Comparison of soil characteristics and carbon content of contrastingly different moist-mixed deciduous and evergreen mangrove forest in Odisha, India

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ABSTRACT
The research associated the comparison of soil properties influencing organic carbon between forest of Chandaka Wildlife Sanctuary (CWS), Bhubaneswar and Bhitarkanika National Park (BNP), Rajnagar of Odisha. Soil samples were collected randomly from sampling plots (20 m × 50 m) and characterized by SEM and FT-IR, etc. The SEM micrographs analyze the aggregate-dominant fabric soil (Fine sand type) of CWS and matrix-dominated fabric soil (Clay loam type) of BNP. The FT-IR spectroscopy ensured the variant and prominent C-functional groups in both forest soils. The soil organic carbon of CWS (47.51 ± 2.16 Mg C/ha) and BNP (54.3 ± 3.0 Mg C/ha) directed through soil physico-chemical properties. The C/N ratio of CWS (51.3 ± 13.8) and BNP (21.6 ± 2.6) soil indicated the freshly added stable carbon compound availability at CWS. These results encourage study of soil organic carbon perspectives for sustainable forest conservation.

Introduction
Worldwide, studying forest area soil carbon has gained momentum for its better management on global carbon storage. The process of land-use land change and deforestation has declined the forest carbon pool, and thus removal of plant biomass and decrease in the organic matter input in soil. Forest soil reserves much higher organic carbon including varying proportion of active organic carbon fractions and stable organic matter, referred to as humus in comparison to agriculture and other land use (Mandal et al., 2014). Transitions of degraded forest to regenerated forest enhance the carbon sequestration in vegetation and soil. However, forest soil can store carbon more than the combined amount present in living biomass and atmospheric CO₂ (Jobbagy and Jackson, 2000). The tropical deciduous forests (33.19%) dominant over tropical semi-evergreen forests and coastal Mangrove forests (0.3%) are destroyed through the growing demand for cultivated land, development of industries and mining, urbanization and over grazing of pasture (FSI, 2013). The soil physical characteristics determine the adoptability, the level of biological activities and regulate the plant ecosystem. In part, soil characteristics depend on forest types rather directly affected through forest biodiversity (Myo, Thwin, & Khang, 2016). The plant composition may alter the soil physical and chemical properties, which in turn disturbs land efficiency (Singh, Tripathi, & Singh, 2011). The soil textural variations are ranging from sandy loam to clay loam. The regenerating capacities of frequent growing species and water lodging make somewhat the soil acidic (Mishra et al., 2017). In context to global coastal zone mangrove forests have 25% of carbon burial, and hence a vital source of terrestrial and oceanic carbon cycling (Alongi, 2008; Liu et al., 2014). The net primary production of mangrove ecosystem was estimated to be 218 × 10⁹ kg C per year, i.e., one of the most productive biome of the earth (Bouillon et al., 2008; Tue et al., 2012). The forests composed of marine alluvium soil rich in organic matter and alkaline in nature. The light-colored topsoil are porous and well aerated rather than the dark-colored topsoil. The soils obtained a complex system by the convoluted interaction among tides, physiography, activities of plant, and invertebrates that may even changes within short distance (Otero et al., 2009).

India possesses 10th rank in the world by 76.87 million ha of forest and tree cover with a large variety of climatic and topographic regimes. About 75% of the total terrestrial carbon pool is soil carbon (Farquhar et al., 1989). Odisha state forests occupy approximately 32.33% of the total Indian forest cover (i.e., 21.23% of the total geographical area). The global soil organic carbon (SOC) is estimated about 3000 Pg, but huge variabilities remain in to the depth >1 m (Kochy, Hiederer, & Freibauer, 2015). Soil classification with their edaphic variables such as pH, conductance, and parent material, texture along with the chemical and physical composition of...
substrate, also regulate the soil organic matter and stock (Ganuza and Almendros, 2003). Thus, the demands for fundamental understanding of mechanisms of SOC stabilization and a systematic scientific work related to forestry, in India, started with the establishment of FRI (Forest Research Institute) in 1905 (Patra et al., 2015). However, there are relatively little data on SOC in connection to tropical and subtropical forest types of India.

