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Assessing soil and sediment organic carbon sequestration potential of selected wetlands at different physiographic regions of West Bengal, India

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ABSTRACT

Wetlands provide numerous ecosystem services including sequestration of atmospheric carbon–dioxide (CO_2) which play an important role in mitigation of greenhouse gases (GHGs). Present study aimed to assess soil / sediment carbon (C) stock of different wetlands under different physiographic regions of West Bengal. West Bengal has a number of wetlands situated in different biogeographic regions like lower Gangetic plains, central Himalaya, Chotanagpur plateau and coasts. A total of 19 wetlands were selected for present study and were categorized into six wetland types *viz.,* floodplain wetlands (FP), wetlands from forested hill region (FH), Himalayan region (HM), Chotanagpur plateau and adjacent area (CP), coastal wetlands (CO) and wastewater–fed fishponds of East Calcutta Wetlands (ECW) ecosystems. Soil / sediment organic carbon (SOC) content of both bank soil and bottom sediments of the wetlands varied widely among study sites. Highest amount of bank SOC were recorded from HM wetlands (50.54 ± 6.65 t ha^{-1}) whereas bottom SOC values from FP wetlands (36.81 ± 17.80 t ha^{-1}). Different allochthonous inputs like sewage water, runoff from catchment area; wetland macrophytes; sediment texture; physicochemical properties of water influence C sequestration potential of wetlands. Findings of present study can be compared with 22.35% of total wetland area of the state and it can be assumed that these types of wetlands can sequester 6.63 M t carbon in soils and sediments.

1. INTRODUCTION

Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) was adopted on 11th December, 1997 in Kyoto, Japan was intended to reduce the emission of greenhouse gases (GHGs) that were responsible for global warming. It came into the force since 16th February, 2005. During the first 'commitment period' (2008–2012) the signatory countries were called for the reduction of the 'basket' of six GHGs *viz.,* carbon–dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF_6) to 5.2% below the level of 1990. The foundation of this protocol was setup on the principle of 'common but different responsibilities' which placed heavier burden on developed nations as they were mainly responsible for the present alarming levels of GHGs emission. Forty–one countries plus European Union were the participating countries but the target was not achieved. Later on, 8th December, 2012 Doha Amendment to the Kyoto Protocol was came in action with the commencement of second 'commitment period' (1st January, 2013 – 31st December, 2020). We have already completed the tenure however, the global emission of GHGs is not reduced. Rockström *et al.* (2009) identified and quantified nine planetary boundaries that must not be exceed the threshold and marked as safe operating space for humanity. Climate change, one of the nine planetary boundaries exceeded the safe limit. Atmospheric CO_2 concentration and change in radiative forcing were the two parameters to quantify the scenario of climate change (UNFCCC, 2020).

The Intergovernmental Panel on Climate Change (IPCC) estimated that atmospheric CO_2 concentration increased from about 280 to 379 ppm from the year 1750 to 2005 *i.e.,* at a rate of 1.9 ppm yr^{-1}. Global average of atmospheric CO_2 in 2018 was 407.4 ± 0.1 ppm. Following this trend, it was expected that global average atmospheric temperature will increase by 1.8°C to 5°C by 2100 (IPCC, 2007). Fossil fuel combustion and change in land use patterns are the principal anthropogenic activities that influence global carbon (C) cycle (Moore III, 1995). Atmospheric CO_2 concentrations were also increasing by activities like deforestation and human–induced soil degradation. Therefore, scientists and environmental activists concentrated on C sequestration by different ecosystems and natural processes.

Wetlands provide numerous ecosystem goods and services (Russi *et al.*, 2013) and are one of the most productive and diverse ecosystems on the earth (Ghermandi *et al.*, 2008). Wetland ecosystems act as both C source and sink (Mitra *et al.*, 2005; Kayranil *et al.*, 2010; Mitsch *et al.*, 2013; Villa and Bernal, 2018). Wetlands have highest C density in compare with other terrestrial ecosystems as wetlands have relatively greater capacities to sequester atmospheric CO_2 (Pant *et al.*, 2003). Wetland sediments acts as long–term storage of C. Approximately 250 Gt C were sequestered in tropical wetlands (Neue *et al.*, 1997). Wetlands also store C for short–term basis as living biomass (plants, animals, bacteria and fungi) and in dissolved components (both organic and inorganic) in the surface and groundwater (Wylynko, 1999).

Wetlands account for 4.7% of total geographical area (TGA) of our country, India. About 757.06 thousand wetlands, comprised an area of 15.3 M ha are situated in India (SAC–ISRO, 2011). West Bengal is very rich in wetland diversity, ranging from high hills of Darjeeling Himalaya to coastal areas facing Bay of Bengal. Wetlands are also present in forested tracks of Tarai–Dooars, vast floodplains of riverine systems and western plateau areas. West Bengal has 147826 number of wetlands covering an area of 1107907 ha. Which includes 747383 ha (8670 in number) of inland wetlands and 221817 ha (449 in number) of coastal wetlands. In addition, West Bengal also harbours large number of small waterbodies (<2.25 ha) (SAC–ISRO, 2010). C sequestration potential of Indian inland, freshwater wetlands are sparsely studied (Prusty *et al.*, 2010; Pal *et al.*, 2018; Jana *et al.*, 2020). However, coastal mangrove wetlands got attention of a group of researchers and are well studied (Rao, 2009; Ray *et al.*, 2011; Banerjee *et al.*, 2012; Mitra *et al.*, 2012 and 2018; Chowdhury *et al.*, 2018; Bal and Banerjee, 2020). Studies on C sequestration potential by diverse wetlands of West Bengal are also rare. However, two Ramsar sites of West Bengal *viz.,* East Calcutta Wetlands (ECW) and Sundarban Biosphere Reserve (SBR) are well studied in terms of C sequestration and GHGs emission. Except wastewater–fed pisciculture ponds of ECW (Pal *et al.*, 2013; 2016; 2017; 2018; Bhattacharyya *et al.*, 2019; Biswas *et al.*, 2018; Chanda *et al.*, 2019; Bhattacharyya *et al.*, 2020; Shaher *et al.*, 2020) and inter–tidal mangrove forested wetlands of Sundarban (Ray *et al.*, 2011; Banerjee *et al.*, 2012; Mitra *et al.*, 2012 and 2018; Chowdhury *et al.*, 2018) other wetlands situated in different biogeographic zones are not well studied (Jana *et al.*, 2020). Present study aimed to assess soil / sediment C sequestration potential of different wetlands under different physiographic characters of West Bengal, India.

