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Phytoremediation of Sewage-Fed Wetlands of East-Kolkata, India - A Case Study

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Abstract

Degree of purification of water qualities had been assessed in different sewage-fed wetlands in Kolkata Metropoliton Area, West-Bengal, India by one of the predominant macrophytic components, Eichhornia crassipes, locally named as water hyacinth from the littoral belts of the studied aquatic systems. This study has revealed that water quality was improved significantly with the reduction in values of BOD, COD, TDS, etc. All those sewage loaded aquatic bodies were considerably polluted which were manifested by higher values of Pollution Load Index and water quality Index during the present study. Besides, toxic metals from this aquatic environment have also been found to be reduced to a considerable extent which was evident by the deduction of bio-concentration factor of toxic metals. These results have indicated that toxic metals were absorbed in this plant community to a great extent from its readily available form in the aquatic medium. Thus, water-hycinth as a most flourishing and abundant macrophyte is being recommended as an important biotic agent for the bio-remediation and eco-restoration of pollution loaded aquatic systems.

Keywords: Wetlands, sewage, water quality index, pollution load index, bio-concentration factor.

Introduction

Aquatic ecosystem is a complex system regulated by functional forces of several biotic and abiotic factors which interact towards maintaining ecological equilibrium. Ecosystems are capable of accommodating mild external forces including human exploitation and management practices[1,2]. But the diverse communities within the system with a stable behavior are very sensitive to such manipulations resulting in decrease in efficiency of ecosystem functioning[3]. The shallow water or littoral zone in a freshwater ecosystem provides the most important habitat for macrophytes, periphyton, phytoplankton, zooplankton, aquatic insects, fish, birds, and other aquatic animals[4]. The runoff water streams from forests, grassland and agricultural lands may enter into lakes or, different wetlands[5]. Land water ecotones are often characterized by higher biological diversity than adjacent patches[5.] In fact, this ecotonal area is the place of greatest production and decomposition as well as represents a hot spot of biological diversity[6]. Ecotone entails an interaction between two or more ecosystems which results in the existence of mechanisms that do not exist in any one of the component of ecosystems. These are universal features on the earth occurring in the tropical, temperate and polar regions[6]. Therefore, this sensitive zone needs to be conserved through scientific ways[7]. In addition, they provide shelter for threatened species of plants and animals and renders economic benefits such as fish breeding[8]. Stored water percolates downward, getting purified in the process and replenishes the ground water. But these wetlands have been shrinking rapidly because of ongrowing urbanization coupled with industrialization[9,10]. In the developing countries, industrialization is being prompted by replacing natural ecosystems with the main objective of commodity production for a short term benefit leading to the reclaimation of peoples by[8] developing industrial colonies and also to dump urban wastes in the altered environmental set-ups.

As for examples, phosphate mining has resulted in the loss of thousands of acres of wetlands in central Florida[11]. The acidity and the high metal concentrations alter the biotic community composition and can result in mortality[11,12]. Although natural wetlands have the capacity to buffer some of the acidity and absorb a certain amount of the pollutants, over time, the assimilative capacity will become saturated[13]. These pollutants enter into the mainstream of wetlands through a network of different canals, channels and nullahs which after being deposited adversely affect aquatic organisms[14].

The present paper has attempted to device Water Quality Index (WQI), Pollution Load Index (PLI) and Bio-Concentration Factor (BCF) based on the pronounced water quality parameters (temperature, pH, turbidity, TDS, alkalinity, calcium, magnesium, chloride, total hardness, conductivity, DO, BOD and COD), soil parameters [moisture content, pH, texture (sand, silt and clay), organic matter, available nitrogen, available phosphorus and available potassium] and concentration of major heavy metals (Pb, Cr, Cd and Hg) estimated through different months of a year (July 2010 – June 2011) from different structural components (water, soil and macrophytes) of selected water bodies in order to evaluate the bio-accumulation and biotransformation processes of heavy metals in changing ecological conditions. This study has also been undertaken to generate information pertaining to recycling of sewage, removal of heavy metals and purification of sewage fed water bodies for their sustainable management based on long-term field based case studies.