The comparative characteristics of soil properties and SOC content covering two separate forests, i.e., Secondary mixed deciduous forest of Chandaka Wildlife Sanctuary (CWS) and mangrove forest of Bhitaranika National Park (BNP) have been focused here. The objectives are (i) to assess and compare the physico-chemical properties of both forest soil and (ii) their correlation study to establish the significant effect of these parameters on SOC.

Materials and method

The sampling enclosed different forest sites of CWS and BNP: the former is the part of Eastern Ghats and later is the part of Coastal Plains of Odisha (Figure 1).

CWS, Bhubaneswar

The area spread over the northwestern fringe of Bhubaneswar and a part of Khurda uplands of “Eastern Ghats” biotic region influence by tropical weather and rich phytodiversity dominated by mostly angiosperms grow on lateritic soil (Biswal, Thatoi, & Sahu, 2005).

BNP, Rajnagar, Kendrapara

Evergreen Mangrove Forest of Mahanadi Delta, Rajnagar is situated on the gateway to Gahirmatha Marine Sanctuary and a forest part of Bhitaranika National Park. This forest comprises alluvial silty soil with comparatively less phytodiversity dominated by gymnosperms (Chaudhuri et al., 2015).

Sample collection, preparation and analysis

Sampling plots were rectangular (20 m × 50 m) based on species area curve (Mueller-Dombois & Ellenberg, 1974). Ten spatial plots locations were tagged for its geographical positioning, i.e., latitude and longitude of each plot using a GRAMIN-global positioning system (GPS). The soil samples randomly collected by T-shaped iron auger (7 cm diameter) up to a depth of 30 cm. pH and electrical conductivity of soil samples were analyzed with pH and EC meter (Systronics 371). The soil samples were air dried and sieved (<0.2 mm) for its laboratory analysis. For moisture content (%), the soil samples were oven dried at 104.5° C for 24 h following gravimetric direct method (Gardner, Robinson, Blyth, & Copper, 2001). Bouyoucos Modified method was followed to determine soil texture (Beretta et al., 2014). SOC was estimated through partial oxidation method (Walkley & Black, 1934). Then the total SOC stock was calculated using bulk density and soil depth (VandenBygaart & Angers, 2006). The data on SOC were evaluated statically though SPSS software and the mean ± standard error of SOC are graphically represented.

For estimation of carbon, hydrogen and nitrogen percentages, homogenized fine powdered soil samples were analyzed through CS-Analyzer (model.no-EMIA920V2) and ONH-Analyzer (model.no.-EMGA-930), respectively, H2O2 treatment of soil had been conducted to remove the organic carbon from the bulk soil sample. The fine-powdered soil samples are compactly treated with KBr pellets and Fourier transform infrared (FT-IR) spectral scanning obtained at 4000–400 cm−1 to compare bulk soil and H2O2 (30%) treated soil. The data of FT-IR were graphically represented through Microsoft origin 9.0. The soil samples were homogenized using 2 mm sieve and sprinkled on double-sided carbon tape, the excess blown off with compressed air to characterize the sample through scanning electronic microscopy (SEM).

Results and discussions

The experimental soil physio-chemical parameters are evaluated through average and standard error of mean. The comparative result of physico-chemical parameters characterized that CWS soil was acidic with lower electrical conductivity (EC) and soil moisture content percentages (Table 1). However, BNP forest soil was alkaline, with higher EC and soil moisture content percentages (Sukardjo, 1994). The Box and Whisker charts of soil texture (Figure 2) classify the variation in the soil types. The fine sand soil type of CWS have characterized 90.9% sand content, 6% silt content, and very low clay (3.0%) content supplying lower SOC i.e., 11 gm/kg. However, BNP soils were characterized by higher

