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Research Note:

Effect of tidal inundation on some chemical properties of soil of the Sundarbans (India)

Tanumi Kumar and Monoranjan Ghose

Agricultural and Ecological Research Unit, Indian Statistical Institute, 203 B.T. Road, Kolkata - 700 108, West Bengal, India

ABSTRACT

Soil samples from twenty seven sites of Indian Sundarbans were analysed for some chemical parameters. These sites were divided into three inundation types namely, diurnal, usual springtide and summer springtide. The study demonstrated that most of the soil properties significantly varied with inundation type. Sites inundated by usual springtides exhibited lowest concentrations of pH, salinity (Sal), available phosphorus (P), and exchangeable potassium (K), sodium (Na) and magnesium (Mg), whereas summer springtide inundated sites had the highest concentrations of Sal, organic carbon (OC), available nitrogen (N), Na, K and Mg. Highest level of P and lowest N in the diurnally inundated sites could be attributed to increased mobility of phosphates and denitrification or volatilization losses of inorganic nitrogen in the soils respectively. Highest concentration of N in summer springtide inundated sites could be attributed to increased ammonium ion mobility in the soils.

Keywords: Indian Sundarbans, tidal inundation, soil parameters, relationship.

Correspondence: T. Kumar *Address*: Agricultural and Ecological Research Unit, Indian Statistical Institute, 203 B.T. Road, Kolkata - 700 108, West Bengal, India. *E-mail*: tanumikumar@yahoo.co.in
Tel. No. +(91) (033) 2575 3225
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INTRODUCTION

There are many environmental factors that can affect primary production and plant-species distribution in intertidal ecosystems; of these, the substrate characteristics are possibly the most important. However, the type of soil and its physical and chemical state are in turn affected by factors such as topography, tidal regimes, riverine sedimentation patterns, climate, tidal range and long-term sea-level changes (Boto, 1984)

Mangrove is a type of coastal woody vegetation that fringes muddy saline shores and estuaries in tropical and subtropical regions (Naskar and Guha Bakshi, 1987). On the Gangetic and Brahmaputra deltas of West Bengal and Bangladesh, lies the world's second largest mangrove forests, the Sundarbans (Ghose, 2001). According to satellite imagery of the Forest Survey of India (1999) total area of the Indian Sundarbans was 2125 kilometer square including 54 conglomerate islands, and excluding the anastomosing network of creeks and backwaters. The creeks and backwaters of the Sundarbans are subjected to tidal influence and are therefore saline. The tidal amplitude throughout the Sundarbans ranges from 3m - 5m depending upon the solar phase and sometimes rises to 8m during summer springtides (Mandal, 2003). Sites here are variously inundated. The inundation can be broadly divided into three types/classes based on the height reached by the tidal waves above the datum line and the frequency of flooding per month (Watson, 1928) - diurnal, usual springtide and summer springtide inundation (Table 1).

Acquisition of physical and chemical data on soil is required for the treatment of the diverse problems of mangrove ecology, such as salinity, inundation and nutrient acquisition (Snedaker, 1982). The relationship between tidal factors and accompanying soil attributes remain largely unexplored for the Indian Sundarbans. Hence in the present investigation the effects of tidal inundation on soil parameters have been analysed for some areas of Indian Sundarbans.

Table 1. Inundation classes, respective height of tides above the datum line and frequency of flooding per month

Tidal inundation class/type	Height above datum line (ft)	Times flooded /month
Diurnal inundation	0-13	56-62
Usual springtide inundation	13-15	2-20
Summer springtide inundation	15-above	0-2

MATERIALS AND METHODS

Study sites

Twenty seven sampling sites were selected from six different areas (including two islands) in the Sundarbans of West Bengal (Figure 1). Each sampling site is equivalent to a quadrate of size 4m x 16m. The latitude-longitude values of the study sites are presented in the Table 2. Sites were broadly divided into three inundation types (Watson, 1928) viz. diurnally inundated sites (Diurnal) - ten, sites inundated by usual springtides (Usp) - nine and sites inundated by only summer springtides (Ssp) - eight.

Soil sampling

Soil sampling was done during the months of December, January and February of the years 2004-2006. Soil samples were collected in sterile polythene bags using metal sheet soil sampler (10 cm diameter and 30 cm height) at a depth of 0-30 cm from 15 random locations in each sampling site. The samples were collected from the rhizospheres of the plants and from bulk soil and finally mixed to get a homogenous mixture of soil for each site.

