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Variability of carbon stored in inland freshwater wetland in Northeast India

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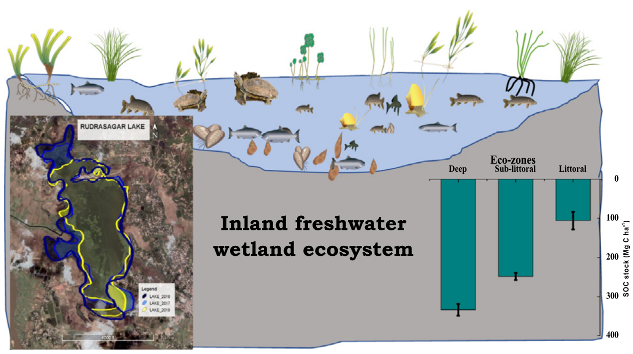
HIGHLIGHTS

- Carbon stock of inland freshwater wetland was estimated along the soil depth and eco-zones.
- SOC concentrations show different patterns in littoral, sub-littoral and deep layer.
- Average SOC stock was estimated at 230 ± 94 Mg C ha^{-1}.
- Deep layer stored highest amount of SOC stock in an inland freshwater wetland.
- Water inundation increases inland freshwater wetland carbon sink potential.

GRAPHICAL ABSTRACT



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ABSTRACT

Inland freshwater wetland ecosystems are among the largest sink of carbon (C) in the biosphere. However, improved scientific understanding of the C stability and sequestration potential is required to predict response of C pool under environmental change and to identify priorities for lacustrine C sink management. This study analyses the concentration of organic C fractions based on their stability and estimates C stock along with depth and eco-zones of the Rudrasagar lake in Northeast India. Sediment samples up to 100 cm depth were collected from littoral, sub-littoral and deep layers, and analysed for organic C concentrations. Results showed that C concentration decreases with depth in the littoral layer but increases with depth in sub-littoral and deep layers. Two-way analysis of variance showed that concentrations of soil organic C (SOC) fractions were significantly different among the eco-zones but not between the soil depth. Average SOC stock was significantly higher in the deep layer (334.9 Mg C ha^{-1}) followed by sub-littoral (248.4 Mg C ha^{-1}) and littoral layer (106.1 Mg C ha^{-1}). Overall, we show that substantial spatial variability in SOC stock exists among the eco-zones and depth that may be driven by water inundation in deep layer and fluctuating hydrological conditions at the edges of the lacustrine ecosystem. Our study demonstrates that inland freshwater wetland is a major sink of organic C and if disturbed it can act as a carbon dioxide source.

1. Introduction

Anthropogenic emissions are the major source of global warming and environmental pollution and to offset these emissions, carbon (C) sequestration strategies have attracted a great deal of scientific and political attention (IPCC, 2014). Likewise, the demand for effective nature-based solutions for climate change mitigation is rapidly growing. Wetlands are globally recognised as C sinks (Mitsch and Gosselink, 2015). They provide essential ecosystem services like water quality improvement, flood regulation, C sequestration and are sensitive indicators of environmental change (O'Beirne et al., 2017; Zedler and Kercher, 2005). Wetlands are often referred to as *kidneys of the landscape* as they received downstream water and waste from both natural and anthropogenic sources (Mitsch et al., 2015). Correspondingly, it is estimated that global wetlands can

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provide renewable ecosystem services up to US$ 13,165 billion per annum (Zedler and Kercher, 2005).

Soils are increasingly recognised as one of the largest sinks of C and nature-based solutions for climate change (Lal, 2004). Soils store 1500 Pg (1 Pg (petagram) = 10^{15} g) of organic C in the top 1 m depth (Jobbagy and Jackson, 2000), and one-third of the soil C pool (450–530 Pg) are stored in wetlands that occupied only 5–8 % of the global land surface (Blue Carbon Lab, 2022; Mitsch and Gosselink, 2015; Nahlik and Fennessy, 2016). Thus, wetlands play an essential role in global C cycling and mitigating C emissions (Blue Carbon Lab, 2022). Wetlands are further categorised based on the source of water as coastal, mangrove, lake and riverine, and their potential to sequester atmospheric C can vary with the plant species, hydrological changes, topography, land use change, and management policies (Xu et al., 2020). Mostly coastal and mangrove ecosystems are globally recognised as a super sequester of atmospheric C (McLeod et al., 2011; Zinke, 2020). Historically, freshwater wetlands are overlooked but recognised for their ecosystem services and benefits to humans after the Ramsar conventions (Global Wetland Outlook, 2018). However, recognizing potential C sink requires accurate quantification of C storage and factors affecting it in a particular setting.