| Table 1. Comparison of soil physico-chemical parameters of CWS and BNP. |
|-----------------|---------|---------|
| Physico-chemical parameters | CWS     | BNP     |
| pH               | 5.4 ± 0.1 | 7.0 ± 0.1 |
| Conductivity (µS) | 75.4 ± 6.1 | 5.3 ± 0.08 |
| Soil moisture content (%) | 9.4 ± 1.8 | 39.6 ± 1.1 |
| Water holding capacity (%) | 42.4 ± 1.1 | 45.0 ± 1.2 |
| Soil textural type | Fine sand | Clay loam |
| Sand (%)       | 90.9 ± 1.7  | 19.7 ± 1.9  |
| Silt (%)       | 60.0 ± 1.0  | 47.4 ± 1.4  |
| Clay (%)       | 3.0 ± 0.8   | 32.7 ± 0.8  |
| Total carbon (%) | 1.3 ± 0.3 | 1.7 ± 0.04 |
| Organic carbon (%) | 1.1 ± 0.2 | 1.3 ± 0.09 |
| Inorganic carbon (%) | 0.2 ± 0.06 | 0.3 ± 0.05 |
| Total nitrogen (%) | 0.09 ± 0.04 | 0.07 ± 0.003 |
| C/N ratio      | 51.3 ± 13.8 | 216 ± 2.6  |
| Organic carbon (gm/kg) | 10 ± 2.8 | 13 ± 0.9 |
| Bulk density (kg/m²) | 1300     | 1000     |
| Soil depth (m) | 0.3       | 0.3      |
SOC (13 gm/kg), for silt (47%) content, clay (33%) content, and low sand (20%) content (Meersmans, De Ridder, Canters, DeBaets, & VanMolle, 2008). Likewise, BNP had the higher water content soil rather than CWS.

**SEM and FT-IR study**

The SEM photographs of CWS and BNP soil samples displayed shape of sand varied rounded to rough and some places angular. The 10 and 5 µm magnification had done in both types interpreted different pattern of arrangement of soil granules (Figure 3). The spectroscopical analysis done through FT-IR technique revealed sharp picks for CWS whereas BNP had more blunted picks (Figure 4).

**SOC and C/N ratios**

The average SOC (Figure 6) in CWS was calculated as 47.51 ± 2.16 t/ha and that of BNP was 57.6 ± 3.2 t/ha. This ratio is comparatively high in CWS, i.e.,
Figure 3. SEM micrographs of soil samples recorded at different magnifications: 5 µm and 10 µm.

Figure 4. FT-IR spectra of CWS and BNP soil samples.

Figure 5. Comparative line graph re-presenting FT-IR spectra of raw and H$_2$O$_2$-treated soil samples.

Figure 6. A line chart showing SOC variations at CWS and BNP.
The study on SEM micrographs of CWS specified large dispersion of particles at a high magnification due to less clay and more sand particles that varied rounded to rough and some places angular (Sergeyev et al., 1980). The spacing in the same crystal confirmed the presence of interstratified clay particles. The less transition between the sand and clay particle indicate less binding of SOC (Kaiser & Guggenberger, 2004). Soil sample consists of granular arrangement with spherical shape of randomly split elementary particles seen at 10-µm magnification. Furthermore, augment up to 5 µm illustrates clean silt granules with few connecters. The BNP soil sample at 10 µm and 5 µm magnification confirms highly dense clay matrices with large inter-assemble pore space and few intra-assemble pore spaces which dominate the fabric. However, the aggregate structure of BNP soil sample has a strong influence on soil strength. This demonstrated the compactness of dry side induces aggregate-dominated fabric of CWS and the wet side causes matrix-dominated fabric of BNP without apparent aggregates of soil particles (Marathe, 2012; Nenadovic et al., 2010).

