MODELING THE NON-POINT SOURCE POLLUTION LOAD IN AN URBAN WATERSHED USING REMOTE SENSING AND GIS: A CASE STUDY OF DAL LAKE

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ABSTRACT

The water quality of Dal Lake (Kashmir, India) has deteriorated considerably in the last few decades due to excessive weed growth, reduction in water clarity, enrichment of waters and high microbial activity. Urban watersheds are particularly vulnerable to non-point pollution as a result of runoff from the surrounding landscape. Remote sensing and GIS have been used for water quality assessment since decades. In the present study, PLOAD (Pollution Load) model with a GIS interface was used to estimate the annual pollutant loadings coming into the lake from urban watershed. The main objective of the study was to estimate pollutant levels generated from various land use activities in the watershed and carried into the lake. The datasets used in the study included Landsat 7 ETM+ satellite image, 40 m digital elevation model (DEM), ancillary data, pollutant loading rates and field data. Though PLOAD model requires a number of parameters, but in the study, only land use / land cover, watershed and export coefficient data were generated for model execution. The PLOAD model gives the pollutant loadings by watershed (lb/yr) and watershed area (lb/ac/yr). The export coefficient values for various pollutants like BOD, TSS, TDS, NH_3, TP and TN were collected from the literature (Rast and Lee, 1978; Loehr *et al*., 1989; Baldys *et al*., 1998; McFarland and Hauck, 2001; Line *et al*., 2002). The land use / land cover map of the watershed depicted 8 land use classes. Chemical analysis of the water samples associated with each land use class was carried out in order to validate the export coefficient values. The urban watershed witnessed significantly high annual loads for almost all the pollutants. The reason for this may be attributed to the fact that this watershed is under direct biotic interference. Further, large number of land use/land cover classes present in this watershed may be another reason for high pollution load.

Keywords: Remote sensing, GIS, PLOAD, landsat, DEM, land use / land cover.

INTRODUCTION

Dal is a Himalayan urban lake. It is one of the most beautiful lakes of India and is surrounded by mountains on its three sides. This lake with its multi-faceted eco-system and grandeur has been inviting the attention of national and international tourists for centuries. The water quality of Dal Lake has deteriorated considerably in the last few decades. The main environmental issues are excessive weed growth, reduction in water clarity, enrichment of waters and high microbial activity. Contaminants enter the lake through direct point sources, diffuse agricultural sources and diffuse urban sources.

Remote sensing and GIS modeling has been widely used in water quality studies. Water quality models of volume, sediment loads, water quality and flow are therefore heavily dependent on geographic data sources which are provided in geographic information systems (GIS) (Usery *et al*., 2004). Various mathematical models have been developed and applied on streams, lakes and estuaries (Lung, 1986; Thomann and Mueller, 1987; Kuo and Wu, 1991; Kuo *et al*., 1994). Modeling of non-point source pollution is still in its early stages. However, model such as the Unites States Environmental Protection Agency's (USEPA) BASINS (Better Assessment Science Integrating Point and Non-point Sources) is beginning to bring a uniform approach (CH2M HILL USEPA, 2001). BASINS is a multi-purpose environmental analysis system for use by regional, state, and local agencies in performing watershed and water quality based studies. BASINS contains many models such as HSPF (Hydrologic Simulation Program Fortran), SWAT (Soil and Water Assessment Tool), PLOAD (GIS Pollutant Load Application) and AGWA.

In the present study, a GIS-based model PLOAD (Pollution Load) was used to estimate the annual pollutant loadings coming into the lake from urban watershed. The main objective of the study was to define pollutant levels coming from various land uses in the watershed into the lake. This study assumes great significance keeping in view the ecological and aesthetic importance of the lake. Urban development around Dal lake is likely to increase pollutant loads into the lake. Because heavy pollutant loads may adversely affect the lake functions, estimating the increase in pollutant load due to the development may be of interest for regulatory and planning purposes.

STUDY AREA

The study area is the urban watershed (Fig. 1) comprising the western part of the Dal lake catchment, which is situated between the geographical coordinates of 34°02′ – 34°10′ N latitude and 74°48′ – 74°53′ E longitude and has an area of 37 km². The area is densely populated towards the western side. The Dal lake is situated in the heart of the Srinagar at an elevation of 1587 m a.m.s.l and has surface area of 11.5 km².