Determination of soil characters

Soil pH and electrical conductivity were determined at 1:2.5 and 1:5 soil:water suspensions respectively according to Jackson (1973). Salinity (Sal) was calculated from electrical conductivity (Jackson, 1973). Potassium

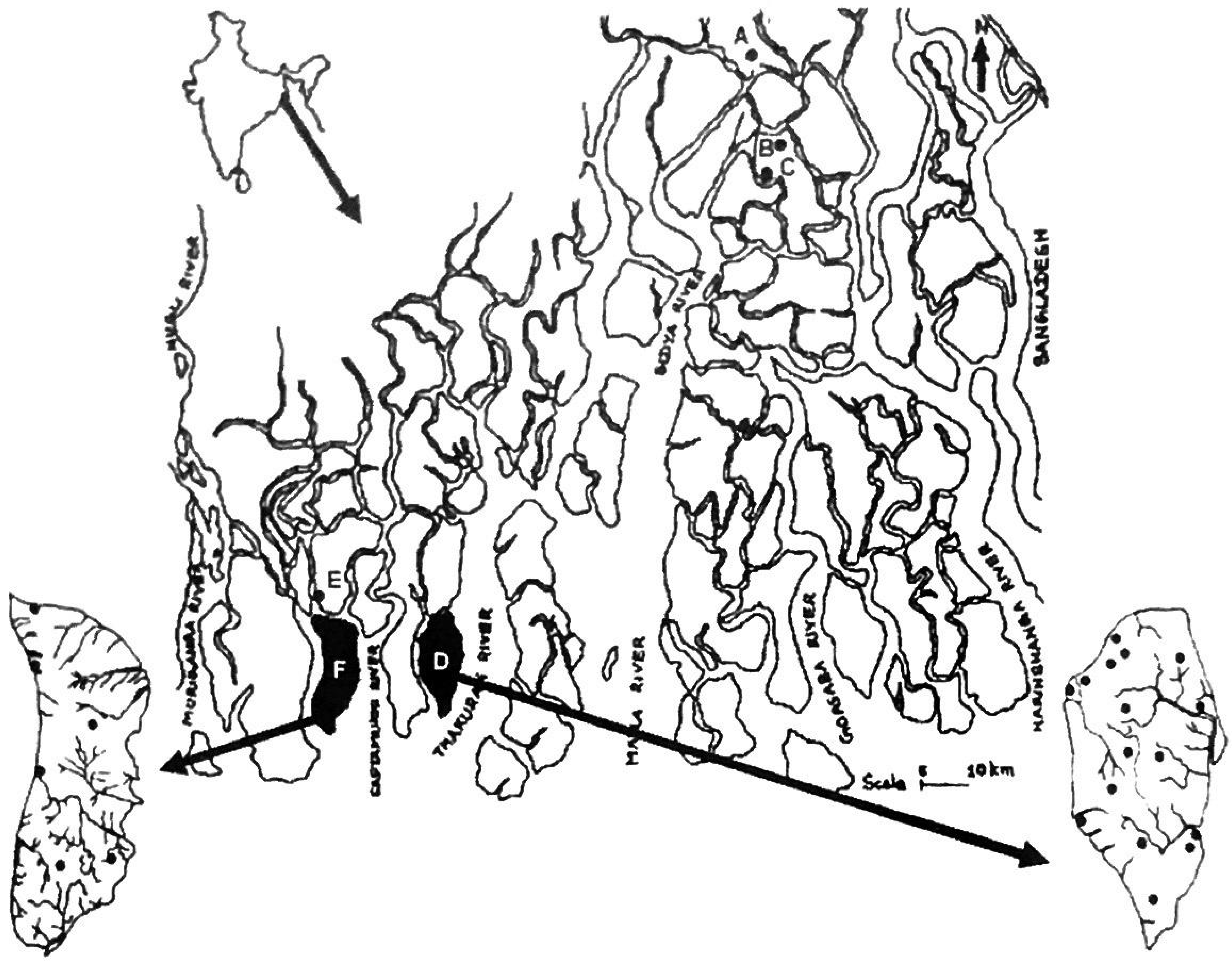

Figure 1. Map showing study areas. A Manmathanagar, B Sajnekhali, C Sudhanyakhali, D Dhanchi island, E Bhagwatpur and F Lothian island. Black dots indicate the study sites.

