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Water Quality Analysis of the Coastal Regions of Sundarban Mangrove Wetland, India Using Multivariate Statistical Techniques

Santosh Kumar Sarkar and Bhaskar Deb Bhattacharya
*Department of Marine Science, University of Calcutta,
35 Ballygunge Circular Road, Kolkata – 700019,
India*

1. Introduction

Rivers are among the most vulnerable water bodies to pollution because of their role in carrying municipal and industrial wastes and run-offs from agricultural lands in their vast drainage basins. Detailed hydro-chemical research is needed to evaluate the different processes and mechanisms involved in polluting water (Helena et. al., 1999). Furthermore, due to temporal and spatial variations in water qualities, monitoring programs that involve a large number of physicochemical parameters and frequent water samplings at various sites are mandatory to produce reliable estimated topographies of surface water qualities (Dixon & Chiswell, 1996). The results are usually compiled into a large data matrix, which requires sophisticated data interpretations (Chapman, 1992). Water quality monitoring has one of the highest priorities in environmental protection policy (Simeonov et al., 2002). The main objective is to control and minimise the incidence of pollutant-oriented problems, and to provide water of appropriate quality to serve various environmental purposes. The quality of water is identified in terms of its physical, chemical and biological parameters (Sargaonkar & Deshpande, 2003). The particular problem in the case of water quality monitoring is the complexity associated with analysing the large number of measured variables (Saffran, 2001). Belonging to the class of a tide-dominated wetland (Selvam, 2003), the Sundarban wetland is comprised of a complex network of estuaries, tidal inlets, tidal creeks and a large number of islands. Most of the creeks act as the pathway for the to-and-from movement of tidal water and downstream flow of river systems. The present day sedimentation of the Ganga-Brahmaputra systems (with average water discharge of 970 km^3/y and average sediment discharge of 900-1200 x 106 t/y) is strongly influenced by the wet summer monsoon covering only 4 months of the year when about 80% of the Ganga discharge (300 x109 m^3/y of water and 520 x 106 t/y of sediments) is contributed to the delta (Goodbred et al., 2003). The balance between freshwater and salt water in this wetland has been suffering modifications from the tilting of the G-B delta toward the east and rising sea level. Increased anthropogenic influences like withdrawal of river water from the upstream region and increase in organic and inorganic pollutants have further led to deterioration of health of the wetland (Bhattacharya, 2008).

Source: Environmental Management, Book edited by: Santosh Kumar Sarkar,
ISBN 978-953-307-133-6, pp. 258, September 2010, Sciyo, Croatia, downloaded from SCIYO.COM

2. Area investigated

The Indian Sundarban (21^0 32′ to 22^0 40′ N and 88^0 85′ N to 89^0 00′ E), the largest delta in the estuarine phase of the river Ganges, is a unique bioclimatic zone surrounded by the more typical geographical conditions exemplified by the coastal region of the Bay of Bengal. Situated in the low lying, meso-macrotidal, humid and tropical belt, the Sundarban harbors the World's largest mangrove forest together with associated flora and fauna. The total estuarine phase of the Indian Sundarban is very irregular and criss-crossed by several tributary rivers, creeks and waterways. There are also many other tributaries rivers like Matla, Gosaba, Muriganga, Saptamukhi etc. Seven sampling sites namely Lot 8 (S_1), Chemagari (S_2), Lower long sand (S_3), Jambu Island (S_4), Gosaba (S_5), Canning (S_6) and Dhamakhali (S_7) have been selected covering both eastern and western flank of Sunderban (as shown in Figure 1). They are of diverse environmental stresses and of different hydrodynamic conditions in the context of depth, tidal amplitude and wave action gradually being less towards the upstream direction. Among all the stations S_3 and S_4 are situated at the most seaward part of the estuary and have direct marine influence. S_2 is a macrotidal Chemaguri creek, situated 9 Km upstream from the mouth of the estuary and S_1 is situated at the Muriganga river, bifurcating distributory channel of the Hugli river. S_5 and S_6 are situated on the Bidya and Matla rivers respectively. The wetland belongs to the tropical climate with a mild winter season between October and March, a hot humid summer season between March to June and the warm and humid monsoon season from June to October when most of the precipitation occurs (average annual rain fall ~ 1800 mm).

3. Materials and methods

Surface water samples were collected in pre-cleaned polythene bottles during high tide in forenoon hours. Winkler's titrimetric method (Strickland and Parsons, 1972) was followed for the estimation of dissolved oxygen (DO) and biological oxygen demand (BOD_5). Temperature was measured onboard using a mercury thermometer (0 – 100^0C) and transparency (cm) of the water was determined using a secchi disc. pH and turbidity (nephelometric turbidity unit, NTU) were measured by a Deluxe Digital pH Meter (Model No. 101 E) and a Turbidity meter respectively. The dissolved micro-nutrients such as nitrate, phosphate and silicate were estimated by colorimetric methods described by Strickland and Parsons, 1972, after filtering the water through 0.45µ Millipore filter paper. Chlorophyll pigments (chlorophyll a, b and c) were analyzed by spectrometry following the standard method (Strickland & Parsons, 1972; Parsons et. al., 1984). Chemical oxygen demand (COD) was estimated adopting the method described by Parsons et. al. (1984).

4. Statistical analyses

Statistical analyses like factor analysis, clustering dendrogram, ANOVA were performed using statistical softwares, MINITAB 14 and XL-Stat. Data were transformed using the $\log_{10}(n+1)$ function to allow the less abundant variable to exert same influence on the calculation of similarities (Clarke & Warwick, 1994).