Carbon stored in inland freshwater wetlands is known as teal C (Nahlik and Fennessy, 2016; Zinke, 2020). Water is a major factor influencing inland freshwater wetlands C pool. Continuous waterlogged conditions create an anaerobic atmosphere that results in a slow rate of organic matter decomposition in wetlands. In addition, high biomass productivity continues to increase organic matter accumulation and thus organic C storage in soils (McLeod et al., 2011; Mitsch et al., 2015). Besides, catchment properties and meteorological and hydrological features are major factors determining dissolve organic C in lacustrine ecosystem (Toming et al., 2020). It is estimated that freshwater wetland soils can sequester 1.38–2.26 Mg C ha^{-1} y^{-1} which is much higher than the forest (Bernal and Mitsch, 2012; Carnell et al., 2018). The rate of C accumulation can be largely determined by the amount of C retained in soils and it depends on the stability of C fractions (Cotrufo et al., 2019). Some of the C fractions are made up of complex organic polymers and retained in the mineral matrix thus resistant to microbial decomposition compared to others which are highly labile in nature and high turnover rate (Kramer and Chadwick, 2018; Rovira and Vallejo, 2002). Moreover, light penetration can also have a substantial effect on the organic matter decomposition in aquatic ecosystems (Hunting et al., 2019). Therefore, the stability of C pools may vary with eco-zones and soil depth.

A plethora of studies reported wetland ecosystems as a large C sink and store 60 to 539 Mg C ha^{-1} in top 100 cm of soils and sediments of costal ecosystems (Adoum et al., 2017; Carnell et al., 2018; Nahlik and Fennessy, 2016). In addition, data collected from 7514 lakes across six continents show that dissolve organic C concentrations are between 0.1 and 332 mg L^{-1} (Sobek et al., 2007). However, our knowledge of variation in C stock and stability of C pools along the eco-zones and depth of lacustrine ecosystems is limited. The interconnectedness of lacustrine ecosystems to humans and biodiversity is changing with increased anthropogenic pressure and resource utilization that may have substantial effects on C storage and associated ecosystem services (Nahlik and Fennessy, 2016). Therefore, improved scientific understanding of the C stability and sequestration potential of inland freshwater wetland ecosystems are critical to predicting responses of C pool under global change and identifying priorities for C sink management. This study aims to estimate the variability of C stored in inland freshwater wetland ecosystem in northeast India. The objectives of this study were to (i) identify the patterns of C fractions along with the soil depth and eco-zones and (ii) estimate the C stock in top 100 cm of soils and sediments of an inland freshwater wetland ecosystem in northeast India.

2. Materials and methods

2.1. Study site

The study was conducted in an inland freshwater wetland ecosystem at the Rudrasagar lake in Sepahijala district of Tripura state in Northeast India (23°29′ N to 23°30′ N and 91°18′ E to 91°19′ E; Fig. 1). It is one of the wetlands of international importance designated as Ramsar sites (site number 1572). The site is located at an elevation of 9 m above sea level (asl), covers an area of 240 ha, and water depth ranges from 2 to 9 m (ISRO, 2010). The climate of this region is warm humid tropical and received a mean annual rainfall of 2500 mm and most of them (60 %) are derived from the southwest monsoon (ISRO, 2010). High rainfall and downstream topography causes flooding with 4–5 times annual peak. The highest temperature ranges between 24 °C and 35 °C in summer and lowest ranges between 5 °C and 27 °C in winter. The area is formed by silt deposition on seabed and soils in the catchment. The site received flow from three perennial streams i.e. Oacherra, Durlanaraya cherra and Kemtali cherra, and discharges into the Gomoti river (ENVIS, 2013). The site is an ideal habitat for numerous aquatic species including Three-striped roofed turtle (*Batagur dhongoka*) which is categories as critically endangered in the international union for conservation of nature (IUCN) Red list of threatened species (Ramsar.org). However, *B. dhongoka* has not been recorded in the last 30–40 years in this lake.

