RESEARCH ARTICLE OPEN ACCESS

GIS based spatial distribution of Temperature and Chlorophyll-a along Kalpakkam, southeast coast of India

Muthulakshmi.AL[1], Usha Natesan[1], Vincent A. Ferrer[1], Deepthi.K[1], Venugopalan.V.P[2], Narasiman.S.V[2]
[1](Centre for Water Resources, Anna University, Chennai, INDIA)
[2](Water and Steam Chemistry Division, Indira Gandhi Centre for Atomic Research, Kalpakkam, INDIA)

ABSTRACT
This paper briefly describes the status of Temperature and Chlorophyll-a trend in Kalpakkam Coast, discusses its ecological and temperature impacts recommending measures to achieve long term sustainability using advanced tools like Geographic Information System (GIS). Present study reveals the monthly spatial distribution of Temperature and Chlorophyll-a at Kalpakkam. Transect based in-situ Temperature and Chlorophyll-a collected at 200m, 500m and 1 km distance into the sea was interpolated using the Inverse Distance Weightage (IDW) method in ARC GIS. Data revealed the extent of spatial distribution of thermal effluent in Kalpakkam. It could be found that temperature range of 26.2 – 31.9°C provided substantial Chlorophyll-a concentration between 0.8 – 2.9 mg/m^3 for surface and bottom waters. Further, increase of Chlorophyll-a levels did not lead to higher productivity. Combined temperature and chlorophyll a showed little synergistic effects. It is concluded that the effect of thermal discharge from the power plant into the receiving water body is quite localized and productivity of the coastal waters are not affected. From the results obtained, the spatial data has been found to be useful in determining zones of safe use of seawater and to understand the extent of relationship between the relatable parameters.

***Keywords* -** Coastal Power Plants, Chlorophyll a, Geographic Information Systems, Temperature, Inverse Distance Weighting (IDW)

I. INTRODUCTION

Natural water bodies are being used as heat sinks by various industries especially by electric power plants. Thermal effluents released by such plants into the receiving water body, sea or lake can directly and indirectly affect the ecosystem dynamics in the receiving water body. Through its effects are confined to density, temperature is also involved in advective mixing processes and in turn is a major factor in primary production [1]. Seasonal fluctuations in water temperature distribution play an important role in influencing biological processes [2]. In this juncture, the environmental effects of thermal discharge from power stations into coastal and inland water bodies have been the focus of research [3-5]. However in developing countries such as India, this area has only recently attracted significant attention particularly with the advent of larger nuclear and thermal power plants.

The Nuclear power plants discharge large amount of heat to cooling water during the process of steam condensation. Nuclear power plants require, on an average about 3 m^3 cooling water per minute per megawatt of electricity (MWe) produced [6]. Since once – through cooling system is the most economical way of condensing the exhaust steam from turbines, there is an increasing tendency for new nuclear power plants to be located in coastal areas, so as to make use of the availability of the abundant seawater for condenser cooling [7]. With an increase in the number of power plants along the coast to meet the growing demands of the society, there is an in comitant increase in the quantity of heated effluents being discharged into coastal marine environments. The marine organisms in the receiving water body may also be entrained into the effluent plume which undergoes a thermal stress on their living and existence. Thus temperature is one of the most important environmental variables which affect the survival, growth and reproduction of aquatic organisms [8-9].

As the heated effluents reaches out to the open sea, they get dispersed spatially over the area depending upon the tidal conditions prevailing over the sea, the direction of the oceanic currents and the wind direction which contributes to the motion of the surface water. Hence it makes it necessary for the temperature to be represented spatially in order to have a clear overview of how the temperature gets dispersed over a period of time. This helps in the assessment of the variation of the temperature derived parameters like DO, salinity etc. With the advent and development of the various remote sensing and Geographic information systems, the spatial mapping of the temperature has found a great leap in the spatial analysis of the field data. Also the near shore regions of the sea being a very turbulent region the data measurement at every region becomes a tedious one and hence the interpolation of the measured available data for the entire region could help in a way to assess the situation therein.

