International Journal of Applied and Pure Science and Agriculture

ISSN Online - 2394-5532 Impact Factor : 5.295 by SJIF ISSN Print - 2394-823X

Evaluate Wetlands as Organic Carbon Reservoirs to Address the Challenges of Climate Change

ManalAbdelrahim Osman[1], ElaminAbdelmajedElamin[2]

[1]National Council for Environment. MekNimir Avenue, P.O. box 306

[2]Professor, University of Khartoum, Faculty of Agriculture, P.O. Box 321

Absract

The effect of climate change is unequivocal. The projected rise of temperature will impair the ecosystems on Earth and hinder their abilities to function properly. Wetlands are an important unseen carbon sink richer than forest and rangeland per area, their preservation could save the situation. In this study tow forested riverine wetlands, and a mangrove forest wetland, were examined. In summer season, samples were taken, carbon concentration was determined in the soil samples collected. In the winter season samples were taken to compare with the summer season. The carbon turnover times were also measured to know the residence time of carbon in the soil using Accelerator Mass Spectrometry (AMS) i.e. C14 dating. The wetlands' floors were richer in carbon content than the forests' floors and the uplands' floors except in one wetland. Temperature and hydrology were taken as controlling factors. One of the wetlands acted as a source of carbon in the second season due to the unsuccessful flooding event. These findings, based on past studies, were very satisfactory. This study revealed that the hydrology is an important controlling factor as well as the temperature and its pattern has been affected by the climate change.

Keywords: *carbon sequestration; radiocarbon; carbon balance; Sudan wetlands' carbon.*

Background

Changes in the atmospheric concentrations of GHGs and aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change. Human activities result in emissions of four long-lived GHGs: CO2, methane (CH4), nitrous oxide (N2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine). Atmospheric concentrations of GHGs increase when emissions are larger than removal processes (IPCC, 2007). Also the climate is defined by a range of meteorological variables, including precipitation, air temperature, wind speed and solar radiation. As greenhouse gases (such as carbon dioxide and methane) build up in the atmosphere, global and regional circulation will change and these meteorological variables will alter. Changes in temperature, wind speed and radiation will alter evaporation and together with changes in precipitation will have major consequences for the hydrological cycle and thus for wetlands, (Acreman et al, 2013).

A warmer Earth speeds up the global water cycle: the exchange of water among the oceans, atmosphere, and land. Higher temperatures cause more evaporation, and soils will tend to dry out faster. Increased amounts of water in the atmosphere will mean more rain or snow overall, (IPCC, 2007-1).

It has been established that equilibrium of C on earth is a function of three reservoirs, the oceans (38000 Pg, Peta= 106), atmosphere (750 Pg), and terrestrial systems (2050 Pg). These three reservoirs are in a dynamic equilibrium, each interacting and exchanging C with the other. A fourth reservoir, the geological reservoir, is estimated to have 65.5 x 106Pg and is a permanent sink, (Eswaran, et al, 1993).

Carbon rich sediment that is brought along floods and hurricanes are trapped and stored, (in case of coastal wetlands) or even drained from watershed sources, (Adhikari, et al, 2009). However, long term storage is often limited due to rapid decomposition processes and rerelease of C to the atmosphere such as in case of paddy fields. Hence, wetlands are dynamic ecosystem where significant quantities of C from both wetland and non-wetland sources may also be trapped and stored in wetland sediments, (Adhikari et al, 2009).

The topography and the geological position of wetland; the hydrological regime; the type of plant present; the temperature and moisture of the soil; pH and the morphology, are the factors that Influence the carbon deposition and long term storage in wetlands known to be (Adhikari et al, 2009). Wetlands can influence global environmental change by removing and sequestering atmospheric CO2 and by emitting greenhouse gases such as CH4 and nitrous oxide (N2O).

Most of the organic matter inputs to a wetland will be broken down through a series of microbial-mediated reactions that yield CO2 and/or methane (CH4). Only the organic matter that does not completely decompose will accumulate as soil organic matter. Wetlands have high carbon densities relative to other ecosystems because they have high rates of primary production, (carbon input) and low rates of decomposition (carbon loss), (Society of wetland Scientist, 2013).

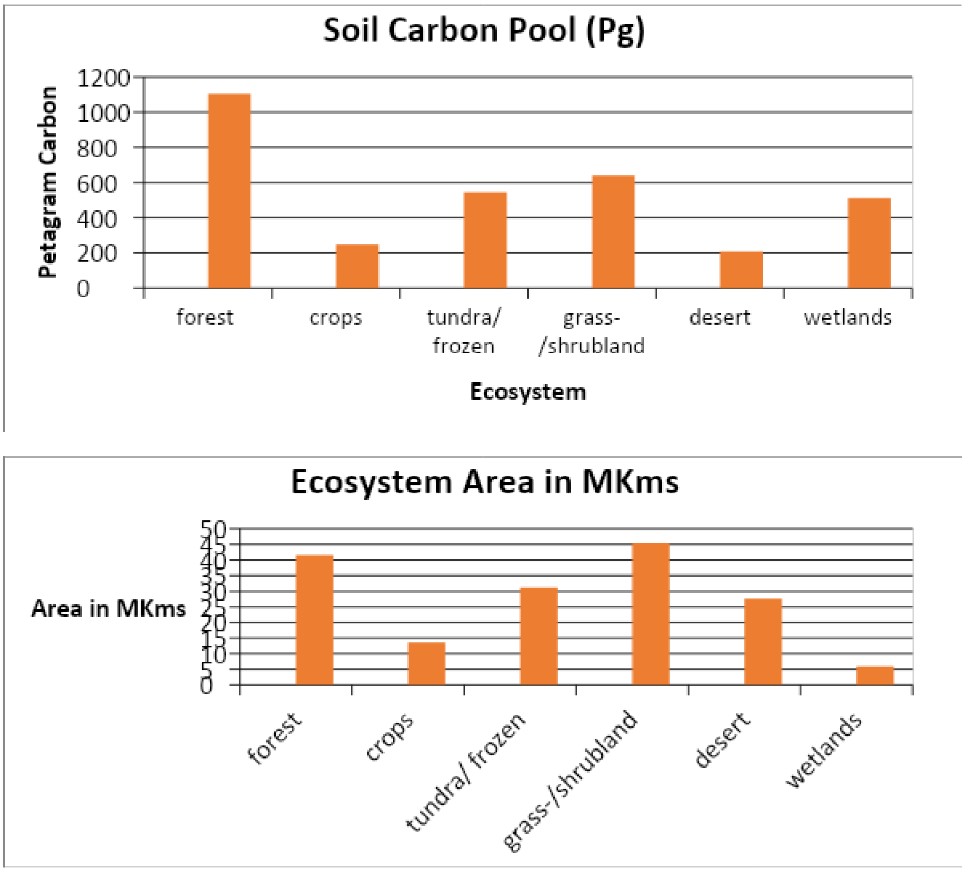
I. Aims and why the study is Necessary

The industrial activities that modern civilization depends upon have raised atmospheric concentrations of carbon dioxide and other principal greenhouse gases, mainly Methane CH4, nitrous oxide N2O, and the halocarbon (a group of gases containing fluorine, chlorine and bromine) to higher levels since the start of the industrial era about 1750 (IPCC, 2007). Pre-industrial levels of carbon dioxide (prior to the start of the Industrial Revolution) were about 280 parts per million by volume (ppmv-1), and the current levels are greater than 380 ppmv-1 and increasing at a rate of 1.9 ppm yr-1 since 2000. According to the IPCC special report on Emission Scenarios (SRES), by the end of the 21st century, we could expect to see carbon dioxide concentrations of anywhere from 490 to 1260 ppm (75-350% above the pre-industrial concentration).

