Asian Journal of Water, Environment and Pollution, Vol. 13, No. 2 (2016), pp. 83–95.
DOI 10.3233/AJW-160019

Spatio-temporal Variability in Soil Macronutrients and Their Relation with Other Soil Properties in a Man-made Wetland of India

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Received October 4, 2015; revised and accepted March 22, 2016

Abstract: Present study was carried out to analyze the nutrient status within the surface soils of Bhindawas wetland, a bird and waterfowl paradise, on a temporal scale. Soil organic carbon (%SOC) and total nitrogen (%TN) in the soil varied from 0.079% -2.94% and 0.014%-0.021% respectively. Total phosphorus (%TP) and total potassium (TK) ranged from 0.067 mg/g and 1.16 mg/g to 1.34 mg/g and 4.6 mg/g. C:N ratio showed a large variation from 16.57 to 798.57 along with C:P from 1.68 to 398.5. C:K and N:P showed narrow variation from 0.41% to 19.7% and from 0.03% to 3.13%. Soil parameters like SOC and TN peaked during May whereas TP and TK were higher during or after rains highlighting the impact of hydroperiod on nutrient distribution. Many of the parameters showed significant variations during months. Significant correlations were observed between SOC, TN and TP ensuring that these nutrients had a common origin and were influenced by other physico-chemical properties i.e. pH and bulk density. Analysis revealed that the wetland had both autochthonous and allochthonous inputs that impact nutrient distribution within the wetland. Principal component analysis was used to analyze and amalgamate the temporal variations within the soil nutrients and other parameters. Three principal components were extracted explaining 78.32% of the total variation. Principal components could be characterized as 'limiting nutrients like TN and TP', 'organic carbon and its ratios' and 'potassium'. Higher levels of SOC within the wetland soil emphasize its potential as a carbon sink. Carbon sequestration potential of this wetland further accentuates the need for better conservation and management of the wetland.

Key words: Soil nutrients, soil organic carbon, nitrogen, phosphorus, Bhindawas Bird Sanctuary, principal component analysis.

Introduction

Wetlands, particularly lakes with their clear-cut boundaries, represent one of the most versatile eco-systems on the earth (Chakrapani, 2002). Since the beginning of scientific studies on wetlands, soils have been recognized as an important feature of wetlands (Tiner, 1999). Wetland soils, often described as 'hydric soils', are both the medium in which many of the wetland chemical transformations take place and are the primary storage of available chemicals for most wetland plants. Estimation of nutrients in soil, a complex heterogeneous system has pedological as well as ecological significance (Chandra et al., 2012).

It is a well-known fact that even though wetlands account for only 4-6% of the Earth's land surface (~530-570 Mha) (Matthews and Fung, 1987; Aselmann and Crutzen, 1989), wetland soils, store 350-535 Gt of

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carbon corresponding to ~20-25% of the total carbon stock (Gorham, 1991; Lal, 2004; IPCC, 2007; Zhang et al., 2008). Along with SOC, it is also necessary to know the status of major and micro nutrients within the soil that help in maintaining the wetland health and productivity. A close synchronization exists between macro nutrients and their cycling within the wetland soils.

The cycling of the nutrients within the wetland ecosystems is controlled by a number of biotic and abiotic factors. Biotic factors include wetlands plants, their productivity and biomass that forms a major input of soil nutrients in the form of organic matter. Abiotic factors, such as parent material, temperature, pH, soil moisture content, hydrological conditions, and oxygen availability also impact the nutrient cycling by altering the microbial activity, organic matter accumulation and decomposition rate. Soil organic carbon and total nitrogen are not only the important components of wetland soils but also the ecological factors of wetland ecosystem that greatly influence the productivity of wetland ecosystem (Mitsch and Gosselink, 2000).

Soil nutrient status affects the distribution (Pan et al., 1998), productivity (Mon et al., 1995), and diversity (Anderson et al., 2004) of plant communities at a larger scale whereas on smaller scale, it impacts plant establishment (Maestre et al., 2003) and the plant interactions (Robinson et al., 1999). Therefore, in-depth understanding of the nutrient concentration and the influencing parameters on a spatio-temporal scale is of prime importance so as to maintain the ecological functioning and values of the wetland ecosystem. Distribution of nutrients in soils is influenced by a number of factors comprising parent material, topography, soil management practices, biota, climate and precipitation. Understanding spatial changes in soil nutrients is important as they may differ markedly among identical locations subjected to natural and man-made disturbances.

Several studies have been carried out to study the nutrient content in the wetland soils and sediments. Anila Kumary (2001) studied the sediment characteristics of Poonthura estuary to understand the seasonal variations in soil organic carbon content along with its probable source. Mattew et al. (2002) addressed the effect of industrial pollution on the sediment quality of urban wetlands in Coimbatore. Prusty et al. (2010) on the other hand, evaluated the distribution of macronutrients along the sediment profile in Keoladeo National Park and Sumesh et al. (2014) assessed the sediments of Ashtmundi estuary for identification of probable environmental pollution sources.

The present investigation was carried out to analyze the soil nutrient status of Bhindawas wetland, an important natural resource of India relishing protected status since 1986. It serves as an important breeding, feeding and wintering site for significant members of bird flora. The objectives of the study were: (i) to determine the spatial and temporal variations of various macronutrients in the wetland soil; (ii) to understand the relationship among physicochemical parameters and nutrient concentration within the soil; and iii) to identify the parameters that are responsible for temporal variations within the wetland soil.