2.2. Sample collection

A total of three sampling stations were demarcated in a triangular shape at the corners of an inland freshwater wetland. Soils and sediment samples were collected at different depths in different eco-zones of the wetland at the end of the winter season during 16–21 February 2016, 13–18 February 2017, and 23–27 February 2018. Sediment samples were collected from the first meter of sediment at an interval of 0–15 cm, 15–30 cm, 30–45 cm, and 45–100 cm. Three eco-zones viz. littoral, sub-littoral, and deep layer were considered for sampling. Samples from littoral and sub-littoral zones were collected directly while temporary boundaries were constructed to remove water in deep zones before collecting sediment samples. A 10 cm internal diameter PVC core tube of different lengths was used to collect sediment samples from different depths in each eco-zone. The sampling core was inserted slowly to minimize compaction up to 1 m depth into the sediments or until the core refusal. A total of three replicate samples were collected from each depth (3 samples × 4 depths × 3 locations = 36 samples per year) and the same procedure was repeated in each zone of the wetland for consecutive three years i.e. 2016, 2017, and 2018. The sampling depth could be site-specific and depends on the presence of an organic layer or the occurrence of hard sediments. If the sampling core doesn't reach 1 m depth, we choose another nearby (1–2 m) sampling spot to extract sediment samples. The extracted samples were extruded and divided into different depths. The samples were packed in a polyethylene zipper bag and transported to the laboratory for further analysis.

2.3. Soil analysis

The temperature of the fresh sediment samples was measured at the site using a digital thermometer (HI98501, Hanna Instruments Inc. Mumbai, India). A part of fresh sediment samples was oven-dried at 105 °C for 48 h to determine moisture content. The rest of the collected samples were air-dried at room temperature to avoid the decomposition of organic-rich materials. Samples were homogenized and passed through the 2-mm sieve for further analysis. We did not find a significant amount of coarse materials in the collected samples. Sediment pH was measured potentiometrically in a deionized solution (1:2.5; *w/v*). The weight of dry sediment samples was used to calculate bulk density.

2.4. Soil organic carbon fractions and stock

Total soil C concentration was determined by direct combustion techniques using the elemental analyzer (EuroVector, EuroEA3000, Italy). Oven-dried samples (<2 mm) were treated with 1 M HCl (1:10 ratio) to extract inorganic C (Jackson, 1973). The difference between total C and inorganic C was considered as total organic C concentrations. SOC fractions were determined based on gradients of oxidizing conditions. We use a