5. Results and discussions

A well - defined spatial and temporal heterogeneity in distribution of different water quality parameters was observed in the studied regions (Figure 2). Average surface water temperature recorded during the study period was 24.63 – 27.89 ^{0}C. In all the stations Lot 8 showed highest mean temperature (27.68 ± 3.15 ^{0}C) and Dhamakhali (S_7) showed highest mean turbidity (24.85 ± 3.49 NTU) during the study period. The correlation coefficient (r) between turbidity and temperature showed a positive value ($r = 0.502$, $P = 0.01$) as turbidity is the condition resulting from suspended solids in the water, including silts, clays, industrial wastes, sewage and plankton. Such particles absorb heat in the sunlight, thus raising water temperature, which in turn lowers dissolved oxygen levels. Dissolved oxygen participates in many chemical and biological processes in marine and estuarine ambience and thus, it constitute an important parameter required for all type of biological investigations. DO concentration in the surface water ranged from 5.18 – 6.49 mg L^{-1} where two sites namely, Dhamakhali (S_7) and Lot 8 (S_1), showed minimum values for dissolved oxygen. Average dissolved oxygen values are greater than 4.0 mg L^{-1} indicating that surface waters are moderately oxygenated. High surface values of DO during monsoon months could be attributed to their addition by phytoplankton photosynthesis. The pH value denotes the buffering capacity of medium water and thus plays an important role in many chemical and biological processes. The surface water pH during present study ranged from 8.13 – 8.74 except Canning where mean surface water pH was low than all other sites 7.51 ± 0.20. The alkaline nature (pH>7), with low variations between the stations, suggests that the water mass remained well buffered throughout the study period and it indicates the presence of biodegradable organic matter in the water column. The high COD values of 101.29 and 114.8 mg L^{-1} at Lower long Sand (S_3) and Jambu Island (S_4) respectively, were encountered. High COD values in a tropical coastal wetland in Southern Mexico were also noticed by Hernandez-Romero *et. al.*, 2004 associated with mangrove-enriched organic matter. During the monsoon months (July - October), nitrate level in water increases considerably which is due to land drainage and precipitation, again the lowering of nitrate can be attributed to the biological utilization of nitrate which appears to play an important role in primary production. Comparatively low values of phosphate observed in all the stations (range from 0.48 – 1.42 µgm atom L^{-1}) which might be due to the utilization by phytoplankton and other primary producers. Mean phosphate levels were observed to be maximum (1.96 µgm-atom L^{-1}) at Dhamakhali (S_7). This indicated that land based nutrients especially, from the adjacent agricultural fields near this site contributed greatly. Mathew and Pillai (1990) reported that the higher concentration of phosphate in coastal waters might be enriched by freshwater drainage. The nitrate and phosphate ratio showed more or less a similar trend in all the stations. It might be due to recycling of nutrients and utilization of secondary producers (Maruthanayagam, 1998). Mean concentration of chlorophyll a varied from 1.29 – 5.5 mg m^{-3} for all the sites and it showed the highest mean value followed by chlorophyll c and b. It has been recorded that concentration of chlorophyll b is always much less than chlorophyll a and c and this might be due to absolute dominance by diatoms in this estuarine system (Mukhopadhyay, et. al., 2006), which mainly contain chlorophyll a, c_1 and c_2 as their phytopigments (Reynolds, 2006).

6. Statistical interpretation

Factor analysis was carried out on the data set (14 variables) to compare the compositional patterns between the water samples analyzed and to identify the related factors that influence each of them. Four factors were extracted explaining more than 73 % of the total variance in the water quality data set. Eigenvalues were taken as criterion for the extraction of the principal components required for explaining the source of variances in the data set.

The Scree plot, as shown in Figure 3, has worked out to clarify the method of extraction of different factors. The factor analysis was actually performed on the correlation matrix between different parameters followed by Varimax rotation and the same has been used to examine their inter relationship. The parameter loadings for the four identified factors from the factor analysis of the data are given in Table 1. The factor 1 accounts for 41.86 % of the total variance. It is positively correlated (loading > 0.75) with salinity, transparency, dissolved oxygen and chlorophyll pigment concentration (chlorophyll a, b and c) while negatively correlated with BOD, turbidity, nitrate and phosphate concentration. This factor appears to be originated from the combined effect of anthropogenic activities accompanied with partial ecological recovery system of the estuary. Factor 2, on the other hand, explains 16.06% of the total variance and is negatively loaded with pH and COD. Since the causes of these two parameters are based on excessive industrial activities and these are removed instantaneously by the natural recovery system. The third factor represents 10.06% of the total variance related to biochemical oxygen demand (BOD) and can be termed as indicator of high microorganism growth, as mangrove waters containing organic matter regulates microorganisms. The fourth factor represents seasonal effects of water temperature at 4.81% level of variance. Factor loading plot (Figure 4) after varimax rotation revealed that the transparency, dissolved oxygen in surface water and chlorophyll a concentration are showing positive loading whereas turbidity, BOD and nitrate concentration showing negative loading. The study revealed the major causes of water quality deterioration which were related to untreated or semitreated wastes from domestic, agricultural and industrial sources along with discharge of dredged materials, storm water runoff, aerial fall out, oil spills, boating and other nonpoint sources. Clustering dendrogram (Figure 5a-c) revealed the clustering of the sampling stations depending on the different seasons. In the monsoon season station Lower long sand (S_2) and Jambu Island (S_4) clustered at about 70% level of similarity overlapping with each other. Both of these two stations are the offshore stations situated on the Bay of Bengal revealing same kind of hydrological patterns. During the postmonsoon season all the stations clustered at about >85% level of similarity.

7. Ecological best designated use

Some ecological parameters were used to decide the best use of the river Hugli flowing in Sundarban coastal region with its numerous tributaries, like irrigation, industrial processing, drinking water resource, bathing, propagation of wildlife, navigation, fishery, recreation, controlled agricultural and aquacultural waste disposal. Based on the parameter values of pH, nitrate, phosphate, DO and COD and the maximum permissible limits for these parameters it may be concluded that the water from eastern flank of the Sundarban is suitable for bathing, wildlife fisheries, recreation and irrigation following water quality criteria for various designated best use as outlined by ADSORBS, 1982. However, in the eastern flank of Sundarban wetland, high phosphate level and low DO level have made this water unfit for fisheries and agricultural use. High COD level in the water does not imply any pollution problem in this area as this high COD can be ascribed from the inundation of the mangrove forest (Romerio-Harnandez, 2003).

8. Conclusion

The deterioration of water quality in the coastal regions of Sundarban wetland is closely related to insufficiency to water resource protection, nonfunctioning of wastewater treatment facilities and lack of environmental planning and coordination. Socio-economic issues must be integrated with proper management of water resources in general and with providing an adequate quantity and quality of water for the human populations and for industrial, agricultural and recreational usages. To achieve the target of regional sustainability, socio-economic issues must be considered with scientific management of water resources involving stakeholders, business sector, non-governmental organizations (NGOs) and the public. The authors strongly recommend the following basic components: (i) baseline and monitoring studies (ii) water quality criteria establishment (iii) identification of sources, pathways and analysis of pollutants and (iv) pollution control, abatement and rehabitation.