Materials and Methods

Study Area

Present study has been carried out in and around the Bhindawas wildlife sanctuary, a man-made wetland designated as eco-sensitive zone by the Ministry of Environment, Forests & Climate change, Govt. of India (The Gazette of India, 2011). It is the largest wetland in state of Haryana spread over 412 ha, with a periphery of 12 km (28°28′00″ to 28°36′00″N; 76°28′00″ to 76°38′00″E, Figure 1). An area of 513 ha was declared a sanctuary in the year 1986 for the protection of waterfowl. 'Bhindawas wildlife sanctuary' is regarded as the Keoladeo National Park of Haryana (Gupta et al., 2011). The sanctuary is located in Jhajjar district about 80 km west of Delhi. Due to the water crisis at Bharatpur Bird Sanctuary over the past few years, Bhindawas has grown importance as an alternative site for a number of migratory birds. Migratory birds belonging to over 250 species visit Bhindawas Bird Sanctuary throughout the year. It is a bird and waterfowl paradise of Haryana.

The wetland is fed by nearby Jawaharlal Nehru canal escape waters. The maximum depth of water in the sanctuary is approximately 8-10 feet (Gupta et al., 2011). Originally a small depression, it was acquired by irrigation department to store water coming from JLN escape. About 6 km away from this depression, JLN canal passes by taking water from Bhakra canal system to the drier areas of Haryana. There is a lift irrigation system on JLN canal in Akeri village where JLN canal water is lifted upto the network of canals in the upland drier parts of Haryana. Whenever there is a power failure in this lift irrigation system, the incoming water flows through JLN escape through which water flows into the lake by default.

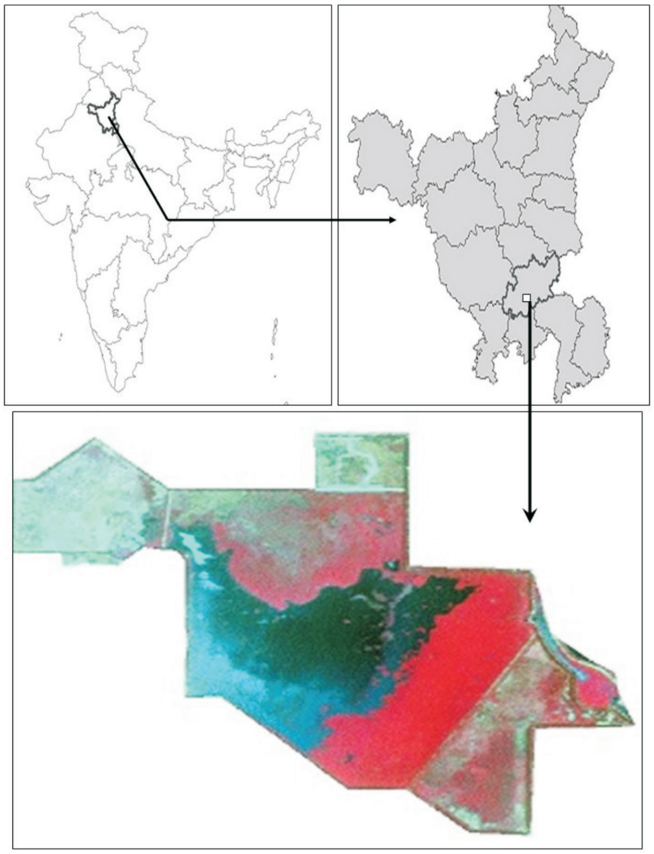

Figure 1: Study area map (Bhindawas Bird Sanctuary, Haryana, India).

The climate of the Jhajjar district can be described as tropical steppe, semi-arid and hot which is characterized by extreme dryness of the air except during monsoon months, intensely hot summers and cold winters. The area experiences climate extremes from hot summer (March-June) to cold winters (January-March) with short monsoon period (June-September) and post-monsoon (October-December). The minimum and maximum temperature recorded is 7°C (January) and 43°C (May and June) respectively. Annual rainfall received is 441 mm (Department of Agriculture, Haryana).

The study area lies in the Indo-Ganga alluvial plain. The soils of the district are fine to medium textured comprising sand to sandy loam in north eastern part covering Bahadurgarh and Jhajjar blocks. Soil contains massive beds of pale reddish brown coloured clay in the southern eastern parts of the area.

Field Sampling and Analysis

Surface soil samples were collected during May, September and December from the wetland system for the year 2014 using a core sampler (4 × 25cm^2) at randomly selected sites accounting for the structural variability within the wetland system. The sampler was inserted into the soil upto 20 cm after removing any dead plant litter from the surface. Three soil cores from each site were composited to one sample with a total of seven samples being collected for each month. The samples were placed in polythene bags, kept on ice in the field and stored at 4°C in the laboratory until further processing and analysis. Half of the sample was air-dried at room temperature for analyses of SOC, total nitrogen, pH, total phosphorus and other half was utilized for analysis of moisture content, bulk density and potassium. The samples were subsequently homogenized gently in a pestle and mortar and finally screened through a standard sieve of 2 mm mesh size.

These samples were then analyzed for several parameters. All analyses were done using three analytical replicates per sample. Soil temperature was measured on site using soil thermometer; pH of soil water suspension (1:5) was measured using pH electrode (Trivedy and Goel, 1984). Bulk density was determined using cutting ring method whereas soil moisture content was determined by drying soil at 105°C for 24 hr. SOC was analyzed using Walkley and Black titration method (Walkey and Black, 1934) and SOM was estimated using conventional conversion i.e. SOC × 1.724. Total nitrogen was estimated with Kjeldahl method (Honda, 1962). Organic phosphorus was converted to inorganic form after digestion with nitric acid. The total phosphorus was estimated by colorimetric method (Trivedy and Goel, 1984). Soil potassium was determined in ammonium acetate leachate using atomic emission spectroscopy (Trivedy and Goel, 1984). The elemental ratios, C:N, C:P, C:K, N:P were empirically calculated.