2. MATERIALS AND METHODS

Study Sites

India has ten biogeographic zones (Rodgers and Panwar, 1988) among these four are present in West Bengal *viz.,* Himalaya (2C – Central Himalaya), Deccan Peninsula (6B – Chotanagpur), Gangetic plain (7B – Lower Gangetic plain) and Coasts (8B – East coast). Beside this biogeographical classification there are several other characteristic wetlands like wastewater contaminated ECW, mangrove swamps, reservoirs etc. For present study 19 wetlands were selected (Fig. 1) throughout the West Bengal and were categorized as following types (details of the study sites are described in Table 1):

Wastewater–fed fishponds of ECW ecosystems: A cluster of wastewater–fed fishponds globally renowned as resource–recovery system. ECW is recognized as world's largest natural organic sewage management system in urban landscape.

Floodplain wetlands (FP): Five wetlands (Purbasthali, Raichenmari, Bochamari, Atiamochar and Nararthali) were selected and all were ox–bow lakes or cut–off meanders. Raichenmari, Bochamari and Atiamochar wetlands were a part of Rasikbeel Wetland Complex (RWC).

Wetlands from sub–Himalayan forested hill region (FH): Adma and Jayanti Pokhri both situated inside the forest of Buxa Tiger Reserve (BTR) at an elevation of about 300 m msl of Sinchula range.

Wetlands from Darjeeling Himalayan region (HM): Four wetlands (Pokhriabong, Namthing Pokhri, Gopaldhara and Mirik) of Darjeeling district were selected at an elevation of 1430 to 1836 m msl.

Wetlands from Chotanagpur Plateau and adjacent lateritic area (CP): Wetlands were selected from top of the Ajodhya hill (part of extended Eastern Ghats mountain range), Sahebbandh (Purulia), Sahebbandh (Adra) of Chotanagpur Plateau and Lalbandh situated in adjacent lateritic zone.

Coastal wetlands (CO): Three wetlands from Gobardhanpur, Bakkhali and Mousuni of Sundarban delta region (a Global Biosphere Reserve and Ramsar site) were selected. These wetlands were located close vicinity (within 500 m) of Bay of Bengal and were experienced with saltwater intrusion during super–cyclone Aila (in 2009).

Sample Collection and Analyses

Soil samples were collected from five sites of each wetlands during 2018–2019 (January, May and September). Bank surface soil samples (0–10 cm) were collected

