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Physico-chemical properties of soils and ecological zonations of soil habitats of Sundarbans of Bangladesh

By

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Abstract

Soil samples were collected during 6 to 10 April 2015 at thirteen different locations from the Sundarban mangrove forests (SMF) of Bangladesh and 7 physico-chemical properties were analyzed. Mean soil pH of SMF soil was slightly alkaline, 7.34, although the minimum value was found to be acidic, 6.2 and maximum was 8.6. Salinity of soils of SMF showed wide range of variations with the mean value was 7.79‰ and minimum and maximum values were 2.06‰ and 24.25‰ respectively. We have proposed ecological zonations in soil habitats of SMF according to Iversen (1936) based on salinity. It has been found that some locations should be considered as mesohaline zones and some as mesohaline to polyhaline zones which were previously designated as oligo-mesohaline zones and polyhaline zones by other workers. The mean values of other soil variables of SMF were moisture content (25.70%), conductivity (12.172 mS/cm), organic carbon (0.833%), N (1.72%), P (0.022%). Salinity showed significant positive correlation with N ($r = 0.444$, $p = 0.000$) and OC ($r = 0.230$, $p = 0.019$) and significant negative correlation with moisture ($r = -0.309$, $p = 0.001$), pH ($r = -0.508$, $p = 0.000$) and P ($r = -0.939$, $p = 0.008$). Highly significant difference was present in case of salinity among the locations ($F = 15.52$, $P = 0.000$) and layers ($F = 9.23$, $P = 0.000$) of SMF. Significant differences were present in pH among the locations of SMF ($F = 22.11$, $P = 0.000$). Principle component analysis (PCA) showed the cluster form between conductivity and salinity. The present study provides present status of edaphic features with changes in ecological zonations of Sundarban mangrove forests.

Keywords: Sundarbans, edaphic features, salinity, ecological zonation, Principle component analysis

1. Introduction

Mangrove ecosystems are important for their intertidal, tropical and subtropical geographic position found along sheltered estuarine shores. These highly productive ecosystems export a substantial amount of organic matter and support detrital food chains in adjacent waters, coastal fisheries and aquaculture (Odum and Heald 1972). The structure and function of mangrove ecosystems are controlled by many environmental factors including climate, geomorphology, hydrodynamics and soil physico-chemical characteristics. The availability of nutrients to mangrove plant production is controlled by the size of dissolved and particulate nutrient pools in mangrove soils (Tam and Wong 1998). These pools are regulated by tidal inundation and elevation, texture, redox status and microbial activities of soils, plant species, uptake, litter production and decomposition (Steinke and Ward 1988, Holmer*et al.* 1994, Lacerda*et al.* 1995). Therefore, mangrove ecosystems of different geographical locations are varied significantly by nutrient status of soils. It has been suggested that N and P content of soils can be used as a surrogate record of nutrient loadings in estuaries and lakes (Khan and Brush 1994). The edaphic factors of a particular location are affected profoundly by soil constitution, soil moisture, soil air, soil conductivity and soil pH.Soil moisture is an important ingredient of soil for filling part of the pores between the solid particles. Many physic-chemical properties of soils are affected intensively and for the under most soil physical phenomena, the behavior of soil water is fundamental (Gupta and Rorison 1975). Studies on soil nutrient concentrations and their availability are mostly focused on tropical mangrove ecosystems. Relatively little attention has been paid to nutrient status in subtropical mangrove soils in spite of their importance in the management of mangrove ecosystems. Therefore, in the present study a focus was given to know the nutrient status of soil of different locations of three ecological zones of Sundarban mangrove forests (SMF) of Bangladesh.

2. Materials and methods

The study site (Sundarban mangrove forests) is located at Khulna division, Bangladesh. Soil samples were collected from 13 locations of three ecological zones from where quadrates for phyto-sociological data were taken (Table-1). Seven locations were situated in Oligo-mesohaline zone, three locations each in Mesohaline and Polyhaline zone respectively. Four soil samples were taken from two depths (0-6cm and 6-12cm) of soil of each location for the determination of soil moisture, pH, conductivity and other chemical properties. This paper describes seven variables of soil. Exchangeable captions and heavy metals have been described elsewhere. Soil pH was recorded within 24 hours of collection from the field in suspension with distilled water (1:2.5, w: v) by a pH meter (Hanna pH meter, pHeP). Soil moisture content was determined by the following formula:

$$\text{Soil moisture content (\%)} = \frac{F - D}{F} \times 100$$

where, F = weight of fresh soil, D = weight of dry soil.

