ESTIMATION OF CARBON STOCK AND SEQUESTRATION POTENTIAL IN RIVERINE FORESTS OF SUKKUR, SINDH

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ABSTRACT

Quantification of forest carbon stocks has gained momentum after emergence of REDD+ as a promising option for climate change mitigation. Forest carbon inventory in the riverine forests of Sukkur was conducted during January-March, 2018. Data was collected from 751 sample plots using a systematic random sampling technique. The total carbon stock in the study area is 303,110 tonnes. Out of this 81% is in the soil, 10% in aboveground biomass, 6% in belowground biomass and 3% in litter. Mean carbon density was estimated as 41.55 t/ha in the landscape. Mean aboveground carbon density was determined at 4.60 t/ha. Mean belowground carbon stock was estimated at 2.57 t/ha. Litter carbon was estimated as 1.42 t/ha. Dead wood was found to be a non-significant pool of carbon in the riverine forest ecosystems. Average organic soil carbon was estimated at 31.95/t. There is a potential of carbon sequestration upto 20 tCO_2/ha/year in this highly fertile landscape. This can be achieved with sustainable forest management practices and effective policy measures. The study recommends to initiate reforestation programs on urgent basis and stop open grazing and illicit cutting for the rehabilitation of these valuable forests.

INTRODUCTION

Forests are the most important terrestrial carbon sink, and carbon sequestration is one of the key ecosystem services provided by the forests. The importance of forests has increased many folds in view of their crucial role in climate change mitigation (Streck and Scholz, 2006). Forests not only act as a sink of carbon but also become source of emissions when forest are cut. Thus protection of forests is very important for addressing the challenge of climate change (Brown, 2002; FAO, 2006). Besides, trees as renewable natural resources and have a high potential in contributing to transition to fossil-free energy systems (Baker *et al.*, 2010). However, there might be trade-offs between the extensive use of forest for reducing human CO_2 emissions and their ability to store carbon.

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Reducing emissions from deforestation, forest degradation, sustainable forest management, conservation and enhancement of forest carbon stocks known as REDD+ has emerged as a promising option for forest-based climate change mitigation in developing countries (Scheyvens, 2010). Under the REDD+ programme, developed countries will provide incentives to the developing countries to keep their forests standing and thus help in reducing GHG emissions. One of the key requirements for carbon based forest management is measurement, reporting and verification (MRV) of carbon stocks in the forests (UNFCCC, 2010).

Pakistan is a forest deficient country with only 5% forest cover. Out of its 87.98 million hectare area only 4.51 m ha is under forest cover. Sindh is a low forested province of Pakistan with only 660,584 ha (4.6%) forest cover which includes 183,835 ha riverine forests (Bukhari *et al*., 2012).

Riverine forests are the most important forest types of Sindh. Besides providing a source of livelihood for thousands of people, these forests provide fuel wood, timber, fodder, honey and tannin. Moreover, they serve as carbon sinks and also protect the surrounding areas from the severity of floods. Sindh Forest Department controls 241,198 hectares areas in the Riverine tract of the province which are categorized as Riverine Forests, locally known as Kacho forests. These forests are located along both the banks of River Indus in Thatta, Hyderabad, Dadu, Larkana, Naushero Feroze, Nawabshah, Khairpur, Sukkur, Shikarpur, Ghotki and Jacobabad Districts and have been declared as “Reserved Forests” under Forests Act, 1927 (SFD, 2018). The total forest area of Sukkur Forest Division is 50,294.4 ha and is situated in three civil districts e.g. Sukkur (26,257.4 ha) Shikarpur 12,275 ha) and Ghotki (11,762 ha) (Wagan and Domki, 2000).

A study was conducted under Sustainable Forest Management Project to estimate carbon stock and sequestration potential in riverine forests of Sukkur Forest Division.

