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Study on non-point source pollution of East Lake in Wuhan, China

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ABSTRACT

While point source pollution gets controlled, nonpoint source pollution has increasingly endangered urban waters around the world. In this paper, taking East Lake in Wuhan as the case study, this study defined the researched water basin and land use types and made a quantitative analysis on water quality statistics. Based on this, this study modeled and analyzed the correlation between land use type and lake water quality, and made a tentative exploration about seasonal effect on water quality of the East Lake and other influencing factors. The results showed that, land use type and climatic change exert a significant impact on water quality of the East Lake. Among others, farmlands and construction lands are the main source of nonpoint source pollution to the lake; green spaces and pond could effectively retain or absorb pollutants, and thus maintain lake water quality; additionally, affected by such climatic factors as precipitation and temperature, water quality changes with seasons.

Key words: urban lake basin, nonpoint source pollution, seasonal effect, regression model

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INTRODUCTION

With rapid urbanization, while point source pollution gets controlled, a majority of urban lakes are affected by nonpoint source pollution [1]. Pollutant concentration of waters exceeds limits greatly; ecological system of lakes degrades sharply and becomes extremely fragile. As a result, functions of lakes are undermined tremendously. It has become an urgent and important issue to research and effectively control urban nonpoint source pollution in China [2]. As early as 1980, American scholars have come to a conclusion that among 129 main pollutants, nearly 50 of them come from urban runoff. United States Environmental Protection Agency rated urban surface runoff the third largest source of pollution to American rivers and lakes. There are large volumes of suspended solids, hydrocarbon and heavy metal in rainfall runoff from roofing, courtyards and roads. Change of land use altered natural hydrologic process. It is one of main reasons for water quality deterioration of receiving waters [3]. Hence, proper administrative measures on land use can help to improve water quality. In addition, related researches show that, under the climatic impact, water quality of urban lakes basin also changes with seasons. Shallow water plants, algae and microorganisms in aquatic ecosystem may absorb pollutants to certain degree [4]. Affected by temperature, the absorption rate also varies with seasons [5].

To date, researches about the impact of urbanization on nonpoint source pollution to water have mainly discussed pollutions related to impervious surface and green space runoff [6]. A common practice is to take samples at some points. Consequently, scholars neglected the route of runoff and interrelation of source, route and sink, which leads to deviation of monitoring data and thus incorrect conclusion [7]. However, this paper is based on the correlation between land use type and pollution severity. Taking East Lake in Wuhan as the case study, this study defined the scope of researched water basin and established a correlation model between land use type and water quality in order to find out correlation between land use type and water quality, source of urban water pollution and seasonal

variation rule and put forward some prevention and control measures for nonpoint source pollution to lakes.

EXPERIMENTAL SECTION

Wuhan East Lake is the largest urban lake in China. Occupying a water area of 33km^2, it consists of five sub basin, namely, Guozheng Lake basin, Tangling Lake basin, Yingwo Lake basin, Shuiguo Lake basin and Miaohu Lake basin. (See Fig.1) The East Lake basin was measured to be 12967.77 hm^2. It has a northern subtropical monsoon climate, with an average temperature for years of 15.8-17.8℃ and an average annual precipitation of 1150-1450mm. The precipitation mainly falls from June through August every year. It is generally flat with small hills on the south bank, hillock plain on the east and west banks and alluvial plain on the northwest bank.

TYPE OF LAND USE

We interpreted the TM image at a resolution of 30m through envi4.8 and generated a map for the East Lake basin by the type of land use through Arcgis9.3 in combination with the traffic artery network in the center of Wuhan. (See Fig.2) There are mainly green spaces, construction lands, farmlands, lakes and pond. Their areas were then calculated respectively.

