



A STUDY ON SEASONAL VARIATIONS IN PHYSICO-CHEMICAL PROPERTIES OF SOIL AND WATER IN MANGROVE ECOSYSTEM OF PRAKASAM DIST. SOUTH COAST, INDIA

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A study was undertaken to determine seasonal variations in seventeen physico-chemical characteristics such as temperature, pH, salinity, dissolved oxygen, organic carbon etc, of soil and water of mangrove ecosystem of Prakasam district at the south coast of Andhra Pradesh during 2012. Besides, seasonal variation in air temperature and rainfall was also recorded. The three mangrove habitats of the district studied include Gundamala-Pathapadu, Etimaga and Gundayapalem. Statistical analysis of the data showed that all the variables except salinity, air temperature, magnesium and sulphur, are affected by seasons, whereas among the seventeen variables, only pH is affected by habitats. Correlation coefficient showed that there was poor correlation among most of the variables.

Key words: Ecosystem, Gundlakamma river, Mangroves, Physico-chemical properties, 2-way ANOVA

Mangroves are a unique, dynamic, evergreen and multi functional ecosystem comprising a specialized group of plants that occur along the intertidal zones of tropical and sub-tropical belts, inhabiting tidal creeks, estuaries, river banks, deltas and broad mud flats. They occur along the sea-land interface and are called tidal forests. Mangrove wetlands are subject to daily exchange between brackish and fresh water and frequent tidal inundation. They are a specialized ecological group adapted to high salinity, anaerobic soils and environmental stress through special morphological, anatomical and physiological features. Among other functions, mangroves act as a bio-shield against tidal waves and sequester carbon in the form of huge standing biomass with accumulation of peat (Spalding *et al.* 1997, Alongi 2002, Duke 1992, Naskar and Mandal 1999, Tomlinson 1986, Kathiresan and Qasim 2005).

While there are several reports on the effect of physico-chemical factors on the mangroves of the south-east coast of Tamil Nadu (Ashok Prabhu *et al.* 2008, Das *et al.* 1997, Govindaswamy *et al.* 2000, Srilatha *et al.* 2013, Vijayakumar *et al.* 2000) there very few such studies on the coastal A.P. (Sai Sastry and Chandramohan 1990.) For the first time

mangroves of Prakasam district were studied in detail (Swain and Rama Rao 2008), but there was no reference to the seasonal variation on physico-chemical factors on the mangrove flora in their study. As there are no reports on the seasonal variations on physico-chemical parameters on the mangrove habitats of south coast of Andhra Pradesh, the present study is undertaken.

MATERIALS AND METHODS

Study Area

The present study was undertaken during 2011-2012. Prakasam district in Andhra Pradesh is a southern district to the north of Nellore district with a coastline of 120 km. The Buckingham canal, a brackish water body situated 1- 2.5 km away runs parallel to the coast of Bay of Bengal. The district is located at 14° 57' 00" -16° 17' 00" N latitude and 78° 43' 00" -80° 25' 00" E longitude. The climate of the district is tropical humid. Gundlakamma is the only major river in the district. Maneru, Paleru and Musi rivers and the Romperu drain are the east-flowing smaller streams carrying surplus flood waters and nutrients and supporting the mangroves. There are mangrove habitats at the estuaries of these rivers and rivulets. The present study was undertaken at three

mangrove habitats of Prakasam district, namely Pathapadu- Gundamala habitat ($15^{\circ} 29' 42''$ – $15^{\circ} 31' 05''$ N and $80^{\circ} 11' 24''$ – $80^{\circ} 12' 18''$ E) sustained by Musi–Paleru rivers , Etimoga habitat of Pallepalem–Pedaganjam ($15^{\circ} 39' 32''$ - $15^{\circ} 41' 06''$ N and $80^{\circ} 14' 30''$ - $80^{\circ} 16' 14''$ E) sustained by Romperu drain and the Gundayapalem habitat ($15^{\circ} 32' 01''$ - $15^{\circ} 32' 10''$ N and $80^{\circ} 12' 56''$ - $80^{\circ} 13' 20''$ E) sustained by the Gundlakamma river.