Material and Methods

Physiography of study sites: Kolkata is sustained by a unique and friendly water regime[15]. To its west flows the river Hooghly, along the levee of which the city has grown. About 30 Km. eastward, there flows the river Kulti-Bidyadhari that carries the drainage to the Bay of Bengal. Underneath the city lies a copious reserve of groundwater. Finally, the central to this regime is the vast wetland area beyond the eastern edge of the city that has been transformed to use city's wastewater in fisheries, vegetables and paddy fields[16,17]. The river side on West of the Kolkata is still the highest part of the city, sloping gradually away from the river towards the East, the original and natural backyard of the city. The entire drainage and sewage networks of entire Kolkata depends heavily on those natural networks of low lying waterlogged areas, ponds, bheries, ditches, nullahs and tidal creeks connecting with estuarine networks of Hoogly Mathla estuarine complex of Mangrove Ecosystems[16,17].

The uniqueness of East Kolkata - wetland networks are for its water recycling system and in the development of sewage fed fisheries on 2500 ha of low lying land supplying 20 tones of fishes daily and employing about thousand of peoples[16-18]. It's resource recovery system, developed by local peoples through cooperative societies, provided employment for a large number of people by way of producing a significant amount of edible biological components as valuable resources for human consumption[19,20].

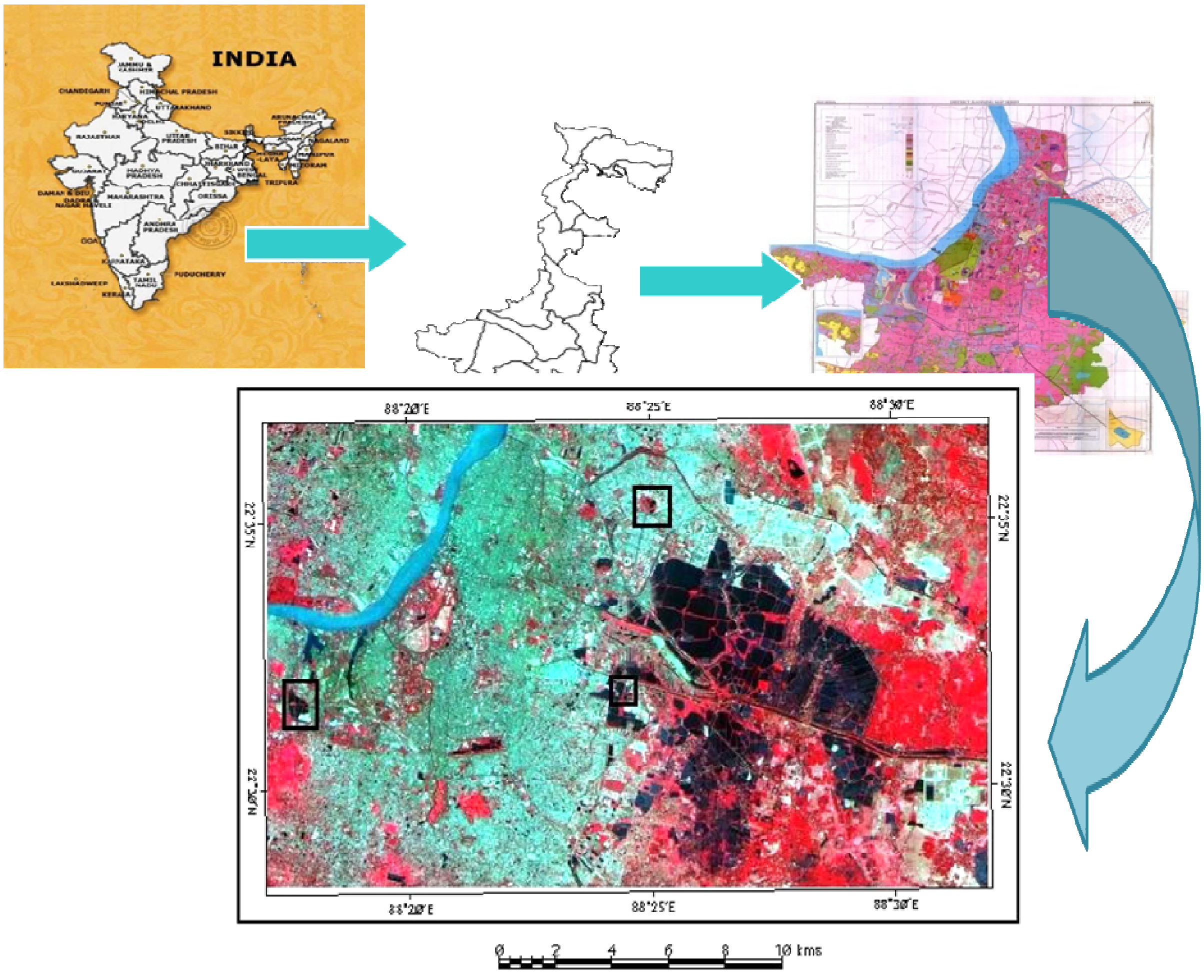

Figure-1
Location Map of the Study Sites

For the present research investigation, four (4) study sites (water bodies) have been selected along a considerable stretch of the

Kolkata Metropolitan based on contrasting ecological characteristics. Study site – I is a managed water body located in the Central park, Banabitan, Salt lake (a site developed for eco-tourism). Study site - II (unmanaged wetland, located at Chhappan Talao, Uttar Panchanna Gram, behind Landmark Hotel, by the side of Eastern Metropolitan Bypass - a major roadways of Kolkata) is ecologically stressed water bodies receiving effluents as municipal sewage, detergent wastes out of the activities of washer-men and wastes from automobile cleaning activities of nearby regions. Study site – III (within Nature Park) is also stressed water bodies receiving huge quantity of wastes, especially sewage. Study site – IV (also in the Nature Park) is an ecorestored aquatic system receiving water after phytoremediation with macrophytes (figure-1).

