Effect of Wetland Degradation and Conversion on Carbon Stock: The Case of Tekuma Wetland, Lake Tana Sub-Basin, Ethiopia

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(Received: July 28, 2015; Reviewed: Aug 10, 2015; Accepted: Sept 08, 2015)

Abstract: *Wetlands are considered as one of the major carbon sinkers that have significant positive effect on reducing the impact of climate change. However, the contribution of wetland to climate change mitigation through carbon sequestration is not well understood by the public. Many developed and developing countries signed in and supported the inclusion of agriculture and wetland projects in the Kyoto Protocol. But Ethiopian government has not yet tried to take advantage of this opportunity and start negotiations to use conservation and improvement of wetland's carbon sequestration potential in the country to obtain carbon funds as an economic incentive for the communities involved. With this background, this research was designed to carry out an in-depth study on the impact of wetland degradation and conversion on carbon sequestration potential in Ethiopia. To meet the stated objectives stratified sampling techniques were used to select sampling sites from the wetland areas having varying wetland degradation level. For the determination of carbon levels in each area replicates of plant and soil samples were collected. The plant organic matter was determined using a loss-on-ignition method and then converted to carbon stock. Carbon stock and bulk density of the sampled soil was determined using Walkely-Black oxidation and gravimetric methods, respectively. ANOVA and mean separation were computed to indicate whether there is significant difference in carbon stock due to wetland degradation. The research findings showed significant difference ($P<0.05$) of carbon storage with different wetland degradation levels. Carbon stock in the soil was on average 24 times higher than carbon stock in plants in each respective wetland area having varying degradation level. The intact wetland was able to sequester579 t/ha of CO_2as compared to converted farmlands and grazing lands that had only 230 and 295 t/ha of CO_2, respectively. The result showed that by protecting wetlands more than double carbon could be stored as compared to grazing and farmlands. Thus, it is recommended that special attention should be given to minimize the conversion of wetlands and maximize their benefits through carbon funding.*

Keywords: *Carbon stock; wetland degradation; carbon sequestration*

1. Introduction

Land management practices having plant crop cover contributes significantly for absorbing and retaining carbon dioxide through photosynthetic process (Agriculture and Agrifood Canada, 2003). Different land use and land management practices have varied CO_2 absorbing capacity depending on the density of the vegetation cover and plant species. Wetlands are considered as one of the major carbon sinkers that have significant positive effect on reducing the impact of climate change (Crooks *et al*., 2011; Zhang and Kuitunen 2012; Pant *et al.,* 2003; Vesterdal and Leifeld 2010). Apart from their carbon sequestration role, wetlands are used as the spawning area for major aquatic fauna, flood and erosion control; provide economic and social benefits to communities living around the wetlands (Yilma and Geheb, 2003).

Although wetlands have many known characteristics that are important to the livelihoods of local inhabitants, population pressure has caused massive encroachment. Agricultural development in wetlands through either the use of drainage systems or change of land use to hydrophilic plants such as rice is among the causes for wetland loss. Likewise, Tekuma wetland, the focus of this research, has been negatively affected.

Lack of adequate knowledge and awareness of the social, economic and ecosystem benefits of wetlands and the increasing demand for agricultural land due to population pressure and degradation of upland areas are believed to be the most significant reason for increased conversion of wetlands to agricultural lands (Belayneh Ayele, 2010, Xiaonan*et al.,* 2008). Wetlands themselves and their socioeconomic value have been little understood and their loss is increasingly accelerated in the face of climate change. Particularly, the contribution of wetlands to climate change mitigation through carbon sequestration is not well understood by the public (Murdiyarso *et al*., 2012).

Even though the Kyoto Protocol (Article 12) provides an opportunity for countries to benefit from the sale of carbon credits (United Nation, 1998), the Ethiopian government has not yet tried to take advantage of this opportunity and start negotiations to use conservation and improvement of wetland's carbon sequestration potential in the country to obtain carbon funds as an economic incentive for the communities involved. The majority of government efforts to implement carbon credit projects are focused only to forest conservation and development neglecting wetlands.