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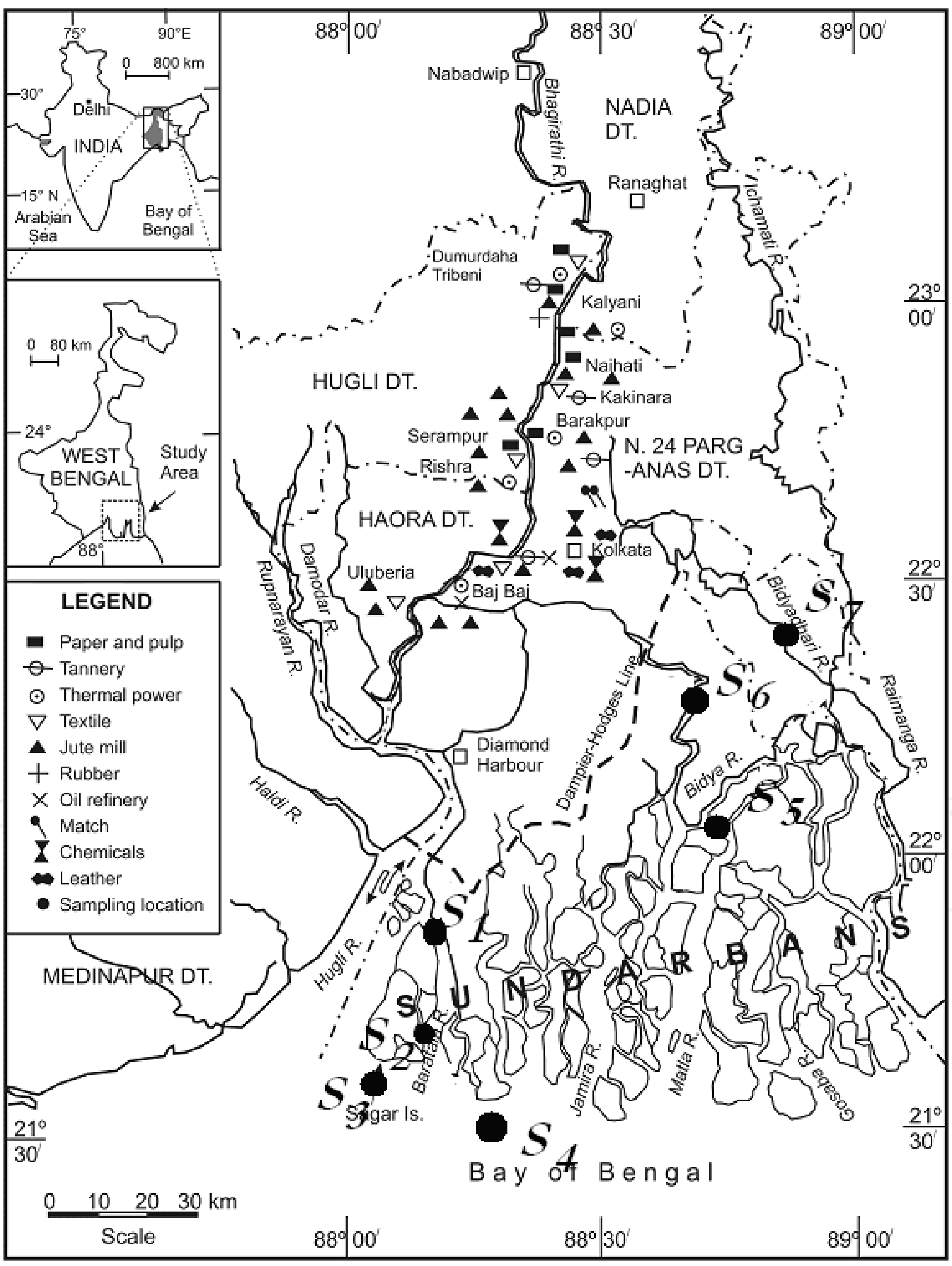
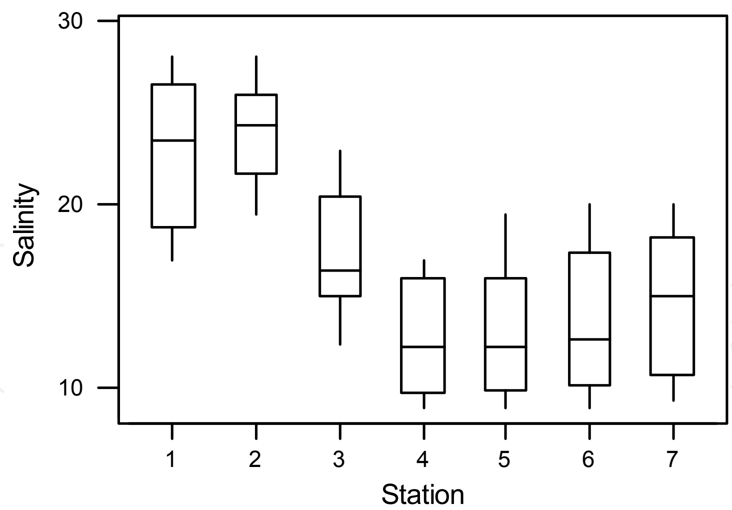
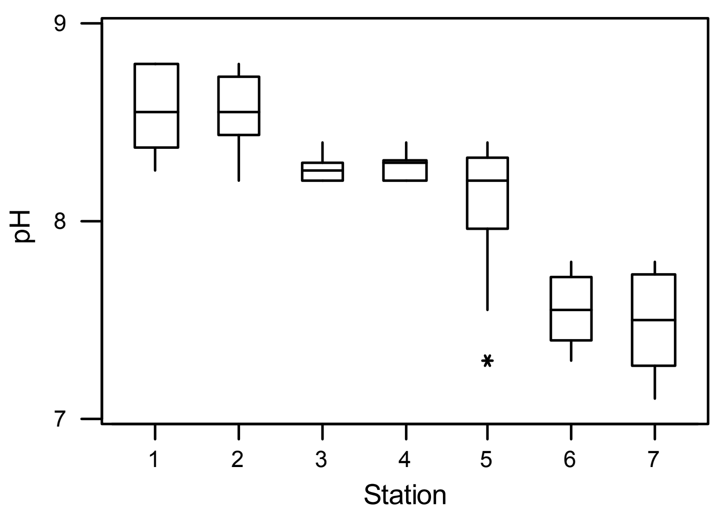


