Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.6, No.9, 2016

Carbon Sequestration Potentials of Selected Wetlands at Lake Ziway, Ethiopia

Tesfau Bekele Brook Lemma Seyoum Mengistou
Department of Zoological Sciences, Addis Ababa University, PO box 1176, Addis Ababa, Ethiopia

ABSTRACT:
Wetlands are known for their high productivity owing to their high biomass content per unit area. This is however changing due to human needs to convert them to various land use types. The objective of this study was therefore to investigate the impact of wetland conversion on carbon sequestration potentials of selected wetland sites at shore area of Lake Ziway. Five sites were selected purposefully and triplicate vegetation and soil core samples were collected from each site in July and August 2015 and analyzed for above ground biomass, above ground plant carbon, and soil organic carbon contents. The results indicated that the least impacted wetland had significantly higher ($p<0.05$) plant and soil organic carbon content than the other land use categories. The above ground plant carbon ranged between 49.23 g C m^{-2} in the converted grazing land to 2066.17 g C m^{-2} in the least impacted wetland. Soil organic carbon content ranged between 7.36 g C kg^{-1} in the converted cultivated land to 91.43 g C kg^{-1} in the least impacted site. Soil organic carbon content was positively correlated ($p<0.01$) with above ground biomass and soil moisture whereas soil temperature showed significant negative correlation ($p<0.01$). The results showed that a high reduction of organic carbon storage of both the soil and above ground as one goes from un-impacted to impacted land use types in wetlands of lake Ziway, implying the need of improved management of wetlands so as to enhance the biomass carrying capacity of such areas to mitigate carbon emissions.
Keywords: Carbon sequestration, Degradation, Lake Ziway, Management, Organic carbon, Wetlands

1. INTRODUCTION

The Earth's climate is changing, as witnessed by higher atmospheric temperatures, decreased snow and ice cover, and increasing sea level in the 20th century and especially towards the end of that century (Mitsch and Gosselink, 2015). The cause of this climate change is the increased concentration of greenhouse gases (GHGs), primarily carbon dioxide in the atmosphere, mostly caused by anthropogenic emissions (Evans *et al*., 2014).

Generally, wetlands play a key role in reducing the emissions of carbon dioxide to the atmosphere. There is a significant amount of carbon stored in wetland soils, peats, litter, and vegetation globally (estimated 500-700 Giga ton). This amount stored in wetlands may approach a total amount of atmospheric carbon estimated at 753 Giga ton (Kusler, 2000).

Despite this, very little attention was given to wetlands regarding their role in carbon sequestration and hence wetlands were neglected and converted to other land use types due to poor management practices especially in developing countries such as Ethiopia. Complete conversion and modification of wetlands to cultivated land, improper large scale farming systems with open-land grazing, improper farming methods, poor tillage systems, removal of grasses and trees for household uses and planting water-demanding crops are some of the major threats to Ethiopian wetlands (Gebresllassie *et al*., 2014). Consequently, as the country is prone to sporadic drought spells, the effect of wetland loss could be more visible on the local climate pattern. Therefore, sustainable management of wetlands is a practical way of retaining the existing carbon reserves and thus avoiding emission of carbon dioxide. In order to achieve these outcomes through vegetation, soil and water management, and more information is required about carbon stock dynamics and land cover changes in wetlands.

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 Worku (2014) on the Fogera wetlands of Lake Tana Basin. However, no recorded studies were found on carbon sequestration potentials of the rift valley wetland systems. This study is therefore focused on the impact of wetland conversion and degradation on the carbon sequestration potentials of selected sites at Lake Ziway wetlands, Ethiopia. These sites were selected because of the high anthropogenic pressure to convert them into other land use forms through poor wetland management practices thereby affecting the carbon storage potentials of these wetlands.

2. MATERIALS AND METHODS

2.1 Description of study area

Lake Ziway, one of the important fresh water rift valley lakes, is located at an altitude of 1,850 m.above-sea level (asl) (Abera, 2005). The lake lies at 8° 01' N/38° 47' E and at an altitude of 1636 m asl (Von Damm & Edmond, 1984 cited in Tamirie and Mengistou, 2014) (Fig. 1). There is well marked vegetation zonation around the shore of the lake in which it is sequenced from the margin to the adjacent dry land. The lake is surrounded by farming communities, which compete for water to supply the adjacent irrigated agricultural fields.

2.2. Data collection methods
2.2.1. Field sampling protocol

Five wetland categories (degradation levels) were selected purposefully, namely, minimally disturbed (Least-impacted wetland), moderately degraded wetland, degraded wetland, grazing land (converted wetland), and cultivated land (converted wetland) (Appendix 1). Sites were selected by preliminary field observation using criteria such as vegetation cover, water level, topography, and human and livestock intervention (Bernal, 2008; Arina *et al*., 2013).

2.2.1.2. Plant sample collection

A field sampling protocol for destructive sampling of under-storey biomass designed by Hairiah (2001) was applied for this study. Accordingly, a 40 by 5 meter vegetation transect was demarcated randomly within the purposefully selected wetland sites. Then, a 1 by 1 meter sampling frames were identified within the 40 by 5 m^2 transect. The major vegetation types which were found in the study area were also collected, zipped in plastic bags, carefully labeled and then transported to Addis Ababa University National Herbarium for identification.