Determining the eutrophication level in a coastal area depends not only on the vast data obtained, but also on the distribution of data throughout the coastal system. Therefore, appropriate methods and tools are needed to reveal this distribution. Geographic Information System applications have the exact features to satisfy this requirement. GIS is a kind of information system which can perform functions such as collecting, storing, processing, and analysing the graphical or non-graphical information obtained with location-based observations, and it presents to the user the information as a whole. The most significant advantage of GIS is that it provides the resulting desired map by superposing the distribution maps created with different parameters within a particular database. For this reason, GIS is used in many studies related to the management of natural resources, especially the management of surface water resources [10 -13].

The present paper has studied the spatial distribution of temperature and Chlorophyll-a at Kalpakkam coastal area for different months. The study locations are provided in Fig. 1. Further, an attempt has been made to understand the relationship between temperature and chlorophyll a using the analysis of GIS.

II. STUDY AREA

The study was carried out in and around the coastal waters of the IGCAR, Kalpakkam which houses the Madras Atomic Power Station (MAPS). The study area extends over a distance of 15 kms from Sadras in the south to Mahabalipuram in the north. A schematic representation of the study area is shown in the Fig 1. The area is an open sandy coast with negligible tidal currents. MAPS consist of two units of pressurized heavy water reactors (PHWR) with an installed capacity of 220 MWe each down rated to 170 MWe each. It is proposed to establish a 500 MWe capacity Prototype Fast Breeder Reactor (PFBR) at about 680 metre south of MAPS. The power station uses sea water as tertiary coolant at a maximum design flow rate of 35 $m^3 s^{-1}$ whereas the actual rate varies depending on the number of units functional at that time. The sea water is drawn from an offshore well located about 400 m away from the shore through a 50 m deep sub – seabed tunnel. In order to have a combined discharge from both PFBR and MAPS an engineering canal has been constructed. After passing through the steam condensers and other auxiliary heat exchangers, the sea water is discharged onshore through an outfall structure on the northern side of the jetty into an engineering canal. The Engineering canal is about 46 metres wide which runs over a distance of 980 metres and is constructed using the synthetic material at the bottom, loaded with stone boulders. Thus the discharge water from the outfall reaches the sea after travelling this engineering canal at a fixed point. Two backwaters drain into the Bay of Bengal in the vicinity of the power plant viz., Sadras in the south and Edaiyur in the north.

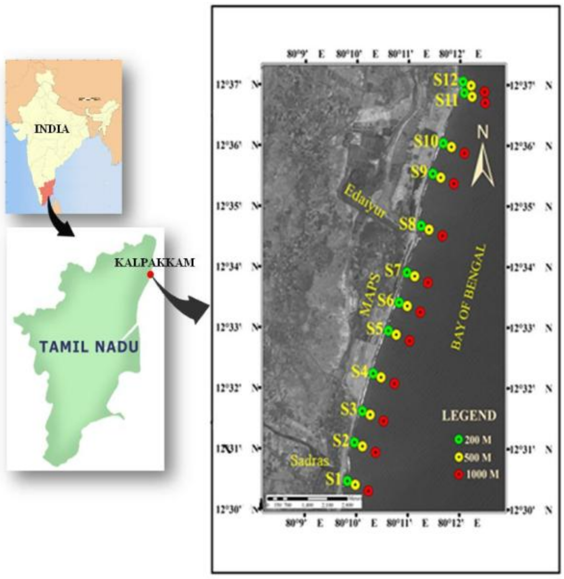

Fig. 1 Study Area and its Monitoring Sites

III. METHODOLOGY

The development of a methodology for the prediction of chlorophyll a production and measurement of temperature involved a structured interdisciplinary approach, which incorporated three distinct stages: (a) Sampling Strategy, (b) data collection and analysis and (c) Spatial interpolation analysis. Each of these stages is discussed below.