Soil conductivity was also recorded within 24 hours after collection from the field. Soil conductivity was determined in suspension with distilled water (1:5, w: v) by conductivity meter (Aqua Lytic CD 22). Soil salinity was calculated by converting the conductivity values into salinity and was cross checked with hand refractro salinity meter.

Table-1: Name of 13 studied locations of the Sundarban mangrove forests with co-ordinate, ecological zones, ranges and dates of samples collection

Location No.	Name of the areas	Co-ordinate	Ecological zone	Range	Dates of sample collection
1	Mrigamari (Sela river east bank)	22°21′36.1″N 89°40′8.7″E	Oligo-mesohaline	Chandpai	06/04/2015 Soil samples 01-04 Quadrat-01
2	Aandarmanik forest office	22°21′36.1″N 89°40′11.3″E	Oligo-mesohaline	Chandpai	06/04/2015 Soil samples 05-08 Quadrat-02
3	Tambulbunia forest office	22°12′34″N 89°41′59.4″E	Oligo-mesohaline	Chandpai	07/04/2015 Soil samples 09-12 Quadrat-03
4	Pathuria River west bank	22°12′33.7″N 89°42′16″E	Oligo-mesohaline	Chandpai	07/04/2015 Soil samples 13-16 Quadrat-04
5	Pathuria River east bank	22°12′33.7″N 89°42′16″E	Oligo-mesohaline	Sarankhola	07/04/2015 Soil samples 17-20 Quadrat-05
6	Supati forest office	22°02′51.6″N 89°49′41.6″E	Oligo-mesohaline	Sarankhola	07/04/2015 Soil samples 21-24 Quadrat-06
7	Katkajamtola	21°51′33.6″N 89°46′40.2″E	Mesohaline	Sarankhola	08/04/2015 Soil samples 25-28 Quadrat-07
8	Katka forest office	21°51′33.6″N 89°46′40.2″E	Mesohaline	Sarankhola	08/04/2015 Soil samples 29-32 Quadrat-08
9	Harbaria forest office	22°15′55″N 89°37′5″E	Oligo-mesohaline	Chandpai	09/04/2015 Soil samples 33-36 Quadrat-09
10	Burigoalini forest office (Opposite side)	22°17′50.5″N 89°19′10.9″E	Polyhaline	Satkhira	09/04/2015 Soil samples 37-40 Quadrat-10
11	Kalagachia forest office	22°12′53.1″N 89°14′13.6″E	Polyhaline	Satkhira	10/04/2015 Soil samples 41-44 Quadrat-11
12	Kobadak River wast bank	22°12′53.1″N 89°14′13.6″E	Polyhaline	Satkhira	10/04/2015 Soil samples 45-48 Quadrat-12
13	Kashitana forest office	22°13′17.2″N 89°20′53.4″E	Mesohaline	Khulna	10/04/2015 Soil samples 49-52 Quadrat-13

Organic carbon of the soil was determined by Walkley and Black method (Walkley and Black 1934). Total nitrogen was determined by following the Kjeldahl method as described by Jackson (1973). Phosphorus content of the digest was determined by vanadomolybdo phosphoric yellow color method in nitric acid system as described by Jackson (1973). Iversen (1936) distinguished a number of salinity ranges and claimed that these ranges overlapped the commonly found ranges of the plants salt tolerance. He thus classified the mangrove habitat into the following categories:

1. Oligohaline habitats - containing 0.01- 0.1% NaCl.
2. Mesohaline habitats - containing 0.1- 1% NaCl.
3. Polyhaline habitats - containing 1% NaCl and up.

To compare the 7 soil variables studied between the locations; and locations and layers, one-way and two-way ANOVA was performed respectively using Minitab 14 software. Pearson's correlations were calculated for soil variables. Principles component analysis was done using Minitab 14 software.

3. Results and discussion

Moisture, pH, conductivity, salinity, organic carbon, nitrogen and phosphorus of soil were determined in soil samples obtained from two depths such as upper layer (0-6 cm) and lower layer (6-12 cm) of 13 locations and the data were presented in Table-2.

