An Interactive Spatial Model of Pulicat Lagoon Using Geographic Information System

Harini Santhanam\textsuperscript{1}, S. Amal Raj \textsuperscript{2} and K. Thanasekaran, \textsuperscript{3}
Centre for Environmental Studies, Anna University, Chennai – 25, India
Corresponding author: santhanam.harini@gmail.com

ABSTRACT

In recent years, modeling has emerged as an invaluable tool for understanding the functioning of coastal lagoons. Modelling the environmental characteristics of the coastal area near the Bay of Bengal, India has received increasing attention from researchers in the past years. This interest has stimulated a scientific investigation of lagoon ecosystems, which have been studied from the physical, chemical, biological and ecological points of view. Finding the inter-relationships among the environmental factors of an ecosystem is crucial to address the measures to be taken for the sustainable development of eco-resources.

In this study, a spatial model has been attempted in applying these inter-relationships to understand and visualize a complex lagoon ecosystem along the south east coast of India. Owing to its unique hydrology and biogeochemistry, Pulicat lagoon, a coastal lake, was chosen for building a spatial model to represent its ecological status. Data concerning the environmental parameters were collected based on a comprehensive study conducted in the lagoon in years 2005 and 2006. An interactive spatial information system has been generated for the lagoon. A modelling environment has been developed using Geographic Information System (GIS) components called MapObjects in a Visual Basic environment. In this study, we attempted to develop and use an interactive GIS application to model a coastal brackish water environment. The output of the research is intended to be used in the process of decision-making in order to help environmental managers and administrators involved in the preservation and restoration of the Pulicat lagoon ecosystem.

Keywords: Spatial model, lagoon ecosystem, GIS, Pulicat lagoon

INTRODUCTION

Coastal lagoons are interesting environmental laboratories with unique physio-chemical, biological, climatological and geological interactions that are of great interest in scientific investigations. The unique hydrology of lagoons makes them highly productive ecosystems, providing a habitat for a variety of plants and animals, serving as nurseries for prawns and shrimps and also as sites for harbour, aquaculture, industry and recreation. Despite being endowed with several well known and hugely variant coastal lakes and lagoons, India has little or ill-defined databases on their environmental status (Reddy and Char, 2004).

However, the scientific survey and modeling of the physical, hydro-chemical and biological characteristics of lagoons and coastal lakes involves an extensive collection of samples from the study area, coordinated in-situ field measurements and analysis of the water and sediment quality in the laboratory. Modeling the environmental status of lagoons and their quality must be complemented with a well-planned sampling strategy spanning over several years scheduled to represent the seasonal variations over the years (Wainwright and Mulligan, 2004). It may not always be possible to organise a research team and resources to undertake such detailed investigations over long periods as the funds are hard to come by. Also, it is not possible to make measurements at all the desired places in all the seasons and hence there is often a need to estimate values for locations where there are no measurements. These estimates are based on the data available and the understanding of the spatial variation of the phenomena under observation.

Further, handling the huge quantum of data generated from such sampling or monitoring programmes becomes challenging. Subsequently, it becomes difficult to visualize such spatial datasets to draw any useful information, inference or a clear conclusion (Anad, 1996). Simplicity in representation of the ecosystem is hence essential for
the basic understanding of the ecosystem system functionalities (Haraldsson and Sverdrup, 2004). This also includes improving the overall effectiveness of the datasets and minimising the complexity of the results obtained from analysing them.

The advancements in computing techniques coupled with GIS have increased the potential of creating and maintaining databases using geographic datasets (Batty et al., 1994; Hutchinson et al., 1995; Clarke and Gaydos, 1998; White and Engelen, 1997; Doucet, 2000). A GIS database is very useful especially for studies of water resources when critical decisions relating to the ecology; economic and socio-economic setup of the area have to be made. Such application based on the holistic approach through the integration of various spatial and non-spatial elements and understanding of their dynamic inter-relationships offers the most uncomplicated solution to management of surface water resources (Burrough, 1986).

Thus, the need of the hour is to design a simple, yet effective modelling tool to handle the huge datasets, extract practical information behind the statistics of the observation, to augment the findings using the available knowledgebase on the study area and to visualize the environmental status of the lagoon using the developed tool. Such a tool could serve as the instrument communicating the scientific studies of the lagoon characteristics in easily understandable and usable format to the coastal managers and environmentalists. They, in turn, can easily visualize the ecological status and formulate integrated management plans to enhance the quality of these unique ecosystems. Further, they can, in conjunction with the policy makers, translate these management strategies into policies benefiting both the ecosystem and the humans dependent on it for their survival.

