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A study of the urban wetland water quality heterogeneity at differing scales

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***Abstract*—15 urban wetlands in Nanjing City were collected to be studied for their vegetation and water quality monthly from March 2008 to February 2009.Further more, the variation of the water quality among 15 urban wetlands was revealed at two scales, i.e, urban wetland ecosystem scale and the catchment scale. Results showed that, (1) the wetland styles including protosomatic wetlands （PWs）, secondary wetlands (SWs) and reconstructive wetlands (RWs), together with plant coverage density impacted the water quality obviously at the ecosystem scale. Water qualities in PWs were better than those in SWs and RWs, and the more plant coverage, the better the water quality was. (2) Land use types and impervious areas were the important factors influenced on the water quality at the catchment scale. Resident land and other construct land made the water quality bad at the catchment scale.**

Key words-urban wetlands; multi-scales; water quality; Nanjing City.

I. INTRODUCTION

Urban wetland plays a significant role in flood storage and regulation, climatic regulation, water conservation and purification, maintenance of biological diversity [1]. Therefore urban wetland ecosystem is an important part of urban landscape. Urban landscape results from the interactions between social and natural factors [2], so urban wetland as a semi-natural ecosystem which located in a high urbanization areas is always interfered by human activities. The process of urbanization have changed the land-use land cover which can result in direct ecosystem loss, as well as fragmentation causing decreases in wetland quality and increases in wetland stress [3]. In addition, land-use land cover change can not only decrease the area of the urban wetland but also enlarge the ratio of the impervious areas and then change the hydrology of the wetland. Therefore the contamination flows into the wetland along with urban storm water, and an increasing concern about the effect of urban sprawls stream degradation due to the increasing impervious surfaces and human activities in the process of urbanization in watersheds [4-6]. In recent years, studies on urban wetland have been a hotspot because of its multifunction and frangibility. In the early 1980s storm water managers and developers were proposing to store urban runoff in wetland to reduce flooding impacts and to protect stream channels from erosion, and then the Puget Sound Wetland and Storm water Management Research Program (PSWSMRP) was established [7-8]. However, Natural resource managers considered that it would damage other biological and habitat functions while the wetlands were used to degrade the urban storm water pollutant [9]. And then a series of researches on the impacts of urbanization have become more and more. For instance, Aichele have found that urban land and other urbanization indicators were highly positively correlated with the water quality indicators during a research on the effects of urban land use change on water quality in Oakland County, Michigan, from 1970 to 2003 and each water quality factor can have a distinct variation with respect to the distance between the different land use types [4]. Tufford and others found that nitrate and total phosphorus were high in urban watersheds, whereas dissolved organic nitrogen and ammonia were high in forested watersheds [10]. Most of these previous studies on the urban wetland water quality used only landscape indicators [2], correlation analysis, and model building [11]. However, there are complicated factors that influence on the urban wetland water quality not only including land use, impervious percentage, and landscape indicators it also including the study scales of the urban wetland.

This study focused on the impacts of urbanization on the urban wetland water quality at different scales and they were the ecosystem scale and catchment scale respectively. Generally, wetland quality is influenced by its own type to a certain extent at the ecosystem scale, such as open water, flow through, plant coverage and the ways of the formation of the wetland. Secondly, the catchment's hydrology, land use, development area ratio are vital factors that affect the wetland water, and lots of scholars have done mass of works on impacts of land use land cover change on wetland water quality at a watershed scale [12]. Therefore, it is necessary for us to reveal the urban wetland water heterogeneity at multi-scales.

In this study, we choose the New City of Xianlin which locates in the eastern Nanjing city in China as a case study, and we have collected 15 sampling sites used for analysis the water quality monthly from March 2008 to February 2009. Land use and land cover data was acquired from the QuickBird images in 2009 and spot images in 2004. The

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objectives of this study concluded two aspects: (1) to analyze the impacts of wetland types and plant coverage on urban wetland water quality at the ecosystem scale; and (2) to find the relationship between the land use and the water quality at the catchment scale.

II. MATERIALS AND METHODS

A. Site description

The New City of Xianlin with an area of about 80 km^2 which locates in the east of Nanjing city in China, and the center longitude and latitude are 118°56′40″, 32°5′84″ respectively (Fig.1). The New City of Xianlin has a subtropical climate, and the annual mean temperature is 15℃, the annual precipitation is about 1100 mm. Furthermore, the study area is a hilly county, and it contains lots of small catchments. However, the New City of Xianlin as a University Town with 12 universities and colleges is under a fast urbanization, and the wetlands in this area are becoming degenerative day by day because of being neglected during the construction of the University Town.