3.1. Sampling Strategy

Monthly boat cruises were carried out in the sea over the period of 12 months from January 2010 to December 2010 in an area of about 15 (alongshore) x 1 km into sea. The study area is divided into twelve transects with three stations in each viz., 200, 500 and 1000 meters. The stations were chosen based upon the prevailing conditions like backwaters, thermal mixing point. A total of 72 samples were obtained for each month (Fig. 1). A schematic representation of the sampling stations was given in figure 1. Sampling was undertaken over a tidal cycle, and sampling locations were fixed using global positioning system (GPS).

Table 1: Study Area Description

Station No.	Area Description
Station 1	200m south of Sadras
Station 2	IGCAR township
Station 3	Meyyurkuppam village
Station 4	Periya Odai (South boundary of IGCAR)
Station 5	200m south of seawall
Station 6	Front of seawall
Station 7	200m north of seawall
Station 8	200m north of Edaiyur
Station 9	Kokillamedeu (North boundary of IGCAR)
Station 10	Venpurusham
Station 11	200m south of shore temple (Mahabalipuram)
Station 12	200m north of shore temple (Mahabalipuram)

3.2. Data Collection and Analysis

Surface and bottom water samples were collected at 12 locations for a period of one year (January 2010 – December 2010) throughout the study area. Table 1 lists the sampling dates and the number of samples collected during the study. Water samples were collected fortnightly in precleaned polythene bottles, and bottom samples were drawn by using a Niskin water sampler. Samples were kept in darkness at a low temperature (4 °C), following collection in order to minimize biological activity. Water temperature measurements were made using standard mercury filled centigrade thermometer. After filtering the water samples through 0.45 µm Millipore filter paper the Chl-a was analyzed by spectrophotometry following the method of [14]. For the spectrophotometric analyses, a double beam UV Visible Spectrophotometer (Chemito Spectrascan UV 2600) was used.

3.3. Spatial Interpolation Analysis

There are several spatial interpolation techniques, including inverse distance weighting (IDW), radial basic functions, local polynomial interpolation, etc. [15]. Compared with others, IDW is the simplest and most practical interpolation method [16 and 15]. IDW uses the measured values surrounding the prediction location and assumes that each measured point has a local influence that decreases with distance [17 and 15]. Using the factor scores of VFs as variables, this study applies IDW to create various continuous surfaces to present the pollution patterns influenced by each potential pollution source [16 and 18 - 21]. The data were subjected to spatial analysis using the Spatial Analyst module of ArcGIS 9.2. The data at different points were interpolated adopting the IDW method which resulted in a more reasonable output.

IV RESULTS AND DISCUSSION

Spatial distribution of temperature and chlorophyll was studied to understand the relationship between these parameters, especially to determine at what levels of temperature, the chlorophyll concentration increases to reach the level of eutrophication, if any. It is well established that in brackishwater and seawater systems, temperature and chlorophyll a is the preferred parameters that leads to enhanced production, at times resulting in eutrophication. The data on temperature and chlorophyll a collected at 36 locations during 2010 were spatially interpolated and spatial data of temperature and Chlorophyll a for the year 2010 are given in Fig.2 to 5. The temperatures were categorized into the classes of low (25.0°C - 27.57°C), normal (27.57°C -30.14°C) and high (30.14°C -32.7°C). Similarly, Chlorophyll a concentrations were categorized into the classes of Low (0.16-1.39 mg/m^3), normal (1.39-2.62 mg/m^3) and high (2.62-3.84 mg/m^3).