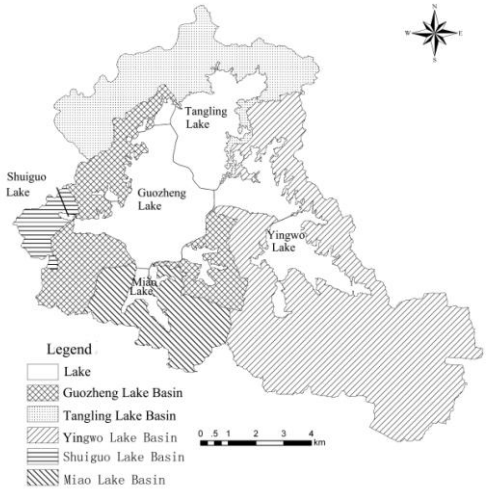

Fig.1 The map of East Lake basin in 2010

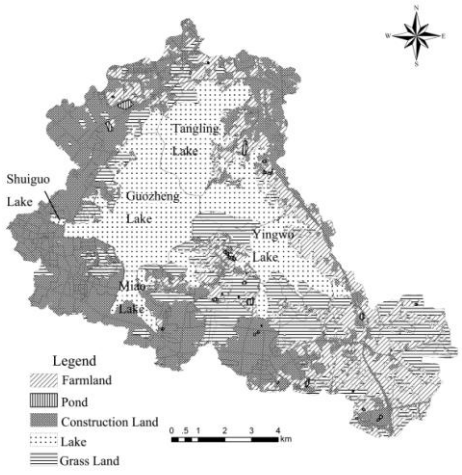

Fig. 2 East Lake basin land use map in 2010

WATER QUALITY MONITORING DATA

Water quality grade and Eutrophication referred to in this research originate from Hubei Monthly Journal of Environment Quality. The statistics are obtained according to the *Environmental Quality Standards for Surface Water* (GB3838-2002), covering all the data from 2004 to 2012 and all the sub basin of the East Lake. The statistics can be classified into four types, e.g. water quality grade, over-limit pollutant, Eutrophication index and Eutrophication level. Water quality of Guozheng Lake, Tangling Lake, Shuiguo Lake basin and Shuiguo Lake basin stays at Grade IV and Grade V, while Miaohu Lake basin, which is polluted seriously, stays at Grade V in most months. Over-limit pollutants include total nitrogen (TN), total phosphorus (TP), permanganate index (COD_{Mn}), biochemical oxygen demand in five days (BOD_5) and chemical oxygen demand (COD).

PROCESSING METHODS OF WATER QUALITY MONITORING DATA

Among existing water quality monitoring data, with exception of Eutrophication index, all the other indicators like over-limit pollutant are all provided in qualitative description without concrete values. This leads to difficulty in quantitative analysis of water quality data. For the sake of accurate quantitative evaluation, we tried to assign a value to those qualitative indicators.

If 1 is assigned, it means one pollutant exceeds limit; if 0 is assigned, no pollutant exceeds limit. The computational formula goes as below:

$$C_i = \frac{\sum w_i}{n_i} \times 100\% \quad (1)$$

where, C_i = the probability that pollutant i appears in the process of eutrophication; the value stays within [0, 1]; the

higher the value is, the more likely the lake is exposed to such pollutant in the nine years; w_i = weight of the over-limit pollutant i; n_i = times of water quality monitoring on the pollutant i; i = over-limit pollutant;

Existing statistics show that, water quality of all sub basin stays around Grade III to Grade V, and the value of 3 through 6 is assigned correspondingly. The computational formula goes as below:

$$D_j = \frac{\sum d_j}{n_j} \times 100\% \quad (2)$$

where, D_j= water quality index of small lake j; it normally stays within [3, 6]; the higher the value is, the more serious the pollution to water is; d_j= water quality grade of the sub basin j; n_j= times of water quality monitoring on the sub basin j; j = sub basin j.

CORRELATION MODEL BETWEEN LAND USE TYPE AND WATER QUALITY

Normally, rainfall runoff flushes surface and takes away large volume of pollutants. These pollutants are absorbed, precipitated and brought to the receiving waters finally. For the researched area, part of rainwater flows into drainage pipes and then sewage treatment plant. However, in case of heavy rainfall, restricted by the capacity of drainage system, some rainwater forms runoff on the surface and flows into receiving waters directly. In this paper, we tried to establish a correlation model between land use type and lake pollution to describe the impact of land use on lake water quality. The formula is as below:

$$LC = \sigma + \sum \alpha_i \times S_i \quad (3)$$

where, LC = water quality of the lake basin; S_i = area of land use i; α_i = impact of land use i on lake water quality; when α_i is a negative value, this type of land retains and absorbs more pollutants than those it sends out, and vice versa; the specific value indicates the weight of impact; σ = a constant value about certain pollutant's impact.