Table 2. Study areas, number of sites studied at each area and their geographic locations

Areas	Number of sites studied	Location of the sites
Bhagwatpur	1	21°44′33′′N & 88°18′29′′E
Dhanchi (island)	16	21°41′23′′N & 88°25′28′′E
		21°36′54′′N & 88°25′27′′E
		21°41′41′′N & 88°26′00′′E
		21°40′13′′N & 88°26′17′′E
		21°41′51′′N & 88°26′15′′E
		21°40′54′′N & 88°24′49′′E
		21°40′21′′N & 88°25′53′′E
		21°39′38′′N & 88°25′58′′E
		21°41′16′′N & 88°25′10′′E
		21°41′44′′N & 88°26′06′′E
		21°40′49′′N & 88°27′44′′E
		21°38′47′′N & 88°27′32′′E
		21°38′39′′N & 88°27′31′′E
		21°41′56′′N & 88°26′04′′E
		21°40′33′′N & 88°25′30′′E
		21°40′18′′N & 88°26′29′′E
Lothian (island)	6	21°37′42′′N & 88°19′06′′E
		21°38′53′′N & 88°18′47′′E
		21°41′20′′N & 88°18′48′′E
		21°37′52′′N & 88°18′59′′E
		21°42′20′′N & 88°18′42′′E
		21°42′01′′N & 88°18′41′′E
Manmathanagar	1	22°11′2′′N & 88°48′44′′E
Sajnekhali	1	22°7′27′′N & 88°49′48′′E
Sudhanyakhali	2	22°6′42′′N & 88°46′46′′E

permanganate oxidation method (Subiah and Asiza, 1956) was employed to measure available nitrogen (N). Available phosphorus (P) was determined using Olsen's bicarbonate extraction method (Olsen *et al.*, 1954). Organic carbon (OC) was quantified using wet digestion method or titrimetric method (Walkley and Black, 1934) as described by Nelson and Sommer (1982). Exchangeable potassium (K) and sodium (Na) were estimated using ammonium acetate extraction, followed by flame photometric method (Jackson, 1973). EDTA or versenate titration method was employed to quantify exchangeable calcium (Ca) and magnesium (Mg), as mentioned by Baruah and Barthakur (1997).

Statistical analyses

The data on soil parameters were subjected to one-way ANOVA to judge whether the variation in the parameters between the inundation types were significant or not. Means and standard errors were estimated for the replicate values. For all the above statistical analyses SPSS software version 11.0 was used.

RESULTS

Table 3 shows the mean values of the soil parameters at the three inundation types. Usually inundated sites had the lowest concentrations of pH, Sal, P, K, Na and Mg; summer springtide inundated sites exhibited highest concentrations of Sal, OC, N, Na, K and Mg. Diurnally and usually springtide inundated areas exhibited the same pH, whereas summer springtide inundated sites showed the lowest pH. P and N did not differ significantly between the inundation types. P was highest and N lowest in the soils of the diurnally inundated sites. The cationic analysis of the soil indicated that Na and Ca ions dominated as soil salinity increased, although Mg and K concentrations were considerable under high soil salinity. Ca ion concentration was of the order diurnal > usual springtide > summer springtide inundated sites.

Table 3. Mean value of each soil parameter at the three specified tidal inundation type

Soil parameters	Inundation[1]			F
	Diurnal	Usp	Ssp	
pH	8.04 b (±0.04)	8.03 b (±0.03)	7.57 a (±0.09)	15.26 **
Salinity (ppt)	15.62 a (±0.40)	9.92 b (±0.40)	21.67 c (±1.39)	87.16 **
Organic carbon (%)	0.68 b (±0.05)	0.74 b (±0.06)	1.08 a (±0.08)	6.69 *
Available nitrogen (mg/kg)	292.19 (±18.97)	310.86 (±28.34)	337.03 (±33.01)	1.54 ns
Available phosphorus (mg/kg)	33.92 (±11.42)	18.67 (±1.46)	27.36 (±2.78)	0.75 ns
Exchangeable potassium (meq/100g)	2.66 a (±0.11)	1.95 b (±0.09)	3.38 c (±0.37)	20.03 **
Exchangeable sodium (meq/100g)	27.26 a (±0.99)	21.97 b (±0.94)	40.53 c (±5.38)	20.87 **
Exchangeable calcium (meq/100g)	19.58 a (±1.02)	13.79 b (±0.73)	12.38 b (±0.99)	15.09 **
Exchangeable magnesium (meq/100g)	10.58 b (±0.51)	9.99 b (±0.55)	14.99 a (±1.11)	8.68 *