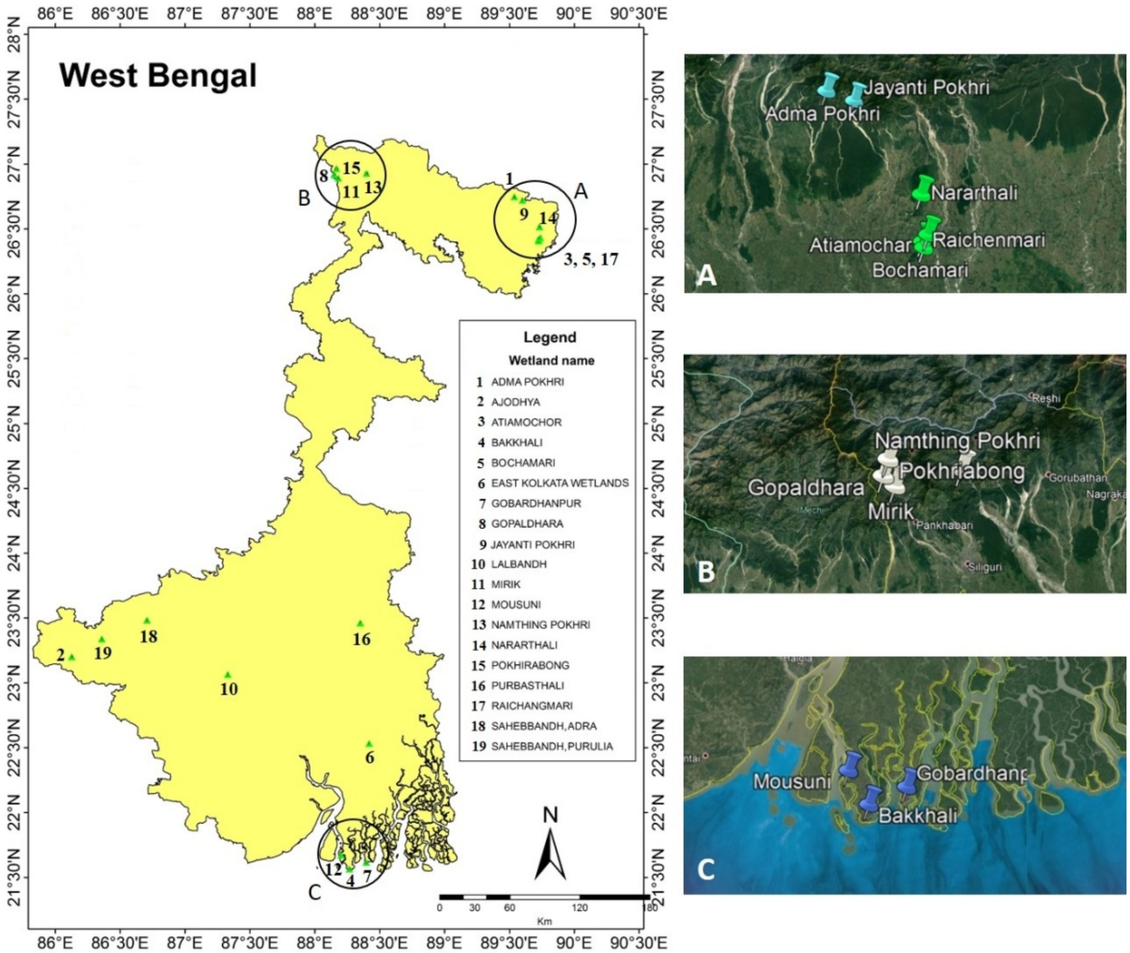

Fig. 1. Map of West Bengal showing studied wetlands (shown as green dots). Clusters of wetlands at the northern and southern parts of West Bengal are specially marked as circles (A–C)

randomly using a handheld core sampler (having a diameter of 5 cm). Bottom sediment samples of wetlands were collected by Ekman dredge (biting area 6" × 6" × 6"). Bank soil samples were collected above the water table while bottom sediments were collected from the depth of 1.5 ± 0.45 m. Chemical parameters of water samples like pH, electrical conductivity (EC), total dissolved solids (TDS) and salinity were measured electronically on the spot by Eutech PCSTestr 35 Multi–Parameter.

For the estimation of bulk density (BD) both wet and dry weights of the soil / sediment samples were taken using an electronic balance (Mettler Toledo AE 240 analytical balance) and the values were calculated following Miller and Donahue (1990). Dried soil / sediment samples were taken and ground carefully using mortar and pestle using gentle pressure. Excessive mechanical force was avoided as it altered the sediment texture. 5 g of ground soil sample was taken and sieved through a series of four brass sieves. Particles above 63 µm was categorized as sand and rest of the fractioned sample was silt–clay. Weight of each fraction were measured separately and expressed as percentage values. Sediment texture was analysed following Wentworth (1922) and Gee and Or (2002).

SOC estimation was carried out following Walkley and Black (1934) method. 2 g of air dried, ground and sieved (using 2 mm sieve) soil samples were taken into a volumetric flask and subsequently 10 mL of potassium dichromate ($K_2Cr_2O_7$) and 20 mL of conc. sulfuric acid (H_2SO_4) were added. The reaction mixtures were shaken, cooled for 1 hr, diluted up to the mark and allowed to stand overnight. The green colour of chromium sulfate [$Cr_2(SO_4)_3$] was read in UV–Vis spectrophotometer (Lamda–25, Perkin–Elmer, USA) in 600 nm red filter following standard protocol (Perkin–Elmer, 1994). The amount of C is read from the standard curve. Obtained values then converted into percentage of SOC using following equation:

Percentage of organic C = (Sucrose reading × 0.42 × 100) / (Weight of soil × 1000).

Where, 1000 = Conversion factor for sucrose mg to g; Percentage values of organic C then converted into representable units.

Table: 1
Details of the wetlands selected for present study situated in different physiographic and biogeographic zones of West Bengal

Studied Wetlands	Character / Locality	Location	Altitude (m msl)	Present category
East Calcutta Wetlands (ECW)	Wastewater-fed fishpond, a Ramsar Site, under NWCP	22°31'54.54"N 88°25'07.25"E	0	ECW
Purbasthali (Pu)	Floodplain wetland, avian congregation site, adjacent agricultural practices, tourist spot	23°27'40.19"N 88°21'02.32"E	7	FP
Raichenmari (Ra)	Floodplain wetland, avian congregation site, tourist spot, a part of RWC under NWCP	26°25'06.33"N 89°43'25.58"E	45	FP
Bochamari (Bo)	Floodplain wetland, avian congregation site, a part of RWC under NWCP	26°24'22.29"N 89°43'30.31"E	43	FP
Atiamochar (At)	Floodplain wetland, avian congregation site, a part of RWC under NWCP	26°25'53.89"N 89°44'17.31"E	45	FP
Nararthali (Na)	Floodplain wetland, avian congregation site, inside BTR	26°30'56.47"N 89°43'54.96"E	54	FP
Adma Pokhri (AP)	Sub-Himalayan forested wetland, inside BTR	26°44'52.03"N 89°32'16.94"E	315	FH
Jayanti Pokhri (JP)	Sub-Himalayan forested wetland, inside BTR, popular tourist spot	26°43'18.24"N 89°35'58.52"E	338	FH
Pokhriabong (PB)	Himalayan wetland, protected Himalayan salamander habitat	26°57'52.15"N 88°09'59.96"E	1836	HM
Namthing Pokhri (NP)	Himalayan wetland, protected Himalayan salamander habitat	26°55'40.77"N 88°23'53.75"E	1430	HM
Gopaldhara (Gd)	Himalayan wetland, adjacent to tea garden	26°55'4.11"N 88°08'56.11"E	1820	HM
Mirik (Mi)	Himalayan wetland, popular tourist spot, under NLCP	26°53'29"N 88°10'53"E	1601	HM
Ajodhya (Aj)	Wetland of Chotanagpur plateau, used for household purposes	23°12'03.09"N 86°07'35.42"E	544	CP
Sahebbandh, Purulia (SP)	Wetland of Chotanagpur plateau, avian congregation site, wastewater inlet, under NLCP	23°20'17.35"N 86°21'28.71"E	250	CP
Sahebbandh, Adra (SA)	Wetland of Chotanagpur plateau, avian congregation site	23°28'59.41"N 86°42'22.71"E	166	CP
Lalbandh (Lb)	Wetland of lateritic zone adjacent to Chotanagpur plateau, avian congregation site	23°03'48.75"N 87°19'44.00"E	68	CP
Gobardhanpur (Gp)	Coastal zone wetland, situated at Sundarban region (a Ramsar site), used for household purposes	21°36'54.89"N 88°23'45.04"E	2	CO
Bakkhali (Ba)	Coastal zone wetland, situated at Sundarban region (a Ramsar site), used for household purposes	21°33'50.09"N 88°16'01.35"E	4	CO
Mousuni (Mo)	Coastal zone wetland, situated at Sundarban region (a Ramsar site), used for household purposes	21°40'19.06"N 88°12'8.90"E	5	CO

