Jianfeng Zhang

Forestry Measures for Ecologically Controlling Non-point Source Pollution in Taihu Lake Watershed, China

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Preface

Taihu Lake basin is located in the core area of the Yangtze River Delta; the total area of the basin is 36.9 thousand km^2 of which the water area of Taihu is 2338 km^2, covering Jiangsu, Zhejiang, and Anhui provinces and Shanghai city. Owing to favorable climate and natural conditions, this region was developed very early and is playing an important role in socioeconomic development of China. In 2005, the GDP (gross domestic product) of the basin area accounted for about 11.7 % of the whole country.

With a rapid development of economy and society in Taihu Lake basin, the water consumption and wastewater discharge are increasing, and the water quality of the basin is declining since past 30 years. During 2005, the water quality of the lake basin along the watershed of 2700 km long was studied and found that for over 89 % of the basin, the annual water quality deterioration was of class III standard, and 61 % was worse than the class V standard. The average water quality comprehensive evaluation of Taihu Lake was for the inferior class V (including TP (total phosphorus), TN (total nitrogen) index), whereas the NH_3^--N index was for the class II, TP was for class IV, TN index was inferior to the class V, and COD_{MN} (chemical oxygen demand) was for class III.

Among various factors of water pollution and eutrophication in Taihu Lake basin, the contribution of non-point source pollution is crucial. The statistics of the Taihu basin showed that the contribution of non-point source pollution to the drainage was around 347,000 tons of COD and 2.5 million tons of NH_3-N. According to an estimate of the former State Environmental Protection Administration, the water pollutants in the country from the industries, human living, and agricultural non-point source pollution were approximately 1/3 each. Of the pollution load in Taihu Lake, 83 % of TN and 84 % of TP were from farmlands, rural livestock and poultry breeding industry, urban and rural combination areas, and rural life. The contribution of non-point source pollution was far more than point source from industries and urban life. In the plain area of Taihu Lake basin, addition of COD to the rivers was 346.9 thousand tons per year with the largest proportion from rural human living, accounting for 41.6 % of the total COD in the river, followed by aquaculture production, accounting for 27.2 % of the total COD. The addition of TP to the rivers was 6.7 thousand tons per year with the largest proportion from rural life, accounting for 50.6 % of the total TP, followed by farmland runoff pollution, accounting for 26.9 %. The addition of TN to the rivers was 64.8 thousand tons per year with the biggest share from rural human living, accounting for 32.8 % of the total, followed by livestock and poultry breeding, accounting for 23.9 %. In specific, addition of NH_3-N to the rivers was 25.1 thousand tons per year with the largest proportion from rural life, accounting for 60.2 % of the total, followed by farmland runoff pollution, which accounted for 26.7 % of the total. Thus, there are various sources for pollution of rivers and lakes, i.e., TN and NH_3-N are the largest pollutants in rural areas, rural life, and farmland runoff, while TP is more in rural life and livestock and poultry farming. Thereby, it is not difficult to understand why in 2007 blue-green algae broke out in Taihu Lake.

In order to overcome the serious non-point source pollution in Taihu Lake watershed, the following measures are generally taken: (1) **Ecological ridge technology**: Runoff is an important way of nutrient loss. The current farmland ridge is only about 20 cm high in the farming area of Taihu Lake basin which can produce surface runoff easily at the time of higher rainfall. It is estimated that by heightening the existing ridge by 10–15 cm, the runoff from 30 to 50 mm rainfall can be effectively prevented and can reduce most of the farmland runoff. At the same time, some plants can be planted on both sides of the ridge to form a buffer zone, which can effectively check surface runoff and thereby reduce nutrient losses through runoff water. (2) **Ecological ditch technology:** Currently, most of the ditches are with hard cement surface which results in the discharge of surface runoff directly into rivers causing eutrophication of water. Therefore, it is wise to change the existing channels to hardened eco-channels by hard boards with holes which make the crops or grasses to grow and absorb nutrients from the leaching water. By this way, the loss of farmland nutrients can be effectively intercepted. At the same time, certain plants can be planted at the center of the ditches, which can reduce the velocity of water flow, increase the retention time, improve crop nutrition, and also improve self-purification capacity of water bodies. (3) **Ecological wetland treatment technology:** Through the construction of ecological ditches and ecological interception system, most of the nutrients lost from farmlands can be intercepted, but still some nutrients go into the river. Man can take advantage of the existing ecological wetlands or artificial floating islands by planting emergent plants, leaf floating plants, etc., to fully absorb and utilize these nutrients. The hydraulic plants having some economic value can be selected to ensure certain economic benefits to local farmers besides improving water quality.