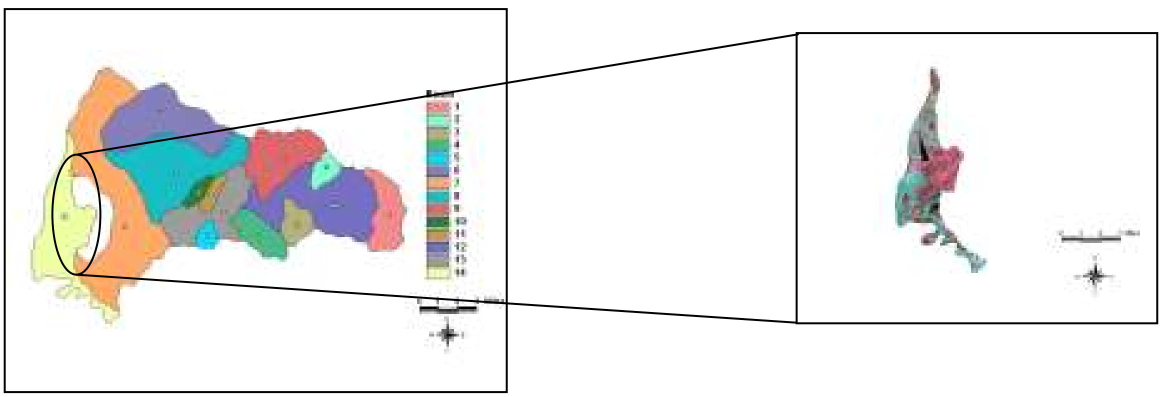

Fig. 1. Location map of the study area

The Dal lake is a multi-basin lake (Fig. 2) having both inflow and outflow channels and is believed to be fed by a number of underground springs, but the main source is the Telbal Nallah that enters into the lake on the northern side after originating from Marsar Lake high up in the mountains and draining the Dachigam Reserve enroute. On the southwest side the surplus water flows via Dalgate into Tsunthkul - a tributary to the river Jhelum. There is another exit also i.e., Nallah Amir Khan connecting the Nagin basin with Khushalsar lake.

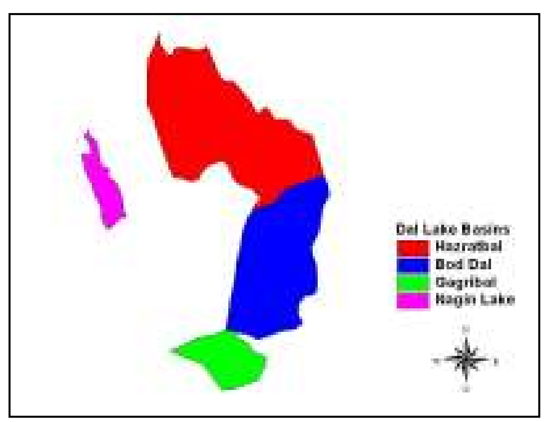

Fig. 2. Map showing the Dal lake basins

The Dal lake catchment is fan shaped and broadens in the westward direction. The western portion of the watershed is a flatter area, whereas the northern and eastern sides rise high. The Dal lake catchment exhibits a varied topography with altitudinal range of 1580-4360 meters. The climate of the area is sub-humid temperate. The average monthly temperature is 11ºC and the average annual rainfall is 650 mm at Srinagar and 870 mm at Dachigam.

DATA SOURCES

In the study, a variety of data sources including Landsat ETM satellite image, 40 m digital elevation model (DEM) (Fig. 3), ancillary data of the export coefficient values for various pollutants (Rast and Lee, 1978; Loehr *et al*., 1989; Baldys *et al*., 1998; McFarland and Hauck, 2001; Line *et al*., 2002) and journals like *Oriental Science* and *Journal of Research and Development* published by Center of Research for Development, University of Kashmir, chemical parameters data of the water samples viz. nitrite, nitrate, total phosphorus, dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia, total dissolved soils (TDS) and total suspended solids (TSS) and ground truth data were used.