**FT-IR analysis and soil organic carbon**

The FT-IR spectroscopy prescribes a wide range of both aliphatic and aromatic carbon compound in the two forest soils. FT-IR graph of CWS (Figure 4) point out the sharp band value 3623 cm\(^{-1}\) confirms –OH axial deformation of Kaolinite and gibbsite and a band of 2914 cm\(^{-1}\) show –CH asymmetric axial deformation in methyl and ethylene. The discrete band at 796 cm\(^{-1}\) and 700 cm\(^{-1}\) indicating the plane folding of aromatic =CH bonds. Likewise, band at 475 cm\(^{-1}\) indicates Si–O deformation of Kaolinite in the soil sample of CWS. The broad intense band of about 3411 cm\(^{-1}\) of BNP indicates the stretching variation of bound and unbound –OH group. The band at 1370 cm\(^{-1}\) attributed O-H deformation of phenolic and aliphatic groups. The sharp discrete band 1049 cm\(^{-1}\) specified the presence of polysaccharides and additionally assigned to Si–O of clay minerals. Bands like

Table 2. Pearson’s correlation matrix among soil physicochemical parameters of CWS, BNP.

| Parameters, CWS | pH | SMC | EC | Sand | Silt | Clay | SOC |
|-----------------|----|-----|----|------|------|------|-----|
| pH              | 1  |     |    |      |      |      |     |
| SMC             | .04| 1   |    |      |      |      |     |
| EC              | .05| .49 |    |      |      |      |     |
| Sand            | .05| .09 | .18|      |      |      |     |
| Silt            | .02| .02 | .21|      |      |      |     |
| Clay            | .09| .23 | .13|      |      |      |     |
| SOC             | .03| .32 | .02|      |      |      |     |

| Parameters, BNP | pH | SMC | EC | Sand | Silt | Clay | SOC |
|-----------------|----|-----|----|------|------|------|-----|
| pH              | 1  |     |    |      |      |      |     |
| EC              | .39|     |    |      |      |      |     |
| SAND            | .74*| .10| .76**| 1 |      |      |     |
| SILT            | .57| .15 | .82**| .91**| 1 |      |     |
| CLAY            | .70*| .04| .32 | .71*| .36 | 1    |     |
| SOC             | .42| .56 | .03|      |      |      |     |

*Correlation is significant at the 0.05 level (two tailed).
**Correlation is significant at the 0.01 level (two tailed), p > 0.
690 cm\(^{-1}\) and 540 cm\(^{-1}\) are due to inorganic materials. Furthermore, 540 cm\(^{-1}\) in BNP, show O=H angular deformation of kaolinite and gibbsite. The common bands of 1600 cm\(^{-1}\) in both CWS and BNP consigns aromatic C=C stretching or asymmetric –C=O stretching in COO- may characterize about the lignin and other aromatic or aliphatic carboxylates vibrations (Cocozza, D’Orazio, Miano, & Shotyk, 2003). The bands between 1080 and 1030 cm\(^{-1}\) direct the combination of C=O stretching and –OH deformations. In both the soil sample, kaolinite and gibbsite were concluded from –OH axial deformation at the sharp band 3623 cm\(^{-1}\) in CWS and –OH angular deformation at 540 cm\(^{-1}\) in BNP (Haider, 2016). FT-IR of Hydrogen peroxide (\(\text{H}_2\text{O}_2\)) treated soil samples of CWS described less variation and presence organic compounds in rigid form (Figure 5). However BNP soil inferred the presence of inorganic carbon with some variation to that of raw soil sample due to fresh addition of the organic materials (Ellerbrock et al., 1999; Margenot, Calderon, & Parikh, 2016).

SOC depends upon the organic matter present in the soil (Rawls et al., 2003; Lutzo et al., 2006). The changes of carbon stock in soil influenced by the quantity and quality of litter fall and particle stabilization by binding with the clay particles (Fontaine et al., 2007; Beare et al., 2014). Organic carbon has significant correlation with moisture content of clay particles of both forest soil (Chaudhari, Ahire, Chkravarty, & Maity, 2013). The SOC in mangrove soil varies greatly because of influenced tidal gradient, forest age, biomass productivity, species composition and sedimentation of suspended matter (Ceron-Breton et al., 2011). Hence, the BNP soil compile varied amount of organic carbon percentage at different areas but in more stabilized form because of more clay content. The heterogeneity vegetation types, plant growth conditions at a different area of CWS affect the SOC percentage (Grigal and Ohman, 1992).

