Quantitative Evaluation of Non-point Pollution of Taihu Watershed Using Geographic Information System*

CUI Guangbai, ZAHEER Iqbal & LUO Jian

(College of Water Resources and Environment, Hohai University, Nanjing 210098, P.R.China)

Abstract This paper focuses the quantitative evaluation of non point sources of pollution by graphical maps of watershed and estimating area based load of pollutants of various land uses with the use of Arc/View Geographic Information System. The representative study is carried out in the Xinshan sub-watershed of Taihu watershed. It involves the simulation of pollutants load by watershed; watershed area and event mean concentration (EMC) by pollutants. Further the NPSP evaluation is carried out with the provision of Best Management Practice (BMP's) scenario in the watershed. BMP's utilization practice has provided the most efficient, practical and cost effective steps for the reduction of NPSP in the watershed. Using watershed boundary and land use data, nutrient EMC, and point Load, NPSP is evaluated based on PLOAD GIS model extension of Watershed 3.0. Model simulation is evaluated using tabular and graphical analysis. Support for this work is provided in the part by funding from the Natural Science Foundation in China for the project No. 50239030

Keywords GIS, Best Management Practice(BMP), non-point source pollution, Taihu Watershed

Geographic Information System (GIS) has provided viable tool to generate, manipulate, and spatially organize disparate for distributed modeling of large amount of data of watershed and land uses. Despite extensive achievement to point sources control, public attention has been diverted for the last decades towards non-point sources pollution (NPSP) of river / Lakes watersheds and watersheds. The utilization of large amount of agrochemicals regarding potential growth of crops and vegetables to meet the requirement for increasing rate of population has caused the contribution of diffused pollutants in the water bodies. Besides the loss of fertile soils, pesticides from agriculture results diffuse loss of nitrogen (N) and phosphorus (P), which are essential input for crop and animal production. Environmentalist and scientist have developed various methods and strategies for the quantification of NPSP. For instance various modeling

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interactions between various techniques including Geographical information system (GIS), Remote sensing (RS), Water quality modeling, Digital evaluation modeling (DEM), and Best management practice (BMP) utilization have provided the comprehensive framework for the evaluation of non-point pollution sources[1]. However NPSP is estimated based on information on land uses, population and geology, most of such techniques are composed of digital description of geographical features of land and soil uses integrated with physical based mathematical techniques describing the process governing return flows, hydrology and transport of pollutants in the watershed. Various such studies are described in CREAMS [2], ANSWER [3], AGNPS [4], SWAT [5], BMP [6] , and WATERSHED 2.0, Better Assessment Science Integrating Point and non-point Sources [7]. In recent, WATERSHED version 3.0 is available to solve environmental pollution problems related to point and non-point sources pollution in the watershed. The model is developed in user-friendly environment to make it more efficient, all management data utilities, assessment and report tool is extended in GIS-Arc/View 3.2. The present studies focuses the GIS based quantification of NPSP in the watershed using PLOAD extension of Watershed 3.0 working with Arc/View 3.2 [8]. BMP's in study area are including Sedimentation retention watershed (SRB) and locations for other BMP's, which are provided for pollutant reduction before final simulation. Based on land use information, pollutants loading coefficient and range of high, low and average annual rainfall, non-point pollutants load is calculated.

1 Description of PLOAD extension of WATERSHED 3.0 Model

PLOAD is a simplified GIS and spreadsheet tool works in GIS-Arc/View 3.2 framework. It is designed to be generic for the wide range of applications as screening tool including storm water permitting, watershed management and non-point sources pollution protection planning. Model is mainly designed in accordance with application's organization provided structured facilities of modification and customization as an analytical tool for end users. PLOAD estimates any specific pollutant of NPS on an annual average basis. Model also provides the provision of BMP approach in accordance with guidelines provided by TNRCC, which is served to reduce the pollutants load. BMP's type is provided as aerial or site features, having similar approach.

2 Development of model database

GIS database is created for the Xishan sub watershed of Taihu watershed, focused on attributes and data necessary to simulate PLOAD model. The major components of watershed database include Xishan county topographic map, watershed and boundary data, land use and BMP site and feature data. Hydrological data includes; precipitation, surface run off and Even mean concentration (EMC) of COD, nitrogen, and phosphorus. All encoded digital data, coverage, and model variables in the Arc/View are spatially organized with the same resolution and co-ordinate system. Most of data is collected from either local planning office or available literature and is managed in accordance with the guidelines provided in the user's manual. Description of acquired database and to establish the watershed GIS for the manipulation of PLOAD model is described as below.