MATERIAL AND METHODS

Forest carbon inventory in the riverine forests of Sukkur was conducted during January-March, 2018. A systematic random sampling technique was used for collecting data in the field. Sample plots were laid out on geo-referenced maps of riverine forests using a grid of 500x500 m (Figure 4). The coordinates of the centers of the sample plots were noted from the maps and uploaded onto GPS and navigated in the field accordingly.

Figure 1: Locating Sample Plot in the Field

As the current inventory is aimed at estimating biomass and carbon stock in different carbon pools of riverine forests, nested circular plot approach was applied for collecting the data. As illustrated in the Figure 2, three subplots were established within each plot for specific purposes. The outermost circular plot with radius 17.84m was used for measurement of trees. The second circular plot with radius 5.64 m was used for measurement of shrubs and sapling; and the innermost plot with radius of 0.56 m was used for measurement of leaf/litter and grasses as well as soil (Subedi *et al*., 2010). Allometric equations were used to convert forest inventory data into biomass and carbon stocks (Ali, 2017; Chave *et al*., 2005).

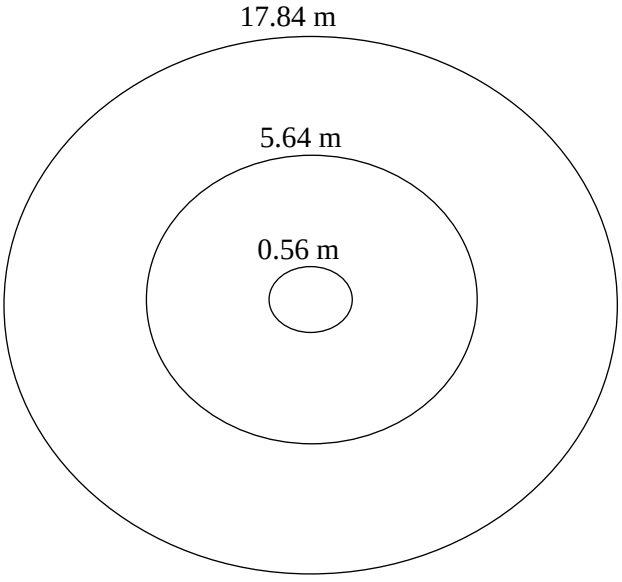

Fig.2. Nested Circular Plot


Fig.3. Field Measurements

A total of 751 sample plots were laid out in different forest areas for data collection. The distribution sample plots in different forest areas are given in Table 1.

Table 1. Distribution of Sample Pots in different Forest strata

Forest Area	Forest Area (ha)	Number of Sample Plots
Bindi Dhareja	2,941	127
Keti Abad	4,585	339
Keti Shah	7,346	97
Keti Shahu	4,512	132
Kadrapur	857	10
Shahpur	5,500	46
Total	**25,741**	**751**