Overall mean of the soil moisture of SMF was 25.701% with minimum value 11.23% and maximum 44.9% (Table-3). Soil moisture showed significant difference between upper and lower layer in location 13 (F = 20.52, P = 0.004) (Table-4). Highly significance difference was present in case of moisture content among the locations of SMF (F = 25.67, P = 0.000) (Table-5). Moisture showed significant positive correlation with pH (r = 0.333, p = 0.001), organic carbon (r = 0.242, p = 0.013), phosphorus (r = 0.375, p = 0.008) and significant negative correlation with conductivity (r = - 0.309, p = 0.001), salinity (r = - 0.309, p = 0.001) and nitrogen (r = - 0.327, p = 0.001) (Table-6). Other studies of the coastal islands of Bangladesh showed higher moisture content than those of soils of SMF. A coastal island named Char Tamaruddin of Noakhali district planted with the mangrove species was found to be rather homogenous in respect to soil quality. The mean value of soil moisture in the island was 39.45% where the minimum value was 30.34% and maximum value was 44.74% (Das 2012).

The pH of the soils of SMF did not show much variations among the locations (co-efficient of variation was 4.78, Table 3). Overall mean of the soil pH of SMF was 7.34 with minimum value 6.2 and maximum 8.6 (Table- 3) indicating the slightly alkaline nature although minimum value was acidic. Soil pH showed significant difference between upper and lower layer in location 10 (F = 6.00, P = 0.05) (Table-4). The pH showed location-wise variation and it was highly significant (F= 22.11, p = 0.000) (Table-5).pH maintained significant positive correlation with moisture (r= 0.333, p= 0.001), phosphorus (r= 0.780, p= 0.028) and significant negative correlation with conductivity (r = -0.508, p = 0.000), salinity (r = -0.508, p = 0.000) and nitrogen (r = -0.444, p = 0.000,) (Table-6). Das (2012) has found that the soil of a coastal island namely Char Tamaruddinat Hatia, Noakhali to be neutral to slightly alkaline in nature with mean of the soil pH was 7.22 and minimum value of 7.00 and maximum 7.50. Ahmed *et al.* (2010) found pH 6.97 - 8.99 in different islands at Buragauranga river estuary as affected by different tidal regimes in Patuakhali district, Bangladesh. Soil pH of other mangrove ecosystems located in Southeast coast of China, ranged from 2.6 - 6.9 (Lin *et al.* 1987). This acidity may be partly due to oxidation of FeS_2 and FeS to H_2SO_4 (Holmer *et al.* 1994) and resulted from decomposition of mangrove litter (Lacerda *et al.* 1995). Various kinds of organic acids

Table-2: Physico-chemical properties of soil of Sundarban mangrove forests (Cond =Conductvity)