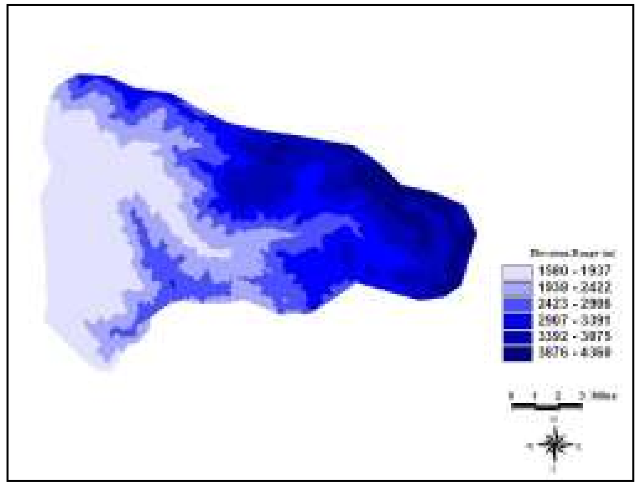

Fig. 3. DEM of the Dal lake catchment

METHODOLOGY

The details of the methodology are described in Fig. 4.

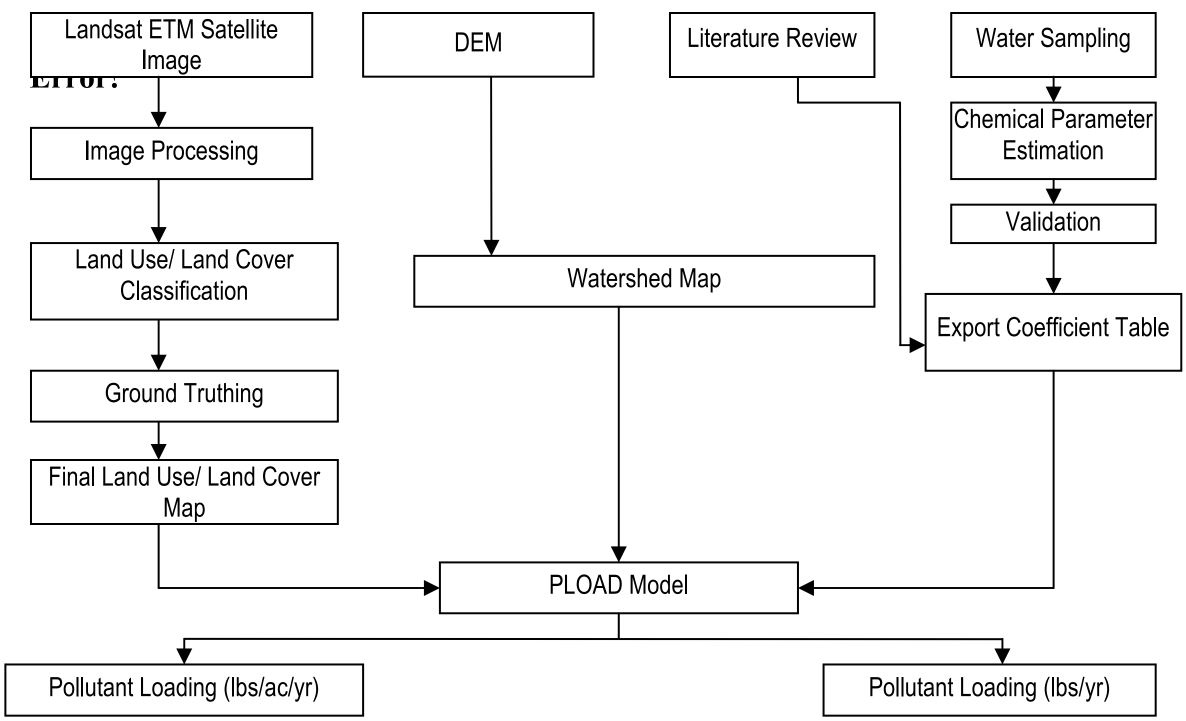

Fig. 4. Flow-chart showing the methodology adopted

The research used an integrated approach by using simulation modeling, remote sensing and laboratory / field data. The methodology is briefly discussed under the following headings:

1. Pollution Modeling

A GIS-based model PLOAD was used in this study. PLOAD is a simplified geospatial model developed by CH2M HILL (USEPA, 2001) for calculating pollutant loads from watersheds. PLOAD estimates non-point loads (NPS) of pollution on an annual average basis, for any user-specified pollutant. The user may calculate the NPS loads using either the export coefficient or the EPA's Simple Method approach. The various requirements of the model include:

- Generating of land use / land cover map in a vector format.
- Watershed map of the area.
- Export coefficient values (in lb/ac/yr)

Optionally, best management practices (BMPs), which serve to reduce NPS loads, and point source loads may also be included in computing total watershed loads. Finally, there are several product alternatives that may be specified to show the NPS pollution results as maps and tabular lists.

2. Generating Model Input Parameters

Delineation of Watershed: A 40m DEM was used for topographic analysis. The topographic details were useful in understanding the different land use classes of the area, as the terrain determines the spatial variability of the land use classes. It was also used in the delineation of catchment and watersheds and for generating a three-dimensional view of the terrain, helping to better understand the three-dimensional nature of the real world. The watershed was identified from DEM and then digitized in GIS to a vector layer along with its associated attribute database.

Image Processing and Land Use / Land Cover Classification: Before using the satellite imagery for classification, the image was pre-processed and processed in ERDAS Imagine. The image was geometrically corrected in ERDAS Imagine and referenced to Lat-Long coordinate system with WGS 84 datum. Different contrast enhancements were used to enhance the interpretability of the image.

To generate the LULC map of the study area, Landsat 7 ETM+ image with three channels of information was selected. Appropriate scene (area of the study) was clipped from the image. A false colour composite (FCC) having a band combination 4:3:2 (IR:R:G) was used. Supervised classification was carried out on the image using maximum likelihood classifier. In supervised classification, the analyst supervises the pixel categorization process by specifying the computer algorithm of the statistical parameters, viz. mean vector and variance-covariance matrix of various thematic classes present in the scene. The ML classifier resulted in a land use/land cover map of the area. Ground validation was carried out for all the land use classes identified in the study area. The necessary changes were incorporated and the final map was prepared.

An accuracy assessment of the classification was carried out taking random samples over the whole study area to cross validate the classification. By selecting random and field sampled ground truth data, 250 data points were collected and were utilized in the analysis.

Ground validation was carried out for all the land use classes in different parts of the study area. Field visits to the area were conducted and water samples were collected for chemical analysis.

Pollution Data: In the study, the data about the export coefficient values for various pollutants were taken from secondary sources (Rast and Lee, 1978; Loehr *et al*., 1989; Baldys *et al*., 1998; McFarland and Hauck, 2001; Line *et al*., 2002) and Journals like *Oriental Science* and *Journal of Research and Development* published by Center of Research for Development, University of Kashmir were also reviewed to get information about the pollutants. The resultant data was used in the generation of export coefficient table.

Estimation of Chemical Parameters: Chemical analysis of the water samples was carried out in the Limnology Laboratory of the Centre of Research for Development (CORD), University of Kashmir. The parameters analyzed were TDS, TSS, BOD, Total Phosphorus, Total Nitrogen and Ammonia. Water samples were collected from different land use / land covers throughout the catchment by dipping 1 litre polyethylene bottles just below the surface of water. Analysis of the chemical parameters was done within 24 hours in accordance with Golterman and Clymo (1969), CSIR (1974) and A.P.H.A. (1998) (Table 1).