Data Treatment and Analysis

Descriptive statistics and Pearson correlation were performed on the analytical data using XLSTAT. Analysis of variance (ANOVA) was used to identify statistically significant differences in the soil parameters among the three months of sampling. In cases where ANOVA results were significant ($p < 0.05$), post hoc analysis was performed to detect the differences between the months. The dataset was further examined using Principal Component Analysis (PCA) for which the parameters that were not normally distributed were transformed before analysis. The statistical analyses were performed using SPSS 19.0 package.

Results

Physico-chemical Characteristics of Soil

The physico-chemical properties of the soils from the study area were listed in Table 1. Within the study area, pH values of the surface soil varied from 4.19 at site 5 to 9.05 at site 3 and the mean value was 7.27 in May. The pH varied from 7.52 at site 6 to 9.17 at site 2 and the mean value was 8.4 in September whereas it varied from 7.07 at site 4 to 8.59 at site 1 and the mean value was 8.08 in December (Figure 2). Comparatively the pH was higher in September than May and December but the difference was not significant (ANOVA, $p < 0.05$). Soil moisture content (SMC) was 44.32-86.79%, 72.49-97.63%, 77.15-95.86% in the month of May, September and December and the average SMC was 68.51%, 85.1% and 83.75% respectively. The differences in soil moisture content were significant (ANOVA, $p < 0.05$) among months. Further, post hoc analysis (LSD, $p < 0.05$) revealed that the moisture content in May differed significantly from other months (Figure 2). Bulk density of the surface soil varied from 0.45 g/cm^3 at site 3 to 1.14 g/cm^3 at site 1 with an average of 0.7 g/cm^3 in May. It varied from 0.52 g/cm^3 at site 4 to 1.17 g/cm^3 at site 7 with an average of 0.88 g/cm^3 in September whereas in December it ranged from 0.84 g/cm^3 at site 1 to 1.02 g/cm^3 at site 4 with an average of 0.92 g/cm^3. The differences in bulk density were not significant among months (ANOVA, $p < 0.05$).

Soil Nutrients

The amplitude of Soil Organic Carbon (SOC) in the surface soil was 0.35% at site 5 to 2.93% at site 3 and the mean value was 1.61% in May. The SOC content amplitude was 0.4% at site 6 to 1.71% at site 2 and the mean value was 0.91% in September. The SOC content amplitude was 0.08 at site 4 to 2.28 at site 1 with a mean value of 0.79% in December. The SOC content was higher in May as compared to other months but the difference was insignificant (ANOVA, Table 2, $p < 0.05$).

Total nitrogen (TN) was between 0.007% at site 2 and 0.021% at site 5 in May, 0.001% at site 4 and 0.015% at site 1 in September and 0.001% at site 4 and 0.18% at site 1 in December with an average of 0.018%, 0.008% and 0.005% respectively. Significant variation in TN was observed among the months (ANOVA, $p < 0.05$). TN values for each of the three months varied significantly from the other two (LSD, $p < 0.05$). Total phosphorus (TP) ranged between 0.067 mg/g at site 6 and 0.1 mg/g at site 2 with an average of 0.087 mg/g in May. TP ranged between 0.33 mg/g at site 4 and 1.33 mg/g at site 6 with an average of 0.58 mg/g in September. TP varied from 0.37 mg/g at site 2 to 0.58 mg/g at site 1 with an average of 0.45 mg/g in December. TP concentrations varied significantly among months (ANOVA, $p < 0.05$). TP concentration in May varied significantly from other months (LSD, $p < 0.05$). Total potassium (TK) varied from 1.29 mg/g at site 5 to 3.42 mg/g at site 1, 1.72 mg/g at site 5 to 4.6 mg/g at site 1, 1.16 mg/g at site 1 to 3.16 mg/g at site 2 and the mean values were 2.38 mg/g, 2.9 mg/g and 1.83 mg/g in the months of May, September and December respectively. Significant variations of TK were not observed (ANOVA, $p < 0.05$).

Table 1: Soil nutrient parameters from Bhindawas wetland in three sampling months

Soil parameter	*May*				*September*				*December*			
	Range	*Mean*	*S.D.*	*C.V*	*Range*	*Mean*	*S.D.*	*C.V.*	*Range*	*Mean*	*S.D.*	*C.V.*
pH	4.2-9.1	7.26	1.72	23	7.5-9.2	8.4	.49	5.9	7.1-8.6	8.1	.54	6.67
Temperature	18-33	26.86	5.3	19.7	26-37	31.94	3.32	10.4	13-19.8	16.7	2.86	17.13
SMC	44.3-86.8	68.5	14.8	21.5	72.5-97.6	85.1	7.37	8.66	77.2-95.9	83.75	5.8	6.9
Bulk Density	0.45-1.14	0.7	0.22	31.2	0.52-1.2	0.87	0.21	24.4	0.8-1.0	0.92	.065	7
SOC (%C)	0.35-2.94	1.62	1.04	64.4	0.7-1.7	0.91	0.49	54.4	0.08-2.3	0.79	0.76	95.9
TN (%N)	0.01-0.02	0.02	0.01	26.9	.001-.02	0.008	0.004	56.3	.001-.018	0.005	0.006	114
TK (K, mg/g)	1.29-3.42	2.38	0.73	30.7	1.7-4.6	2.9	0.98	34	1.2-3.2	1.83	0.77	41.8
TP (P, mg/g)	0.067-0.1	0.09	.015	17.2	0.3-1.3	.58	.33	56.2	0.37-0.58	0.45	0.06	14.35
C:N	16.6-161.5	96.9	56.7	58.5	56.9-306.4	135.9	82.36	60.5	56.4-789	221.3	260	117
C:P	34.8-398.5	193.7	133.3	68.8	2.9-33.3	18.64	10.65	57.1	1.68-39.2	16.62	13.45	245.8
C:K	1.4-17.3	7.5	5.75	76.6	1.12-7.9	3.37	2.14	63.5	0.41-19.7	5.47	6.76	123.5
N:P	0.70-3.1	2.14	0.78	36.4	0.04-0.3	0.16	0.09	56.3	0.03-0.31	0.11	0.106	99.99