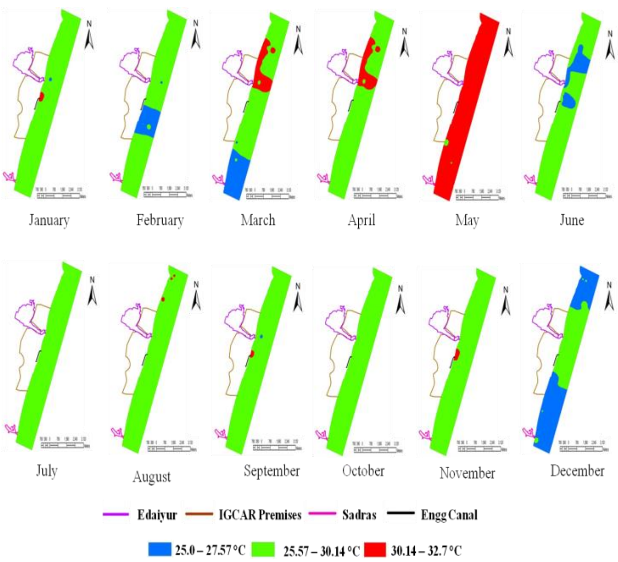

Figure 2: Spatial plots of surface water temperature

Fig. 2 shows spatial trends of temperature for surface and bottom waters. Temperature is high in the station S7 (Mixing point from MAPS) during January, September and November where more influence of thermal effluent from MAPS. Surface pattern shows highest temperature at station S8 to S10 during March and April due to current direction towards north of MAPS and normal pattern of temperature in south of MAPS, reflecting the spatial trends. The similar spatial patterns were observed in all stations during the month of May. A decline temperature is noticed in north (Station S1 to S5) and south (Station S10 to S12) part of Kalpakkam, whereas middle part (Station S6 to S9) shows slightly increased temperature. The bottom temperature showed similar pattern like surface water temperature. During the month of May, the plume structure is formed towards north of MAPS (Station S7 to S12) due to current direction. The northern part (Station S7 to S12) of the Kalpakkam shows decline temperature in the month of June (Fig. 3), whereas lowest temperature pattern were noticed during December in all stations due to the effects of monsoon.

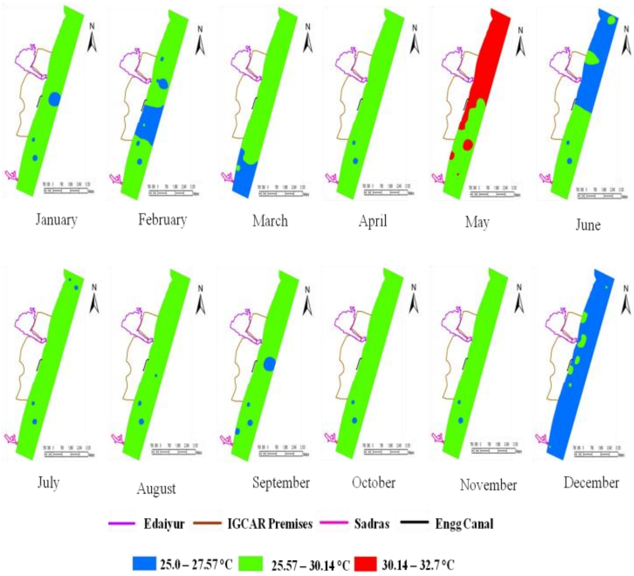

Figure 3: Spatial plots of bottom water temperature

Among the 36 sampling stations occupied during each cruise, a station about 500m south of the MAPS jetty was not influenced (in terms of temperature) by the discharge from the power plant. This station, which represented ambient sea conditions, was designated as the control station, for the purpose of determining seasonal variation of temperature in the coastal waters.

As shown in Fig.4, decline chlorophyll-a concentration in northeast monsoon and post monsoon for surface water, exhibit significant trends in chlorophyll-a. Such declines appear to be associated with monsoonal activities. Thirty- Six monitoring stations show decreasing trends in chlorophyll-a during January. Only one station exhibit increasing trend at station S8 (Edaiyur backwater), illustrating the freshwater influx. Whereas bottom water also shows increased in chlorophyll a concentration at station S8, associated with freshwater influence. The final map (Fig. 4 & 5) showing the spatial distribution of coastal eutrophication based on the distribution maps of the trophic level, based on annual values for chlorophyll a in the GIS environment. The map shows that the trophic level of the Kalpakkam coastal water. The results prove that coastal water is not affected by power plant effluents. The concentrations of Chl-a were the lowest in northeast monsoon, and the normal concentration in rest of the months (Fig. 5).

