Estimation of soil carbon stocks in Pabitora Sanctuary and Manas National Park in Assam

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North East India known for its rich flora and fauna, is covered by the mighty Brahmaputra–Barak river systems and their tributaries and comprises hilly terrain interspersed with valleys and plains. A field study was done to layout the soil carbon stock of Pabitora Wildlife Sanctuary and Manas National Park in Assam. Maximum average carbon stock in both was estimated in the upper layer of the soil sample, while least carbon stock was obtained at deepest layer (20–30 cm). The average carbon stock of the Manas National Park was higher than that of Pabitora Wildlife Sanctuary.

Keywords: Carbon sequestration, carbon stock, climate change, global warming, soil analysis.

CLIMATE change due to global warming is one of the major concerns of the 21st century. High concentration of atmospheric carbon is the main cause of global warming. Environmental and ecological degradation due to human interference is the major factor behind the changing climate. Mitigation of climate change through restoration and enhancement of natural ecosystem has become an important strategy around the globe. Batjes[1] reported that globally 684–724 Pg of carbon is stored in the soil up to 30 cm depth. This signifies the importance of soil as a sink for atmospheric carbon. Soil carbon sequestration is the process of transferring atmospheric carbon and storing it in the soil. Carbon is primarily stored in the soil as soil organic matter (SOM), which is a complex mixture of carbon compounds[2]. Lal[3] reported that soil organic carbon (SOC) pool is of great value to the human society as far as economical and ecological aspects are concerned. Amongst them, its relation to greenhouse gases emission and sequestration is an important factor and hence it is necessary to maintain soil carbon in order to arrest the increasing atmospheric CO_2. Carbon pools are divided into four groups, viz. oceanic, geologic, land and atmospheric pools. Soil pool is one of the major carbon pools; it is more than the biotic and atmospheric pools by about four and three times respectively[3]. Total soil carbon sequestration (SCS) potential of India is estimated around 39.3–49.3 Tg C/year (ref. 4). From the various studies done around the world, it is understood that any change in the soil carbon pool will lead to serious effects on global carbon budget. This is because change in land use alters the soil moisture content as well as the decomposition activity of microbes[5]. Soil can store atmospheric CO_2 through crop residues and other organic solids for millennia if undisturbed[6]. According to IPCC[7], improvement and enhancement of soil carbon is one of the most economical mechanisms to meet the global carbon reduction criteria. UNFCCC stresses the necessity and importance of all nations to provide and identify soil organic pool and changes hereto from land-use change in forestry sector. Decrease of SOM is also the main factor behind low agricultural productivity, equilibrium and sustainability of natural systems[8].

As the population increases, carbon emission due to anthropogenic activities and land-use change is expected to increase. Percentage change in land-use area, subsequent decrease in SOC and increase in CO_2 emission have been studied. The changes in SOC also depend on the previous management mechanism of the area[9]. The carbon emitted due to global scale land-use change in 1980s was 1.7 ± 0.8 Pg with an annual increase rate of 1.6 ± 0.8 Pg C/year (ref. 3). Loss of SOC up to 48% was noted in hilly watershed area of Nepal[10]. A reduction in SOC of 39.4% was noted during 1960 and 2000 in the northeastern region of India[4]. The country is facing a huge task of degradation in the quality of natural resources (soil, water and atmosphere), which are the backbone of sustainable development. These changes have been mainly due to anthropogenic activities[4]. The changes which might take place in the Indian forestry due to climate change were studied by Ravindranath *et al.*[11]. They used various models for prediction and found that by 2085, around 68–78% of Indian forestry will undergo a drastic change in biodiversity. They also predicted that the northeastern region of India will become wetter, while the northwestern region will be drier without human influence. According to the Forest Survey of India[12], the forest cover of the country has decreased from 69.23 million ha in 2009 to 69.20 million ha in 2011.

Climatic conditions of the area and soil temperature also play an important role in organic carbon transformation. According to IPCC[13], the average global temperature has been increasing at 0.17°C/decade. As a result, there has been major change in land surface precipitation in various places. These in turn, alter SOC in the region. The main effect of climate and temperature on SOC is related to their influence on the microbial species and it differs from region to region[3]. The temperature sensitivity of clayey soil is less because of the chemical protection of SOM, while temperature sensitivity is high in the case of tilled soil. Thus, the older and more recalcitrant soils are not sensitive to temperature. Even though their temperature sensitivity is minimal, it is important to consider this pool because of their large contribution to soil carbon stock and hence a small change in decomposition may be disturbing[14]. Gupta *et al.*[15] studied SOC variation due to

