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STUDY ON GIS SIMULATED WATER QUALITY MODEL

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ABSTRACT

"A GIS-based watershed load model" which basically is the modeling of lake water quality by using geostatistical modeling techniques to understand the dynamics in a watershed. Simulation is illustrated through a case study for The Hussain sagar lake, Hyderabad which allows to the govern parameters of water quality like BOD, DO of lake water and phosphorus, nitrogen loads discharging into the lake from the primary influent streams. Results from the multi-layered geospatial model are expected to show a satisfactory coalescence between measured and simulated water parameters. This model enables prioritizing and effective management alternatives for protecting the water quality.

Index Terms: Compartment Model, ArcGIS Mapping, Water Characteristics, Data Sampling.

I. INTRODUCTION

The development of water quality models has reached an extremely important stage. Clean and Pure water is becoming more and more precious, although it is known that in absolute terms there is no 'clean water', in the management of water quality, we are trying to reduce the level of water pollution economically at the lowest possible cost. To achieve this goal, we perform a lot of numerical and statistical simulations to find out the best trade-off management solution. The final goal of using water quality management models is to simulate the consequences of different measures that can be taken to improve the water quality, and then to determine the measure which is optimal in both senses, economical and environmental [1]. Another major advantage of water quality models is that we can simulate different, even not quite well known, processes and the response of a physical system to certain forcing. By comparing the results of such simulations with field measurements and observations we can better understand physical, chemical and biological processes and find more accurate mathematical and statistical descriptions of these processes. Long-term continuous monitoring is not currently being conducted due to high costs. Therefore, there is a need for an alternate tool such as a basin-scale hydrologic/water quality model that is capable of predicting the effects with reasonable level of accuracy [2].

It is important that the right choice and use of numerical models can reduce to a minimum the number of necessary usually very expensive - field measurements. The Numerical water quality model is a complete integrated model for the simulation of water quality processes and transport, dispersion and the growth or decay processes of the relevant quantity (i.e. of a contaminant), through interaction with the biochemical processes.
Water Quality models can be zero-dimensional (generally compartment models), where complete mixing of all quantities inside the 'compartment' is assumed; one-dimensional, where subsequent connection of compartments is made (typically along a river reach); or two- or three-dimensional (2D, 3D) models. As the transport, dispersion of water parameters are considered on Lake Surface only 2D model will be discussed in this paper.

II. GEOGRAPHIC INFORMATION SYSTEM

A geographic information system (GIS) is a computerized database management system designed to capture, store, manipulate, analyze, manage, and present all types of geographical data and display of spatial (e.g. locationally defined) data. It digitally creates and "manipulates" spatial areas that may be jurisdictional, purpose, or application-oriented. The technology can be used to overlay and combine data into a single computerized map that can summarized geographic, cultural, and scientific land attribute.

GIS proving to be an effective tool for numerical models offers distributed parameter and continuous time simulation with flexible watershed configuration, inter-basin water transfer, and lake water quality simulation capabilities [4]. It has been proven to be an excellent tool to aggregate and organize input data for distributed parameter hydrologic/water quality models.

A GIS can be divided into five components: People, Data, Hardware, Software, and Procedures. All of these components need to be in balance for the system to be successful. No one part can run without the other. There are several things to consider before acquiring geographic data. It is crucial to check the quality of the data before obtaining it. Errors in the data set can add many unpleasant and costly hours to implementing a GIS and the results and conclusions of the GIS analysis most likely will be wrong.

Spatial modeling represents the structure and distribution of features in geographical space. In order to model spatial processes, the interaction between these features must be considered. There are several types of spatial data models including: vector, raster, surface, and network [11].

The vector data model is a method of storing and representing data on an X, Y Cartesian plane. A coordinate and an equation defining the curvature of each feature are stored for both the beginning and the end point of each feature. The building block of the vector structure is the point; lines and areas are composed of a series of points in a specific order that gives the object direction.