Collection of water and soil samples: Water samples were collected once in a month during early morning at a depth of 0.5m from the surface from four (4) different study sites during one year (July'10 - June'11) and were kept in 2 liters plastic containers. The bottles were placed in ice-box immediately after samplings.

Soil sediment samples were collected from the selected water bodies with hand operated grab samples from July 2010 to June 2011. After collection of samples, any lithogenic shells and foreign detritus if present were removed by hand picking. Samples from each site were made composite (equal amount of soils from all sites in a particular location) by mixing up thoroughly using a mechanical homogenizer.

Analysis of water samples: Different Water Quality parameters (viz. temperature, pH, turbidity, TDS, alkalinity, calcium, chloride, total hardness, conductivity, DO, BOD, COD, Pb, Cr, Cd and Hg) were estimated by standard methods as outlined by APHA[21]. Water quality assessment was done on the basis of average values of physico-chemical components during study period (2010-2011).

The water quality of four study sites have been assessed by using National Sanitation Foundation Water Quality Index (NSF-WQI)[22] calculated on considering ratings and weighings of the parameters like pH, DO and BOD.

Water Quality Index (WQI):

$$WQI = \sum_{i=1}^{n} w_i q_i$$

Where w_i and q_i are the unit weight and the quality rating of the i^{th} parameter respectively.

Table-1
Values of w_i, used in the calculation of WQI

Parameter	w	1 / w=w_i
DO	0.17	0.31
pH	0.12	0.44
BOD	0.10	0.26
	0.39	

Table-2
Values of q_i, used in the calculation of WQI

Parameter	Range	Equation for q_i
DO	0-40%	0.18+0.66*(%saturation DO)
(at NTP, 8.5ppm DO =100% saturation)	40-100%	(-)13.5+1.17*(%saturation DO)
	100-140%	163.34-0.62*(%saturation DO)
pH	2--5	16.1+7.35*(OV of pH)
	5--7.3	(-)142.67+33.5*(OV of pH)
	7.3--10	316.96-29.85*(OV of pH)
	10--12	96.17-8.0*(OV of pH)
BOD	0—10ppm	96.67-7.0*(OV OF BOD)
	10—30ppm	38.9-1.23*(OV OF BOD)

Analysis of soil samples: Moisture content was determined by the standard method (IS:2720, Part-II, 1973). The pH was recorded by potentiometer in aqueous (1:2.5) solution of soil and the organic matter by means of modified Walkly and Black method of M. L. Jackson, 1967[23,24]. Conductivity was measured with the help of the method–IS: 14767 (2000). Available nitrogen was followed by the method – IS :14684 (2000). According to M.L. Jackson, 1967[23,24], determination of both available phosphorus and available potassium were being possible.