2.2.1.3. Soil sample collection

Composite soil samples were collected from the ground to only 60 cm depth (Junbao *et al*., 2013) since it was reported that carbon profiles rapidly decrease with soil depth in tropical wetlands (Bernal, 2008; Villa, 2014). Composite sample from three soil cores per site was taken to capture variations in organic matter deposition in the area (Bernal, 2008) using standard soil sampling auger. Soil samples were taken from the same sites where plant samples were collected. Each sample was then placed in clean plastic zip-lock bags, carefully labeled and transported for laboratory analysis in ice boxes.

2.3. Laboratory analysis and procedures
2.3.1. Above ground biomass and Plant organic carbon

Plant organic matter was determined using ignition method by warming the ground (<2mm), oven dried samples to 550^oC for 4 hours. Once organic matter was determined, then organic carbon was obtained using a conversion factor (45%) (USDA, 2007)

2.3.2. Soil sample analysis

2.3.2.1. Physico-chemical parameters

Physical and chemical parameters were measured according to the soil manual prepared by Kalra and Maynard (1991). Soil temperature was recorded on site at a depth of 60 cm while sampling using soil thermometer. Soil pH and electrical conductivity (EC) were determined using 1:2 and 1:5 Soil-To-Water Extraction Method with a digital HACH multi parameter meter (HQ40d model). Soil moisture was also estimated using oven-drying method. Soil texture was determined using a hydrometer method. To estimate bulk density, soil samples with a known volume were oven dried at 105^oC for two days (48 hours). Bulk density was determined by dividing the dried sample to its volume (Kuffman and Donato, 2012).

2.3.2.3. Estimation of soil organic carbon concentration

Soil organic carbon concentration was determined using loss on ignition method (Kuffman and Donato, 2012). Ground Soil samples (<2mm) were placed in a muffle furnace at 550 ^0C for 4 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 and Donato, 2012).

2.4. Data Analysis
To analyze the data descriptive statistics (frequency, crosstab, mean, standard deviation) were performed. One-way Analysis of Variance (ANOVA) with Post-hoc test (Tukey) was performed for the detection of differences in carbon sequestration potential within and among different categories of wetland using SPSS software (Version 21).

Bi-variate Correlation Statistics (Pearson) was also performed to determine the strength of relationship between aboveground vegetation biomass and soil organic carbon content as well as soil physico-chemical parameters and soil organic carbon content.

3. RESULTS
3.1. Identified Vegetation
According the National Herbarium at Addis Ababa University, 10 emergent plant species belonging to six families were identified (Table 1).

3.2. Soil physico-chemical parameters
Mean values for temperature, pH, soil moisture, electrical conductivity, and bulk density recorded were as follows (Table 2). Temperature and moisture were inversely related with each other. Soil temperature increased as degradation level of the wetland increased. Whereas soil moisture decreased as degradation level of the

wetland increased. The highest mean pH value was recorded at the grazing site (9.1) and the minimum mean pH in the moderately degraded wetland (8.2). A minimum value of EC was observed in the degraded wetland whereas the maximum value was observed in the moderately degraded wetland site. Soil texture in almost all the sites had a medium sandy clay texture class except the soil of cultivated land which was very fine clay.

Significantly high temperature was recorded in the cultivated land (converted wetland) whereas the least value was recorded in the non-impacted wetland site although the difference was not significant. Soil moisture content was significantly lower in the cultivated land ($p<0.05$) whereas the highest value was obtained at the least-impacted site ($p<0.05$). There was no significant difference in bulk density and pH among sites.

3.3. Aboveground biomass

Above ground biomass of the sites varied from 122.1 g DW m^{-2} (grazing land) to 4410 g DW m^{-2} (least impacted wetland) and the highest mean biomass value was recorded at the least-impacted wetland site which is 3252.6 g DW m^{-2} followed by moderately degraded wetland, cultivated land (cabbage biomass), degraded wetland and grazing land which accounted for 1193.6, 852.9, 457.7, 146.6 g DW m^{-2}, respectively, with the least-impacted wetland having significantly higher difference than the other remaining sites at $p<0.05$.There was also significant difference ($p<0.05$) between moderately degraded wetland and grazing land. But no significant difference was observed ($p>0.05$) among degraded wetland, grazing land, and cultivated land.

3.4. Carbon sequestration potential

3.4.1. Plant organic carbon

The plant organic carbon content of the study sites varied from 49.2 g C m^{-2} to 2066.2 g C m^{-2}. The highest mean plant organic carbon content was obtained in the least-impacted site followed by moderately degraded wetland site, converted cultivated wetland, degraded wetland and finally grazing land where plant organic carbon was 1513.6, 526.5, 207.9, 207.8, and 57.9 g C m^{-2}, respectively (Fig. 2).

Statistically significant differences were observed in the plant organic carbon content of the study sites ($p<0.05$). There were significantly ($p<0.05$) higher values of aboveground plant organic carbon in the least-impacted wetland than the other land use types (degradation levels) and moderately degraded wetland with grazing land. However, there was no significance difference ($p>0.05$) between degraded wetland, grazing land, and cultivated land.