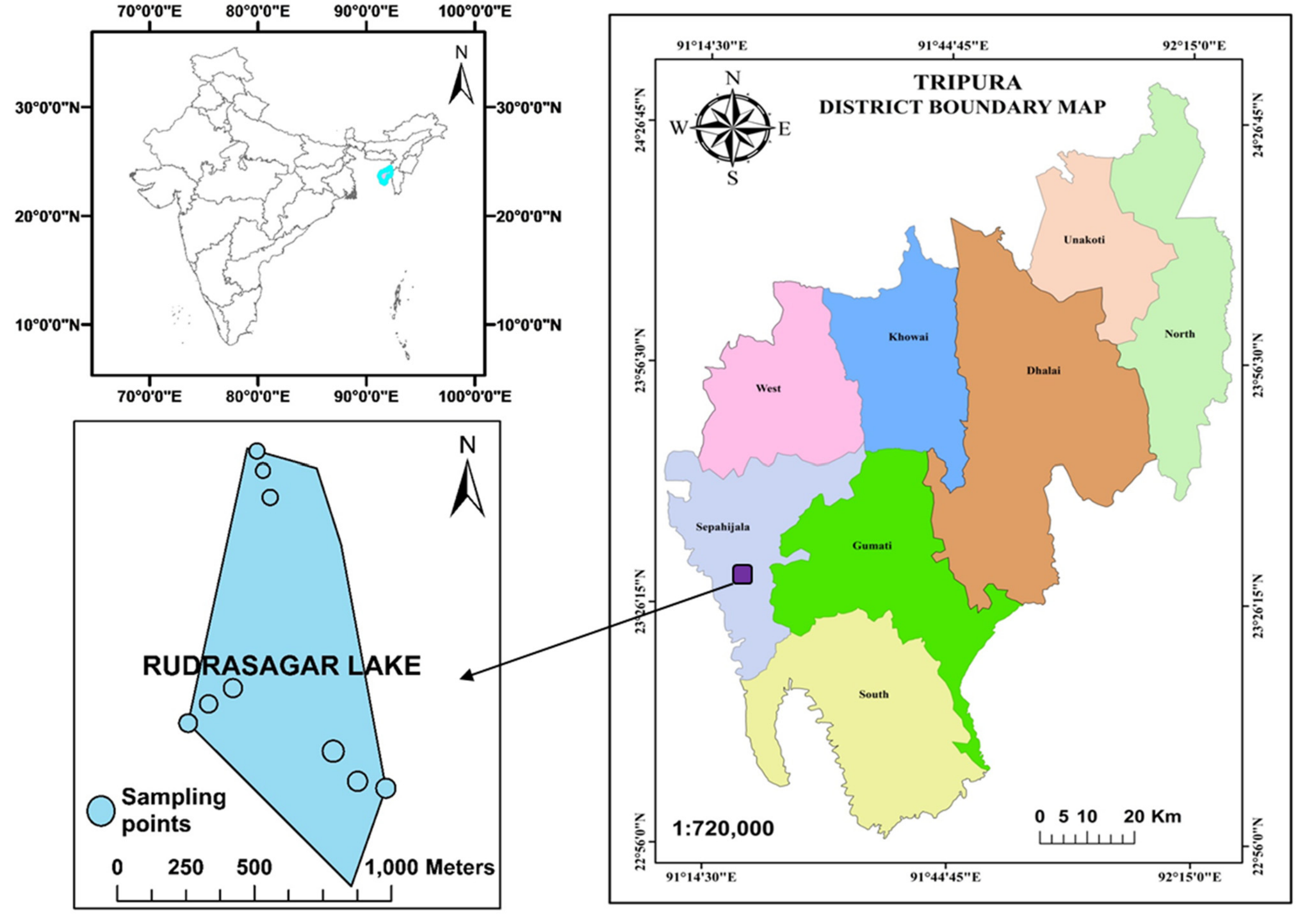

Fig. 1. Map of the study area and sampling points at Rudrasagar lake in Tripura, India.

three-step oxidation method in which the H_2SO_4 concentration varies at a stable concentration of $K_2Cr_2O_7$ to determine SOC fractions (Chan et al., 2001). Three different concentrations, 12 N, 18 N, and 24 N of H_2SO_4 were used to analyse four fractions of decreasing lability or oxidizability. Organic C oxidizable under 12 N H_2SO_4 was considered very labile C (VLc). The difference in oxidizable organic C extracted between 18 N and 12 N H_2SO_4 was considered labile C (Lc). Less labile C (LLc) was determined as the difference between 24 N and 18 N H_2SO_4 and non-labile C (NLc) was the difference between organic C extracted with 24 N and total organic C concentrations.

Soil C stock for each depth was estimated using the following equation:

$$\text{SOC stock} = \Sigma_{\text{horizon}=1}^{\text{horizon}=n}(\text{SOC} \times \text{Bulk Density} \times \text{soil depth} \times 100) \quad (1)$$

where SOC stock is soil organic C stock (Mg C ha^{-1}), SOC is soil organic C concentration (%), bulk density (Mg m^{-3}) and depth is the thickness of soil layer (m).

2.5. Statistical analysis

All the data were presented as mean ± standard deviation ($n = 9$ sample/depth/year). One-way analysis of variance (ANOVA) was conducted to evaluate the effect of eco-zones on the selected soil properties. The significant differences between the mean values of the selected soil properties were tested using Tukey's post hoc test. Soil C concentrations were log-transformed prior to ANOVA to meet assumptions of normal distribution and homogeneity of variance. Two-way ANOVA was used to check the effect of eco-zone and soil depth and its interaction with SOC concentration. A statistically significant difference was considered at $P < 0.05$. All the statistical analyses were performed with IBM SPSS Statistics 21.0 for windows.

3. Results

3.1. Soil physicochemical properties

Selected soil properties were analysed to determine the effect of eco-zones on the soil characteristics (Table 1). One-way ANOVA shows that only soil pH and temperature of the top layer (0–15 cm) were significantly different among the eco-zones of the wetland. Soil moisture and SOC concentration of the top layer were insignificantly higher in the deep layer and recorded in the order of littoral < sub-littoral < deep layer. In contrast, bulk density was recorded highest for the littoral layer and decreased in the order of littoral > sub-littoral > deep layer.

3.2. Variations in SOC fractions

Variations in SOC fractions based on the lability i.e. VLc, Lc, LLc, and NLc were analysed in chronosequence for three years among the eco-

Table 1
Soil physicochemical characteristics (0–15 cm) of the inland freshwater wetland ecosystems. Different letter in a same row indicates a significant difference among the eco-zones at $P < 0.05$.

