CARBON SQUESTRATION POTENTIAL OF SANDSPIT BACKWATER MANGROVE AND SEDIMENT, PAKISTAN

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خلاصہ

اس تحقیق کا بنیادی مقصد تمر کے درختوں کے درختوں میں کاربن کی انجزاب کا پتا چلتا تھا۔ یہ مطالعہ کراچی کے ساحل سنڈپٹ کے تمر کے جنگل میں کیا گیا جہاں یہ واحد درختوں کے نوں کے بطور Avicenia marina پائی جاتی ہے۔ اس علاقے میں اس کے درختوں کی تعداد 3875 ایکڑ جبکہ بنیادی گھر اور علاقہ 6.59 میٹر اسکوائر فی ایکڑ تھا۔ اس میں کاربن کا اسٹاک جو کہ سطح زمین اور زیر زمین پر تھا۔ 2.60±99.33 ٹن فی ایکڑ اور 4.50±39.0 ٹن فی ایکڑ تھا۔ زمینی تہہ میں اسکی مقدار 3.92±51.66 ٹن فی ایکڑ تھی۔ مجموعی طور پر تمر میں اور تہہ دار زمینی سطح پر سینڈپٹ کے علاقہ میں اوسطا 11.02±183.99 ٹن فی ایکڑ کاربن کے اسٹاک کا اندازہ لگایا گیا ہے۔ جو کہ 675.24 ٹن فی ایکڑ کاربن ڈائی اکسائیڈ کے بزیر ہے۔ تمر کا $6.59m^2$ فی ایکڑ بنیادی علاقہ ایک محتاط مطالعہ کے بعد 1212.49 ٹن کاربن جمع کرنے کی صلاحیت رکھتا ہے۔ اس کی بنیاد پر یہ سمجھا جا سکتا ہے کہ تمر کے جنگلات یا درخت اپنے اندر ایک بڑی مقدار کاربن ڈائی اکسائیڈ کو جزب اور جمع کرنے کی صلاحیت رکھتے ہیں۔ لہذا انکے تحفظ کا خیال راکھنے اور انکو مناسب انداز سے استعمال کیا جانا چاہیئے تا کہ انکی ابادی کو نقصاں لاحق نا ہو سکے۔

Abstract

The main objective of the study was to evaluate the potential of mangroves to sequester carbon. This study was carried out in Sandspit mangrove forest which is covered by the monospecifc stands of *Avicennia marina* (density 3895 plants ha^{-1} and basal area 6.59 m^2 ha^{-1}). The C-stocks of above-ground and root biomass were 93.33 ± 2.60 t C ha^{-1} and 39 ± 4.50 t C ha^{-1}, respectively, while the C-stock in sediment was estimated to be 51.66±3.92 t C ha^{-1}. The estimates of mean combined C-stocks in the mangrove biomass and sediment of Sandspit backwater showed that this estuarine mangrove wetland stored 183.99±11.02 t C ha^{-1}, equivalent to 675.24 t CO_2 ha^{-1}. The mangroves with basal area of 6.59 m^2 ha^{-1}, is assumed to have a potential to sequester and store a substantial quantity of 1212.49 t C which is equivalent to 2478.13 t CO_2. This value suggests that natural mangrove forest has a potential to sequester and store substantial amounts of atmospheric carbon, hence need for sustainable management and protection of this important coastal ecosystem.

Introduction

Climate change has been altering the productivity, bio-diversity and functions of the terrestrial and coastal ecosystem. Increasing rate of CO_2 in the atmosphere due to anthropogenic activities is responsible for climate change (Sharma *et al*., 2010). Forest ecosystem is the important component of global carbon cycle. In Kyoto protocol of the UNFCCC forests are recognized, a potential source for the mitigation and stabilization of the rising level of CO_2 in the atmosphere (Masera *et al*., 2003; Tobin & Nieuwenhusis, 2007; Sohail *et al*., 2014).