3.4.2. Soil organic carbon

The highest mean organic carbon content (g C Kg^{-1}) was obtained in the least-impacted wetland site which was about 67.5 g C Kg-^{1}, followed by the moderately degraded wetland site, grazing site, cultivated wetland site, and degraded wetland site which contained 39.5, 17.3, 14.5, and 12.9 g C Kg^{-1}, respectively (Fig. 3).

There were significant differences ($p<0.05$) between least-impacted wetland and the other land use types. But according to the post-hoc multiple comparison test there was no significant difference ($p>0.05$) among degraded wetland, grazing and cultivated land types.

3.4.3. Soil organic carbon in relation to aboveground biomass and soil physico-chemical parameters

In this study, there was a significant positive correlation ($p<0.01$) between soil organic carbon content and aboveground biomass. As aboveground biomass (g DW m^{-2}) increased, soil organic carbon content (g C kg^{-1}) also increased. The highest value of soil organic content was found in the least impacted wetland site where the aboveground vegetation biomass was also highest.

Soil temperature (^{0}C) was negatively correlated with soil organic carbon content which was significant ($p<0.01$); as soil temperature increased organic carbon content of the soil decreased. But, Soil moisture content was correlated positively with soil organic carbon content ($p<0.01$). Bulk density, pH, and electrical conductivity of the soils of the various land types were not correlated with soil organic carbon content.

4. DISCUSSION

4.1. Variability of carbon sequestration between different categories of wetlands

4.1.1. Aboveground plant carbon

Emergent macrophytes form some of the productive plant communities (Jones and Humphries, 2002) and can fix large amounts of atmospheric CO_2 and store carbon in their tissues. In this study, the highest value was recorded in the least-impacted and the moderately degraded wetland sites. This was not unexpected as these areas are visibly good in terms of aboveground vegetation composition due to lesser disturbances as compared to the other sites.

Results found in this study were higher than the earlier results reported in Ethiopian wetlands such as by Afework (2013) in the Tekuma Wetlands of Lake Tana Basin (0 to 500 g C m^{-2}), but it is almost within the range of other reported studies. Saunders *et al.* (2014) in their study on papyrus wetlands of Lake Navishia, Kenya, found that aboveground plant carbon ranged from 490 to 5540 g C m^{-2}. Jones and Mathuri (1997) and Jones and Humphries (2002) also reported 3600 and 1500 g C m^{-2} in the living vegetation of papyrus wetland, respectively in the same study area. Barbera *et al.* (2015) also reported 1900 g C m^{-2} and 3800 g C m^{-2} were fixed by individual plants of *Cyperus papyrus* and *Cyperus zizanioides.*

Land use changes such as converting wetlands to grazing and cultivation land by draining and clearing the wetland biomass could result in loss of the above mentioned stored carbon to the atmosphere. According to Saunders *et al*. (2014), clearance of wetlands to other forms could result in significant emissions of CO_2 due to vegetation loss. In this study, the least value found in the grazing land could be due to the effect of heavy livestock grazing intensity on the vegetation cover far beyond the carrying capacity of the land. Reeder and Schuman (2002) clearly stated that aboveground plant carbon decreased as grazing intensity increased. The study by Enriquez *et al.* (2015) also supported the effect of long term grazing on plant carbon and the result indicated that overgrazing has an effect on carbon storage and reduced on average 35% of the total ecosystem carbon pool. In this study, it was hypothesized that converted cultivated wetland site will have the least value of plant organic carbon. However, it had an average value higher than grazing and degraded wetland sites. This could be due to the seasonal cover of the area by different vegetables that can enhance fixation of carbon dioxide from the atmosphere. This indicated that better management methods of wetlands like seasonal grazing could have a big role in fixing atmospheric carbon into plant tissues.

4.1.2. Soil organic carbon (SOC)

The highest SOC content was found in the least-impacted site followed by moderately degraded wetland than in other study sites. This could be due to the enhancement of the soil organic matter accumulation from the litter fall of the aboveground biomass and the presence of flooded soil in the areas. Freshwater wetlands are known to be significantly carbon sinks due to their high productivity and water logged conditions (Bernal & Mitsch, 2012). Since high soil moisture and lower temperature favor reduction of aerobic decomposition, accumulation of biomass predominates in this site. (Chimner & Ewel, 2004; Bernal & Mitsch, 2013; and Villa, 2014).

Results of SOC found in this study are more or less within the range of other results reported in other related studies of Ethiopian wetlands and other worldwide studies on tropical wetlands. In a similar study, Werku (2014) compared the soil carbon sequestration potentials of natural wetlands, semi disturbed (sedimented), and agricultural land in Fogera wetlands of Lake Tana Basin; and found out that natural wetlands were the best carbon storage areas. (See also the works of Bernal (2008) in tropical wetlands of Costa Rica and Eid & Shaltout (2013) in Egypt).