Parameter	Eco-zones			P-value
	Littoral	Sub-littoral	Deep	
pH	6.16 ± 0.02a	6.11 ± 0.01a	5.76 ± 0.14b	0.006
Temperature (°C)	25.4 ± 1.59a	22.8 ± 1.87ab	19.4 ± 0.12b	0.015
Moisture (%)	27.8 ± 5.19a	34.9 ± 2.23a	37.7 ± 2.0a	0.069
Bulk density (g cm^{-3})	1.21 ± 0.46a	0.95 ± 0.32a	0.62 ± 0.05a	0.272
SOC (%)	1.35 ± 0.56a	1.66 ± 0.54a	1.85 ± 0.42a	0.637

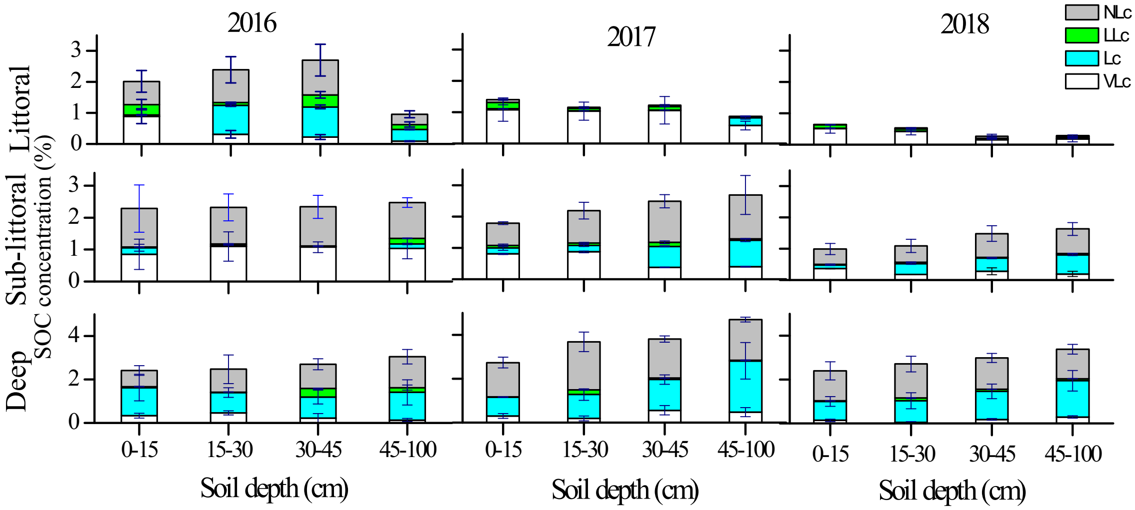

Fig. 2. Variation in soil organic carbon fractions among the eco-zones of inland wetland ecosystem. VLc-very labile carbon, Lc-labile carbon, LLc- less labile carbon, and NLc-non-labile carbon concentrations ($n = 9$). Hanging bars represent standard deviation from the mean value.

zones of the wetland (Fig. 2). In the littoral layer, VLc concentration was highest in top layer and decreased with depth while Lc concentrations increased with depth. LLc concentrations invariably decreased with depth while NLc concentrations had not shown any pattern with depth. In the sub-littoral layer, VLc concentration was lesser than the NLc and decreased with the soil depth. However, NLc concentration increased with soil depth and had a dominant contribution to total organic C. Both Lc and LLc concentrations had not shown any specific patterns with soil depth. In the deep layer, NLc concentration was highest among the SOC fractions followed by Lc concentration and invariably increased with soil depth. Overall, the patterns of SOC fractions showed deviation in different eco-zones and soil depths. Two-way ANOVA showed that concentrations of SOC fraction (except LLc) were significantly different among the eco-zones but differences were insignificant between the soil depths. Similarly, the interactive effects of eco-zones and soil depth on the concentrations of different SOC fractions were insignificant (Table 2).

3.3. SOC concentrations along the soil depth and eco-zones

SOC concentrations showed different patterns along with depth and eco-zones of the wetland. In littoral layer, average SOC concentration increased with depth down to 45 cm (1.35 % to 1.41 %) but showed lesser concentration for 45–100 cm depth (0.70 %) compared to upper depth. Unlike, SOC concentration in sub-littoral (1.69 % to 2.26 %) and deep layers (2.51 % to 3.71 %) increased with depth (Supplementary Fig. 1). Two-way ANOVA showed that SOC concentration was significantly different among the eco-zones ($p < 0.001$) but insignificant among the soil depth ($p = 0.644$). The interactive effect of eco-zones and soil depth ($p = 0.458$) on the SOC concentration was also insignificant (Table 2).

Table 2
Results of two-way analysis of variance testing the effects of eco-zones and soil depth on the soil organic carbon concentrations.