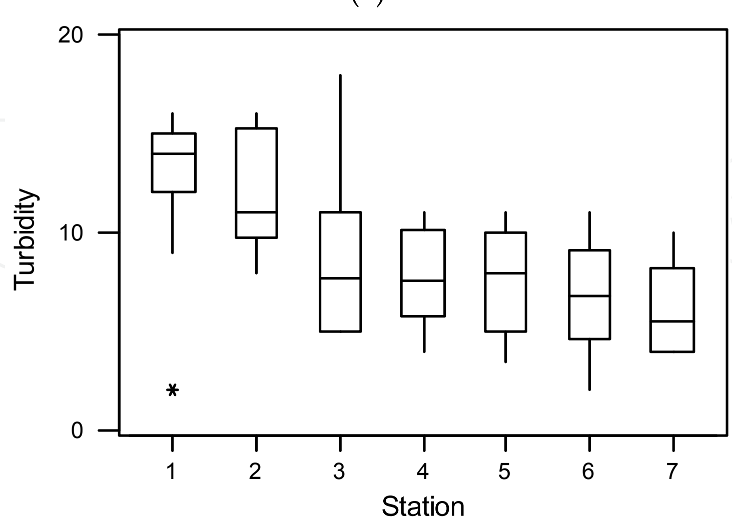
Fig. 1. Map showing the sampling sites in Sundarban wetland



(a)

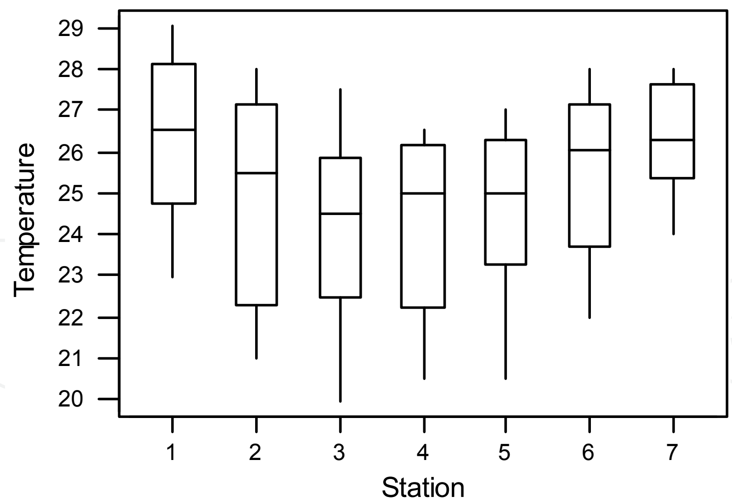


(b)

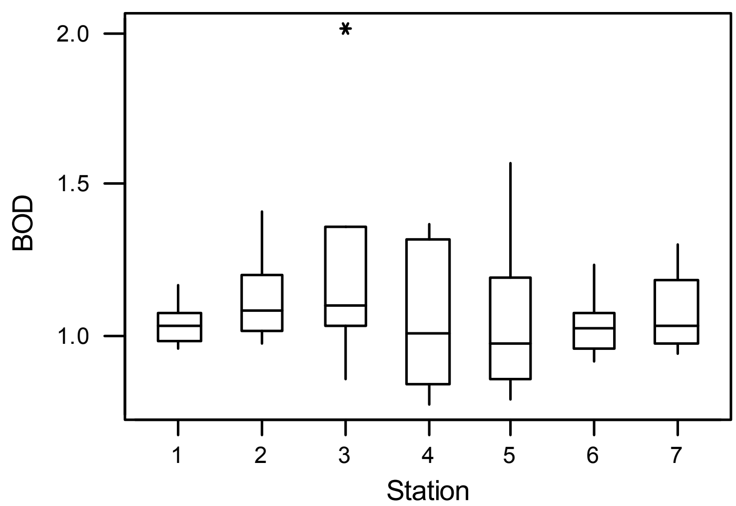


(c)

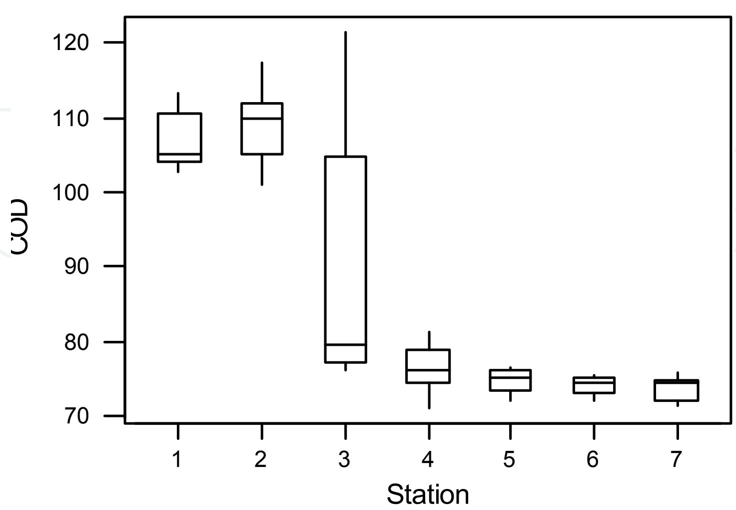
Fig. 2(a-c). Box plot diagrams of the 14 water quality parameters form coastal waters of Sundarban wetland



(d)

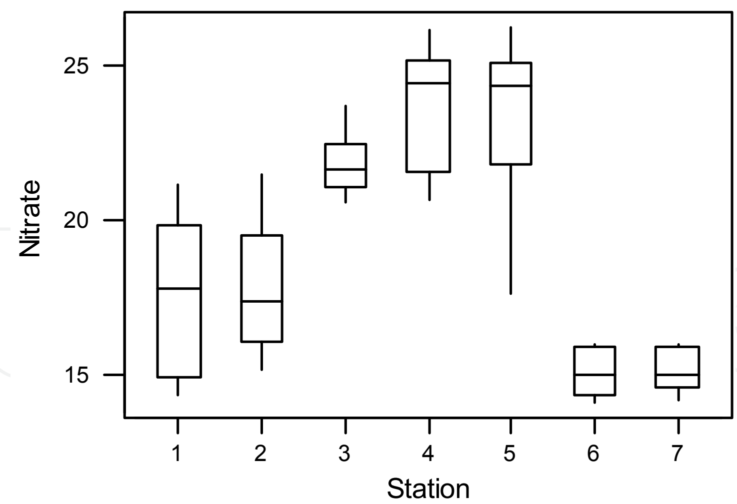


(e)