Table 1: Methodology adopted for chemical parameter estimation

S. No.	Parameter	Methodology
1	Biochemical Oxygen Demand (mg/l)	CSIR (1974)
2	Total Phosphorous (μg/l)	Spectrophotometrically by Stannous Chloride Method (A.P.H.A., 1998)
3	Nitrate- nitrogen (μg/l)	Spectrophotometrically by Salicylate Method (CSIR, 1974)
4	Nitrite – nitrogen (μg/l)	Sulphanilimide method (Golterman and Clymo, 1969)
5	Ammonical Nitrogen (μg/l)	Spectrophotometrically by Phenate Method (A.P.H.A., 1998)
6	Total Dissolved Solids (mg/l)	A.P.H.A. (1998)
7	Total Suspended Solids (mg/l)	A.P.H.A. (1998)

3. Model Simulations

PLOAD model was used to simulate the pollutant loads into the Dal lake. Among GIS data, land use and watershed data were generated in the present study. Best Management Practices (BMP) data being optional were not generated due to unavailability of data. Among tabular data, export coefficient table was generated. Impervious terrain factor data tables were not developed, since they are used only when using simple method for pollutant loading calculation, whereas export coefficient method was used in this study. Pollutant reduction BMP data tables and point source facility locations and loads being optional were not generated due to unavailability of data.

For calculating pollutant loading into the Dal lake, export coefficient method was used, since the application of the simple method is limited to small drainage areas of less than one square mile. After the generation of all the required inputs, the PLOAD was executed and the model results showing the pollutant loading were represented as maps and tables.

RESULTS

1. Land Use / Land Cover Map: 8 different land use / land cover classes viz. forest, boulder, water, agriculture, plantation, barren, aquatic vegetation and built-up were observed in the study area (Fig. 5). The satellite derived land use / land cover information was verified in the field. The overall classification accuracy was found to be 89.60% with overall Kappa statistics equal to 0.8780.

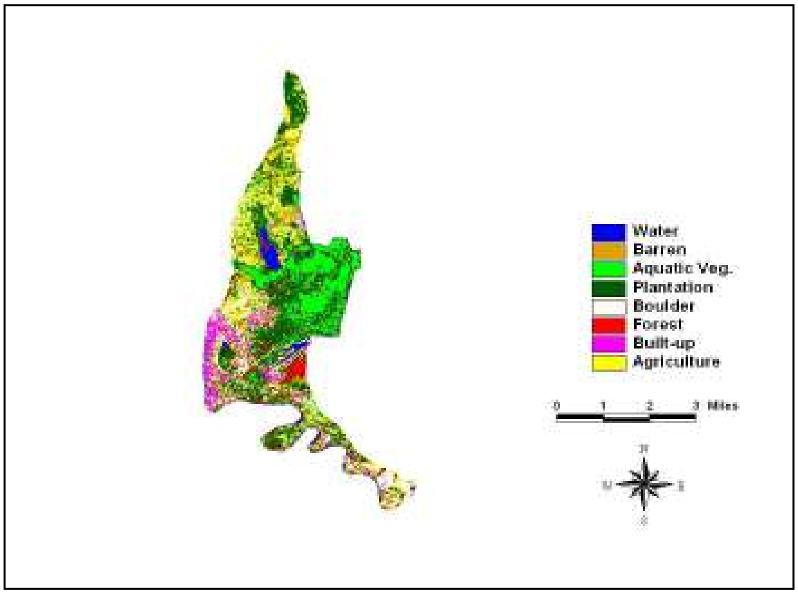

Fig. 5. Land use / land cover map of the study area

Plantation dominates the study area covering 29.79 % of the total study area (Table 2). Aquatic vegetation ranks second with 17.61 %, whereas agriculture comes next with 14.92 %. The least representative of the land use is water covering just 3.39 % of the area. The land use map helped in having an understanding of various pollution loads coming from different points in the catchment, as the pollution load is directly related to the land use/land cover type.

Table 2: Percentage-wise distribution of different land use classes.

S. No.	Class Name	Area (Km^2)	Percentage (%) Area
1	Water	1.25	3.39
2	Barren	4.61	12.46
3	Aquatic Vegetation	6.52	17.61
4	Plantation	11.02	29.79
5	Boulder	1.80	4.87
6	Forest	2.48	6.71
7	Built up	3.77	10.20
8	Agriculture	5.52	14.92
TOTAL		**37**	**100**

2. Watershed Map: The watershed map represents the urban watershed (Fig. 6). The map forms an essential input to the model. Pollutant loadings in PLOAD are estimated by watershed and/or watershed area. Many water quality problems are best solved at the watershed level rather than at the level of an individual water body or discharger. It is important that a watershed approach be used to address water quality concerns because land-use decisions made in one area of a watershed will inevitably affect those living in another part of the watershed. Watershed data was then used in the model to get the pollution load for each watershed.

