Spatial and temporal variations of water quality in Pallikaranai wetland, Chennai, India

M. Sridevi Karpagavalli*,
A. Ramachandran and K. Palanivelu

Centre for Climate Change and Adaptation Research,
College of Engineering, Guindy Campus,
Anna University,
Sardar Patel Road, Chennai, 600-025, India
Fax: 044-2235-2244
Email: sridevi.cc@gmail.com
Email: ram7@annauniv.edu
Email: kpvelu@annuniv.edu
*Corresponding author

Abstract: This paper analysed the spatial-temporal variations of surface water quality of the Pallikaranai wetland, located in the region known as Chennai City. An extensive study pertaining to seasonal variations in nutrients, dissolved carbon, dissolved gases and heavy metals in surface water was studied at 16 locations of Pallikaranai wetland during three seasonal cruises from March 2010 to December 2010. GIS and statistical techniques such as interpolation method (IDW), Pearson correlation and principal component analysis (PCA) were applied to evaluate the spatial pattern and variation in water quality of Pallikaranai wetland and to identify pollution sources. The results revealed that there is a remarkable seasonal variation in the analysed parameters which are attributed to the natural sources (monsoon) and anthropogenic activities. PCA resulted in three factors explaining 73.8% of the total variance. Factor 1 exhibited a high correlation with environmental parameters, nutrients and organic carbon representing the influence of seasonal runoff. Factor 2 envisaged heavy metal pollution results from anthropogenic activities. Factor 3 explored moderate correlation with SPM and nutrients.

Keywords: Pallikaranai wetland; interpolation technique; principal component analysis; PCA; water quality.

Reference to this paper should be made as follows: Karpagavalli, M.S., Ramachandran, A. and Palanivelu, K. (2019) 'Spatial and temporal variations of water quality in Pallikaranai wetland, Chennai, India', *Int. J. Global Environmental Issues*, Vol. 18, No. 1, pp.86–106.

Biographical notes: M. Sridevi Karpagavalli completed her PhD related to the carbon sequestration potential in the urban wetland ecosystem of Pallikaranai, Chennai, India at the Centre for Climate Change and Adaptation Research, Anna University, Chennai. Her area research includes carbon sequestration, wetland management, carbon dating and geo-spatial analytical techniques and ERDAS image processing tools.

A. Ramachandran is the Founder and the former Director of the Centre for Climate Change and Adaptation Research, Anna University, Chennai. He is working as a Visiting Professor at the Centre for Climate Change and Adaptation Research, Anna University, Chennai. He has expertise in climate

Copyright © 2019 Inderscience Enterprises Ltd.

change modelling and forest carbon sequestration, vulnerability assessment, sea level rise and climate change adaptations. He is the recipient of the Prestigious National Award 'RajivGandhi Wildlife Conservation Award' of the Ministry of Environment of Forestry, Government of India.

K. Palanivelu is the Director of the Centre for Climate Change and Adaptation Research, Anna University, Chennai. He is also a Professor at the Centre for Environmental Studies, Anna University. He has expertise in climate change modelling, environmental monitoring, carbon sequestration, physical and chemical methods of pollution control.

1 Introduction

Wetlands are patchy and dynamic ecosystems where a high number of species occur in different periods of the year and were described as 'kidney of the landscape' as they function as the downstream receivers of water and waste from both natural and human sources (Ravichandran and Teneson, 2015). Accelerated wetland degradation is a serious problem in many places around the world due to the heavy nutrient input and deteriorated water quality, which is caused by the fast urbanisation and industrialisation (Davies et al., 2008; Li et al., 2011). Also, seasonal and climatic changes affect the quality and physico-chemistry of surface waters. The flow in surface waters is a function of many factors including precipitation, surface runoff and interflow. Seasonal variations of these factors have strong effects on flow rates and on the concentration if pollutants in surface waters (Vega et al., 1998; Choudhury and Panigrahy, 1991).

As a result of these, the wetland water has received a significant amount of pollution from numerous sources such as point source and non-point source (Li et al., 2011; Srinivasan and Natesan, 2013). Due to spatial and temporal variations in water quality, a monitoring program, providing a representative and reliable estimation of the quality of surface waters is necessary (Dixon and Chiswell, 1996; Pejman et al., 2009). However, the large and complicated datasets of water quality parameters generated by monitoring programs are often difficult to interpret latent meaningful information and require data reduction methods to simplify the data structures so as to extract useful and interpretable information. To sequel this challenge, the application of GIS (Tikle et al., 2012) and principal component analysis (PCA) (Zhao and Cui, 2009) facilitates the interpretation of complex data matrices to better understand the water quality and ecological status of studied systems. These methods also help to identify possible sources that influence water systems and offer a valuable tool for the reliable management of water resources as well as rapid solutions to pollution problems (Bhat and Pandit, 2014).

The Pallikaranai wetland has recently been the focus of attention due to the recognition of the increasing stress being placed on its water resources and of the resulting environmental degradation. Since from the 1980s, the wetland area has undergone rapid encroachment like municipal solid waste dumpsite, sewage treatment plant and settlements have posed great pressure on the ecological environment, especially the aquatic environment. In order to suspend the deterioration of water environments and improve the surface water quality, the Tamil Nadu Forest Department has been urged to take serious actions. In order to have an effective, long-term management and reduce the constituent concentrations in the wetland system, it needs to acquire an understanding of the behaviours and the variation of water quality parameters and the major pollution sources within the system. However, only a few studies on water quality in the Pallikaranai wetland have focused on physicochemical parameters. Further investigation of water contamination and pollution sources is needed. Hence, the objective of this study is to analyse the spatial and temporal variations of the water quality of the wetland and to identify the pollution sources.