RESULTS AND DISCUSSION

As Table 1 shows, water quality grade, Eutrophication index and over-limit pollutant keep consistent with each other. In the aspect of pollution severity of sub basin, Miaohu Lake ＞ Shuiguo Lake basin＞ Shuiguo Lake basin＞ Shuiguo Lake basin＞ Tangling Lake. Normally, highly polluted lakes have a small area and a regular shape, while less polluted lakes have a large area, an irregular shape and good landscape connectivity in space. In terms of water quality grade, Miaohu Lake stays at Grade V with a value of 6, which indicates the pollution is most serious among all sub basin; Shiuguo Lake and Guozheng Lake stay at Grade V and Yingwo Lake and Tangling Lake stay at Grade IV. In terms of Eutrophication index, Miaohu Lake is moderately eutrophic at 69.60; Shuiguo Lake, Guozheng Lake, Yingwo Lake and Tangling Lake are lightly eutrophic at 56.7, 52.99, 50.18 and 50.05 respectively, 52.99, 50.18 and 50.05 respectively. In terms of over-limit pollutant, TN, TP, COD_{Mn}, BOD_5 and COD in Miaohu Lake are much higher than in other four lakes; Yingwo Lake contains the least TP, COD_{Mn}, BOD_5 and petroleum; Tangling Lake contains the least TN and COD.

Table 1: East Lake water quality status and main pollutants

Lake	Water quality grade	Eutrophication index	Main Pollutants					
			TN	TP	COD_{Mn}	BOD_5	Petroleum	COD
Guozheng Lake	4.59	52.99	31.33%	85.54%	21.69%	30.12%	24.10%	7.23%
Tangling Lake	4.15	50.05	25.30%	72.29%	20.48%	15.66%	21.69%	4.82%
Yingwo Lake	4.23	50.18	42.17%	59.04%	12.05%	13.25%	19.28%	8.43%
Shuiguo Lake	4.87	56.70	57.83%	92.77%	39.76%	43.37%	30.12%	6.02%
Miao Lake	6.00	69.60	100.00%	97.67%	95.35%	60.47%	62.79%	11.63%

SEASONAL EFFECT ON WATER QUALITY OF SUB BASIN

We took Eutrophication of East Lake sub basin in recent five years as an example and converted monthly data into seasonal data correspondingly (spring: from March to May; summer: from June to August; autumn: from September to November; winter: from December to January and February of next year) to analyze seasonal change of water quality. See the results in Table 2. It is showed that pollution severity of East Lake changes as follows: autumn ＞ summer ＞ winter ＞ spring. The Eutrophication is at the lowest level in spring. As time changes, it climbs to the highest point in autumn and drops down again in winter. According to Wuhan pollution situation and meteorological data, rain falls frequently in autumn and summer so scouring erosion is strong in these two seasons and nonpoint source pollution leads to deterioration of lake water. In summer, water pollution is mitigated, because precipitation reaches the peak value and thus helps dilute pollutant concentration; additionally, high temperature accelerates

reproduction of algae and microorganisms to consume pollutants in waters. Water quality is pretty good in winter and spring. It is because that the precipitation amount and frequency both at a low level and pollutants can be effectively treated by urban drainage and sewage system.

Table 2: The season dynamic change of Eutrophication index in East Lake sub basin

Year	Season	Eutrophication index in East lake sub basin			
		Shuiguo Lake basin	Shuiguo Lake basin	Shuiguo Lake basin	Shuiguo Lake basin
2008	Spring	38.47	31.63	32.87	32.53
	Summer	48.37	42.70	45.87	40.90
	Autumn	64.27	59.10	61.13	56.00
	Winter	49.50	44.65	45.05	44.00
2009	Spring	52.13	46.40	53.30	47.33
	Summer	56.75	52.96	55.78	55.63
	Autumn	61.10	59.10	59.30	53.23
	Winter	55.20	51.77	53.93	52.17
2010	Spring	55.45	49.15	53.63	37.20
	Summer	61.04	52.62	57.38	54.77
	Autumn	62.58	56.05	58.48	55.91
	Winter	54.71	48.27	52.14	54.64
2011	Spring	50.00	42.76	47.04	41.53
	Summer	58.35	52.83	56.97	54.76
	Autumn	61.28	56.25	57.07	57.93
	Winter	51.79	49.28	51.97	49.10
2012	Spring	55.43	48.07	55.51	52.09
	Summer	62.33	59.32	59.17	56.59
	Autumn	60.69	59.42	55.20	56.80
	Winter	54.49	46.09	53.29	52.50

LAND USE ANALYSIS

As Fig.2 and Table 3 show, East Lake basin covers a total area of 12967.77 hm^2. Construction lands occupy the largest part, 4826.75 hm^2, 37.22% of the whole water basin. They are mainly distributed in west and southwest of East Lake. Located in city center, this part is highly urbanized. The second largest part is lakes, 3456.25 hm^2, nearly 1/4 of the whole water basin. Green spaces and farmlands occupy 2362.13 hm^2 and 2268.99 hm^2 respectively, about 18%. They are mainly distributed in east and southeast of East Lake basin. Located in suburb area, this part is less urbanized. Distributed in a scattered way, pond occupies the least area, merely 55.31 hm^2, less than 1% of the total area.