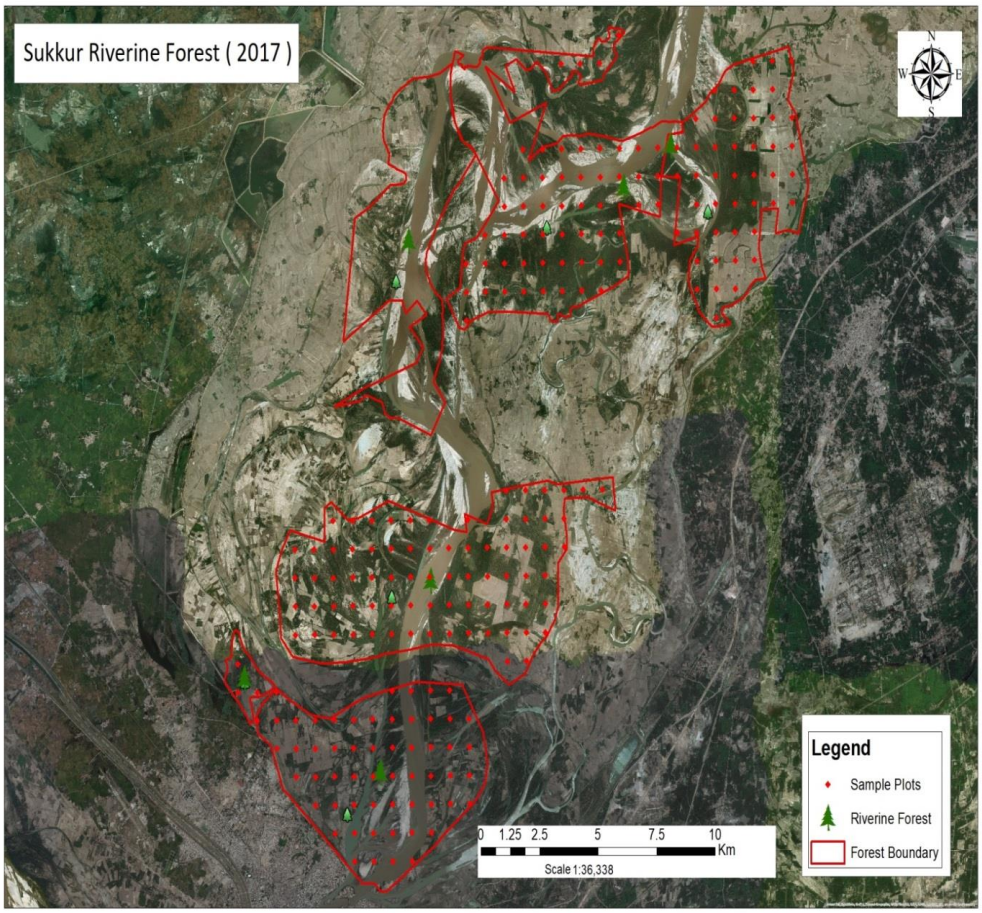

Fig.4. Study Area Map showing Sample Plots

RESULTS AND DISCUSSION

Aboveground Carbon Stock

The aboveground biomass comprises trees and shrubs and it is the most important pool of carbon in a forest ecosystem. Mean aboveground carbon stock was estimated at 4.60 t/ha. Out of this, tree carbon was 3.26 t/ha and shrub carbon was 1.34 t/ha. Out of the six selected sites, Bindi Dhareja has the highest carbon density i.e. 7.12 t/ha followed by Keti Shahu (4.74 t/ha) and Keti Abad (4.74 t/ha). The lowest carbon density was found in Shahpur i.e. 2.92 t/ha. The detail of aboveground carbon stock is given in Table 2.

Table 2. Aboveground carbon stocks in different forest areas

Area	AGTC	Shrub C	AGC (Trees+shrub) t/ha
Keti Shahu	3.51	1.23	4.74
Keti Abad	2.99	1.55	4.54
Keti Shah	2.69	1.19	3.88
Shahpur	2.47	0.44	2.91
Bindi Dhareja	4.21	2.91	7.12
Kadrapur	3.72	0.70	4.42
Average	3.26	1.34	4.60

As currently only 27% of the forest cover has been left and the rest has been deforested, out of the total 25,741 ha, only 4290 ha area ha canopy cover more than 10%. The total above ground carbon stock in the existing forest in the riverine landscape was estimated at 30,315 tonnes. Distribution of aboveground carbon stocks in different forest areas is given in Table 3.

Table 3. Distribution of aboveground carbon stocks

Forest Area	Forest Area (ha)	Existing Forest area (ha)	AGC t/ha	AGC tonnes
Bindi Dharjea	2941	509	7.12	3624
Keti Abad	4585	1231	4.54	5588
Keti Shah	7346	2878	3.88	11167
Keti Shahu	4512	1196	4.74	5669
Kadrapur	857	257	4.42	1136
Shahpur	5500	1076	2.91	3131
Total	25,741	4290		30,315

Belowground Biomass

Carbon in the belowground biomass was taken as 56% of the aboveground biomass (IPCC, 2006). Mean belowground biomass was estimated at 2.57 t/ha. The total below ground carbon was estimated at 16,955 tonnes. Detail of carbon stock in belowground biomass in different forest areas is given in the Table 4.