Among coastal ecosystem, mangrove forests store largest amount of carbon. This ecosystem provides numerous environmental services to human beings including marine resources, rest place of migratory birds, pollution sink, protection of coastline from erosion, storm surges etc. In some regions, it is estimated that 75% of commercial fish spend their early life stages in mangroves. Mangroves store significant amount of carbon to help in climate change mitigation. Giri *et al*., (2011) stated that though mangrove forests cover only 0.7% of tropical forests of the world, but they have the potential to store up to 20 billion t C, according to Donato *et al*., (2011) it is much higher than the mean carbon stock recorded in tropical upland, temperate and boreal forests.

The coast line of Pakistan is about 1050 Km long having prominence by the presence of coastal mangrove forests, covering an area of about 0.132 million ha (less than 3 percent). These forests mainly occur in Indus Delta and in a few patches westward along the Balochistan coast (Saifullah & Rasool., 2002). Mangrove biomass and substrate are important habitat for carbon sink within the tropical coastal zone. The degradation of mangroves due to various biotic or abiotic factors, global warming, sea intrusion etc creates a negative impact on the carbon sequestration potential of the mangrove habitat. Compared to other land forest, mangrove ecosystem accumulates sequestered carbon in the sediment. Hence, clearing of mangroves can rapidly result in significantly reduced carbon stores. Carbon sequestration provides associated ecosystem co-benefits such as increased soil water holding capacity, better soil structure, improved soil quality nutrient cycling and reduced soil erosion (Derner & Schuman., 2007). Besides immense significance to sequester carbon, these forests are the most threatened ecosystems, due to anthropogenic activities (Nazim *et al*., 2016) . Duarte *et al.*, (2013) & Hu *et al*., (2017) the reduction of mangrove area leads to loss of future carbon sinks and greater emissions of carbon dioxide back into the air and ocean, which may be much higher than terrestrial habitats (Li *et al*., 2018). According to FAO, (2006) more than 20% of global mangrove cover has been destroyed since 1980, this rate is about 4 times the rate of global deforestation. It is further predicted that 30-40% of coastal wetlands and 100% of mangrove forests could be lost during the next hundred years.

This paper discusses a mangrove forest of Pakistan in term of its cover and carbon sequestration. This case study would be helpful to plan the assessment methods and standard indicators of change for future research and management planning. This study is first of its kind in Pakistan to estimate the potential of mangroves to sequester carbon in sediments and biomass. According to Chave *et al.,(* 2005) & Shaheen *et al*., (2016) the estimation of forest biomass is a key to evaluate the forest productivity, structural attributes, carbon sequestration potential as well as carbon stock values.

Materials and Methods

Description of the study area: Sandspit stretches about 20 km along the Arabian Sea coast with extensive inter tidal mudflats with some mangrove swamps behind the beach. It is located south –west of Karachi. The average rainfall is 125 mm and the mean temperature is 32 ºC. The backwater at Sandspit consists of 1600 ha of mangroves of *Avicennia marina* while *Rhizophora*
mucronata was planted here in small area. The mangroves in this area have been denuded because of grazing by camels and cutting for fodder. There is a considerable amount of domestic and industrial pollution entering in the mangrove forest. Average height of mangrove trees was also recorded.

Size class structure: Ten quadrates (10 X 10 m each) in similar elevation at mid intertidal zone were established after ten meter interval in study area. Tree density, basal area and height were recorded following Ahmed and Shaukat, (2012). Diameter size class structure diagram was prepared for the particular site to determine the present and future trend of this mangrove species. Diameters of trees were divided in following five classes as shown in Nazim *et al*., (2011).

1. Juvenile size classes (2 to 10 cm dbh)
2. Small size classes (10.1 to 20 cm dbh)
3. Medium size classes (20.1 to 30 cm dbh)
4. Large size classes (30.1 to 40 cm dbh)
5. Mature size classes (40.1 to 50 cm dbh)

These classes were subjected to excel spread sheet and graph was constructed.