Statistical Analyses

One–way analysis of variance (ANOVA) between six categories of wetlands was performed based on SOC sequestration properties to test the differences within groups which was followed by Levene's test for testing homogeneity of variance from means and the Post–hoc analysis (Tukey's HSD) test for pairwise comparison of means to indicate significant differences. Dendrogram was constructed using hierarchical cluster analysis to group the wetlands types according to C sequestration potential of wetlands under study. Hierarchical cluster analysis was made on the basis of Euclidean distances and single linkage method. Statistical analyses were carried out using Past 4.01 software.

3. RESULTS AND DISCUSSION

West Bengal, the only state of India where we can see the Himalayan in the north and sea (Bay of Bengal) in the south along with plateau and plains. For this unique biographic characteristics West Bengal has diverse climatic conditions, vegetation types, animal diversity, soil properties, land use patterns and several other features. Wetlands from different physiographic or climatic regions have its own characteristic features. There are several factors which influence C sequestration potential and physicochemical characteristics of the wetlands (Cao *et al.*, 2017).

Chemical properties of wetlands varied widely in spatial scale (Table 2). pH values ranged from 6.75 ± 0.34 (at Bakkhali) to 9.41 ± 0.04 (at Gopaldhara). Generally, use of lime is a common practice in tea gardens for improvement of plant growth and better yield (Hirono and Nonaka, 2014; Saha *et al.*, 2015). Gopaldhara wetland situated adjacent to the Gopaldhara tea estate. Allochthonous inputs *i.e.,* runoff from tea gardens increased the pH of the wetland at alkaline level. EC, TDS and salinity values were highest for Gobardhanpur and lowest for Atiamochar. Salinity levels in coastal wetlands were highest and the mean values

Table: 2
Chemical properties of water of the studied wetlands (For abbreviation of study sites see Table 1)

Wetland / Site	pH	EC (µS cm^{-1})	TDS (mg L^{-1})	Salinity (mg L^{-1})
ECW	7.02 ± 0.04	713.50 ± 29.50	503.50 ± 20.50	399.00 ± 17.00
Pu	7.41 ± 0.18	317.81 ± 65.79	257.71 ± 62.97	98.48 ± 9.33
Ra	7.56 ± 0.36	60.48 ± 1.73	43.23 ± 1.29	37.31 ± 2.60
Bo	6.96 ± 1.15	93.20 ± 13.42	67.53 ± 9.21	52.22 ± 5.40
At	7.22 ± 0.50	15.73 ± 4.90	11.07 ± 3.30	16.42 ± 0.43
Na	7.40 ± 0.15	158.98 ± 17.04	117.54 ± 15.60	85.27 ± 5.42
AP	8.48 ± 0.88	18.07 ± 6.25	12.72 ± 4.53	17.23 ± 3.72
JP	7.46 ± 1.22	22.52 ± 0.45	15.45 ± 5.05	21.82 ± 3.19
PB	7.16 ± 0.05	32.73 ± 7.28	20.80 ± 4.84	21.59 ± 2.91
NP	7.46 ± 0.03	28.71 ± 6.73	21.94 ± 5.61	24.53 ± 4.24
Gd	9.41 ± 0.04	26.61 ± 4.17	17.06 ± 4.05	17.31 ± 2.27
Mi	7.08 ± 0.20	127.84 ± 22.43	89.97 ± 5.46	65.71 ± 4.40
Aj	6.86 ± 0.29	187.10 ± 33.72	133.27 ± 24.45	104.70 ± 19.65
SP	7.53 ± 0.90	445.50 ± 17.20	319.33 ± 21.59	247.00 ± 11.32
SA	8.00 ± 0.50	161.98 ± 10.56	115.04 ± 7.88	91.59 ± 6.49
Lb	7.86 ± 0.10	274.42 ± 21.52	221.98 ± 16.01	144.85 ± 35.04
Gp	6.76 ± 0.01	7264.11 ± 5013.91	5367.67 ± 3662.62	4728.00 ± 3309.17
Ba	6.75 ± 0.34	4421.00 ± 3159.00	3115.00 ± 2225.00	2782.00 ± 2058.00
Mo	7.10 ± 0.17	4899.00 ± 348.50	3432.00 ± 679.00	3011.33 ± 135.00

was 3507.10 ± 2156.20 mg L^{-1}. These wetlands experienced saltwater intrusion during super–cyclone Aila (in 2009). Therefore, the water is still saline in nature.