It is important to note that wetlands covered a significant portion of the land (1.14% of the total landmass of the country), compared to total forests cover that was approximately 2% (Yilma and Geheb, 2003). Therefore, use of wetland protection and improvement, in combination with forest improvement could increase the potential for securing carbon funds by almost 50%, as the wetland covered half of the forestland. If wetlands are managed well and if their contribution in storing carbon is documented based on study, the country's claim for carbon trading can be successful. Assessment of the carbon sequestration capacity of wetlands may help in minimizing their conversion and can be used as a means for considering wetlands as an alternative means for protecting their status. With this background, this paper aims to investigate the carbon content of wetlands having a varying degradation level in Tekuma wetland, Ethiopia.

2. Materials and Method

2.1 Description of the Study Area

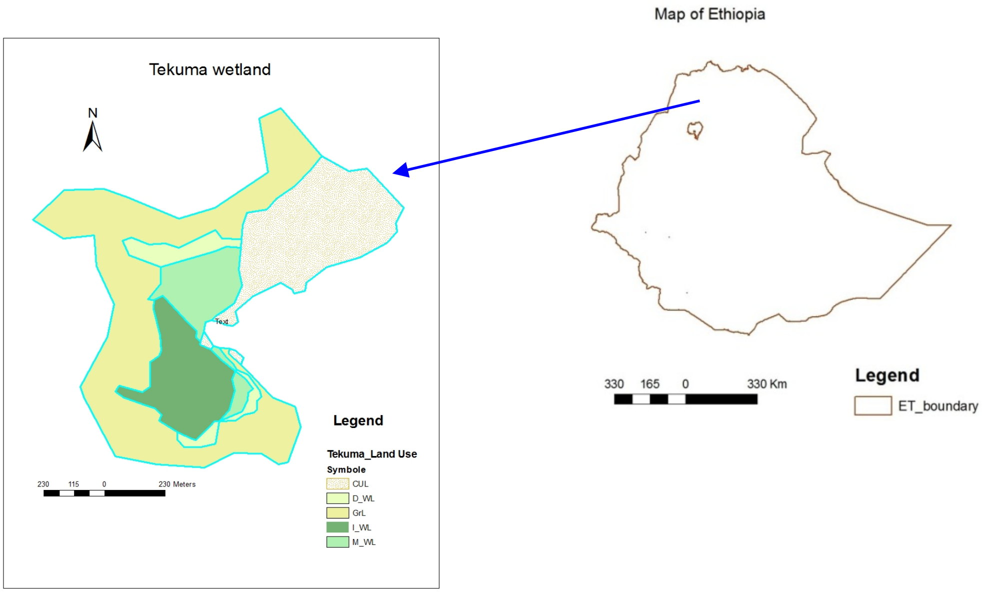
The research site, Tekuma wetland, is located 19 km Northwest of Bahir Dar city and 3 km Southwest of Lake Tana (Figure 1). The site is found in Wonjeta *Kebele* (the smallest administrative unit in town or rural area) in Bahir Dar Zuria District, West Gojjam Administrative Zone. Soil around the wetland is Nitosol: a soil commonly found in West Gojjam Administrative Zone (Belayneh Ayele, 2010). The topography of the area ranges from flat to moderately flat. The agro-climatic zone of the research area is categorized as mid-highland with an annual average rainfall of 1353 mm and average daily minimum and maximum temperature of 11.5^{o}C and 26.9^{o}C, respectively (MulugojjamTaye and Ferede Zewdu, 2012). Tekuma wetland comprises intact, moderately degraded, severely degraded wetlands, converted grazing land and cultivated land that covered 88 ha of land. Tekuma wetland is non-tidal wetland, which has a characteristic of marsh wetland (Ramsar Convention Secretariat, 2006).