Location	Layer	Moisture (%)	pH	Cond. (mS/cm)	Salinity (‰)	OC (%)	N (%)	P (%)
1	U	30.25± 3.74	7.40± 0.086	9.625± 2.016	6.120± 1.178	0.901± 0.216	1.662± 0.247	0.084± 0.007
	L	30.40± 3.09	7.35± 0.100	9.500± 1.958	6.080± 1.089	0.892± 0.268	0.841± 0.043	0.0002± 0.00002
2	U	32.50± 1.74	7.22± 0.125	9.000± 1.472	6.154± 1.025	1.106± 0.058	2.111± 0.054	0.037± 0.0009
	L	32.77± 2.66	7.15± 0.057	9.875± 0.854	6.149± 1.002	1.111± 0.084	0.834± 0.134	0.00018± 0.000007
3	U	33.27± 4.79	7.35± 0.331	11.75± 0.926	3.097± 0.373	1.199± 0.181	1.600± 0.200	0.0426± 0.003
	L	31.90± 8.66	7.27± 0.236	11.87± 0.946	3.229± 0.806	1.218± 0.215	1.175± 0.138	0.00017± 0.000014
4	U	27.75± 1.30	8.10± 0.391	4.840± 0.583	6.560± 1.048	0.931± 0.213	1.582± 0.303	0.0421± 0.0027
	L	27.80± 1.34	7.97± 0.330	5.046± 1.260	5.512± 0.350	0.965± 0.139	0.679± 0.009	0.00026± 0.000052
5	U	22.45± 4.27	7.12± 0.170	10.25± 1.639	7.984± 0.864	1.126± 0.0802	1.36± 0.054	0.044± 0.002
	L	24.30± 5.44	7.15± 0.129	8.614± 0.548	5.512± 0.358	1.145± 0.139	1.377± 0.0377	0.000133± 0.000009
6	U	20.25± 2.38	7.50± 0.081	12.47± 1.351	7.984± 0.864	0.653± 0.170	1.362± 0.015	0.045± 0.007
	L	19.47± 1.77	7.47± 0.095	12.25± 1.119	7.840± 0.716	0.672± 0.101	0.949± 0.036	0.00018± 0.000006
7	U	16.63± 2.29	6.47± 0.221	19.72± 5.695	12.624± 3.645	0.887± 0.164	4.404± 0.137	0.035± 0.002
	L	14.78± 3.65	6.77± 0.050	11.86± 2.736	7.592± 1.751	0.774± 0.097	1.605± 0.185	0.00024± 0.000005
8	U	17.90± 1.19	7.02± 0.330	30.47± 10.172	19.504± 6.510	0.799± 0.188	2.747± 0.281	0.022± 0.001
	L	18.56± 0.63	7.35± 0.310	13.42± 5.105	8.589± 3.267	0.814± 0.234	1.765± 0.217	0.00024± 0.000013
9	U	26.01± 0.98	7.37± 0.221	11.39± 1.965	7.288± 1.257	0.828± 0.191	2.854± 0.099	0.043± 0.0023
	L	24.11± 2.08	7.47± 0.150	10.62± 1.001	6.799± 0.640	0.843± 0.177	1.286± 0.257	0.000058± 0.000006
10	U	27.11± 1.19	7.45± 0.057	11.78± 2.454	7.550± 1.571	0.716± 0.073	1.438± 0.173	0.042± 0.001
	L	26.03± 1.39	7.55± 0.057	11.42± 2.193	7.308± 1.404	0.726± 0.134	1.817± 0.133	0.00015± 0.000024
11	U	30.98± 1.77	7.30± 0.081	14.50± 1.866	9.280± 1.194	0.741± 0.027	1.644± 0.242	0.044± 0.002
	L	31.94± 1.34	7.25± 0.057	15.21± 1.083	9.736± 0.693	0.736± 0.018	1.505± 0.002	0.00012± 0.000027
12	U	22.23± 3.122	7.45± 0.057	11.43± 2.252	7.313± 1.441	0.580± 0.135	1.506± 0.320	0.043± 0.002
	L	24.65± 1.900	7.37± 0.170	12.388± 0.980	7.928± 0.627	0.594± 0.116	3.066± 0.040	0.00012± 0.000014
13	U	25.25± 1.407	7.47± 0.095	12.04± 0.298	7.704± 0.190	0.3168± 0.018	2.137± 0.136	0.0402± 0.0045
	L	28.66± 0.538	7.52± 0.095	15.21± 0.243	9.736± 0.155	0.370± 0.015	1.379± 0.372	0.000178± 0.000015

are derived from hydrolysis of tannin in mangrove plants and breakdown of organic matter. Seawater has a strong buffering capacity which helps to neutralize acidic pH (Wakushima*et al* 1994).

Table-3: Descriptive statistics of physic-chemical properties of soil of overall Sundarban mangrove forests (StDev = Standard deviation, CoefVar = Coefficient of variance)

Variables	Mean ±StDev	CoefVar	Minimum	Median	Maximum
Moisture (%)	25.701 ±5.944	23.13	11.23	26.505	44.9
pH	7.3433 ±0.351	4.78	6.2	7.4	8.6
Conductivity (mS/cm)	12.172 ±5.342	43.89	3.22	11.55	37.9
Salinity (‰)	7.7900 ±3.419	43.89	2.061	7.392	24.256
OC (%)	0.833 ±0.264	31.81	0.292	0.780	1.540
N (%)	1.72 ±0.807	46.96	0.667	1.507	4.5670
P(%)	0.0220 ±0.023	108.94	0.000052	0.0109	0.0956