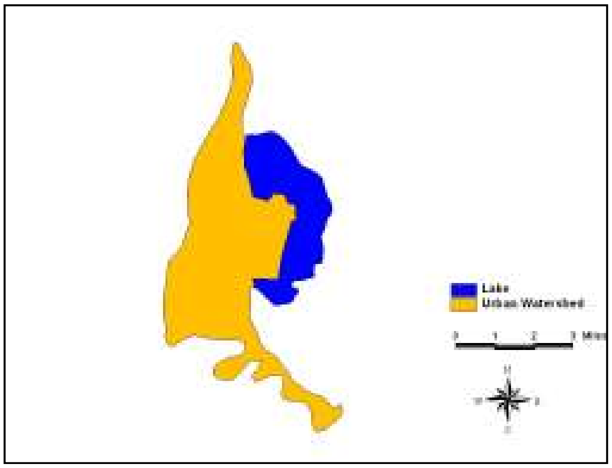

Fig. 6. Map showing the urban watershed of the Dal lake.

3. Export Coefficient Table: Export coefficient table was generated from the export coefficient values (in lbs/ac/yr) collected from the literature. The values were obtained for Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD), Total Phosphorus (TP), Total Nitrogen (TN) and Ammonia (NH_3), pertaining to different land use/ land cover categories. The values after validation were given the shape of an export coefficient table (Table 3), which was used in the estimation of the pollutant loads.

Table 3: Export Coefficient table

CLASS	BOD	TSS	TDS	NH_3	Total Nitrogen	Total Phosphorus
	(lbs/ac/yr)					
Plantation	59	124	424	4.7	31	6.4
Barren	29	492	137	2.8	18	5.3
Forest	33	162	521	3.9	22	5.6
Boulder	43	632	197	4.4	33	9.7
Agriculture	52	136	587	4.4	34	9.5
Water	-	-	-	-	-	-
Built-up	132	505	201	6.1	30	12.6
Aquatic Vegetation	157	144	462	5.5	31	8.6

4. Model Simulations: After running the PLOAD model, graphic and tabular output results were obtained for two simulation categories viz. annual pollutant loading by watershed area (Fig. 7; Table 4) and total annual pollutant loading by watershed (Fig. 8; Table 4). PLOAD model, thus, simulated the pollutant loads coming from the urban watershed into the Dal lake.

