulk density equation [1] is as follows:

$$\text{Soil bulk density (g cm}^{-3}) = \frac{\text{Oven dry sample mass (g)}}{\text{Sample Volume (m}^3)} \quad [1]$$

Similarly, the soil carbon mass per sampled depth is calculated as follows:

$$\text{Soil carbon (Mg ha}^{-1}) = \text{bulk density (g cm}^{-3}) * \text{soil depth (cm)} * \%\ \text{C} \quad [2]$$

hence, % C is the carbon concentration expressed as a whole number. The formulas used for the study purpose were adopted from Kauffman and Donato (2012) and finally, the results was presented in Tables 1, 2 and Figures.2, 3

Results and Discussions

Land use/cover change detection analysis

Wetland loss and degradation have become serious environmental and ecological issues. Hence, wetland sy-

Class Name	2001		2011		2021	
	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
Shrub land	1296.6	38.3	994.1	29.4	969.0	28.6
Forest land	524.9	15.5	429.0	12.7	285.1	8.4
Wetland	585.5	17.4	234.0	6.9	106.0	3.1
Cultivated land	976.1	28.8	1626.0	**51.0**	2023.0	59.9
Total	3383.1	100.0	3381.1	100.0	3383.1	100.0

Table 1.
Wichi wetlands status during the last three decades

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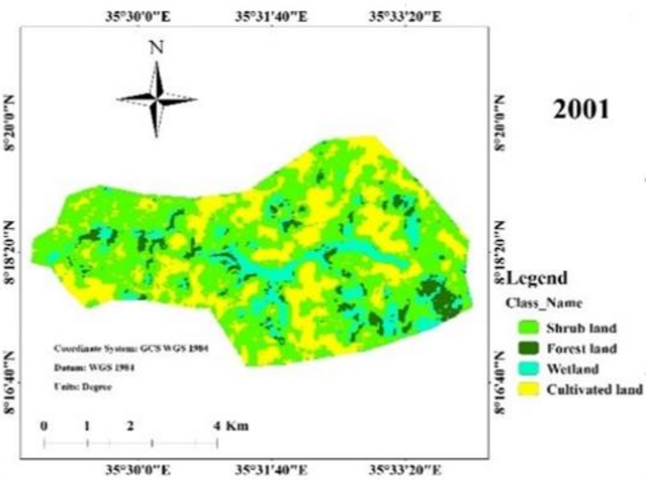
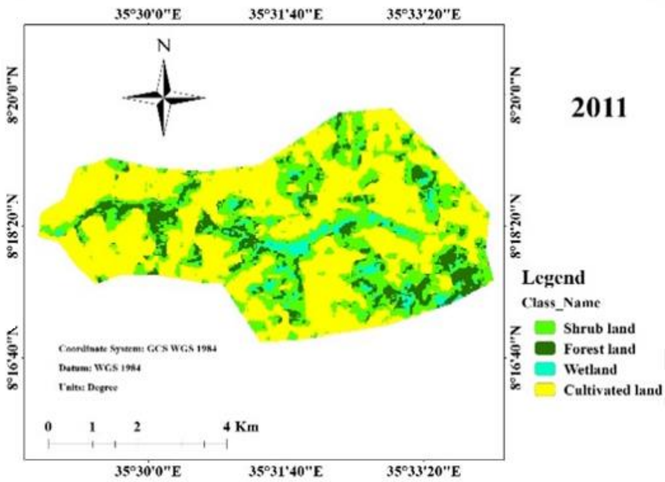
stems have been threatened and degraded in both spatial extent maily due to human activities. Therefore, accurate monitoring and understanding of changes to wetlands are important. In order to understand wetlands loss and its driving factors in the study area, satellite imageries of the year 2001, 2011 and 2021 were used to analyze the changes in wetland cover. Besides, socio-economic data were collected to indentify the drivers of wetland degrdation in the study area.





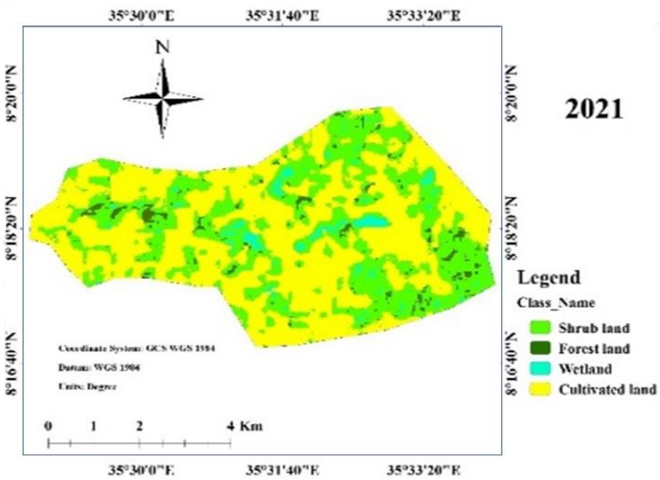


Figure 2
LULC map of Wichi watershed in 2001, 2011 and 2021
(Source: landsat imageries)

