

## MAPPING SPATIAL VARIATION OF ENVIRONMENTAL POLLUTANTS IN AN ESTUARINE ECOSYSTEM AT KARACHI HARBOUR: AN APPLICATION OF GEOGRAPHIC INFORMATION SYSTEM (GIS)

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### ABSTRACT

Karachi Harbour is an estuarine ecosystem which hosts a major shipyard, and also serves as a receiving body to a river Lyari which brings untreated domestic and industrial effluents. This study has focused on mapping spatial variation of environmental pollutants in the Karachi Harbour using the Geographical Information Systems (GIS) Technology. A Pollution Index (PI) was developed by integrating all the water quality parameters. Finally, thematic-contour maps of all water quality parameters and pollution index were generated using ArcGIS 9.1 and Surfer 10 softwares.

### Key-words:

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### INTRODUCTION

The term 'Estuary', is derived from the Latin word *aestuarium* that means marsh or channel (Ahmed and Shaukat, 2012). Estuarine ecosystem is a dynamic environment receiving river outfall and a tidal intrusion of sea. It contains brackish water that supports growth of mangrove forests, which serve as breeding grounds for number of aquatic life forms. Rapid population growth and uncontrolled development in many coastal areas results in significant anthropogenic input into this imperative ecosystem (Santos *et al.*, 2009).

Many of the chemical substances are known to concentrate in the water, or accumulate in estuarine sediments (Riba *et al.*, 2002) or bioaccumulation by sediment-dwelling organisms (Meador *et al.*, 1995). Sediment quality has also received increasing concern because sediment is known to act as both a repository for contaminants and a pollutant source with potential impact on the quality of estuarine ecosystem (Chapman and Wang, 2001).

Karachi Harbour is located in an estuarine ecosystem which is fenced by a belt of mangrove forest along the ridge that joins Manora Island with Karachi. Its total surface area is about 31.2 sq km out of which 11.61 sq km comprises of mangrove forest. Karachi Harbour has become one of the most highly polluted harbours in the region. It receives heavy pollution load from a perennial river Lyari that is responsible for its degradation. The river Lyari is one of the rivers, which flows through the great metropolitan area of Karachi. This river plays an important role in the natural drainage of Karachi city. It carries the wastewater that is characterized by untreated domestic and industrial effluents. Due to natural geographical situation of Karachi Harbour, marine pollutants are not completely flushed out into the open sea that makes the harbour waters hazardous from many aspects (Memon, 2007).

Geographic Information System (GIS) technology is known to play an eminent role in mapping spatial variation of pollutants in aquatic environment (Robinson and Metternicht, 2006; Butler *et al.*, 2002; Ahn and Chon, 1999). With this technology one could have a bird's eye view of existing situation of a water body. Through GIS, water quality parameters could be integrated at all locations within the study area and an overall outcome of pollution can be mapped into a thematic layer (Balakrishnan *et al.*, 2011; Asadi *et al.*, 2007). This way of exposing the patterns of pollution helps in predicting potential zones of pollution within the study area.

This study focuses on mapping the spatial variation of pollutants in the Estuarine ecosystem located at Karachi Harbour. In this study, water quality of the study area has been analyzed on the basis of physical (pH, temperature, turbidity, salinity, Total Suspended Solids (TSS)) and chemical (BOD<sub>5</sub>, COD, phosphate, ammonia) parameters. In addition to that, the existing microflora was also evaluated. To express an overall pollution status, a Pollution Index (PI) was calculated by integrating all the water quality parameters. Finally, thematic-contour maps of all water quality parameters and pollution index were generated using ArcGIS 9.1 and Surfer 10 softwares.

### MATERIALS AND METHODS

#### Study area

The study was conducted at an estuarine area that comprises of 15.5 sq km within the latitude 24°47'33'' to 24°50'28'' and longitude 66°56'27'' to 66°59'10''. The vast biological diversity has become limited by the pollution of Lyari River (Durrane *et al.*, 2008). The significance of the study area is the presence of Karachi shipyard and the activities of vessels that are carried out daily for transportation purpose.