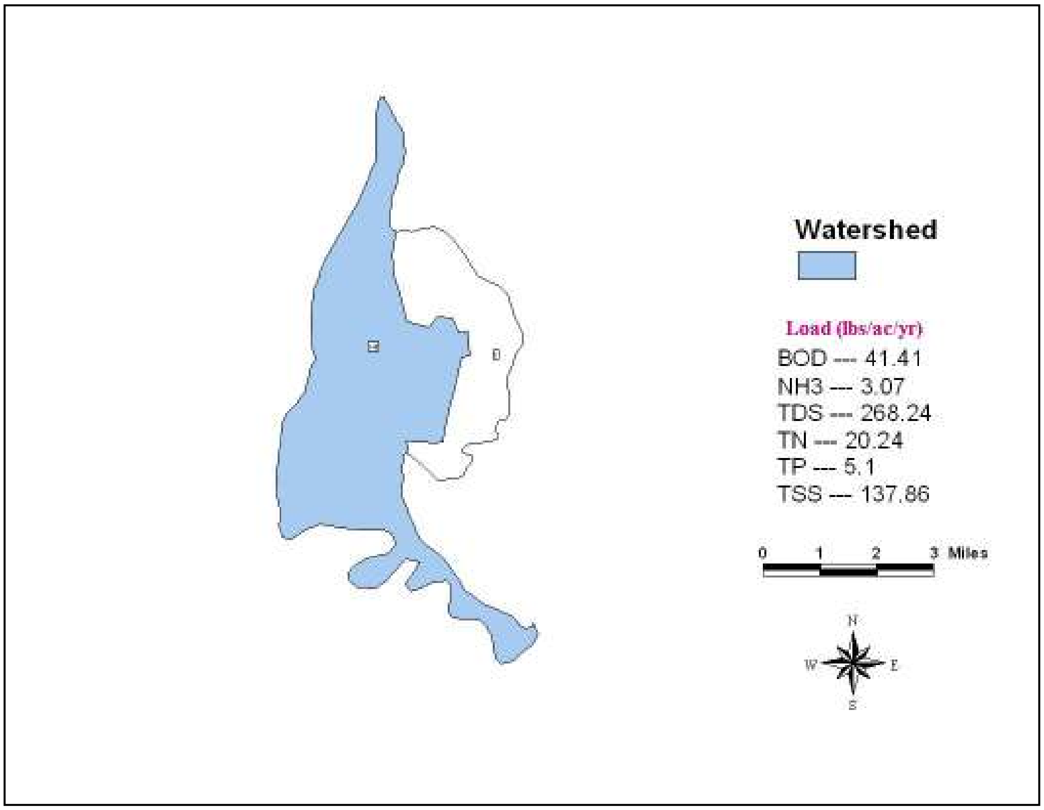

Fig. 7. Map showing annual pollutant loading by watershed area

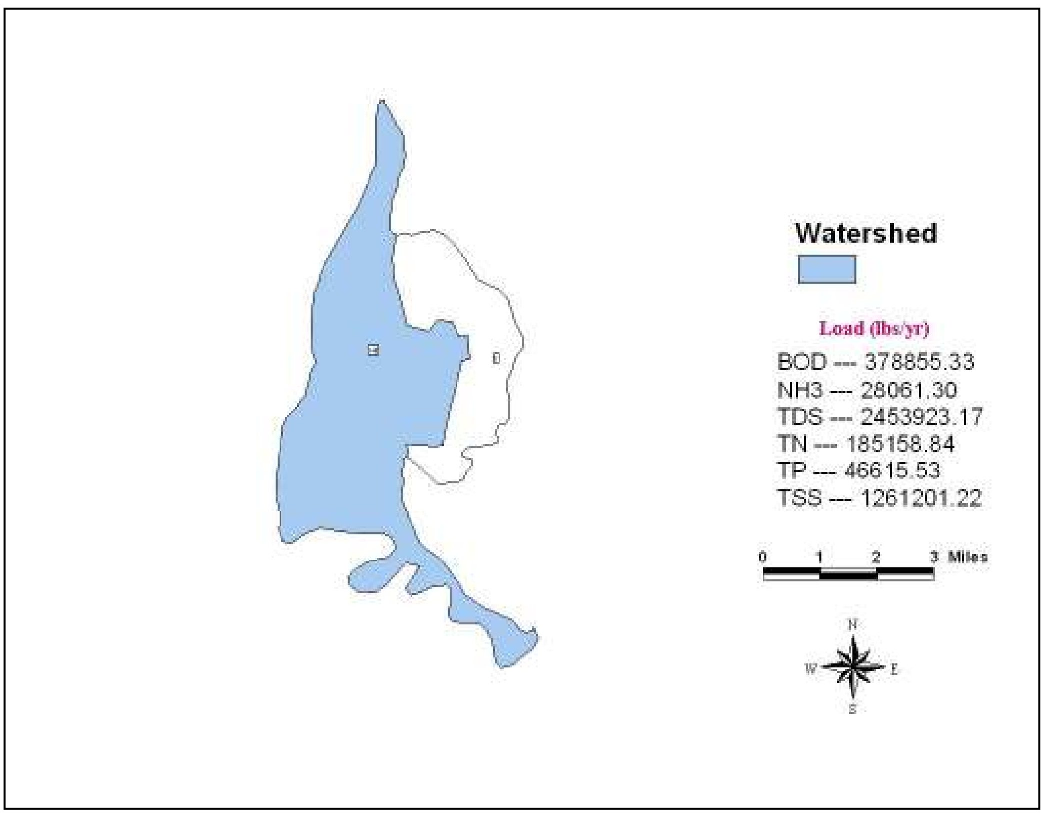

Fig. 8. Map showing total annual pollutant loading by watershed

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Table 4: Table showing annual pollutant loading by watershed area and total annual pollutant loading by watershed.