Mean of the soil conductivity of SMF was 12.172 mS/cm with minimum value 3.22 mS/cm and maximum 37.9 mS/cm (Table-3). Soil conductivity showed significant difference between upper and lower layer in location 7 (F = 6.2, P = 0.047), location 8 (F = 8.98, P = 0.024) and location 13 (F = 272.6, P = 0.000) (Table-4). Highly significance difference was present in case of soil conductivity among the locations (F = 15.52, P = 0.000) and layers (F = 9.23, P = 0.003) of SMF (Table-5). There was also a significant interaction present between location and layer (F = 6.6, P = 0.000) (Table-5). Conductivity maintained significant positive correlation with N (r = 0.444, p = 0.000), organic carbon (r = 0.230, p = 0.019) and significant negative correlation with moisture (r= -0.309, p = 0.001), pH (r = -0.508, p = 0.000) and P (r = 0.939, p = 0.008) (Table-6). The mean value of the soil electrical conductivity of Char Tamaruddin was 322.8 µS/cm, the minimum value was 275.0 µS/cm and maximum value was 410.0 µS/cm (Das 2012). High soil conductivity is due to the penetration of seawater during high tides, the evaporation of water and capillary rise of ground water during low tides, thus electrical conductivity in the top soil had a more complex spatial structure than that at a larger depth (Sylla*et al.* 1995). Ahmed *et al.* (2010) found 3-16 mS/cm soil electrical conductivity in different islands at Buragauranga river estuary, Rangabali, Patuakhali, Bangladesh as affected by different tidal regimes.

Table-4: Summary of analysis of variance (one way) of 13 locations of Sundarban mangrove forests

Var.	Location 1		Location 2		Location 3		Location 4		Location 5		Location 6		Location 7	
	F	P	F	P	F	P	F	P	F	P	F	P	F	P
Moist.	0.000	0.961	0.03	0.868	0.07	0.798	0.000	0.980	0.28	0.615	0.27	0.621	0.76	0.416
pH	0.600	0.468	1.17	0.320	0.14	0.725	0.24	0.643	0.05	0.823	0.16	0.705	6.97	0.039
Cond	0.01	0.932	1.06	0.343	0.13	0.733	0.09	0.776	3.59	0.107	0.07	0.806	6.20	0.047
Sal.	0.01	0.932	1.06	0.343	0.13	0.733	0.09	0.776	3.59	0.107	0.07	0.806	6.20	0.047
OC	0.000	0.957	0.01	0.927	0.02	0.894	0.07	0.798	0.06	0.816	0.04	0.851	1.39	0.283
N	42.70	0.001	311.5	0.000	12.20	0.013	35.35	0.001	0.28	0.618	446.97	0.000	587.2	0.000
P	530.1	0.000	6413	0.000	735.73	0.000	922.25	0.000	1505.6	0.000	163.11	0.000	1064.4	0.000

Var.	Location 8		Location 9		Location 10		Location 11		Location 12		Location 13	
	F	P	F	P	F	P	F	P	F	P	F	P
Moist.	0.73	0.425	2.72	0.150	1.46	0.272	0.83	0.397	1.75	0.234	20.52	0.004
pH	2.05	0.202	0.56	0.483	6.00	0.050	1.00	0.356	0.69	0.437	0.55	0.488
Cond.	8.98	0.024	0.48	0.514	0.50	0.826	0.44	0.533	0.610	0.464	272.6	0.000
Sal.	8.98	0.024	0.48	0.514	0.50	0.826	0.44	0.533	0.610	0.464	272.6	0.000
OC	0.01	0.926	0.01	0.914	0.02	0.903	0.09	0.780	0.03	0.875	19.11	0.005
N	30.48	0.001	129.3	0.000	11.99	0.013	1.32	0.295	93.16	0.000	14.60	0.009
P	803.2	0.000	1336	0.000	6892.1	0.000	996.72	0.000	1332.1	0.000	317.18	0.000