Scientists agree that it is very likely most of the global average warming is due to this increase in the level of carbon dioxide, since the mid-20th century which in turn is due to the human-induced increases in greenhouse gases, rather than to natural causes. This concern over global climate change has stimulated much interest in identifying existing and potential carbon sinks (Ned et al, 2005).

Wetlands endowed with unique soil very rich in carbon, and globally estimated to be 500-700 GTC (Giga Tone = 109 ton). The amount stored in wetlands soil may approach the total amount of atmospheric carbon (estimated at 753 GT) (Kusler, 2005). Thus, they play important role in climate change mitigation and adaptation if they kept as pristine as possible with minimum disturbance or they used wisely when they are vital to people's livelihood.

Figure: (1) Soil Carbon Pool and Ecosystem Area



Source: adapted from Society of wetland Scientist, 2013

Also hydrology is the most important characteristic of wetlands; it is the periodic presence of saturated conditions or inundation that makes wetlands different from terrestrial and fully aquatic habitats, thus any changes in hydrology will have significant implications for wetlands and climate change (Acreman et al, 2013). Mangroves are expected to be the keystone coastal ecosystems providing numerous environmental services and critical ecological functions, affecting both upland and oceanic resources. They are found throughout the tropics, providing critical ecosystem goods and services to coastal communities and supporting rich biodiversity (Jones et al, 2014). These values include protection from storms and tsunamis, regulation of water quality, breeding and rearing habitats for many species of fish and shellfish, important sources of wood and other forest products for local populations, and biodiversity, including habitats for many rare and endangered species. Mangrove forests are also among the major carbon sinks of the tropics (Kauffman et al, 2012).

Findings indicate that wetlands can be both sources and sinks of carbon, depending on their age, operation, and the environmental boundary conditions such as location and climate, (Kayranli et al, 2010),

It is now evident that when degraded wetlands are restored they act as carbon sink and keep sequester more and more even the peat beside; there is a pressing need for accurate C assessments in tropical wetland ecosystems to establish baseline C stocks, and real and potential C losses from disturbance (Warren et al, 2012). Therefore, the specific objectives of his study are:

To check the changes, if any, in the carbon stock of wetlands with changing temperature and inundation.

Hypothesis: temperature and dryness reduce the carbon stock by decomposing organic matters which lead to evaporation of organic carbon as carbon dioxide.

To check the effect of tide on the carbon stock of Mangrove by comparing the stock pre- and post- tide (water logged in this case).

Hypothesis: in mangrove, organic soil carbon susceptible to loss via tide movement.

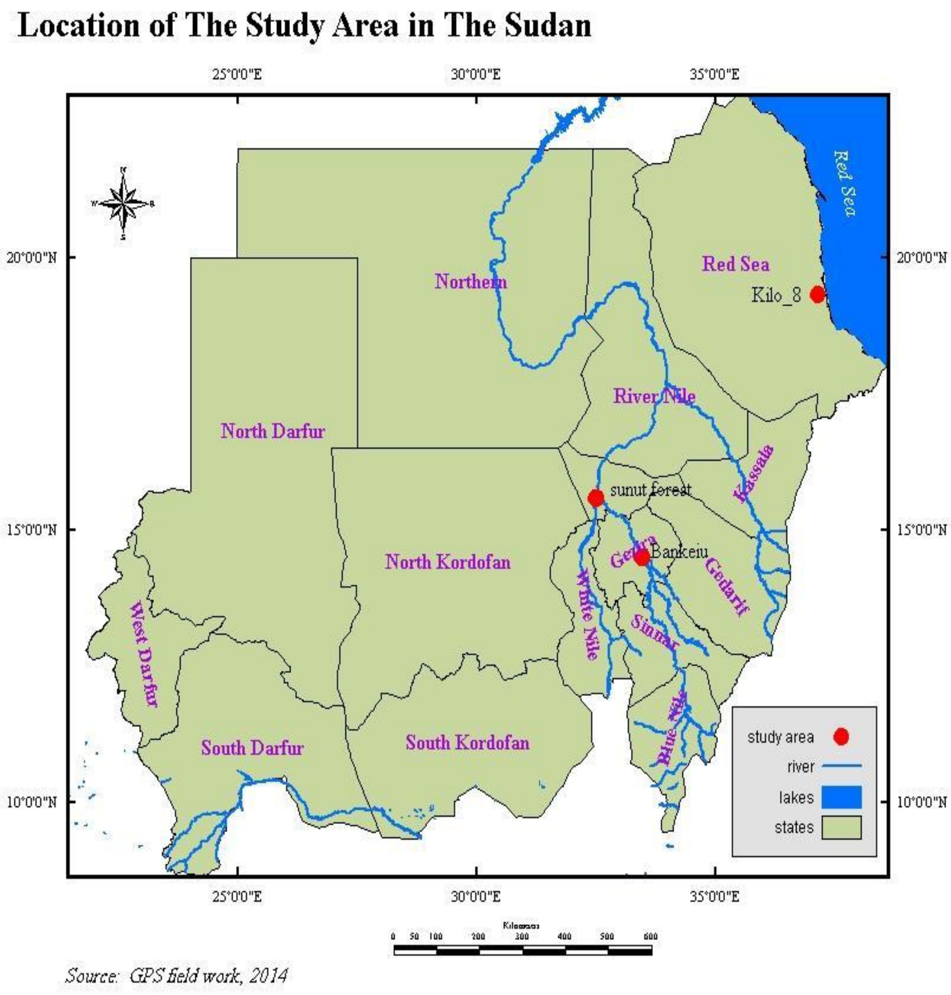
To determine the residence time of the upper layer of the soil which is most vulnerable to land-use change effects.

Hypothesis: upper layer (0-30 cm) contains only labile carbon, which is fast cycling with the atmosphere.

II. Methdology

Three wetlands, (wetland called Mayaa locally), were chosen according to the hydrology regime, that is the mangrove forest wetland on the Red Sea Coast, Sunut forested riverine wetland on the White Nile and Bankieu forested riverine wetland on Blue Nile.