Analysis of Heavy metals (Pb, Cr, Cd and Hg): Lead (Pb), Chromium (Cr), Cadmium (Cd) and Mercury (Hg) of water were estimated by the methods as outlined in APHA[21] and in case of soil and water hyacinth were followed by USEPA, 1996. Pollution Load Index (PLI)[25] proposed by Tomlinson et al, 1982.

Pollution Load Index: $PLI = (CF_1 * CF_2 * \ldots\ldots C\,Fn)^{1/n}$

Where n = number of metals and CF = Contamination Factor = $[M_{soil}] / [M_{std}]$ where M = Metal concentration.

Table-3
Base line level of four heavy metal(Pb, Cr, Cd and Hg) standards used in PLI value for comparison

Parameter	Lead (pb)	Chromium (cr)	Cadmium (Cd)	Mercury (Hg)
Standard value	50 (Clean sediments, 1995)	50 (Clean sediments, 1995)	1 (Clean sediments, 1995)	0.3 (Earth crust)

Bio-Concentration Factor :

$$\text{Bio-Concentration factor (BCF)} = \frac{\text{metal concentration of Water Hyacinth}}{\text{metal concentration of Water}}$$

Statistical analysis: Experimental results were subjected to statistical analysis of Pearson's correlation coefficient. The statistical analysis was carried out using the standard and software package (Microsoft Office XP, excel) and SPSS (version 21.0).

All chemicals and standard solutions used in the study were obtained from Merck (GR and Pure grade). Double distilled water was used throughout the study. All glass-wares and containers were thoroughly cleaned,[21] finally rinsed with double distilled water several times and air-dried prior to use. Validation for the estimation of all parameters were done using certified reference material (CRM, NIST). The analytical results were in good agreement with the certified values.

Quality Assurance and Quality Control: Quality Assurance (QA) and Quality Control (QC) protocols were used to maintain integrity of the analytical results. QA and QC protocol for the sampling plan included duplicate samples for each sampling event for all analyses. The analytical results of the samples collected in duplicate did not exhibit any significant differences between two analytical results of individual sampling event[26].

Results and Discussion

Water Quality Parameters and Water Quality Index (WQI): Temperature showed clear seasonal trend with maximum temperature during pre-monsoon followed by monsoon at all study sites. Maximum turbidity was recorded during monsoon at site - III, site - IV and site - I, whereas the turbidity registered highest result at site - II during post-monsoon (Dec'10) (30.6 NTU) and that of lowest during pre-monsoon (6.7 NTU). Highest and lowest values of pH were more or less same in all four study sites. TDS showed distinct seasonal trend with the maximum value during monsoon at site - III, site - I and site - II. The highest value of alkalinity was estimated during monsoon (Aug'10) (518.7 mg/l) at site - III followed by site - II, site - IV and site - I. Total hardness showed highest result also during monsoon (Aug'10) (755.6 mg/l) at site - III followed by site - II, site - IV and site - I. The chloride content was found to be higher at site - III than other three sites. After reviewing the values of both chloride and conductivity of four study sites, chloride was found to be directly co-related with conductivity. Lowest maximum value of BOD (4.1mg/l) and COD (26.3mg/l) were exhibited at site - IV during monsoon (Aug'10) followed by site - I, site - II and site - III.

During 2010-2011, after assessment of grain size (texture) of bottom soil, both site-I and site-II. displayed more sand concentration than site - III and site - II. On the other hand, the clay concentration was maximum at site - III and site - IV during monsoon than other two sites. The concentration of available nitrogen was found to be maximum (0.051%) at site - IV during monsoon (September '10), which is supposed to promote better development for pisciculture with higher nutrients input. Available phosphorus and available potassium of soil exhibited maximum concentrations (254.2mg/kg and 693.5mg/kg, respectively) at site - III than others. The maximum range (7.4% – 43.8%) of organic matter was found at site - III followed by other three different sites.