Forestry measures play a certain role in controlling non-point source pollution and protecting water security. In order to understand the role of forestry measures on water quality improvement, some projects have been undertaken since 2008 which are supported by State Ministry of Science and Technology and Department of Science and Technology of Jiangsu Province. This book has been written based on the research findings of the projects.

This book mainly focuses on ecological approaches of preventing and controlling non-point source (NPS) pollution based on forestry measures. Firstly, the characteristics of NPS pollution in Taihu Lake watershed and water eutrophication evaluation methods are described. Then, the role of relevant forestry measures in combating water pollution such as public welfare forest development, urban forestry development, techniques of hedgerows planting in slope lands, shelter belt establishment, N and P absorption by willows, hydrophyte selection, and land use pattern optimization is presented. Correspondingly, quantified data on the effect of forestry measures on soil properties, plant species diversity and source reduction and sink increase of NPS pollution are given in this book. Moreover, for the first time, the landscape change and its effect on water quality in Taihu Lake are discussed, in addition to purification of eutrophicated water and dynamic kinetics of nitrogen absorption by trees. Finally, the techniques of development of riparian forest buffers and ponds–wetlands integrated management system are indicated and described.

This book is useful for researchers, lecturers, professionals, and administrators working on water environment and ecological development as well as graduate students, senior undergraduates, and persons interested in water security.

Hongzhou, China Jianfeng Zhang
April 2016

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Chapter 1
Characteristics of Non-point Source (NPS) Pollution in Taihu Lake Watershed

Abstract Taihu Lake is located at the center of Changjiang delta region. The Lake and its effluent rivers are important water sources for about 40 million inhabitants and rapidly increasing industrial factories in Shanghai, Jiangsu, and Zhejiang. The pollutants originate mainly from acidy rain, home sewage of the vast number of inhabitants, livestock manure, agricultural fertilizers, and pesticides applied over fields in the drainage basin, and the industrial sewage. Some research studies have indicated that industrial sewage, domestic wastewater, and agricultural non-point source (NPS) pollutants accounted for 16, 25, and 59 % of total nitrogen for water eutrophication, respectively, and for 10, 60, and 30 % of total phosphorous, respectively, in Taihu Lake. Due to pollutants, the Lake water is getting highly eutrophic, with frequent blooms of blue-green algae. Compared with point source pollutants, diffuse pollution is much complicated and difficult to control. It is clear that NPS pollution in Taihu Lake region has been quite serious and has become the main threat for water environment health. Thus, combating NPS pollution must be paid great attention.

Keywords Non-point source pollution · Source–sink · Taihu Lake · Blue-green algae bloom · Eutrophication

The Taihu Lake basin has an area of 36,500 km^2, located in three provinces and one municipality. The percentage area in Jiangsu, Zhejiang, Anhui provinces, and Shanghai is 52, 33.4, 13.5, and 0.1 %, respectively. The water area in the lake basin accounts for 17.5 % of the entire lake area (Qin 1999). The Lake has the multi-function of flood water storage, irrigation, navigation, water supply, aquaculture, and tourism. It is the main drinking water source for 40 million residents in areas such as Wuxi and Suzhou and neighboring Shanghai and Zhejiang. The Lake is also famous for its abundant production of fishes and crabs and skillfully managed aquaculture farms on the coast (Chai et al. 2006).