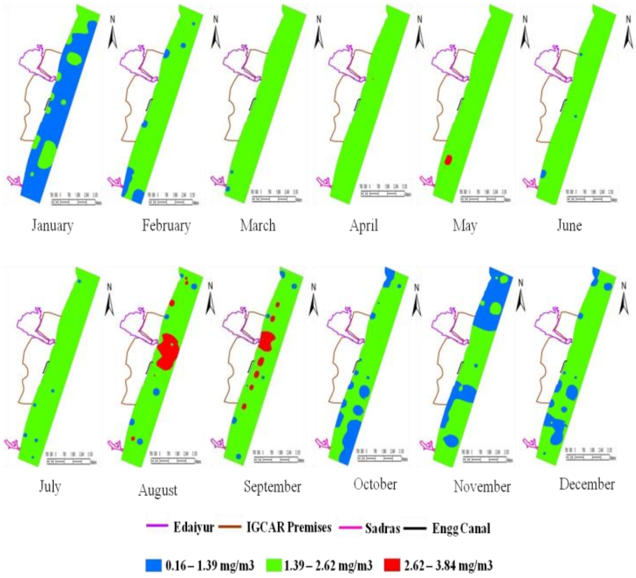

Figure 4: Spatial plots of surface water Chlorophyll - a concentration

Higher Chlorophyll-a concentration were observed in the Edaiyur (Station S8) than in other areas of the bay, with maximum during southwest monsoon. Chlorophyll-a concentration shows two opposite trends for surface and bottom in station S8. Approximately all stations do not exhibit significant trends in Chlorophyll-a during summer. Annual monthly variations between temperature and chlorophyll a in all stations are given in Fig. 3. It shows a pattern with one peak, in all stations during May month at station S7. The highest temperature (31.9°C) was recorded in May and the lowest (26.2 °C) in January (Fig. 6 & 7).

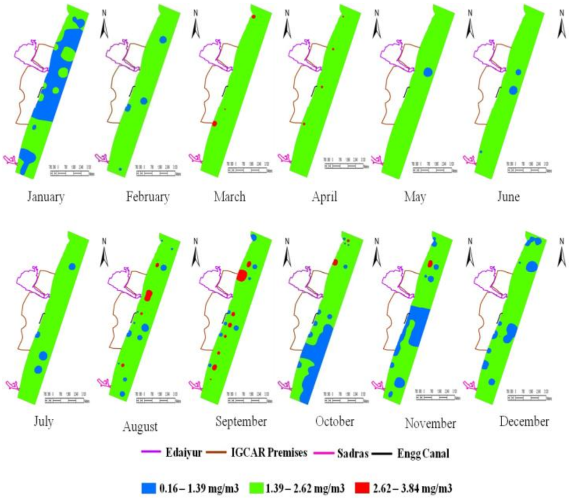

Figure 5: Spatial plots of bottom water Chlorophyll-a concentration

V CONCLUSION

A GIS-based IDW interpolation method was used to generate spatial trend indicating the spatial distribution of temperature and chlorophyll a. The use of spatial data derived from the point data has been found to be useful in determining the extent of quantitative spatial distribution of physical parameters in the coastal waters. The pattern of spatial distribution of temperature and chlorophyll a indicated the influence of freshwater influx from backwaters, thermal effluents from MAPS outfall and physical parameters like coastal currents on the zonal spatial distribution of these parameters.