2.1 Topography of study area

Xishan County covering the total area of 878 km^2 is representing a sub watershed of Taihu Watershed, which occupies a total area of 36355 km^2 including 18500 km^2 of lake catchments, located on the Yangtze River delta (Fig.1). The climate is sub-tropical with warm wet summer and cold dry winter with average rainfall of 1050-1240 mm. The average catchments flow is 8.7 $\times 10^9$ m^3 including 30% of rainfall directly falls into the lake. The rapid economic growth of agriculture and industrial development is causing severe impairment of river network system of Xishan County. The major sources of pollution are agriculture, urban and industrial. DEM data is showing most of the area plain having extensive agriculture including pastureland, paddy fields and kale yards where most of the pollutants are concentrated. The dominant land use in the study area is paddy field, which is calculated as about 71.52% of total area.

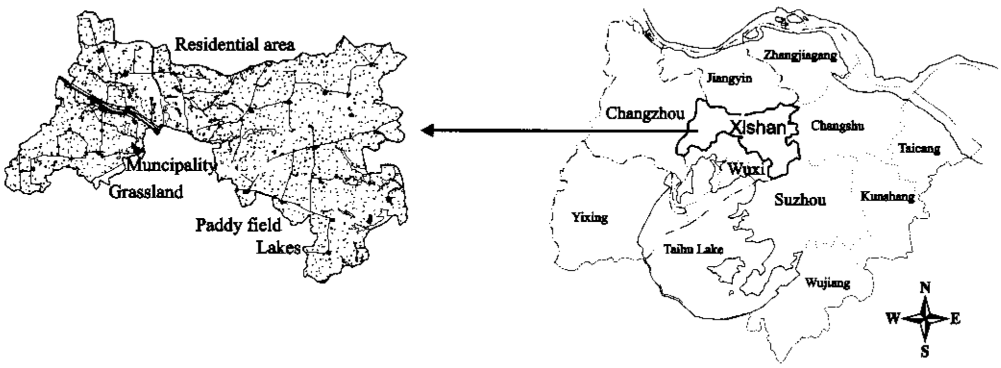

Fig.1 Topographic map of Taihu Watershed and studied area —Xishan County

2.2 Watershed delineation and processing of DEM

Digital evaluation model (DEM) data of Xishan County is processed at information resolution scale of 1:250000 for the delineation of watershed using automatic delineation option of WATERSHED 3.0. The delineation process is performed using data of watershed boundary, river reach file and DEM. GIS data is transferred into local geo-reference system and transferred to non-earth projection using Map/Info. In this study the cell, size of 1000 m is used resulting delineation into 5 sub-watersheds and 5 outlets (Fig.2). Stream is defined using the threshold area of 200 ha, creating 2 numbers of cells. The overall processing of DEM data is required for defining the flow direction after filling of pits[9]. After defining the flow direction, flow accumulations created by counting the number of contributing cells to each cell in the grid, defining flow accumulation value.

2.3 GIS Land use and Watershed Boundary Data

The GIS interface in PLOAD greatly facilitates the calculation of pollutants loading from specific land uses in the study area. Digitized land uses data for each watershed is obtained from grid database such as data layers maintained by Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences. All land use coverage is defined as unique code field to identify the land use type. Model spatially overlaid and intersected watershed and land use coverage in order to determine the area of various land uses type for each watershed i.e. land use coverage encompasses the entire watershed coverage.

