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Original Research Paper

A Non-Point Source Load Simulation of the Yangtze River Basin, China

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ABSTRACT

This study uses an interpolation method in spatial simulation to simulate immeasurable factors affecting the non-point source (NPS) load on the Yangtze River basin. Spatial simulation is also applied by the improved export coefficient model to present NPS loads. Self-organizing maps are used to expose the correlation of these factors to NPS load. The results show that the highest precipitation impact factor value distributes mainly in the eastern region of the basin; the lower value locates at north western of the basin. The lowest terrain impact factor located mainly at the eastern and western region; the highest terrain impact factor value distributes spread at middle region of the basin. The highest non-point source load value distributes at middle region of the basin; the lowest value distributes in the western region of the Yangtze River basin. Grassy land factor; agriculture land factor; forest land factor; precipitation factor; and fertilizer factor have correlation with population factor in the highest value. Precipitation factor and forest land factor; population factor and agriculture land factor; grassy land factor and barren factor have correlation with each other at the lowest value. Wetland factor and barren land factor; total nitrogen load factor and total phosphorus factor have closely correlation each other at the lowest and highest value. Forest cover rate factor has no correlation with others.

INTRODUCTION

The real problem of water pollution nowadays is non-point source (NPS) pollution. Unlike pollution from industrial and sewage treatment plants, non-point source (NPS) pollution comes from many diffuse sources (Shen et al. 2012). The nutrient input pathways include irrigation, fertilization, seeding, atmospheric deposition and biological nitrogen fixation, while the output pathways consist of plant uptake, surface runoff, leaching and other direct discharges of agricultural/rural wastes into the environment (Chen et al. 2010). NPS inputs, especially from agricultural activity, have resulted in large amounts of nitrogen (N) and phosphorous (P) (Ding et al. 2010, Chang et al. 2004). As the runoff moves, it picks up and carries natural and anthropogenic pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters and ground water systems (Shen et al. 2012).

In the last two decades, NPS pollution has become a stimulus for research that resulted in the development of several computer simulation models and model techniques (Liu et al. 2009). Computer simulation models have been useful tools for the analysis of watershed processes (Liu et al. 2009). They provide a quantitative description for the entire basin system, and aid in the analysis of spatial and temporal features of NPS pollution (Shen et al. 2012). They also provide estimates of the different effects of various land use, management, and technical measures on NPS pollution (Shen et al. 2012). In which, export coefficient model has been widely used in the identification of pollution sources in basins and the estimation of non point source pollution loads (Han et al. 2011, Susanna & Chen 2002, Shrestha et al. 2008, Sivertun & Prange 2003). It has been used successfully in many studies (Ding et al. 2010, Mattikalli & Richards 1996) due to the advantages including a lower demand for input data and a simpler calculation process (Shen et al. 2012). However, owing to this simplicity that it has still not been completely revealed yet spatial simulation, regional analysis, and the correlative relationship of non-point source pollutant factors. Therefore, this study mentions new methods in spatial simulation as interpolated method, and spatial simulation of non-point source loads of the Yangtze River basin in China. Moreover, the confirmation of relative relationships in non-point source pollution affecting factors is applied by self organizing maps (SOMs). The study aims at: (1) Spatial simulation of the factors affecting the NPS loads; (2) Simulates and analyses spatial distribution of NPS loads after the contribution of

NPS pollutant is estimated; (3) Confirms the correlation of the factors affecting the NPS load in self organizing maps.

MATERIALS AND METHODS

Study area: China is one of the largest producer and consumer of chemical fertilizers in the world, and the excessive nutrient loading from agricultural watersheds is considered the principal source of NPS pollution (Ma et al. 2011). The Yangtze River in southern China, is the largest river in China and the third largest river in the world (Liu et al. 2009). It is about 6380 km long and originates from the Tibetan Plateau at an elevation higher than 5000 m, flowing from its source in Qinghai Province eastwards into the east China Sea in Shanghai (Cao et al. 2011). The Yangtze River basin, with an area of about 1.8 million km^2, lies between 24.50°N-35.75°N and 92.43°E-122.45°E (Sang et al. 2012). Most parts of the basin have a subtropical monsoon climate (Zeng et al. 2011, Zhang et al. 2008, Zhang et al. 2005) and the annual mean temperature in the basin is between 15°C and 19°C (Zhang et al. 2008) with its average annual precipitation of 1067 mm (Xu et al. 2008).