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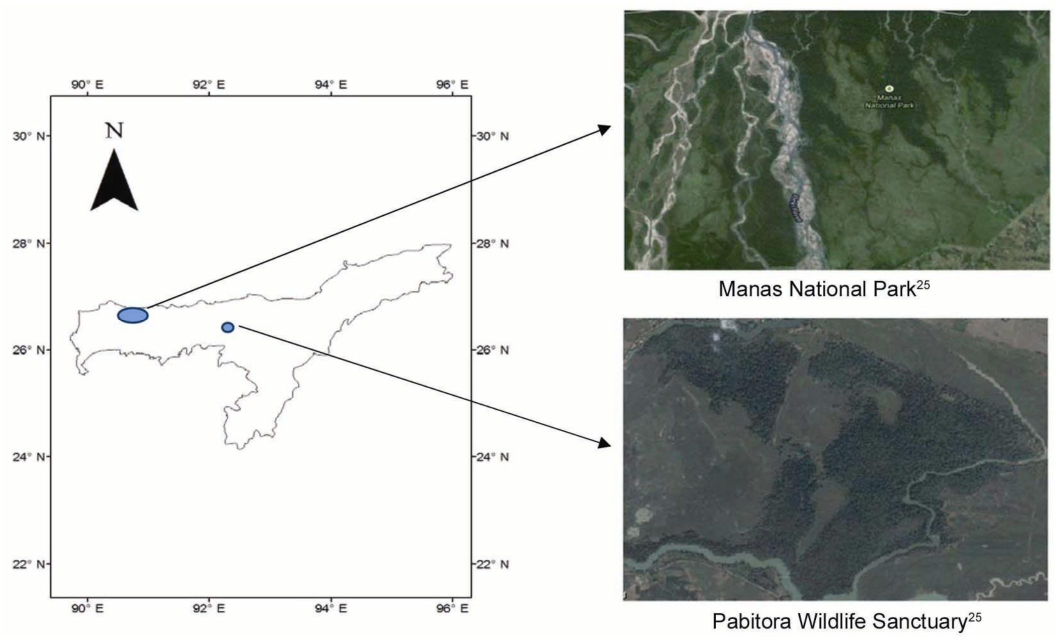

Figure 1. Study area.

different land-use and vegetative cover in Uttarakhand, India. SOC estimation was done up to 30 cm depth by collecting five samples randomly from the forest. SOC was high in forest region because of greater canopy and maximum litter input, followed by grassland, orchards and plantation area.

Studies have been done to estimate carbon stocks in the Indian subcontinent. Bhattacharya *et al.*[16] estimated and summarized the SCS of different regions in India. Maximum SOC stock of 7.89 Pg (40%) was noted in the northern mountain comprising the Himalayan and the northeastern region, while the coastal plains and islands have the least SOC with only 2.24 Pg (10%) of the country's total SOC stock. Similarly, Lal[4] estimated the SOC pool of India as 21 Pg C up to 30 cm depth and 63 Pg C up to 150 cm depth. Tarafdar *et al.*[17] estimated soil carbon under different land use categories in the arid and semi-arid regions of Rajasthan. Soil carbon was higher in the semi-arid area. Considering year-round canopy cover and no anthropogenic disturbance, carbon sequestration potential of 4200–4600 kg/km^2/year was predicted for the arid regions. Patil *et al.*[2] estimated the organic carbon potential of a forest in Gujarat. The average organic carbon was estimated around 54.16 t C/ha. NE India lies in the northern mountain region of the physiographical zone of India as classified by the National Atlas and Thematic Mapping Organization (NATMO)[18]. The northeastern region of India covers a meagre area of 10% of the total Indian land mass, but contributes maximum SOC stock. This may be due favourable weather and high rainfall. Thus, there is slow rate of decomposition[16].

To the best of our knowledge, no studies are available in the literature dealing with the estimation of carbon sequestration potential in the forests of Assam such as Manas and Pabitora. Thus, the objective of the present study is to conduct field investigations at the Pabitora Wildlife Sanctuary and Manas National Park, Assam, in order to estimate the potential carbon sequestration of the forest soil.

Assam extends from 89.7E–96.0E long. and 24.133N–28.033N lat. (ref. 19). It is a temperate region and experiences heavy rainfall and high humidity. The region receives an average annual rainfall of 2818 mm[19]. Temperature in the region ranges from 35–38°C in summer to 6–8°C in winter. The total forested area of Assam is 28,832 sq. km.