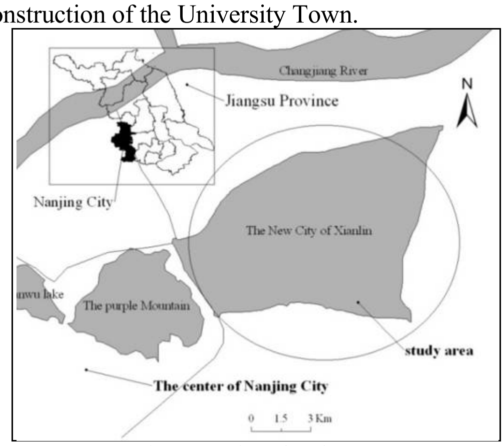

Fig.1. Location of study area

B. Land use and sample sites collection

15 wetlands were collected to conduct their characters and to reveal the relationship between research scales and water quality（Fig.2）. Firstly, we have figured

Fig.2. Description of land use and sampling sites and their catchments

out the boundary of the 15 catchments based on the GIS technique. The detailed method was that the 1:50000 Topographic Map was digitized to create DEM, and then watersheds were generated by the hydrology analysis model by ArcGIS9.2. Boundaries were defined by the roads or the buildings around the wetlands in the plain places (Fig.2). Secondly, land use data were obtained from the 3 meter resolution QuikBird satellite image in 2009; and the land use types had divide into six classifications according to Chinese current land use classification, *i.e.*, forest land, grass land, cultivated land, water surface, technology and education land, residential land, traffic and transportable land, and bare land. Thirdly, we divided the 15 wetlands into three categories, and they were protosomatic wetlands （PWs）, secondary wetlands (SWs) and reconstructive wetlands (RWs) with the method of overlapping the QuikBird satellite image in 2009 to the 3 meter resolution spot image in 2004. The protosomatic wetlands (PWs) primarily describe the wetlands which have been existed before 2004 when at the beginning of constructing the New City of Xianlin. And the secondary wetlands (SWs) are the definition of the wetland which regenerated after 2004. The reconstructed wetlands (RWs) are the wetlands whose area or shape has changed during 2004 to 2009.

C. Water sampling and plant investigation

Water quality data from March 2008 to February 2009 were obtained via the monthly monitoring. Seven parameters, including total nitrogen (TN), ammonia nitrogen (NH_3-N), total phosphorus (TP), specific conductance (SC), dissolved oxygen (DO), permanganate index (COD_{Mn}), and chlorophyll a (chl a) were used as the water quality indicators. SC and DO were obtained from 20 centimeters under the water surface by the YSI 556 Multi-Probe System. And we collected monthly water samples from each wetland to monitor changes of the other parameters. Water samples were collected 5 to 10 cm below the water surface with effort taken not to stir bottom sediments or include any film present on water surface. The samples were immediately stored at 4 ℃, on ice, for preservation. And then samples would be analyzed in the laboratory within 24 hours. Laboratory processing and analysis of water samples followed standard protocols of China. And ultraviolet or visible absorption spectroscopy was used to detect the TN, TP, and NH_3-N.

The sample lines were built between the water patches and other patches to assess the plant coverage by three specialists or laboratory assistants. And five categories were divided according to the plant coverage, *i.e.*, category I (plant coverage≤5%), category II(5%＜plant coverage≤10%), category III(10%＜plant coverage≤20%), category IV(20%＜plant coverage≤30%), and category V(plant coverage＞30%).

D. Statistical analyses

Multiple factor variance analysis and Least Significant difference (LSD) were employed to analyze the water quality variations at three different scales. Also multiple regression analysis was adopted to analyze the water quality trend. And all above methods are based on the SPSS12.0.