Mean of the soil salinity of SMF was 7.79 ‰ with minimum value 2.061 ‰ and maximum 24.256‰ (Table-3). Soil salinity showed significant difference between upper and lower layer in location 7 (F = 6.2, P = 0.047), location 8 (F = 8.98, P = 0.024) and location 13 (F = 272.6, P = 0.000) (Table-4). Highly significance difference was present in case of soil salinity among the locations (F = 15.52, P =0.000) and layers (F= 9.23, P =0.003) of SMF (Table-5).There was also a significant interaction present between location and layer (F = 6.6, P=0.000) (Table-5).Salinity maintained significant positive correlation with N (r = 0.444, p = 0.000), organic carbon (r= 0.230, p= 0.019) and significant negative correlation with moisture (r= -0.309, p= 0.001), pH (r= -0.508, p=0.000) and P (r= 0.939, p=0.008) (Table-6). The variability of the mangrove forest in terms of soil salinity is observed all over the world. In some forests the salinity values are obtained more than 30‰ (Sukardjo 1994, Moreno and Calderon 2011). However, the salinity value of 14.99‰ was also observed by Das *et al.* (2012). Mangrove vegetation is more luxuriant in lower salinities (Kathiresan *et al.* 1996) and experimental evidence indicates that at high salinity, mangroves spend more energy to maintain water balance and ion concentration rather than for primary production and growth. It is also evident that under high salinity levels mangrove biomass production and retention are adversely affected that influence vegetation in mangrove forest (Lin and Sternberg 1993, Suwa *et al.* 2009). Salinity of Char Tamaruddin was low which ranged from 1.0 - 2.0 ‰ and mean value was 1.33 ‰ (Das 2012). In other mangrove soils such as in the Northern Australian Mangrove Forest, salinity was found to be 30-50‰ (Boto and Wellington 1984). Soil salinity decreased with increasing distance from the tidal coast. Salinization leads to a partial or total loss of the productive capacity of a soil, because of degradation of its chemical and physical properties.

Table-5: Two way ANOVA showing the joint effects locations and layers on different variables of soil of Sundarban Mangrove Forests

Variables			**Variables**		
Moisture	F	P	**OC**	F	P
Loc	25.67	0.000	Loc	19.88	0.000
Lyr	0.120	0.733	Lyr	0.040	0.841
Interaction	0.580	0.849	Interaction	0.130	1.000
pH			**N**		
Loc	22.11	0.000	Loc	71.91	0.000
Lyr	0.780	0.379	Lyr	305.1	0.000
Interaction	1.140	0.340	Interaction	64.15	0.000
Conductivity			**P**		
Loc	15.52	0.000	Loc	55.97	0.000
Lyr	9.230	0.003	Lyr	7314	0.000
Interaction	6.600	0.000	Interaction	56.00	0.000
Salinity					
Loc	15.52	0.000			
Lyr	9.230	0.003			
Interaction	6.600	0.000			

Mean of the soil organic C of SMF was 0.832% with minimum value 0.292 % and maximum 1.54 % (Table-3). Soil organic C showed significant difference between upper and lower layer in location 13 ($F = 19.11$, $P = 0.005$) (Table-4). Highly significance difference was present in case of organic carbon among the locations of SMF ($F = 19.88$, $P = 0.000$) (Table-5). Organic carbon maintained significant positive correlation with moisture ($r = 0.242$, $p = 0.013$), P ($r = 0.914$, $p = 0.011$), conductivity ($r = 0.230$, $p = 0.019$) and salinity ($r= 0.230$, $p= 0.019$) (Table-6). In some mangrove forests above 10% organic carbon is reported (Sukardjo, 1994; Rambok *et al.*, 2010; Moreno and Calderon, 2011), reflecting the peaty nature of the soils. However, less than one

Table-6: Correlation of variables of soil samples collected from Sundarban mangrove (Moist.= moisture, Cond. = conductivity, Sal. = salinity)

forests Variables	Moist.	pH	Cond.	Sal.	OC	N	r/p values
pH	0.333						R
	0.001						P
Cond.	-0.309	-0.508					R
	0.001	0.000					P
Sal.	-0.309	-0.508	1.000				R
	0.001	0.000	1.000				P
OC	0.242	0.120	0.230	0.230			R
	0.013	0.227	0.019	0.019			P
N	-0.327	-0.444	0.444	0.444	-0.143		R
	0.001	0.000	0.000	0.000	0.147		P
P	0.375	0.780	-0.939	-0.939	0.914	-0.145	R
	0.008	0.028	0.008	0.008	0.011	0.012	P