SOC of both bank soil and bottom sediments of the wetlands also varied widely (Fig. 2) and the mean values (with standard deviation) were portrayed in Fig. 3. Highest amount of bank SOC were recorded from HM wetlands (50.54 ± 6.65 t ha^{-1}) and ranging from 44.46 ± 3.31 t ha^{-1} (at Gopaldhara) to 56.18 ± 8.38 t ha^{-1} (at Pokhriabong). However, lowest value was recorded from Jayanti Pokhri (19.08 ± 5.96 t ha^{-1}) followed by Ajodhya (19.14 ± 9.05 t ha^{-1}) and Lalbandh (19.56 ± 4.92 t ha^{-1}). However, bottom SOC values were close for wetlands from FP (36.81 ± 17.80 t ha^{-1}), CO (36.58 ± 22.09 t ha^{-1}) and HM (35.71 ± 9.63 t ha^{-1}) wetlands. Highest SOC (53.34 ± 19.04 t ha^{-1}) content was recorded from wetland sediments of Purbasthali followed by Sahebbandh, Purulia (50.24 ± 13.76 t ha^{-1}) whereas lowest values were recorded from Ajodhya (10.30 ± 2.67 t ha^{-1}). Bulk density, sand and silt–clay composition of bank soil and bottom sediments were depicted in Table 3. Highest value of BD was recorded from Ajodhya (1.01 ± 0.04 g cm^{-3}) followed by Lalbandh (0.99 ± 0.05 g cm^{-3}) and Sahebbandh, Adra (0.98 ± 0.03 g cm^{-3}). All the sites were categorized as CP wetlands. Bank soil of Bochamari showed lowest value of BD (0.68 ± 0.02 g cm^{-3}). For bottom sediments highest BD was recorded from Nararthali (0.88 ± 0.03 g cm^{-3}); Sahebbandh, Purulia (0.88 ± 0.03 g cm^{-3}) and Ajodhya (0.88 ± 0.04 g cm^{-3}). Both of the FH wetlands *i.e.,* Jayanti Pokhri (0.87 ± 0.06 g cm^{-3}) and Adma Pokhri (0.86 ± 0.03 g cm^{-3}) also showed combatively higher values of BD. Lowest value of BD in bottom sediments was recorded from Mirik (0.62 ± 0.03 g cm^{-3}) followed by Pokhriabong (0.64 ± 0.04 g cm^{-3}), Bochamari (0.65 ± 0.04 g cm^{-3}), Mousuni (0.65 ± 0.04 g cm^{-3}) and Gobardhanpur (0.65 ± 0.06 g cm^{-3}). Sand particles

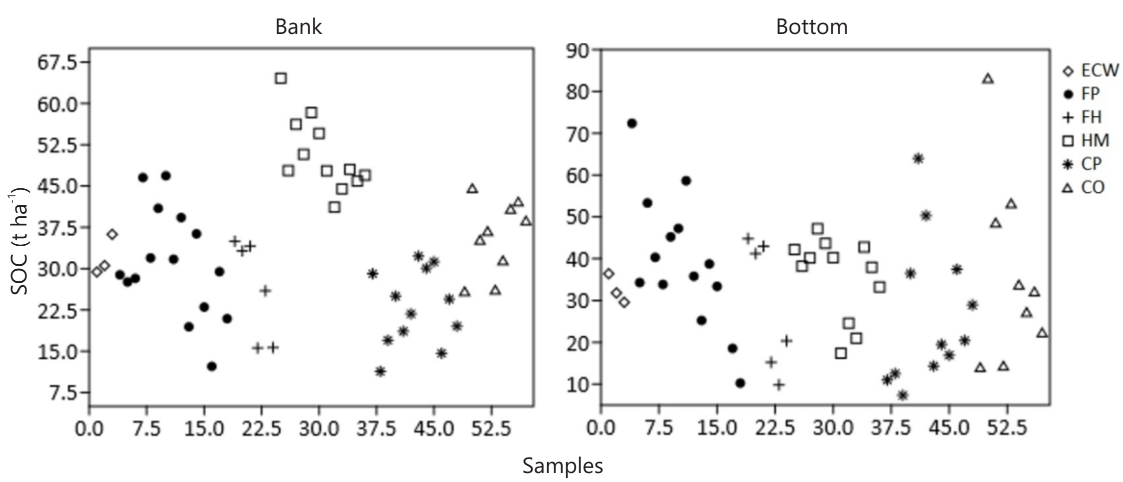

Fig. 2. Pattern of C sequestration by different wetland types (For abbreviation of wetland types see Table 4)

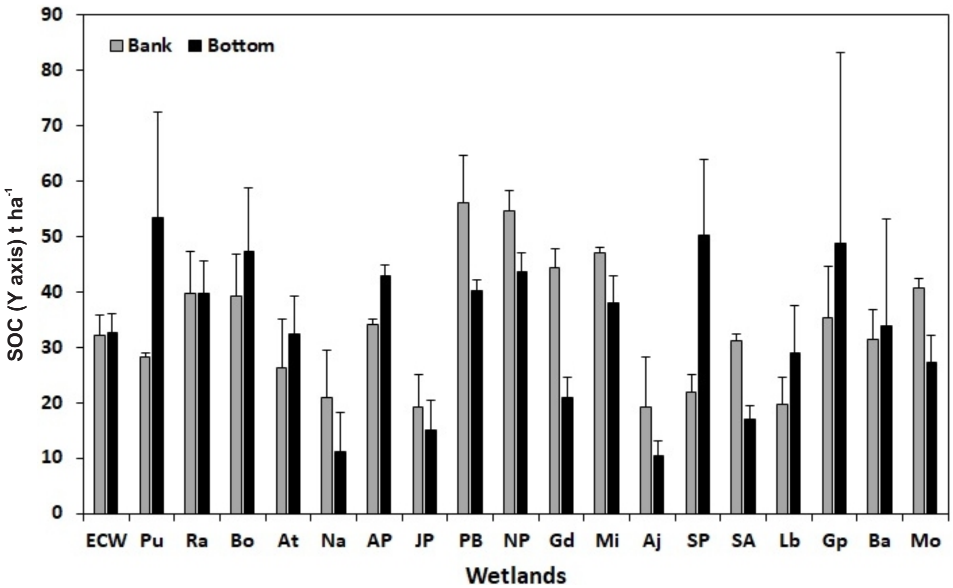

Fig. 3. Carbon sequestration potential of bank soil and bottom sediments of the wetlands under study (For abbreviation of study sites see Table 1)

Table: 3
Properties (bulk density, sand and silt–clay content) of bank soil and bottom sediments of the studied wetlands (For abbreviation of study sites see Table 1)