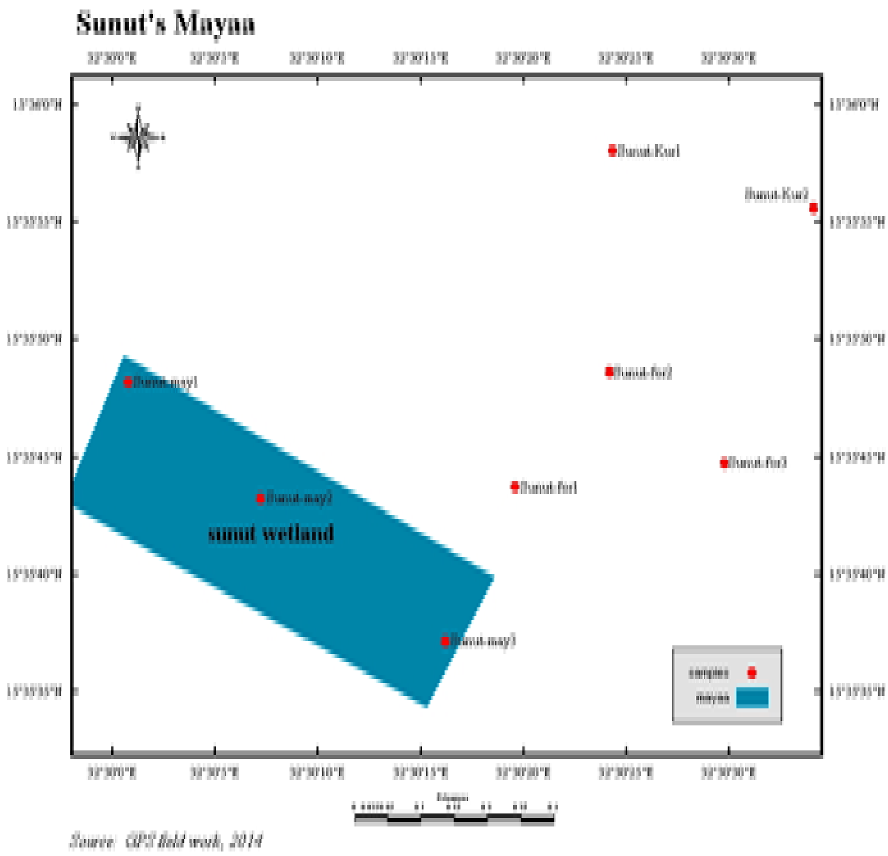
Figure (2): Location of the Three Study Areas in Sudan



The Blue Nile from the Ethiopian Highlands contribute between 80 and 90 per cent of the Nile's flow, but are highly seasonal and carry high sediment loads, the White Nile, by contrast, has a steady flow, with low sediment content, and contributes 10 to 20 per cent to the annual Nile discharge.

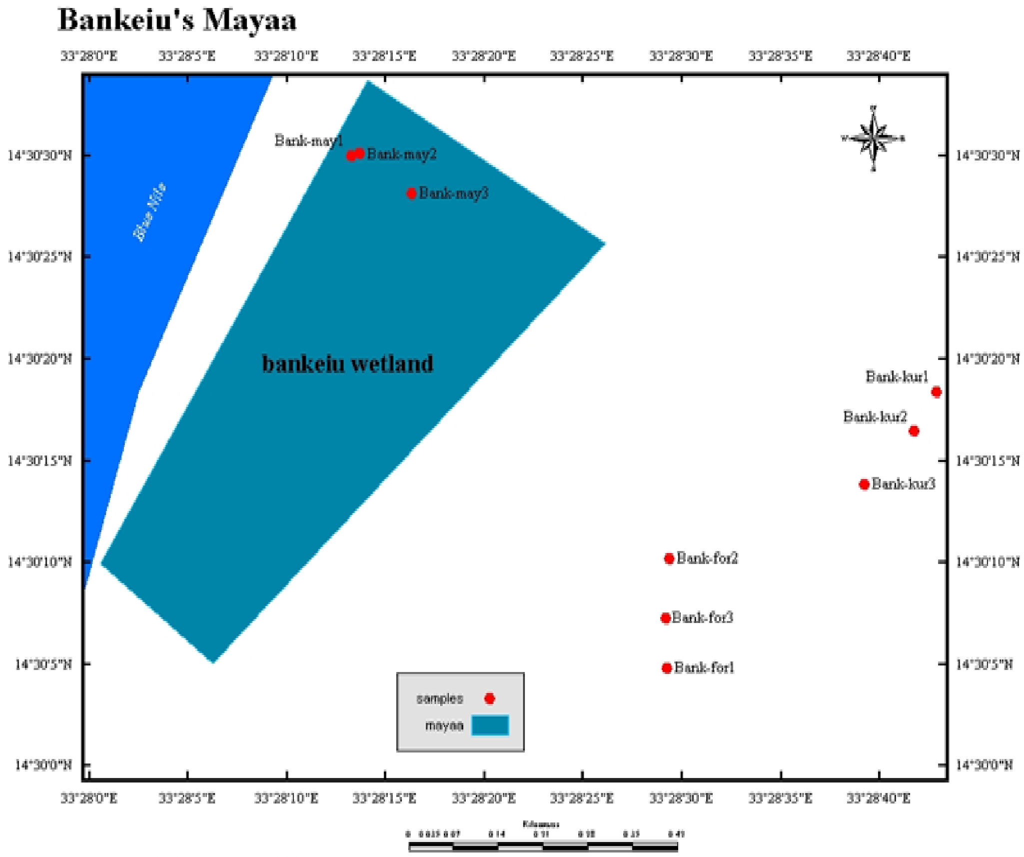
Sunut and Bankieu Mayas are a forested wetlands fall within Sunut Forest on the White Nile and Bankieu Forest on the Blue Nile respectively, the main plant community in both is Acacia Nilotica trees, Sunut Mayaa occupying an area of 252.0522 faddan (106 hectare) positioned between N: 15.59530 E: 32.499340, N: 15.59491 E: 32.50101, N: 15.59617 E: 32.50124, N: 15.59669 E: 32.49997 (Figure 2.1).

Figure (3): Sunut Wetland



while Bankieu occupying an area of 580.7085 faddan (244 hectare) the mayaa is positioned between N: 14.50141 E: 33.46840, N: 14.50042 E: 33.47301, N: 14.50936 E: 33.47057, N: 14.50713 E: 33.47392 (Figure 2.2).