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1.1 Introduction

The region along Taihu basin is developed very earlier owing to the favorable natural conditions (see Table 1.1), which is called "Kingdom of fishing and farming." The vegetation resources are also abundant there. Important types of forest (main species of trees) are pine forest (*Pinus massoniana*), bamboo forest (*Phyllostachys pubescens*), and mixed evergreen-deciduous scrub. Important herbaceous vegetations are swampy grassland of reeds and other emerged water plants on the lake shore and along water courses. The major crops grown are rice (single or double cropping), wheat, rapeseed, tea, mulberry, and fruit trees [peach, orange, loquat, myrica, plum, Japanese apricot (*Prunus mume*), and jujube] (Zhang et al. 2007) (see Figs. 1.1, 1.2, and 1.3).

In addition to supporting heavy boat traffic, Taihu Lake provides some of the best known water-side scenery in China for domestic and foreign sightseeing visitors. Hence, the urbanization level of the lake basin ranks the first in the entire country.

Table 1.1 Natural condition in Taihu Lake basin

Longitude: E 116°28′–123°
Latitude: N 23°33′–32°08’
Elevation (meters above sea level): 3.1–4.5 m
Rainfall:
Mean annual rainfall (mm): 974 mm
Month of highest rainfall: June 156 mm
Month of lowest rainfall: January 38 mm
Other notes on rainfall (fog, snow, and/or other forms of precipitation): sometimes storm in summer
Temperature:
Mean annual temperature: 15.6 °C
Month of highest temperature: July 29.9 °C
Month of lowest temperature: January 2.9 °C
Other notes on temperature: hot summer (June, July, and August)
Soil:
Depth to parent material: 1–5 m
pH: 6.2–8.0
Color: brown
Texture: sand loam
Geological origin: sedimentation by flooding
Other notes on soil: paddy soil in some parts
Exposure to sunlight: 2000 h annually
Terrain:
Slope steepness (% or degrees): plain area, 0–5°
Drainage: not so heavy
Depth of water table: 0.5–3 m

Fig. 1.1 Forests grow around Taihu Lake (Photograph taken by Jianfeng Zhang)

Fig. 1.2 Forests grow in hills (Photograph taken by Jianfeng Zhang)

Fig. 1.3 Agricultural production around Taihu Lake (Photograph taken by Jianfeng Zhang)

Table 1.2 Water quality state in Taihu (August 17–23, 2008)

Location	Profile	pH	DO[a] (mg/l)	COD (mg/l)	NH_3–N (mg/l)	Water quality grading
Shazhu, Wuxi	Lake body	8.14	6.46	2.80	0.28	II
Lanshanzui, Yixing	Lake body	8.23	6.52	3.70	0.30	II
Xishan, Suzhou	Lake body	7.44	4.69	4.90	0.23	IV

[a]DO means dissolved oxygen

However, due to the excess consumption of resources for the regional socioeconomic development, forest coverage reduced from 17 % in 1950s to 13 % in 1980s, wetland area reduced more than 40 % with land transition, on an average decreased 1469 ha (hectare) annually during 1950–1985. With forest felling and soil erosion, the farm ecosystem was damaged, wetland reduced, buffer zone disappeared, and pollutants moved into rivers and lakes directly. Consequently, the eco-environment has been drastically deteriorated. In the period of 1981–2000, TP increased by 25.0 % annually in the Lake, while TN by 11.7 % and COD by 4–6 %. From 1980s, the water quality of Taihu Lake has been reduced by one grade in every 10 years, and now, it has become a typical area which lacks quality water (Zhang 2004). The water quality state of Taihu Lake as per Chinese General Station of Water Environmental Monitoring is shown in Table 1.2.