2.2 Data Collection and Analysis Methods

Vegetation and soil sample collection followed stratified sampling techniques. Stratification of different degradation level of wetlands (sampling units) was made following Harding (2005). Accordingly, five sampling units (strata) were delineated for the study (Figure 2). These wetland strata were: intact wetland, moderately degraded wetland, severely degraded wetland, converted grazing land and converted cultivated land. Intact wetlands are wetlands that have relatively good biomass/vegetation cover with less or no human disturbance, with specialized wetland vegetation type. Moderately degraded wetlands are wetlands that are used for grazing livestock in the dry season when the water is dried up. They are with high human disturbance; their biomass/vegetation cover is low compared to intact wetland. Severly degraded wetlands are wetlands that are highly affected by human interference compared to moderately degraded wetlands. Vegetation status and their cover is found in poor condition; they are being changed to grazing lands. Converted grazing lands are lands that was used to be wetlands, but due to sedimentation and overgrazing they are permanently converted to grazing lands. It is characterized with low vegetation cover attributable to the existing overgrazing practices. Converted cultivated lands are lands that were used to be wetland, but they are permanently converted to cultivated land. They are with lower biomass/vegetation cover.

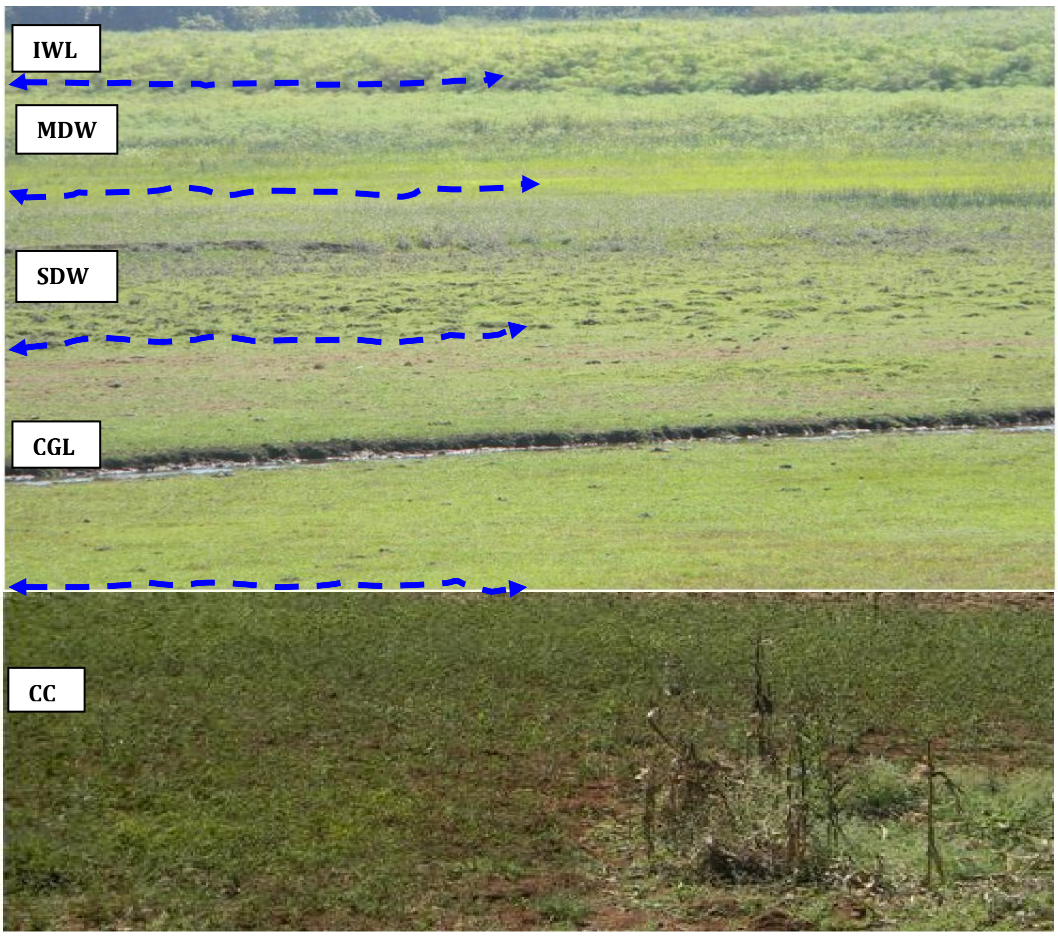
Three replicates of soil and plant sample were collected from each stratum (sampling units) following simple random sampling technique. One-meter square quadrant was used to collect plant samples from the selected sites following methods of Larry and Macha (2007). The above ground biomass (standing plant materials and materials lying on the ground or un-decomposed and partially decomposed plant materials or residues) found within one meter square were collected, chopped and were taken for laboratory analysis. Plant samples were collected between December 2012 and February 2013