The raster data model uses a grid composed of rows and columns to display map entities. Each cell in the grid is equivalent to one map unit or one pixel. Spatial resolution determines the precision of spatial representation by raster data. The smaller the size of the pixel implies the higher the resolution and the better the precision of spatial representation [14]. An entity code is assigned to each cell that is connected to a separate attribute table, which provides information to the user as to what entity is present in what cell. In this model, instead of dividing the entire area into cells of equal size, only areas with specific details are broken down into smaller cells [12].

Fig. 1 Shows mapping of a lake and its surroundings along with its influent, effluent stream system in various data models of GIS.

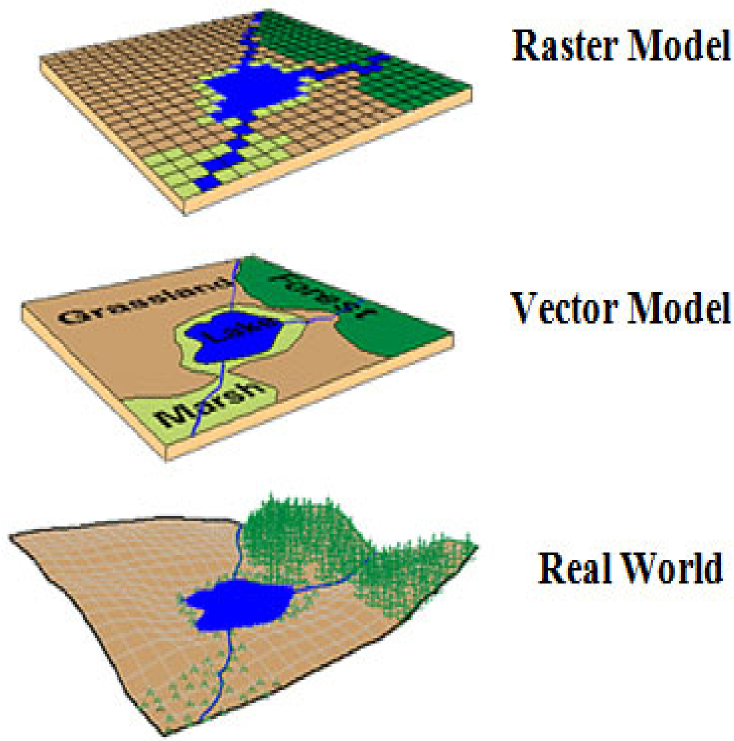

Fig. 1 Illustrative mapping of a lake and its influent stream by vector and raster data models of GIS (Color print required)

III. AREA OF INTEREST

Hussain Sagar Lake was built in 1562 A.D across a tributary of the Musi River. The lake joins the twin cities of Hyderabad and secunderabad and adds dimensions of historical aestheticism to twin cities. The lake was utilized for irrigation & drinking water needs up to 1930. Hussain Sagar Lake is an artificial lake that holds water perennially fed by influent canals or streams (now named nalas) and its outlet is connected to Musi River.

Gradually after 1930, the lake became receptacle of Domestic sewage and industrial effluents from catchment areas. Due to eutrophication, growth of water weeds, algal bloom and bad odour the watershed became redundant for recreation and pisci-culture [1].

As a result of heavy anthropogenic pressures such as unplanned urbanization, the entire ecosystem of Hussain Sagar Lake has become a cesspool, the main sewage collection zone of the twin cities. The lake has become shallow due to siltation and accumulation of plant debris and the water quality has deteriorated considerably. As shown in Fig. 2, There are approximately about 80 lakes in the catchment area of Hussain Sagar Lake making it a tank with combined catchment.

Hussain Sagar Lake Characteristics as in [2]:

1. Coordinates: 17.45^{O}N - 78.5^{O} E.
2. Total combined catchment area = 240 Sq. km.

3. Maximum lake water spread area = 5.7 Sq. km.
4. Present Water spread area @ FTL = 4.81 Sq. km.
5. Shore line length = 14 km.
6. Volume of the Lake at spill level = 27.18 M.cum.
7. Maximum depth of the lake = 9.75 m.
8. Average depth at full capacity = 5.02 m.
9. Full Tank Level (FTL) = 513.43 m (above MSL).