Soil and water samples from the study site were collected and analyzed for determining the parameters like , pH, Electrical Conductivity (EC), Salinity, Organic Carbon (OC) and Dissolved Oxygen (DO). Air temperature and surface water temperature were also measured. Sampling and analyses were carried out during summer (April- June), South-west monsoon (July-Sept), North-east monsoon (Oct-Dec) and Post-monsoon (Jan- Mar) periods during the year 2012. Samples were collected with the help of soil corer from a depth of 15 cm. Sample size depended on the extent of the mangrove habitat. Accordingly, 10 soil samples were collected at Gundamala-Pathapadu, 8 at Etimoga and 6 at Gundayapalem. Sampling was consistently done at exactly the same spots during the four seasons. Soil samples were collected in sterile plastic bags, labeled, brought to laboratory and shade-dried to remove moisture and were again

Walkley and Black (1934), Dissolved Oxygen: Parsons *etal.* (1989), Available Nitrogen: Subbaiah and Asija (1956), Phosphorus: Olsen *etal.* (1954), Potassium Toth and Prince (1949), Calcium and Magnesium: Cheng and Bray (1951), Sulphur: Pandey and Girish (2007) and the micronutrients, Zn., Fe, Cu and Mn, as per Lindsay and Norvell (1978). Data on year-wise temperature and rainfall from year 2000 was obtained from District Information Office, Ongole and Meteorological Centre, Hyderabad, respectively.

RESULTS AND DISCUSSION

In Prakasam district the rainfall is slightly higher during south-east monsoon than the north-east monsoon; the yearly annual rainfall is 871 mm. The rainfall data during 2001 to 2012 for Prakasam district is shown in Table 1.

Rainfall is an important feature in mangrove habitats as the run-off water transports nutrients, decreases salinity and influences pH for the benefit of mangroves. The rainfall ranged from 542 to 1157 mm over the past 11 years (Table 1). However, normal annual rainfall in Prakasam district (871 mm) is quite inadequate for robust growth of mangroves. But, distribution of rainfall between south-west and north-east monsoon is of some benefit. Rainfall is the most significant cyclic phenomenon in tropical countries as it brings

Table 1: Annual rainfall for Prakasam district during 2001 to 2012*

Year	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Rainfall (mm)	725	542	759	550	1010	709	1021	763	767	1157	602

*Normal annual rainfall for Prakasam district: 871 mm

duly labelled. The fully dried samples were ground and passed through a 2 mm steel sieve and labelled. The pH and electrical conductivity were measured with Elico Digital pH meter and Digital Conductivity meter, respectively. Salinity was measured with the help of Atachi (Japan) hand refractometer, The protocol followed in respect of the other parameters is as follows: Organic Carbon:

important cyclic changes in hydrographical properties of marine and estuarine environment (Ashok Prabhu et al. 2008). The temperature data for the corresponding period in Prakasam district is shown in Table 2.

The maximum temperature range (36°C - 43°C) during May and the minimum temperature (19.4°C - 20.7°C) during December-January over the last 12 years (Table 2) is a pointer to the

Table 2: Maximum and minimum temperature for Ongole from 2000 to 2012 *

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Max temp (0 ⁰)	41.5	40.5	41.5	36	39.5	38	41	42.5	39.5	39	40.1	43
Min temp (0 ⁰)	20	19.7	19.4	19.3	21.1	19.8	19.4	19.6	19.3	20.7	20.1	19.8

*Normal max. temp: 39.2⁰C, Normal min. temp: 20.1⁰C

humid, tropical nature of the region. The air and surface water temperature at the mangrove habitats was high (Table 3). Generally, surface water temperature is influenced by solar radiation, evaporation, fresh water influx and cooling and mix up with ebb and flow from adjoining neritic waters. The effect of seasonal variations on physico- chemical parameters on mangrove habitats is shown in Table 3.