Table-4
Pearson Correlation among different heavy metals within water, soil and water-hyacinth at site – I (2010-2011)

	Water Pb	Water Cr	Water Cd	Water Hg	Soil Pb	Soil Cr	Soil Cd	Soil Hg	WH-Pb	WH-Cr	WH-Cd	WH-Hg
WaterPb	1											
WaterCr	-0.227	1										
WaterCd	-0.054	0.384	1									
WaterHg	0.336	0.516	0.412	1								
SoilPb	-0.258	0.486	0.363	0.23	1							
SoilCr	-0.113	0.414	0.353	0.151	0.469	1						
SoilCd	-0.11	-0.05	-0.034	0.081	-0.332	0.145	1					
SoilHg	0.085	-0.372	-0.083	-0.27	-0.568	0.032	.614*	1				
WHPb	-0.079	-0.269	-0.167	-0.295	-0.019	-0.364	0.318	-0.042	1			
WHCr	-0.318	-0.141	-0.082	-0.193	-0.255	-0.142	-0.319	-0.126	-0.292	1		
WHCd	0.287	0.097	-0.107	0.42	0.221	-0.215	-0.243	-.794**	0.292	-0.061	1	
WHHg	-0.398	-0.105	0.156	-0.195	0.513	0.093	-0.129	-0.343	0.138	-0.19	0.101	1

Table-5
Pearson Correlation among different heavy metals within water, soil and water-hyacinth at site – II (2010-2011)

	Water Pb	Water Cr	Water Cd	Water Hg	Soil Pb	Soil Cr	Soil Cd	Soil Hg	WH-Pb	WH-Cr	WH-Cd	WH-Hg
WaterPb	1											
WaterCr	0.046	1										
WaterCd	0.082	0.236	1									
WaterHg	-.637*	0.114	-0.061	1								
SoilPb	0.034	0.148	0.06	-0.242	1							
SoilCr	-0.142	-0.432	-0.266	0.445	-0.315	1						
SoilCd	-0.009	0.262	0.146	-0.029	-0.431	-0.301	1					
SoilHg	0.163	0.141	0.222	-0.329	0.141	-0.26	0.369	1				
WHPb	-0.312	0.301	-0.131	0.224	-0.198	0.172	0.454	0.382	1			
WHCr	-0.005	.733**	0.433	-0.079	0.23	-0.439	0.167	0.215	-0.041	1		
WHCd	0.54	0.009	0.328	-0.406	-0.276	0.174	0.142	0.294	0.351	-0.192	1	
WHHg	-0.081	-0.11	0.049	0.226	-0.083	0.015	-0.189	-0.11	-.617*	-0.004	-0.42	1

Table-6
Pearson Correlation among different heavy metals within water, soil and water-hyacinth at site – III (2010-2011)

	Water Pb	Water Cr	Water Cd	Water Hg	Soil Pb	Soil Cr	Soil Cd	Soil Hg	WH-Pb	WH-Cr	WH-Cd	WH-Hg
WaterPb	1											
WaterCr	.709**	1										
WaterCd	0.517	0.448	1									
WaterHg	0.214	.597*	-0.07	1								
SoilPb	-0.485	-0.546	-0.551	-0.035	1							
SoilCr	0.343	0.487	0.036	0.514	-0.124	1						
SoilCd	.596*	0.39	0.256	0.341	-0.157	0.269	1					
SoilHg	-0.058	-0.192	-0.47	0.363	.633*	0.44	0.202	1				
WHPb	0.155	-0.212	-0.45	-0.004	0.523	-0.103	-0.073	0.488	1			
WHCr	.586*	.750**	0.431	0.438	-0.462	.822**	0.231	0.097	-0.242	1		
WHCd	.650*	0.424	.767**	-0.118	-.619*	0.233	0.329	-0.293	-0.423	0.562	1	
WHHg	0.224	-0.023	-0.409	-0.195	0.12	0.018	-0.072	0.165	.670*	0.043	-0.145	1

Table-7
Pearson Correlation among different heavy metals within water, soil and water-hyacinth at site – IV (2010-2011)