2 Methodology

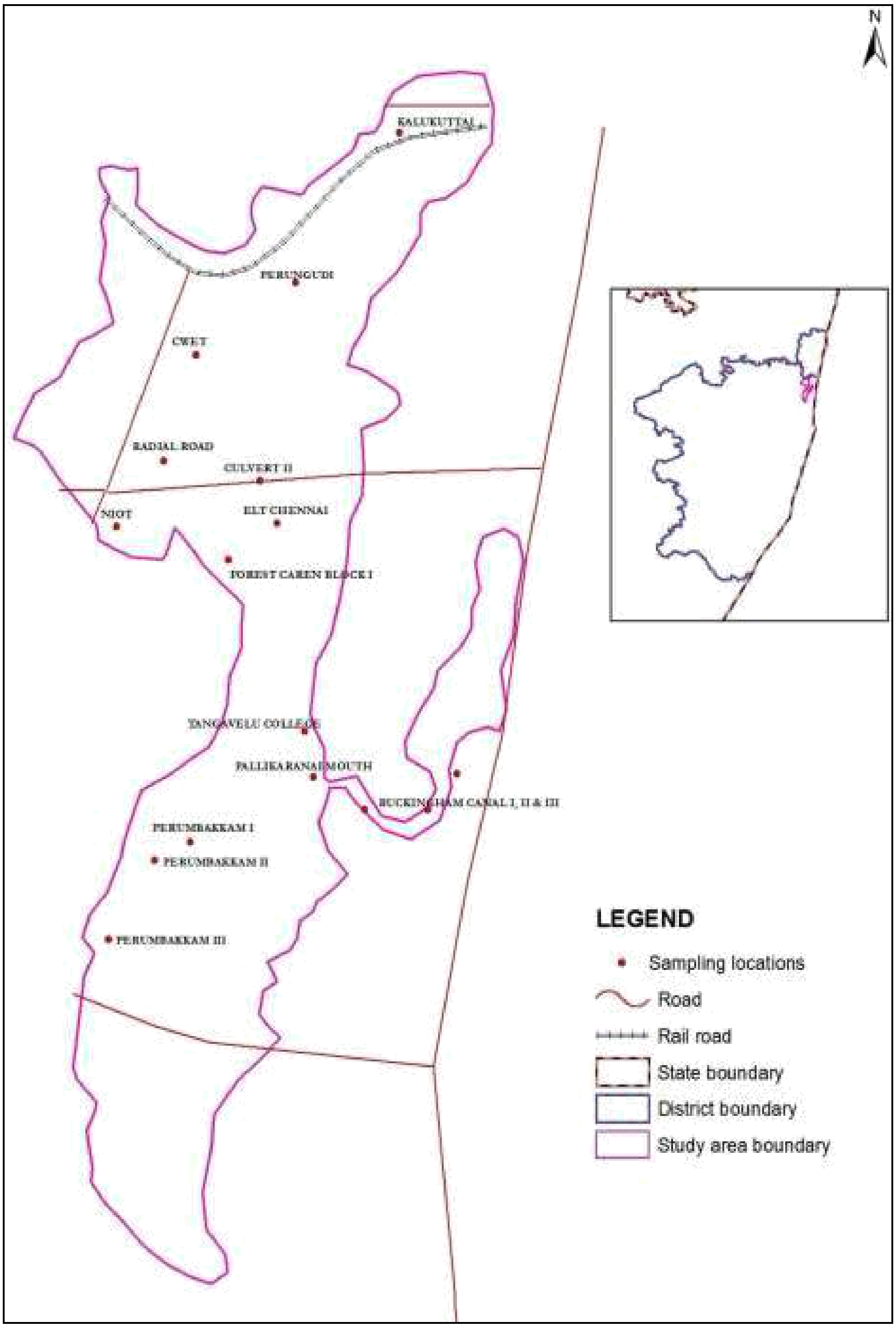
2.1 Study area

Pallikaranai wetland (12°59′00″ N, 80°14′33″ E on the North side, 12°52′48″ N, 80°13′05″ E on the south side, 12°56′07″ N, 80° 14′44″ E on the east side, 12°56′03″ N, 80°13′16″ E on the west side) is located in the region known as Suburban Chennai, falling within the District of Kanchipuram, adjoining to east of Old Mahabalipuram Road, in the west by Tambaram-Velachery Road, Velachery Village in the north and by Medavakkam-Karapakkam Road on the south. It drains through two outlets, viz., Okkiyam Madavu and Kovalam creek and falls into the Bay of Bengal in the east. The wetland is shallow with a maximum depth of 1 m at the tail end, whereas in most other areas the depth is 1 m or less. The topography of the wetland is such that it always retains some storage of water, thus forming an aquatic ecosystem. The study area receives major rainfall during the northeast monsoon (NEM) and partially from the southwest monsoon (SWM). Rainfall recharge is the main source of aquifer replenishment. The study area covers 2,155 ha, out of this, only 1,087 ha remains as a wetland. The remaining portions are occupied by different government and non-government organisations. The Chennai City has spread over the years in all directions and such expansion has caused shrinkage of the natural drainage of the Pallikaranai wetland. Moreover, most of the channels connecting the Pallikaranai wetland have disappeared due to encroachment. The constant polluting sources of the wetland are solid waste dump yard leachate and sewage treatment plant discharges have a strong effect on the concentration of pollutants in surface water (Apfelbacher, 2008).

2.2 Sample collection

Surface water samples were collected from 16 sampling locations in the study area for the year 2010 during summer (March, April and May), South west monsoon (June, July, August and September) and NEM (October, November and December) periods to evaluate the seasonal variation in physicochemical composition in the surface water (Figure 1). Each sample was collected by 1 litre acid-washed polyethylene bottle. The bottle was filled with the sample water with the caution that no air bubble was trapped within the sample. The sample was transferred to the laboratory and stored at a temperature below 4°C prior to analysis in the laboratory.

Figure 1 Study area with sampling locations (see online version for colours)



2.3 Laboratory analysis

Samples were analysed in the laboratory for the physicochemical attributes like pH, salinity, dissolved oxygen, nitrate, phosphate, dissolved organic carbon (DOC), suspended particulate matter (SPM), dissolved inorganic carbon (DIC), particulate organic carbon (POC), dissolved carbon dioxide (pCO_2), dissolved methane (pCH_4) and heavy metals. Parameters such as salinity and dissolved oxygen were measured in situ with a Horiba multiprobe W-22.2. Subsamples were filtered through 0.45 µm Whatman glass fibre filter paper to study SPM, DOC, DIC and POC followed by Tamooh et al. (2012), nutrients were determined following the method APHA. pCO_2 and pCH_4 were analysed following Upstill Goddard et al. (1996). Heavy metals were determined acid digestion followed by flame atomic absorption spectroscopic method (Analytic Jena, AAS6 Vario).

2.4 GIS mapping

To visualise the spatial patterns of the water quality within Pallikaranai wetland, spatial interpolation method (IDW) (Arc GIS, 9.2) were applied mapping all variables. The value of the water quality parameters is classified according to the data range of the each season. The IDW is an algorithm used to interpolate data spatially or estimate values between measurements. Each value estimated in an IDW interpolation is a weighted average of the surrounding sample points (Magesh and Chandrasekar, 2013; Srinivasan and Natesan, 2013).

2.5 Statistical analysis

Statistical analysis of the physicochemical parameter of the water sample was subjected to computations such as Pearson correlation and PCA using XLSTAT 2016. PCA facilitates to explain the relationships among numerous important variables with a smaller set of independent variables well (Pejman et al., 2009; Zhao and Cui, 2009). PCA were performed on the surface water quality parameters to determine the relationship between water quality variables, in order to identify the important variable which affects the chemistry of the surface water and to investigate the possible source of different pollutants. It extracts eigenvalues and eigenvectors from the covariance matrix of original parameters to produce principal components (PCs) that are linear combinations of the original variables. PCs provide information on the most meaningful parameters that describe a whole dataset allowing data reduction with minimum loss of original information. Also, it attempts to explain the correlation between the observations in terms of the underlying factors, which are not directly observable (Garizi et al., 2011).

3 Results and discussion

The physicochemical properties of the surface water samples in summer, southwest and NEM periods were statistically analysed and the results such as maximum, minimum, average and standard deviation of the parameters are given in Table 1. To study the distribution pattern of the concentration of different element, spatial maps for various elements were generated by use of Arc GIS 9.2 software.

Table 1 Mean values (±SD) and range (n = 16) of physicochemical parameters

Component	*Summer*	*SWM*	*NEM*
Water temperature (°C)	32.32 ± 0.14	30.64 ± 0.07	26.32 ± 0.12
	(31.6–32.8)	(21.2–30.3)	(25–26.8)
Salinity (PSU)	12.57 ± 4.09	5.15 ± 1.42	1.92 ± 0.19
	1.17–54.41	0.99–17.70	1.11–3.88
DO (mg L^{-1})	4.03 ± 0.13	4.30 ± 0.23	3.69 ± 0.22
	2.8–4.5	2.5–5.9	1.5–4.3
SPM (mg L^{-1})	205.55 ± 49.88	162.37 ± 30.90	265.80 ± 27.65
	31.33–631.33	15.33–401.33	103.33–497.33
Nitrate (mg L^{-1})	1.43 ± 0.22	0.27 ± 0.06	1.67 ± 0.41
	0.12–3.47	0.05–0.90	0.04–4.56
Phosphate (mg L^{-1})	0.45 ± 0.14	0.11 ± 0.03	0.74 ± 0.24
	0.01–1.56	0.01–0.42	0.03–2.56
DOC (mg L^{-1})	65.31 ± 14.0	32.51 ± 1.77	41.72 ± 8.68
	16.061–161.68	19.52–45.22	16.45–121.9
DIC (mg L^{-1})	63.03 ± 4.82	43.25 ± 6.09	77.92 ± 6.53
	38.94–101.61	23.59–82.64	25.31–132.21
POC (mg L^{-1})	2.54 ± 0.27	2.37 ± 0.25	3.40 ± 0.23
	1.21–4.21	0.98–3.96	1.2–4.78
pCO_2 (mg L^{-1})	6,838.87 ± 1,803	4,502.8 ± 875	11,262.9 ± 2,224
	1,803–22,924	875–11,142	2224–29,988
pCH_4 (mg L^{-1})	5,081.29 ± 1,303.79	3,080.64 ± 813.06	1,741.85 ± 477.18
	790–17,823	458–9,980	308–6,238.05
Fe (mg L^{-1})	3.42 ± 0.15	-	2.50 ± 0.61
	7.49–1.36		9.48–0.65
Mn (mg L^{-1})	0.58 ± 0.13	-	0.60 ± 0.15
	1.70–0.12		1.91–0.01
Ni (mg L^{-1})	0.81 ± 0.15	-	0.63 ± 0.09
	2.14–0.10		1.63–0.20
Co (mg L^{-1})	1.46 ± 0.48	-	0.51 ± 0.04
	6.87–0.011		0.93–0.13
Cd (mg L^{-1})	0.24 ± 0.07	-	0.05 ± 0.01
	0.73–0.01		0.17–0.002
Cr (mg L^{-1})	0.59 ± 0.11	-	0.71 ± 0.17
	1.43–0.15		2.8–0.24
Zn (mg L^{-1})	0.59 ± 0.17	-	0.27 ± 0.02
	1.95–0.11		0.48–0.10
Cu (mg L^{-1})	0.20 ± 0.06	-	0.04 ± 0.006
	0.79–0.005		0.11–0.01
Pb (mg L^{-1})	0.36 ± 0.15	-	0.32 ± 0.10
	2.02–0.005		1.30–0.08