Figure (4): Bankeiu Wetland



Source: GPS field work, 2014

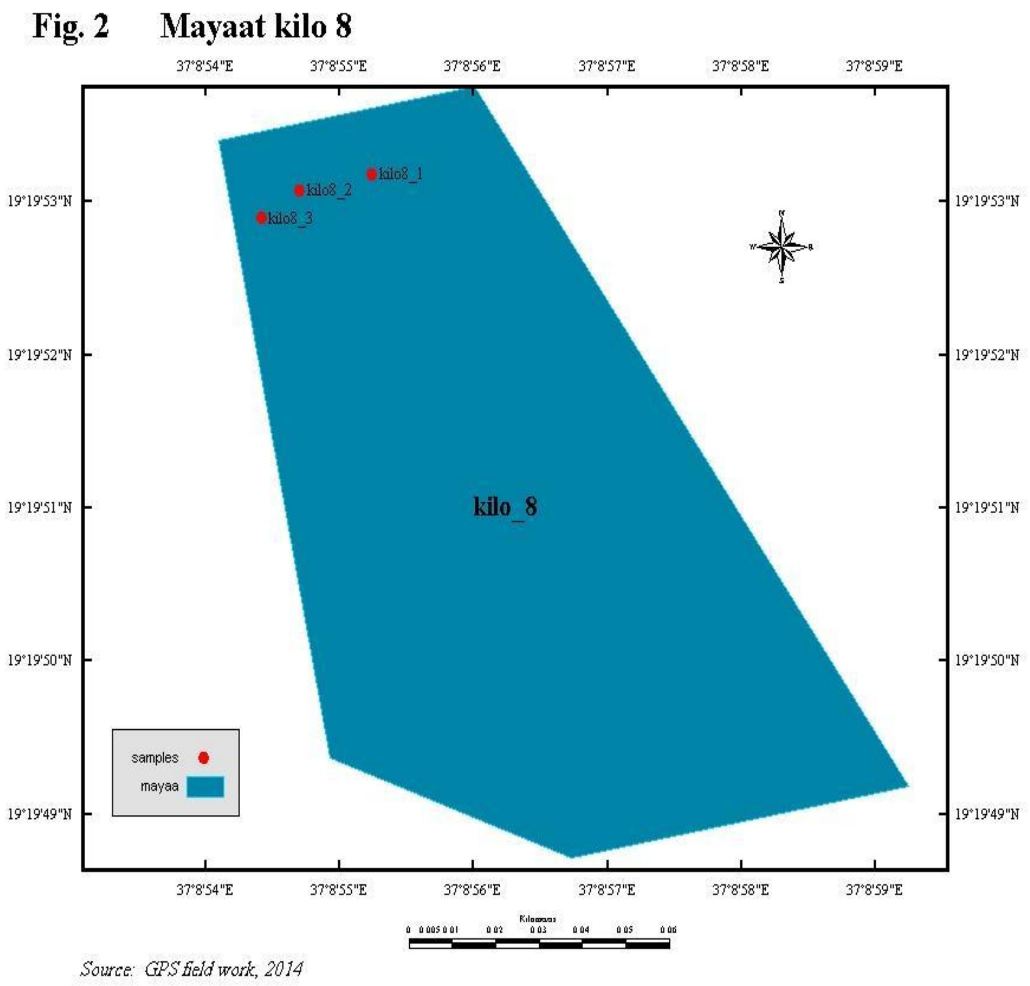
The management practice in these two Mayaas include thinning periodically and felling every 15-16 years, and grazing of goats is all year around. The average rainfall in the rainy season in these two regions is 600 mm-1000mm. and the average temperature during 2013 summer extending from May to July was 41.4°C in both wetlands, the average relative humidity was 20.3% and 26.7% in Sunut and Bankieu respectively. The NNW wind speed was 7.3 Knots and 4.75 Knots respectively.

In the second season, the Mayaas should go through flooding and endure winter time, as such the stock is expected to increase, but the flooding in Bankieu was not successful and the rain was very few that the Mayaa was dry over the wet season (from July through September). During 2013 summer.

The soil type in Sunut and Bankieu is Entisols. The soil have recently being formed and they also occur along the water ways, seasonal streams and rivers and along the River Nile on its flood plains, (Adam, 2012).

The mangrove forest is located on the southern outskirts of Port Sudan city between N:19.33166 E:37. 14889, N: 19.33033 E:36.14979, N:19.33020 E:37.14909, N:19.33150 E:36.14836 (Figure 5) occupying an area of (281.7054) faddan (118.4 hectare), facing the oil refinery and close to a camping beach area used as a recreation site for night's and weekend's visitors from the city, (PERSGA, 2004).

Figure (5): Kilo Tammania Wetland



The mangroves grow in two adjacent stands 500-600m long dominated by Black Mangroves (Avicennia marina). The widest part of each is 200-250m. They grow on a sandy mud and muddy substratum. More than 30% are trees up to 20 feet. The inundation is seasonal and 60- 100% of the wetland is usually inundated. Now Amwag Resort has being built beside the oil refinery and the water desalination plant which its effluent water discharged directly in the wetland. The locals also graze their camels and chop trees for building. With building Amwag Resort paved roads has been constructed, besides; there is a campus of unplanned building that is the Fisher's men Kiosks. The outer zone is muddy with a very compact top layer, merging to softer mud towards the lower eulittoral and an enclosed lagoon (PERSGA, 2004). The inland zone is muddy with spares dwarf mangrove trees. The average rainfall is 800 mm-1200mm in the winter. The average temperature during 2013 summer which extended from June to September was 41.8°C, the average relative humidity was 37.5% and the average speed of the W and N wind was 8.5 Knots.

Sampling

In Sunut and Bankieu Wetlands; samples for the hot dry season were taken on 9th May and 16th May 20142014 respectively, the average temperature was 34.25°C and 32.5ºC respectively, the relative humidity was 15% and 19% respectively, and the north north west wind speed was 12 knots.

In total 9 profiles were made distributed equally between Maya, forest and the upland (called the Karup) i.e. three profiles for each site. The forest and upland profile were taken as reference. The Mayaa profiles were at: N: 15.59672 E: 32.50021, N: 15.59535 E: 32.50201, N: 15.59365 E: 32.50450. The forest profiles were at: N: 15.59548 E: 32.50545, N: 15.59684 E: 32.50672, N: 15.59576 E: 32.50827. The upland (Karup) profiles were at: N: 15.59946 E: 32.50677 and N: 15.59878 E: 32.50949, here two profiles were dug due to the difficulty arises from the presence of construction in the narrow upland (Karup). Thirty nine (39) samples in total were taken with an interval of 30 cm down the profile to the depth of approximately 150 cm.

In Bankieu; The Maya profiles were at: N: 14.50834 E: 33.47036, N: 14.50836 E: 33.47078, N: 14.50782 E: 33.47121. The forest profiles were at: N: 14.50284 E: 33.47483, N: 14.50202 E: 33.47477, N: 14.50134 E: 33.47479. The upland (Karup) profiles were taken at: N: 14.50511 E: 33.47858, N: 14.50457 E: 33.47827, N: 14.50385 E: 33.47757. In total 45 samples were taken.