[1] Inundation: Diurnal - diurnally inundated sites, Usp - sites inundated by usual springtides and Ssp - sites inundated by only summer springtides, ppt-parts per thousand, meq milliequivalent. Value of F from one-way ANOVA for detecting the significance of difference in the values amongst these types. Values in parentheses represent standard errors. The means followed by the same letter are not significantly different (P=0.05) according to LSD. *P<0.05, **P=0.01, ns=not significant.

DISCUSSION

Seawater is one of the major factors determining soil salinity and pH of mangrove forests (Tomlinson, 1986). Soil pH is an important parameter controlling the chemical status and mobility of many important elements. At high pH, the $H_2PO_4^-$ quickly reacts with Ca ions to form less soluble compound tricalcium phosphate [$Ca_3(PO_4)_2$] (Sample *et al.*, 1980). Our study indicates that at higher pH, concentrations of both Ca ions and available P were also high, thereby depicting a positive correlation between pH, Ca ions and P. The present study also reveals a positive correlation between salinity and concentrations of Na, Mg and K ions, as the amount of these cations were higher under high salinity. When a soil is flooded, the concentration of oxygen is gradually reduced (Brady and Weil, 2002). When all the oxygen is consumed, Mn^{4+}, NO^{3-} and Fe^{3+} are converted to Mn^{2+}, N_2 and Fe^{2+} respectively (Turner and Patrick, 1968; Patrick and Jugsujinda, 1992). In such anoxic environment inorganic P which might have been previously sequestered in the insoluble Fe^{3+} and Mn^{4+} oxides/ hydroxides are partially released, resulting increase in phosphate forms (e.g.,PO_4^{3-}, HPO_4^{2-} and $H_2PO_4^-$) [De Laune *et al.*, 1976; Wright *et al.*, 2001] . This could serve as one of the possible reasons for the highest concentration of available P in the soils of the diurnally inundated sites. Moreover, phosphorus availability might also increase because of a decrease in biological (plant and microbial) phosphorus demand under anaerobic conditions due to flooding (Schlesinger, 1997; Mitsch and Gosselink, 2000). Amongst the cations sodium ions occur in highest concentrations in all the inundation levels. Epstein (1972) opined that excess Na^+ might cause nutrient deficiency by reducing the amounts of available K^+, Mg^{2+} and Ca^{2+}. In addition, Na^+ interferes with the function of K^+ as a cofactor in various reactions (Hseu and Chen, 2000). Hence sodium is a crucial factor affecting the soil properties of a mangrove marsh. Moreover, a high level of sodium ions in mangrove soils can displace ammonium ions in the cation exchange sites, resulting in their enhanced mobility (Chiu *et al.*, 1996). This fact might be partly responsible for highest concentration of available N in the soils of the summer springtide inundated areas. In anaerobic soils microbial decomposition processes slow down, denitrification and volatilization losses of inorganic N increase (Turner and Patrick, 1968; Isirimah and Keeney, 1973; Sexstone *et al.*, 1985; Brady and Weil, 2002). This could be responsible for the lowest concentration of available N in the diurnally inundated sites. Underground water table of the Sundarbans is shallow and enriched with high salt contents (Naskar and Guha Bakshi, 1987). During the dry season, salt molecules move along with water to the surface soil. As the water in the soil evaporates the salt molecules are left in the surface soil (Yadav *et al.*, 1981). Since the summer springtide inundated sites receive the least number and lowest duration of tides, hence mean salinity as well as the concentrations of Na, K and Mg were highest in this case. Quite high salinity and high concentrations of the estimated cations might suggest that though in the diurnally inundated sites water runs in opposite directions twice-a-day (Mandal, 2003), yet the leaching of the salt molecules are not much for these sites.

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