1. pH: The pH at Gundamala - Pathapadu was maximum (8.9) during north-east monsoon and post -monsoon and minimum (6.5) during summer. At Etimoga, it was maximum (8.31) during north-east monsoon and minimum (6.3) during summer. At Gundayapalem it was maximum (8.31) during post-monsoon and minimum (6.3) during summer.

Except during summer, the pH remained alkaline at all three habitats. Alkaline pH is a characteristic feature of marine environment and this is due to presence of sufficient quantities of carbonate (Trivedi and Goel 1984). The increase in pH during monsoon could be attributed to the uptake of CO₂ by phytoplankton for their photosynthetic activity. High pH values observed during monsoon may be attributed to fresh water influx, dilution of sea water, low temperature and organic matter decomposition as suggested by Ganesan (1992). The pH trends observed in the present study are in agreement with earlier reports from southeast coast (Manikannan *et al.* 2011, Palanichamy and Rajendran 2000, Ashok Prabhu *et al.* 2008, Damotharan *et al.* 2010 and Sundaramanickam *et al.* 2008)

2. Electrical Conductivity: E.C.(μS/ cm) At Gundamala-Pathapadu it was maximum (9200) during south-west monsoon and

minimum (1100) during summer .At Etimoga it was maximum (4840) during south-west and north-east monsoons and minimum (1300) during summer. At Gundayapalem, EC was maximum (5210) during north-east monsoon and minimum (700) during summer. In the present study EC was consistently lower during summer than the other three seasons at all three habitats. Generally, EC is expected to be lower during monsoon due to rain water mix up, decline in rate of evaporation and temperature. Results obtained here are at variance with earlier studies. (Manikannan *et al.* 2011, Ramanathan *et al.* 1999)

3. Salinity (ppt): At Gundamala-Pathapadu, salinity was maximum (31) during summer and post-monsoon and minimum (24) during south-west monsoon. At Etimoga it was maximum (34) during summer and minimum (15) during north-east monsoon. At Gundayapalem it was maximum (33) in post-monsoon and minimum (24) in north-east monsoon.

4. Air Temperature (°C): At Gundamala-Pathapadu it was maximum (32.5) during summer and minimum (31) during post-monsoon. At Etimoga it was maximum (32) during summer and post-monsoon and minimum (31) during south-west monsoon. At Gundayapalem it was maximum (33) in summer and south-west monsoon, and minimum (32) during north-east monsoon.

5. Surface Water Temperature (°C): At Gundamala - Pathapadu it was maximum (31.5) during summer and minimum (28.5) during post-monsoon. At Etimoga it was maximum (31) during summer and minimum (28.5) during north-east monsoon. At Gundayapalem the maximum (30) was during summer and the

Table 3. Seasonal variations in the physico-chemical parameters on the mangrove habitats of Prakasam district