In our study, the SOC% in 0–30 cm. depth showed a positive relation with the soil properties, the amount of fine soil mineral particles and above ground vegetation. However, the soil topography moisture contents, pH, and conductivity showed less variation in the different zone of both forest types in relation to their vegetation (Aizat, Mohamad-Roslan, Sulaiman, & Karam, 2014).

The C/N ratio of soil samples provides information relating nutrient storage as well as their recycle and an index of organic matter quality (Igwe, 2001). The higher C/N ratio in CWS indicates the recent addition of above ground, and below ground plant residues in soil, poor in carbonate content and humification (Freixo et al., 2002; Sabiene, Kusliene, & Zaleckas, 2010). However, the lower C/N ratio indicated more carbonate content and well humification of BNP soil and high release of \(\text{CO}_2\) (Simson, 2005).

### Conclusion

The comparison revealed the influence of environmental factors like pH, conductance, and soil moisture on carbon content of soil with their mineral associated C-content and clay fractions. The resulted higher SOC value in BNP may due to dense vegetation and carbon stored in clay fractions in comparison to CWS. However, the soil physico-chemical parameters may establish little variation in different zone of both forest types in relation to their vegetation. The comparative results were analyzed and disrupt the recovery percentage of carbon in soil. Thus, various carbon functional groups and soil structural impact on binding carbon need detail characterization through FT-IR and SEM. Both the ecosystems obtained significant level of SOC which are priority areas for restoration and conservation, and will enhance carbon stock for future climate change mitigation programs.

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### Disclosure statement

The authors reported no potential conflict of interest.

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**Table 3. SOC of different deciduous and mangrove forest areas of world.**

| Deciduous forest areas                      | SOC (Mg/ha) | Soil depth in cm | References                           |
|--------------------------------------------|-------------|------------------|--------------------------------------|
| Sathanur Reserve forest, Eastern Ghats      | 16–47       | 30               | Gandhi and Sundarapandian (2017)     |
| Tropical Dry Forest, Chhattisgarh           | 122.5       | 30               | Iqbal and Tiwari (2016)              |
| Different Forest Type of entire India       | 22.42–100.33| 30               | Velmurugan, Kumar, Dadhwal, and Gupta (2014) |
| Tropical Dry Deciduous Forest, India        | 7.7–85.6    | 30               | Chhabra, Palria, and Dadhwal (2003)  |
| Tropical Secondary forest, Australia        | 78.8        | 30               | Paz et al. (2016)                    |
| Tropical Dry Forest, Brazil                 | 47.73–61.4  | 30               | Santos et al. (2015)                 |
| Tropical Monsoon Forests, Cambodia          | 53.2–108.7  | 30               | Torijama et al. (2011)               |
| Mangrove forest of Australia                | 118–296     | 100              | Alongi et al. (2003)                 |
| Mangroves of Micronesia                    | 107–135     | 100              | Kauffman, Heider, Cole, Dwire, and Donato (2011) |
| Mangroves of China                          | 44–192      | 100              | Lunstrum and Chen (2014)             |
| Mangrove of Egypt                           | 85          | 40               | Eid and Shaltout (2016)              |
| Study on BNP, Odisha, India                 | 54.30       | 30               | Sahu et al. (2016)                   |
| Estimated SOC of CWS, Odisha, India         | 47.51       | 30               | Present study                        |

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**Source:** Table 3. SOC of different deciduous and mangrove forest areas of world. The authors are grateful to Prof. B.K. Mishra, former Director, CSIR-IMMT, Bhubaneswar for laboratory facilities and DFOs of CWS and BNP as well as forest department Govt. of Odisha for financial support.
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