Figure 1. Location of Tekuma wetland.



Sources: Data analysis using combination of google earth and GIS analysis

Figure 2. Wetland degradation levels in the study areas: Intact wetland (IWL); moderately degraded land (MDWL); severely degraded wetland (SDWL) Converted grazing land (CGL) and Converted cultivated land (CCL).



taking the maturity of the plant biomass into account.

Soil samples were collected from the top to a depth of 60 cm from the same place where plant samples were taken for carbon stock determination. Although Mitra *et al.,* (2005) stated that soil organic carbon can be accumulated to a depth of more than 2.5 meters; it was not possible to take samples at a depth greater than 60 cm due to the high ground water table in Tekuma wetlands. The soil sample, then was thoroughly mixed and 200 g soil was taken for lab analysis. For bulk density determination, core sampler method was used. Soil samples were collected on May 2013 when the water table was reduced.

Total organic matter in the plant samples was determined in the laboratory by using the loss-on-ignition method. Once organic matter was determined, organic carbon was calculated by using conversion factors. As a "Rule of Thumb" depending on the type of vegetation, on average, 45% of the total organic matter is carbon stock (USDA, 1977). Once the carbon stock from a sample site was determined, the total carbon stock per hectare from the vegetation was calculated. Walkley and Black's method were used for determination of the percentage by dry mass of organic matter in a soil sample. Once organic matter was determined in the laboratory, organic carbon was calculated by dividing organic matter by 1.724 (USDA, 1977) (Figure 2).

Total carbon sequestered in soil per hectare was determined by calculating the volume of soil using bulk density (Yu*et al.,* 2012). To calculate the total carbon stock per unit area of sampling unit, the sum of carbon content found in plant and soil were taken. Finally, the total carbon sequestered in each land use type was calculated in the form of CO_2equivalent (i.e. ton CO_2 equivalent) following Zerihun *et al*. (2011): CO_2 equivalent = Carbon stock in ton/ha * 44/12.

2.3 Data Analysis

Both descriptive and inferential statistics were used for the analysis of the data. The Analysis of Variance (ANOVA) procedures of statistical procedures for social sciences (SPSS 16) was used to see carbon stock content in the studied sample sites. Post hoc test was used to indicate mean difference between different wetland degradation levels.

3. Results and Discussion

Land use conversion has played significant role in increasing or decline of carbon stock across land use types (Ostlea *et al.,* 2009; Larionova *et al.* 2003).The mean soil organic carbon, plant organic carbon and total organic carbon content obtained in the current study is presented in Table 1. The mean soil organic carbon content showed significant ($p<0.05$) difference in different degradation levels considered. The higher soil organic carbon content was obtained in the intact wetland area while the lowest was in the converted cultivated land (123±11.72 t/havs. 61±17.01 t/ha).