III. RESULTS

A. Water quality heterogeneity at the ecosystem scale

Water quality variation at the ecosystem scale was analyzed in two aspects, which were wetland type and plant coverage. Means of water parameters among different wetland types were compared with single factor analysis of variance and LSD method. Results showed that the differences of water quality indexes among the three wetland types were significant at the significant level 0.05 except for SC whose probability (*P*) was 0.096 while the others ranged from 0.000 to 0.017. Both statistics and LSD result are available in Table 1, and the significant differences (level 0.05) among the three types of wetland (PWs, RWs, and SWs) were marked with the lowercase letter. Examination of Table 1 reveals several general points about wetland water quality. First, concentrations varied greatly, as indicated by the relatively high coefficients of variation (CV). Medians and means are all at a similar level, suggesting that the individuals are evenly distributed. Second, the means of all water quality indexes varied significantly between secondary wetlands (SWs) and other kind of wetlands. However, the variations of means between PWs and RWs were not generally significant at level 0.05 except for DO. Third, the variables (TN, TP, COD_{Mn}, and chla) generally increased with each step from PWs to SWs. At the ecosystem scale, wetlands were divided into five categories according to the plant coverage, because vegetative cover can directly affect wetland conditions [13]. Scatter plots were figured out and then the regression analysis was carried out by means of Excel (Fig.3). The results of LSD significance testing of difference had been also marked on the data in Fig.3 with lowercase letters. Fig.3 has exhibited the water quality variations with different plant coverage. From the pictures, we can know that most of the water parameters decreased with each step up in plant coverage level. And the ability of wetlands to remove nutrients from water is primarily dependent on wetland vegetations [14]. However, some water quality variables did not appear to depend on plant coverage, such as COD_{Mn}. It is probably because the organic pollutant degradation has an affinity with microorganism [15] instead of wetland vegetations. From Fig.3, we can find that values of square R in picture e and f are lower than others. We can also find that TN in category Ⅰ significantly bigger than category III, IV, and V at level 0.05; The difference of TP between category I and category V is significant but not significant among other categories; The tendencies of variations of NH_3-N and chla are similar, and both of them have a significantly high value in category I; That is because wetland vegetation has absorbed the nutrients to some extent [16]. Picture e shows that SC has a significantly low value in category V, but there is not a significant trend in the whole steps. Furthermore, the mean concentration of TN in category I is more than 3 times as high as in category V; TP in category I is nearly 4 times high in category V; And NH_3-N in category Ⅰ is nearly 7 times as high as category V.

TABLE 1. WATER QUALITY FOR DIFFERENT TYPES OF WETLANDS

Wetland types	Statistic	TN (mg/L)	TP (mg/L)	NH_3-N (mg/L)	COD_{Mn} (mg/L)	Chla (mg/m^3)	SC (ms/cm)	DO (mg/L)
PWs	Mean	0.508b	0.056b	0.089b	6.1b	9.7b	0.38ab	8.0a
	Maximum	1.635	0.216	0.314	12.8	75.6	0.58	16.2
	St.Dev	0.269	0.046	0.064	2.7	11.5	0.08	3.1
	CV	53%	82%	72%	44%	119%	20%	38%
	Median	0.468	0.040	0.074	5.1	6.7	0.37	8.0
RWs	Mean	0.611b	0.089b	0.083b	7.4b	13.1b	0.37bc	6.6b
	Maximum	1.922	2.604	0.677	13.7	103.5	0.56	13.6
	St.Dev	0.336	0.357	0.124	2.8	18.8	0.07	3.1
	CV	55%	402%	148%	38%	144%	18%	46%
	Median	0.538	0.028	0.048	7.1	7.7	0.36	6.7
SWs	Mean	3.143a	0.338a	1.036a	10.9a	51.6a	0.41a	8.7a
	Maximum	15.701	2.031	9.933	33.0	476.0	0.59	22.2
	St.Dev	3.464	0.453	1.830	7.2	93.3	0.10	5.0
	CV	110%	134%	177%	66%	181%	26%	57%
	Median	1.506	0.163	0.273	9.1	16.8	0.41	8.6

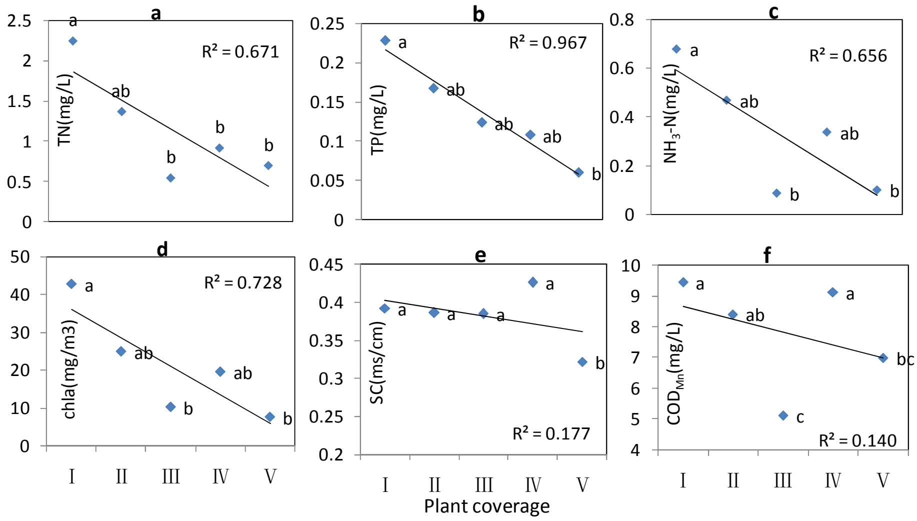

Fig.3.water quality with different plant coverage (Note: lowercase shows significantly different at level 0.05, the below is same.)