S.No.	Pollutant	Load	
		(lbs/ac/yr)	(lbs/yr)
1	BOD	41.41	378855.33
2	NH3	3.07	28061.30
3	TDS	268.24	2453923.17
4	TN	20.24	185158.84
5	TP	5.10	46615.53
6	TSS	137.86	1261201.22

DISCUSSION

In this study, the urban watershed of the Dal lake catchment was assessed for pollution loadings coming from different land use/land covers. The watershed receives significantly high annual loads of almost all the pollutants (Table 4). The reason for this may be attributed to the fact that this watershed is under direct biotic interference. Also the maximum number of land use/land cover classes is present in this watershed.

Excessive nutrients such as nitrates and phosphates, commonly originate in domestic sewage, runoff from agricultural fields, waste material from animal feed lots, packing plants etc. These nutrients are responsible for water pollution primarily because they stimulate the growth of microorganisms which often increase the biochemical oxygen demand (BOD). The total annual BOD load was estimated at 378855.33 lbs/yr. BOD is an indicator and not a pollutant. Higher BOD values indicate strong sewage and hence it is used to measure the degree of water pollution and waste strength.

The total annual load of ammonia was estimated to be 28061.30 lbs/yr. The ammonia loading may be attributed to the presence of organic pollution. Baumeister (1972) reported that ammonia is a good indicator of sewage pollution. Srivastava and Sahai (1976) reported very high free ammonia concentration in polluted area of the Chilwa Lake.

The total annual loads of total nitrogen and total phosphorous were estimated to be 185158.84 lbs/yr and 46615.53 lbs/yr respectively. Hutchinson (1957) reports the higher levels of phosphorous are the results of sewage contamination. Thomas (1969) pointed out that addition of phosphorous brings about eutrophication mechanism by increasing the bacterial content, increase in the oxygen demand and increase in growth of algae. Hammer (1971) reveals that as contrasted to most of other major ions the contribution of nitrogen and phosphorous to water is directly or indirectly attributable to the activities of man. Edwards and Goodman (1972) while outlining the main pollution problems of air, water and soil support the view of phosphorous and nitrogen being implicated in accelerating eutrophication process. Frecker and Davis (1975) discussed the man-made eutrophication in a Newfoundland (Canada) Harbour and found that phosphorous and nitrogen were the major culprits in accelerating the process. Similar findings have been reported by Prasad and Qyum (1976).

The total annual load for total dissolved solids and total suspended solids was estimated to be 2453923.17 lbs/yr and 1261201.22 lbs/yr respectively. Total solids of water are dependent upon the concentration of suspended and dissolved solids. Increase in the dissolved solids indicates increase in the concentration of the included elements and, therefore, eutrophication. Brehmer (1965) observed the latter is caused as a result of decrease in compensation depth by increasing the concentration of suspended solids. Hem (1970) related deterioration of water quality to increase of total solids. Seddon (1972) uses high dissolved solids content of water as a criterion for confirming the eutrophic nature of water. Goel *et al*. (1980) also reported higher values of dissolved and suspended solids in sewage polluted Mansagar waters.

CONCLUSIONS

Dal lake pollution provides us with a classic example of how little we appreciate the beauty of nature. There has never been a time when man has not modified his environment, but the changes that are taking place now are major and rapid as compared to the past. Significantly higher pollutant loadings were observed for different pollutants in the urban watershed. The higher loads may be attributed to the biotic interference experienced by this watershed. The different pollutants are contributing towards the steady degradation of this beautiful lake. As a result, the Dal is dying an unsung death. It is concluded that the urban watershed in Dal lake catchment assumes top most priority and thus need to be effectively managed on pollutant basis.

Despite some problems, this research has demonstrated the usefulness of remote sensing, GIS and simulation modeling for understanding the pollution loads and mechanisms in an urban watershed. Due to the shortage of time and resources, the data on the best management practices and point source location data which are used as inputs to the PLOAD model could not be generated / collected. The research can be taken forward by incorporating this data inputs required by the model to calculate pollution loads having higher degree of precision and accuracy.

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