Kilo Tammania Wetland (Mangrove)

The samples were taken from three soil profiles perpendicular to the eco-tone. The distance of the first one from the shore is 15 meter and they are apart from each other by 25 meters, (Kauffman et al, 2012). The depth of each was found to be 80 cm below which a layer of shells obstruct further digging. Nine samples were taken on 15/9/2014 from each profile at 20 cm, 50 cm and 80 cm interval. The soil profiles were at N: 19.33144 E: 37.14868, N: 19.33141 E: 37.14853, N: 19.33136 E: 37.14845. On that day the average temperature was 36.6ºC, the relative humidity was 55% and the north east wind speed was 7 knots.

Season two End of Winter 2015

Samples in winter season were taken from Sunut wetland in March 16th temperature was 31ºC and was taken from the same three profiles in the wetland (Mayaa). In Bankieu Wetland it was taken on 19th of March. The temperature was the same as in Sunut. Samples were analyzed according to Page et al. 1982.

In Kilo Tammania the continuous inundation prevented sampling for the winter season.

Sampling for Turnover

Samples for measuring the carbon turnover in the soil were taken in season two on the 16th and 19th of March from Sunut and Bankeiu wetland respectively. Samples were taken from 30 cm depth. Analysis was made using Accelerator Mass Spectrometry (AMS) as described lately.

Sampling Strategy: Soil samples were extracted, taken from profiles up to 150 cm depth at an interval of 30 cm i.e. 5 samples from each profile. In the second season three soil profiles were made in the wetlands only, so fifteen samples were extracted to calculate the stock change in the wetlands carbon content.

Samples' Analysis

4-1- Carbon Concentration

It is the gm carbon/100 gm soil, measured using the famous Wakley and Black method according to Page et al. (1982).

4-2- Bulk Density:

The bulk density of a soil sample of known volume is the mass (or weight) of that sample divided by the bulk volume.

4-3- Turnover Time

The following equation of the analytical solution is used to calculate the turnover:

$$\tau = (Aabs - A)/A\lambda$$

where :

τ : the turnover time

Aabs : the activity of the input at steady state level of pre-bomb atmospheric activity equals 226 Bq/Kg C.

A : the specific activity of the sample equals to ASN corrected with δ13C.

λ : the decay rate constant of 14C equals (1/8267) yr-1

Description of Analytical Processes Used in Testing the Samples

Pretreatments

After macroscopic contaminants and granules were removed using tweezers, the sample was ground and treated as bulk. The sample was soaked in HCl (1M) in order to eliminate carbonates, then, neutralized with ultra pure water, and dried. It is described as "HCl" in the table. The sample was oxidized by heating to produce CO2 gas. The produced CO2 gas was purified in a vacuum line. The purified CO2 gas sample was reduced to graphite by hydrogen using iron as a catalyst. The produced graphite was pressed into a target holder with a hole of 1 mm diameter for the AMS 14C dating, using a hand-press machine.

Measurement

The graphite sample was measured against a standard of Oxalic acid (HOxII) provided by the National Institute of Standards and Technology (USA), using a 14C-AMS (accelerator mass spectrometry) system based on the tandem accelerator. A blank for the background check was also measured.

Calculation of Age

The Libby half-life of 5568 years was used for the calculation of 14C age (Stuiver and Polach 1977). 14C age (conventional 14C age: yrBP) refers to an age going back from the year 1950 (= 0 yrBP), assuming a constant 14C concentration in the past atmosphere. The value was corrected for its isotopic fractionation using the δ13C value. 14C age and error are rounded off to tens place. The error range is expressed by one σ, meaning that the 14C age lies within ±1σ range in probability of 68.2%. The δ13C value refers to a difference of the 13C concentration (13C/12C) of a sample from that of a standard. The value is expressed by ‰ for the difference from the standard value. The ratios are measured using an accelerator mass spectrometer, and it is noted as (AMS) in the table. pMC (percent Modern Carbon) refers to a ratio of the 14C concentration in the sample relative to that of the year 1950. Calibrated calendar age is a range of age corresponding to 14C age via a calibration curve, which was produced from the 14C concentration of samples of known age. It is expressed by one σ error range (68.2% probability) or two σ error range (95.4% probability). The 14C age without rounding off was used for calibration. Calibration curve and calibration program can be updated by the database revision, and therefore, the calibrated age may vary depending on the program used. The calibration in this report was conducted by OxCal v.4.2 (Bronk Ramsey 2009) based on IntCal13 database (Reimer et al. 2013).

Statistical Analysis

The data was analyzed using SAS and the means were separated using Student T-test and analysis of variance (ANOVA).

III. Result

Organic Carbon Concentration and Bulk Density (First Season):

Organic carbon density is greater at the upper layer and diminishes down ward with the greater density found at Bankieu, (Table 2), ranging from (62.152 g C/cm2) at the top to (26.616 g C/cm2) at the bottom. At Sunut it ranges from (29.2 g C/cm2) at the top to (13.73 g C/cm2) at the bottom, (table 1). In general the OC concentration range from 0.08 to 0.96% and it varies through all the profiles in the locations examined (Bankieu and Sunut) with the mean equals to 0.5067% at Bankieu and 0.48% at Sunut. The difference in OC concentration and density is insignificant ($p > 0.05\%$) except the 2 wetlands and in the 2 uplands, where it is more in Sunut upland than in its wetland ($p < 0.05\%$). The OC density at the forests and uplands, taken as reference measurement, are (26.728 g C/cm2) and (28.552 g C/cm2) respectively at Bankieu and (23.144 g C/cm2) and (41.568 g C/cm2) respectively at Sunut.

In the Mangrove wetland, were there are three layers, the greater density found at layer two (50 cm, table 3), and the density from top to bottom is 26.005, 105.88 and 133.84 g C/cm2. In the lower depths i.e. layer two and three the OC concentration difference is significant ($p < 0.05\%$) and at the top layer is insignificant ($p > 0.05\%$).

Table (1):Carbon Concentration and Bulk Density in Sunut Wetland 1st and 2nd Seasons

	First season			Second Season		
Average depth (cm)	Carbon content (C%)	Bulk density (g/cm^3)	Carbon density g C/cm^2 at 30 cm depth	Carbon content (C%)	Bulk density (g/cm^3)	Carbon density g C/cm^2 at 30 cm depth
0-30	0.58	1.65	28.71	0.821	1.583	38.989
30-60	0.29	1.65		0.501	1.73	
60-90	0.32	1.64		0.461	1.58	
90-120	0.32	1.54		0.735	1.630	
120-150	0.27	1.64		1.023	1.567	

Table (2): Carbon Concentration and Bulk Density

inBankieu Wetland (1st and 2ndseaons)

	First season			Second Season		
Average depth (cm)	Carbon content (C%)	Bulk density (g/cm^3)	Carbon density g C/cm^2 at 30 cm	Carbon content C%	Bulk density (g/cm3)	Carbon density g C/cm2 at 30 cm depth

			depth			
0-30	1.31	1.59	62.48	1.011	1.443	43.766
30-60	0.91	1.57		0.913	1.490	
60-90	0.85	1.5		0.781	1.513	
90-120	0.74	1.43		0.368	1.587	
120-150	0.58	1.48		0.552	1.513	

Table (3): Carbon Concentration and Bulk Density in Kilo Tammania Wetland (1st season)

Average depth (cm)	Carbon content (C%)	Bulk density (g/cm^3)	Carbon density g C/cm^2 at 50 cm depth
0-20	0.743	1.75	105.88
20-50	1.21	1.75	
50-80	0.956	1.75	

Second Season:

What applied to season one is applied to season two, but there is density change in both wetlands. A drop in density occurred in Bankieu and an increase in Sunut. In Bankieu it drops from 62.152 g C/cm2 to 43.766 g C/cm2, and in Sunut it jumps from 29.2 g C/cm2 to 38.989 g C/cm2 at the top layers.