3.1 Seasonal variations of environmental parameters

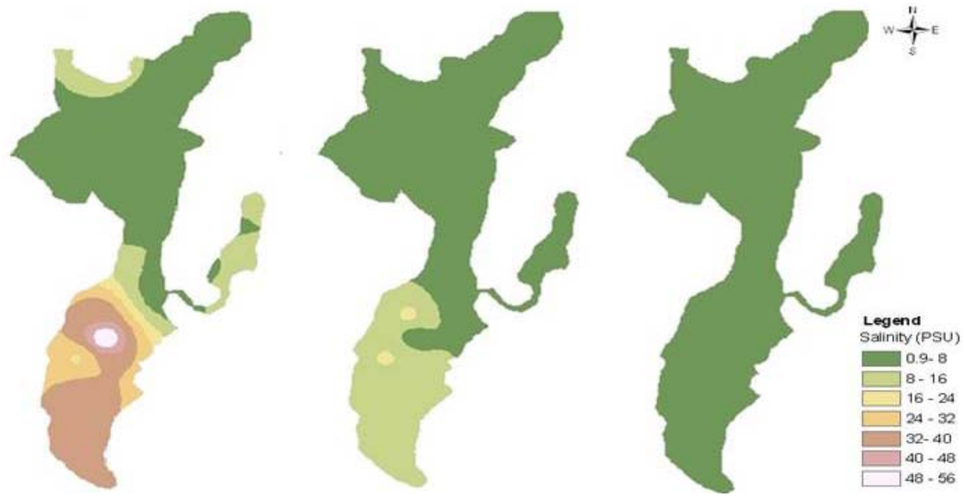
The seasonal and spatial variations of the environmental parameters in the wetland system are chiefly controlled by monsoon rainfall pattern. The seasonal values of the parameters are depicted in Table 1. The average surface water temperature varied 32.32°C in summer, 30.64°C in SWM and 26.32°C in NEM. Spatial variation of salinity showed significant variations during the study period. The salinity had varied between 1.17–54.41 PSU during summer, 0.99–17.70 PSU during SWM and 1.11–3.88 during NEM. Salinity was lower during NEM in accordance with higher rainfall and was elevated in the summer could be attributed to the higher rate of evaporation (Senthilkumar et al., 2008). The similar kind of observation was made by Damotharan et al. (2010) for Point Calimere coastal waters and Gadhia et al. (2012) for Tapi estuary. The spatial interpolation map [Figure 2(a)] reveals high salinity values during summer near Perumbakkam area, the southern part of the wetland due to the fragmented nature of the wetland and less lateral movement of backwater from Buckingham Canal.

In the present observation, dissolved oxygen varied from 2.5–5.9 mg L^{-1}. Higher values of dissolved oxygen were recorded during SWM (4.30 ± 0.23) followed by summer (4.03 mg L^{-1} ± 0.13) and NEM (3.69 mg L^{-1} ± 0.22). The higher mean dissolved oxygen value recorded in the SWM and summer did not agree with the finding of Senthilkumar et al. (2008) and Srinivasan and Natesan (2013) who reported that dissolved oxygen is generally higher during the monsoon period. The lower mean dissolved oxygen values in the NEM could be the turbidity nature of the surface water of this period due to inflow from runoffs and decomposition of organic matter in the water. The similar kind of observation was noticed by Abowei (2010) and Braide et al. (2004). This would be further supported by the SPM concentration in the surface water (265.80 ± 27.65 mg L^{-1} in NEM, 205.55 mg L^{-1} ± 49.88 in the summer and 162.37 mg L^{-1} ± 30.90 in SWM). The correlation studies showed a strong negative correlation between DO and SPM (–0.66). The levels of DO were low at the middle part of the wetland which results from several factors such as leachates, waste inputs (organic load) from the nearby dumpsite, sewage treatment plant and settlements [Figure 2(b)].

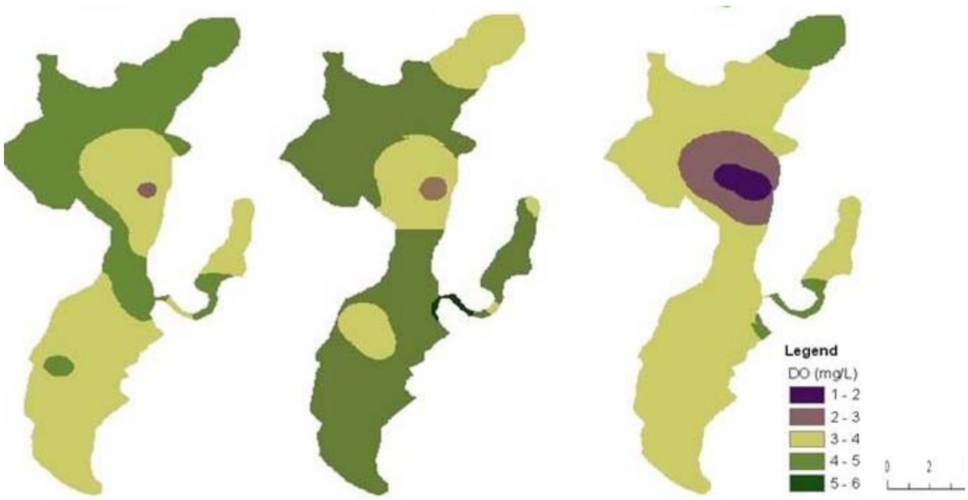
3.2 Seasonal and spatial variation in dissolved nutrients

A seasonal variability of range and mean nitrate (NO_3-N) concentration was shown in Table 1, with higher values were recorded in NEM (1.67 mg L^{-1} ± 0.41) and summer (1.43 mg L^{-1} ± 0.22) at the sampling points located along the northern and southern part of the wetland [Figure 3(a)] and lower mean (0.27 mg L^{-1} ± 0.06) concentration was recorded during the SWM. The highest nitrate values observed during NEM could mainly due to the organic materials received from the surface runoff and nutrient rich backwater discharge (from the Buckingham Canal) into the wetland. Another possible reason for the maximum concentration of nitrate during monsoon season might be due to the anthropogenic input from nearby solid waste dump site. Further, very low concentration of nitrate observed during SWM could be attributed to the rapid utilisation of nitrate by phytoplankton. A similar trend was reported by Gopinath et al. (2013), Kamalkanth et al. (2012) and Satpathy et al. (2010). Seasonal variation in the phosphate (PO_4-P) concentration varied between 0.01 to 2.56 mg L^{-1} with the lowest value (0.11 mg L^{-1} ± 0.03) recorded during SWM and maximum value during NEM (0.74 mg L^{-1} ± 0.24) and summer (0.45 mg L^{-1} ± 0.14). The recorded high concentration of phosphate during NEM might possibly be due to land drainage and runoff.

Figure 2 Spatial distribution of environmental parameters, (a) salinity (b) DO (see online version for colours)



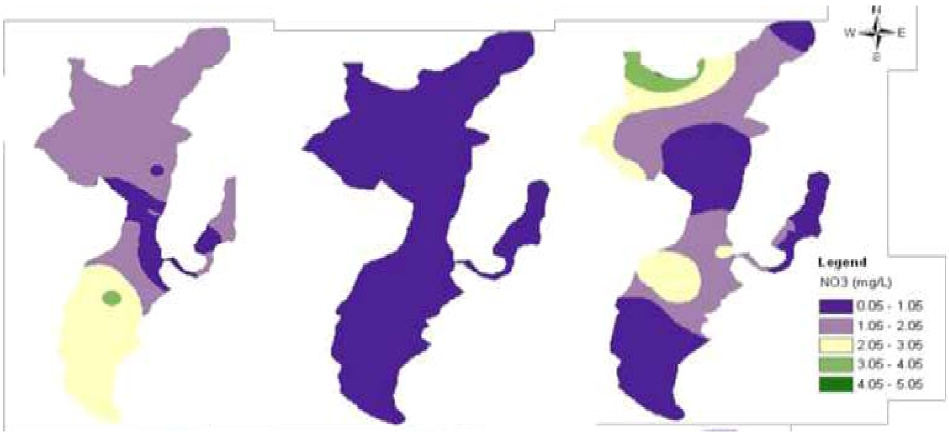
(a)