Although the government gave importance to the water pollution treatment and took several measures, mainly focusing on point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate and the status of water pollution is austere. The affair of blue-green algae bloom occurred in May 2007 alarmed the people and the government and made to recognize the risk and hazards of eutrophication. Therefore, much more attention needs to be given. No doubt, the function of forests is significant in controlling agricultural non-point source (NPS) pollution in Taihu Lake basin.

1.2 Analysis on Source and Sink of Agricultural Non-point Pollution

1.2.1 Framework of Source and Sink of NPS Pollution

For Taihu Lake basin, the inflowing water comes mainly from mountains to the west and southwest of the Lake, while the draining rivers start mostly from the east coast of the Lake. Several rivers and channels connect the lake with Changjiang, but the water flux is controlled by dams to maintain the Lake water level fluctuation within a range of 2–3 m (Qin 1999).

According to the source–sink theory, the source means inputs of pollutants, and sink indicates outputs of pollutants. In this basin, source–sink of agricultural non-point pollution could be described as in Fig. 1.4. It can be inferred from Fig. 1.4 that the causes of water body pollution and eutrophication are complicated and multiple.

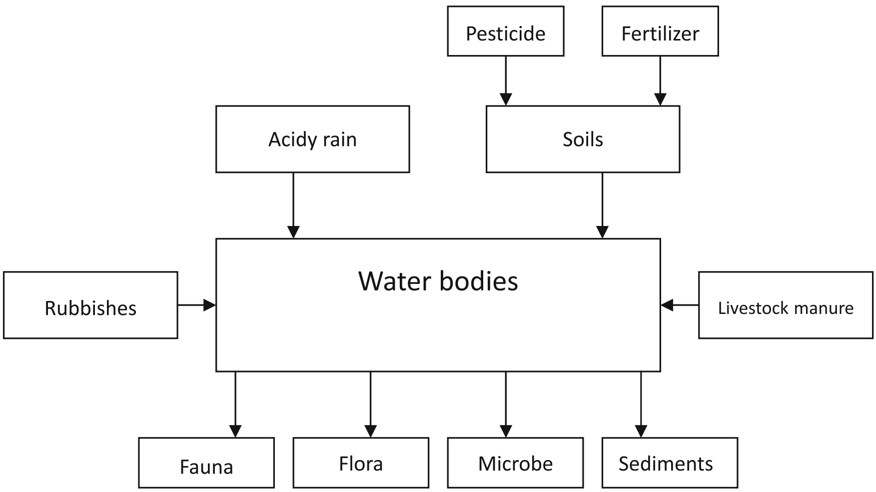

Fig. 1.4 Source–sink of agricultural non-point pollution in Taihu Lake basin

1.2.2 Components of the Source

According to the framework of source–sink of NPS pollution as shown in Fig. 1.4, the major agricultural NPS pollution is the result of acidy rain, livestock manure, fertilizers and pesticides, and rubbishes and garbage. Of these sources, acidy rain occurred naturally, while the others are concerned with human activities (see Figs. 1.5 and 1.6).

Located upstream of the Lake basin, Xitiaoxi River and Dongtiaoxi River both lied in Zhejiang province are recognized as the headwaters of the Lake. In the region, local people live on the mountain range, planting bamboo and/or tea trees, cultivating grain, or cash crops. During these farming activities, agrochemicals were applied, usually at higher dose to get good harvest and income. During heavy rains or storms, water and soil erosion will occur and the soil nutrients moved into the Lake through runoff water (Zhang et al. 2007).

With rapid development of industry and excess consumption of pesticides for agriculture, large amount of pollutants and nutrients such as nitrogen and phosphorus are drained into surrounding channels and finally into the Lake resulting in overgrowth of algae and deterioration of water quality including oxygen depletion leading to severe pollution.