Stock Change

The stock changed in Bankieu by droping by (-6765.73 t/h), and in Sunut by increment by (3556.67t/h).

Turnover Time

Calculating turnover time which is called also the Mean Residence Time, (MRT) is not straight forward, some parameters are measured using Accelerator Mass Spectrometry, (AMS), i.e. Δ14C, and from them MRT was calculated. In this study the following equation was used to calculate ASN to be used in the analytical solution:

$$\Delta 14C=(ASN/Aabs-1)X1000‰$$

(Ding et al, 2010), With δ13C correction.

Δ14C : is the 14C isotopic ratio, (14C/12C), of a material relative to the modern standard after correction for fractionation to d 13C = -25 o/oo. Δ14C. is only reported if a date of collection or other date to apply the decay correction to is provided, since otherwise it is a meaningless value.

ASN : Measured 14C/12C value of the sample, which was corrected with δ13C.

Aabs : the activity of the input at steady state level of pre-bomb atmospheric activity equals 226 Bq/Kg C.

Assuming that A in our original equation is equals to ASN, from it turnover time was calculated using the analytical solution equation mentioned in the methodology.

The measurements were done for bulk soil due to the difficulty and unavailability of accurate method to separate organic carbon from organic matters. The century to millennial time scale results of the mean resident time indicated the organic carbon found in the 0-30 cm layer of the three wetlands is passive carbon and not labile carbon as expected, i.e. it cycles with the atmosphere in centuries to millennial years, (Table 4). The turnover time found to be (-634.57 yrs) at Bankieu, (404 yrs) at Sunut and (3,397.74 yrs) at KilloTammania, the age is Modern, (330+/- 20 yrs PB) and (2,680 yrs PB) respectively. See discussion for explanation.

Table (4): Turnover Time and Age of the Three Wetlands

Parameter	Sunut Wetland	Kilo Tammania Wetland	Bankieu Wetland
Turnover time (year)	404	3,397.74	-634.57
$\Delta^{14}C$ (‰)	-47.98+/-2.74	-289.38+/-2.25	83.16+/-2.92
Turnover rate (atom/yrs)	8.80	1.87	10.66
Age (yrs BP)	330+/-20	2,680+/-30	Modern

Discussion

Carbon Concentration and Bulk Density

The 2 forested riverine wetlands examined are fed by river water, and thus the change in their hydrology will depend on how climate change alters the river flow. In the second season Bankieu had no flooding water due to the failure of the rainy season in the catchment of the Blue Nile which feed the river therefore there was no inundation which reduce the carbon stock greatly. This proves that the hydrology is one of the important factors that affect the OC accumulation and the anaerobic conditions really enhance the accumulation and hinder the decomposition of the organic materials, so Bankieu acted as a source by emitting C in large quantity amounts to (6765.73 CO2- equivalent), this finding is in line with the finding of Bernal et al (2008) who stated "the presence of continuous anaerobic conditions is more powerful in enhancing carbon storage in wetland soils than the presence of greater organic inputs into the soil". On the other hand the stock in Sunut increased due to the successful event of flooding. It increased by a considerable amount (3556.67 CO2- equivalent) and thus acted as sink although they undergo the same degree of heating where the temperature was almost the same in both wetlands ranged in the winter between 12º-29ºC and in the summer between 32º-44ºC. Although Sunut wetland is degraded because of the recreation activities and the roads crossings it, but it still sequester. The degradation appears from the comparison between Sunut and Bankieu in the carbon density, where the upper layer (0-30 cm) in Sunut in some extent similar to layer four (120 cm) in Bankieu wetland. The carbon inventory for the upper layer in this study exceeds the amount in Bernal et al (2008) study and the world's mean organic carbon density by 2 to 3 folds and far exceeding Neupane, (2012), (Table 5), although the stocks were calculated in this study to only 30 cm depth and Bernal et al (2008) to 24 cm and 54-60 cm depth.

Table (5): Comparison of carbon stock in Sudan (arid tropical) with temperate, tropical and subtropical in t/h

This study Arid tropical			Bernal et al, 2008		Neupane, 2012	world's mean organic carbon density
Sunut	Bankieu	Kilo Tammania	temperate	tropical	subtropical	~1060 t/h
3556.67 t/h	6765.73 t/h	3932.13 t/h	1760 t/h	970 t/h	36.32(+/-) 12.91 t/h	

Sunut and Bankieu are expected to fix this amount, (3556.67 t/h and 6765.73 t/h respectively), of carbon because of their tree species and also by containing high amount of nitrogen from goats' dung since carbon and nitrogen are associated and they fix each other (C/N ratio), beside the seasonal flooding which inhibit the decomposition of the organic carbon. This is explained by the work of Carré et al (2010) who stated that in order to assess the actual situation of land carbon stock, the climate, soil type, land cover (vegetation type) and land management (mineral fertilizers and manures) need to be considered in combination (Carré et al, 2010). Both wetlands have the same climate, soil type, land cover and both undergo the same management plan but the flooding regime is different, since their feeding rivers come from different catchments. Soil carbon stocks vary with soil drainage class, with the largest C stocks occurring in poorly drained sites, this explain the increase in the C density in Sunut wetland. It is quite clear now that more of the carbon stored in wetlands will be released if wetlands continue to be drained. Upon drainage, fungi and bacteria which thrive in the newly aerated conditions will oxidize much of the carbon stored previously, and return it to the atmosphere, (McGuire et al, 2012).

The high bulk density, due to wetter – shrinking periods, reduce water infiltration into the soil, and the compaction can lead to increased runoff and erosion from sloping land or waterlogged soils in flatter areas, (USDA, 2008) as the case in Kilo Tammania and Sunut wetland (water logged). On one hand this will restrict the growth of the plant but on the other hand it will reduce the infiltration and thus lower the moisture content of the subsoil, and decrease the decomposition rate of organic matter which explains the high content of organic matter in the lower layers (120 and 150 cm) in Sunutwetland , 2nd season. Also the compaction enhances erosion which explains the lower organic matter content in the upper layer, (30 cm) of Sunut wetland.