Habitats	Seasons	Variable	pH	EC	Salinity	Airtemp	S.W.temp	D.O	O.C	Avl. N	P	K	Ca	Mg	S	Zn	Fe	Cu	Mn
Gundamala- Pathipadu (n= 10)	Summer	Range	6.0-7.0	600-1500	22-37	32-35	31-33	3.2-4.2	0.32-0.63	20-38	2.0-4.4	44-103	200-1900	800-4000	1800-3500	0-0.848	66.02-90.3	1.604-4.088	20.70-25.82
		Avg	6.5	1100	31	32.5	31.5	3.4	0.45	29.7	3.16	82.8	740	1820	3040	0.277	65.83	2.13	24.18
	S.W.Monsoon	Range	6.77-7.84	5030-13400	20-28	30-32	29-30	4.8-5.9	0.45-1.35	35.56-101.6	12.8-31.2	277.50-475.0	600-1800	1000-2500	2400-3900	1.504-22.66	11.22-32.10	1.944-5.348	4.684-23.06
		Avg	7.47	9200	24	31	29.5	5.1	0.98	69.21	21.9	399	1200	1900	3250	10.91	19.29	4.621	16.95
	N.E.Monsoon	Range	7.45-8.51	3100-3800	25-30	31-32	28-30	5.4-5.8	0.54-1.45	45.72-106.68	15.2-33.0	177.5-412.5	1000-2700	1500-4000	1890-3450	0.638-1.416	45.82-69.7	2.03-6.792	22.26-39.24
		Avg	8.09	3300	27	31.5	29.5	5.5	0.95	78.23	23.14	301.50	1730	3250	2730	1.085	57.64	4.191	37.20
	Post-Monsoon	Range	7.63-8.33	2500-3500	28-32	31-33	28-30	4.6-5.3	0.45-1.3	35.56-111.76	18.4-42.4	277.5-457.5	600-2900	1600-3400	1960-3080	2.99-3.56	19.04-38.8	2.09-15.91	25.3-46.5
		Avg	8.09	3100	31	31	28.5	4.8	0.54	74.49	31.12	388	1800	2400	2530	3.214	24.43	8.3	29.87
	Erimogga (n=8)	Summer	Range	6.0-7.0	800-1700	15-35	31-33	2.5-3.4	0.3-0.9	32-60	2.0-7.0	72-126	300-900	1200-2900	2500-4800	0-0.588	21.52-48.5	0.418-2.462	12.29-22.64
			Avg	6.32	1300	34	32	31	3.1	0.49	38.75	4.8	94.6	600	2030	3230	0.145	33.36	1.15
S.W.Monsoon		Range	7.34-7.78	3400-7100	28-30	30-32	28-29	5.3-6.8	0.6-1.2	25-96.2	12.0-36.0	325-440	800-3400	1000-3000	1800-3400	1.324-6.344	13.31-25.46	1.554-5.844	10.08-21.48
		Avg	7.52	4840	30	31	29	5.9	0.75	61.68	25.7	384	1700	2350	2400	3.99	19.40	3.943	17.04
N.E.Monsoon	Range	8.10-8.67	2050-7750	5-20	32-36	28-29	5.5-5.9	0.5-1.1	60.9-106.68	15.2-37.6	197.5-412.5	500-2300	2300-3600	2750-3530	0.638-1.902	1.654-51.68	0.082-8.438	9.59-38.46	
	Avg	8.4	4840	15	32.5	28.5	5.8	0.68	83.18	23.9	296.56	1560	2950	3250	0.895	29.14	5.06	31.48	
Post-Monsoon	Range	7.94-8.23	2790-6600	26-35	29-34	27-30	3.92-6.8	0.4-1.0	55.8-106.68	26.4-75.2	417.5-542.5	1300-2600	2700-5400	2520-3920	0.15-3.08	19.78-31.10	0.182-20.10	6.95-41.28	
	Avg	8.04	3500	32	32	29	4.3	0.53	85.69	37.96	479.5	2300	3200	3200	1.360	25.91	12.47	29.57	
Summer	Range	6.0-6.5	500-1600	30-34	32-34	30-30.5	2.9-3.8	0.5-0.8	36-50	2.2-3.2	53-126	300-1200	2000-3600	2100-2800	0-0.084	24.26-44.28	0.242-2.308	15.21-24.34	
	Avg	6.3	700	32	33	30	3.2	0.65	40	2.66	87.6	620	2600	2470	0.014	33.66	1.14	18.80	
S.W.Monsoon	Range	7.65-8.24	4090-5760	30-35	32-34	28-30	4.8-5.3	0.7-1.4	15.24-96.52	14.4-41.6	305-395	1600-3000	3300-4000	2400-3400	16.21-20.4	10.97-17.49	2.51-57.74	10.51-19.39	
	Avg	7.59	5000	32	33	28.5	4.9	0.8	47.4	27.33	347	2250	3600	3000	17.84	14.34	4.219	16.65	
N.E.Monsoon	Range	7.98-8.36	3100-6780	23-25	30-37	25-28	4.9-5.1	0.6-1.2	50.8-96.5	13.6-35.2	217.5-427.5	900-2000	1700-3100	1870-3500	0.966-1.822	7.946-72.38	2.16-16.32	38.02-39.12	
	Avg	8.3	5210	24	32	28	5	0.72	70.26	20.87	329.17	1430	2450	2680	1.286	37.90	6.53	38.52	
Post-Monsoon	Range	8.08-8.64	1820-3680	30-36	32-33	27-29	3.8-4.7	0.45-1.1	45.7-96.5	11.2-34.4	330-407.5	1300-2700	2700-3500	2520-3360	3.09-3.43	25.78-28.72	6.546-12.45	15.55-35.04	
	Avg	8.31	3200	33	32.5	29	4.2	0.58	73.15	19.6	367.92	2560	3000	2800	3.192	27.24	9.92	25.82	