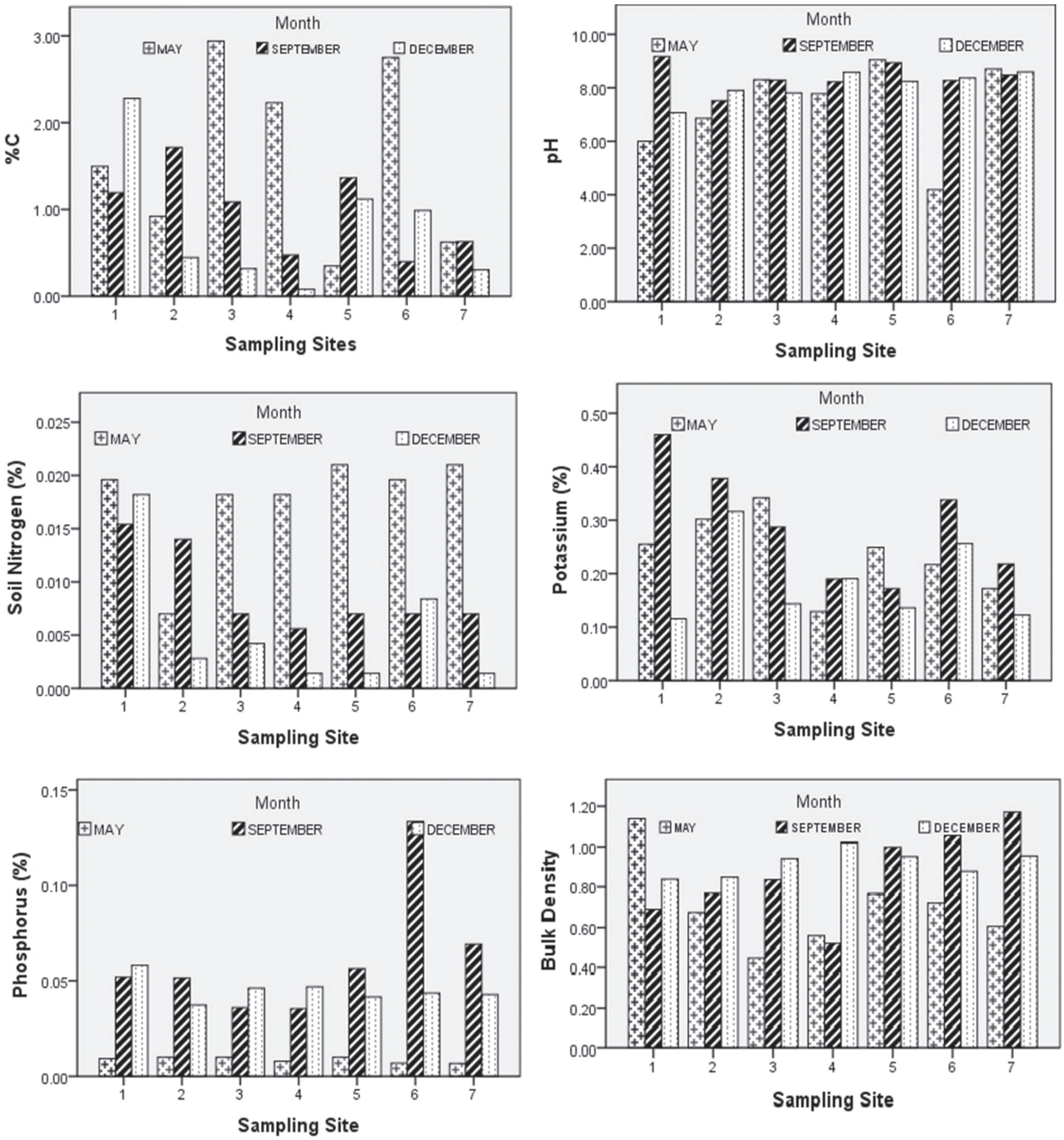

Figure 2: Spatial distribution of soil parameters in surface soils in three sampling months.