Fig. 1.5 Pollution from industrial production (Photograph taken by Jianfeng Zhang)

Fig. 1.6 Pollution from livestock and poultry breeding (Photograph taken by Jianfeng Zhang)

1.2.3 Distribution of the Sink

Figure 1.4 shows that the nutrients leading to eutrophication could be taken up and/or digested by aquatic animals such as plankton, fishes, shrimps, aquatic plants, or riparian forests which are naturally grown or planted. Nowadays, some fries such as grass carp and chub are often released to rivers, lakes, and reservoirs to purify water. On the other hand, around the watershed, usually wetlands are established comprising aquatic plants such as duck weeds, butter cup, and water lily and are harvested annually to reduce nutrient content in water bodies. Sometimes, certain woody species are chosen and planted such as *Nyssa aquatica*, *Liquidambar styraciflua*, *Quercus nuttallii*, *Carya illinoinensis* Koch, and *Phyllostachys nigra*.

Meanwhile, the microbes played an important role to consume nutrients and prevent algae from blooming (Daniel et al. 1998). Some compounds and elements, especially heavy metals, sunk into river bed or lake bottom and became sediments.

1.3 Formation of Non-point Source Pollution

1.3.1 Rainfall

Direct driving force of NPS pollution is surface runoff oriented from rainfall so that temporal distribution of the rainfall determines temporal characteristics of NPS pollution. Normally there are 3 rainy seasons throughout the year in Taihu Lake region, namely spring season during April and May, plum season during June and July, and typhoon season during August and September. Ma's research (1997) concluded that the load of agricultural NPS pollution increased with increase in annual precipitation. Taking Suzhou River region NPS pollution as an example, the load quantity in different rainy reasons showed that plum reason > autumn season > spring season > winter season (Wang et al. 2002). Hence, the local farmers should choose rational fertilizing time in order to avoid the loss of N and P.

1.3.2 Human Activity

Natural and human activities are the important causes leading to NPS pollution, produce various pollutants, and resulted in different spatial distributions of NPS pollution. The research by Yu et al. (2003) observed that water quality of Xitiaoxi River region in western Zhejiang Province worsened gradually from upstream to the downstream. The important reason for water quality deterioration in the region was NPS pollution, which was mainly originated from fertilizer loss from farmlands and bamboo forests, surface runoff of cities and towns, and domestic sewages. Research on agricultural NPS pollution in Hangzhou–Jiaxing–Huzhou Plain indicated that the load contribution rates of livestock manure, domestic sewage, and surface runoff to water pollution were 43.81, 29.91, and 22.43 %, respectively (Qian et al. 2002) (see Figs. 1.7, 1.8 and 1.9). The load of NPS pollution in Shanghai suburbs was sizeable, and the COD, TN, and TP drained into water environment were 16.73×10^4 t, 2.54×10^4 t, and 0.473×10^4 t, respectively, which had substantial impact on the water quality of Shanghai suburbs (Zhang et al. 1997). Moreover, the farmlands were in intensive management in Taihu Lake region of southern Jiangsu Province, and more N and P fertilizers were applied (345 and 18 kg ha^{-1} a^{-1}, respectively); and the load quantity of N and P reached 3.37×10^4 t and 440.4 t, respectively in 1987 (Ma et al. 1997). The research which analyzed various types of N non-point source pollution in Xueyan town of first-class nature reserves of Taihu Lake indicated that sources of diffuse N pollution including farmlands, rural residential areas, urban residential areas, and livestock accounted for 72.7, 18.9, 7.2, and 1.2 % (Guo et al. 2003). This showed that N loss from farmlands was the main diffuse pollution source. Besides, the agricultural NPS pollution of Yili River region in western Taihu Lake was increasingly serious owing to the same reason (Xu et al. 2001). The average output of TN in the farmland in Hufu, Yixing city was 4.643 kg ha^{-1} a^{-1} (Jiao et al. 2003).

Fig. 1.7 Pollution from domestic sewages (Photograph taken by Jianfeng Zhang)

Fig. 1.8 Pollution from damaged fields (Photograph taken by Jianfeng Zhang)

Fig. 1.9 Pollution from surface runoff (Photograph taken by Jianfeng Zhang)

1.4 Management and Prevention of NPS Pollution

Management and control from NPS pollution could be started with controlling the pollution source and transmission pathways of pollutants, and enhancing scientific study on its formation mechanism and migration law of pollutants.