The difference of organic carbon in the first three degradation levels was mild (Figure 3). However, the difference of organic carbon showed a sharp decline from the three degradation levels towards the

Figure 3. Trend of carbon stock in different wetland degradation levels (t/ha)

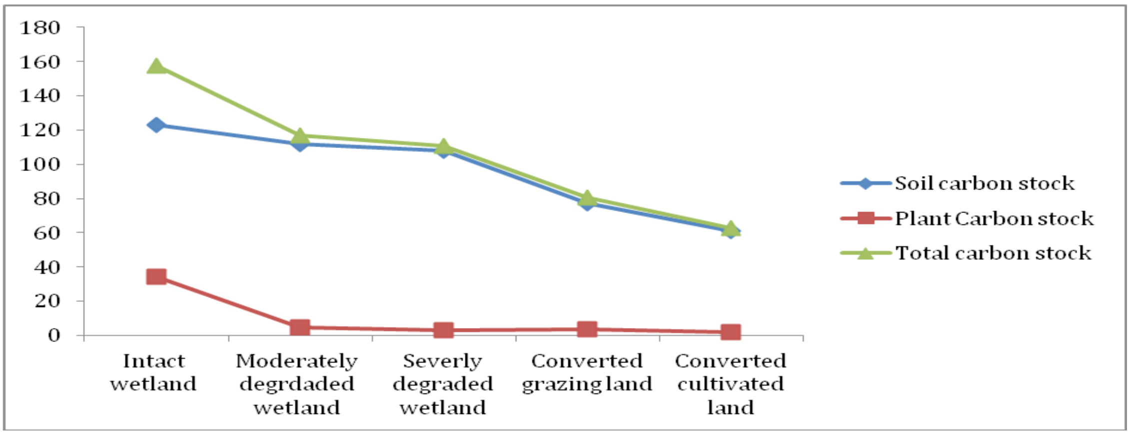


Table 1. Soil, plant and total organic carbon (t/ha) of different strata of Tekuma Wetland

Parameter	Soil organic carbon			Plant organic carbon			Total organic carbon		
	Mean±SD	Min	Max	Mean±SD	Min	Max	Mean±SD	Min	Max
Overall mean	96.2±13.62			9.44±1.97			105.84±15.86		
Strata	*			*			*		
Intact wetland	123±11.72[a]	110	132	34.5±9.82[a]	27.35	45.75	157.6±20.5[a]	137.00	178
Moderately degrdaded wetland,	112±12.77[a]	101	126	4.5±2.80[ab]	2.03	7.58	117±14.9[ab]	106.00	134
Severly degraded wetland	108±18.03[a]	93	128	3.0±2.53[b]	1.29	5.94	111±18.1[b]	94.00	130
Converted grazing land	77±8.6[b]	68	85	3.4±0.76[bc]	2.55	3.97	80.6±8.7[bc]	71.00	88
Converted cultivated land	61±17.01[b]	44	78	1.8±1.16[c]	1.00	3.17	63.0±17.1[c]	45.00	79

[a,b, c]*Means within the same column having different superscripts are significantly different at the indicated p-value; *p<0.05; SD= standard deviation*

converted grazing and cultivated lands. Reasons that contributed for the lower organic carbon content on the converted cultivated lands could be decreased fallout from vegetation (Khresat *et al*., 2008), lower carbon inputs because of less biomass carbon return on harvested land, accelerated water erosion and livestock grazing (Islam and Weil, 2000) and; in addition, soil organic carbon decomposition is accelerated due to the provision of better aeration by tillage. Masto *et al.*,(2008), moreover, elaborated that organic matter in cultivated soil has less physical protection, because tillage periodically breaks up macro-aggregates and exposes previously protected organic matter. Ultimately, the lower organic matter content on farm lands will lead to a reduced nutrient holding capacity.

Soil organic carbon stock varied due to degradation and conversion occurred on wetlands. The average soil organic carbon stock for converted farmland, converted grazing land, severely degraded, moderately degraded and intact wetlands were 61, 77, 108, 112, and 123 t/ha, respectively. The mean carbon stock showed consistent and gradual increase from converted farmland to converted grazing land, then to severely degraded wetland, to moderately degraded wetland and finally to intact wetlands (Fig.3). The ANOVA showed that there is significant difference at 0.05 levels in soil carbon stock among the five wetland degradation levels. The soil carbon stock is on average more than 10 times carbon stock in plants almost in all sampling units. In some of the sampling units, the soil carbon stock is more than 30 times carbon stock in plants. According to Larry and Macha (2007); Post and Kwon (1999) soil is the largest pool of sequestered carbon provided that the integrity of the vegetation cover is maintained, soil disturbance is avoided and soil erosion is prevented.