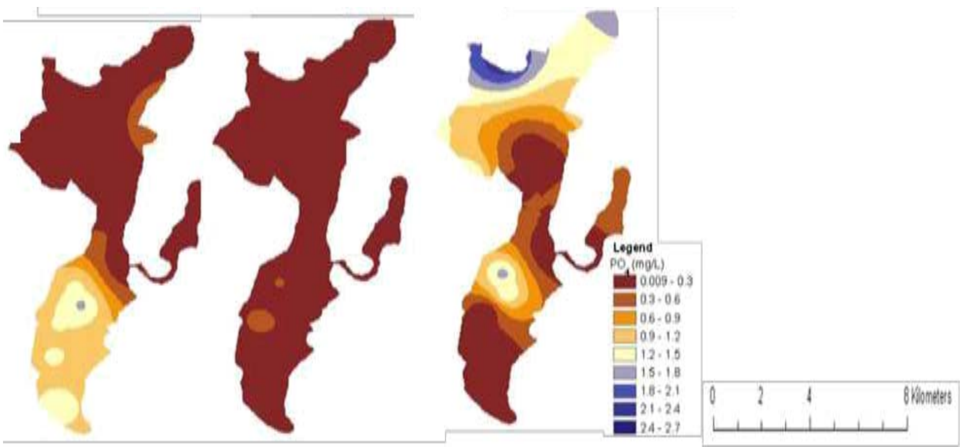
(b)

The low concentration value during SWM could be attributed to the limited flow of fresh water, salinity and utilisation of phosphate by phytoplankton (Gopinath et al., 2013; Kamalkanth et al., 2012; Robina et al., 2011; Senthilkumar et al., 2002). The sources of phosphate in Pallikaranai wetland are from the discharge of domestic sewage from nearby sewage treatment plant and leachate from dumpsite. During the NEM season, northern portion of the wetland showed the highest phosphate content which might have received through runoff from nearby settlements, since this part is highly agglomerated with corporate sectors and settlements. However, in the summer season, the higher concentration of phosphate was observed specifically near the southern portion of the wetland, due to desorption of phosphate (phosphate mineralisation) which release nutrient from the suspended matter to the system (Geerts et al., 2012). This statement was further supported by the concentration of SPM and salinity in this part showed high during the summer which was represented in Figure 3(b).

Figure 3 Spatial distribution of dissolved nutrients, (a) nitrate (NO_3-N) (b) phosphate (PO_4-P) (see online version for colours)



(a)



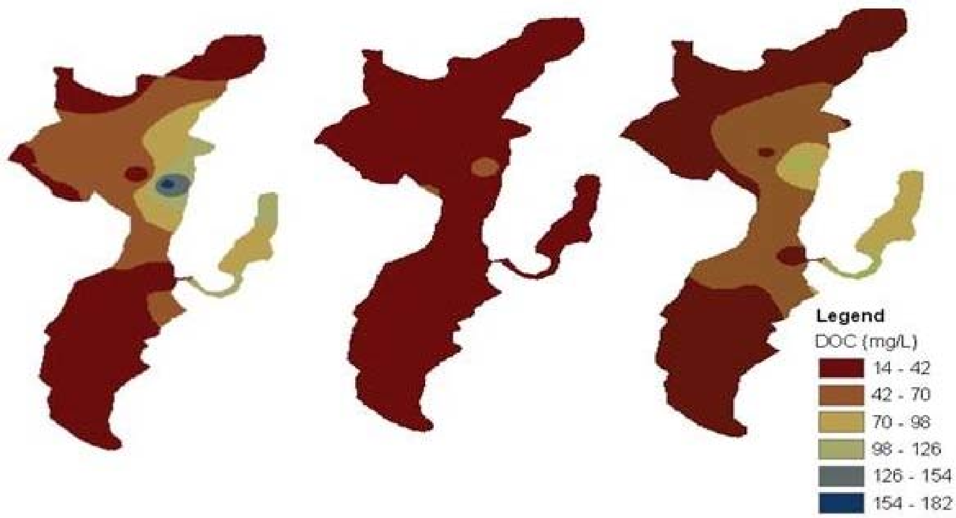
(b)

3.3 Seasonal variations in dissolved carbon

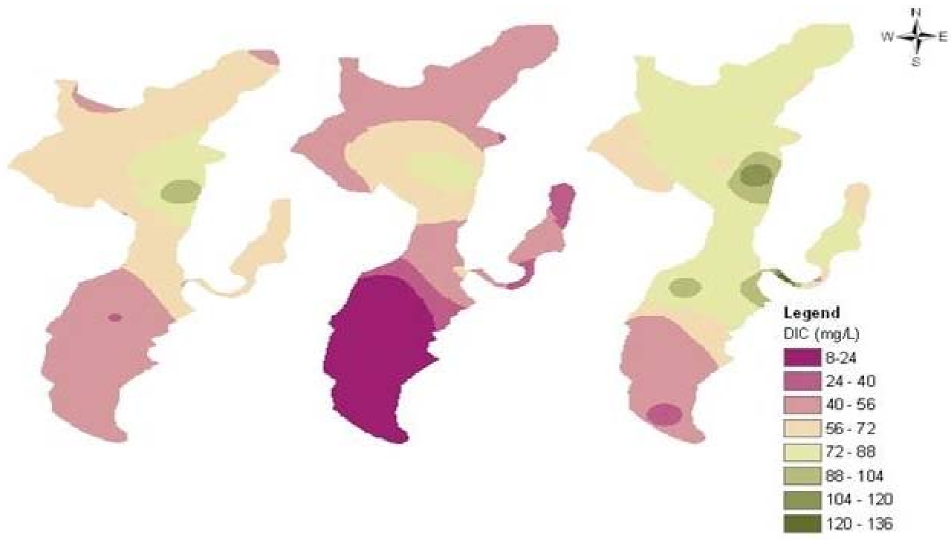
DIC is the largest carbon pool in most aquatic systems and consists primarily of CO_2, HCO^{3-} and CO_3^{2-}. Maximum DIC concentrations were observed during NEM (77.92 mg L^{-1} ± 6.53), followed by summer (63.03 mg L^{-1} ± 4.82) and minimum during the SWM

(43.25 mg $L^{-1} \pm 6.09$). The highest concentration of DIC during the monsoonal period could be related to high surface runoff with the associated lowering of water transparency, which led to dominant respiration over productivity, ultimately fuelled DIC production (Banerjee, 2012).

Figure 4 Seasonal distribution of dissolved nutrients, (a) DOC (b) DIC (c) POC (see online version for colours)

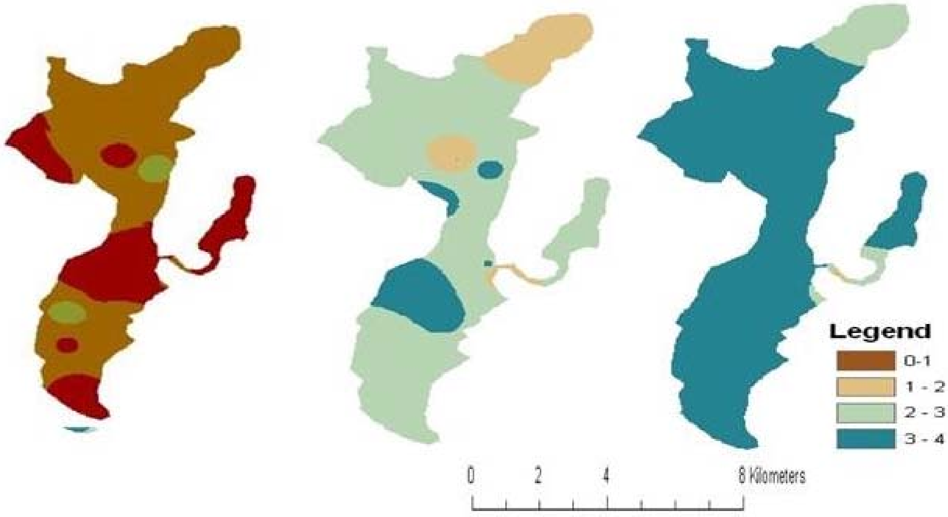


(a)



(b)

Figure 4 Seasonal distribution of dissolved nutrients, (a) DOC (b) DIC (c) POC (continued) (see online version for colours)



(c)

The concentration of DOC ranged from 16.061–161.68 mg L^{-1}, with the lowest concentration were measured during the SWM ranging from 19.52–45.22 mg L^{-1} (average 32.51 mg L^{-1} ± 1.77), whereas the maximum value of 65.31 mg/L was measured during the summer. The distribution of DOC and DIC was high in the middle of the wetland [Figures 4(a) and 4(b)] during summer and NEM. Freshwater discharge from the surface runoff and back water from the Buckingham canal supplies both organic and inorganic compounds from land to the wetland. In summer, high temperature driven microbial activities degrade the complex organic compounds, i.e., autochthonous material which in turn supplied to the system (Prasad and Ramanathan, 2008).