Parameters	Eco-zones		Depth		Interaction (eco-zones × depth)	
	F	P	F	P	F	P
Very labile	3.516	0.046	0.641	0.596	0.468	0.825
Labile	35.54	<0.001	2.939	0.054	0.964	0.470
Less labile	2.051	0.151	0.582	0.633	1.171	0.354
Non-labile	23.83	<0.001	0.489	0.693	0.334	0.912
SOC	21.44	<0.001	0.565	0.644	0.984	0.458

3.4. Spatial and temporal variation in SOC stock

Spatial distribution of SOC stock in littoral, sub-littoral and deep layers follow similar patterns (littoral < sub-littoral < deep layer) in all the studied years (Fig. 3). SOC stock (148.9 Mg C ha^{-1}) in littoral layer was highest in 2016 and then decreased in 2017 and 2018. However, SOC stock in sub-littoral layer increases over the years of observation and was found highest in 2018 (259.7 Mg C ha^{-1}). Similarly, SOC stock in deep layer was highest in 2018 (358.6 Mg C ha^{-1}). The average SOC stock for all three eco-zones in 2016, 2017, and 2018 was 236.7 ± 72.7 Mg C ha^{-1}, 221.5 ± 94.1 Mg C ha^{-1} and 231.1 ± 144.1 Mg C ha^{-1}, respectively.

One-way analysis of variance showed that SOC stock (0–100 cm) was significantly different among the eco-zones of the wetland (Fig. 4). The deep layer store significantly higher SOC stock (334.9 ± 36.4 Mg C ha^{-1}) and littoral layer had lowest SOC stock (106.1 ± 31.6 Mg C ha^{-1}). The respective SOC stock of the different eco-zones was increased with depth and found highest in the deeper depth (45–100 cm). Though the

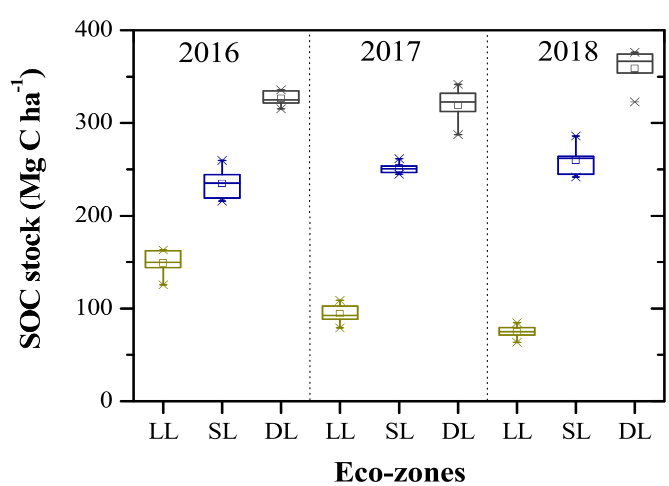

Fig. 3. Temporal variation in soil organic carbon stock (0–100 cm, Mg C ha^{-1}) among the eco-zones of wetland ecosystem. LL: littoral layer, SL: sub-littoral, DL: deep layer, n = 9, Whiskers represent the upper and lower range of the data. Box represents the interquartile range of the data, and the upper and lower limits of the box show the first quartile and third quartile of the data. Middle line and small box show median and mean value, respectively.

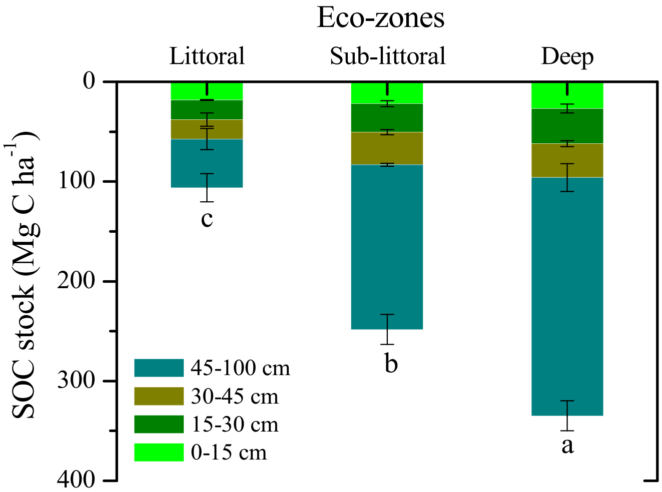

Fig. 4. Differences in soil organic carbon stock (0–100 cm, Mg C ha^{-1}) among the eco-zones of wetland ecosystem. Different alphabets indicate significant differences at $P < 0.05$ ($n = 27$ for each depth), and hanging bars represent standard deviation from the mean value.

average SOC stock varied significantly at spatial and temporal scales, the average SOC of the wetland was estimated at 229.8 ± 94.3 Mg C ha^{-1}.