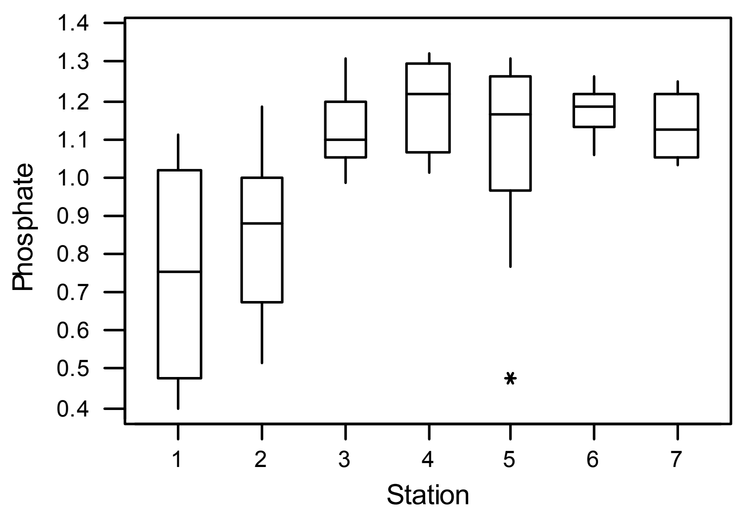


(f)

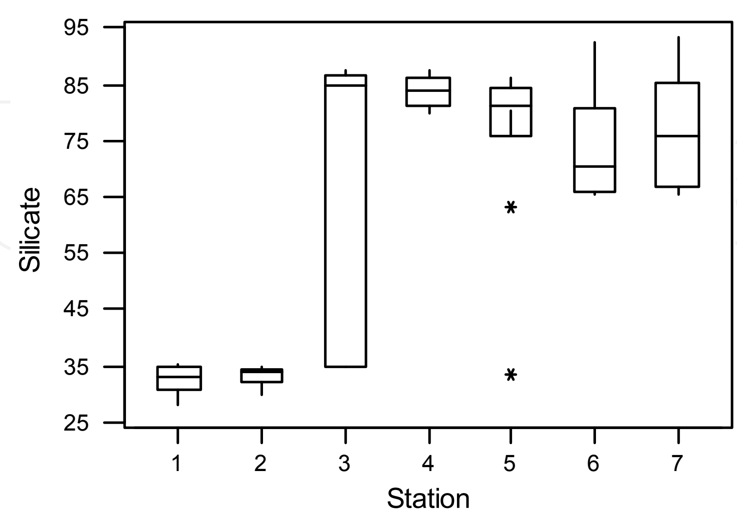
Fig. 2(d-f). Box plot diagrams of the 14 water quality parameters form coastal waters of Sundarban wetland



(g)

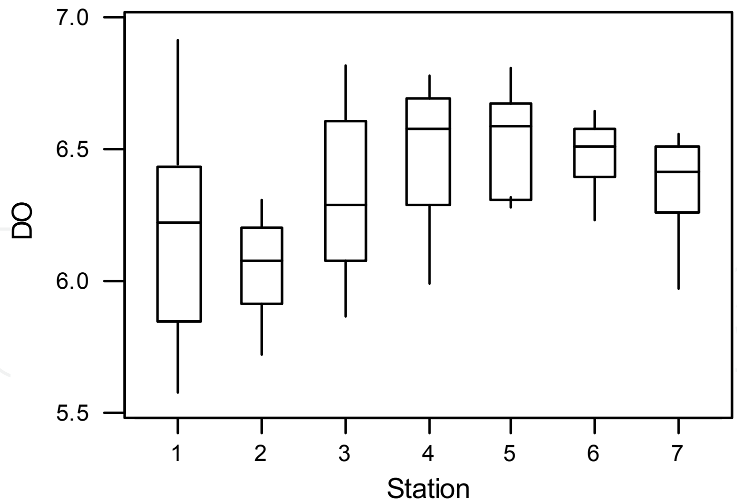


(h)

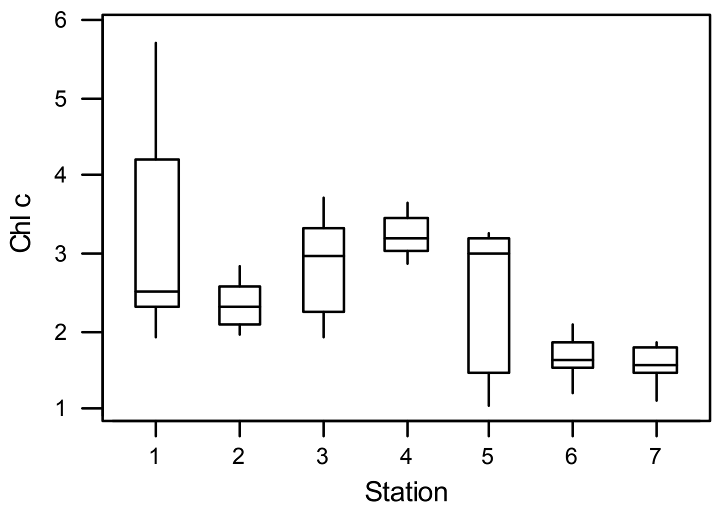


(i)

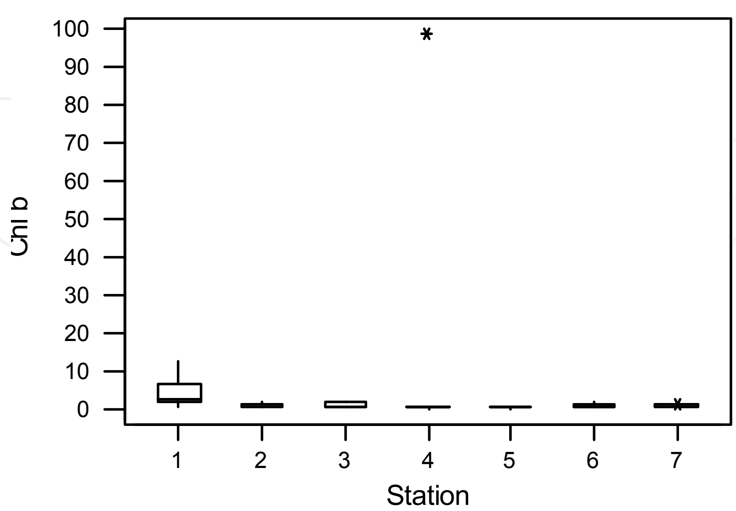
Fig. 2(g-i). Box plot diagrams of the 14 water quality parameters form coastal waters of Sundarban wetland