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. In this study, despite the assumption that converted cultivated land would have the least SOC, degraded wetland sites were found to have the least SOC content. Although this site was better than grazing and cultivated land both in terms of aboveground biomass and the hydrology of the soil, other associated factors might have affected the storage of SOC. Villa (2014) suggested that it is a combination of factors that enhance CO_2 accumulation in wetlands besides the hydrology and vegetation status only. One possible reason for this variation could be the high bulk density of soil (2.15 g cm^{-3}) recorded in the soil due to its sandy nature (Table 2). This high bulk density could be an indication of peat loss from the soil (Drexler *et al.,* 2009). Another reason could be the texture of the soil where fine clay may have some role in protecting the SOC. Soils high in clay content are higher in SOM content than sandy soils since there is restricted aeration in fine-textured soils with reducing the rate of organic matter oxidation (McCauley *et al.,* 2009).

The outcome in this study that there is high reduction of organic carbon storage of the soil after a wetland is converted into other land use types such as grazing and cultivated land is also supported by the statement that conversion of wetlands to cultivated fields results in a significant decrease in the total carbon dioxide storage capacity (Nelson *et al.,* 2007), Further, Berhongaray *et al.* (2013) reported that there is 16% reduction of SOC after conversion of a wetland in to cultivated field. Gauangyu *et al.* (2010) also reported the decrease of SOC content by 49.3 %. The former is lower while the latter is almost similar compared to the current study which is approximately 53.01% even though the study area was being cultivated for more than 20 years. Similarly, this study also concluded that.

4.1.3. Soil organic carbon in relation to above ground biomass (AGB)

The correlation statistics done for this study has shown that AGB was related positively with SOC. Many studies have also indicated the same where the aboveground vegetation biomass affects the relative amount of carbon that eventually falls to the surface of soil. The study by Junbao *et al.* (2013) and Eid & Shaltout (2013) showed that the inputs of plant litter to the soil were correlated positively ($p<0.01$) with soil organic carbon content.

Although the grazing site had the least aboveground biomass in this study (Fig. 1), it contained better soil carbon than cultivated and degraded wetlands. According to Reeder & Schuman (2002), sometimes high soil organic carbon could be found in grazing sites due to the immobilization of carbon in aboveground biomass and livestock could enhance breakdown and incorporation of litter to the soil.

4.1.4. Soil organic carbon in relation to physico-chemical parameters

Other studies conducted in wetlands also corroborate the present study and found negative correlations among SOC and temperature (Ali *et al.,* 2006; Kirschbaum, 1995; Jobbagy & Jackson, 2000), and a positive correlation among SOC and water content (Ali et al., 2006; Muniz *et al.* 2014; Murillo *et al.,* 2015; Villa, 2014; Wang et al., 2011).

This study showed that as temperature of the soil decreases, SOC content increases since lower temperature limits decomposition by affecting soil microbial activities leading to accumulation of organic matter, which is also supported by the works of Bernal (2008);, Bernal & Mitsch (2012 & 2013); Franzuleberies *et al.* (2011); Jones & Humphries (2002); & Villa (2014).

In this study, soil pH was not correlated with SOC. Unlike soil temperature and water content, it is not a major factor which can affect SOC (Wang *et al.,* 2011) although the increase in pH could enhance mineralization of SOC by stimulating soil microbes (Guangyu *et al.,* 2010).

5. CONCLUSION AND RECOMMENDATIONS

From this study it can be concluded that a high reduction of organic carbon storage of both the soil organic carbon and aboveground plant carbon was observed after a wetland was converted and degraded into other land use types such as grazing and cultivated land. In addition, significantly positive correlation was found among soil organic carbon content and aboveground vegetation biomass, and soil moisture; where as a negative correlation between SOC content and temperature.

Wetlands of the study area, namely, Ziway wetlands, are declining in surface area over time due to many reasons. This is also having a significant impact on ecological values of the wetlands including their carbon sequestration potential. It is therefore recommended that special attention should be given to improve the management of wetlands in the area so as to enhance their capacity to mitigate carbon emissions. Such management scheme should however be realistic by considering the cost-benefit analysis of processing wetland products (e.g. vegetation, fishes, etc.) by local populations and allowing sufficient regeneration time and space for the wetlands sustainability.

Acknowledgments

Our special thanks extends to the Austrian Development Cooperation (ADC) for sponsoring this research. We would like also to thank taxonomists of National Herbarium of Addis Ababa University who helped us in the identification of vegetation. All laboratory and data processing activities were conducted at Addis Ababa University, Addis Ababa, Ethiopia.

REFERENCES

Ali, M., Taylor, D., & Inubushi, K. (2006). Effects of Environmental Variations on CO_2Efflux from a Tropical Peatland in Eastern Sumatra. *WETLANDS*, Vol. 26(2):612–618

Abera, L. (2005). Site Action Plan for the Conservation and Sustainable Use of the Lake Ziway Biodiversity (Rift valley Lakes project): *Institute of Biodiversity Conservation* (IBM). 64pp

Arina, P., Schrier, U., & Gusti Z.A. (2013). Methods for determining greenhouse gas emissions and carbon stocks from oil palm plantations and their surroundings in tropical peatlands. In: *Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil* (RSPO). 196pp

Barbera, A.C., Borin, M., Cirelli, G.L., Toscano, L. & Maucieri, C. (2015). Comparison of carbon balance in Mediterranean pilot constructed wetlands vegetated with different C4 plant species. *Environ SciPollut Res*22:2372–2383. DOI 10.1007/s11356-014-2870-3

Bernal, B. (2008). Carbon pools and profiles in wetland soils: The effect of climate and wetland type. M.Sc. thesis, The Ohio State University. 99pp

Bernal, B. & Mitsch, W. J. (2012). Comparing carbon sequestration in temperate freshwater wetland communities. *Global Change Biology*: doi: 10.1111/j.1365-2486.2011.02619.