The comparison result depicted that there was no significant difference in soil organic carbon content between converted cultivated land and converted grazing lands. However, the carbon content of the converted cultivated land and converted grazing land are significantly lower than the remaining three wetland degradation levels at 0.05 levels. Other scholars have also proved that organic carbon in converted lands is lower than the natural land use (Askari *et al.,* 2014; Fisseha *et al.,* 2011). Although, carbon stock content showed a declining trend from the intact wetland to severely degraded wetland, there was no significant difference in the soil organic carbon content (Table 2).

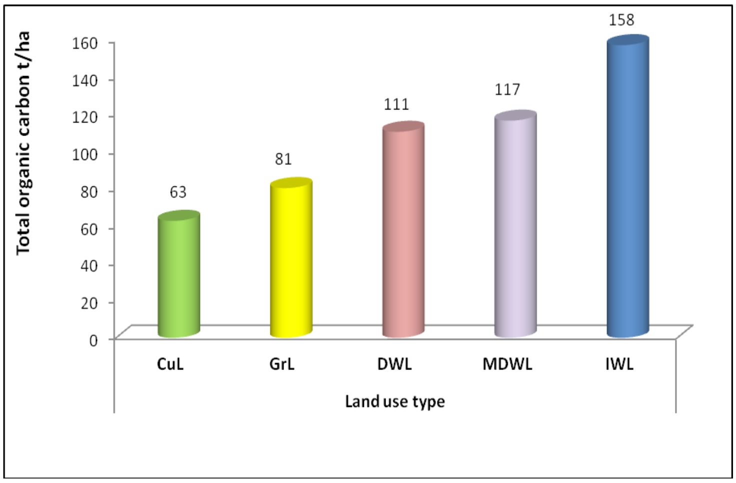
Plant organic carbon content in converted cultivated land, grazing land, severely degraded and moderately degraded wetlands was in the order of 2, 3, 3 and 5 t/ha, respectively (Figure3 and Table 1). Plant organic carbon in the intact wetland (35 t/ha) was significantly higher than other land use types. This significant organic carbon increment in the intact wetland is attributable to the very good and healthy stand of vegetation cover during plant sampling period. The *post hoc test* showed that significant mean difference was observed between the intact wetland and other land use types at 5% significance level.

Table 2. Post hoc test (LSD) on soil carbon mean difference.

Dependent Variable	(I) Level of wetland degradation	(J) Level of wetland degradation	Mean Difference (I-J)	Sig.
Soil Organic Carbon (t/ha)	Converted cultivated land	Converted grazing land	-16 [b]	0.194
		Degraded wetland	-47 [a]	0.002
		Moderately degraded wetland	-51 [a]	0.001
		Intact wetland	-62 [a]	0.0003
	Converted grazing land	Degraded wetland	-31 [a]	0.023
		Moderately degraded wetland	-35 [a]	0.013
		Intact wetland	-46 [a]	0.002
	Severely Degraded wetland	Moderately degraded wetland	-4 [b]	0.735
		Intact wetland	-15 [b]	0.211
	Moderately degraded wetland	Intact wetland	-11 [b]	0.347

Note:
[a] The mean difference is significant at the 0.05 level.
[b] The mean difference is not significant at the 0.05 level.

Figure 4. Average total organic carbon stock t/ha in each land use types



Total organic carbon (TOC), the sum of organic carbon in the soil and plant, was used to measure the carbon stock of the study area. The TOC stock for converted cultivated land, grazing land, severely degraded, moderately degraded and intact wetlands was 63, 81, 111, 117, and 158 t/ha, respectively (Figure 4). The trend of carbon stock showed gradual increment along the gradient from converted cultivated land to intact wetland.