4. Discussion

The present study assesses spatial and temporal patterns of SOC stock and demonstrates two important insights of inland freshwater wetland C stock related to its variability among the soil depth and eco-zones at one of the internationally important Ramsar sites in Northeast India. First, our estimates of soil C stock for different eco-zones show that SOC stock was higher in deep zones compared to littoral and sub-littoral zones because of inundation conditions around the year which retard the decomposition process in inland freshwater wetlands. Secondly, the stability of SOC concentrations based on the lability along the soil depth shows that deeper layers had higher NLc concentrations thus playing a vital role in C storage. Although little information on SOC fractions based on chemical composition and stability is available in the literature (Grasset et al., 2017; Ji et al., 2020; Wang et al., 2012), it is vital to assess the variability of SOC pool and to implement conservation policies under future global change.

The composition of organic C in wetland soils and sediments provides important information on plant productivity, microbial activity, decomposition of necromass, and C cycle (Grasset et al., 2017). Therefore, SOC fractionation is essential to investigate the role of wetland in C storage and cycling. Based on the lability, four major SOC fractions were analysed in top 1 m depth in different eco-zones of the freshwater wetland. The patterns of SOC fractions in littoral zone show that labile fraction decreases with depth while non-labile fractions increase with depth. The variations in labile and non-labile fractions along the soil depth may be attributable to differences in microbial decomposition, nutrient status, and temperature which are lesser in deeper depth (Wang et al., 2012). In sub-littoral zone, concentrations of VLc and NLc remained similar at different depths except for 2018 but the overall SOC concentration increases with depth in sub-littoral and deep zones. In contrast, deep layer shows higher concentrations of NLc because of lower temperatures that substantially reduce the microbial decomposition process compared to the littoral layer (Wang et al., 2012).

The contribution of VLc (19–80 %) to total SOC was higher in littoral layer while NLc contribute up to 49 % in sub-littoral layer and 47 % in deep layer. Concentrations of SOC fractions show that only labile and non- labile fractions are significantly different among eco-zones and soil depth did not have a significant impact on the SOC fractions. Labile C pools act as a source of energy for microorganisms and the interface between terrestrial and aquatic ecosystems provides sufficient oxygen for microbial activity that, in turn, increases the decomposition process (Ji et al., 2020). Labile C fractions have a higher turnover rate and are most sensitive to environmental changes compared to other organic C fractions (Wang et al., 2012). A study of the distribution of C fraction based on density in a converted natural wetland to paddy fields in China also reported decreases in light fraction organic C with soil depth from 20 to 60 cm (Zhao et al., 2020). Our study shows that surface layer exhibits a higher labile C pool in a littoral layer which is vulnerable to anthropogenic activities while it decreases substantially in flooded/saturated soils at deep layer.

The present study shows that SOC concentrations in freshwater wetlands are significantly different ($p < 0.001$) among the eco-zones but insignificant ($p = 0.644$) between the soil depth. Moreover, the interactive effects of eco-zones and soil depth on SOC concentration were insignificant. A study of inland freshwater wetlands in the USA reported a significant effect of soil depth on SOC concentration for 0–15 and 15–30 cm depth (Tangen and Bansal, 2020). Though our study showed increases in SOC concentration with soil depth in sub-littoral and deep layers, the differences are insignificant. SOC concentration decreases with soil depth in littoral zone but increases in sub-littoral and deep zones. Low SOC concentration at a deeper depth of littoral layer may be due to continuous reduction in the lake area and depletion of water at the edges of lacustrine ecosystems which leads to soil C loss. The average SOC concentration of the studied freshwater wetlands (2.1 ± 0.9 %) is lesser than those reported for Australia (7.7 ± 0.3 %) in 1 m depth (Carnell et al., 2018), France (2.0–9.7 %) in top 20 cm (Grasset et al., 2017) and USA (3.1–15.8 %) for top 2 cm layer (Bernal and Mitsch, 2008). Hydrological conditions are the major factor determining C storage in wetland soils (Nahlik and Fennessy, 2016). The variability in SOC concentration may be driven by the water inundation that creates anxious conditions in deep zones compared to fluctuating hydrological conditions at the edges of wetlands that promote oxidation of organic matter (Kayranli et al., 2009; Mitsch and Gosselink, 2015). Thus, deeper layers inundated around the year store higher SOC and act as a net C sink.