Elemental Ratios

During the study period, the C: N ratio was observed to be between 16.57 at site 5 and 161.48 at site 3 in May, 56.86 at site 6 and 306.43 at site 5 in September and 56.4 at site 5 and 798.57 at site 7 in December (Figure 3). The C:N did not vary significantly among the months ($p < 0.05$). C:P ranged from 34.80 at site 2 to 398.55 at site 6 with a mean value of 193.66 in May, 2.98 at site 7 to 33.3 at site 2 with a mean value of 18.64 in September and 1.68 at site 4 to 39.23 at site 1 with a mean value of 16.62 in December. Significant variations were observed in C:P ratio during the months. Post-hoc analysis showed C:P in May to be distinct from other months (LSD, $p < 0.05$). C:K varied between 1.4 at site 5 and 17.29 at site 4, 1.18 at site 6 and 7.92 at site 5 and 0.41 at site 4 and 19.7 at site 1 in May, September

Table 2: Depiction of seasonal variations in soil parameters using Analysis of Variance (ANOVA)

Parameters	*Sum of squares*	*df*	*Mean square*	*F*	*Sig.*
pH	5.032	2	2.516	2.247	.133
Temperature	886.488	2	443.244	28.519	**.000**
Soil moisture content	1222.674	2	611.337	6.147	**.009**
Bulk density	.187	2	.093	2.784	.087
%C	2.818	2	1.409	2.292	.128
Soil nitrogen (%)	.001	2	.000	11.067	**.001**
Potassium (mg/g)	.043	2	.021	3.011	.073
Phosphorus (mg/g)	.010	2	.005	11.817	**.000**
C:N	56909.142	2	28454.571	1.144	.339
C:P	147789.452	2	73894.726	12.939	**.000**
C:K	63.840	2	31.920	1.201	.323
N:P	19.286	2	9.643	48.023	**.000**

bold values significant at 95%

and December respectively with an average of 7.5, 3.37 and 5.47. N:P ranged from 0.7 at site 2 to 3.13 at site 7 in May, 0.04 at site 6 to 0.3 at site 1 in September and 0.03 at site 7 to 0.31 at site 1 in December with average value of 2.14, 0.16 and 0.11 respectively. N:P varied significantly among months ($p < 0.05$). Further analysis revealed that May was significantly different from other months (LSD, $p < 0.05$).

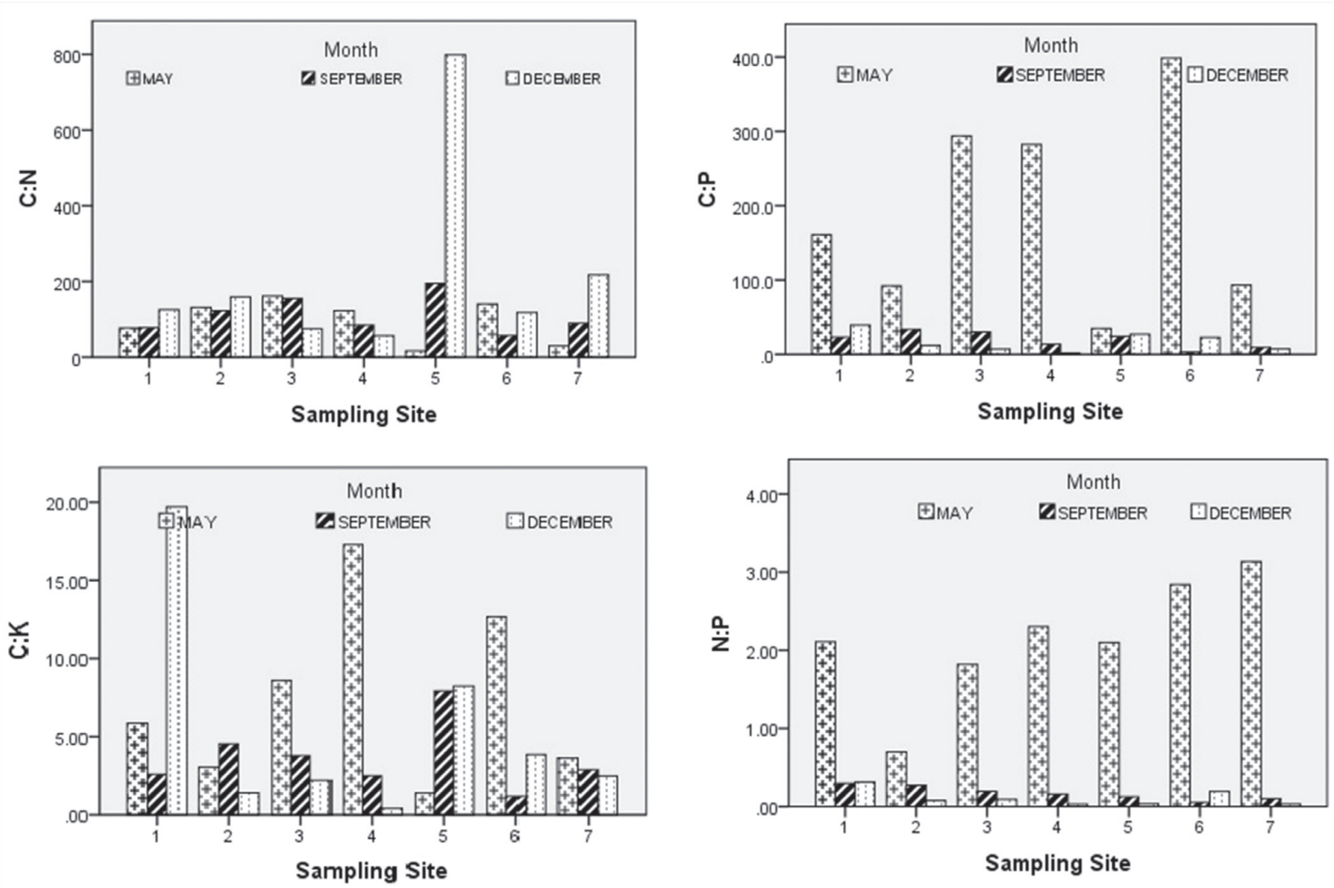

Figure 3: Spatial distribution of element ratios in surface soils in three sampling months.