Wetland / Site	Bank soil			Bottom sediment		
	BD (g cm^{-3})	Sand (%)	Silt-Clay (%)	BD (g cm^{-3})	Sand (%)	Silt-Clay (%)
ECW	0.78 ± 0.02	46.81 ± 7.29	53.19 ± 7.29	0.78 ± 0.04	60.15 ± 5.34	39.85 ± 5.34
Pu	0.79 ± 0.03	62.01 ± 0.36	37.99 ± 0.36	0.72 ± 0.03	67.41 ± 3.26	32.59 ± 3.26
Ra	0.71 ± 0.02	68.32 ± 4.81	31.68 ± 4.81	0.79 ± 0.05	70.61 ± 7.16	29.39 ± 7.16
Bo	0.68 ± 0.02	27.62 ± 3.60	72.38 ± 3.60	0.65 ± 0.04	30.86 ± 8.34	69.14 ± 8.34
At	0.81 ± 0.04	41.18 ± 2.45	58.82 ± 2.45	0.73 ± 0.06	54.31 ± 0.88	45.69 ± 0.88
Na	0.88 ± 0.06	88.48 ± 2.07	11.52 ± 2.07	0.88 ± 0.03	93.07 ± 1.46	6.93 ± 1.46
AP	0.82 ± 0.04	79.44 ± 5.89	20.56 ± 5.89	0.86 ± 0.03	81.77 ± 11.75	18.23 ± 11.75
JP	0.85 ± 0.08	80.17 ± 1.66	19.83 ± 1.66	0.87 ± 0.06	86.45 ± 1.41	13.55 ± 1.41
PB	0.76 ± 0.05	62.25 ± 2.94	37.75 ± 2.94	0.64 ± 0.04	51.03 ± 6.94	48.97 ± 6.94
NP	0.77 ± 0.05	68.26 ± 0.57	31.74 ± 0.57	0.67 ± 0.05	62.54 ± 3.06	37.46 ± 3.06
Gd	0.75 ± 0.05	67.89 ± 1.20	32.11 ± 1.20	0.86 ± 0.03	84.08 ± 1.72	15.92 ± 1.72
Mi	0.70 ± 0.02	69.71 ± 2.26	30.29 ± 2.26	0.62 ± 0.03	47.62 ± 4.46	52.38 ± 4.46
Aj	1.01 ± 0.04	85.83 ± 6.14	14.17 ± 6.14	0.88 ± 0.04	92.16 ± 4.45	7.84 ± 4.45
SP	0.78 ± 0.03	74.40 ± 4.23	25.60 ± 4.23	0.88 ± 0.03	90.97 ± 0.81	9.03 ± 0.81
SA	0.98 ± 0.03	84.45 ± 5.19	15.55 ± 5.19	0.84 ± 0.02	81.55 ± 10.86	18.45 ± 10.86
Lb	0.99 ± 0.05	82.53 ± 2.42	17.47 ± 2.42	0.83 ± 0.03	81.15 ± 1.40	18.85 ± 1.40
Gp	0.73 ± 0.02	58.91 ± 9.98	41.09 ± 9.98	0.65 ± 0.06	50.97 ± 14.42	49.03 ± 14.42
Ba	0.78 ± 0.03	56.11 ± 2.87	43.89 ± 2.87	0.76 ± 0.05	59.55 ± 4.21	40.45 ± 4.21
Mo	0.77 ± 0.09	51.09 ± 4.08	48.91 ± 4.08	0.65 ± 0.04	59.30 ± 2.86	40.70 ± 2.86

were present in highest percentage in both bank soil and bottom sediment of Nararthali (88.48 ± 2.07% and 93.07 ± 1.46%, respectively) followed by Ajodhya (85.83 ± 6.14% and 92.16 ± 4.45%, respectively). However, highest silt–clay fraction was obtained from the bank soil and bottom sediment samples of Bochamari (72.38 ± 3.60% and 69.14 ± 8.34%, respectively) followed by Atiamochar (58.82 ± 2.45% and 45.69 ±0.88%, respectively).

Wetland macrophytes sequester significant amount of C in their biomass through the process of photosynthesis (Pal *et al.*, 2017; Lolu *et al.*, 2019). Dead biomass of wetland vegetation add organic matter in wetland sediment. Besides different growth stages of vegetation are vital factors controlling wetland SOC sequestration (Liu *et al.*, 2020). Further, the varieties and biomass of vegetation are depended on the nutrients and other supportive bioactive elements in soil / sediment. Thereby, present study recorded varying degree of C reserve in wetlands at different physiographic zones of West Bengal. In present study highest mean bottom SOC stock was recorded from the FP wetlands, all the wetlands were infested with macrophyte (dominated by water hyacinth, *Eichhornia crassipes*) and important avian congregation site especially for wintering migrants. Purbasthali a FP, contained highest amount of bottom SOC stock, was infested by different wetland macrophytes dominated by free–floating and submerged macrophytes. A study by Ganesan and Khan (2008) revealed that in Purbasthali ox–bow lake 14 species of macrophytes were present including substantial portion of vegetation cover of water hyacinth. Agricultural runoff from nearby agricultural fields and guanotrophy by avian community in Purbasthali also influenced C sequestration property of this wetland by elevating nutrient concentration which in turn increased net primary productivity (Maynard *et al.*, 2011; Chatterjee *et al.*, 2017).