The carbon stock difference in the gradient could be attributed to many factors, including: climatic condition, topographic condition, biological activity, biomass condition, sedimentation rate, land management, and socioeconomic condition of the area (Mitra *et al.,* 2005). Climate change is also a contributing factor for the reduction of organic carbon in the wetlands as increasing temperature causes an increase in organic matter decomposition rate. It is believed that every 10^0C temperature increase doubles decomposition rate of carbon (Gebrekidan, 2014). Therefore, climate change can have significant impact on the reduction of carbon stock in wetlands. However, intact wetlands are still the largest store of soil carbon stocks per unit area in the study area. My result is also supported by Mitra *et al.* (2005) who reported higher carbon stocks in the wetlands. According to Carré *et al.* (2010), in peat soils, average carbon density ranged between 600 and 1500 t ha^{-1} within the upper one meter of the deposit although peat soils are usually found in cool climate with low oxidation rate that is different from the warm and tropical climatic condition of Tekuma wetland.

The relatively low carbon stock (158 t/ha) in Tekuma wetland as compared to the finding of Carré *et al*. (2010) is mainly due to the nature of wetland soils in the area that is devoid of peat material. Besides, samples for Tekuma wetland were taken at a depth of 60 cm although organic matter can be stored in depths below one meter. According to Carré *et al*. (2010), wetland soils alone (without plant organic carbon) have organic carbon content ranging from 86 to 146 t/ha in which the soil organic carbon content of the current study area was found within this indicated range. In the case of the grazing and cultivated lands, as in most soils, organic matter content reduces with depth in the soil profile.

The ANOVA showed the presence of significant difference in organic matter content along the wetland gradient (**Table 3**).

Table 3. Post Hoc Test on Total Carbon Mean Difference.

Dependent Variable	(I) Level of wetland degradation	(J) Level of wetland degradation	Mean Difference (I-J)	Sig.
Total organic carbon ton/ha	Converted cultivated land	Grazing land.	-17.66[b]	0.685
		Degraded wetland	-48.00[a]	0.031
		Moderately degraded wetland	-54.00[a]	0.016
		Intact wetland	-94.66[a]	0.0001
	Converted grazing land	Degraded wetland	-30.33[b]	0.231
		Mod. degraded wetland	-36.33[b]	0.120
		Intact wetland	-77.00[a]	0.001
	Degraded wetland	Mod. degraded wetland	-6.000[b]	0.990
		Intact wetland	-46.66[a]	0.037
	Moderately degraded wetland	Intact wetland	-40.66[b]	0.073

[a,b]*The mean difference is significant at the 0.05 level.*

The mean separation result indicated that the total organic carbon content of the converted cultivated land was significantly lower form the remaining wetland degradation gradients except with the converted grazing land at 5% significance level. Converted grazing land showed significant lower total organic carbon with the intact wetland ($P<0.03$). However, the intact wetland had significantly higher total organic carbon content than all other sampling units except with the moderately degraded wetland. However, significant mean difference was observed in plant carbon stock between intact and moderately degraded wetlands. According to local residents, moderately degraded wetlands were part of intact wetland three years ago. That can be a possible reason for why soil organic carbon in these two sampling units was close to each other. The statistical analysis indicates that intact wetlands have higher carbon stock potential compared to other highly degraded wetland and converted cultivated and grazing lands.

The findings were in agreement with the work of Gebrekidan (2014) who reported a significant difference in total carbon content among undisturbed, sedimented, semi-disturbed and agricultural lands, although the amount of carbon stock was low as compared to carbon stock in the current study site. According to him, the lowest carbon content was found in soils of sedimented wetland and the highest total organic carbon content was in soils of undisturbed wetlands. Both studies demonstrated a reduction of carbon stock from intact/pristine wetlands to highly disturbed wetlands, although the findings on the carbon content of these two studies is completely different. Scholars have also have shown that wetland have played significant role on carbon stocking (Xiaonan *et al.,* 2008; Lloyd *et al*., 2013; and Whiting and Chanton, 2001).