Table 3 East Lake basin land use type area in 2010 (hm^2)

Sub basin	Land use type					
	Green space	Construction land	Farmland	Pond	Lake	Total
Guozheng Lake basin	515.64	1042.45	115.73	2.25	1446.40	3122.46
Tangling Lake basin	172.24	1212.73	374.19	19.31	810.68	2589.14
Yingwo Lake basin	1514.43	1424.87	1759.00	33.13	1023.50	5754.94
Shuiguo Lake basin	8.38	308.79	0.00	0.00	10.91	328.08
Miao Lake basin	151.44	835.92	20.07	0.63	164.76	1172.82
Tatal	2362.13	4826.75	2268.99	55.31	3456.25	12967.44

By the area of lake basin, Yingwo Lake basin ＞ Guozheng Lake basin ＞ Tangling Lake basin ＞ Miaohu Lake basin ＞ Shuiguo Lake basin. By the land use type, construction lands in Shuiguo Lake basin take a percentage up to 94.12% with complete traffic and drainage system. Sewage and most rainwater are sent to Shahu Lake Sewage Treatment Plant without flowing into Shuiguo Lake basin. Construction lands in Miaohu Lake basin are the second largest, 71.27% of the total basin. There are many sources of pollution, like restaurants and schools. The construction lands in Yingwo Lake basin take up the least percentage, 24.76%, most of which are for tourism. Farmlands in Yingwo Lake basin account for 30.57%; those in Tangling Lake basin account for 14.45%; other three basins cover minor farmlands. Specifically, farmlands in urban and suburb areas are mainly vegetable fields with high economic benefit, while those far away from city are dry lands and paddy fields. Similar to farmlands, green spaces in Yingwo Lake basin account for the highest percentage, 26.32% of the whole basin, followed by Guozheng Lake basin and Miaohu Lake basin, 16.51% and 12.91% respectively. Green spaces in Tangling basin and Shuiguo basin take up a minor percentage. Green spaces are mainly gardens, scenic spots and campus grassland and woodlands. Among all the five small lake basins, Shuiguo Lake basin contains no swag. Other four basins contain pond no more than 1%.

ANALYSIS ON THE CORRELATION BETWEEN LAND USE TYPE AND WATER QUALITY

With the help of statistic package for social science (SPSS), we made an analysis of regression on the statistics related to land use and water quality and ultimately obtained the correlation between units areas of lands used for certain purpose and water quality, Eutrophication and over-limit pollutant. See Table 4 for the expression. The equation has passed significance testing at 95% confidence interval with 5 samples. The relation coefficient R is 1.

Table 4: Regression analysis between land use types and water quality in East lake basin

water quality	Regression analysis	R	P	N
water quality type	LC_{SZ}=3.635+0.004*Construction land+0.010*Farmland-0.007*Green space-0.368*Pond	1	0.05	5
Eutrophication	LC_{YY}=42.564+0.048* Construction land +0.116* Farmland -0.085* Green space -4.129* Pond	1	0.05	5
TN	LC_{TN}=7.105+0.174* Construction land +0.477* Farmland -0.340* Green space -16.156* Pond	1	0.05	5
TP	LC_{TP}=85.710+0.024* Construction land +0.067* Farmland -0.051* Green space -3.054* Pond	1	0.05	5
COD_{Mn}	LC_{Mn}=-21.57+0.209* Construction land +0.497* Farmland -0.375* Green space -17.22* Pond	1	0.05	5
BOD_5	LC_{BOD}=22.08+0.073* Construction land +0.202* Farmland -0.144* Green space -7.539* Pond	1	0.05	5
Petroleum	LC_{SY}=-4.567+0.118* Construction land +0.271* Farmland -0.202* Green space -9.481* Pond	1	0.05	5
COD	LC_{COD}=0.692+0.018* Construction land +0.040* Farmland -0.026* Green space -1.453* Pond	1	0.05	5