	Water Pb	Water Cr	Water Cd	Water Hg	Soil Pb	Soil Cr	Soil Cd	Soil Hg	WH-Pb	WH-Cr	WH-Cd	WH-Hg
WaterPb	1											
WaterCr	-0.171	1										
WaterCd	-0.018	.588*	1									
WaterHg	.660*	-0.049	0.227	1								
SoilPb	-0.048	0.238	0.354	-0.186	1							
SoilCr	0.419	0.412	-0.007	0.479	-0.359	1						
SoilCd	-0.352	-0.383	-0.487	-0.099	-0.328	0.047	1					
SoilHg	0.248	-0.013	0.504	0.512	0.461	-0.031	-0.282	1				
WHPb	-0.004	0.103	0.333	-0.289	.806**	-0.317	-0.222	0.489	1			
WHCr	0.324	0.21	000	0.506	-0.178	.675*	-0.239	0.264	-0.152	1		
WHCd	0.015	-0.402	-0.31	0.029	0.285	-0.29	0.504	0.08	0.289	-0.285	1	
WHHg	0.457	0.056	0.295	.852**	-0.115	0.315	-0.244	.664*	-0.133	0.512	-0.042	1

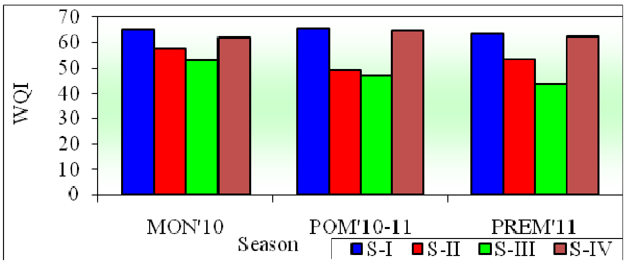

Figure-2
Seasonal variation in Water Quality Index (WQI) of different study sites during 2010-2011

The calculated Water Quality Index (WQI) values (Figure-2) in the present study ranged from minimum 43.9 (postmonsoon'10-11) to the maximum of 53.0 (monsoon'10) at site - III indicating Grade – C (Bad) in the classification scheme and it ranged from minimum of 61.9 (monsoon'10) to the maximum of 64.8 (postmonsoon'10-11) at site - IV indicating Grade – B (Good) and ranged from minimum of 49.3 (postmonsoon'10-11) to the maximum of 57.6 (monsoon'10) at site - II indicating C (Bad). According to WQI, both sites - III and site - II showed Grade – C (Bad) and site - IV and site - I both were Grade – B (Good).

Heavy Metals and Pollution Load Index (PLI): The concentrations of lead (Pb) and chromium (Cr) in soil were recorded in higher levels in comparison to cadmium (Cd) and mercury (Hg) concentrations in each study site. The correlation coefficient values of all metals were presented in tables - 4, 5, 6 and 7. It was also recorded that concentrations of all heavy metals (Pb, Cr, Cd and Hg) were found to be considerably higher in soil and water-hyacinth than their concentrations in the water. At study site - III, Cr in water-hyacinth displayed significant positive correlation with Cr of water and soil ($P < 0.01$). These findings are supposed to be because of gradual and steady deposition of all those heavy metals from water to soil after entering into selected water bodies from the sewage loaded water, especially at site - III. Cd in water-hyacinth has shown positive significant correlation coefficient value (r=o.767**) with Cd in water of site - III. At site - IV, Hg in water was found to bear positive significant correlation with Hg in water-hyacinth (r=0.852**). There was a significant positive correlation in between Pb in soil and Pb in water-hyacinth (r=0.806**) at site - IV. Besides, both Cr and Hg of soil displayed significant (P<0.05) positive correlations with water-hyacinth at site - IV. Hg in soil revealed significant positive (P<0.05) correlation with Cd in soil at site - I whereas, significant negative (r= - 0.794**) correlation was found in between Hg in soil and Cd in water-hyacinth. So, it can be concluded that Hg was highly associated with Cd at site - I. Cr in water-hyacinth showed significant positive (P<0.01) correlation with Cr of water (r=o.733**) at site - II.

The Pollution Load Index (PLI) values (Figure-3) in the present study ranged from minimum of 0.61 to the maximum of 0.73 at site - I indicating unpolluted water; ranged from minimum of 2.41 to the maximum of 3.04 at site - II indicating polluted water; ranged from minimum of 2.44 to the maximum of 4.11 at site - III indicating polluted water and ranged from minimum of 0.80 to the maximum of 2.02 at site - IV indicating unpolluted to moderately polluted water; According to PLI, both site – III and site - II indicated Polluted water while both site - IV and site - I – showed unpolluted water.