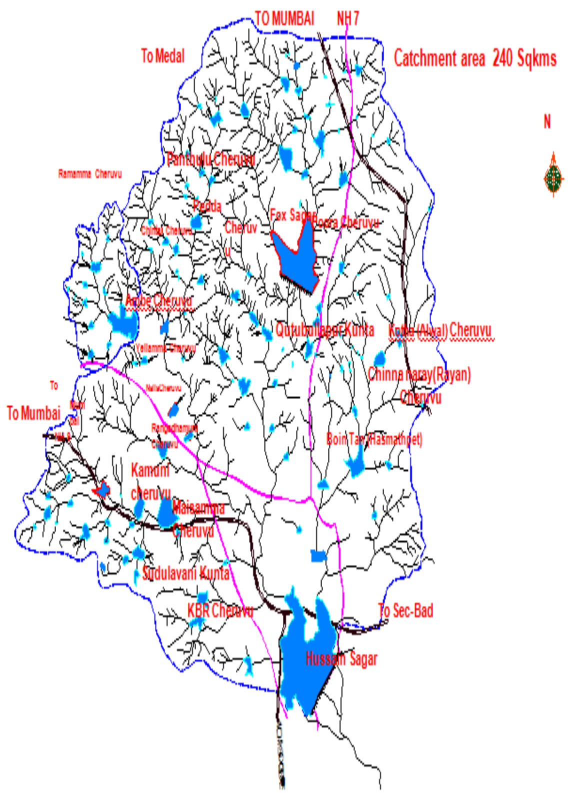

Fig. 2 Hussain Sagar Lake along with its Combined Catchment Area (Color Print required)

IV. POLLUTION SOURCES

A. Inlets

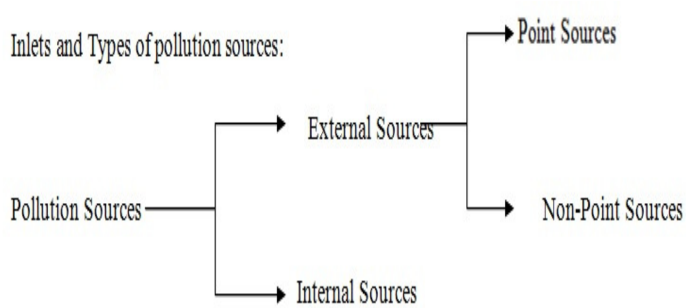

Fig. 3 Types of Pollution Sources in Hussain Sagar Lake

Pollution in Hussain Sagar is caused by external and internal sources (as in Fig. 3) in which External Point sources include raw sewage through nalas viz. Picket, Banjara, Kukatpally & Balkapur Nalas, Industrial effluents from Kukatpally Nala, Solid Waste Dumping into the Nalas –Leading into Lake. External Non-point sources include Slums, Dried Flowers, Garlands–Puja material, Commercial Establishments, Immersion of Ganesh and Durga Idols, Visitors and Tourists etc. Internal sources include Nutrient rich sediments on the lake bed and Floating matter on Lake Surface, Dissolved chemicals present in the deeper layers of the lake which do not have favorable conditions to diffuse out through the lake outlets.

B. Outlets

There are two outlets for Hussain Sagar Lake, They are - Surplus outlet opposite to Marriot Hotel and Surplus Outlet at Liberty. The location of inflows and Outflows of Hussain Sagar Lake are shown in Fig. 4.