(j)

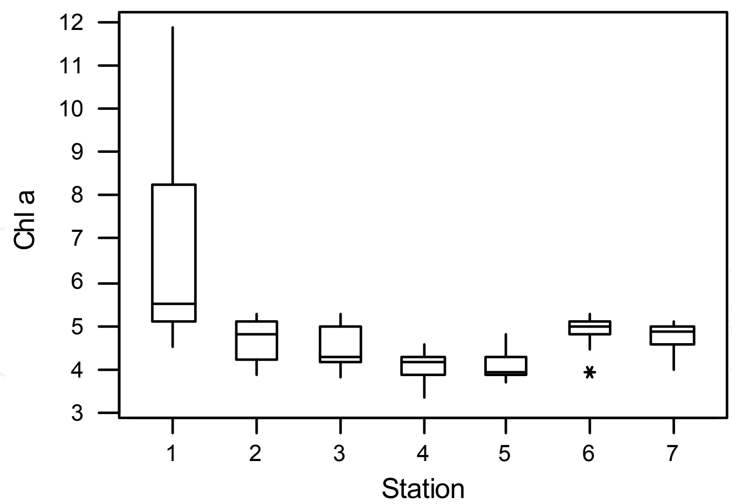


(k)



(l)

Fig. 2(i-l). Box plot diagrams of the 14 water quality parameters form coastal waters of Sundarban wetland



(m)

Fig. 2(m). Box plot diagrams of the 14 water quality parameters form coastal waters of Sundarban wetland