*Temperature :⁰C; Salinity : ppt ; EC : μ S/cm; D.O: mg/l ; O.C : %; All other nutrients : μ g/g

minimum (28) was during north-east monsoon.

Temperature regulates the rate of photosynthesis in aquatic ecosystems. Higher values of air temperature during summer and lower values during monsoon observed during this study confirmed the established trends along the southeast coast and is in conformity with earlier studies (Manikannan *et al.* 2011, Rajendran and Kathiresan 1999; Saravanan 1999; Rajasekar 1998). Surface water temperature largely depends upon solar radiation, evaporation, fresh water influx, cooling and mixing due to water currents and tidal flow.

6. Dissolved Oxygen D.O.(mg/L): At Gundamala-Pathapadu, D.O content was maximum(5.5) during north-east monsoon and minimum (3.4) during summer. At Etimoga it was maximum (5.9) during south-west monsoon and minimum (3.1) in summer. At Gundayapalem, D.O. was maximum (5.0) during north-east monsoon and minimum (3.2) during summer.

7. Organic Carbon: O.C. (%) At Gundamala-Pathapadu, O.C content was maximum (0.98) during south-west monsoon and minimum (0.45) during summer. At Etimoga it was maximum (0.75) during south-west monsoon and minimum (0.49) during summer. At Gundayapalem O.C. was maximum (0.8) during south-west monsoon and minimum (0.58) during post-monsoon.

8. Available Nitrogen: N ($\mu\text{g/g}$): At Gundamala-Pathapadu, available nitrogen content was maximum (78.23) during north-east monsoon and minimum (29.7) during summer. At Etimoga it was maximum (85.69) during post-monsoon and minimum (38.75) during summer. At Gundayapalem it was maximum (73.15) during post-monsoon and minimum (40) during summer.

9. Phosphorus: P ($\mu\text{g/g}$) P content was maximum (31.12) at Gundamala-Pathapadu during post-monsoon and minimum (3.16) during summer. It was maximum (37.96) at Etimoga during post- monsoon and minimum

(4.8) during summer. At Gundayapalem it was maximum (27.33) during south-west monsoon and minimum (2.66) during summer.

10. Potassium: K ($\mu\text{g/g}$): Potassium content was maximum (399) at Gundamala-Pathapadu during south-west monsoon and minimum (82.8) during summer. At Etimoga K was maximum (479.5) during post-monsoon and minimum (94.6) during summer. At Gundayapalem it was maximum (367.92) during post-monsoon and minimum (87.6) during summer.

11. Calcium: Ca ($\mu\text{g/g}$): At Gundamala-Pathapadu Calcium content was maximum (1800) during post-monsoon and minimum (740) during summer. At Etimoga it was maximum (2300) during post-monsoon and minimum (600) during summer. At Gundayapalem Ca was maximum (2560) during post-monsoon and minimum (620) during summer.

12. Magnesium: Mg ($\mu\text{g/g}$): Magnesium content was maximum (3250) at Gundamala-Pathapadu during north-east monsoon and minimum (1820) during summer. At Etimoga it was maximum (3200) during post-monsoon and minimum (2030) during summer. At Gundayapalem, Mg was maximum (3600) during south-west monsoon and minimum (2450) during north-east monsoon

13. Sulphur: S ($\mu\text{g/g}$): At Gundamala-Pathapadu Sulphur content was maximum (3250) during south-west monsoon and minimum(2530) during post-monsoon At Etimoga it was maximum (3250) during north-east monsoon and minimum (2400) during south-west monsoon. At Gundayapalem S was maximum (3000) during south-west monsoon and minimum(2470) during summer.