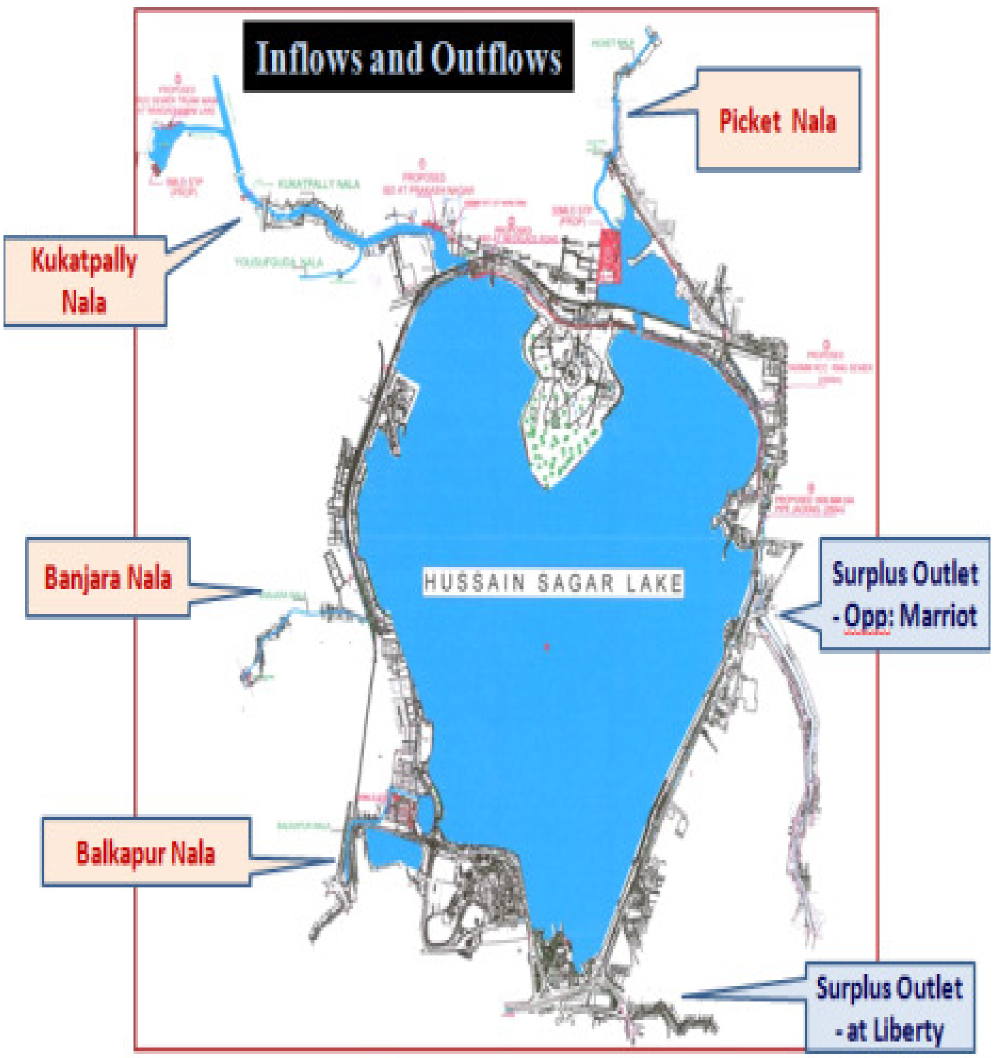

Fig. 4 Inlets and Outlets of Hussain Sagar Lake.(Color Print required)

TABLE I

INFLOW PEAK DISCHARGES AT DIFFERENT NALAS OF HUSSAIN SAGAR

S.No	Nala & Location of I&Ds	Existing	Enhanced for projected population of 2021
		Peak	Peak
1	Picketnala – Opp: Kims Hospital	15 MLD	171 MLD
2	Balkapur Channel	22 MLD	52 MLD
3	Yousufguda Nala near Divyashakthi Apartment	23 MLD	--
4	Bajara Nala near Yashoda Hospital	12 MLD	--
5	Kukatpally Nala at Fathenagar	75 MLD	185 MLD
6	Kukatpally Nala at Prakashnagar	30 MLD	44 MLD
7	Kukatpally Nala at Necklace Road (New)	-	100 MLD
	Total	177 MLD	552 MLD

MLD = Million litres per day; I & D = Interception and Diversion.