Methodology: The main data in this study include land use layer of the Yangtze River basin in 2005 year. It is classified into many land use types by ERDAS 9.2 software from the landsat 7 ETM+30 m resolution satellite imagery as forest, grassy land, agricultural land, built-up land, water, barren land, wetland and desert land. Digital elevation model (DEM) data are analysed in topography, and separated to produce data of watersheds. Especially, the study uses an interpolation method for the precipitation impact factor and terrain impact factor to interpolate regionalized values at immeasurable location. The Improved Export Coefficient Model (IECM), applied in the study from development of the Export Coefficient Model (ECM) of Johnes (Johnes 1996), combines with precipitation and terrain impact factors. The Improved Export Coefficient Model that allows accurate estimation of nutrient pollutants is described as:

$$L = \sum_{i=1}^{n} \alpha\beta Ei[Ai(Ii)] + P$$

Where, L is loss of nutrients (kg); α is the precipitation impact factor; β is the terrain impact factor; Ei is the export coefficient for nutrient source (kg/km^{2}yr); Ai is the area of the catchment occupied by land use type i (km^2); Ii is the input of nutrients to source i (kg); and P is the input of nutrients from precipitation (kg).

The data in the model used was collected via the spatial distribution of land use, nitrogen and phosphorus, and applied in each land use type. Input of nutrients in the basin is through nitrogen and phosphorus fixation and atmospheric deposition. The key parameters of Export coefficient (Ei) are derived from literature sources and field data in past researches (Table 1). Moreover, the research also applies self organizing maps to expose the correlation of the factors affecting the NPS loads.

RESULTS AND DISCUSSION

Factor simulation: Precipitation and terrain are two important impact factors in non-point source load estimation and simulation. From temporal impact factor and spatial impact factor, the study obtained a spatial simulation of precipitation impact factor. Its value is revealed from 0.063 to 1.835, and the highest precipitation impact factor value not only locates at the eastern, but also distributes sparse on the centre of basin. But the spatial distribution of lowest precipitation impact factor value locates at the north western region on the high elevation area of basin. Medium precipitation impact factor value extends from the eastern region to 3/4 area of the basin, and distributes intersperse on the regions having the high precipitation impact factor value. The Fig. 1 indicates that the medium and high precipitation impact factor value locate intersperse with each other and occupy the largest area of the basin.

Terrain impact factor is also a factor which strongly influences the NPS load. Based on the slope values of Yangtze River basin, the research obtained spatial distribution map of terrain impact factor (Fig. 2). It indicates that the lowest terrain impact factor value locates sparse from eastern to western region of the basin. The highest terrain impact factor value, except for distribution mainly at middle region of the basin, also locates alternately with the lowest terrain impact factor value and medium terrain impact factor value. Especially, the spatial distribution of terrain impact factor value appears a deep valley in low value, locates at middle region of the basin, which is surrounded by the high terrain impact factor values. Thus, the spatial simulation of terrain impact factor indicates that its value changes from 0.85 to 1.1475, and the highest terrain impact factor value located mainly at middle region, and the lowest ter-

Table 1: Export coefficient of NPS sources (Liu et al. 2008).

ID	Land use pattern	Estimating non-point Source TN (kg/ha)	TP (kg/ha)
1	Forest	2.38	0.15
2	Grassy land	10	0.2
3	Agricultural land	29	0.9
4	Built-up land	11	0.24
5	Wetland	0.2	0.01
6	Water	0	0
7	Desert	1	0.51
8	Barren	2	0.08

rain impact factor located mainly at the eastern and western region of the basin.

Non-point source load simulation: The land use layer is combined with improved export coefficient model to make the maps of non-point source load, in which land use layer is separated into eight types: forest, grassy land, agricultural land, built-up land, water, barren land, wetland, and desert land. The land use layer is divided into 180, 716, 249 cells in the shape of a square 100m × 100m size, with each square grid cell is represented for a basic land unit; a land use type in the basin includes many small cells. The Fig. 3 is a spatial simulation of total nitrogen (TN) load on the Yangtze River basin. It indicates that the high total nitrogen load value distributes extension on 2/3 region of basin from the eastern region to over haft of the basin. The western region of basin appears mainly the low total nitrogen load value. It locates intersperse with the high total nitrogen load value at central region and east of the basin. Total nitrogen load value on the whole basin receives from 0 to 50.07 kg/ha and obtains the highest value as 50.07 kg/ha. There are some factors affecting the NPS load such as land use, topography, precipitation, etc. But, the precipitation and terrain impact factors are regarded as the most important element affecting strongly the non-point source load simulation of the improved export coefficient model. Via spatial distribution of total nitrogen load on the Yangtze River basin, the Fig. 3 can demonstrate that where is the high total nitrogen load value; those regions have very low terrain impact factor value and the high precipitation impact factor value. Thus, the distribution of total nitrogen load is appeared to be in the whole basin, especially the lowest total nitrogen load value locates at the west of basin, and the highest total nitrogen load value occupies a large region in the Yangtze River basin.