14. Zinc: Zn($\mu\text{g/g}$): At Gundayapalem - Pathapadu Zn content was maximum (10.91) during south-west monsoon and minimum (0.848) during summer. At Etimoga it was maximum (3.99) during south-west monsoon and minimum (0.145) during summer. At Gundayapalem Zn was maximum (17.84)

Table 4. ANOVA of effects of physico-chemical variables in seasons and mangrove habitats

Variables	SOURCE OF VARIATION					
	Among Seasons			Among Habitats		
	SS	MSS	F	SS	MSS	F
pH	4.67	1.55	24.3*	0.89	0.44	6.95*
E.C	9.16	14995097	6.85*	1433717	716858	3.05
Salinity	206.92	68.97	3.93*	14	7	2.51
Air temp	1.51	0.5	1.61	2.62	1.31	4.22
S.temp	9.16	3.05	12.19*	1.54	0.77	3.18
D.O.	9.24	3.08	27.37*	0.46	0.23	2.07
O.C.	0.23	0.07	6.84*	0.02	0.01	1.25
Avl. N.	3641.44	1213.81	24.04*	185.51	92.79	1.83
P	1181.79	393.93	17.97*	63.67	31.83	1.45
K	189641.55	63213.85	52.48*	1969.95	984.97	1.22
Ca	3842700	1280900	11.55*	241525	60381	1.84
Mg	1052292	350764	1.1	649867	324933	1.02
S	7500	2500	64.08*	159817	79908	2
Zn	218.16	72.72	6.58*	31.97	15.98	1.44
Fe	1453.96	484.64	4.98	559.65	279.82	2.87
Cu	120.08	40.03	21.92*	1.55	0.77	2.34
Mn	634.31	211.63	32.45*	20.37	10.18	1.56

*Statistically significant at 5% level

[d.f: degrees of freedom, SS: Sum of Squares, MSS: Mean of Sum of Squares (SS/d.f.) F: MS Group/MS within group]

Table 5: Effect of coefficient of correlation among the physico-chemical parameters

	pH	E.C.	Salinity	Air temp	S.W.temp	D.O	O.C.	Avl.N	P	K	Ca	Mg	S	Zn	Fe	Cu	Mn
pH	1.0000																
E.C.	-0.7123	1.0000															
Salinity	-0.3369	0.3889	1.0000														
Air temp	0.3429	0.2237	0.1320	1.0000													
S.W. temp	-0.2795	0.5987	0.2954	0.4733	1.0000												
D.O.	-0.0913	-0.2468	0.5142	-0.3312	-0.3590	1.0000											
O.C	-0.0587	-0.1780	0.0746	-0.3734	-0.4242	0.3088	1.0000										
Avl.N.	0.5281	-0.3421	0.4764	0.4331	-0.1687	0.4784	0.2946	1.0000									
pH	-0.1760	0.3717	-0.1940	-0.0078	0.3314	-0.7116	-0.0051	-0.4566	1.0000								
K	-0.4607	0.4364	0.4081	-0.3550	0.3214	-0.0952	-0.2550	-0.4127	0.5274	1.0000							
Ca	-0.2041	-0.2233	0.1430	-0.6377	-0.5522	0.7834	0.0664	-0.0315	-0.4827	0.1400	1.0000						
Mg	-0.5124	0.3135	0.2398	-0.5727	-0.2009	0.5780	0.0897	-0.2551	-0.1887	0.3520	0.8065	1.0000					
S	0.1890	0.1901	-0.0923	0.4855	0.1030	-0.1063	0.0639	0.1594	-0.3354	-0.5443	-0.3179	-0.1293	1.0000				
Zn	-0.6058	0.4462	0.8454	-0.1112	0.3061	0.3365	-0.1223	0.0510	-0.1266	0.5944	0.1818	0.2552	-0.2697	1.0000			
Fe	-0.5012	0.5945	0.5820	0.3931	0.6278	0.0157	-0.5115	-0.0814	-0.1579	0.2958	-0.1383	0.0035	0.1823	0.7285	1.0000		
Cu	0.4496	-0.6043	-0.8109	-0.3521	-0.5854	-0.1525	0.1532	-0.2163	-0.1944	-0.2652	0.2100	-0.0094	-0.2257	-0.8194	-0.8561	1.0000	
Mn	0.1153	-0.0076	-0.3528	0.2163	0.4324	-0.3130	-0.4000	-0.2487	0.4506	0.0776	-0.1699	-0.1338	-0.3355	-0.3993	-0.1139	0.3770	1.0000