Table 4. Distribution of below-ground carbon stock

Forest Area	Forest Area (ha)	Existing Forest Cover	BGC t/ha	BGC tonnes
Bindi Dharjea	2941	509	3.98	2026
Keti Abad	4585	1231	2.54	3126
Keti Shah	7346	2878	2.17	6245
Keti Shahu	4512	1196	2.65	3169
Kadrapur	857	257	2.47	635
Shahpur	5500	1076	1.63	1754
Total	25741	7147	2.57	16,955

Leaf/Litter/Grass Carbon

Leaf/litter/grass is also an important pool of carbon in a forest ecosystem. The total carbon stock in leaf/litter was estimated at 9,505 tons. Mean litter carbon in the riverine forests was estimated as 1.42 t/ha. Shahpur has the highest amount of litter followed by Keti Shahu forest. The lowest amount of litter was found in Keti Shah forests (Table 5).

Table 5. Estimates of leaf/litter carbon stocks in different forest areas

Forest Area	Existing Forest Cover (ha)	Litter C (t/ha)	Litter C tonnes
Bindi Dharjea	509	1.41	717.69
Keti Abad	1231	1.30	1600.3
Keti Shah	2878	1.08	3108.2
Keti Shahu	1196	1.54	1841.8
Kadrapur	257	1.46	375.22
Shahpur	1076	1.73	1861.5
Total		1.42	9505

Soil Organic Carbon

Soil sample have been collected from different forest areas in the riverine forest ecosystem upto 30 cm depth. The average soil bulk density was found as 0.59 g/cm^3 showing that the soil is porous, loamy and non-compact. Mean soil organic matter was found as 3.4% in the forest area. Average organic soil carbon was estimated at 31.95 t/ha (Table 6). IPCC has provided 31 t/ha for soil in dry

tropical areas (IPCC, 2003). Thus it is clear that in the study area soil carbon is much more than the carbon in aboveground biomass. Soil carbon is generally low due to high temperature which results in quick decomposition of the organic matter. Soil organic carbon in the landscape is given in Table 7.

Table 6. Soil organic carbon in the landscape

Forest Area	Existing Forest area (ha)	SOC (t/ha)	SOC tonnes
Bindi Dharjea	509	26.03	13,249
Keti Abad	1231	19.85	24,435
Keti Shah	2878	41.41	119,178
Keti Shahu	1196	28.19	33,715
Kadrapur	257	32.06	8,239
Shahpur	1076	44.16	47,516
Total		31.95	246,332

Total carbon stock in the Landscape

The total carbon stock in the study area is 303,110 tonnes. Out of this 81% is in the soil, 10 % in aboveground biomass, 6% in belowground biomass and 3% in litter (Figure 5). Distribution of carbon stocks in various pools in different forest areas is given in Table 7.

Table 7. Distribution of carbon stocks in different pools and forest areas

Forest Area	Existing Forest area (ha)	AGC tonnes	BGC tonnes	Litter C tonnes	SOC tonnes	Total C (tonnes)	Carbon Density (t/ha)
Bindi Dharjea	509	3624.1	2025.8	717.69	13249.27	19616.9	39.54
Keti Abad	1231	5588.7	3126.7	1600.3	24435.35	34751.1	29.23
Keti Shah	2878	11167	6245.3	3108.2	119178	139699	49.54
Keti Shahu	1196	5669	3169.4	1841.8	33715.24	44395.4	38.12
Kadrapur	257	1135.9	634.79	375.22	8239.42	10385.3	41.41
Shahpur	1076	3131.2	1753.9	1861.5	47516.16	54262.8	51.43
Total	7147	30316	16956	9504.7	246333	303,110	41.545