**Fig. 1. Location of study area and sampling points**

### Sampling and analysis

A total of 16 water samples were collected by random sampling method in the month of January, 2012 (Figure 1). Surface water temperature was measured using a mercury filled thermometer, pH was detected by the help of Hanna Instruments pH Tester, Turbidity was measured by using EUTECH-TN 100 turbidity meter and salinity was measured by salinity meter. For further analysis, samples were immediately kept in an ice box at 4°C for storage (APHA, 2001), and then brought to laboratory of The Institute of Environmental Studies, University of Karachi. Samples for BOD<sub>5</sub> were incubated in laboratory for five days at 20°C. Ammonia was determined by Kjeldahl (Nesslerization) method, and phosphate was estimated by ammonium phosphomolybdate method. Cellulose acetate filter papers (45µm) were used for the analysis of TSS and for the determination of COD, dichromate reflux method was used (APHA, 2001).

To examine bacterial populations, samples were collected in a saline medium (adjusted to sea salinity) and kept in a cool ice box. One ml of the sample was dispensed into nutrient broth and kept for incubation for 24 hrs at 37°C. Gram-staining was performed and later bacteria observed under an oil immersion 100X objective lens.

### Pollution Index

This index is used for water quality parameters and allows the identification of priority contamination sites that helps us to the pollution movement and accumulation (Caeiro *et al.*, 2005).

$$PI = \sum_{i=1}^n W_i C_i$$

Where PI is Pollution index or contamination index;  $W_i$  is the weight for pollution variable  $i$ ;  $C_i$  the highest concentration of pollution variable  $i$  reported in a location of interest. For each pollutant  $i$ , the weight was based on the reciprocal of the median of observed magnitude.

### Interpolation and Thematic mapping

To interpret the results of individual pollution parameters and to evaluate pollution conditions for the study area, the interpolation method was used that estimates the contaminants at unmonitored sites. The interpolation method estimates the contaminants in the entire study area by assessing the results of individual pollution parameters. Kriging interpolation was computed for each parameter. Kriging is one of the more flexible method and is useful for gridding almost every type of data set. Subsequently, thematic maps were generated for each parameter that helps to display the pattern of variation in the intensity of a particular variable.

### Software analysis

The Kriging interpolations of the contaminant concentrations were computed by Surfer 10. Afterward, the interpolated layer was imported into ArcGIS 9.1 software to produce thematic maps of environmental pollutants and

the pollution index (PI). Finally, layouts of each map were generated in ArcGIS 9.1 and export as “.tif” file for visualization.

## RESULTS AND DISCUSSIONS

The present study aimed to monitor the pollution level in an estuarine ecosystem of the Karachi Harbour area. With the help of parameter analysis, different pollution index values were computed. Contour maps were then designed from these index values to disclose pollution levels in that particular area.

The pollution index (PI) (Figure 2) differentiates the sites on the basis of accumulation (level) of pollution. The highest pollution index value observed is 17.88 at site S-1 (near Kemari port trust) and the lowest value is 7.00 at site S-3. The high pollution level is mainly due to industrial and domestic wastewater that is discharged through Lyari River and it is also due to the presence of port where continuous movement of boats or ships that release deleterious oils which affect the quality of life in and around estuaries. The lowest pollution level is due to flushing into open sea which makes the water less polluted as compared to site-1.

### Physical parameters

#### pH

Estuarine pH levels generally average from 7.0 to 7.5 in the fresher sections, to between 8.0 and 8.6 in the more saline areas (Ohrel and Register, 2006). The pH at mix industrial and domestic effluent at Lyari River varied between 7.1 and 7.74 (Qadir *et al.*, 2011). The pH of research area water body was basic that ranged from 7.9 to 8.1 (Fig. 3). pH varies from 7.9 to 8.0 in highly polluted area due to the wastewater and also due to the intrusion of salt water because samples were taken at high tide but in the saline areas (open sea) pH goes up to 8.1 which is within the prescribed limit. The pH of seawater of Sindh coast ranged from 8.02 to 8.38 (Saleem *et al.*, 2009; Shahzad *et al.*, 2009).