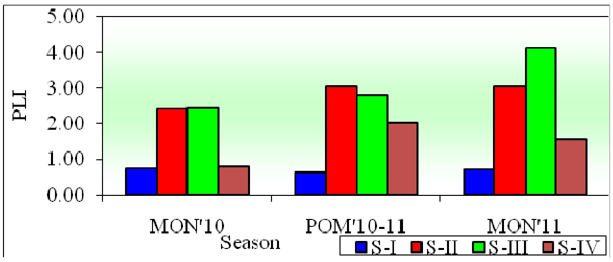

Figure-3
Seasonal variation in Pollution Load Index (PLI) Of different study sites during 2010-2011

According to bio-concentration factor (BCF), (Figure-4) at site - III, Pb highlighted maximum value (12762.8) during monsoon (2010) and Cr exhibited maximum value (18573.18) during pre-monsoon (2011) than other three study sites. Cr showed the higher values during pre-monsoon (2010-2011) at four selected study sites (figure-4). Cd at both site - III and site - IV showed highest peaks during pre-monsoon (2010-2011). In the present study, the range of values of Hg as deducted from bio-concentration factors was from a minimum of 371.6 (postmonsoon'10-11) to the maximum of 1972.5 (pre-monsoon'11) at site - II.

Conclusion

The present study dealt with recycling, reuses and rectification capacities of the different structural components (water, soil and macrophytes) in natural aquatic ecosystem functioning of some selected wetlands having contrasting ecological features in the East - Kolkata Wetlands, India, a Ramsar site. The sewage loaded water after entering into an arrays of natural wetlands, locally named as 'Ponds' (<1acre) / 'Bheries' (>1acre) based on their sizes, undergo a lot of ecological changes because of intricate interactions among different structural components of these aquatic ecosystems. Initially, the very thick, dense, black coloured sewage water having very high BOD (>200ppm), COD (>600ppm), high TDS (>400ppm), high TSS (>500ppm), least DO (<1ppm) and undesirable pH (<5 / >10) are subjected to flow modification and bioaccumulation capacity of macrophytic components of the receiving water bodies where most of the heavy solid substances including heavy metals get deposited in the bottom of the water bodies and heavy metals also get accumulated within macrophytes. The semi purified water are then allowed to enter into the other water bodies through a screen of macrophytes mostly composed of water-hyacinth[27 & 28]. The uptake of heavy metals by water-hyacinth is supposed to have been taken place from both water or soil mainly by the root organs. This study has revealed that BOD, COD and other water quality components were found to be significantly removed from aquatic medium in time and space because of interactions of biotic and abiotic components. According to WQI, both site – II and site - III have been designated as Grade – C (Bad) and both site - I and site - IV have been assigned the status of Grade – B (Good). According to PLI, site - II and site - III both indicated as polluted and site - I and site - IV both showed Unpolluted. This work also revealed changing spectrum of ecological properties of different wetlands as manifested by the changes of Water Quality Index (WQI) values. Pollution Load Index (PLI) also tended to highlight the similar results like those of WQI values. On the other hand, Bio-Concentration Factor (BCF) in different wetlands highlighted the significant differences on the pattern of bioaccumulation of heavy metals vis - a - vis concentration in the contrasting aquatic systems. Considering all those facts, the present study corroborates the other research studies[29 – 34] undertaken in the different parts of the world using aquatic macrophytes in water purification.