This paper highlights the procedure involved in utilization of the available spatial and non-spatial datasets of water and sediment quality of Pulicat lagoon in developing an interactive spatial tool using GIS in a Visual Basic environment using Mapobjects. Development of a ‘user-friendly’ and spatial interpolation-based exploration and modeling package is the main objective of this work.

STUDY AREA

Pulicat lagoon (Lat. 13° 24' - 13° 47' N and Long. 80°16' E) is the second largest salt water lagoon of the east coast of India (Fig 1). About 84% of the lagoon lies in the state of Andhra Pradesh and the rest in the state of Tamilnadu. It is a shallow brackish-water lagoon with an average depth of 1.2 m and a high water spread area of 460 sq. km and average water spread area of about 350 sq. km. It is connected to the Bay of Bengal through a narrow (200m) and shallow opening. Freshwater flow is scarce and seasonal. Two small rivers one at the either ends of the lagoon and the land runoff bring very little freshwater into the lagoon. Water flows in the river only during the rainy season (October to December). Salinity and reduction in area and depth of the lagoon are the major physical factors influencing the ecosystem.

Figure 1. Study Area

The mixing regime and biogeochemistry of Pulicat Lake are highly seasonal. Fresh water inflow is limited to monsoon season. The mouth of the lagoon gets silted up periodically restricting the inflow of seawater. Freshwater input occurs from two small rivers, the Arani and Kalangi. Of these, the Kalangi is quantitatively the most important mainly due to its high discharge approximately 700m$^3$ s$^{-1}$ during the monsoon season. The ecosystem illustrates a multi-environment within; the northern, southern, eastern and western zones of the lagoon showing their own characteristics of water and sediment quality. These observations suggest that nutrient generation and cycling patterns are different in the various zones of the lagoon. Nitrogen and phosphorus are the major nutrients controlling the productivity.

METHODOLOGY

The methodology employed for achieving the objectives of this study is presented as follows:
Environmental Data Collection

The baseline data on the water and sediment quality of Pulicat lagoon were collected during four seasons – postmonsoon (Jan – Mar), summer (Apr - Jun), premonsoon (July – Sep) and monsoon (Oct – Dec) for the years 2005 and 2006 at selected sampling locations within the lagoon. The samples were analysed for water and sediment quality parameters including depth, temperature, pH, salinity, dissolved oxygen (in situ measurements) and ions, nitrogenous nutrients, phosphorus and photo-pigments in the laboratory using the methodology outlined in Strickland and Parsons (1954). The collateral data from various literatures form the knowledge base from which the non-spatial elements of the database were prepared.

Spatial Data Preparation

The base map was prepared for Pulicat lagoon by digitising from Survey of India (SoI) toposheets and LANDSAT (year 2000) satellite images. The geographic features of Pulicat lagoon including the islands, the rivers and the mudflats were mapped along with the sampling stations from which the environmental data were collected for different periods, using their geographic locations obtained using Global Positioning System (GPS). Then, a spatial database was prepared and updated with the results of the in situ and laboratory analyses of the environmental quality parameters along with the sampling locations.

Development of Spatial Model

The objective of this research was to build a well-designed user interface incorporating the spatial modelling strategy to predict the environmental status of the lagoon at any desired location. This includes the following steps in model building as illustrated in Figure 2.

![Figure 2. The Methodology for Building the Interactive Spatial Modelling Tool](image-url)
Interface Design

The model was designed using Visual Basic and MapObjects components. Some basic map elements like legend, scale bar were appropriately included in the design of the application so as to create an easily understandable map. A key map was designed to provide all navigational functions for the main map area (Figure X). The key map and the main map were created using the Map component of MapObjects. Other interfaces for obtaining the user inputs and providing model outputs were designed using common Visual Basic components.

Model Functionalities

The current model has been designed to provide the following functionalities for the users which are discussed in detail under the head results and discussion. The functionalities provided by the developed system are listed below:

1. Navigation and Exploration
2. Neighbourhood search
3. Spatial interpolation based on IDW
4. Visualisation of environmental parameters
5. Exporting data

Temporal data search

The temporal search option incorporated into the development of the model allows the user to click on the lagoon water body to mark the location where from which the status is required to be predicted. In general, there are two types of spatial interpolation techniques: Global and Local. In this model local interpolation method has been adopted keeping in mind the area of study and the extent of its water body. The user is given the option to fix the search radius for finding local data sources. Further, the user can also fix the search for data sources over a particular period. The data sources obtained from the search was used to interpolate all the environmental parameters for any user-defined location (Figure 3).