Darjeeling Himalayan region is situated in Eastern Himalayan biodiversity hotspot. This region sequestered more than one third of the C pool of India and the forested tracts along altitudinal gradients were studied by Banerjee (2014), Devi *et al.* (2019). It was estimated that the soil C stocks were 257.02–527.79 Mg C ha^{-1} and SOC stocks were 152.55–398.88 Mg C ha^{-1} in this region (Devi *et al.*, 2019). SOC sequestration potential in forest soils of Himalayan region was influenced by litter input to the soil and rate of decomposition (Chaturvedi *et al.*, 2014). In present study highest amount of bank SOC and comparable higher amount of bottom SOC were also recorded from HM wetlands. Soils of tea gardens from this area contain higher amounts of SOC (Ray and Mukhopadhyay, 2012). The average C level in soil in tea–growing areas of Darjeeling is much higher than other regions of India (Datta, 2010). Runoff from catchment areas bring significant quanta of sediments especially in Himalayan foothills (Yousuf *et al.*, 2017). Wetlands like Pokhriabong and Namthing Pokhri were protected salamander (Himalayan newt, *Tylototriton verrucosus*) habitat and devoid of anthropogenic interferences. Mirik, a popular tourist spot, received sewage input from nearby settlements and hotels. Allochthonous inputs from nearby natural vegetation or tea gardens may influence the C content of the HM wetlands. Present study also revealed highest amount of SOC from bank soil samples and comparatively higher amount of bottom SOC. CO wetlands, characterized by higher salinity and it had a pronounced impact on the C sequestration potential of the wetlands. Qu *et al.* (2019) stated that higher soil salinity inhibited the rate of decomposition rate of organic C which in turn increase the organic C content of wetland and its persistence time.

Some interesting findings regarding wetland C stock were came out in this study. Though the highest mean C stock values for bottom sediments was recorded from FP wetlands but in Nararthali wetland C content was comparatively much lower (11.22 ± 6.94 t ha^{-1}) than other wetlands belonging to this category. Nararthali, being a floodplain wetland bottom SOC stock was much lower which may be attributed for greater proportion of sand particles in sediment. For same reason the similar situation was also recorded from wetlands of Ajodhya. Both of the wetlands were also characterized by higher values of BD for bottom sediments due to the presence of significant amount of sand particles. Sandy soils had limited capacity to stabilize organic compounds on mineral surfaces in comparison to clay particles which directly affected the SOC storage capacity of the soil (Zhong *et al.*, 2018). de Oliveira Marques *et al.* (2015) stated that about 70% of SOC was retained by clay fractions at 1.0–2.0 m depth and sand fractions had the lowest percentage of SOC retention capacity.

ECW ecosystem receives varied quanta of municipal wastewater and composite industrial effluents through a series of wastewater carrying canals which contain huge amount of organic load (Chattopadhyay *et al.*, 2002; Pal *et al.*, 2018). Mean level of TOC in composite wastewater in ECW was recorded 348.05 ± 154.98 mg L^{-1} which was much higher than the safe limit (2–4 mg L^{-1}) recommended by United States Environmental Protection Agency (USEPA). This wastewater is traditionally used in fishponds for cost–effective pisciculture practices over a century (Ghosh, 1983). Organic matter is added to ECW not only from external sources (mostly municipal sewage water and industrial wastewater) but also internal (dead biomass of macrophytes, detritus matter from algae and microbial mats, below ground portions like roots and rhizomes and crop residuals) sources (Pal *et al.*, 2017). Therefore, it is concluded that significant amount of C is sequestered in ECW ecosystem (Pal *et al.*, 2018). Like ECW, Sahebbandh, Purulia also received municipal wastewater input from outside. This particular wetland contained significantly higher amount of C in bottom sediments than other wetlands belonging to same region (Chotanagpur plateau). Traditionally the wastewater–fed fishponds receive wastewater by inlets and were drained out by outlet. In the meantime, wastewater retained in fishponds which gave the opportunity for wastewater amelioration by natural processes and enhanced growth of phyto and zooplankters which serves as food base for cultured fishes (Mukhopadhyay *et al.*, 2007; Bunting *et al.*, 2010). As the water was not permanently stagnant in fishponds of ECW ecosystems, they sequestered less amount of C in comparison to lentic wetlands that also received wastewater, such as Sahebbandh, Purulia. Drainage of wetlands lead to higher rate of CO_2 emission from the wetland which causes subsequent losses of stored SOC (Ramsar Convention Secretariat, 2018).

Both Adma Pokhri and Jayanti Pokhri (both categorized as FH) were situated in similar physiographic condition (inside BTR) and showed similar physical (BD and sediment texture) properties of sediment and chemical (EC, TDS and salinity) properties of water. However, the C stock of Jayanti Pokhri was much lower (19.08 ± 5.96 t ha^{-1} and 15.13 ± 5.26 t ha^{-1} for bank soil and bottom sediments, respectively) than Adma Pokhri (34.08 ± 0.88 t ha^{-1} and 43.00 ± 1.80 t ha^{-1}, respectively). Jayanti Pokhri is a holy wetland and visited by a large number of tourists regularly. Another attraction of the pond was large number of Asian catfish, locally called magur (*Clarias batrachus*) fishes that lived in this wetland which were regularly fed by tourists (Pal, 2017). Anaerobic condition in wetland sediment reduces the organic matter decomposition rate and increases C stock in wetlands (Holden, 2005). However, anthropogenic disturbances in terms of feeding of catfishes agitated the surface water and sediments which may accelerated the decomposition rate by creating aerobic environment. Lower values of SOC in Jayanti Pokhri may attributed for this reason. The catfishes mainly feed on small fishes, insect larvae, worms, shrimps along with organic debris. Study by Sakhare and Chalak (2014) pointed out that organic debris accounted for 7.05% of the diet of Asian catfishes from different wetlands at Ambajogai, Maharashtra. Therefore, the presence of substantial biomass of *Clarias batrachus* with a small, isolated lentic ecosystem may also responsible for reduction of SOC stock in bottom sediments.

From the results of Tukey's HSD test significant differences ($p < 0.05$) was observed within FH–HM (p = 0.0039) and HM–CP (p = 0.0003) wetland types. The result of Levene's test for homogeneity of variance, from means also showed significant results (p = 0.0049). Pairwise comparison of means to indicate the significant differences, the Tukey's test was performed and the results were summarized in Table 4. Hierarchical cluster analysis based on SOC content values revealed that all the regions (CO, FP, ECW, FH and CP) except HM together formed a single cluster and HM appeared as an outgroup. ECW–FP–CO and FH–CP were the two sub clusters which form the single cluster (Fig. 4). Due to higher potential of C sequestration, HM wetlands appeared as an outgroup in hierarchical cluster analysis and also show significant differences with wetlands of other physiographic zones.