The Pabitora Wildlife Sanctuary is located in Morigoan district of Assam about 30 km east of Guwahati (Figure 1). It lies between 26.22N–26.25N lat. and 92.05E–92.1E long., covers an area of 38.80 sq. km and comprises flat flood plain and hillocks. In 1971, it was declared as a reserved forest and consequently as a Wildlife Sanctuary in 1987 (ref. 19). The sanctuary is rich in flora and fauna and has 15 inspection camps inside the forest. It is a tropical evergreen forest and thus maximum area of the forest is covered by green vegetation. The soil is of clayey nature with little silt content. Grazing of wild cows and other animals can be observed in most parts of the sanctuary. The elevated hillocks are exposed to heavy erosion and high run-off but the abundance of broad leaf, deep-rooted trees minimizes the effect.

The Manas National Park situated between 26.71N lat. and 90.93E long., is a wildlife sanctuary located in the eastern foothills of the Himalayas (Figure 1). It is known for its rare and endangered endemic wildlife. The forest is spread over an area of 950 sq. km. It was declared as a

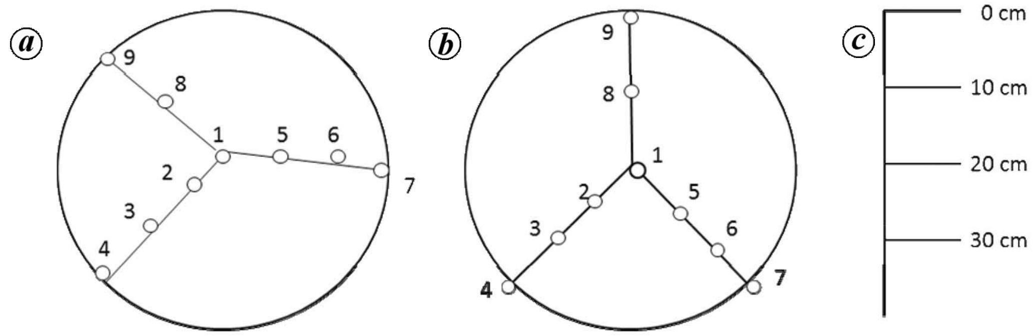

Figure 2. Sampling location layout of (***a***) Manas National Forest and (***b***) Pabitora Wildlife Sanctuary with markings of sample sites from 1, 2, …, 9 respectively. (***c***) Depth of sampling.

sanctuary in 1928 and as a World Heritage Site in December 1985 by UNESCO[19]. Manas and five other small rivers flow through the National Park. The forest is managed under the administration of Assam Forest Department. It is a semi-evergreen forest and is densely forested. The region experiences a minimum temperature of 15°C and maximum temperature of 37°C. The annual average rainfall is around 333 cm. The northern part of the park is composed of limestone and sandstone and the region is of savanna type, whereas the grasslands in the south are made up of deep deposits of fine alluvium. Most of the area is low-lying and flat and thus prone to inundation during rainy season.

The site to be studied was selected using the map of the area and through discussions with the officials of the sanctuary. GPS readings of the selected points were noted. The undisturbed soil samples at different depth, i.e. 0–10, 10–20 and 20–30 cm were dug out and stored in labelled ziplock plastic bags. Likewise, soil samples from nine different places were taken. Core-cutter method was followed in order to estimate the bulk density of the place. Stratified random soil sampling technique was used for sampling. A circular area of radius 30 m was chosen and samples were taken from different parts of the area in October 2013 (Figure 2). As shown in Figure 2, the sample sites are marked 1, 2, 3, …, 9 respectively. At all the sites three soil samples were collected at different depths. The soil samples collected were dried under natural conditions and later on in a heated oven at 65°C for 6 h to remove moisture content. The dried samples were sieved through a 2 mm sieve and the finer particles only were considered for analysis.

In the Pabitora Wildlife Sanctuary, sites 1, 4–7 were covered with grass but no trees. Grazing was observed at sites 5–7. Site 2 was totally disturbed. Site 3 was elevated and sites 8 and 9 were located inside the deep forest, covered with trees.

In Manas National Forest, sites 6, 8 and 9 were located in forested areas covered with fully grown trees. Site 9 was totally undisturbed with limited exposer to sunlight. Sites 1–5 and 7 were found to be grazed by animals and have little grass cover with shrubs. Of all the selected sites, clay content was less at sites 3–5 and 7.