The spatial and temporal variations in POC and SPM concentrations were similar, reflecting the close association POC and terrestrial particulate matter. Higher POC and SPM concentrations occurred during the NEM and summer with POC ranging from 1.2 to 4.78 mg L^{-1} and SPM ranging from 103.3 to 497.3 mg L^{-1}. During the NEM, large amounts of terrestrial particulate matter are transported to wetland by rainfall, resulting in higher POC concentrations in the NEM than in the other seasons (Ni et al., 2008). The distribution of POC corroborates the distribution of SPM [Figure 4(c)] and was high in the middle and northern part during NEM and in the northern part during the summer. Statistical analyses showed that a significant exponential relationship (correlation coefficient of 0.78) was found between the concentrations of POC and SPM which can be described by Table 2.

Table 2 Correlation between the environmental parameters in Pallikaranai wetland (significant level at 0.05)

	DO	*Sal*	*SPM*	*NO_3*	*PO_4*	*SO_4*	*DOC*	*DIC*	*POC*	*Fe*	*Mn*	*Ni*	*Co*	*Cu*	*Zn*	*Pb*	*Cd*	*pCO_2*	*pCH_4*
DO	1	0.71	*–0.66*	0.32	0.47	0.65	–0.29	–0.24	0.83	–0.24	–0.08	0.20	0.26	0.22	–0.11	–0.38	0.16	–0.12	–0.55
Sal		1	–0.34	–0.61	0.78	0.75	–0.27	–0.77	0.75	–0.61	–0.48	0.29	0.02	0.09	–0.32	–0.40	0.03	*–0.41*	*–0.77*
SPM			1	0.15	–0.02	–0.63	0.29	0.12	*0.77*	0.05	–0.11	–0.31	–0.60	–0.52	–0.37	–0.13	–0.57	0.19	0.49
NO_3				1	*0.92*	0.23	–0.38	–0.50	0.26	–0.65	–0.17	0.50	0.18	0.26	0.01	–0.57	0.16	0.11	–0.15
PO_4					1	0.41	–0.31	–0.61	0.47	–0.77	–0.30	0.51	0.23	0.29	–0.02	–0.57	0.22	–0.21	–0.43
SO_4						1	–0.37	–0.59	0.76	–0.41	–0.03	0.19	0.21	0.29	–0.02	–0.007	0.27	–0.36	*–0.73*
DOC							1	*0.37*	–0.48	–0.14	–0.33	–0.49	–0.32	–0.39	–0.22	0.40	–0.27	–0.17	0.04
DIC								1	–0.57	0.48	0.56	–0.24	0.10	0.03	0.29	0.38	0.07	0.37	0.62
POC									1	–0.27	–0.18	0.301	0.32	0.26	–0.02	–0.39	0.24	–0.27	–0.69
Fe										1	0.29	–0.38	–0.24	–0.30	–0.07	0.13	–0.30	0.42	0.52
Mn											1	0.23	0.49	0.52	0.63	0.13	0.46	0.26	0.29
Ni												1	0.79	0.84	0.64	–0.27	0.76	–0.22	–0.31
Co													1	0.96	0.91	–0.04	0.96	–0.07	–0.19
Cu														1	0.89	0.03	0.97	–0.11	–0.20
Zn															1	0.14	0.91	0.06	0.08
Pb																1	0.14	0.01	0.23
Cd																	1	–0.14	–0.19
pCO_2																		1	0.75
pCH_4																			1

3.4 Seasonal variations of pCO_2 and pCH_4 in surface water

The seasonal distributions of pCO_2 and pCH_4 in the Pallikaranai wetland are given in Table 1 shows a pronounced seasonal variation. The pCO_2 and pCH_4 quantification revealed that the studied sites were supersaturated with respect to atmospheric CO_2 and CH_4 concentrations in all the three seasons. The seasonal trend of pCO_2 showed that the highest concentration during NEM with an average of 11,262.9 µatm ± 2,224, followed by summer with an average of 6,838.87 µatm ± 1,803 and lowest during SWM with an average value of 4,502 µatm ± 875. During the NEM, the higher dissolved nutrient concentrations associated with a higher level of SPM (265.80 mg L^{-1} ± 27.65) which led to high bacterial respiration will influence the higher pCO_2 concentration. Shiah et al. (2006) also reported in Chanjiang estuary that the increase in bacterial respiration was due to the availability of more organic carbon which led to intense bacterial decomposition of organic carbon during the high discharge. The levels of pCO_2 concentrations were within the range of some other salt marshes like, Xijiang River (China) 600–11,000 µatm (Yao et al., 2007), Rhine (Netherlands) 340–25,000 µatm (Kempe, 1982), Scheldt (Belgium) 100–15,200 µatm (Borges and Frankignoulle, 2002), Godavari estuary (India) 100–33,399 µatm (Sarma et al., 2011) and Chilika lagoon (India) 555–22,487 µatm (Muduli et al., 2012).

The significant seasonal variation of pCH_4 was observed with highest concentrations during the summer with an average value of 5,081 nmol L^{-1} ± 1,303, followed by SWM with an average value of 3,080.64 nmol L^{-1} ± 813.06 and lowest during the NEM with an average value of 1,741.85 nmol L^{-1} ± 477.18. In all the season's, dissolved CH_4 concentrations were supersaturated with respect to atmospheric CH_4 concentration. In the present observation, highest CH_4 concentration was observed during summer when the maximum water temperature was 31.6°C–32.8°C which enhances microbial decomposition. Although CH_4 is produced primarily by microbial activity, plants have strong effects on CH_4 emission from wetland ecosystem (Kolbener, 2010). Since the study area covered with aquatic macrophyte *Typha angustata* which contributes more autochthonous organic carbon derived from the macrophyte litter fall. The higher SPM (31.33–631.33 mg L^{-1}), DOC (16.06–161.68 mg L^{-1}) and POC (1.21–4.21 mg L^{-1}) concentration during the summer also supports the above statement. Low water level, higher temperature and high concentration of organic matter might allow the sediment to be more anoxic and intensify the methane production (Purvaja and Ramesh, 2001). During NEM, the height of water restricted the transfer of CH_4 from the subsurface to the atmosphere, resulting in a decrease in CH_4 rates, though a significant amount of SPM (103.33–497.33 mg L^{-1}), DOC (16.45–121.9 mg L^{-1}) and POC (1.2–4.78 mg L^{-1}) was observed. The decrease in temperature (25°C–26.8°C) which inhibited methanogenesis could be the reason for the low rate of emission. Mallick (2009) also reported the same kind of observation in north Indian subtropical wetland.

The correlation between the measured environmental parameters (salinity and sulphate) and gas concentrations showed, significant negative correlation between salinity and pCO_2 (–0.41) and pCH_4 (–0.77). It was observed that a higher concentration of dissolved gases in a lower concentration of salinity and lower level towards high salinity concentrations. The similar kind of observation, linear negative correlation of

CH_4 concentration (Table 2) with increasing salinity was observed by Shalini et al. (2006) for shallow estuaries in South India and Ramesh et al. (1997) for Adyar estuary. The higher salinity will inhibit the methanogenesis and the rates of methane production (Olsson et al., 2015). Dissolved CH_4 showed a negative correlation with dissolved sulphate in the study area (–0.73). Sulphate inhibition of methanogenesis is a widely known mechanism for reduced CH_4 production (Shalini et al., 2006; Ventura, 2014). Prevailing waterlogged, anaerobic and rich in organic carbon environments is suitable for growth of sulphate reducing bacteria and methanogens exist for the utilisation of hydrogen and acetate to the extent that they lower the rate of methane production (Kumar and Ramanathan, 2014). Ramesh et al. (1997) also reported similar observation in Adyar estuary. The similar observation was observed by Marinho et al. (2012) in mangrove wetland.