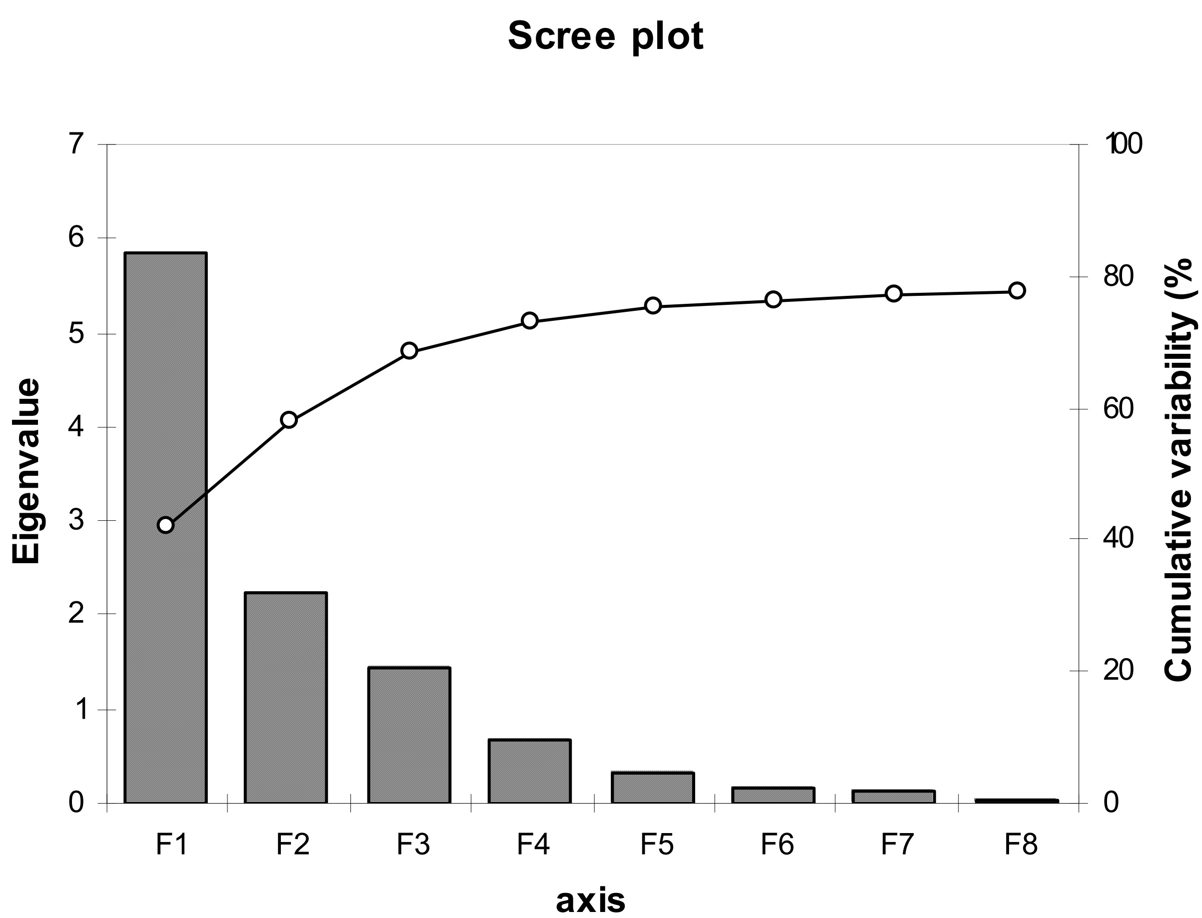


Fig. 3. Scree plot of the factor analysis after varimax rotation

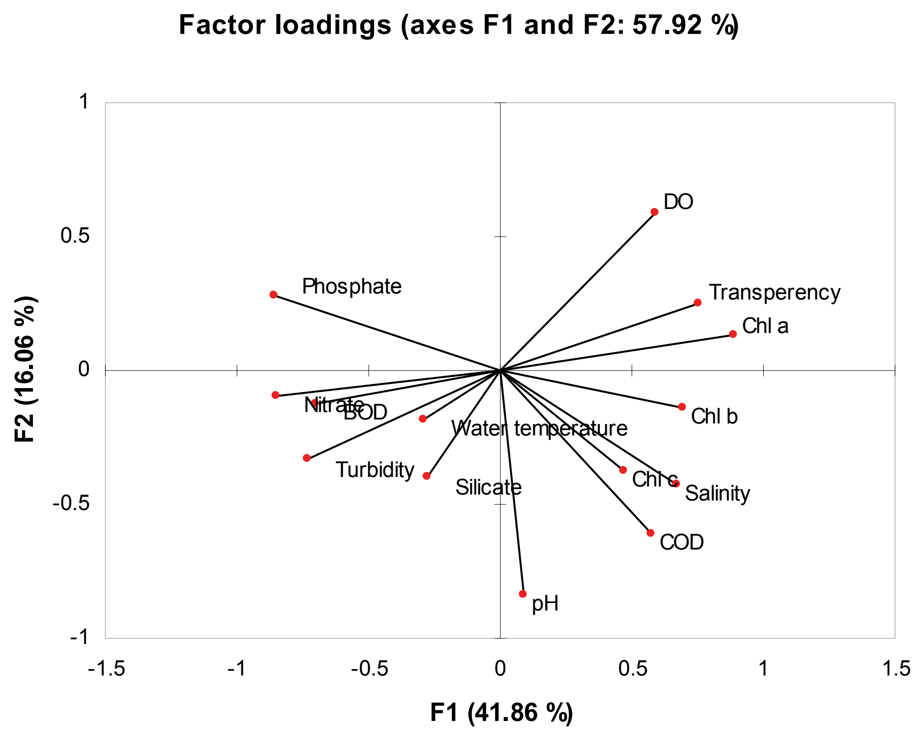
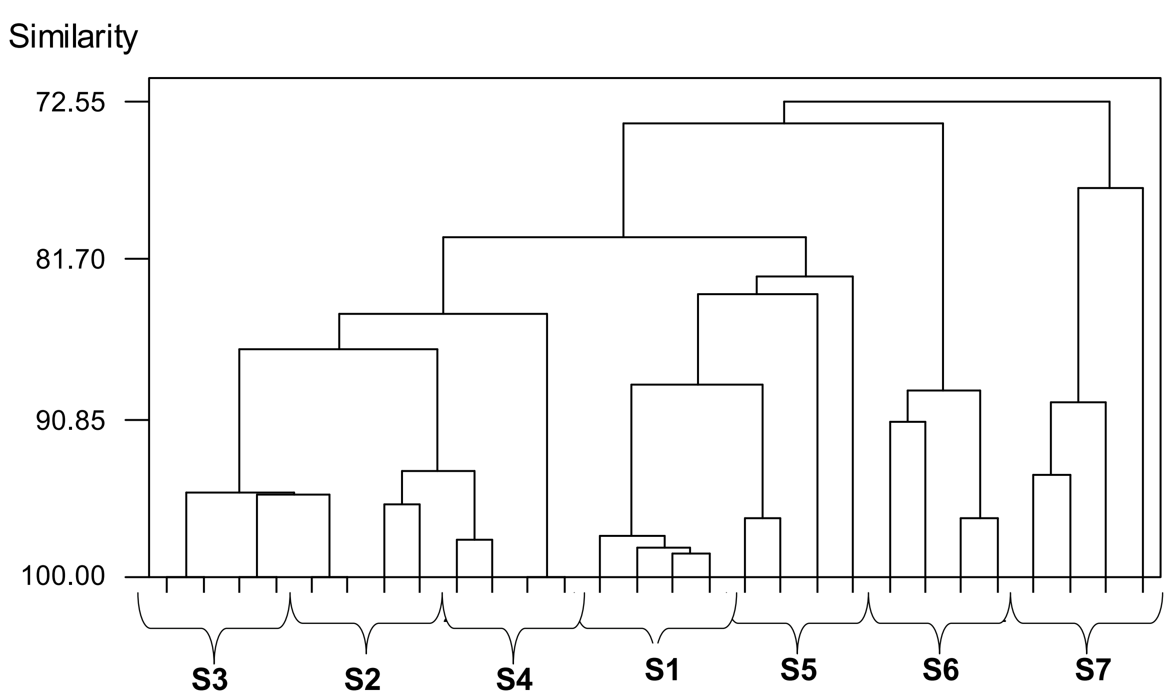
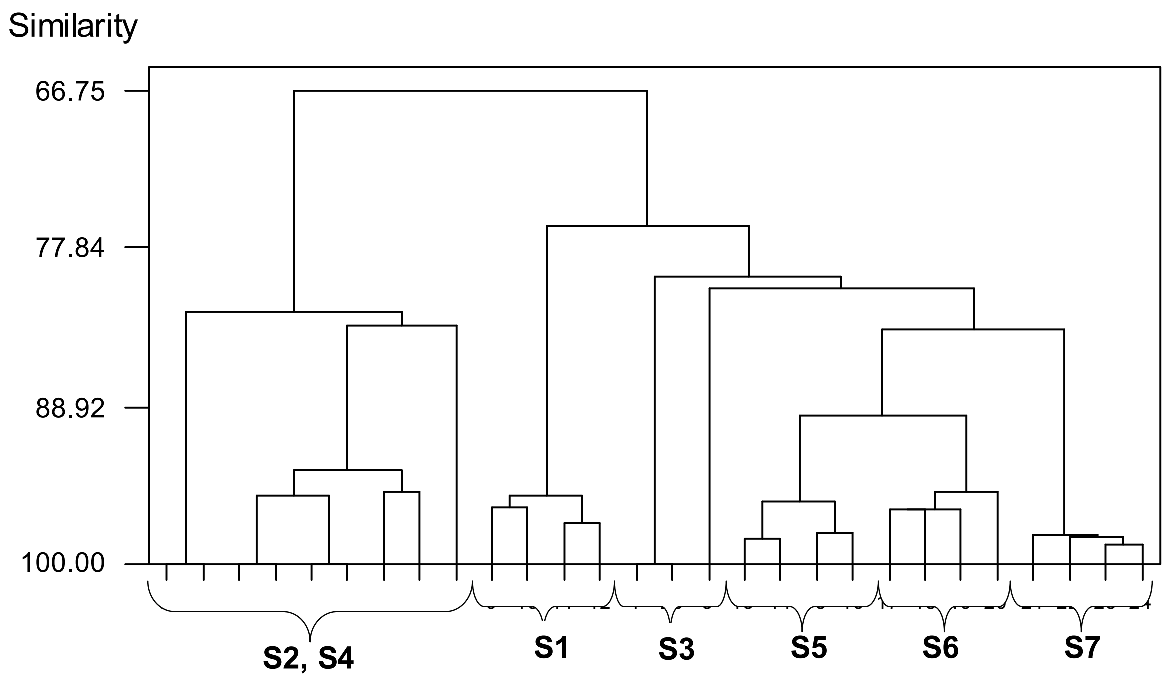