In general Bankieu is richer than Sunut in OC because it is pristine and Modern, young, in age and not vulnerable to disturbance like Sunut which is susceptible to heavy traffic by pedestrians and by recreation activities. Bankieu and Sunutwelands fall in the arid tropical zone, their inventory proved that it is a rich zone in organic carbon than the tropical and subtropical zone

The bulk density stayed almost constant through the depth interval, regardless of the SOC content although it is well documented in the literature that lower SOC associated with high bulk density and vice versa.

In Kilo Tammania the upper layer (0-20 cm), i.e. the siltation layer, the density is 39.3213 (gC/cm2) consists of fine silt with low carbon content. With the redistribution of C resources linked to erosion/deposition processes, there is a considerable potential for systematic net movement of soil C resources along the biogeochemical gradients associated with topographic elements within the landscape. For example, the net movement of soil C into wetter areas of the landscape would tend to stabilize eroded C by decreasing the potential for C oxidation as the case in Kilo Tammania where the top layer brought by the sea water. In this context, much of the consideration for increased C storage is associated with passive mechanisms such as C burial which would also suppress C oxidation. This may be the main influence on C dynamics in ecosystems with relatively low productivity such as reservoirs. Deposition in wetlands with high net primary productivity, however, likely stimulates active C sequestration in a mechanism similar to that of dynamic replacement at erosion sites. Under this scenario, influx of low C sediment into ecosystems that support high soil C content stimulates new C storage by diluting the concentration of soil C (McCarty et al, 2009).

In Kilo Tammania, the middle layer (20 – 50 cm); which I believe is the original surface of the wetlands consists of soil rich in organic carbon with the density amounts to (105.88g C/cm2). This layer had been physically protected by the deposition event; this stock is far exceeding the amount measured elsewhere like in the study published in the riverine wetland of Chiapas, in the south Pacific coast of Mexico, Kauffman et al, 2011, (mean of 864.76 t/h, maximum of 1,229.076 t/h). And when changed to t/h and compared to Micronesia state at the Western Pacific Ocean, it exceeds its Palau wetland soil: (528 - 1,199.4708 t/h) and Yap wetland soil: (940.270 - 1,526.699 t/h) mangrove ecosystems (tropics) (Table 6). Regarding the notion that tide wash carbon from soil, the case in Kilo Tammania, (the high density of carbon in the middle layer), negate it, instead the tide bring a lot of sediment that protect the surface of the wetland physically and in the same time accumulate carbon. The upper layer's density in Kilo Tammania is (39.3213 gC/cm2), noting that the age of the wetland is 2,680 +/-30 years BP.

Table (6): Comparison of carbon stock in Sudan Mangrove Forest with Republic of Palau and Yap, Federated States of Micronesia

KilloTammania (Sudan) layer B	Palau- tropical	Yap- tropical
10588.00 t/h	528 - 1,199.4708 t/h	940.270 - 1,526.699 t/h

The degradation of Kilo Tammania, as explained earlier, and the development project are posing a threat to its carbon stock and they will degrade it more. There is a consensus in the literature that the sea level rise will shift the wetland landward, if this is to happen the development approaching will hinder the shift and these wetlands will be lost.

Turnover Time

The turn over time of the three wetlands are in general agreement with the that of Trumbore et al (1997) who stated that turnover times varied from 14 years to 400 years for different ecosystems in the upper 1 m depth, and also with Perruchoud et al (1999) who measured 155-10,018 years (3,570 years mean) for a slowly overturning compartment. Using this Δ notation, positive values indicate incorporation of recent atmospheric CO2 enriched in 14C produced by nuclear weapons testing, and a high positive value of Δ14C indicates decadal-scale- cycling versus a very negative value indicating millennial-scale cycling (Ewing et al, 2006). This is very applied to Bankieu wetland. Although the depression in the stock in the 2nd season but its Δ notation, (positive value), indicates it is recently deposited carbon.

In Bankieu wetland the positive value of Δ14C supported by the Modern age of this wetland mean that it is still been cycling with the atmosphere for decades only. Accordingly the negative sign of the turnover times of Bankieu would mean Bankieu still accumulating carbon and sequestering, and the emission of carbon only in the 2nd season due to unsuccessful flooding, and needs 634.57 year to fill the soil with carbon if it continues to act as sink and no emission episodes is encountered. Here comes the importance of the hydrology which is linked directly to the climate change and here appears where exactly the climate change will affect the carbon content of these wetlands. On the other hand Sunut and Kilo Tammania wetlands are sequestering also and need 404 years and 3,397.74 years respectively to empty. This explained by their negative value of Δ14C, which indicate no recent deposition is happened. This is supported by the fact that soils that are accumulating C will have higher Δ14C values, (Bankieu), compared with an undisturbed ecosystem (presumed at steady state), whereas soils that are losing C will have lower Δ14C (Sunut and Kilo Tammania) than the undisturbed site as stated by (Trumbore et al, 1997). When the turnover rate is calculated i.e. the number of carbon atoms leaving the reservoir per year, Bankieu ranked at higher rate (10.66/yr) followed by Sunut (8.80/yr) and Kilo Tammania (1.87/yr). This is generally a low rate compared to 20 – 22 atoms per year in literature.

The age is one of the factors that determine whether the wetland is a source or sink as elaborated in the introduction, (Kayranli et al, 2010). The old wetlands soil being saturated and can no more sequester carbon, as the case in Sunut and Kilo Tammania wetlands. This is also proved by their AMS analysis, (negative values of Δ14C), which means no recent carbon were incorporated, while the Modern young wetland soil cycle actively with the atmosphere and has the tendency to sequester more carbon.

IV.Conclusions

Although Bankieu acted as source; but the AMS analysis indicated that it is Modern and still sequestering and accumulating carbon.

Although Sunut wetland is heavely degraded; but it is still sequestering and acted as sink.

The hydrology is more important than temperature as controlling factor in sequestering and accumulating carbon.

The richness of these wetlands may greatly be due to their green cover, Acacia Nilotica (Sunut and Bankieu) and Avicennia marina (Kilo Tammania) where there is a great potential that these different plants species, since they have different productivity and different decay rate, would enrich the soil differently than the plant species in Bernal et al. (2008) study.

By attaining the land conversion intended for Sunut wetland and the surrounding development in Kilo Tammania the land use change will affect those two wetlands greatly by changing their cover and thus affect their ability to sequester carbon. Policies to solve this problem should focus on the potential land-use planning.

Recommendation

Further investigation is recommended to examine the relation between the soil carbon concentration and the type of plant species.

Declaration

I, ManalAbdelrahim Osman, do here by declare to the Journal that this paper entitled Evaluate Wetlands as Organic Carbon Reservoirs to Address the Challenges of Climate Change is a product of my original research work and it has not been submitted to any other universities for award of any academic degree. Information used from various other sources is duly acknowledged.