The Fig. 4 is the spatial distribution of total phosphorus (TP) load. It indicates that the low total phosphorus load value is distributed sparsely in the whole basin, particularly in the western region of the basin. The high total phosphorus load value is dominated at middle region and the eastern region of the basin. Total phosphorus load value is revealed from 0 to 1.55 kg/ha. The terrain and precipitation impact factor also strongly affect the total phosphorus load because the regions have the high total phosphorus load value in those areas with high precipitation and low terrain impact factor value. Furthermore, the region having the high precipitation impact factor value also reveals total phosphorus load with higher value than others. Therefore, via spatial simulation of total phosphorus load, we can identify the value of total phosphorus load; spatial distribution of total phosphorus load on the whole basin; and terrain impact factor as well as precipitation impact factor, which affect strongly the total phosphorus load.

Factor correlation: The self organizing map (SOM), which is based on an unsupervised neural network algorithm, uses powerful pattern analysis and clustering methods, and provides excellent visualization capabilities at the same time (Lee & Scholz 2006, Garcia & Gonzalez 2004). It is presented in Fig. 5 with different factors affecting the non-point source load in the Yangtze River basin. It indicates that neurons are distributed clusters on the map and they are represented in different colours from blue to brown colour in the lowest value to the highest value. The U-matrix is represented for an average distance of neurons. The map shows that the neurons have the distance nearly, and the lowest values are distributed almost of the map. Some hexagons of the highest value and the medium values locate at below haft portion of the map.

From left to right maps in the Fig. 5 show that the precipitation factor and forest land factor distribute separately into three values including the lowest, medium and highest value. The lowest value locates at 3/4 of the map and the highest values are at bottom left corner of the map. The highest value of precipitation factor is displayed by a hexagon, and forest land factor in three hexagons. The next factor is the total nitrogen load and total phosphorus load. The distribution of the neurons are very similar with each other, particularly the value is separated into two regions, including the lowest value distributing at the upper region of the map, but the highest and medium values locate at below the region of the map, in which the lowest value locates almost of the map. Moreover, the highest value is presented by a hexagon at bottom left corner of the map. Moving down population factor and agriculture land factor, the distribution of neurons is similar in the lowest value, but they differ in the highest and the medium values. Particularly, the lowest value locates at the upper portion of the map, and below portion of the map is the medium and highest values. They are made up of clusters in separately, and the highest value locates at bottom left corner of the map in three hexagons of population factor, and one hexagon of agriculture land factor. Moving to fertilizer factor, the nodes distribute into two haft portions of the left and right on the map, including the lowest value on the right, and the medium and highest values on the left of the map. Particularly, the highest value is displayed by a hexagon at bottom left corner of the map. But in pesticide factor, the lowest value locates at central region from below portion to the upper of the map. The highest value and the medium value distribute into two sides at below left side and upper right side of the map. The forest cover rate factor shows that the nodes make clusters intersperse between the lowest value and the medium value on the whole map, in which the lowest value locate in three

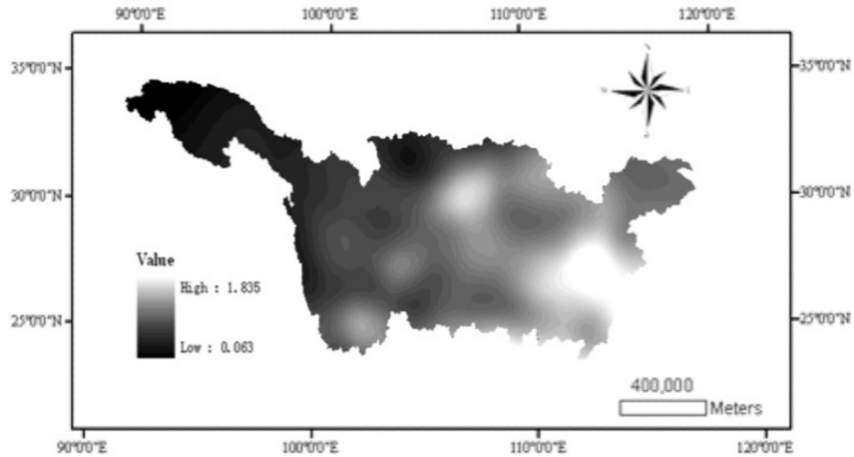

Fig. 1 Precipitation impact factor simulation of the basin.