V. SAMPLING AND COLLECTION OF DATA

A total of 9 samples (as shown in Fig. 5) are collected at about the same time of each sampling day (at 9:30am) & the Sampling interval is taken as two weeks. The location of the sample collection points is fixed based on Periodical change in water level at the location and development of pressure around the point in the lake [6]-[7].

Sampling at shore, near inflows or in the windward direction where prevailing winds blow algae and debris down the lake and toward the sampling point is avoided. If collected, samples at these areas are less representative of the lake's overall water quality [3].

During sample collection, things recorded are the presence of storm water runoff culverts or pipes, types of shoreline vegetation (lawns, native vegetation, or agricultural land), Range of change in temperature, Probability of formation of shadow on the lake water surface due to adjacent structures and adjacent land use [3].

Characterization of wastes is essential for an effective and economical waste management programme [8]. It helps in the choice of treatment methods, deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the waste purification capacity of natural bodies of water in a planned and controlled manner.

The factors which contribute to variations in characteristics of the domestic sewage which comprises of spent water from kitchen, bathroom, lavatory, etc are daily per capita use of water, quality of water supply and the type, condition and extent of sewerage- system, and habits of the people. Municipal sewage which contains both domestic and industrial wastewater may differ from place to place depending upon the type of industries and industrial establishment.

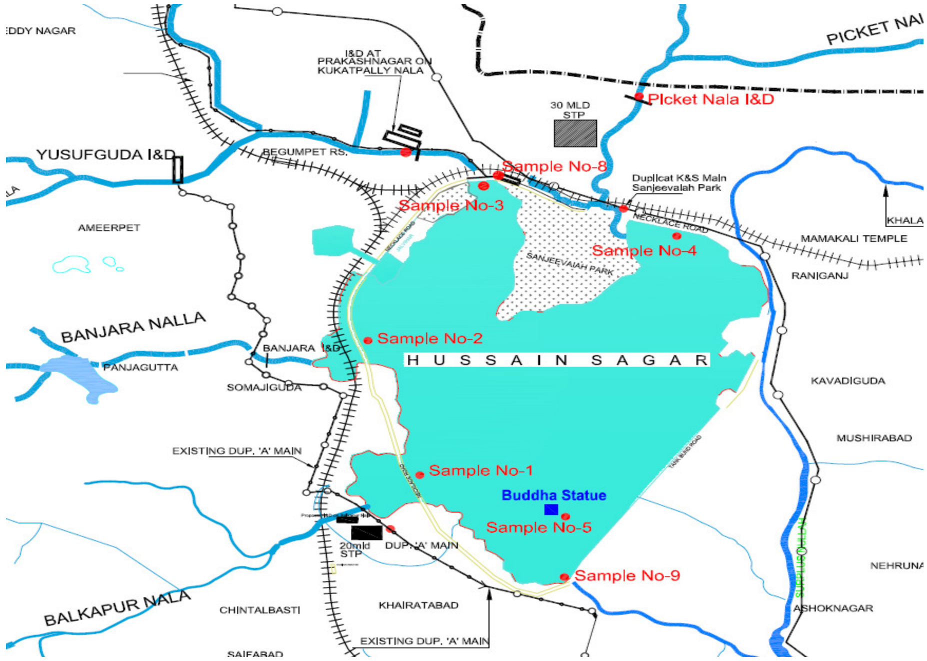

Fig. 5 Representation of all nine data sampling points(Color print required)

TABLE II

Lake water characteristics sampled on 22/07/13

Lake Water/Nala Water Analysis Report (22/07/13)