Table 2. *LULC Change rate of Wichi watershed (2001, 2011 and 2021)*

ClassName	2001	2011	2021	Rate of change Ha/years		
	Area (Ha)	Area (Ha)	Area (Ha)	2001-2011	2011-2021	2001-2021
Shrub land	1296.6	994.1	969.0	-0.25	-2.51	-32.76
Forest land	524.9	429.0	285.1	-9.59	-14.39	-23.98
Wetland	585.5	234.0	106.0	-35.15	-12.80	-47.95
Cultivated land	976.1	1626.0	2023.0	74.99	29.70	104.69

The study result indicated that 17.4% of the area was wetland in 2001, while it was vastly decreased to 6.9% in 2011. In contrast, the area of cultivation land has shown an increasing trend from 28.8% to 51% during the period of 2001 to 2011 (Table 2 and Fig. 3). The result of the satellite image analyses described above is also confirmed by the local communities and concerned government experts. The communities and the experts contacted for the study purpose have explained that during this time, there was a mass mobilization from the government side to use wetlands for agricultural purposes.

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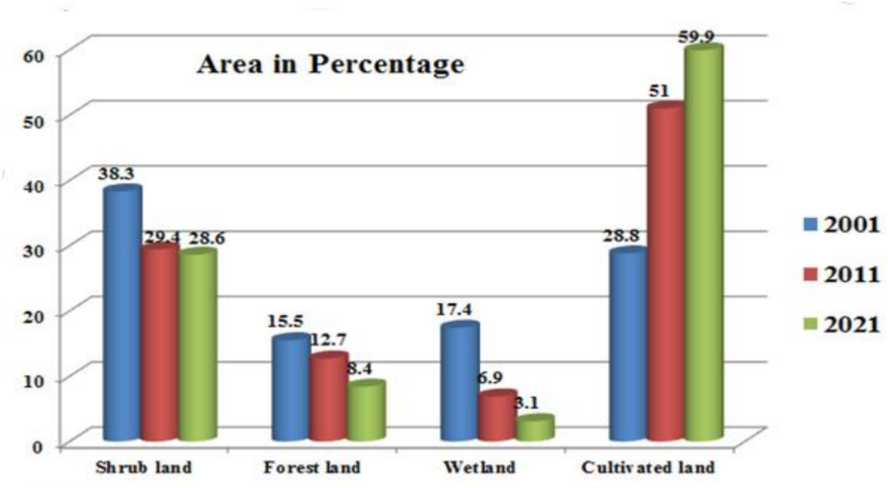

Figure 3. *LULC change rate of Wichi watershed (2001, 2011 and 2021)*

Later, during 2011-2021, even though there is a decline of wetlands coverage from 6.9% to 3.1 %, the rate of decrease is not similar to the former (Figure 3). The participants of FGD and KII have shown their own views for the rates of wetlands decline during those periods. About 35.15 Ha of wetland was converted into other land types. During 2001-2021, the wetlands coverage was shrunked in the study area. The data gathered through satellite image also revealed that 12.8 Ha of land was converted into other forms during 2011-2021. When it is compared with a decade before, there is a substantial difference between the two periods. Discussion held with FGD participants clearly demonstrated that there is a loss/ shrinkage of Wichi wetland which strongly agree with satellite image result of wetlands loss from 17.4% in 2001 to 3.1% in 2021. In agreemen to this result, study conducted by Gebrekidan (2014) shows the decline of Fogera wetland from 25% in 1973 and to 19.59% in 2011. According to the data gathered from the farmers, "the area of the land covered by wetland is decreasing from time to time and this is a good fortune for us to plough different annual and perennial crops that support us to address our food securities". Furthermore, they mentioned that, before two decades, there was grass grown on the wetlands which they locally call it "Chefe". During then, the grass was used for different purposes like for animal forage, local house roofing and to prepare local beehives and different types of hand crafts. From this viewpoint, the study result agrees with the study conducted by (Dixon & Wood 2007). Hence, their study pronounced that in Ethiopia, the government and farmers need converting the wetlands to gain more products at a time. Moreover, the study result is similar with the study conducted by Gebrekidan (2014), in that the community has shown their reflection as "the area of the land covered by water is decreasing from time to time and this is a good fortune for us to plough". From satellite imageries and field observation, the researcher realized that the wetlands have been under severe threat due to different factors.

Drivers of wetland degradation in the study area

Wetlands provide enormous socio-economic and environmental values. Regardless of indispensable values, wetlands are under severe pressure and degradation in southwestern parts of Ethiopia. Owing inappropriate uses and misconceptions forwarded to wetland resources, the health of the wetlands is continuously decreasing from time to time that in doubt their existence in the near future.