Relationships between Nutrients and Physico-chemical Parameters

Statistical dependencies between various soil parameters were computed by means of correlation analysis. Table 3 summarizes the results of Pearson correlation test (two tailed, $p < 0.05$) performed on the parameters. It was highlighted that pH had strong negative correlation with SOC ($p < 0.05$), C:P ($p < 0.01$) and C:K ($p < 0.05$). Soil moisture, on the other hand, was positively correlated with TP ($p < 0.05$) and negatively correlated with carbon to nutrient ratios ($p < 0.05$). Bulk Density was negatively correlated with C:P and N:P. SOC in the wetland soil was positively correlated with TN ($p < 0.01$) and elemental ratios and also negatively correlated with SBD. TN was positively correlated with elemental ratios and negatively correlated with bulk density. TP was positively correlated with SBD and negatively correlated with C:P and N:P.

PCA is a statistical technique used to reduce the dimensionality of a dataset consisting of a large number of interrelated parameters while maximizing the variation present in the data. Principal component analysis was performed to analyze and amalgamate the variation patterns within the soil nutrient parameters and physico-chemical parameters. PCA showed three components based on the scree plot. The significant factors loading matrix of PCA is listed in Table 4. The results showed that accumulative percentage of the three principal components reached 78.32% with each extracted component having an eigenvalue >1. The eigenvalue of PC1 was 5.47 with significantly high loadings from TN, TP, C:P and N:P accounting for 49.75% of the total variance explained. PC2 had an eigenvalue of 2.05 with significant loadings from %C, pH, C:K and C:N explaining 18.63% of the variation within the data. PC3 with an eigenvalue of 1.09 had significant loadings from TK explaining 9.93% variation. The ordination results from PCA are shown in Figure 4. Thus, the three PCA components can be characterized as 'limiting nutrients like nitrogen and phosphorus', 'organic carbon and its ratios' and 'potassium'.

Discussion

Physico-chemical Characteristics

pH is an important parameter since it controls the base status and microbial activities within the soil (Miller and Donahue, 1997). Major factors governing the pH of soil include the concentration of reduced metals like iron, manganese as well as carbonates, carbonic acid and humic acid (Patrick and Mikkelsen, 1974). pH of the wetland soil was alkaline for almost every month of analysis. pH in the wetland soil was comparable to the values reported by Mathew et al. (2002) from urban wetlands of Coimbatore city receiving runoff from urban and sub-urban catchments and contrary to those reported by Prusty et al. (2010) from Keoladeo National Park. There was no significant variation in pH with reference to the season which may be due to

Table 3: Pearson's correlation matrix for soil parameters and their ratios

Soil parameters	*pH*	*Temperature*	*SMC*	*%C*	*TN (%)*	*K (mg/g)*	*TP (mg/g)*	*BD*	*C:N*	*C:P*	*C:K*	*N:P*
pH	1											
Temperature	.045	1										
SMC	.052	-.275	1									
%C	**-.533***	.260	-.331	1								
TN (%)	-.327	.129	-.290	**.627****	1							
K (mg/g)	.079	**.452***	-.014	.061	.126	1						
P (mg/g)	.311	.054	**.426***	-.328	**-.430***	.152	1					
BD	.027	-.221	.384	**-.431***	**-.451***	-.152	**.525***	1				
C:N	.031	-.092	.013	.074	-.413	-.235	-.006	.149	1			
C:P	-.649**	.194	**-.533***	**.793****	**.618****	-.029	**-.569****	**-.477***	-.066	1		
C:K	**-.452***	-.020	-.144	**.813****	**.498***	-.404	-.223	-.276	.165	**.590****	1	
N:P	-.409	.017	**-.452***	**.465***	**.822****	-.095	**-.670****	**-.455***	-.270	**.773****	.361	1

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 4: PCA of the soil parameters from all three sampling months—Factor loadings

Parameters	*Principal component*		
	1	*2*	*3*
Temperature (T)	-.716		
pH		.623	
Bulk density (BD)	.611		
Soil organic carbon (C)		.790	
Soil nitrogen (N)	.889		
Soil phosphorus (P)	-.871		
Soil potassium (K)			.931
C:N	-.528	.722	
C:P	.798	.577	
C:K		.831	
N:P	.976		
Eigen value	4.704	2.767	1.144
% of variation explained*	42.760	25.158	10.404
Cumulative %	10.404	67.918	67.918

Extraction Method: PCA; Rotation Method: Varimax Rotation
*Sums of squared loadings

the alkaline nature of the input water. Sankaran et al. (2014) opined that alkaline pH could be attributed to carbonate-rich soils. Mineral soils often have neutral or alkaline conditions as in this study.

Soil Moisture Content affects primary productivity of a wetland not only by affecting nutrient availability, but also nutrient transformations and soil biological behaviour. It also controls microbial activity in soil and thus determines the rate of mineralization. Soil moisture content was higher during the month of September due to rainfall and water availability within the wetland. Higher moisture content within the soil promotes anaerobic environment in the soil by the exclusion of oxygen. Thus, decreasing the rate of organic matter decomposition and reducing the nutrient release to the wetlands plants (Eglin et al., 2008; Mitsch and Gosselink, 2000).