3.5 Spatial and seasonal variations in heavy metals

The results of heavy metal concentrations in surface waters are shown in Table 1. The average concentration of metals in surface water followed the decreasing order of: Fe > Co > Ni > Mn > Cr > Zn > Pb > Cd > Cu. The mean concentration of Fe in water was observed as 3.42 and 2.5 mg L^{-1} during summer and NEM, respectively. The highest concentration recorded for Fe was 3.42 and 2.50 mg L^{-1} for summer and NEM, respectively. The least concentration recorded for Cu was 0.20 and 0.04 mg L^{-1} for summer and NEM, respectively. The mean concentration of Cr in water was observed 0.56 and 0.71 mg L^{-1} during summer and NEM season, respectively which was much higher than the Indian drinking water standard level. The average concentration of Cd was observed 0.24 and 0.05 mg L^{-1} during summer and NEM season, respectively. The highest value of the Cd was observed at the middle portion of the wetland during the summer season which might be attributed to the leachate from the dumpsite and domestic sewage from the sewage treatment plant. The average concentration of Pb was higher in summer (0.36 mg L^{-1}) than that in NEM (0.32 mg L^{-1}) which were higher than the drinking water quality standards. Zn during summer recorded highest values (1.95 to 0.11 mg L^{-1}) than the NEM season (0.48 to 0.10 mg L^{-1}) and all the values are less than the mean values of Indian drinking water standard. During NEM, the concentration of Ni varied from 1.63 to 0.20 mg L^{-1} and the mean was 0.63 mg L^{-1}. Summer exhibited the highest concentrations ranging from 2.14 to 0.10 mg L^{-1} with a mean of 0.81 mg L^{-1}. Cr during NEM season is significantly higher (0.71 mg L^{-1}) than the summer (0.59 mg L^{-1}). The considerable increasing trend in Mn concentration from NEM season to summer with an average of 0.60 and 0.58 mg L^{-1}. The maximum concentration of Cu is 0.79 mg L^{-1} during summer and 0.11 mg L^{-1} during NEM season showed significant seasonal fluctuation. Highest values recorded during summer than the NEM season for Co with a mean concentration of 1.46 and 0.51 mg L^{-1}. Among all the metal, Iron found to be maximum in all the sampling location in all the season followed by cobalt and nickel. Elevated concentration of Pb, Ni, Co, Fe, Zn and Cd observed in the middle part of the wetland [Figures 5(a) to 5(i) may be related to the leachate from the nearby dumpsite.

Figure 5 Spatial distribution of heavy metals, (a) Cr (b) Pb (c) Fe (d) Mn (e) Co (f) Ni (g) Cu (h) Zn (i) Cd (see online version for colours)

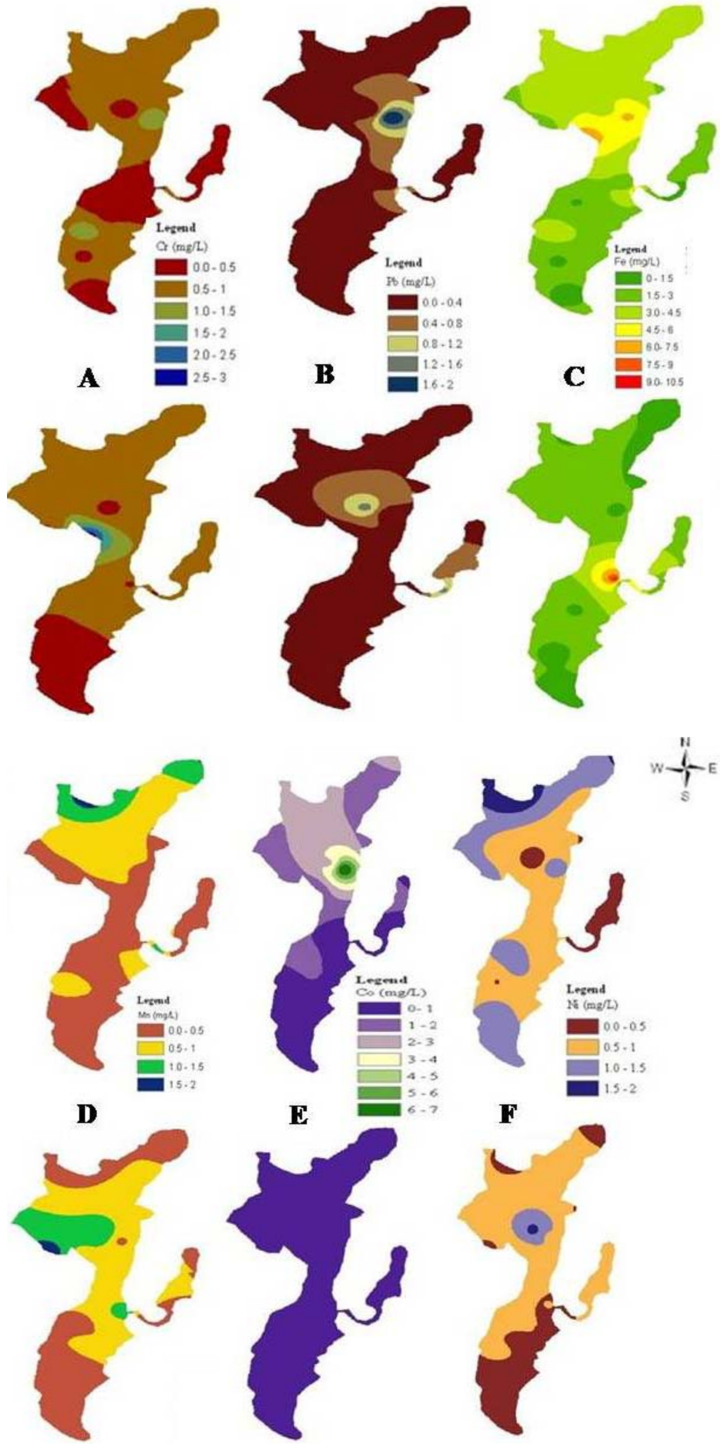
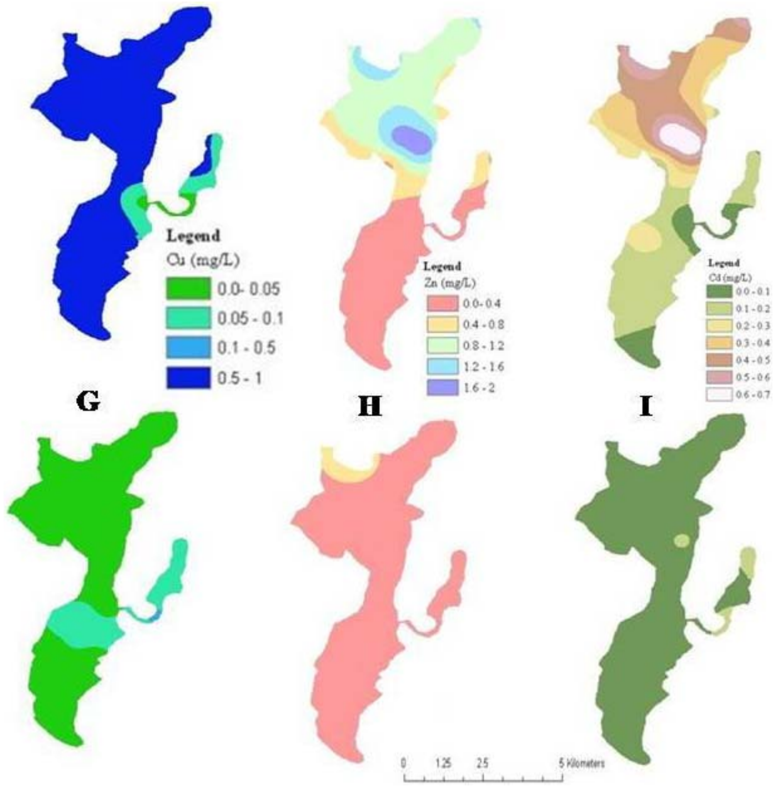


Figure 5 Spatial distribution of heavy metals, (a) Cr (b) Pb (c) Fe (d) Mn (e) Co (f) Ni (g) Cu (h) Zn (i) Cd (continued) (see online version for colours)



The Pearson's correlation coefficient for analysed metal parameters was calculated to understand the interrelation of parameters with each other. The elements in surface water did not show much correlation with each other except Co, Cu, Zn and Cd showed significant positive correlation suggesting the similar source of inputs for these metals in the wetland system. High correlations between specific heavy metals in water may reflect similar levels of contamination or release from the same sources of pollution, mutual dependence and identical behaviour during their transport in the system (Ali et al., 2016).

4 Statistical analysis – PCA

PCA was performed to extract the most important factors and physicochemical parameters affecting the water quality. Based on the eigenvalues for each component represented in the screen plot (Figure 6), the 22 physicochemical parameters were reduced to three main factors (factors 1, 2 and 3). An eigenvalue gives a measure of the significance of the factor. The factors with highest eigenvalues are the most significant. Eigenvalues of 1.0 or greater is considered significant (Pathak and Limaye, 2011). The first three factors corresponding to the largest eigenvalue (8.02, 5.33 and 2.88) accounts for approximately 36.48%, 24.22% and 13.17% of the total variance. The remaining factors have eigenvalues of less than unity. The PCA results along with factor loading values and parentage variance are depicted in Table 3.