Bernal, B. & Mitsch, W. J. (2013). Carbon sequestration in freshwater wetlands in Costa Ricaand Botswana. *Biogeochemistry*115:77–93. DOI 10.1007/s10533-012-9819-8

Chimner, R.A. & Cooper, D.J. (2003). Influence of water table position on CO_2 emissions in a Colorado subalpine fen: An in situ microcosm study. *Soil Biology and Biogeochemistry* 35: 345–351.

Chimner, R.A. & Ewel, K. C. (2004). Differences in carbon fluxes between forested and cultivated Micronesian tropical peatlands. *Wetlands Ecology and Management* 12: 419–427.

Drexler, J.Z., Fontaine, C.S., & Deverel, S.J. (2009). The Legacy of Wetland Drainage on the Remaining Peat in the Sacramento – San Joaquin Delta, California, USA. *WETLANDS*, Vol. 29: 372–386.

Eid, E.M., & Shaltout, K.H. (2013). Evaluation of carbon sequestration potentiality of Lake Burullus, Egypt to mitigate climate change. *Egyptian Journal of Aquatic Research*39:31–38.

Enriquez, A.S., Chimner, R. A., Cremona, M. V., Paula, & D., Bonvissuto, G. L. (2015). Grazing intensity levels influence C reservoirs of wet and mesic meadows along a precipitation gradient in Northern Patagonia. *Wetlands Ecol Manage*. pp. 13. DOI 10.1007/s11273-014-9393-z

Franzluebbers, A.J., Haney, R.L., Honeycutt, C.W., Arshad, M.A., Schomberg, H.H. & Hons, F.M. 2001. Climatic influences on active fractions of soil organic matter. *Soil Biology & Biochemistry* 33:1103-1111

Friedrich, Z. 2012. Feasibility study for a Lake Tana Biosphere Reserve, Ethiopia. Federal agency for nature conservation: ISBN 978-3-89624-052-1, Germany.

Worku, G. 2014. Assessment on the Shrinkage and Ecological Importance of Wetlands of Fogera Plain, North West Ethiopia. *Journal of Environment and Earth Science*: ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online):4 (11)

Tamirie, G., & Mengistou, S. 2014. Biomass and net aboveground primary productivity of macrophytes in relation to physico-chemical factors in the littoral zone of Lake Ziway, Ethiopia. *Tropical Ecology* 55(3): 313-326

Guangyu, C., Xin, C., and Yi, S. (2010). Profile distribution of soil organic carbon under different land use type in Sanjing Plain. 19th World Congress of Soil Science, Soil Solutions for a changing World 1 – 6.

Gebresllassie, H., Gashaw, T., & Mehari, A. (2014). Wetland Degradation in Ethiopia: Causes, Consequences and Remedies. *Journal of Environment and Earth Science*, Vol.4, No.11

Hairiah, K., Sitompul, S. M., van Noordwijk, M. & Palm, C. A. (2001). Methods for sampling carbon stocks above and below ground. A Manual, Bogor, Indonesia. ASB_LN 4B. pp. 23

Jobbagy, E. & Jackson, A. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, 10(2): 423– 436.

Jones, M. B. & Muthuri, F. M. (1997). Standing biomass and carbon distribution in a papyrus (Cyperus papyrus L.) swamp on Lake Naivasha, Kenya. *J. Trop Ecol*. 13: 347–356.

Jones, M. B., & Humphries, S. W. (2002). Impacts of the C4 sedge *Cyperus papyrus L.* on carbon and water fluxes in an African wetland. *Hydrobiologia* 488: 107–113.

Junbao, Y., Hongfang, D., Yunzhao, L., Huifeng, W., Bo, G., Yongjun, G., Di, Z., & Yongli, W. 2013. Spatiotemporal Distribution Characteristics of Soil Organic Carbon in Newborn Coastal Wetlands of the Yellow River Delta Estuary. *Clean – Soil, Air, Water* 00(0): 1–8

Kalra Y.P. & Maynard, D.G. (1991). Methods manual for forest soil and plant analysis. Northwest Region Information Report NOR-X319, Forestry Canada.

Kauffman, J.B. & Donato, D.C. (2012). Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86. CIFOR, Bogor, Indonesia.

Kirischbaum, U.F. (1995). The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic carbon storage. *Soil Biol. Biochem*. (27) 6:753-760

McCauley, A., Jones, C. & Jacobsen, J. (2009). Soil pH and Organic Matter. In:*Nutrient Management Module No. 8.* Montana State University-Bozeman. pp 1-12

Mitsch W. J. & Gosselink J. G. (2015). *Wetlands*. Fifth ed. Wiley, New York. pp. 721

Muniz, J.M., Hernández, M.E. & Casasola, P.M. (2014). Comparing soil carbon sequestration in coastal freshwater wetlands with various geomorphic features and plant communities in Veracruz, Mexico. *Plant Soil* 378:189–203. DOI 10.1007/s11104-013-2011-7

Murillo, J.C., Almendros, G., Knicker, H. (in press). Wetland soil organic matter composition in a Mediterranean semiarid wetland (Las Tablas de Daimiel, Central Spain): Insight into different carbon sequestration pathways.