Walkey and Black[20] method for organic soil testing was followed for analysis. Two blank samples were prepared for calibration. These samples were titrated against ferrous sulphate solution prepared in the laboratory. The soil samples were mixed with the required volume of sulphuric acid and potassium dichromate solution and finally titrated with ferrous sulphate solution in the presence of phenolphthalein indicator. The organic matter of the sample was calculated as follows[21].

$$\text{Organic matter (\%)} = (1 - S/B) \times 10 \times 0.68,$$

where S is the volume of ferrous sulphate solution required to titrate the samples (ml); B the average volume of ferrous sulphate solution required to titrate the two blanks; 10 the conversion factor for units and 0.68 is the factor derived from the conversion of percentage of organic carbon to percentage of organic matter.

Conversion of OM (%) into carbon stock (kg/m^2) = $d \times BD \times$ SOC-content × CFst, where d is the depth of horizon (m); BD the bulk density (kg/m^3), SOC-content is in g/g and CFst is the correction factor for stone and gravel content; CFst = 1 – (% stone + % gravel)/10.

A higher carbon content at the upper surface layer (i.e. 0–10 cm depth) was noticed in most of the cases. The abundant availability of grass cover and trees might be the reason for the higher carbon content. In Pabitora Wildlife Sanctuary, location 2 (Figure 3) shows the least value of carbon content in the top layer. Location 2 was selected in a fully disturbed area often used by humans as a path into the forest and hence there was complete absence of green cover. This site was chosen to take into account the areas disturbed by humans for building camps inside the forest (all together there were 15 camps). Organic carbon content of the soil was higher at sites 8 and 9 for all soil depths. These were densely forested areas with shade and litter inputs. SOC content was found to decrease from surface layer to the 10–20 cm depth and then 20–30 cm depth, except in locations 2 and

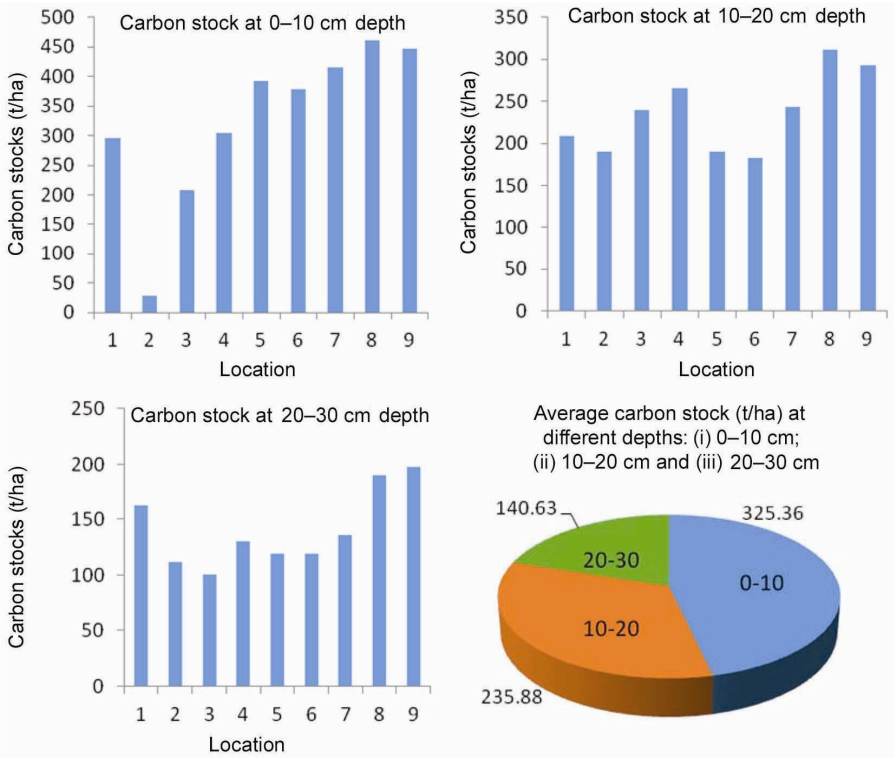

Figure 3. Carbon stock distribution of Pabitora Wildlife Sanctuary.

3, where the SOC content at 10–20 cm depth was higher than the surface layer. This may be because, location 3 is situated at a higher elevation compared to the other locations and hence there might be more seepage of organic matter. As for location 2, the surface is fully exposed with no vegetation and is constantly disturbed; thus less organic carbon. Large scale grazing activities were seen at locations 4–7 and hence the SOC content were comparatively less in these areas. The respective graphical representation of carbon stock of sites at different depths is shown in Figure 3.