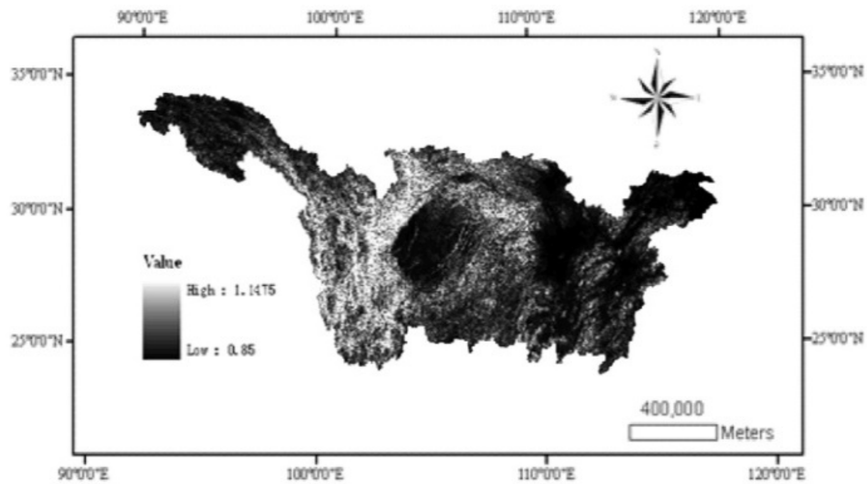

Fig. 2: Terrain impact factor distribution of the basin.

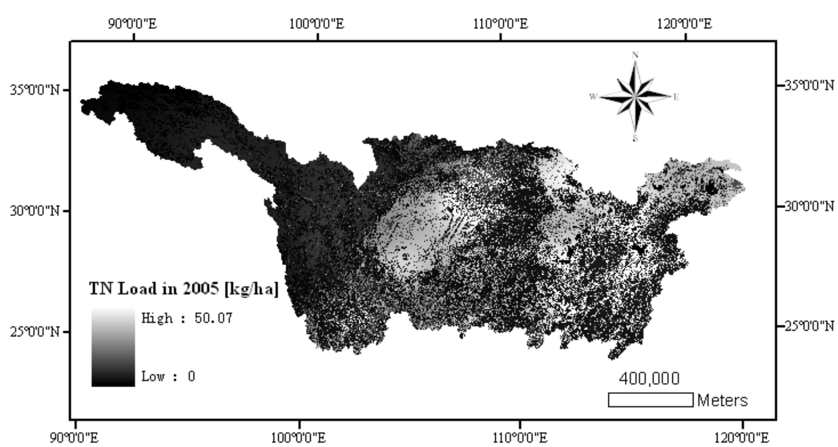

Fig. 3: Total nitrogen load simulation of the basin.

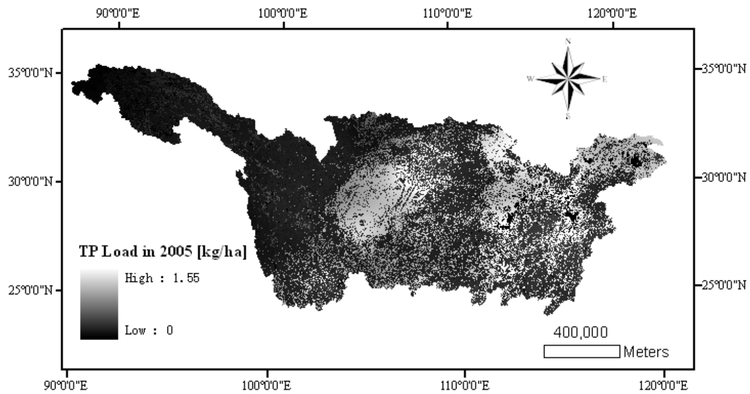

Fig. 4: Total phosphorus load simulation of the basin.