As far as water quality grade and Eutrophication index are concerned, the regression analysis on the correlation model shows, farmlands and construction lands are the primary source of pollution for water deterioration and eutrophication. Pond and green spaces can effectively retain and absorb pollutants and protect lakes. Pollutants from lands used for residence, traffic and commerce, e.g. household garbage, atmospheric deposition and building material wastes, and various chemical pesticides and fertilizers from farmlands flow with rainwater and run into lakes with surface runoff. Consequently, lakes are polluted. On the contrary, the same as functions of lakes, pond can collect and retain rainwater effectively, reduce amount of rainwater runoff that flows into lakes and water quality of lakes is significantly improved. For the green spaces, vegetation like woodlands and grasslands, help to reduce potential energy of rainfall and thus lower down scouring erosion. In this way, pollutants settle down and plants absorb such pollutants as nitrogen, phosphorus and heavy metal. Therefore, green spaces can also protect lakes.

From the perspective of weight of over-limit pollutants, farmlands are the primary source of pollution leading to over limitation of various pollutants in lakes. Pollutants in unit area of farmlands are higher than any other four types of lands. Among others, TN and COD_{Mn} are the highest, followed by BOD_5. TP and COD is the lowest. Nevertheless, they are still twice or three times more than those of construction lands. For construction lands, nonpoint source pollution leads to the result that COD_{Mn} is the highest, followed by TN and COD. Other pollutants exert a minor impact. These indicate that lake pollution is mainly caused by farmland fertilizer, organ phosphorus pesticide, household wastes, industrial dusts and auto exhaust. TP, TN, organic matters that can be oxidized and some reducing inorganic matters exceed relevant limits and lead to eutrophication of waters. Algae and planktons reproduce tremendously and cause algal bloom, or even death of aquatic organisms. As a result, water body maintains an anaerobic condition and becomes black and stinking.

Pond and green spaces showed a negative correlation with pollutants. They play a positive role in absorbing and retaining pollutants carried by runoff. Especially ponds help to sink pollutants before they enter lakes. At the early stage of rainfall, pond may effectively retain sewage, but due to the limited volume, their effect is restricted in case of strong rainfall. Green spaces have a significant pollution prevention effect as well. Unit area of green space can completely absorb or retain nonpoint source pollutants from construction lands of the same area. Plus the large scale of green spaces, they play a main role in protecting lake water.

Brought by rainfall runoff, nonpoint source pollution is uncertain to some extent. It's hard to make certain the polluted area, pollution route, specific pollutants and spatial distribution of pollutants. As population and buildings increase around East Lake, many pollutants leave on urban surfaces, including heavy metal, inorganic and organic pollutants from traffic, farming, fishery, building construction and household wastes. These pollutants come from various sources and are distributed randomly. Different pollutants lead to different pollution to receiving waters of runoff. As the sewage system of East Lake covers both rainwater and sewage. Some rainwater enters urban sewage system and mixes with point source pollutants, like household sewage and industrial sewage, and drains off into lakes after sewage treatment. However, in the event of heavy rain, excessive rainwater together with point source pollutants overflows out of the sewage system into lakes. When studying the source sink effect of nonpoint source pollution, scholars should take the contribution of point source pollution into consideration as well. Apart from these, sub basin also differs from each other in self-purification capability due to their different areas and initial status. Climatic factors make the correlation between land use type and water quality more complicated. Furthermore, these lakes are highly connected, which also affects the source-sink effect. In conclusion, the nonpoint source pollution brought by land use to urban lakes is a complicated systematic problem. Scholars need to continue their research based on uncertainty of pollutions and have a better understanding of the evolvement of nonpoint source pollution.

CONCLUSION

Taking East Lake, the largest urban lake in China, as the object of research, this study defined the scope of researched areas and established a correlation model between land use type and lake water quality through quantification. According to the analysis on the land use type and hydrologic characteristics of the researched area, this study came to the following conclusions:

(1) Affected by human activities, East Lake becomes deteriorated and eutrophicated greatly. The pollution severity of small water basins is ranked as below: Miaohu Lake ＞ Shuiguo Lake ＞ Guozheng Lake ＞ Yingwo Lake ＞ Tangling Lake;

(2) Affected by precipitation and temperature, lake pollution also changes with seasons. The pollution is the most serious in autumn, followed by summer. In winter and spring, the pollution is relative minor.

(3) Land use type is highly correlated with water quality of lakes. Farmlands and construction lands serve as the main source of nonpoint pollution and green spaces and pond serve as the sink of nonpoint source pollution. It is recommended that the lake pollution can be controlled and remedied through reasonable planning of urban lands.

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