percent organic carbon reported by Sah *et al.* (1989) indicated the poor nutritional conditions of the soils of some mangrove forests. Content of organic matter in Char Tamaruddin was very low where mean value was 0.80% with minimum 0.65% and maximum 1.02% (Das 2012). Ahmed *et al.* (2010) reported almost similar amount of organic matter (0.88 - 1.56%) from different offshore islands of Patuakhali, Bangladesh. Mean of the soil N of SMF was 1.719 % with minimum value 0.667 % and maximum 4.567% (Table-3). Soil N showed significant difference between upper and lower layer in location 1 ($F = 42.70$, $P = 0.001$), location 2 ($F = 311.52$, $P = 0.000$), location 3 ($F = 12.20$, $P = 0.013$), location 4 ($F = 35.35$, $P = 0.001$), location 6 ($F = 446.95$, $P = 0.000$), location 7 ($F = 587.19$, $P = 0.000$), location 8 ($F = 30.48$, $P = 0.001$), location 9 ($F = 129.31$, $P = 0.000$), location 10 ($F = 11.99$, $P = 0.013$), location 12 ($F = 93.16$, $P = 0.000$) and location 13 ($F = 14.6$, $P = 0.009$) (Table-4). Highly significance difference was present in case of soil N among the locations (($F= 71.91$, $P=0.000$) and layers (($F=305.1$, $P= 0.000$) of SMF (Table-5). There was also a significant interaction present between location and layer ($F= 64.15$, $P=0.000$) (Table-5). Soil N showed significant positive correlation with conductivity ($r = 0.444$, $p= 0.000$), salinity ($r = 0.444$, $p= 0.000$) and significant negative correlation with moisture ($r = -0.327$, $p= 0.001$), pH ($r = -0.444$, $p= 0.000$) and P ($r = -0.145$, $p= 0.012$) (Table-6). Tam and Wong (1998) found negative significant correlation of total N with pH and organic matter. Total Nitrogen of Char Tamaruddin varied from 0.056 - 0.13% where mean value was 0.078% (Das 2012).

The P content of the SMF soils showed high variations among locations (Coefficient of variation was 108.94, Table-3). Mean of the soil P of SMF was 0.022 % with minimum value 0.000052% and maximum 0.0956 % (Table-3). Soil P showed significant difference between upper and lower layer in location 1 (F = 530.1, P = 0.000), location 2 (F = 6413.33, P = 0.000), location 3 (F = 735.73, P = 0.000), location 4 (F = 922.25, P = 0.000), location 5 (F = 1505.65, P = 0.000), location 6 (F = 163.11, P = 0.000), location 7 (F = 1064.41, P = 0.000), location 8 (F = 803.28, P = 0.000), location 9 (F = 1336.52, P = 0.000), location 10 (F = 6892.16, P = 0.000), location 11 (F = 996.72, P = 0.000), location 12 (F = 1332.09, P = 0.000) and location 13 (F = 317.18, P = 0.000) (Table-4). Highly significance difference was present in case of soil P among the locations (F=55.97, P=0.000) and layers (F=73.14, P= 0.000) of SMF (Table-5). There was also a significant interaction present between location and layer (F=73.14, P=0.000) (Table-5). Soil P showed significant positive correlation with moisture (p= 0.008, r=0.375), pH (p= 0.028, r= 0.780), OC (p= 0.011, r= 0.914) and significant negative correlation with conductivity (p= 0.008, r= -0.939), salinity (p= 0.008, r= -0.939) and N (p= 0.12, r= -0.145) (Table-6). Rambok *et al.* (2010) reported the highest (25.27%) phosphorus in Sibuti mangrove, Sarawak, Malaysia. In mangrove soils, N was considered the primary nutrient that affects species composition and structure of forest, although more recent analysis found that N and P influence structure and composition in approximately equal proportions (Elser and Hamilton, 2007). Mean value of total P in Char Tamaruddin 0.05% with minimum value was 0.025% and maximum value was 0.056% (Das 2012). Almost similar results were found in different mangrove forest by other workers (Tam and Wong 1998, Boto and Wellington 1984). But Ahmed *et al.* (2010) reported about 10 times more P content (0.276 - 0.638%) in their studies in Bangladesh.