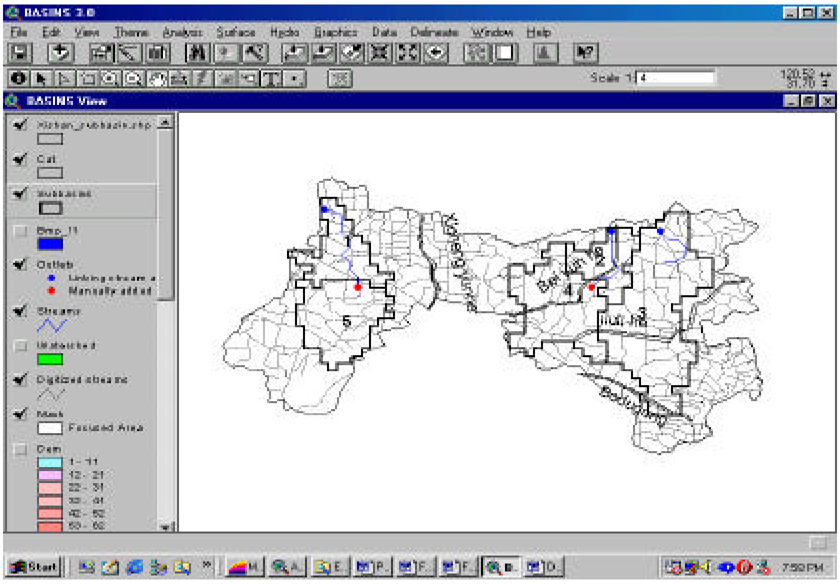

Fig. 2 Automatic delineation of watershed into sub-watershed using DEM and digitized river data in WATERSHED 3.0 interface

2.4 Implementation of fertilizers

The most common fertilizers are including urea, ammonium carbonates, potassium chloride and mixed form, which are implemented during assessment period 2000-2001 for thirteen sub-counties in Xishan sub watershed. Study mainly has focused the quantification of nutrients including TN and TP, and COD from the agriculture fields in the 13 sub counties of Xishan sub watershed, which are contributing NPSP into the tributaries of Taihu Lake.

2.5 GIS Best Management Practice utilization data

BMP's in the study area is presented either in the form of aerial features or specific site, describing optional activity of PLOAD model. Arial BMP's is defined as polygon file, while site BMP is defined as point GIS file; both are contained attribute code for each BMP type. BMP's served to reduce pollutants load using natural process of settling, filtration or uptake for the BMP area of influence. In the study area, BMP's are defined in the form of SRB, for which separate study was carried out [10]. Various wetlands are proposed for SRB in the Xishan County depending upon the depth and covered area, required to construct SRB. Moreover, Filter strips (FS), Land forming (LF) and Field border (FB) sites are selected for agriculture (paddy field and pasture lands) BMP's, which are used to remove sediments and other pollutants from agriculture runoff. These BMP's are set near the cropland at the lower edge of field or above terrace or diversion.

2.6 Spreadsheet data

PLOAD model input data is prepared in spreadsheet (xls, txt, dbase, info) tabular format including even mean concentration (EMC) of pollutants from various land uses and land uses impervious data. Extra column is placed in each table for land use code to identify fields (Tab. 1). Moreover, annual precipitation data is incorporated during simulation. EMC table is developed using average concentration, which occurs in the runoff from specific event by taking the flow sample at regular interval during the event from runoff using following equation;

Tab.1 Estimated EMC and selected Impervious factors
for various land uses in 13 sub-counties of Xishan county

Lucode	Land use	Estimated Event Mean Concentration(mg/L)			Impervious factor*(%)
		TN	TP	COD_{Mn}	
11	Paddy field	15.397	0.513	7.740	2
12	Dry land	7.164	0.144	7.446	15
13	Kale yard	8.740	0.331	8.383	2
21	Orchard	7.023	0.235	7.563	2
31	Forest	11.206	0.426	8.388	5
41	Grass land	8.561	0.331	8.380	5
51	Municipality	2.776	0.171	2.910	85
52	Residential	11.51	0.348	10.773	25
71	Wetlands	8.927	0.221	9.370	2
74	Lakes	7.282	0.332	8.340	2

* The value of impervious factor taken from the literature provided by NRCCS, TR-55 user's manual[7].

LUCODE=Land use code for each land use

$$EMC=\Sigma C_iQ_i/\Sigma Q_i \tag{1}$$

Where C_i is concentration of sample i and Q_i is flow rate of sample i. The value of percentage impervious factor is used to calculate runoff coefficient. BMP efficiency table (pollutant removal efficiency of each land use) is developed with use of literature and guidelines provided by TNRCCS, TR-55 user's manual [7], is also shown in Table1. The data should be in format of percentage of impervious (0 to 100).

3 Model application and evaluation

PLOAD model is developed based on the available data from Xishan County. Using developed PLOAD input data, model is simulated for the quantification of non-point pollutants in the sub watershed.