S.NO	Parameters	Units	Sample-1 Balkapur Nala at the joining point of lake	Sample-2 Banjara Nala water at the joining point of lake	Sample-3 Kukatpally Nala water at the joining point of lake	Sample-4 Picket Nala at the joining point of lake	Sample-5 Lake Water at Bhudha Statue	Sample-6 Jeedimetla Nala water before joining point of confluence	Sample-7 Kukatpally Nala water at Fathenagar after joining kukatpally and Jeedimetla nala	Sample-8 collection chamber of I&D necklace Road	Sample-9 Lake Water at Weir out let at BPPA office
1	pH	(--)	7.26	6.96	7.06	7.39	7.38	7.29	7.27	7.42	7.53
2	Temperature	^{0}c	23	23	23	23	23	23	23	23	23
3	TDS	(mg/l)	598	617	732	708	633	1043	668	703	721
4	TSS	(mg/l)	18	29	31	24	17	56	33	21	18
5	DO	(mg/l)	0.8	Nil	Nil	Nil	0.7	Nil	Nil	Nil	0.9
6	Nitrates as N	(mg/l)	4.06	4.51	4.74	3.83	3.16	4.96	4.51	3.83	3.16
7	Ammonical Nitrogen as N	(mg/l)	8.4	12.28	15.32	8.28	5.86	10.82	11.8	9.56	8.82
8	Total Nitrogen as N	(mg/l)	13.26	17.72	21.14	12.9	9.92	16.62	17.18	14.3	12.8
9	Total Phosphorus as P	(mg/l)	1.88	2.11	2.4	2.18	1.2	1.55	1.22	1.38	1.09
10	COD	(mg/l)	62	86	124	96	74	118	78	66	70
11	BOD	(mg/l)	16	21	30	23	18	28	20	16	17

VI. DATABASE CONSTRUCTION AND EXPERIMENTATION

From the point samples (measurements), two continuous surfaces (maps) predicting the values of lake parameters or concentrations for every location within the boundary of lake were produced in Environmental Systems Research Institute's (ESRI) ArcGIS 9.0 which is the software used for visualation of the data and for map creation. The first map that is created will simply use all the default options to introduce you to the process of creating a surface from the sample points. A Digital Elevation Model (DEM) was obtained from the Geological Survey of India (GSI) in 1:50k in Digital format. Several DEM tiles were assembled to attain a complete coverage of entire study area using MOSIAC command of Arc Info. The DEM was then REPROJECTED in Arc Info to the Universal Transverse Mercator (UTM) projection. The reprojected DEM was FILLED in Arc Info to correct to any internal drainage errors in the data layer. FLOWDIRECTION and FLOWACCUMULATION grids were derived from the DEM in Arc Info. Finally, the Hussain sagar Watershed was delineated using Arc Info's WATERSHED command. The last grid cell in the Hussain Sagar Lake before outlet to the Musi River was used as the pour point. The outlet of the watershed (pour point) was selected using the FLOWACCUMULATION grid. The second map that is produced will allow you to incorporate the assembled geo-spatial data to hussain Sagar lake boundary which is done using GRIDCLIP and CLIP commands of Arc Info. When creating this second map, the exploratory spatial data analysis (ESDA) tools are used to examine sample point data [10]. The database was complied by obtaining data layer from a large number of sources. By using the ESDA tools and working with the geostatistical parameters, one can able to create a more accurate surface [5].

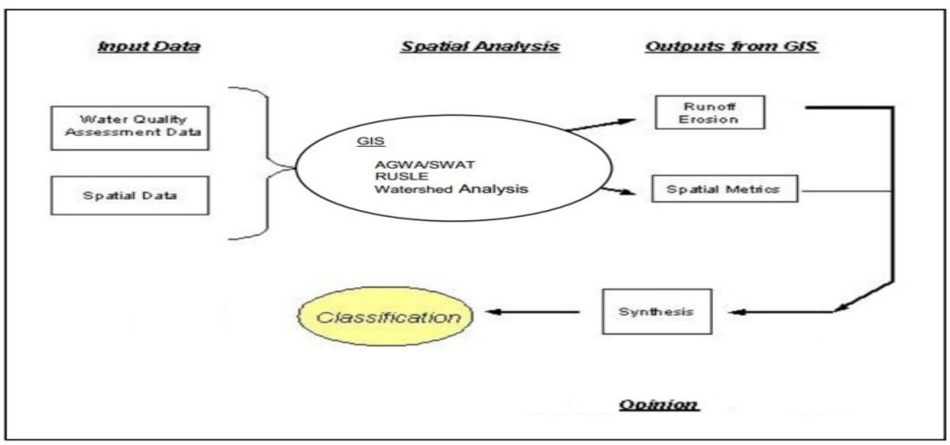

Fig. 6 Representation of experimentation procedure

The ca_lake.gdb (lake geo database file) is to be opened as in [9] which contain two datasets as