Fig. 4. Factor loading plot of the water quality parameters



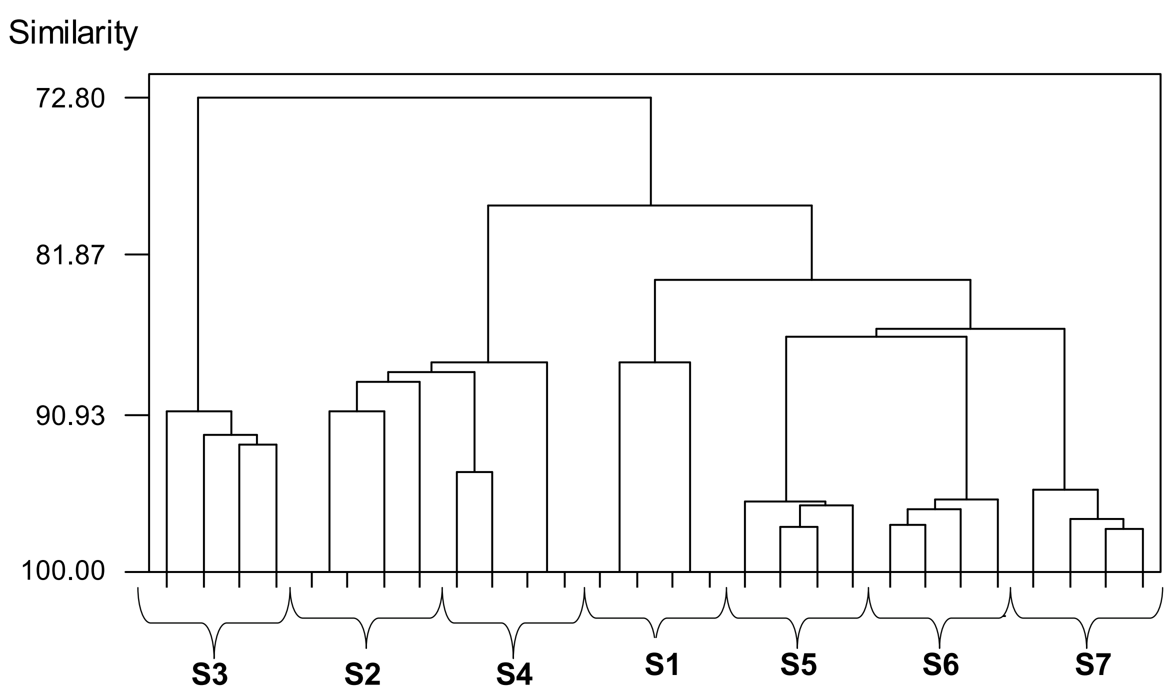
(a)

Fig. 5. Clustering dendrogram of the seven studied stations (S_1 – S_7) depending on the water quality parameters for (a) premonsoon



(b)

Fig. 5. Clustering dendrogram of the seven studied stations (S_1 – S_7) depending on the water quality parameters for (b) monsoon



(c)

Fig. 5. Clustering dendrogram of the seven studied stations (S_1 – S_7) depending on the water quality parameters for (c) postmonsoon seasons

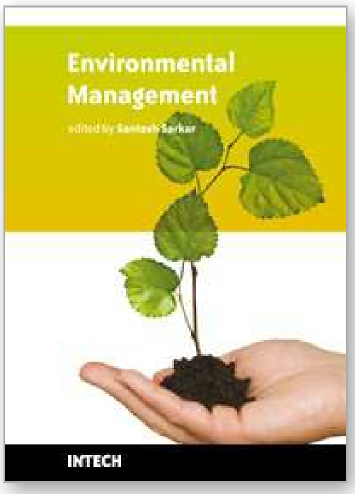
	F1	F2	F3	F4
Water temperature	-0.291	-0.184	0.037	**0.418**
Salinity	**0.673**	-0.430	0.412	-0.243
Turbidity	**-0.733**	-0.333	0.402	0.095
Transperency	**0.756**	0.248	0.473	-0.163
pH	0.089	**-0.837**	0.030	-0.153
DO	**0.593**	0.587	-0.143	-0.021
BOD	**-0.703**	-0.126	**0.520**	0.161
COD	0.573	**-0.609**	0.006	0.123
Nitrate	**-0.848**	-0.093	0.155	0.006
Phosphate	**-0.855**	0.279	0.120	0.073
Silicate	-0.274	-0.398	**-0.691**	-0.185
Chl a	**0.890**	0.130	0.019	0.436
Chl b	**0.696**	-0.141	0.304	0.024
Chl c	**0.468**	-0.379	-0.296	0.327
% of variance	41.86	16.06	10.36	4.81
Cumulative	41.86	57.91	68.27	73.09

Table 1. Factor analysis of the water quality parameters after varimax rotation

Parameter	USPH standards[a]	WHO standard
pH	6.0 - 8.5	6.5 - 9.2
DO	4.0 - 6.0	-
Nitrate	<10	45
Phosphate	0.1	-
COD	4	10

Except pH, all units are in mg l^{-1}
A Maximum permissible concentrations

Table 2. Drinking water standards as recommended by USPH and WHO



Environmental Management

Edited by Santosh Sarkar

ISBN 978-953-307-133-6
Hard cover, 258 pages
Publisher Sciyo
Published online 12, August, 2010
Published in print edition August, 2010

There has been a steady increase in anthropogenic pressure over the past few years due to rapid industrialization, urbanization and population growth, causing frequent environmental hazards. Threats of global environmental change, such as climate change and sea level rise, will exacerbate such problems. Therefore, appropriate policies and measures are needed for management to address both local and global trends. The book 'Environmental Management' provides a comprehensive and authoritative account of sustainable environmental management of diverse ecotypes, from tropical to temperate. A variety of regional environmental issues with the respective remedial measures has been precisely illustrated. The book provides an excellent text which offers a versatile and in-depth account of management of wide perspectives, e.g. waste management, lake, coastal and water management, high mountain ecosystem as well as viticulture management. We hope that this publication will be a reference document to serve the needs of researchers of various disciplines, policy makers, planners and administrators as well as stakeholders to formulate strategies for sustainable management of emerging environmental issues.

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
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