3.1 Pollutants load estimation

Model is designed for the estimation of annual pollutant load (APL) using two methods[11], called Export coefficient and Simple methods depending upon the availability and nature of input data. APL is calculated on an annual average basis, based on land use information, pollutants loading coefficient and annual rainfall from the watershed containing BMP's, and non-point sources. In the present study, simple method is used for APL estimation using two equations. First equation calculated runoff coefficient for each land use type and second equation is used to calculate APL in form of pollutant load allocation, described as follows;

$$R_{VU}=0.05+(0.009\, L_U),\ PLA= \sum U(P \cdot P_j \cdot R_{VU} \cdot C_{EMC} \cdot A_U) \qquad (2)$$

Where R_{UV} is the runoff coefficient for land use type U, runoff (mm)/runoff (mm) and L_U is percent imperviousness for respective land use. Similarly, PLA is pollutants load allocation, P is precipitation (mm/a), P_j is ratio of storm producing runoff, R_{VU}, run off coefficient for land use type, C_{EMC} is EMC (mg/L) and A_U is area (m) of land use type.U, The value of each parameter is obtained by manipulation of input data. Further analysis is carried out for the estimation of pollutants concentration during single rainfall event including BMP's to reduce load computation. The nitrogen loading by watershed from all watersheds (LD) is ranges from 0.40×10^5 kg/a to 0.64×10^4 kg/a from all land uses including pasture lands/ paddy field and urban with the generation of average surface runoff, 0.48 m^3/s to 0.82 m^3/s from each sub-watersheds. Event Mean Concentration (EMC) by pollutants (TN) is estimated from runoff ranging from 9.3 mg/L to 12.3 mg/L, which is realistic against the application of rate of fertilizers. Similarly, nitrogen pollutant by watershed area (AR) is estimated as 0.42 to 0.74 kg/(hm^2 • a). Results for other NPSP are compiled in Table 2. It is a model output showing layout of non-point pollutants based on watershed area scale from Xishan sub watershed surface runoff, which are released into the existing tributaries of the region considering the impervious factor of various land used and without utilization of BMP's options.

Tab.2 Computation of NPSP in all delineated watersheds of Xishan sub watershed

ID	Pollutant Load by Watershed (kg/a)			Flow		Event Mean Concentration (EMC) (mg/L)			Pollutant Load By watershed area (kg/(hm^2 • a))		
	COD_{Mn}	TN	TP	(m^3/s)	(m^3/a)	COD_{Mn}	TN	TP	COD	TN	TP
1	217155.3	49902.31	23977.75	0.67	20971408	51.5	12	5.7	2.95	0.62	0.30
2	243537.9	49125.11	25061.54	0.72	22493370.9	53.2	11.3	5.7	4.02	0.74	0.39
3	247031.2	63363.25	31231.27	0.82	25731201.2	47.7	12.3	6	2.54	0.60	0.31
4	203672.8	45987.46	21720.68	0.59	18947047.2	45	9.3	4.5	2.18	0.42	0.21
5	156434.2	40445.15	18168.45	0.48	15144307.8	40.3	10.9	4.9	2.01	0.49	0.22

3.2 BMP reduced load computation

In BMP's scenario, model is simulated and calculated pollutants load using three steps, (i) percent area of watershed served by BMP is calculates as ratio of area served by respective BMP and area of watershed, (ii) pollutants load of BMP i.e

$$L_{BMP}=(PLA \cdot \%AS_{BMP}) \cdot [1-\%Eff_{BMP}/100],$$

Where L_{BMP} is BMP load (kg), PLA is watershed load (kg) and %*Eff* is reducing efficency of respective BMP, (iii) total pollutants load is calculated as sum of L_{BMP} and PLA i.e

$$PL_{total}=(\sum_{BMP}(L_{BMP}))+PLA\cdot(A_B-(\sum_{AS}(AS_{BMP}))$$

where A_B is area of watershed (m^2). BMP's scenario option during the model simulation is showing the reduction of non-point pollutants load by 16% to 67% depending upon the kind and features of BMP's provided in the sub watershed (Table 3).