Spatial variation in SOC stock shows that the deep layer had higher SOC stock compared to littoral and sub-littoral layer while temporal patterns demonstrate that overall SOC stocks in 2018 are lesser than estimated in 2016. SOC stock in littoral layer decreases but increases for sub-littoral and deep layers along the observation period. The SOC stock follows the same patterns as it was highest in deep layer > sub-littoral layer > littoral layer across the observation period. The average SOC stock of deep layer was more than three times the littoral layer which can be attributable to inundation conditions around the year which retard the decomposition process (Nath et al., 2016). The average SOC stock of the entire ecosystem was estimated at 229.8 ± 94.3 Mg C ha^{-1}. A decrease in the total area of Rudrasagar lake during the observation period is one of the major factors responsible for decreases in C density (Supplementary Fig. 2). Fluctuating hydrological conditions in littoral and sub-littoral layer expose the soils to direct atmospheric conditions that result in enhanced oxidation of accumulated C and increase C loss. Estimated SOC density (down to 100 cm of soils) for the present study is in range of other inland freshwater wetlands (220 Mg C ha^{-1}) reported for similar study areas in northeast India (Nath et al., 2016). Numerous studies reported SOC stock for freshwater wetlands in many parts of the world but at different soil depths. For example, SOC density was estimated at 300 Mg C ha^{-1} down to 120 cm of soils in the USA (Nahlik and Fennessy, 2016), 110 Mg C ha^{-1} for 60 cm soil in South-eastern Australia (Carnell et al., 2018), 550 Mg C ha^{-1} for 60 cm soil in Sri Lanka (Dayathilake et al., 2021), 70 Mg C ha^{-1} for 30 cm soil in North America (Tangen and Bansal, 2020), and 58.9 Mg C ha^{-1} for 20 cm soil in the USA (Mazurczyk and Brooks, 2018). Though the SOC stock varies with the soil depth, our estimates are in the range of previously reported SOC stock for inland freshwater wetland ecosystems. Moreover, differences in SOC stock between the particular soil depth demonstrate large variability among the total SOC stock.

The estimated area of Rudrasagar lake in 2016 was 1.50 km^2 which was reduced by 13.6 % in 2017 and further reduced by 11.8 % in 2018

(Supplementary Fig. 2). Reduction in total lake areas over the years have a significant impact on lacustrine ecosystems and in particular, littoral layer as most of the area was dried up and exposed to higher temperatures resulting in the decomposition of organic matter. Continuous decrease in lake area imperiled the aquatic flora and fauna, resulting in loss of biodiversity. The global convention on wetlands recognizes that wetlands are the most threatened ecosystems and emphasize wetland conservation while getting benefits (Courouble et al., 2021). However, being recognised as an internationally important Ramsar site, area of the Rudrasagar lake has been continuously reduced which indicates the need for further conservation measures in national conservation plans. Moreover, the implementation of the UN decade on Ecosystem Restoration (2021 – 2030) and UN Sustainable Development Goals (SDG # 6, SDG # 13, and SDG #14) are vital to protect and restore degraded wetlands.

Though the present study only investigates spatial and temporal changes in SOC stock and supports the findings with changes in the areas of lake, the reduction in SOC stocks over the years can also be correlated with atmospheric conditions such as a change in temperature and rainfall patterns of the area in future studies. Encroachment of lakes by human activities and changes in land use patterns such as increases in human settlement has also led to a loss of C and other ecosystem services provided by the wetland ecosystem. It is widely reported that inland freshwater wetlands are among the largest C sink (Carnell et al., 2018; Nahlik and Fennessy, 2016). Therefore, the conservation of wetland ecosystems is essential to protect natural C sinks and associated ecosystem services such as drought management, biodiversity conservation, and other cultural services provided to humans.

5. Conclusions

This study demonstrates the variability of SOC stock among the eco-zones and depth of the inland freshwater wetland. Concentrations of different SOC fractions based on the stability changes along with the soil depth where labile fractions were more accumulated in top layer and non-labile fractions were retained at a deeper depth. The spatial variability of SOC stock shows that deep zone inundated around the year and prevailing anaerobic condition retards the organic matter decomposition thus storing more C than the littoral layer. Temporal patterns of C stock show substantial reduction over the years which dominantly attributed to a reduction in lake area that exposed littoral layer to organic matter decomposition. Overall, the inland freshwater wetland act as natural C sink but can be a significant source of greenhouse gasses, if not protected. Our data provide important findings based on the variability of C stock that can be used to predict teal C stock and implement conservation policies under future global change.

CRediT authorship contribution statement

MT and SD designed the study; MT performed the field work; JA, SD and UKS analysed the data, JA, MT, SD and UKS wrote the first draft; all authors revised the manuscript and gave final approval for publication.

Data availability

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2022.160384.

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