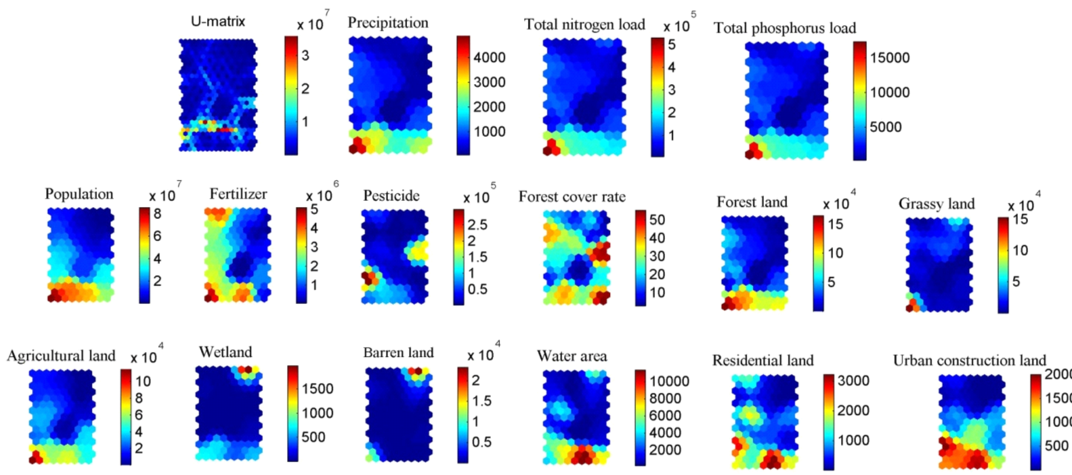

Fig. 5: Correlation of factors on Yangtze River basin.

different positions of the map. But, the highest values distribute in second positions of the map including at bottom right side and centre right side of the map. Besides, for the grassy land factor, the neurons are presented in the lowest value a lot, and they occupy almost on the map. The highest value and medium value in this factor are represented by clusters such as the highest value is only a hexagon and locates at bottom left corner of the map, or the medium value locates at beside the highest value in some neurons.

Continuously, moving to wetland and barren land factors, the distribution of nodes is similar with each other because the lowest value distribute almost of the map; the highest value and the medium value include some hexagons locating at the top right corner and bottom left corner of the map. Particularly, in wetland factor, the medium also locates at bottom right corner of the map. Next is water area factor and residential land factor, which show that the highest values are distributed similarly to each other in three hexagons at the centre bottom side of the map. The medium values occupy almost of the map. But, the lowest value of the residential land factor locates at the top right corner, and the lowest value of water area factor is at top left corner. Last factor is urban construction land factor, the nodes make clusters and distribute into three positions from bottom portion to top of map. First position is lowest value locating at the upper haft portion of the map; second position is at centre of map and is displayed by the medium value; and the last position is the high value at bottom of map, in which the highest value is separated into two positions at below left side and bottom centre side of the map.

Therefore, the maps in Fig. 5 indicated the distribution of neutrons and the correlation of the factors affecting the non-point source load. They reveal that the precipitation factor and the forest land factor; the population and the agriculture land factor; the grassy land and the barren factor have correlation with each other at the lowest value. But, the distributed positions are the different on the map, such as the population factor and the agriculture land factor locate at upper right corner; the grassy land factor and the barren factor are from top left corner to bottom right corner. Moreover, the grassy land factor, the agricultural land factor, the forest land factor, the precipitation factor, and the fertilizer factor have correlation with the population factor at the highest value. Furthermore, the pesticide factor and the urban construction land factor have high correlation with each other as well. The water area factor correlates with the residential land factor at the highest value. Especially, the wetland factor and the barren land factor; the total nitrogen load factor and the total phosphorus load have close correlation with each other at the lowest value and the highest value, respectively. The forest cover rate factor has no correlation with others.

CONCLUSION

From non-point source load simulation on the Yangtze River basin, this study is drawn some significant points as: The highest precipitation impact factor value distributes mainly in the eastern region of the basin, and the lower value locates at north western of the basin. The lowest terrain impact factor located mainly at the eastern and western region, and the highest terrain impact factor value distributes at middle region of the basin. The highest non-point source load value distributes at middle region of the basin, and the lowest value distributes in the western region of the Yangtze River basin. Grassy land factor; agriculture land factor; forest land factor; precipitation factor; and fertilizer factor have correlation with population factor in the highest value. Precipitation factor and forest land factor; population factor and agriculture land factor; grassy land factor and barren factor have correlation with each other at the lowest value. Wetland factor and barren land factor; and total nitrogen load factor and total phosphorus factor are closely correlated to each other at the lowest and highest value, respectively. Forest cover rate factor has no correlation with others.

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