Biomass estimation:
Three pools of carbon *viz*., i) above-ground biomass (ABG), ii) below-ground biomass (root biomass, BGB) and iii) sediment were considered for the estimation of carbon, stored in mangrove ecosystem. From each quadrate a similar sized trees were harvested for above ground and below ground biomass estimation. Two hundred leaves were collected from harvested trees to measure leaf area. In each quadrate one 1 X 1m small quadrate was also laid to estimate the number and height of the pneumatophores. Biomass was analyzed following the method described by Kaufman and Donato, (2012); Albino et al., (2014). First time allometric equations for *Avicennia marina* was used in Pakistan to estimate carbon followed by Patil *et al*., (2015).

Sediment samples:
At each sampling plot, sediment duplicate samples were collected at 0–30 cm depth in each 10 m x 10 m plot using a corer having 2 cm radius and systematically followed Kauffman and Donato (2012). A total of 20 soil samples were collected in pre-labelled plastic bags and brought to the laboratory for organic carbon estimation. Soil salinity, pH, total disscolved solids and conductivity were obtained using Hanna multiparameter (model HI9828). Bulk density for undisturbed soil samples was determined by dividing oven-dried samples (at 70 °C for 48 h or until constant weight) by the volume of the corer. Soil carbon content was estimated in the laboratory using the Walkley-Black method (Pearson *et al*., 2005). The soil organic carbon was calculated following Kairo *et al*., (2008).

$$\textbf{Soil Carbon (t ha}^{-1}\textbf{) = Bulk density (g}\cdot\textbf{cm}^{-3}\textbf{)} \times \textbf{Soil depth interval (cm)} \times \textbf{\% Organic Carbon}$$

Results and Discussion

Physical parameters: Table 1 shows the physical characteristics of sediments collected from Sandspit mangroves forests. The mean values of organic carbon (5.4±0.2) and water holding capacity (36.1±0.1) show that this site has some available nutrient which are crucial for emission or sequestration of CO_2. It may also be relevant for the control of the CO2 content of the atmosphere (Miltner, 2009).The salinity and pH values of the present result showing the highly saline and alkaline nature of the environment such alkaline pH values in coastal saline soils of Sundarbans is well documented and attributed to high salt content of these soils (Bandyopadhyay and Sarkar,1987). In the present study, the mangrove soils appeared to exhibit considerably higher conductivity values this could be largely attributed to occurrence of the slightly higher percentage of finer particles in mangrove soils might have increased the conductivity values of mangrove soils in addition to the effects of organic matter in such soils (Dasgupta *et al*.,2018). Conductivity relates with total dissolved solids to benefit the mangrove vegetation growing in these soils.

Table1. Physical characteristics of sediments collected from Sandspit mangroves forests.

Parameters	Mean± SE
Organic Carbon (%)	5.4±0.2
Mean water holding capacity (%)	36.1±0.1
Salinity (‰)	39.7±0.6
Conductivity (mS/cm)	57.5±0.8
Total dissolved solids (g/L)	38.2±0.01
pH	8.4±0.03