Dataset	Description
[1] ca_outline	[2] Outline of lake
[3] lake_points_9:30am	[4] point sample values (ppm)

Fig. 7 Datasets Included

The ESRI's Arc Info 7.2.1 and Arcview 3.3 were the GIS software programs used to integrate and process the data. All data layers were converted to the universal transverse mectator projection in ArcInfo. Data layers exist in ESRI's Coverage /Grid and Shapefile formats.

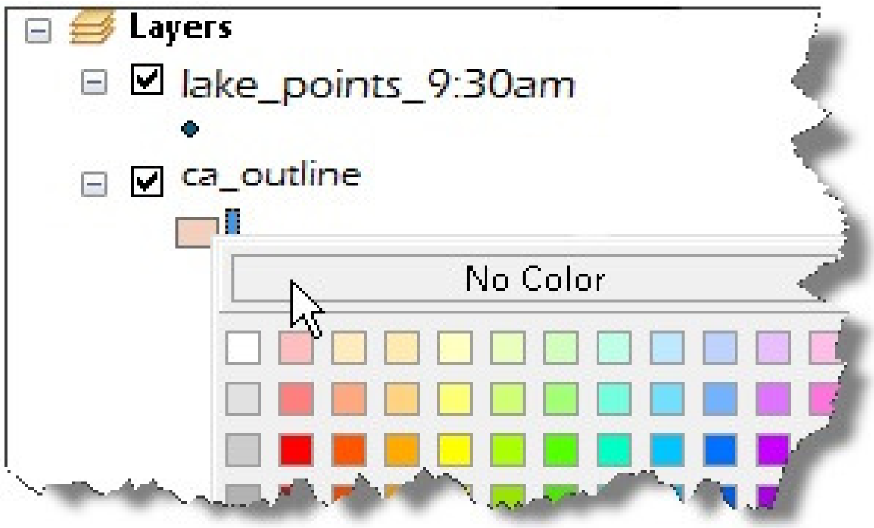

Fig. 8 Data Layers that are converted in to UTM Projection (Color print required)

Layers along with their properties (as in Fig. 8), Datasets (as in Fig. 7) are included into the software and the results obtained are in the form of a graph for the water parameters. Fig. 9 represents the obtained output, representing the simulation of water parameter i.e., BOD.