Nelson, J. D. J., Schoenau, J. J., Malhi, S. S. & Gill, K. S. (2007). Burning and cultivation effects on greenhouse gas emissions and nutrients in wetland soils from Saskatchewan, Canada. *Nutr Cycl Agroecosyst* 78:291–303. DOI 10.1007/s10705-007-9092-8

United States Development of Agriculture. (1977). Conservation agronomy technical notes: relationships of carbon to nitrogen in crop residues. pp 1-2.

Reeder, J.D. & Schuman, G.E. (2002). Influence of livestock grazing on C sequestration in semi-arid mixed grass and short-grass rangelands. *Environmental Pollution*116: 457–463

Saunders, M. J., Kansiime, F. & Jones, M.B. (2014). Reviewing the carbon cycle dynamics and carbon sequestration potential of *Cyperus papyrus* wetlands in tropical Africa. *Wetlands Ecol Manage*22:143–155. DOI 10.1007/s11273-013-9314-6

Villa, A. (2014). Carbon Dynamics of Subtropical Wetland Communities in South Florida. PhD dissertation, the Ohio State University. pp. 160.

Wang, H., Wang, R., Yu, Y., Mitchell, M.J. & Zhang, L. (2011). Soil organic carbon of degraded wetlands treated with freshwater in the Yellow River Delta, China. *Journal of Environmental Management*92: 2628-2633.

Afework, Y. (2013). The impact of wetland degradation and conversion on carbon sequestration potential: The case of Tekuma wetland, Lake Tana sub-basin, Ethiopia.Unpublished M. Sc. thesis, Bahar Dar University, Bahir Dar, Ethiopia.

Appendix 1. Definition of different wetland categories selected for sampling

Least-impacted wetlands	These are wetlands in which human and animal disturbance are very low. There is no direct animal grazing and human pressure on these sites. As a result, they have a good volume of aboveground vegetation biomass and undisturbed soil. These areas are well saturated with water since their topography is very close to the lake, and are mostly covered by two dominant emergent vegetation i.e. *Typha latifolia*(Local name; Filla)and Echinochloa stagnina (Local name; Kesme). Other vegetation types like *Schoenoplectus corymboses (Local name; Chufo), Aeschynomene elaphroxylon,* and *Ageratum conyzoids* are also found rarely. So, it is assumed that high level of biomass, good vegetative cover or specialized vegetation types and hydric soil are common characteristics of these wetlands so that highest carbon store was expected both in the vegetation as well as in the soil compared to the other types.
Moderately degraded wetlands	These are wetland sites in which there is human and animal disturbance to some degree of extent compared to the least-impacted sites. There is harvesting of emergent vegetation especially the dominant vegetation of *Typha latifolia*(Local name; Filla),*Cyperus papyrus,* and *Cyperus latifolius* (Local name; Ketema*)* to some extent by the people although it is not that much disturbed by livestock. So, due to this human disturbance, it was assumed that these wetlands lost their biomass volume and soil organic matter content to some degree, but still they are found in better condition than the degraded sites as they have already a good vegetation cover and hydrology which can moderate the soil organic carbon store.
Degraded wetlands i.	These sites are still wetlands, but are highly affected by human pressure compared to the least-impacted and moderately degraded wetlands. They have less vegetation cover, especially composed of some grass groups of *Cyperus rigidifolius* (local name; kuni), *Leersia hexandra* (local name; sar), and *Persicaria senegalensis* (Local name; Obeta). Emergent vegetations like *Schoenoplectus corymboses* (Local name; Chufo) and *Typha latifolia* (Local name; Fila) are also rarely found in this wetland type. Compared to the moderately degraded wetlands, there is a very high human disturbance and many animals graze on these sites especially during the dry season.
Grazing land	These wetlands were highly (severely) degraded due to over-grazing. As a result, they are assumed to loss their wetland properties due to the high disturbances of the soil and the vegetation due to the high stocking density of livestock. These areas are mostly dominated by grass species of *Cyperus rigidifolius* (local name; Kuni) and *Leersia hexandra* (local name; Sar) which are grazed to the ground. Hence, their biomass production was expected to be less with lower carbon sequestration potential in the soil due to less input of organic matter from the vegetation and due disturbance of the soil profile by livestock.
Cultivated land	These lands were used to be wetlands in the past, but they were converted in to agricultural land for production of some vegetables such as cabbage, lettuce, and onions by the surrounding community. They cultivate three times a year in these areas. As a result, these lands lost the characteristics of wetland almost completely.