Structural attributes: Stand structure in Sandspit mangrove forests is relatively simple due to frequent absence of understory species, which are usually found in other forest systems (Janzen, 1985). Table 2 shows the mean ± SE of density ha^{-1}, basal area, area of leaves, height of the trees, number of pneumatophores and height of pnuematophorers. This site occupied density 3895±138trees/ha, Juveniles share 27.77% individuals, 61.11% individuals in small size class and 11.11% individuals in medium size classes (Fig 1). The absence of the trees in large and mature classes indicates high degree of disturbances. However, individuals in small size classes (10 to 30 cm dbh) entailed a wave of recruitment in the stands, large number of *A.marina* juveniles/saplings indicating a balanced population structure in this area. According to Manoj *et al.*, (2008) seedling and saplings are regarded as indicators of regeneration potential of species and the prevalence of good regeneration potential shows suitability of the species to the environment. Dawson and Sneddon, (1969) stated that in unstable forests**,** dead trees of the various species do not get replaced by nearly equal number of younger trees but this is not in the case of Sandspit mangrove forest. *A.marina* is a fast growing and regenerating species which provides better chances of survival and could maintain the balance between death of old and birth of new trees but it requires a long time (Lacerda and Marins, 2002) and proper management**.** Thousands of seeds and seedlings produced every year while hundreds of trees and regenerating seedlings showed mortality by natural selection or anthropogenic activities (IUCN, 1994; IUCN, 1995 ; Vistro, 2000). Normal and balanced structure of forests show large number of small sized trees or seedlings in small size classes with a gradual decrease in large sized trees in larger classes (Ahmed, 1984 and Ogden *et al*, 1987). Though, this area is showing regenerative capability but the least value of basal area (6.59±0.31 m^2 ha^{-1}) may be due to the close proximity of human settlements which causes excessive pollution, harvesting and grazing. Many local people are involving in cutting trees, results in higher consumptive wood extraction from the forest (Nazim et al., 2011). The logging of trees for fuel, charcoal making and construction materials are the threats to mangrove destruction (IUCN, 2005). Kairo *et al.*, (2002) stated that anthropogenic activities have an accumulated effect on the current structure and the regeneration of the forest.

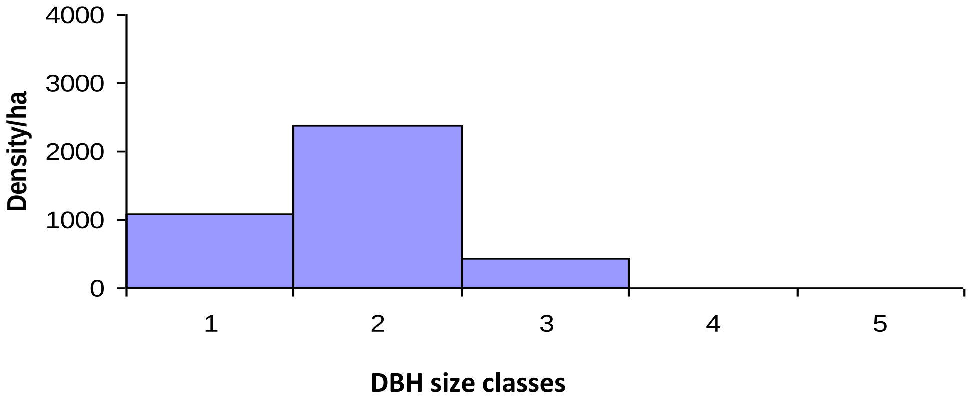

Fig. 1 showing the size class distribution of mangrove tree species at Sandspit.

Table2. Stand characteristics of Sandspit mangroves forests.

Parameters	Mean±SE
Tree Density (ha^{-1})	3895±138
Basal Area (m^2/ha)	6.59±0.31
Height (m)	5.0.±0.19
Leaf Area (cm^2)	18.33±2.35
Height of Pneumatophores (m)	25.34±1.34
Number of Pneumatophores	71±13

Carbon stocks: An important carbon stock in forestry is the above-ground and below-ground biomass. Trees dominate the aboveground carbon pools and serve as an indicator of ecological conditions of the most forests. The result of biomass and sediments measurements for carbon content in the mangroves is a first order exploration of carbon values in the Pakistan using this technique. Relatively low number of samples were taken therefore, it's an approximation for carbon content in biomass and sediment for the mangroves. Table 3 shows the mean carbon in sediment, above ground biomass (AGB), below ground biomass (BGB) and the total ecosystem carbon (TEC) in backwater mangrove forest. The estimate of mean combined C-stocks in the mangrove biomass and sediment of Sandspit mangrove showed that this estuarine mangrove wetland stores 183.99 t C ha^{-1} (AGB 93.33 ± 2.60 t ha^{-1} and BGB 39±4.5 t ha^{-1} and sediment 51.66±3.92), which was equivalent to 675.24 t CO_2 ha^{-1}. The mangroves which cover an area of 6.59 ha^{-1}, is assumed to have a potential to sequester and store a substantial quantity of 1212.49 t C which is equivalent to 2478.13 t CO_2. Donato *et al*., (2011) stated that mangrove soils have been found to be a major reservoir of organic carbon and given the importance of this carbon pool.