1.4.1 Key Measures on NPS Pollution Control

For different types of NPS pollution, we should take appropriate control measures. Obviously, the NPS pollution from farmlands is one of the most crucial pollution sources in Taihu Lake region. Hence, rational tillage pattern and irrigation method not only should be adopted to prevent NPS pollution, but also the management for chemical fertilizer and pesticides be strengthened. Meanwhile, in order to prevent the agricultural diffuse pollution from the source and to develop ecological agriculture, the government should encourage and guide farmers to apply chemical fertilizer and pesticide scientifically, advocate soil analysis before fertilizing to enable farmers to apply optimum fertilizer considering economic and ecological effects. On the other hand, keeping the city clean, reducing the pollution and reinforcing the garbage collection and treatment in the city can prevent the diffuse pollution of urban areas from the source.

1.4.2 Reduction on Pollutants Diffusion

Some measures should be adopted to strengthen controlling diffusion pathways of pollutants and reducing pollutant quantity draining into underground or surface water. It is reported that different plants have varied pollutants absorbing capabilities (Chen et al. 2002). Based on the principle combining with the process of landscape construction, some vegetation buffers could be built to intercept and filter diffuse pollutants (see Figs. 1.10 and 1.11). So in some places, we can create artificial gulley, wetlands (Jiang and Gui 2002), sand filter, and vegetation buffers to decrease the diffuse pollution from the farmlands surface and underground water. For the city and towns, the most effective way to fight against diffuse pollution is to accelerate the construction of pipelines of sewage collection and improve domestic sewage treatment.

Fig. 1.10 Vegetation buffers to intercept surface runoff (Photograph taken by Jianfeng Zhang)

Fig. 1.11 Vegetation buffers to protect riverbanks in Yixing (Photograph taken by Jianfeng Zhang)

1.4.3 Strengthening of Pollution Monitoring

The formation mechanism and migration law of NPS pollution have not been clarified at present. This has brought difficulties to control and manage the NPS pollution, and therefore, relevant research should be strengthened. At the same time, according to the law and regulations, different departments and different levels of the governments should set up relevant organizations to monitor and manage regularly the NPS pollution. These organizations are responsible for and approaching the origin, characteristics, and change of NPS pollution. The data of pollution monitoring are helpful for controlling and managing NPS pollution based on the study on the formation characteristics and the migration mechanism of pollutants.

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Chapter 2
Evaluation of Water Eutrophication on Taihu Lake-Connected Channels in Yixing City

Abstract Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the basin has an important contribution to the whole country. Meanwhile, it is the main source of drinking water for 40 million residents of the region. Hence, it is significant to take up research on water pollution prevention. In order to approach deeply the countermeasures for controlling eutrophication of the lake, 10 channels connected to Taihu Lake in Yixing were chosen to test the degree of eutrophication based on the Carlson trophic state index (TSI). By employing techniques to measure chlorophyll “a” and other chemical indicators such as nitrogen and phosphorus in water body of the channels, TSI was computed using formula, TSI = 10 (2.46 + ln Chla/ln 2.5). The results indicated that TSI, between 53.77 and 70.03, and chlorophyll “a” were suitable parameters to indicate the degree of eutrophication, as well as the content of TP. Through the measurement and evaluation, it was found that all the 10 channels were eutrophic, and the major cause was possibly the higher quantity of P in the channels. The location and land use type of these channels indicated that eutrophication, although a natural process over time, was often accelerated by human activities. Human beings influence the lake by increasing the concentration of plant nutrients, primarily phosphorous. These nutrients can enter the waterway through agricultural land, sewage, or wastewater and cause over enrichment.