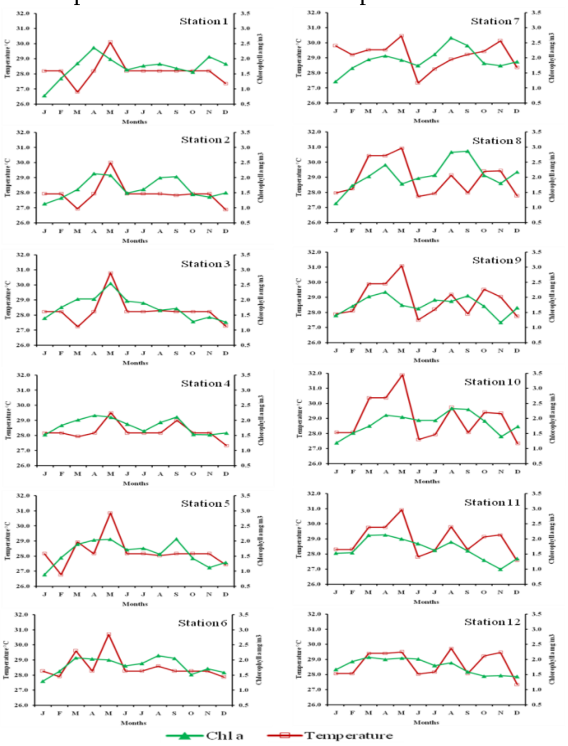

Figure 6: Monthly variation of Temperature and Chlorophyll-a for surface water

The increase of temperature at station S7 to S9 clearly revealed the effectiveness of thermal effluents. But the presence of high concentration of chlorophyll a in seawater revealed that freshwater influx. Further, information on study area of seawater with normal temperature and chlorophyll a can be used of seawater for condenser cooling and other human related use. The analysis of GIS proved to be an excellent tool to study the trend of vital parameter like temperature and chlorophyll a. An exercise done using this tool to study the effect of temperature on chlorophyll a revealed that even at temperature below 31.9°C, normal concentration of chlorophyll could be achieved indicating that the coastal waters of Kalpakkam not affected by thermal effluents. The existence of such a relationship can be demonstrated using the location specific GIS based spatial point data, as it clearly indicates the extent of quantitative spatial distribution of concentrations and also facilitate better understanding of reality of correlations between the parameters. A conclusion section must be included and should indicate clearly the advantages, limitations, and possible applications of the paper. Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

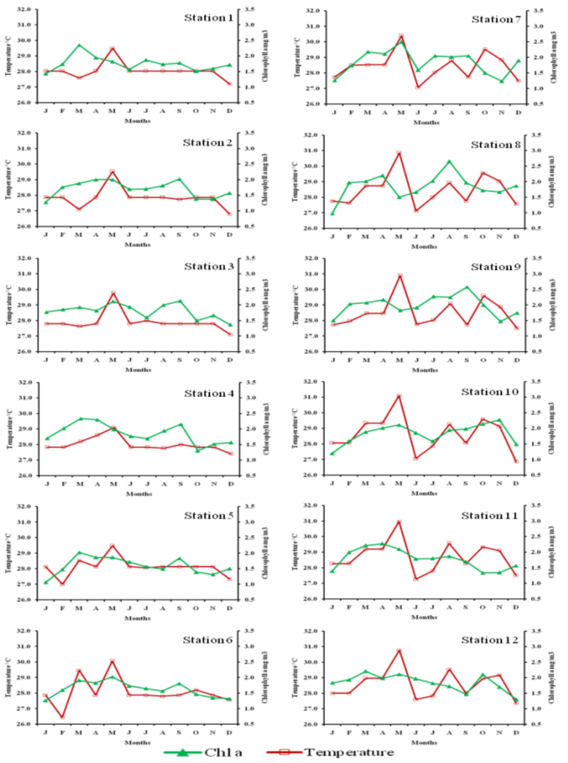

Figure 7: Monthly variation of Temperature and Chlorophyll-a for bottom water

Acknowledgements

The authors are thankful to the financial assistance provided by the Board for Research in Nuclear Sciences, Government of India.