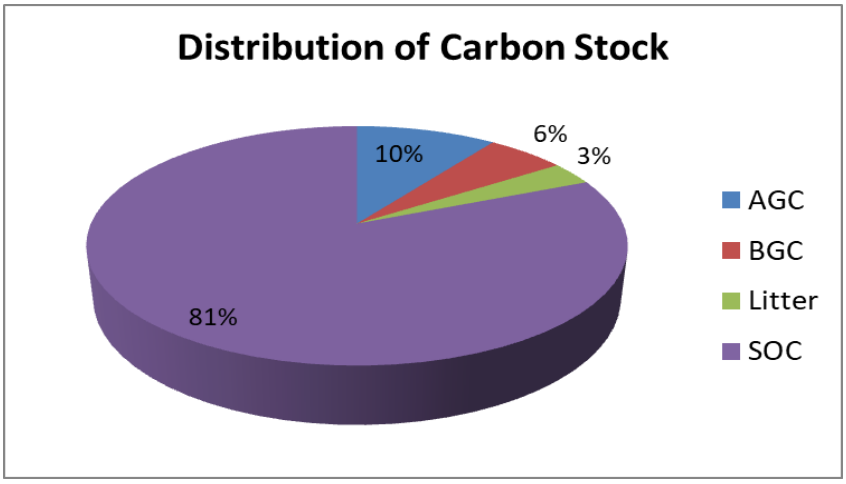

Fig.5. Distribution of Carbon Stocks in Different Pools

Carbon sequestration Potential

It was observed during field inventory that the forests are severely degraded and these are facing severe anthropogenic pressure. Open grazing and cutting for fuelwood are serious threats to these forests which have significantly reduced the aboveground carbon stock in the area. Current aboveground carbon stock was estimated at 5.20 t/ha in the forests. Some small protected patches have carbon stock as high as 40 t/ha which indicates that there is a gape of about 35 t/ha carbon in the aboveground biomass which may reach to 50 t/ha when belowground carbon is also included. Thus there is a potential of carbon sequestration upto 20 tCO_2/ha/year in this highly fertile landscape.

CONCLUSION AND RECOMMENDATIONS

Riverine forests of Sukkur are highly degraded at the moment due to which their current carbon stock is much lower than the potential. The total carbon stock in the study area is 303,110 tonnes. Out of this 81% is in the soil, 10% in aboveground biomass, 6% in belowground biomass and 3% in litter. Mean carbon density was estimated as 41.55 t/ha in the landscape.

The total above ground carbon stock in the existing forest in the riverine landscape was estimated at 30,315 tonnes. Mean aboveground carbon density was determined at 4.60 t/ha. Mean belowground carbon stock was estimated at 2.57 t/ha. The total below ground carbon was estimated at 16,955 tonnes. Litter carbon was estimated as 9,505 tonnes with average of 1.42 t/ha. Dead wood was found to be a non-significant pool of carbon in the riverine forest

ecosystems. Average organic soil carbon was estimated at 31.95 t/ha and the total soil organic carbon was estimated at 246,332 tonnes.

The forests are severely degraded and these are facing severe anthropogenic pressure. Open grazing and cutting for fuelwood are serious threats to these forests which have significantly reduced the aboveground carbon stock in the area. Current aboveground carbon stock was estimated at 4.60 t/ha in the forests. Some small protected patches have carbon stock as high as 40 t/ha which indicates that there is a gape of about 35 t/ha carbon in the aboveground biomass which may reach to 50 t/ha when belowground carbon is also included. Thus there is a potential of carbon sequestration upto 20 tCO_2/ha/year in this highly fertile landscape. This can be achieved with sustainable forest management practices and effective policy measures.

It is therefore recommended that reforestation programs may be initiated on urgent basis for the rehabilitation of these valuable forests. Open grazing and illicit cutting are the major threats to these forests which must be controlled.

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