Spatial Interpolation

Based on sampled data values an estimated value was assigned to all other locations using Inverse Distance Weighted (IDW) interpolation. The form of inverse distance weighted interpolation used in the study was obtained from Shepard (1968). The equation used is as follows:

\[ Z_i = \frac{1}{\sum_{i=1}^{n} d_i^2} \sum_{i=1}^{n} w_i X_i \]

Where, \( w_i \) is the weight functions assigned to each point and \( d \) is the distance between the points. Data obtained from such interpolation are based on the fact that objects that are near are more important than those that are far away. In accordance to the basic decision in any interpolation, the method of IDW was chosen to model the statistical relationship between data inputs. A spatial interpolation model was thus designed using results of the above interpolation activity as input theme for the water and sediment quality data.

In this interpolation technique, the contribution of each input (control) points was weighed by a normalized inverse of the distance from the control point to the interpolated point. It was assumed that each input point had a local influence that diminishes with distance as per the standard methodology used in IDW (Lam, 1983; Burrough, 1986). The points closer to the processing points were weighed greater than those farther away. A specified number of points or all points within a specified radius were used to determine the output value for each location. The power parameter in the IDW interpolator was used to control the significance of the surrounding points upon the interpolated value. A higher power resulted in less influence from distant points.

Validation of the model

In order to validate the results obtained through the model, out of the total available samples, few known samples of each parameter were randomly selected and used as test samples. It has been observed that values at test samples were nearly similar to the values at corresponding points over surface generated without considering those test samples. Again this result was found to be similar to those considering all the sampling points. This confirms that the sampling locations available were able to predict or interpolate values at points beyond or at locations where sampling points were not available.

Predicting environmental status

Inferences about the ecological status of the lagoon were derived from the available knowledgebase on the well-established interactions of the environmental components, the inter-relationships between the physico-chemical and the biological components in a natural lagoon ecosystem (Odum, 1971; CPCB, 1979; Sawyer, McCarthy and Parkin, 2000; CPCB, 2002; ZSI, 2003) apart from the specific literature on the ecosystem behaviour of Pulicat lagoon researched over the past years (Lagoons of India report, ENVIS - CAMB, 2000).
RESULTS AND DISCUSSION

The present research has culminated in the development of a simple, yet successful geographic information system (Figure 3). The newly developed lagoon information system has exhibited the following main functionalities:

1. **Navigation and Exploration**: The developed tool provides a navigational map and a key map, using which the user can explore the different parts of the lagoon. Information about various places of interest within and near the lagoon is provided to the user as he/she explores the lagoon. This makes it easier to visualize the ecosystem setting and provides key information on its features (Figure 3).

2. **Neighbourhood search**: This functionality helps the user determine the different data sources available to him, by providing the search radius to the tool. The tool identifies and displays the number of data sources in the neighbourhood of the location defined by the user, for which the environmental data can be retrieved for spatial interpolation (Figure 3).

3. **Spatial interpolation based on IDW**: this functionality helps the user obtain the values of different environmental parameters for any user-defined location within the lagoon water body using the built-in spatial interpolation algorithm incorporated in the tool. The values so obtained can be used for visualisation of the ecosystem characteristics (Figure 3).

4. **Visualisation of environmental parameters**: this functionality helps the user visualize the variations in a specified environmental parameters such as pH, salinity etc. for the years 2005 and 2006. The water quality, sediment quality and biological characteristics of the lagoon are displayed for user defined location and time. The changes in the values of all environmental parameters are represented graphically. The graphs as well as the values of the parameters over the four different seasons can give the user an idea of the ecosystem behaviour over spatial, temporal and seasonal scales. The inference drawn from the above is also displayed (Figure 3).

5. **Exporting data**: Using this functionality, the user can export the data obtained by the spatial modelling above into a text file. The exported file allows the user to store the values of all water quality, sediment quality and biological parameters for any location in the lagoon, during all the seasons for a selected year (Figure 3).

Thus this study has demonstrated the potential of spatial modelling in representation of the environmental status of a coastal brackish water lagoon environment over multi-periods using multiple datasets, which was very tedious by any other means, not only in terms of accuracy but also by the use of derived information as input for other environmental analyses. A vast number of data points for every environmental parameter have been generated using this model. This can be provided as an input to more complex modelling tools that...
require a large number of datasets. Further, it has been demonstrated using this interactive spatial information tool, it is easy for scientists and non-scientists to visualize and infer the environmental status of the lagoon. The output of the research can be used in the process of decision-making in order to help environmental managers and administrators involved in the preservation and restoration of Pulicat lagoon ecosystem.

CONCLUSION

A new interactive spatial tool has been developed for predicting the values of environmental parameters using a spatial interpolation model. It can further be modified in future according to the needs of the study to accommodate more complex spatial analyses or ecosystem models, wherever required. Spatial mining techniques if applied to such large databases can also bring to light the hitherto unknown spatial relationships between environmental variables, help to understand the available spatial data better, reorganising and update the spatial databases, constructing spatial knowledgebase and to optimise spatial queries.

REFERENCES