Table 1. Major vegetation types identified from the study sites

No.	Botanical_Name	Family
1	*Cyperus rigidifolius* Steud.	Cyperaceae
2	*Leersia hexandra* Sw.	Poaceae
3	*Persicaria senegalensis* (Meisn.)Sojak	Polygonaceae
4	*Schoenoplectus corymboses* (Roem. & Schult.)Rayn.	Cyperaceae
5	*Echinochloastagnina* (Retz.)P.Beauv.	Poaceae
6	*Cyperus papyrus* L.	Cyperaceae
7	*Aeschynomen eelaphroxylon* (Guill. & Perr.)Taub.	Fabaceae
8	*Ageratum conyzoids* L.	Asteraceae
9	*Cyperus latifolius* Poir.	Cyperaceae
10	*Typha latifolia* L.	Typhaceae

Table 2. Results of some physico-chemical parameters recorded from the study sites (Mean ± Standard deviation).

Wetland Categories	**Temperature (^{0}C)**	**Soil moisture (%)**	**Soil pH**	**Electrical conductivity (µS/cm)**	**Bulk density (gcm^{-3})**
Least impacted wetland	21.0±1.095	20.1±6.280	8.42±.618	275.7±9.235	1.87±.342
Moderately degraded wetland	21.5 ± .547	19.4±5.118	8.20±.054	476.0±17.88	1.70±.728
Degraded wetland	22.0 ± 2.190	14.5±3.234	8.86±.027	185.9±.054	2.15±.342
Grazing land	24.5 ± .547	13.7±2.536	9.11±.887	384.0±19.20	1.84±.232
Cultivated land	27.5 ± 1.643	5.05±1.074	8.41±.410	258.6±5.201	1.98±.029