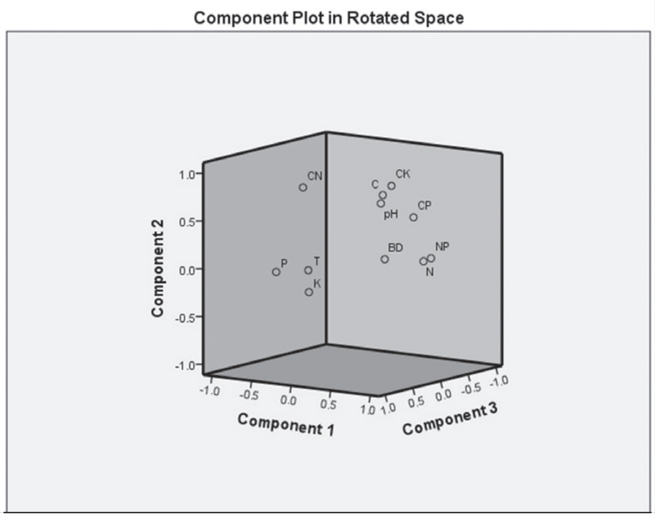

Figure 4: Principal component loading plot in the 3D space.

Bulk density is dependent on soil texture and the densities of soil mineral and organic matter particles as well as their packing arrangement. The bulk density of fine texture mineral soils ranges from about 1.0 to 1.3 g/cm^3 and that of sandy soils ranges between 1.3 and 1.7 g/cm^3. The BD of organic soils is usually much less than that of mineral soils and may be as low as 0.4 g/cm^3. Sleutel et al. (2008) reported that wetland soils have lower soil bulk densities and often a macroporous structure due to high organic matter.

Nutrients and Elemental Ratios

Disparities in the distribution of nutrients in wetland soil were expected since the hydroperiod and/or water availability are known to have significant influence on the system. Soil organic matter within a wetland has two predominant sources, one is autochthonous that originates within the wetland and gets accumulated at different stages and other is allochthonous that is carried from various terrestrial sources into the wetland. The main outputs of SOM include decomposition, mineralization and erosion which are influenced by many biological and non-biological conditions (Reddy and Patrick, 1975). Degradation and decomposition of SOM is dependent on a number of factors including quality of detritus (Lovett et al., 2004), period of water stagnation (Zech et al., 1997), presence and absence of macro-invertebrates (Bunn, 1988b), insects (Rusell et al., 2004), microbes (Rejamnkova et al., 2004) and other abiotic properties of the study site (Manlay et al., 2004). Organic matter is the primary source of the soil organic carbon that gets accumulated in the top soil (Brady, 1996). SOC is a reliable index of nutrient degradation and productivity of the water body (Anila Kumary et al., 2001). In the present study higher levels of SOC were observed during the month of May. Increased surface water evaporation and decomposition of overlying organic matter supports higher levels of SOC during the month of May. Murthy and Veerya (1972) opined high oxygen content, higher temperatures and lower water levels seem to favour the oxidation of organic matter in soil. SOC levels during September were lower which might be due to rainfall causing unsettling of organic carbon.

Soil nitrogen is an important environmental factor that affects the nutrient uptake by plants and often limits the uptake. Total nitrogen levels in soils depend on the organic matter buildup, decomposition and mineralization of organic matter in different systems, nitrogen fixation, atmospheric deposition and flood water (Zhang, 1998; Chen and Twilley, 1999). Because 95% of total nitrogen consists of organic nitrogen, organic nitrogen mineralization in top layers of soils plays an important role in nitrogen supply for wetland plant growth. Total nitrogen was higher during the month of May due to the oxidation of dead organic matter which has settled on the top layer. According to Bai et al. (2010) change in nitrogen levels could be significantly influenced by air temperature, soil drying and wetting cycles. Nowicki et al. (1999) and Kleeberg and Heidenreich (2004) also reported that plant senescence and microorganism's decomposition could return nitrogen in plants to surface soils, resulting in nitrogen accumulation in surface soil. Total nitrogen was within the range reported by Mandal et al. (2003) from North Bihar wetlands in India (0.001-0.47%).

Phosphorus plays a major role in biological metabolism. In comparison to other macronutrients required by the biota, phosphorus is the least abundant and commonly is the first element to limit biological productivity. Distribution and forms of phosphorus in soils help in evaluating the phosphorus status and degree of chemical weathering of soils (Majumder et al., 2007; Chang and Jackson, 1957). TP was also in line with the results reported from North Bihar wetlands (0.001-0.423%) but were higher from those reported by Prusty et al. (2010) from Keoladeo national park (0.001-0.034%). Higher soil phosphorus content in the study area might also be due to inflow of agricultural runoff. The runoff water is likely to contain high phosphorus contamination from chemical fertilizers used for agriculture within the catchment. Soil phosphorus is known to be absorbed by soil particles and transported by erosion due to surface runoff (Sileika at al., 2005). Differential water input to the wetland could be a substantial reason for high seasonal variability in the soil nutrient contents (nitrogen and phosphorus) highlighted by the results of LSD. Drainage or aeration of wetland soils in the month of May has shown to increase nitrogen mineralization and subsequent release for plants.

Potassium, among major and secondary nutrient elements, is the most abundant in soils (Sparks, 1980). Of the total pool, only 0.1-2.0% of potassium is available for plant absorption (Schroeder, 1978; Berstch and Thomas, 1985). Although potassium is a potentially growth-limiting nutrient in some wetlands, its biogeochemistry in wetlands is only rarely reported (Olde Venterish et al. 2001). Potassium release in soils is primarily controlled by physical adsorption to clay particles (Mengel, 1982; Scheffer and Schachtschabel, 1989). During September, potassium concentration is highest probably due to the input water and runoff. The input water to the wetland is the channel escape surface water and runoff from the agricultural landscape. Potassium also has additional biogenic sources. Potassium concentrations are almost equivalent to those reported by Mathew et al. (2002) from Coimbatore wetlands and higher than those from Keoladeo National Park (Prusty et al., 2010). Lower potassium concentration in the month of December highlights the assimilation of nutrient by the macrophytes.