#### Salinity

The salinity distribution of the study area is shown in Figure 4. In the polluted areas (S-1, S-2, S-3, S-13, S-14, S-15 and S-16) salinity levels varied from 31.9ppt to 34ppt and increased up to 36ppt towards seawater. Lyari River has carried salinity 2ppt to 4ppt (Qadir *et al.*, 2011) and seawater salinity of Sindh coast varied from 35ppt to 36ppt (Saleem *et al.*, 2009). The salinity values were higher because during sampling the tide was rising and due to this salinity levels have increased. Site 4 and site 12 were the sampling sites where salinity levels reaches up to 35.5ppt because these sites are located in saline area where salinity levels are generally high.

#### Turbidity

Turbidity is mainly due to the dispersion of suspended particles. Abnormal values of turbidity are usually due to floating sediments carried by the river from catchment areas. Similarly in polluted areas (S-1, S-2, S-3, S-13, S-14, S-15 and S-16) turbidity varied from 8NTU up to 37NTU as shown in Figure 5. In an increasing tide turbidity becomes low because of the sea water mixing with the wastewater and dilution process takes place. The non-polluted areas were S-4 to S-12 where turbidity values are low up to 2.5NTU at site-6 which is located in the open sea.

#### Total Suspended Solids (TSS)

Total suspended solid (TSS) varied from 122 to 166mg/L. The maximum value 166mg/l was observed at S-12 and minimum 122mg/l at S-8. The maximum value could be due to turbulence and ocean currents in water column. Past studies showed that Lyari River carries the mean TSS values 142.39mg/L and similar values were observed in our study area. As shown in Figure 6, TSS values decrease towards the open sea because of high tide flushing or mixing.

### Nutritional parameters

#### Ammonia

Ammonia concentrations trend can be seen in Figure 8, higher values were recorded at site 1, 4-8, 10-16 ranges from 0.543 to 0.757mg/L and these sites are situated near the mouth of Lyari River. At sites 2, 3 and 9 low concentrations were recorded which ranged from 0.258 to 0.297mg/L. The recorded concentration of NH<sub>3</sub> was significantly high at Lyari River that is greater than 40mg/L (Qadir *et al.*, 2011). Our values of ammonia showed that an immense flushing of seawater decreased the ammonia concentration at study area. Higher concentrations could be due to de-nitrification, death and decay of phytoplankton and also due to the breakdown of urea by urease

bacteria in sewage waste. Low levels of ammonia are possibly due to nitrification and minimal influence of industrial waste.