Wang *et al.* (2017) pointed out that the reserve of wetland SOC was one of the most important C stocks on the earth and performed a dynamic role in the global climate

Table: 4
Pairwise comparison values obtained by Tukey's HSD test within six wetland groups i.e., East Calcutta Wetlands (ECW), Floodplain wetlands (FP), Wetlands from forested hill region (FH), Himalayan region (HM), Chotanagpur Plateau and adjacent areas (CP) and coastal wetlands (CO) based on C sequestration potential

	ECW	FP	FH	HM	CP
FP	0.9989				
FH	0.8619	0.6508			
HM	0.0872	0.1962	0.0039*		
CP	0.4059	0.2140	0.9712	0.0003*	
CO	0.9255	0.9915	0.2972	0.5039	0.0597

**marked values with bold faces are significant at p < 0.05*

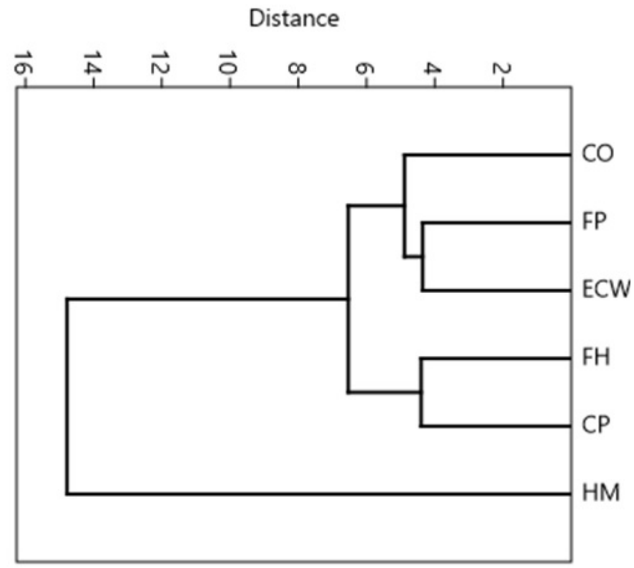

Fig. 4. Hierarchical cluster analysis of different wetland types bases on C sequestration potential (For abbreviation of wetland types see Table 4)

change. However, regional information on the C sequestration and storage potential of wetland soil / sediment in relation to different physiographic characters is rare. West Bengal harbours vast types of wetlands including lakes, ponds, tanks, reservoirs, barrages, waterlogged areas, rivers, streams, creeks, riverine wetlands, ox–bow lakes, cut–off meanders, salt pans, intertidal mudflats, mangroves etc. (SAC–ISRO, 2010). Among them inland wetlands like lakes, ponds, tanks, riverine wetlands, ox–bow lakes, cut–off meanders and high–altitude lakes are considered which can compared with the findings of the present study. Aquaculture ponds are also considered as representative of coastal wetlands. All of the mentioned wetland types collectively constitute 247674 ha area which represents 22.35% of total wetland area of the state can sequester 6.63 M t carbon in soils and sediments. Therefore, the present study on the soil / sediment C stock in wetlands was carried out to provide a base–line information on the SOC distribution, storage, and variation under the influence of regional physiography across the length and breadth of the state of West Bengal, India.

4. CONCLUSIONS

Wetlands provide innumerable ecosystem goods and services including C sequestration (Mitsch *et al.*, 2013). Long term storage of C in wetland sediments play a crucial role in mitigation of climate change (Erwin, 2009; Moomaw *et al.*, 2018). However, tropical wetlands of India are exploited for resources as they have immense socio–economical values or they were drained or converted for other purposes. The main drivers of the change from wetland ecosystem to others are climate change, changes in land use (agricultural intensification and infrastructure development), population growth (illegal human settlement and urbanization), pollution, poor institutional and land governance factors due to weak policies, deforestation, over exploitation of wetland resources, invasive alien species, land encroachment by brick kilns etc. (Bassi *et al.*, 2014; Sarkar *et al.*, 2020). Highly populous states like West Bengal are not an exception. Two wetlands of West Bengal ECW (2002) and Sundarban (2019) are designated as Ramsar site. ECW, Sundarban, Ahiron beel, Rasikbeel, Santragachi and Patlakhawa–Rasomati wetlands are listed for National Wetland Conservation Programme (NWCP) by Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India. MoEF&CC also listed wetlands like Mirik, Rabindra Sarovar, Sahebbandh (Purulia) under National Lake Conservation Plan (NLCP). Besides a number of wetlands are situated under protected areas like National Parks, Wildlife Sanctuaries. Apart from these large number of wetlands were facing serious threats of urbanization, rapid encroachment, pollution etc. Though there are laws and regulations like Wetlands (Conservation and Management) Rules, 2017 under the provisions of the Environmental (Protection) Act, 1986 for wetland conservation but the scenario is not changed. In last four decades India lost one–third of its natural wetlands as a result of urbanization, agricultural expansion and pollution (Bassi *et al.*, 2014). Das *et al.* (2000) reported that in West Bengal wetland degradation (change in wetland area and water quality) was also a matter of great concern. However, these wetlands are not only important for its ecosystem goods and services it provided but the wetlands of lower Gangetic plains of West Bengal were also important for income generation of local people (Adhikari *et al.*, 2017). Therefore, it is need of the hour to conserve the diverse wetland ecosystems of the state of West Bengal for not only ecosystem services, such as, cultivation of fish and agriculture produces, groundwater recharging, mitigation of pollutants in influents and several other means to support socioeconomic means but also to combat with climate change through effective C sequestration.

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