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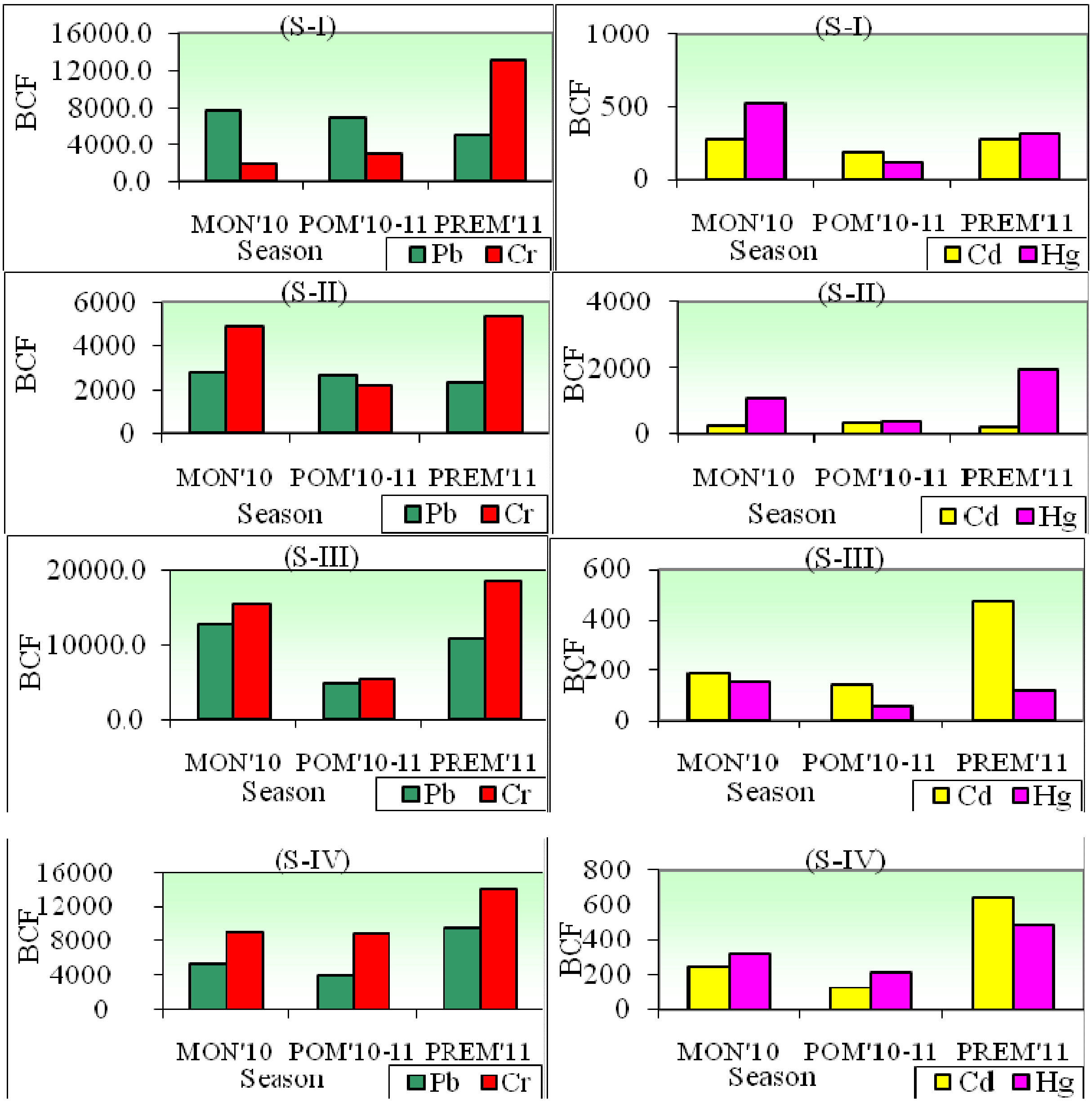

Figure-4
Seasonal variation in Bio-Concentration Factor (BCF) of four different study sites during 2010- 2011

The uptake of heavy metals by water-hyacinth is supposed to have been taken place from both water or soil mainly by the root organs. This study has revealed that BOD, COD and other water quality components were found to be significantly removed from aquatic medium in time and space because of interactions of biotic and abiotic components. According to WQI, both site – II and site - III have been designated as Grade – C (Bad) and both site - I and site - IV have been assigned the status of Grade – B (Good). According to PLI, site - II and site - III both indicated as polluted and site - I and site - IV both showed Unpolluted. This work also revealed changing spectrum of ecological properties of different wetlands as manifested by the changes of Water Quality Index (WQI) values. Pollution Load Index (PLI) also tended to highlight the similar results like those of WQI values. On the other hand, Bio-Concentration Factor (BCF) in different wetlands highlighted the significant differences on the pattern of bioaccumulation of heavy metals vis - a - vis concentration in the contrasting aquatic systems. Considering all those facts, the present study corroborates the other research studies[29–34] undertaken in the different parts of the world using aquatic macrophytes in water purification.

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