The carbon stock at the upper layer of the soil was much higher than the other deeper layers. A decreasing trend of carbon storage with depth was observed in all the sites. Carbon stock was the highest at the locations covered with tree canopies. This is because of better condition for microbial activities in the region. Carbon stock was less in silty soil samples and high in clayey soil. These show the interlinking of organic carbon content and soil taxonomy. As a whole the carbon stock of the region was high. Figure 4 shows graphical representation of carbon stock of sites at different depths.

Few researchers have estimated the soil carbon stock in NE India. Singh *et al.*[22] estimated the carbon stock in the tropical evergreen forest of Mizo hills to be 24.6–60.9 t C/ha. Soil carbon stock of East Khasi hills was 42.2–184.3 t C/ha (ref. 23) and that of Assam (Jorhat) was 86.7–151.2 t C/ha (ref. 24). In all the studies, estimation was done up to 50 cm depth and the texture of the soil was sandy loam with little clay content. The soil carbon stock in Pabitora Wildlife Sanctuary and Manas National park was found to be 233.96 and 260.9 t C/ha respectively, which was higher than the previous studies. Carbon stock estimated by other researchers was found consistent to our study, barring some exceptions which may be due to difference in estimation depth and texture of soil. Highest amount of carbon stock was observed in the surface layer in both Pabitora and Manas forests. This may correspond to abundant availability of root system and better microbial activities in the upper layer. Variation in carbon stock according to the type of soil was noted. The SOC was less in silt and sandy soil in some of the locations of Manas National Park. In some of the elevated locations of Pabitora Wildlife Sanctuary, carbon stock was higher at deeper layers. This may be because of the seepage of organic matter and erosion prevailing in the location. Organic carbon content was relatively higher in locations covered with tree canopies, resulting in higher litter input and roots.

The average carbon stock of Manas National Park was higher than that of the Pabitora Wildlife Sanctuary. On the basis of this, the following conclusions can be made. First, Manas forest region is low-lying and flat, while the Pabitora consists of small hillocks inside the forest; thus, erosion of soil carbon along with the run-off is higher. Secondly, five rivers flow through the Manas forest and hence temperature of the forest is influenced by the land–water interchange. Thirdly, Manas is located in the foothills of Himalayas and hence temperature is less in this region. The average soil organic stock of Pabitora and Manas

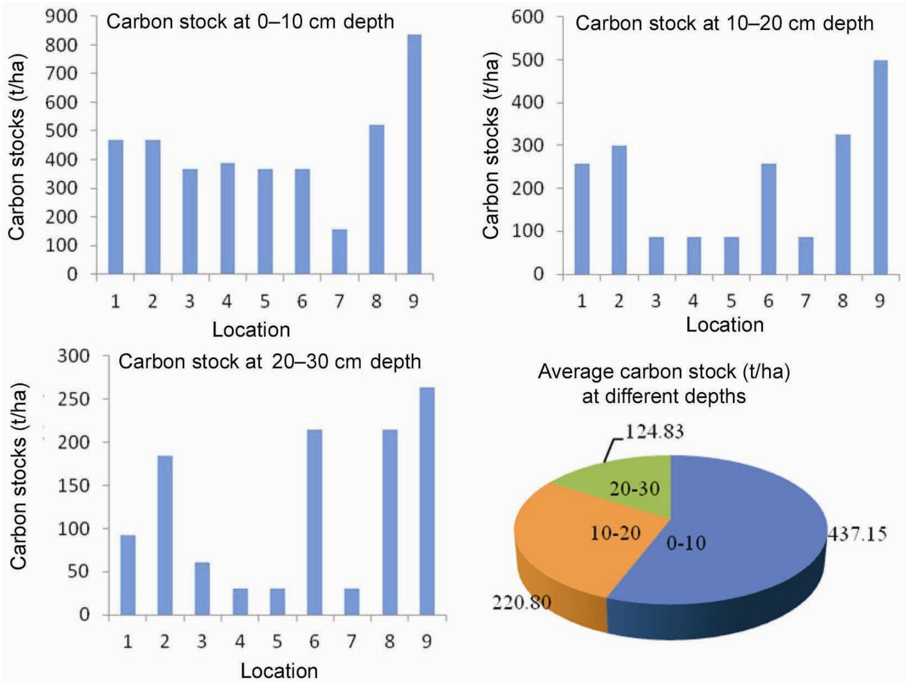

Figure 4. Carbon stock distribution of Manas National park.

forests was 233.9 and 260.9 t C/ha respectively. These values were higher than the carbon stock in other regions of India. The favourable climatic condition and higher rainfall may be the factors for higher soil carbon stock.

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