Sundarban mangrove forest areas have been divided into different ecological zones based on salinity (Nazrul-Islam 2003). Ranges of salinity differ from water habitats to soil habitats. Nazrul-Islam (2003) showed ecological zonations of SMF in case of water habitat, where location 1-6, 9 and 13 were shown as oligo-mesohaline zone, location 7, 8 as mesohaline zone and location 10,11 and 12 as polyhaline zone (Table-7). We have found and there by propose ecological zonations in soil habitats of SMF according to Iversen (1936) (Table-7). It has been found that location 1-6, 9, 10, 12 and 13 should be considered as mesohaline zone and location 7, 8 and 11 as mesohaline to polyhaline zone (values ranged in these two zones).

Table-7: Proposed ecological zonations (according to Iversen 1936) of 13 studied locations of Sundarban mangrove forests

Loc.	Name of the areas	Ecological zones (Nazrul-Islam 2003)	Ranges	Salinity (‰) range	Proposed ecological zones (Soil habitat)
1	Mrigamari (Sela river east bank)	Oligo-mesohaline	Chandpai	0.48-0.80	Mesohaline
2	Aandarmanik forest office	Oligo-mesohaline	Chandpai	0.48-0.70	Mesohaline
3	Tambulbunia forest office	Oligo-mesohaline	Chandpai	0.67-0.83	Mesohaline
4	Pathuria River west bank	Oligo-mesohaline	Chandpai	0.20-0.37	Mesohaline
5	Pathuria River east bank	Oligo-mesohaline	Sarankhola	0.51-0.78	Mesohaline
6	Supati forest office	Oligo-mesohaline	Sarankhola	0.67-0.88	Mesohaline
7	Katkajamtola	Mesohaline	Sarankhola	0.52-1.63	Mesohalineto Polyhaline
8	Katka forest office	Mesohaline	Sarankhola	0.37-2.42	Mesohalineto Polyhaline
9	Harbaria forest office	Oligo-mesohaline	Chandpai	0.56-0.86	Mesohaline
10	Burigoalini forest office (Opposite)	Polyhaline	Satkhira	0.54-0.91	Mesohaline
11	Kalagachia forest office	Polyhaline	Satkhira	0.80-1.08	Mesohalineto Polyhaline
12	Kobadak River wast bank	Polyhaline	Satkhira	0.61-0.93	Mesohaline
13	Kashitana forest office	Oligo-mesohaline	Khulna	0.74-0.98	Mesohaline

Principle component analysis (PCA) was carried out for soil variables of overall Sundarban mangrove forests and the result was shown in the Fig-1. PC-1 showed the positive loading of moisture, pH, P with negative loading of conductivity, salinity, OC and N. PC-2 showed positive loading of pH with negative loading of moisture, conductivity, salinity, OC, N and P. PC-3 showed positive loading of moisture, conductivity, salinity, N and P with negative loading of pH, OC. PCA also showed the cluster form between conductivity and salinity.

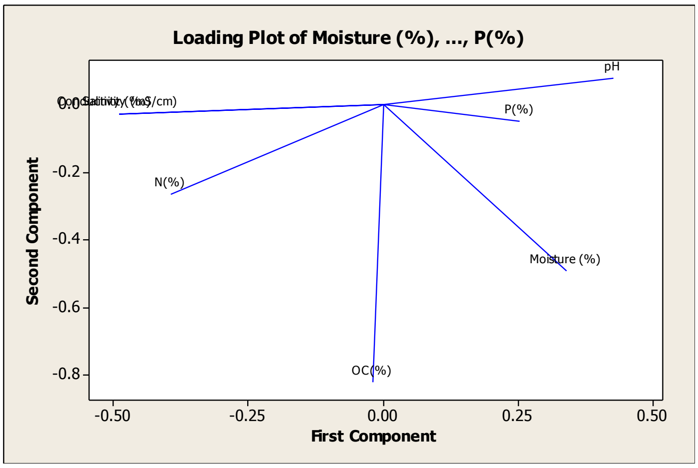

Fig.-1: PCA (Principle Component Analysis) of soil variables of overall Sundarban mangrove forests.

Variables	PC1	PC2	PC3
Moisture(%)	0.340	-0.493	0.013
pH	0.427	0.078	-0.293
Conductivity(mS/cm)	-0.491	-0.026	0.109
Salinity (‰)	-0.491	-0.026	0.109
OC(%)	-0.019	-0.822	-0.109
N(%)	-0.394	-0.267	0.031
P(%)	0.254	-0.050	0.937

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