Figure 6 Screen plot graph with eigenvalues (see online version for colours)

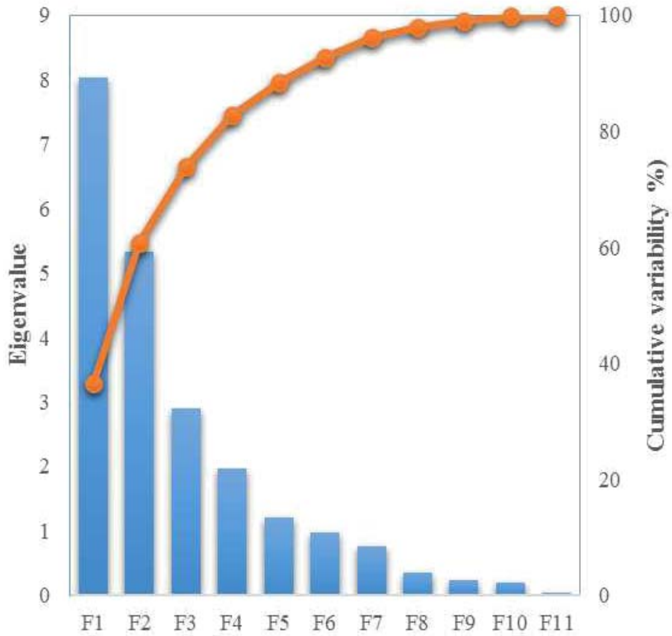


Table 3 Component matrix, loading and variance of 22 experimental variables on PCs of Pallikaranai wetland

	F1	*F2*	*F3*
Eigenvalue	8.026	5.330	2.889
Variability	36.481	24.228	13.176
Cumulative	36.481	60.709	73.884
pH	–0.165	–0.523	0.284
DO	0.747	–0.051	–0.397
Salinity	0.864	–0.463	–0.036
SPM	–0.619	–0.424	0.613
NO_3	0.577	–0.215	0.678
PO_4	0.756	–0.280	0.533
SO_4	0.788	–0.080	–0.360
DOC	–0.459	–0.229	–0.117
DIC	–0.650	0.546	–0.131
POC	0.856	–0.074	–0.389
Fe	–0.615	0.210	–0.417
Mn	–0.144	0.796	0.034
Ni	0.626	0.488	0.455

Table 3 Component matrix, loading and variance of 22 experimental variables on PCs of Pallikaranai wetland (continued)

	F1	*F2*	*F3*
Co	0.504	0.822	0.155
Cu	0.534	0.794	0.240
Zn	0.165	0.917	0.252
Pb	–0.389	0.283	–0.363
Cd	0.480	0.806	0.173
pCO_2	–0.403	0.197	0.095
pCH_4	–0.774	0.225	0.257

Factor 1 accounting for 36.48% of the total variance, which was positively loaded with DO (0.74), salinity (0.86), phosphate (0.75), sulphate (0.78) and POC (0.85) and negatively loaded with pCH4 (–0.77). The strong positive loading of DO, salinity, phosphate, sulphate and POC and negative loading of pCH_4, seemed to be related to surface runoff (NEM season) and anthropogenic discharge of pollutants from nearby dumpsite, sewage treatment plant and settlements. The high positively loaded was Zn (0.91), Cd (0.86), Mn (0.79) and Cu (0.79) in factor 2, which accounted for 24.22% of the total variance. This component is represented by contribution of heavy metal pollution from the dump site leachate. The third factor accounts for approximately 13.17% of the total variance and had a moderate positive loading on SPM (0.61), NO_3 (0.67) and PO_4 (0.53).

5 Conclusions

This study has focused on temporal and spatial changes in the water quality for Pallikaranai wetland using GIS and statistical tools. Based on analysis of the water quality parameters, it was shown that the present status of the water quality in Pallikaranai wetland was in poor status due to the possible influence of different environmental factors on surface water quality. The high fluctuation in the various parameters on the wetland during the NEM season suggested that this is the period of large variability, in which environmental processes as a backwater from the Buckingham Canal, surface runoff and runoff, from the nearby dump yard, sewage treatment plant, settlements which determine the spatial behaviour of the wetland. The PCA supports to extract the origins responsible for water quality variations in the wetland, which includes discharge from the runoff, heavy metals from dumpsite leachate, organic nutrients, SPM and pCH_4 were the most significant parameters contributing to water quality variations in the wetland system. The continuous monitoring of conventional water quality parameters appears to be a useful tool help to identify system conditions.

References

Abowei, J.F.N. (2010) 'Salinity, dissolved oxygen, pH and surface water temperature conditions in Nkoro River, Niger Delta, Nigeria', *Advance Journal of Food Science and Technology*, Vol. 2, No. 1, pp.36–40.

Ali, M.M., Ali, M.L. Islam, S. and Rahman, Z. (2016) 'Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh', *Environmental Nanotechnology, Monitoring & Management*, Vol. 5, No. 5, pp.27–35.

Apfelbacher, J. (2008) *Land Use/Cover Change in the Context of Global Change around the Pallikaranai Marsh Land*, MSc thesis, Albert Ludwigs University.

Banerjee, K. (2012) *Biogeochemistry of the Hooghly Estuary and the Adjoining Sundarbans Mangrove*, unpublished PhD thesis, Anna University, Chennai, India.

Bhat, S. and Pandit, A.K. (2014) 'Surface water quality assessment of Wular Lake, a Ramsar site in Kashmir Himalaya, using discriminant analysis and WQI', *Journal of Ecosystems*, Vol. 2014, pp.1–18.

Borges, A.V. and Frankignoulle, M. (2002) 'Distribution and air-water exchange of carbon dioxide in the Scheldt plume off the Belgian coast', *Biogeochemistry*, Vol. 59, Nos. 1–2, pp.41–67.

Braide, S.A., Izonfuo, W.A.L., Adiukwu, P.U., Chindah, A.C. and Obunwo, C.C. (2004) 'Water quality of Miniweja stream, a swamp forest stream receiving non-point source waste discharges in Eastern Niger Delta, Nigeria', *Scientia Africana*, Vol. 3, No. 1, pp.1–8.

Choudhury, S.B. and Panigrahy, R.C. (1991) 'Seasonal distribution and behaviour of nutrients in the creek and coastal waters of Gopalpur, East Coast of India', *Mahasagar*, Vol. 24 No. 2, pp.81–88.

Damotharan, P., Perumal, N.V., Arumugam, M., Vijayalakshmi, S. and Balasubramanian, T. (2010) 'Seasonal variation of physic-chemical characteristics in Point Calimere coastal waters (South East coastal waters of India)', *Middle-East Journal of Scientific Research*, Vol. 6, No. 4, pp.333–339.

Davies, O.A., Ugwumba, A.A.A. and Abolude, D.S. (2008) 'Physico-chemistry of trans-Amadi (Woji) creek, Port Harcourt, Niger Delta, Nigeria', *Journal of Fisheries International*, Vol. 3, No. 3, pp.91–97.

Dixon, W. and Chiswell, B. (1996) 'Review of aquatic monitoring program design', *Water Research*, Vol. 30, No. 9, pp.1935–1948.

Gadhia, M., Surana, R. and Ansari, E. (2012) 'Seasonal variation in physic-chemical characteristics of Tapi estuary in Hazira industrial area', *Our Nature*, Vol. 10, No. 1, pp.249–257.

Garizi, A.Z., Sheikh, V. and Sadoddin, A. (2011) 'Assessment of seasonal variations of chemical characteristics in surface water using multivariate statistical methods', *International Journal of Environmental Science and Technology*, Vol. 8, No. 3, pp.581–592.

Sarma, V.V.S.S., Kumar, N.A., Prasad, V.R., Venkataramana, V., Appalanaidu, S., Sridevi, B., Kumar, B.S.K., Bharati, M.D., Subbaiah, C.V., Acharyya, T., Rao, G.D., Viswanadham, R., Gawade, L., Manjary, D.T., Kumar, P.P., Rajeev, K., Reddy, N.P.C., Sarma, V.V., Kumar, M.D., Sadhuram, Y. and Murthy, T.V.R. (2011) 'High CO_2 emission from the tropical Godavari estuary (India) associated with monsoon river discharges', *Geophysical Research Letters*, Vol. 38, No. 8, pp.1–4.

Geerts, L., Maris, T. and Meire, P. (2012) *An Interestuarine Comparison for Ecology in TIDE. The Scheldt, Elbe, Humber and Weser*, Study in the framework of the interreg IVB Project TIDE, Ecosystem Management Research Group, University of Antwerp, Antwerp, Belgium.

Gopinath, M., Jayasudha, S., Umamageswari, P. and Sampathkumar, P. (2013) 'Physico-biochemical variations in Parangipettai and Nagapattinam coastal waters, Southeast coast of India', *International Journal of Research in Biological Sciences*, Vol. 3 No. 4, pp.149–156.