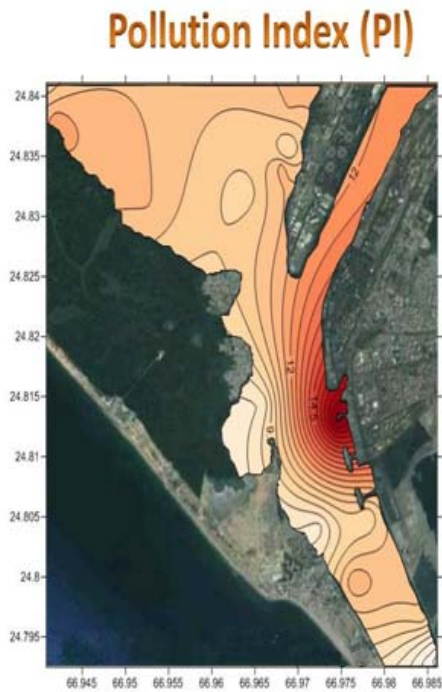


Figure 2: Spatial distribution of Pollution index

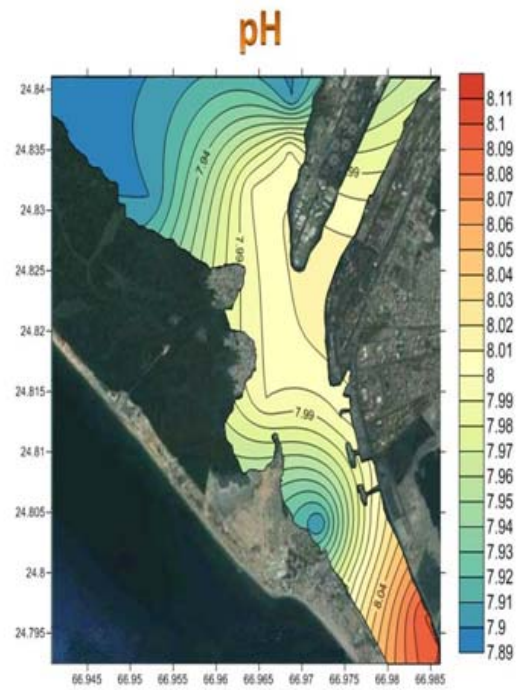


Figure 3: Spatial distribution of pH

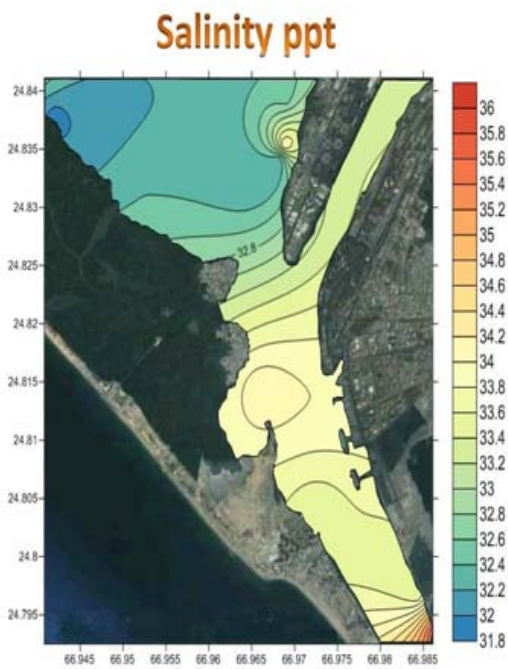


Figure 4: Spatial distribution of Salinity

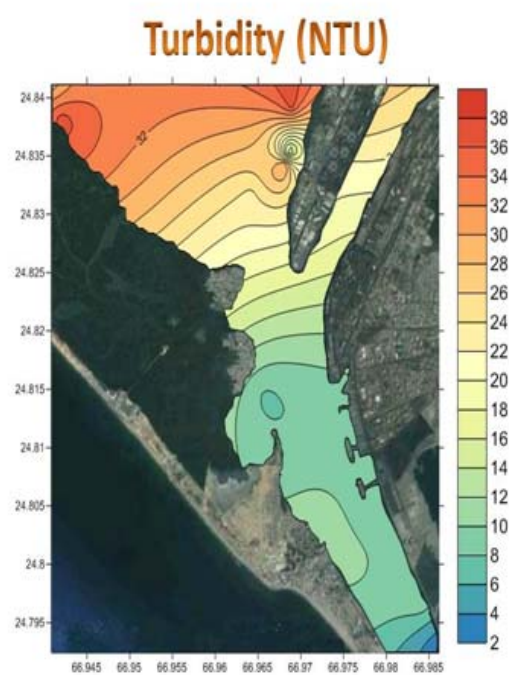


Figure 5: Spatial distribution of Turbidity

### Total Suspended Solids (TSS) mg/L

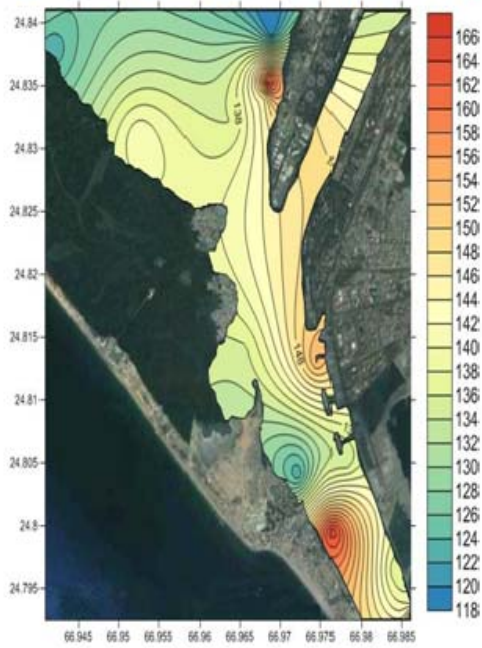


Figure 6: Spatial distribution of TSS

### Temperature (°C)

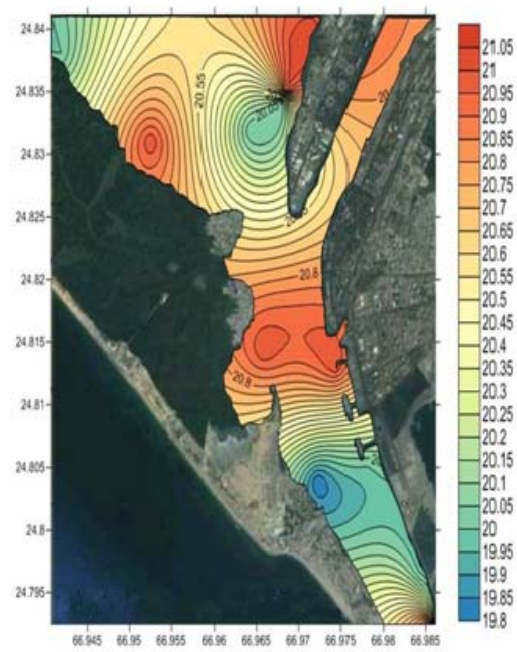


Figure 7: Spatial distribution of Temperature

### Ammonia mg/L

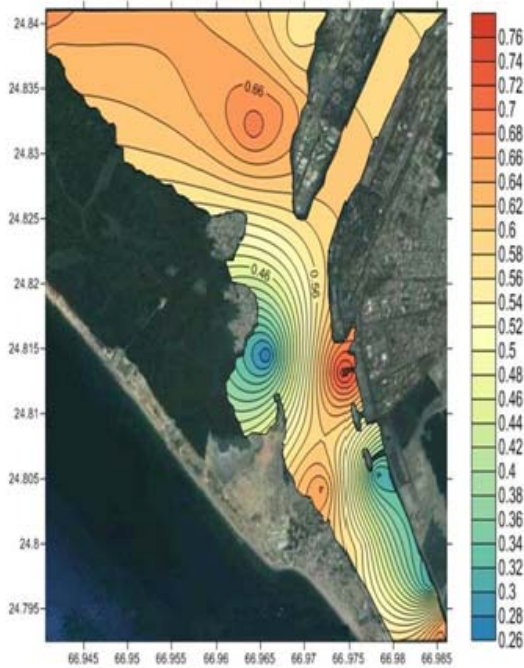


Figure 8: Spatial distribution of Ammonia

### Phosphate mg/L

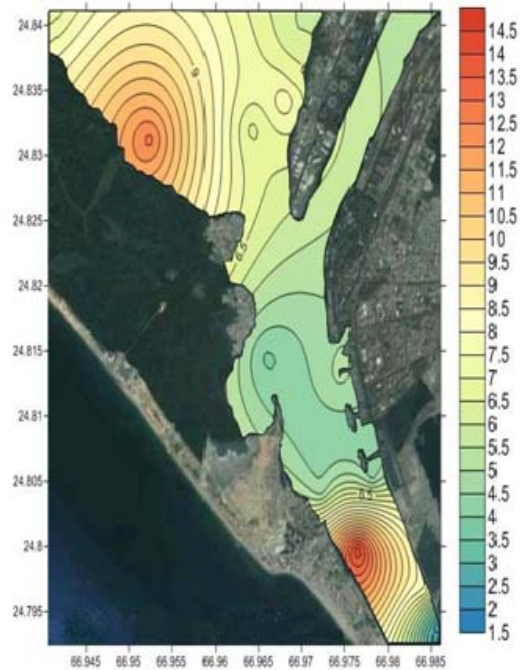


Figure 9: Spatial distribution of Phosphate

### Biochemical Oxygen Demand (BOD<sub>5</sub>) mg/L

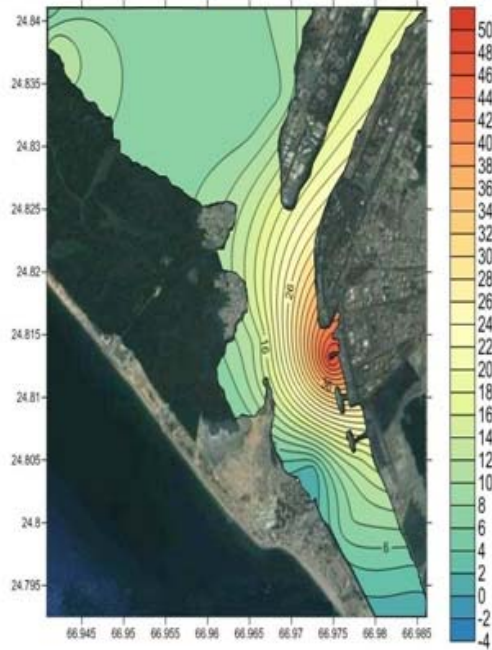


Figure 10: Spatial distribution of BOD<sub>5</sub>

### Chemical Oxygen Demand (COD) mg/L

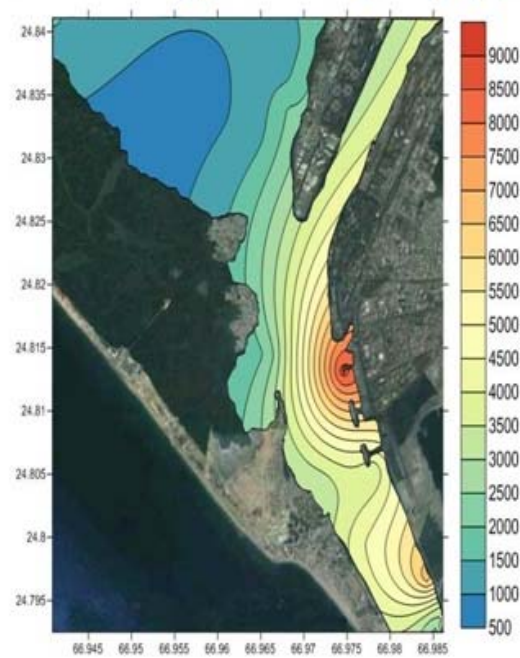


Figure 11: Spatial distribution of COD

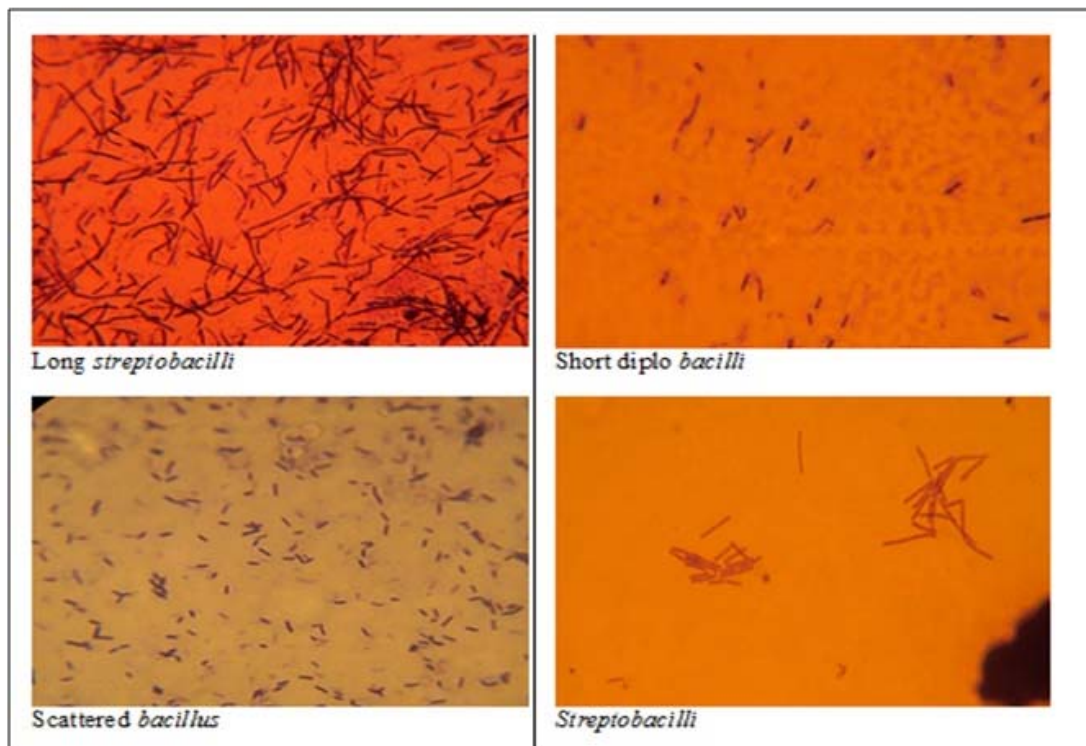