B. *Relationship between water quality and land use at the catchment scale*

The relationship between land use and water quality has been clearly demonstrated [17], however a felicitous spatial scale to conduct the relationship between them has been undetermined. We take the small catchments as the study units in this paper, and then multi-factors liner regression was employed to analyze the relationship between water quality and land use type at catchment scale, and the percentages of land use areas were collected to be independent variables while the water quality indexes as dependent variables. Next we had used the backward to collect the regression coefficient and used the T test to check to significant of regression coefficient during this research. And then the regression equations were given in Table 2. Examination of Table 2 reveals several general points about wetland quality and land use types. First of all, the fitness (R^2) is range from 0.254 to 0.754, and the model of chla is better than the others, whatever the fitness (R^2) of TN, NH_3-N, and SC were all over 0.600, but the R^2 values of TP and DO are less than 0.450. However all of them have passed T test at level 0.001. This means that land use types and areas can explain the variation of urban wetland quality at some extent. Secondly, water parameters are affected mostly by GL, CL, TTL, FL, TEL and BL according to the regression equations. Moreover, regression coefficients have revealed that TTL affects chla more than the other land use types, because the value of TTL regression coefficient is nearly two times bigger than others; The mainly factors that affected TN are GL, CL, FL, BL, and RL, and their regression coefficients are a little bigger than the others. The R^2 value of both NH_3-N and SC are all about 0.61, and NH_3-N are mainly influenced by GL, CL, TTL while SC are mainly affected by WS and RL; The R^2 values of the other three water parameters which include COD_{Mn}, TP and DO are 0.442, 0.315 and 0.254 respectively.

TABLE 2. REGRESSION EQUATIONS BETWEEN LAND USE AND WATER QUALITY

Regression Equations	R^2	*P*
chla(mg/m^3)=-4.162*GL-4.168*CL-7.324*TTL-3.691*FL-4.376*BL-3.374*WS+396.832	0.754	0.000
TN(mg/L)=-0.096*GL-0.084*CL-0.062*TTL+0.042*TEL-0.081*FL-0.093*BL-0.073*WS-0.087*RL+ 8.689	0.624	0.000
NH_3-N（mg/L）= -0.052*GL -0.05*CL-0.08*TTL+0.0241*TEL-0.041*FL-0.048*BL- 0.034*WS+4.370	0.614	0.000
SC（ms/cm）= -0.002*GL-0.002*FL+0.004*BL-0.01*WS-0.014*RL+0.521	0.613	0.000
COD_{Mn}(mg/L)=-0.469*GL-0.408*CL-0.867*TTL+0.256*TEL-0.369*FL-0.502*BL- 0.308*WS+46.094	0.442	0.000
TP（mg/L）=-0.003*GL+0.013*TEL+0.111	0.315	0.000
DO（mg/L）=-0.063*GL-0.113*CL-0.165*TTL+0.148*TEL-0.095*BL+0.664*RL+8.918	0.254	0.000

FL=forest land(%, the below is same), GL=grass land, CL=cultivated land, WS=water surface, TEL=technology and education land, RL=residential land, TTL=traffic and transportable land, BL=bare land

IV. CONCLUSIONS

Urban wetland is important to urban climate, pollution degradation and water permeation and impoundment. It is more influential by human factors, especially different from the natural evolution process under the urbanization development [2]. And landscape metrics related to amount of agriculture, wetlands and urban all contributed to increasing nutrients in surface water but at different scales [18]. Therefore, it is helpful to reveal water quality variations at two different scales.

At the ecosystem scale, both plant coverage and wetland type affect the water quality heterogeneity significantly. And water qualities in SWs are usually worse than those in PWs and RWs (Tab.1). That is because a perfect wetland ecosystem which including complicated vegetations or microbial community has not formulated [19]. We can also find the similar tendency according to plant coverage. It is clearly that water qualities in high level plant coverage wetlands are better than those in low level plant coverage wetlands in the gross according to Fig.3. Therefore, the integrity of wetland ecosystem is one of the vital factors to maintain wetland water quality. At the catchment scale, although the land use can pass the significant test as independent variable, the fitness (R^2) is not so big. And different water parameters were influenced by divergent land use types. Furthermore, the distance between wetlands and other landscape patches may be a vital factor to influence the water qualities [17] even if we have not testified this point.

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