during south-west monsoon and minimum (0.014) during summer.

15. Iron: Fe ($\mu\text{g/g}$) At Gundamala-Pathapadu, Iron content was maximum(65.83) during summer and minimum(19.29) during south-west monsoon. At Etimoga it was

maximum(33.36) during summer and minimum(19.40) during south-west monsoon.

At Gundayapalem it was maximum (37.90) during north-east monsoon and minimum(14.34) during south-west monsoon.

16. Copper: Cu ($\mu\text{g/g}$): At Gundamala-

Pathapadu Copper content was maximum (8.30) during post-monsoon and minimum (2.13) during summer. At Etimoga, it was maximum (12.47) during post-monsoon and minimum (1.15) during summer. At Gundayapalem Cu content was maximum (9.92) during post-monsoon and minimum (1.14) during summer.

17. Manganese: Mn($\mu\text{g/g}$): At Gundamala-Pathapadu Manganese content was maximum (37.20) during north-east monsoon and minimum (16.95) during south-west monsoon. At Etimoga its content was maximum (31.48) during north-east monsoon and minimum (17.04) during south-west monsoon. At Gundayapalem its content was maximum (38.52) during north-east monsoon and minimum (16.65) during south-west monsoon.

Considering all the macro- and micronutrients together a pattern is apparent. Organic carbon, available nitrogen, phosphorus, calcium and magnesium levels were higher during monsoon and post-monsoon while sulphur levels were slightly higher during summer. As for the micronutrients, copper and zinc were higher during monsoon while iron was consistently higher during summer over the other three seasons, manganese levels were an exception to the above trend; it was lower during south-west monsoon than the other three seasons.

Islam et al. (2004) reported higher levels of organic matter, calcium, total nitrogen, phosphorus, copper and iron during monsoon, but levels of magnesium, potassium, sulphur, and zinc and manganese were higher during summer in mangrove soils of Sundarbans. In a study on the decomposition and seasonal changes in nutrient constituents in mangrove litter of Sundarban mangroves, Enamul Hoq *et al.* (2002) found that mixed mangrove litter contained higher levels of N, P, K, Cu and Zn during monsoon while Ca, Mg and Na levels were higher during pre-monsoon. In their study, Srilatha *et al.* (2013) reported higher levels of total phosphorus, total nitrogen, ammonia and nitrite during monsoon at

Muthupettai mangrove region.

From Table 4 it is apparent that the mean levels of all the seventeen variables except salinity, air temperature, Mg and Fe are affected by seasons in a statistically significant way. In contrast, in the case of habitats, it is seen that the mean levels of all the variables except pH are not affected by habitats, in a statistically significant way. In other words, all the variables except salinity, air temperature, Mg and S are affected by seasons, whereas among the seventeen variables, only pH is affected by habitats.

From Table 5, we may conclude that there very high positive correlation ($r > 0.75 < 1$) between the pairs of parameters: Salinity- Zinc (0.8454), Calcium- Magnesium (0.8065) and DO-Calcium (0.7834), high positive Correlation ($r > 0.6 < 0.75$) between: Surface Water Temperature – Iron (0.6278) and almost so between Surface Water Temperature - E.C (0.5987), E.C – Iron (0.5945) and Potassium-Zinc (0.5844).

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