Figure 12: Bacterial analysis

### Phosphate

Phosphate distribution is shown in Figure 9. Higher concentrations were observed at sites 8-16 ranged from 3 to 12mg/L while at site 4 and 6 low concentrations were detected ranged between 1.40mg/L and 1.97mg/L respectively, which are located in open sea. Previous studies showed low concentration (1.8ug/L) of phosphate along Karachi coast and it is normal for primary productivity (Saleem *et al.*, 2009). High values were mainly due to intrusion of seawater into creek, which in turn causes turbulence and mixing. Turbulence unlocks phosphorus from bottom sediments yield higher values. Other possible ways of phosphate are discharge of sewage waste, agricultural drainage and certain industrial wastewater. Low levels of phosphate could be due to high utilization of phosphate by phytoplankton. Variation in phosphate levels may also be due to adsorption and desorption of phosphate and buffering action of sediments under varying environmental conditions (Adeyemo *et al.*, 2008).

### Chemical parameters

#### Biochemical Oxygen Demand (BOD<sub>5</sub>)

BOD<sub>5</sub> was observed to be in the range of 0.4 - 49mg/L at sites 1-3, 7-16 while the levels were below detection limit at site 4-6 (<1mg/L). Highest value of BOD<sub>5</sub> was observed at site-1 that is 49mg/L. Decreasing trend was observed immediately after site-1 as shown in Figure 10. If we look at past studies, highest value of BOD<sub>5</sub> was observed 97mg/L at Karachi Harbour area during the year 2007 (Saleem *et al.*, 2009). The flushing system of Estuary makes the area less polluted, however low BOD<sub>5</sub> values were observed in increasing tide. Higher values of BOD<sub>5</sub> were due to the organic load in wastewater as it enters in the river and close to point source of the pollution where DO is at minimum level due to biological decomposition of organic load. Nutrients such as nitrogen and phosphorus act as a buffer to maintain pH for bacterial growth and due to this nitrification occurs at low temperature. Low levels were observed due to de-nitrification and dissolution which in turn increases dissolved oxygen levels.

#### Chemical Oxygen Demand (COD)

Overall high values of COD were recorded but a decreasing trend was also observed from site 1-16 which ranged from 1200 to 8800mg/L (Figure 11) during pre-monsoon season. In 2007, the highest value of COD was recorded 2076mg/L at "Kala Pani" (black water) within Karachi Harbour area (Saleem *et al.*, 2009). The highest level was observed at site-1 and lowest level was at site-13 and 15. High levels of COD due to low levels of dissolved oxygen and presence of non-biodegradable compounds that enter in the form of industrial, municipal and agricultural waste, increasing tide cause intrusion of seawater into creek which results in mixing of effluent with seawater. COD can be empirically related to BOD<sub>5</sub>, organic matter and organic carbon (Radojevic and Bashkinet, 1999).

### Bacterial analysis

The whole ecosystem is *Bacillus* dominant. Various species of *Bacillus* were found. These included scattered *Bacillus*, *Diplobacilli*, long *Streptobacilli* and short *Streptobacilli* (Figure 12). There were few sites, where *Cocci* of the species *Staphylococci* were found.

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