Tab.3 Model simulation using BMP's utilization in Xishan sub watershed based on watershed area scale

Model Simulation	NPSP	Pollutant concentration (Without BMP's)	Pollutant concentration (With BMP option)	Difference	% of Difference
Load by watershed	LD_COD	6209524.08	2850848.85	3358675.23	54.09
(kg/a)	LD_TN	1480889.36	487153.35	993736.01	67.10
	LD_TP	735395.16	495565.09	239830.07	32.61
EMC by pollutants	EMC_COD	10.14	5.10	5.04	49.69
(mg/L)	EMC_TN	2.42	1.03	1.39	57.54
	EMC_TP	1.20	1.00	0.20	16.78
Load by watershed	AR_COD	28.06	17.13	10.93	38.94
area	AR_TN	6.69	4.21	2.48	37.04
(kg/($hm^2\cdot a$))	AR_TP	3.32	2.07	1.25	37.70

3.3 Model verification

Computed results are calibrated and verified using the observed data, graph in Figure 4 is showing the satisfactory percentage of error between observed and computed values, thus authenticate the developed model for the future evaluation studies in the region. Model implementation helps to solve the top priority problems of sub-watershed in the County, evaluate the effectiveness of BMP approaches to reduce non-point sources of pollutants load into Taihu Lake.

4 Discussion and conclusion

This study has described a framework for the quantification of non-point sources of polluation of each watershed of Xishan county using GIS. Model is developed to generate a variety of graphical plots and tabular data including calculation of annual pollutants load using GIS based PLOAD model at watershed scale sources[12]. Once the PLOAD is simulated, results will be obtained in the form of map view and its output tables from various sessions. The model calculates NPSP (N, P and COD) with three different types of layout showing the pollutants load by watershed (kg/a), pollutant load by watershed area (kg/($hm^2\cdot$ a) and even mean concentration by COD_{Mn}, TN and TP (mg/L) (Table 2). Acceptable percentage error during model verification shows the authentication of model application for future study. Study also evaluates the effectiveness of BMP approaches to reduce pollutants loading by 30% to 70 % depending upon rate of imperviousness for each land use and BMP's options. Results can be used to meet the need of Xishan county watershed management to protect further deterioration of Taihu Lake after adjustment of fertilizers application at optimum amount. Model implementation helps to solve water environmental pollution problems of sub counties of Xishan region under existing scenario of economic development. Since, monitoring and evaluation of NPSP are more or less neglected in the watershed, BMP's helps to define those practices, which are determined to be efficient, practical and cost effective in the region. This study is helpful to evaluate current and future land uses scenario under the different development conditions.

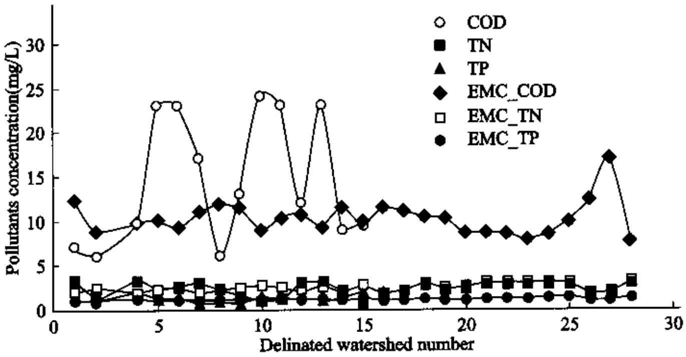

Fig.4 Verification of model simulation using observed and computed data

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利用 GIS 定量评价太湖流域的非点源污染

崔广柏 扎黑尔 罗 建

（河海大学水资源环境学院，南京 210098 ）

摘 要

利用流域地图和地理信息系统（Arcview）软件评估的不同土地利用状况下的基本污染负荷，以太湖流域的子流域——锡山流域为例定量评价了流域的非点源污染．本文包括根据流域面积和污染物平均浓度模拟流域污染负荷，进而在设施流域最优管理措施的情况下评价非点源污染．最优管理措施提供最有效的、最实用、最大成本效益的步骤减少流域的非点源污染．结合流域边界和土地利用资料、营养物的平均浓度、及点源负荷资料，利用 WATERSHEDS 3.0 软件的扩展的 PLOAD GIS 模型评价了非点源污染，并利用表格和图形对模型的模拟结果进行了评估．

关键词 GIS 最优管理措施 非点源污染 太湖流域

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