Perceived drivers of wetland degradation	% of respondents (N= 384)
Improper agricultural practices and expansion	95%
Enchrochement for human settlement	83%
Over exploration of wetland resources	87%
Deforestation and degradation of catchment	68%
Livestock grazing or overgrazing	51%
Poor wetland management practice and unwise utilization	90%

Table 3
Perceived drivers of wetland degradation in the study area

Note: the total is not 100 due to multiple response option

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As indicated in Table 3 above, the main perceived drivers of wetland degradation in the study area includes: improper agricultural practices and expansión, enchrochement for human settlement, poor wetland management practice and unwise utilization, over exploration of wetland resources as well as deforestation and degradation of catchment. Information obtained from focus group discussions revealed that the conversion of wetland to cultivated land, inappropriate farming methods and poor tillage systems as well as planting more water requiring perennial crops and plants are some of the agriculture related threats of wetland in the study area.

Information obtained from key informants showed that Ethiopia lacks a specified policy to wetlands that preserves wetland from deleterious actions. Thus, absence of separate policy to wetland let the wetlands under pressure in Ethiopia in general and in the study area in particular. Furthermore, the study found that there is lack of coordination and collaborative works that harmonizes the relationship among the stakeholders and sets better management of wetlands in the area understudy. Hence, absence of institutional arrangement has resulted in the deterioration of wetland resources.

Comparative soil carbon sequestration capacities of wetlands

Ecosystem services are becoming increasingly important and a reason to promote the sustainable use of natural resources. Wetlands provide many valuable ecosystem services, including carbon sequestration & therefore, wetlands are an important carbon sink, playing a key role in climate regulation (Villa and Bernal, 2018). Because of their wet conditions, wetlands are optimum natural environments for sequestering and storing carbon from the atmosphere (Mitsch et al., 2015). However, the role of Ethiopian wetlands in carbon sequestration has not been well studied. Therefore, considering limited studies on the subject matter, this study was geared to understand and compare soil carbon sequestration capacities among different wetland features for which Wichi wetland. According to the study result, the highest mean organic carbon content and mean sequestration capacity was obtained in the undisturbed/intact wetland site, followed by the moderately degraded wetland site and the wetland converted to agricultural land (Table 4). The study result explores that soil organic carbon sequestration of intact/undisturbed wetland is much better than other wetland features. As Ali et al. (2006) stated the conversion of wetlands could lead to loss of atmospheric carbon dioxide from their soils by modifying the temperature and water table of the areas which in turn could influence the microbial processes and oxidation of organic matter in the soil. Hence, the outcome reveals that there is high reduction of organic carbon storage of the soil after a wetland is converted into other land use types like cultivated land. According to the study result, 8898.3 ton/ ha^{-1}, 6094.9 ton/ha^{-1} and 4637.5 ton/ha^{-1} are sequestrated by intact, semi-degraded and wetlands converted to Agricultural land respectively for the study site. Similarly, result shown that the SOC content of the area (ton/ha^{-1}) are 2424.6, 1660.7 and 1263.62 respectively for intact (undisturbed), semi-disturbed and wetlands converted to agricultural land respectively.

The study agrees with studies conducted by various scholars viz. Wilson et al. (2005) noted that wetland associated with intact feature would be likely to have high total carbon accumulation because of additional external organic inputs and nutrients in the inflow water, while wetland communities on semi disturbed and converted to Agricultural sites have shown less carbon storage than the intact ones.

The result of the study tells that as wetlands also play a vital role in the carbon cycle, its loss or degradation result in its low carbon sequestration capacity, which may further aggravate climate change. This is also supported with the study conducted by Nelson et al. (2007) that conversion of wetlands to cultivated fields results in a significant decrease in the total carbon dioxide storage capacity.

Table 4
Summary of one-way ANOVA

Calculated parameter	Wetland Features (ton ha^{-1})			P-value
	Intact	Semi disturbed	Disturbed *	
SOC	2424.61 ±205.17	1485.67±385.68	274.25 ±76.66	.000
SOC_{02}	8898.30 ±752.98	6094.90 ±445.07	4637.50 ±261.39	.000

SOC Soil Organic Carbon - SOC_{02} Soil Organic Carbon Sequestration
* Converted to Agricultural land

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Thus, when wetlands are degraded, the broad range of benefits including carbon sequestration capacities they produce begins to deteriorate and eventually vanish. The result of One-Way ANOVA showed that there is significant difference in soil organic carbon and sequestration capacities between different classes of wetlands at $p<0.01$ significance level (Table 4) .Therefore, land use changes such as converting wetlands to cultivation land by clearing the wetland biomass could affect capacities of wetlands to absorb carbon.

Conclusion and policy implications

Ethiopia owns different types of wetlands which have national, regional as well as global ecological and socio-economic significance. Despite all their indispensable functions and values, wetlands are the most highly threatened ecosystems in Ethiopia in general and Ilu Aba Bor zone in particular. The main perceived drivers of wetland degradation in the study area includes: improper agricultural practices and expansion, enchrochement for human settlement, poor wetland management practice and unwise utilization, over explotation of wetland resources as well as deforestation and degradation of the catchment. To reverse these problems, integrated problem-solving approach through collaboration of stakeholders from policy level down to grassroots community is found to be essential for sustainable wetland management in the area.

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