C:N ratio is an indicator of an approximate state of resistance of complex mixtures of organic matters to decomposition (Wetzel, 2001). The carbon content of organic matter is on the average atleast an order of magnitude greater than that of nitrogen (Wetzel, 2001). The C:N ratios of the study area are on higher side which is an indication of accumulation of plant detritus in a saturated, anaerobic environment that retards decomposition (Ewing and Vepraskas, 2006) and lesser mobilization of nutrients from decaying detritus layer. The rates of decomposition become slower with greater chemical recalcitrance of the residual organic compounds and the selective removal of microbes results in a net increase in the C:N ratio. Also, the large values of C:N point out that the influence of allochthonous matter is more than autochthonous. Other elemental ratios, i.e. C:P, C:K and N:P are much lower than those reported by Prusty et al. (2009, 2010) from Keoladeo and Coimbatore wetlands (Mathew et al., 2002).

Relationship between Nutrients and Physico-chemical Properties

Nutrients are largely interlinked and influenced by other physico-chemical properties or characteristics of soil, depending upon seasonal changes (Hagedorn et al., 2001). A number of factors affect wetland's soil carbon storage potential including topography, hydrologic regime, plant community and soil characteristics

(Collins and Kuehl, 2001). Soil pH was significantly correlated with SOC content in the study area although the pH values were alkaline indicating that microbial activity could still affect the content and distribution of SOC in the wetland area. Soil organic carbon (SOC), soil organic matter (SOM) and the correlation between bulk densities are frequently used to estimate the carbon pools (Post et al., 1982). Bulk density when correlated with SOC showed a strong positive correlation (Catherine et al., 2007; Aşkin and Özdemir, 2003). A negative correlation is stated between organic carbon and bulk density in this study. Similar results were determined by Curtis and Post (1964) and Choudhari et al. (2013) indicating that with increase in organic carbon content, bulk density decreases which is closely related to plant root growth and productivity. Lower levels of soil bulk density advocate an increase in the total macro- as well as micro-nutrient content of the soil. Phosphorus and nitrogen also showed negative correlation with bulk density, inferring as the TP and TN increase as bulk density decreases. Correlation analysis also revealed that a strong positive correlation exists between the SOC and TN in the wetland soil which suggests that soil nitrogen was dominated by organic nitrogen. It also highlights that the carbon and nitrogen amount in newly deposited fresh organic matter were synchronized with the transformation process. Bai et al. (2012) also reported that significant correlations exist between SOC, TN, TP and soil pH in surface soils of a Chinese wetland. Positive correlation of SOC with carbon ratios such as C:P, C:N and C:K indicates that organic matter plays an important role in biogeochemical processes within the wetland. Despite similar source of origin in organic matter SOC and TP have a strong negative correlation signifying an anthropogenic source of phosphorus.

The three principal components resulting from the temporal data set can be summarized as ‘limiting nutrients like nitrogen and phosphorus’, ‘organic carbon and its ratios’ and ‘potassium’. The dataset in the study was collected seasonally and highlighted the impact of the hydroperiod on the wetland soil properties. Wetland soil properties have shown to be impacted by the water source which in this case is the canal water. Also, the quality and quantity of water released plays a crucial role in the spatial variability of the parameters (Saluja and Garg, 2015). Anthropogenic activities in the catchment area by the way of this external source would impact the wetland.

Conclusions

Present investigation reports the nutrient levels in the surface soil of the wetland ecosystem on a temporal scale. Nutrients like SOC and TN peaked during summer whereas TP and TK were higher during or after rains emphasizing the influence of hydroperiod on the wetland nutrient distribution. Many of the parameters showed significant variations during the sampling months. Spatially, the wetland demonstrates high variability in the nutrient concentration highlighting the impact of spatial heterogeneity within the wetland w.r.t human interference, agricultural inputs, proximity to water sources, plant community structure etc.

Temporal variation of nutrients like TN, TP and TK indicates the influence of allochthonous materials fed into the wetland by the rainfall event. Comparatively lower nitrogen levels within the wetland might be attributed to the inherent lower levels in the parent level and rapid utilization by the plants. Phosphorus and potassium might be entering the system along with agricultural runoff.

Analysis also revealed significant correlation among SOC, TN, TP, bulk density and carbon ratios. The higher levels of SOC and TN during May and higher levels of TP and TK during September indicate that the wetland has both autochthonous and allochthonous inputs impacting the distribution of nutrients within the wetland system.

The SOC levels within the wetland were on the higher side throughout the year at all the sampling sites emphasizing its potential as a carbon sink. Carbon sequestration of this ecologically important wetland further accentuates the need for better conservation and management of the wetland.

Acknowledgement

First author thankfully acknowledges INSPIRE Division, Department of Science and Technology, Ministry of Science and Technology, Govt. of India for INSPIRE Fellowship and contingency grants. The authors also express gratitude to Dr. Amrinder Kaur, Additional PCCF cum Chief Wildlife Warden, Haryana Forest Department; Mr. Jai Bhagwan, Wildlife Inspector and Field Staff at Bhindawas Lake for cooperation and necessary support during sampling.

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