Table 3. Total Carbon stocks in the Sandspit mangrove forest.

Components	Carbon (t ha^{-})	% of total carbon
Total Above Ground carbon (live and dead trees herbaceous, pneumatophores and litter) (AGB)	93.33±2.60	50.72
Total Below-ground carbon (soil and roots) (BGB)	39.00±4.50	21.19
Total Carbon^{-} in sediment (the top 30 cm)	51.66±3.92	28.07
Total ecosystem Carbon	**183.99±11.02**	**99.98**

Different species produce different biomasses and its carbon stock based on its sizes and length of above/underground part including environmental conditions. In Pakistan no other data of *Avicennia marina* from different sizes and location is available therefore; biomass estimate in present study was worth comparing to the studies undertaken from different mangroves and other trees in different part of the world. The overall mean AGB recorded in present study (93.33 ± 2.60 t ha^{-1}) was considerable higher than stunted *Avicennia marina* (6.8 t ha^{-1}) recorded by Woodroffe (1985). He estimated much higher (104.1 t ha^{-1}) biomass from taller trees of same species. Chandra *et al*., (2011) found 116.8 t ha^{-1} from Malaysian mangroves. Sahu *et al*., (2016) presented 124.91 t ha^{-1} and 125.55 t ha^{-1} values from Mahanadi wetland and plantation mangrove in inland respectively. Christensen, (1978) reported higher amount (159 t ha^{-1}) from *Rhizophora apiculata* forest of Thailand. Khan *et al*., (2009) showed less amount (80.5 t ha^{-1}) of *Kandelia abovata* from Manko Wetland, Okinawa, Japan while Murdiyarso *et al*., (2009) presented 61.4 t ha^{-1} from North Sulawesi.

The estimated mean biomass C-stock (132.33 t C ha-^{1}) was close to that obtained values from same depth in the Micronesian coastal fringes of Palau (128.1 t C ha^{-1}) and Yap (119.5 t C ha^{-1}) (Kauffman *et al*., 2011). The total ecosystem carbon in present study was lower than that of *Rhizophora mucronata* and *Avicennia marina* of Micronesian coastal fringes of Yap (363.0 t ha^{-1}) and Palau (225.0 t ha^{-1}) (Kauffman *et al*., 2011) but higher than estuarine complex along the Bay of Bengal, India (60.0-117.7 t ha^{-1}, Kathiresan *et al*., 2013). It is hoped that this data can be refined with more intense research efforts in future. While comparing the results of the backwater Sandspit mangroves with other mangrove species and areas, it is evident that the above-ground biomass varies greatly from region to region in response to combination of natural and anthropogenic variables (Shaheen *et al*., 2016). The biomass is determined by various factors such as species-species composition, tree density, growth forms, tree height, stem diameter and age of the mangrove stands (Lugo and Snedaker, 1974; Woodroffe, 1985; Knox, 1986). The mangroves of Sandspit has well established 12 to 20 year-old predominant population of *A. marina* (Nazim *et al.,* 2013) which has contributed significantly to the mean above-ground biomass of 93.33 t ha^{-1}. It may be concluded that this area is playing an important role in carbon sequestration by acting as sink for carbon. It is highly recommended that long term research is required in other mangrove sites of Pakistan for successful mangrove reforestation and to estimate rate of carbon for climate change mitigation. There are also many morphological differences in *A.marina* so it is anticipated that this may be due to the genetical difference in this species. It is suggested that we should explore the genetic differences for different morphological forms (species) and different allometric equations should be developed for accurate and reliable carbon estimation. The key priority should be given to manage and conserve unbalanced mangrove forests; seedling/ sapling should be properly introduced and monitored time to time.

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