Abbreviations

AMS: Accelerator Mass Spectrometry

Gt: gigatonne (= 109 tonne)

Mg: megagramme (=106g = tonne)

MRT: mean resident time

Pg: petagramme (= 1015 g)

Ppm: parts per million

Ethic approval and consent to participants

Not Applicable.

Consent for publication

Not Applicable.

Availability of Data and Materials

Presented in the main paper and its additional supporting files.

Competing Interest

We declare that we have no competing interest, financial or non-financial.

Funding

Funding was possible from the National Center for Training- Sudan, the Ministry of Environment, Natural Resource and Physical Development and the First author.

Authors' Contribution

Corresponding, First Author made substantial contribution to the conception, design, acquisition of data, analysis and interpretation of data.

Second Author revised it critically for important intellectual content.

Acknowledgement

First and foremost, I would like to thank Allah, the most merciful, the most gracious for giving me strength when everything looked bleak.

Second, thanks is due to Mr. Mamoun Isa who drew my attention to the subject of wetlands and climate change and also to Dr. Khalid Riak who, discussion with him emerged into Title and objectives to this study. Thanks is due also to Mr. Ali Mohamed Ahmed who was the director of Training Department at that time for trusting me to be nominated for this fellowship.

I would also like to express my sincere thanks to Mr. Salah YusifElbadawi director of The General Technical Directorate in the Forests Corporation for the great facilitations he dispose to this project and his participation personally in the collection of samples, although his tight schedule, in the two seasons. My sincere thanks is also due to Mr. Musa, Mr Kamal and Mr. Amar in Red Sea Forests Office for disposing time, cars and themselves to the sample collections, also my best gratitude to Mr. Osman (Molana) and his family for facilitating samples collection from Medani and accommodating me in their generous house.

I would like to sincerely thank my advisor Professor Elamien Abdel Majed for his tremendous patience, assistance, support, and guidance throughout this research, and to UstazGamalEltahir from laboratory in the Faculty of Agriculture.

I would like also to thank my brother Professor Mohamed Osman who discussing with him helped a lot in the course of writing.

Last but not least my thanks is to my sister Dr. Nahid Osman from Red Sea University Faculty of Marine Sciences for finding time to devote to samples collection and being of great help in the field.

REFERENCES

[1] Acreman M. and Blake J., Guidance on using the Wetland Toolkit for Climate Change, Project sponsors Environment Agency, Natural England. English Heritage, Wildfowl and Wetlands Trust, Royal Society for the Protection of Birds, Wildlife Trusts, 2013.

[2] Adam, A manual of Introductory Soil Sciences and Water Uses, Prepared for Land Evaluation Research Section, Khartoum University Press, 2012.

[3] Adhikari S., Bajracharaya R. M. and Sitaula B. K., A Review of Carbon Dynamics and Sequestration in Wetlands, Journal of Wetlands Ecology, 2009, vol. 2, pp 42-46.

[4] Bernal B., Mitch W. J., A comparison of soil carbon pools in wetlands in Costa Rica and Ohio, Ecological Engineering Journal34, 2008, pp 311-323.

[5] Bruun S., Six J., Jensen L. S., Paustian K., , Estimating Turnover of Soil Organic Carbon Fractions Based on Radiocarbon Measurements, RADIOCARBON, Vol. 47, 2005, p 99–113.

[6] Carré et al, Background Guide for the Calculation of Land Carbon Stocks in the Biofuels Sustainability Scheme, Drawing on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, European Commision and Institute of environment and Sustainability, 2010.

[7] Ding et al, turnover rate of soil organic matter and origin of soil 14CO2 in deep soil from a subtropical forest in dinghushan biosphere reserve, south china, RADIOCARBON, Vol. 52, Nr 2–3, p 1422–1434, 2010.

[8] Eswaran H., Den Berg E. V., and Reich P., Organic Carbon in Soils of the World, Soil Sci. Soc. Am. J. 57:192-194, 1993.

[9] Ewing et al, Role of large-scale soil structure in organic carbon turnover: Evidence from California grassland soils, Journal of Geophysical Research: Biogeosciences (2005–2012), 2006, Vol. 111 Issue G3.
[10] IPCC, Climate Change, the Physical Science Basis, 2007.
[11] IPCC, Fourth Assessment Report- Synthesis Report, 2007-1.
[12] Jenkinson et al, The turnover of soil organic matter in some of the Rothamsted classical experiments, Vol. 123, No. 5, Soil Science, 1977.
[13] Jones T.G., Ratsimba H. R., Ravaoarinorotsihoarana L., Cripps G., and Bey A., Ecological Variability and Carbon Stock Estimates of Mangrove Ecosystems in Northwestern Madagascar, Open Access, Forests, 2014, doi:10.3390/f5010177.
[14] Kauffman et al, Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests, Working Paper, Center for International Forestry Research, 2012.
[15] Kauffman et al, Ecosystem Carbon Stocks of Micronesian Mangrove Forests, Wetlands No. 31:343–352, 2011.
[16] Kayranli et al, Carbon Storage and Fluxes within Freshwater Wetlands: a Critical Review, Wetland, vol. 30, issue 1, 2010.
[17] kusler, Common Questions: wetland, climate change, and carbon sequestering, association of state wetland managers, inc. in cooperation with: the international institute for wetland science and public policy, 2005.
[18] McCarty et al, Impact of Sedimentation on Wetland Carbon Sequestration in an Agricultural watershed, technical reports: wetlands and aquatic processes, Journal of Environmental Quality 2009, 38:804–813.
[19] McGuire et al, Reducing climate change impacts and promoting fish and wildlife: findings and recommendations for biological carbon storage and sequestering, 2012, Published on line.
[20] Ned et al, North American prairie wetlands are important non-forested land-based carbon storage sites, Science of the Total Environment, 2005, Science Direct, Elsevier.
[21] Neupane S., a comparative assessment of Ghodaghodi lake soil carbon stock with adjoining forest and grassland, academia. Edu, 2012.
[22] Perie´ et al, carbon, organic matter and bulk density relationships, Canadian journal of Soil Science, 2007
[23] Status of Mangroves in the Red Sea and Gulf of Aden, PERSGA Technical Series No. 11, 2004.
[24] Trumbore et al, Potential responses of soil organic carbon to global environmental change, National Academy of Sciences, Vol. 94, 1997, pp. 8284–8291.
[25] Trumbore et al, Soils and the Global Carbon Cycle, In EA Holland, Soils and Global Change, NATO Advanced Study Institute, in press, 2003.
[26] USDA, Soil Quality Indicator, USDA Natural Resources Conservation Service, 2008.
[27] Warren et al, A cost-efficient method to assess carbon stocks in tropical peat soil, Biogeosciences, 2012.