Keywords Carlson trophic state index · Eutrophication · Taihu Lake · Chlorophyll · Evaluation · Lake-connected channel

Taihu Lake is one of the five largest freshwater lakes in China. The gross economy of the lake basin has significant contribution to the national economy. It is located at 119°31′–120°03′E and 31°07′–31°7′N and covers 2300 km^2, vastly situated/falling in Jiangsu Province (see Fig. 2.1). It is the main source of drinking water for 40 million residents of surrounding area and neighboring Shanghai and Zhejiang (Qin 2009). However, due to excess consumption of resources for the regional economic development, the eco-environment has been drastically deteriorated. From 80s in the last century, the water quality of Taihu Lake has descended one grade in every 10 year, and now, it has become a typical area of lacking quality water (Zhang et al. 2009). Although the government has given importance/attention

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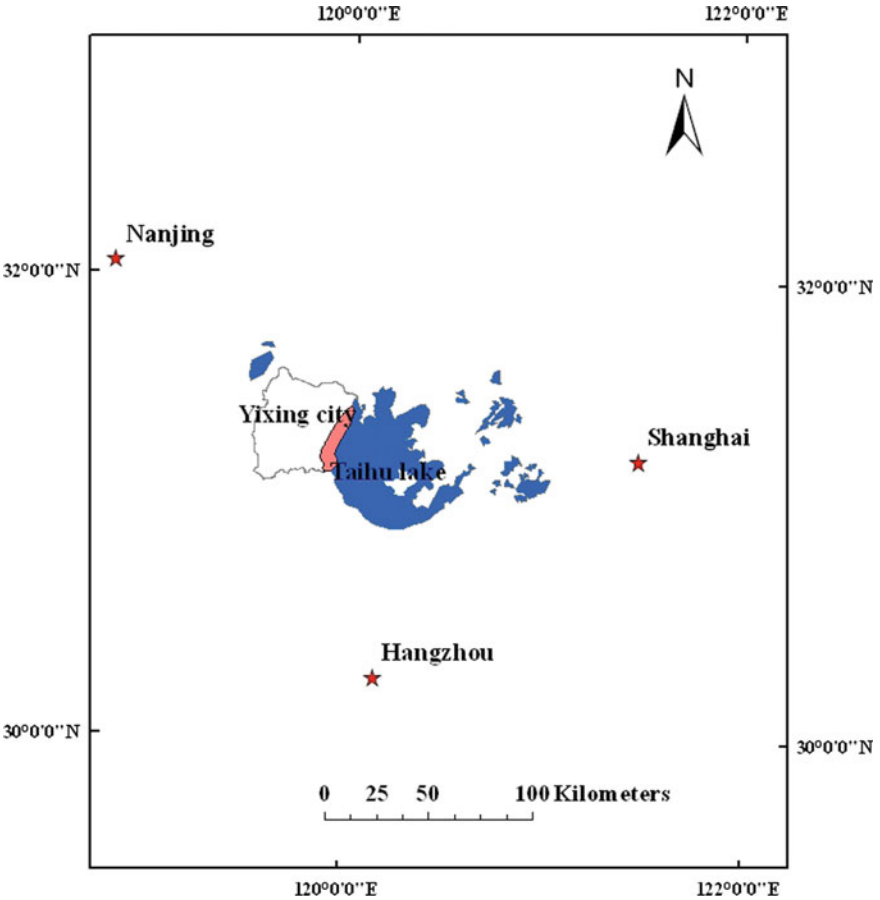

Fig. 2.1 Location of Taihu

to control the water pollution and taken many measures, mainly focusing on the point source pollution such as industrial wastewater decontamination and lake water cleaning, the water quality of Taihu Lake is still exasperate and the situation of water pollution is austere. The affair of blue-green algae bloom occurred in May 2007 alarmed the people and the government to realize the risk and hazards of eutrophication (Zhang et al. 2010; Zhu et al. 2008).

2.1 Introduction

The causes of water body pollution and eutrophication problem are complicated and multiple (Daniel et al. 1998; Heiskary 1985). With the rapid development of industry and the excess consumption of pesticide for agriculture, large amount of