Kamalkanth, S., Muniyan, M. and Ponni, A.C. (2012) 'Seasonal variations in physico-chemical parameters at Tranquebar Coastal Nagapattinam, Tamilnadu, India', *International Journal of Environmental Biology*, Vol. 2, No. 4, pp.203–207.

Kempe, S. (1982) 'Long-term records of the CO_2 pressure fluctuations in fresh water', in Degens, E.T. (Ed.): *SCOPE/UNEP Sonderbd.*, Vol. 1, No. 52, pp.91–332.

Kolbener, A. (2010) *Influence of Plants upon Methane Emissions from Wetlands*, unpublished PhD thesis, ETH, Zurich.

Kumar, G. and Ramanathan, A.L. (2014) 'Biogeochemistry of methane emission in mangrove ecosystem-review', *Indian Journal of Geo-Marine Sciences*, Vol. 43, No. 6, pp.899–997.

Li, Y., Ma, J., Yang, Z. and Lou, I. (2011) 'Influence of non-point source pollution on water quality of Wetland Baiyangdian, China', *Desalination and Water Treatment*, Vol. 32, Nos. 1–3, pp.291–296.

Magesh, N.S. and Chandrasekar, N. (2013) 'Evaluation of spatial variations in groundwater quality by WQI and GIS technique: a case study of Virudunagar District, Tamil Nadu, India', *Arabian Journal of Geosciences*, Vol. 6, No. 6, pp.1883–1898.

Mallick, S. (2009) 'Estimation of methane emission from a North-Indian subtropical wetland', *Journal of Sustainable Development*, Vol. 2, No. 2, pp.125–132.

Marinho, C.C., Campos, E.A., Guimaraes, J.R.D. and Esteves, F. (2012) 'Effect of sediment composition on methane concentration and production in the transition zone of a mangrove (Sepetiba Bay, Rio de Janerio, Brazil)', *Brazilian Journal of Biology*, Vol. 72, No. 3, pp.429–436.

Muduli, P.R., Kanuri, V.V., Robin, R.S., Kumar, B.C., Patra, S., Raman, A.V., Rao, G.N. and Subramanian, B.R. (2012) 'Spatio-temporal variation of CO_2 emission from Chilika Lake, a tropical coastal lagoon, on the east coast of India', *Estuarine, Coastal and Shelf Science*, Vol. 113, pp.305–313.

Ni, H.G., Lu, F.H., Luo, X.L., Tian, H.Y. and Zeng, E.Y. (2008) 'Riverine inputs of total organic carbon and suspended particulate matter from the Pearl River Delta to the coastal ocean off South China', *Marine Pollution Bulletin*, Vol. 56, No. 6, pp.1150–1157.

Olsson, L., Ye, S., Yu, X., Wei, M., Krauss, K.W. and Brix, H. (2015) 'Factors influencing CO_2 and CH_4 emission from coastal wetlands in Liaohe Delta, Northeast China', *Biogeosciences Discussion*, Vol. 12, pp.3469–3503.

Pathak, H. and Limaye, S.N. (2011) 'Study of seasonal variation in groundwater quality of Sagar City (India) by principal component analysis', *E-Journal of Chemistry*, Vol. 8, Nos. 1–4, pp.2000–2009.

Pejman, H., Bidhendi, G.R.N., Karbassi, A.R., Mehrdadi, N. and Bidhend, M.E. (2009) 'Evaluation of spatial and seasonal variations in surface water quality using multivariate statistical techniques', *International Journal of Environmental Science and Technology*, Vol. 6, No. 3, pp.467–476.

Prasad, M.B.K. and Ramanathan, A.L. (2008) 'Dissolved organic nutrients in the Pichavaram mangrove waters of east coast of India', *Indian Journal of Marine Sciences*, Vol. 37, No. 2, pp.141–145.

Purvaja, R. and Ramesh, R. (2001) 'Natural and anthropogenic methane emission from coastal wetlands of South India', *Environmental Management*, Vol. 27, No. 4, pp.547–557.

Ramesh, R., Purvaja, G.R., Parashar, D.C., Gupta, P.K. and Mitra, A.P. (1997) 'Anthropogenic forcing on methane efflux from polluted wetlands (Adyar River) of Madras City, India', *Ambio*, Vol. 26, No. 6, pp.369–374.

Ravichandran, C. and Teneson, R. (2015) 'Assessment of water quality in Koothapar wetland, Tiruchirappalli District', *International Research Journal of Engineering and Technology*, Vol. 2, No. 2, pp.240–250.

Robina, R.S., Pradipta, R., Mudulib, K., Vardhanb, V., Raob, G.N. and Balasubramanian, T. (2011) 'Seasonal variation of nutrient concentration in a tropical estuary, southwest coast of India', *PIET, Rourkela MIP – 2011*.

Satpathy, K.K., Mohanty, A.K., Natesan, U., Prasad, M.V.R. and Sarkar, S.K. (2010) 'Seasonal variation in physicochemical properties of coastal waters of Kalpakam, east coast of India with special emphasis on nutrients', *Environmental Monitoring and Assessment*, Vol. 164, pp.153–171.

Senthilkumar, B., Purvaja, R. and Ramesh, R. (2008) 'Seasonal and tidal dynamics of nutrients and chlorophyll a in a tropical mangrove estuary, southeast coast of India', *Indian Journal of Marine Sciences*, Vol. 37, No. 2, pp.132–140.

Senthilkumar, S., Santhanam, P. and Perumal, P. (2002) 'Diversity of phytoplankton in Vellar estuary, southeast coast of India', in Ayyappan, S. et al. (Eds.): pp.245–248, AFSIB, Mangalore, AeA, Bhubanewar, India.

Shalini, A., Ramesh, R., Purvaja, R. and Barnes, J. (2006) 'Spatial and temporal distribution of methane in an extensive shallow estuary, South India', *Journal of Earth System Science*, Vol. 115, No. 4, pp.451–460.

Shiah, F.K., Gong, G.C. and Xiao, T. (2006) 'Effects of Changjiang River summer discharge on bottom up control of coastal bacterial growth', *Aquatic Microbial Ecology*, Vol. 44, No. 2, pp.105–113.

Srinivasan, K. and Natesan, U. (2013) 'Spatio-temporal variations in water quality of Muttukadu Backwaters, Tamilnadu, India', *Water Environment Research*, Vol. 85, pp.1–9.

Tamooh, F.K., Meersche, K.V., Meysman, F., Marwick, T.R., Borges, A.V., Merckx, R., Dehairs, F., Schmidt, S., Nyunja, J. and Bouillon, S. (2012) 'Distribution and origin of suspended matter and organic carbon pools in the Tana River Basin, Kenya', *Biogeosciences*, Vol. 9, No. 8, pp.2905–2920.

Tikle, S., Aboori, M.J. and Sankpal, R. (2012) 'Spatial distribution of ground water quality in some selected parts of Pune City, Maharashtra, India using GIS', *Current World Environment*, Vol. 7, No. 2, pp.281–286.

Upstill Goddard, R.C., Rees, A.P. and Owens, N.J.P. (1996) 'Simultaneous high precision measurements of methane and nitrous oxide in water and seawater by single-phase equilibration gas chromatography', *Deep Sea Research*, Vol. 33, No. 10, pp.1669–1682.

Vega, M., Pardo, R., Barrado, E. and Deben, L. (1998) 'Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis', *Water Research Journal of International Association of Water Quality*, Vol. 32, No. 2, pp.3581–3592.

Ventura, R.E. (2014) *Wetlands and Greenhouse Gas Fluxes: Causes and Effects of Climate Change – A Meta-analysis*, Senior theses, Paper No. 107.

Yao, G.R., Gao, A.Z., Wang, Z.G., Huang, X.K., He, T., Zhang, Y.L., Jiao, S.L. and Ding, J. (2007) 'Dynamics of CO_2 partial pressure and CO_2 outgassing in the lower reaches of the Xijiang River, a subtropical monsoon river in China', *Science of the Total Environment*, Vol. 376, Nos. 1–3, pp.255–266.

Zhao, Z. and Cui, F. (2009) 'Multivariate statistical analysis for the surface water quality of the Luan River, China', *Journal of Zhejiang University Science, A*, Vol. 10, No. 1, pp.142–148.

Websites

http://scholarship.claremont.edu/pomona_theses/107 (accessed 21 July 2016).

https://www.academia.edu/1631068/Seasonal_variation_of_nutrient_concentration_in_a_tropical_estuary_southwest_coast_of_India (accessed 11 August 2016).