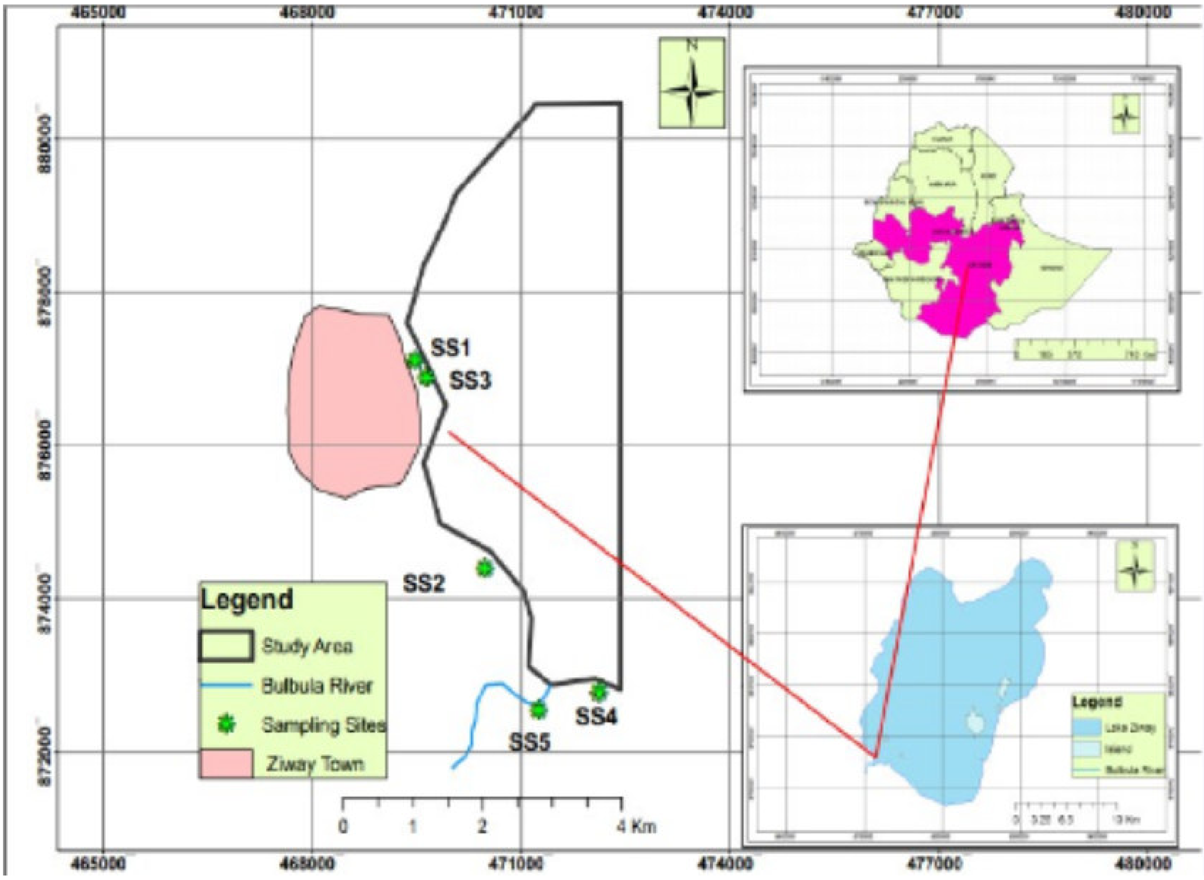

Fig. 1. Location map of the study area and sampling sites

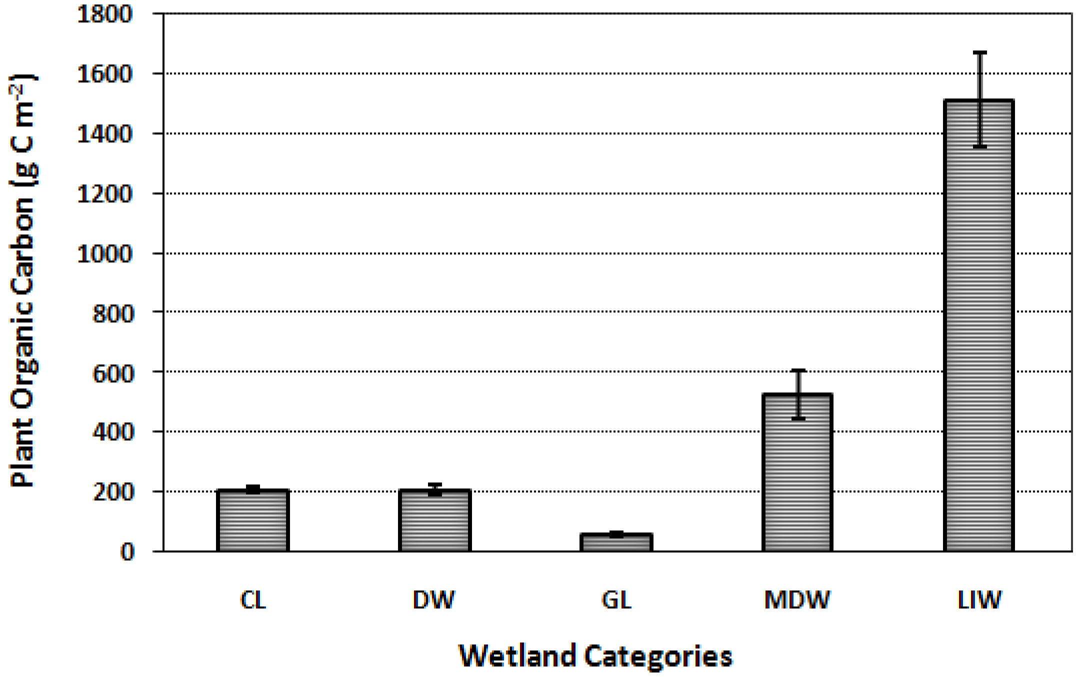

Fig. 2. Mean aboveground plant carbon of different wetland categories (Note: 'CL' is for cultivated land, 'DW' for degraded wetland, 'GL' for grazing land, 'MDW' for moderately degraded wetland, and 'LIW' for least impacted wetland)

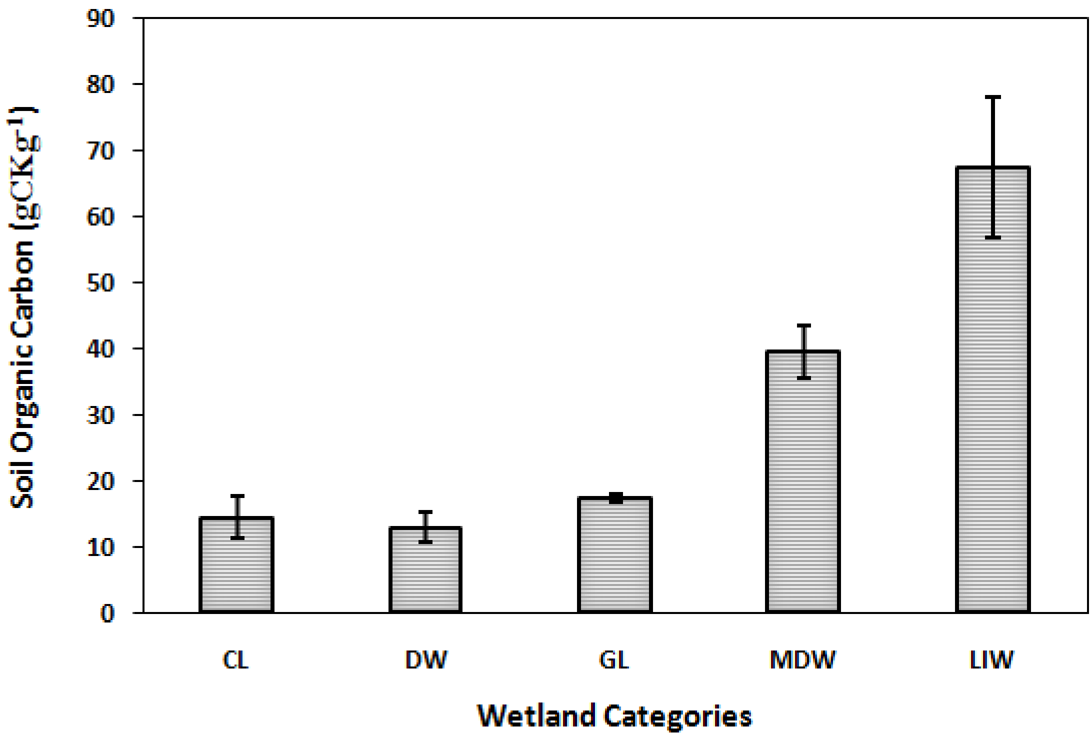

Fig. 3. Mean soil organic carbon content of different wetland categories (Note: 'CL' is for cultivated land, 'DW' for degraded wetland, 'GL' for grazing land, 'MDW' for moderately degraded wetland, and 'LIW' for least impacted wetland)