CO_2-equivalent was used to quantify the amount of carbon sequestrated in the form of carbon dioxide, using a conversion factor following Zerihun *et al.* (2011). The mean CO_2-equivalent for converted cultivated land, converted grazing land, severely degraded wetland, moderately degraded wetland and intact wetland was: 231, 295, 407, 459, and 578 t/ha, respectively. Similar to the trend of total organic carbon in the soil,

Table 4. Post hoc test for meanCO2-equivalent comparison

Dependent Variable	(I) Level of wetland degradation	(J) Level of wetland degradation	Mean Difference (I-J)	Sig.
CO2-equivalent ton/ha	Converted cultivated land	Converted grazing land	-64[b]	0.7
		Severely degraded wetland	-176[a]	0.033
		Moderately degraded wetland	-228[a]	0.007
		Intact wetland	-347[a]	0.0003
	Converted grazing land	Severely degraded wetland	-112[b]	0.235
		Moderately degraded wetland	-163[a]	0.05
		Intact wetland	-283[a]	0.001
	Severely degraded wetland	Moderately degraded wetland	-51[b]	0.832
		Intact wetland	-171[a]	0.039
	Moderately degraded wetland	Intact wetland	-119[b]	0.19

[a,b]*The mean difference is significant at the 0.05 level.*

the amount of CO_2-equivalent sequestrated in the intact wetland was more than double the amount of CO_2-equivalent sequestrated in converted cultivated land.

A significant difference was observed on CO_2-equivalent across the wetland degradation gradient. The mean difference for CO_2-equivalent between converted cultivated land and other wetland gradients was significant except converted grazing land. A significant difference was observed between converted grazing land and moderately degraded and intact wetlands (Table 4). No significant difference was observed between converted grazing land and severely degraded wetland land; between severely degraded and moderately degraded wetlands in terms of CO_2-equivalent. On the other hand, there was significant mean difference between severely degraded and intact wetlands. The result of the analyses showed that if wetlands are conserved and properly managed more than 579 t/ha of CO_2 can be sequestered from the atmosphere, unlike the converted cultivated lands that only stored 231 t/ha of CO_2. If cultivated lands which are not converted from wetland are considered for analysis, the amount of CO_2 taken from the atmosphere would be lower than 231 t/ha. The organic carbon content of recently converted cultivated land is better than the organic carbon content of cultivated land, which is not converted from the wetland. Because the organic carbon content of recently converted cultivated land is not completely oxidized and released to the atmosphere.

4. Conclusion

In the study site, different levels of wetlands were mapped as intact, moderately degraded, severely degraded wetlands, converted grazing land, and converted cultivated lands. Carbon stock significantly differs along the wetland gradient. The Intact wetland has the highest total carbon stock while the converted farmland has the lowest. Carbon stock in soil is by far greater than carbon stock in plants. Generally, the total carbon stock in wetlands was more than double as compared to converted cultivated as well as grazing lands. This implies that wetlands can be considered as a good carbon sink, allowing for the sequestration of CO_2 from the atmosphere. The results of this study demonstrated that the contribution of wetlands to climate change mitigation through carbon sequestration was significant if they are conserved and well managed. Although wetlands are providing such important ecological benefits and are potential sources of income from carbon trading, they are being degraded and/or changed into different land use types. Land use change has played a vital role in carbon storage in soils. This calls for taking appropriate actions to safeguard them. Based on the research findings it is recommended that government should give special attention to wetlands and develop a conservation plan; Experts or institutions engaged on wetland management should let higher officials know the importance of wetlands and their impact on climate change mitigation through carbon sequestration. Future research activities should be considered to determine the carbon sequestration potential of different plant species and assemblages within the wetland.

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