REFERENCES

[1] Langford, T.E, Effects of Thermal Discharges (London: Elsevier), 1990.
[2] Kinee, O., Marine Ecology. Vol. I, Environmental Factors Part I (New York: Wiley Intersciences), 1972.
[3] Dey, W.P, Jinks, S.M, Lauer, G.J., The 316(b) assessment process: evolution towards a risk-based approach. *Environmental Science & Policy, 3(supplement 1),* 2000, 15–23.
[4] Mayhew, D.A., Jensen, L.D., Hanson, D.F, Muessig, P.H., A comparative review of entrainment survival studies at power plants in estuarine environments. *Environmental Science & Policy, 3(supplement 1),* 2000, 295–301.
[5] Choi, D.H, Park, J.S, Hwang, C.Y, Huh, S.H, Cho, C., Effects of thermal effluents from a power station on bacteria and heterotrophic nanoflagellates in coastal waters. *Mar. Ecol. Prog. Ser.*, 2002, 229, 1–10.
[6] Schubel, J.R., Marcy, Jr., B.C. (Eds.), Power Plant Entrainment—A Biological Assessment. *Academic Press, Inc., New York*, 1978, pp. 19–189.
[7] Winter, J.V., Conner, D.A., Power Plant Siting. Van Nostrand Reinhold Environmental Engineering Series. *Litton Educational Publishing, Inc., New York*, 1978, pp. 61–81.
[8] Kinne, O. (Ed.), 'Marine Ecology' Environmental Factors Part I, vol. 1. *Wiley, New York*, 1970, pp. 321–363.
[9] Langford, T.E.L., Ecological effects of thermal discharges. *Elsevier Applied Science Publishers Ltd., England*, 1990, pp. 28–103.
[10] Xu, F.L, Tao S, Dawson, R.W, Li, B.G., A GIS-Based Method of Lake Eutrophication Assesment. *Ecological Modelling* 2001, 144: 231- 244.
[11] Akdeniz, S., Water quality assessment of Lake Uluabat and analysis of geographic information system, M.Sc. Thesis (In Turkish). *Uludağ Üniversitesi, Fen Bilimleri Enstitüsü, Bursa*, 2005, 126p.
[12] Küçükball, A, Karaer, F, Akdeniz, S, Ertürk, A., The use of geographic information system for natural resource management (in Turkish). In: Symposium on modern methods in science, 272-279, Kocaeli, 2005, 16-18 November 2005.
[13] Karaer, F, Küçükballi, A., Monitoring of water quality and assessment of organic pollution load .n the Nilüfer Stream, Turkey, *Environmental Monitoring and Assessment,* 2006, 114 (1-3):391-417.
[14] Strickland, S. C., Parsons, T. R., A Practical Handbook of Seawater Analyses, *Bulletin of Fisheries Board of Canada, Ottawa,* 1979.
[15] Wang, F.H., Quantitative methods and applications in GIS [M], *New York: Taylor & Francis*, 2006.
[16] Facchinelli, A, Sacchi, E, Mallen, L., Multivariate statistical and GIS-based approach to identify heavy metal sources in soils [J]. *Environ Pollut*, 2001, 114: 313–324.
[17] Mueller, T.G, Pusuluri, N.B, Mathias, K.K et al., Map quality for ordinary kriging and inverse distance weighted interpolation [J]. *Soil Sci Soc of Am J,* 2004, 68: 2042–2047.
[18] Lee, C.S, Li, X.D, Shi, W.Z et al., Metal contamination in urban, suburban, and country park soils of Hong Kong: A study based on GIS and multivariate statistics[J]. *Sci Total Environ*, 2006, 356: 45–61.
[19] Zhang, C.S., Using multivariate analyses and GIS to identify pollutants and their spatial patterns in urban soils in Galway, Ireland [J]. *Environ Pollut*, 2006, 142: 501–511.
[20] Chowdary, V.M, Rao, N.H, Sarma, P. B. S., Decision support framework for assessment of non-point-source pollution of groundwater in large irrigation projects [J]. *Agr Water Manage*, 2005, 75: 194–225.
[21] Zhou, F, Huang, G.H, Guo, H.C et al., Spatiotemporal patterns and source apportionment of coastal water pollution in eastern Hong Kong [J]. *Water Res*, doi: 10.1016/j.watres.2007.04.022, 2007.