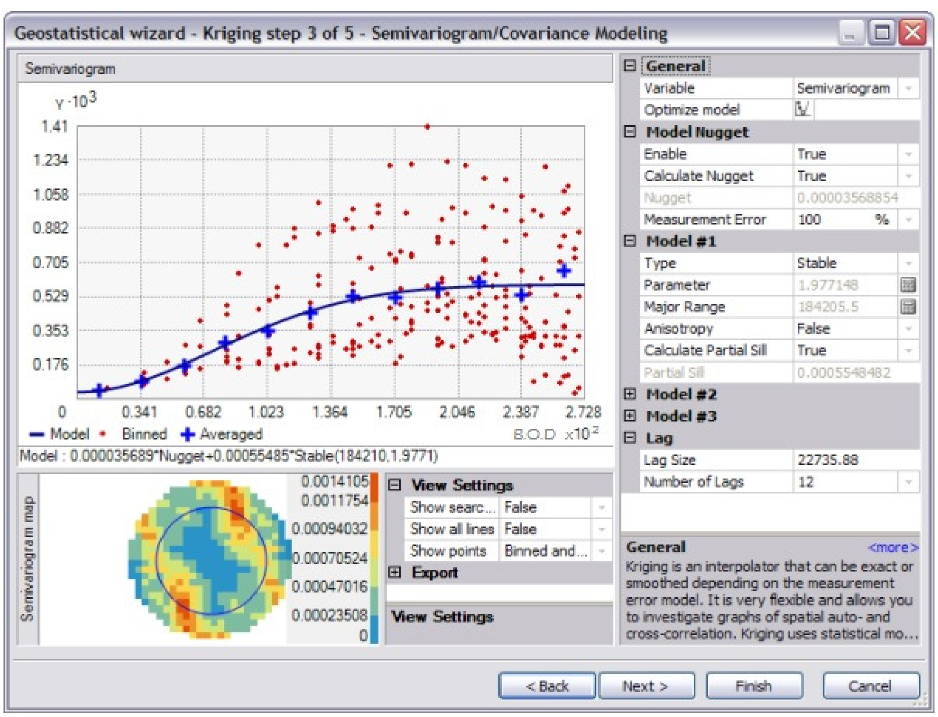

Fig. 9 Output obtained (Color print required)

The obtained output shown is water quality representation graph in terms of BOD. The values obtained from Model are shown as a blue line, the values sampled are shown as red dots and the averages of measured values are represented as blue plus symbols. The Modeled values are comparable and are approximately matching the sampled BOD values. As shown in Fig. 10, A cross validation check is done in the geostatistical wizard to check the quality of output from the simulation by calculating various prediction errors for all the samples measured values and model simulation output values.

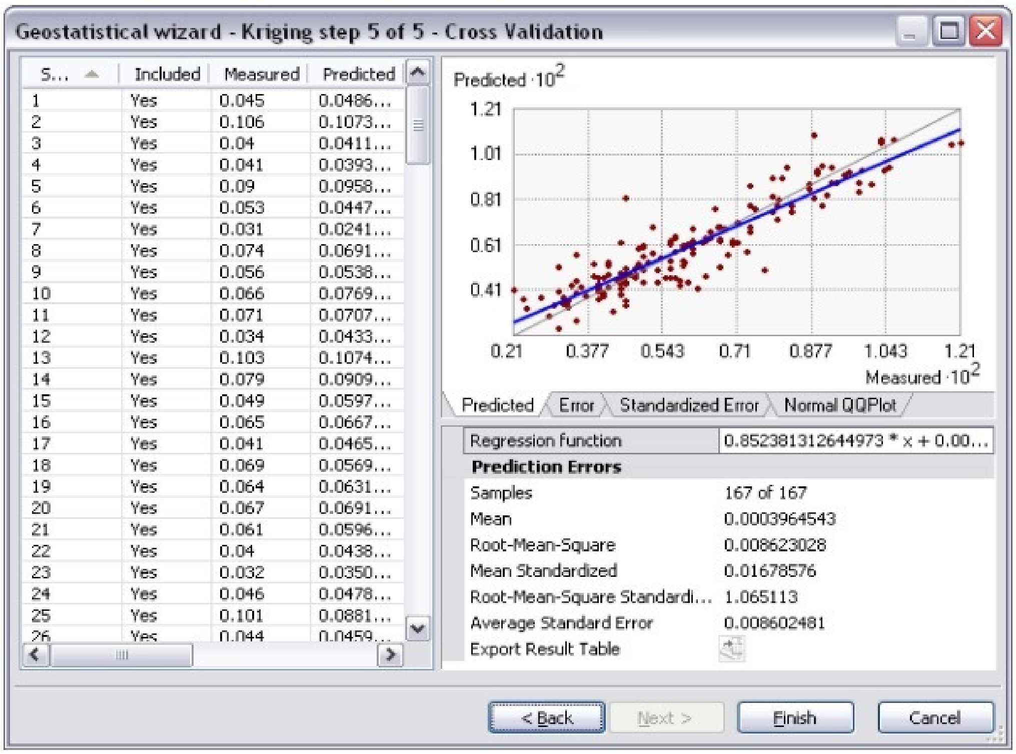

Fig. 10 Cross Validation of Simulation

As the Average standard error obtained (as shown in Fig. 10) is approximately zero, the model is eligible for usage in determining water quality parameters at any anonymous point on the lake surface.

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