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Modelling the Linkage Between Landscape Metrics and Water Quality Indices of Hydrological Units in Sihu Basin, Hubei Province, China: An Allometric Model

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Abstract

Studying quantitative relationships between landscape pattern and water quality is a fundamental step to assess the impacts of non-point source pollution. Many hydrological models with multi-functionality have been developed as useful tools to study several key mechanisms in non-point source pollution. In landscape ecological studies, however, the empirical modelling approaches have been dominated with emphasis on the relationships between the landscape metrics and water quality indices. The main techniques for developing those models of landscape-water quality are statistical regression analysis based on linear models. In this article, Allometric models and the traditional multiple linear regression models for estimating the linkage between landscape metrics and water quality were tested in Sihu Basin, Hubei Province, China. The models at patch class level were established in 24 hydrological units of the basin, which took nine water quality indices (*EC*, *pH*, *SS*, *DO*, *COD*, *TN*, *TP*, NO_3^--*N*, NH_4^+-*N*) as the dependent variables and eighteen landscape metrics calculated in FRAGSTATS 3.3 as independent variables. The results suggested that, compared with the traditional multiple linear regression models, Allometric models were more suitable for *SS*, *DO*, *TP*, *TN*, NH_4^+-*N*, in which landscape pattern metrics could explain the 80.5%, 77.7%, 58.2%, 43.9%, 67.6% of total variation, respectively. There had little difference between multiple linear regression models and Allometric models for *EC* and NO_3^--*N*. The coefficients of determination in Allometric models were not as strong as that obtained in the multiple linear regression models for *pH* and *COD*. The above results indicated that using Allometric model may potentially provide a new way to study the linkage between landscape metrics and water quality indices, which will help protect our regional water resources.

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Nomenclature

PLAND	Percentage of landscape
NP	Numbers of patches
PD	Patch density
TE	Total edge
ED	Edge density
LSI	Landscape shape index
LPI	Largest patch index
AREA_MN	Mean patch area
AREA_SD	Standard deviation in patch area
AREA_CV	Coefficient of variation in patch area
PARA_MN	Mean perimeter-area ratio
SHAPE_MN	Mean shape index
SHAPE_AM	Area-weighted mean shape index
FRAC_MN	Mean patch fractal dimension
FRAC_AM	Area-weighted mean patch fractal dimension
AI	Aggregation index
IJI	Interspersion & juxtaposition index
COHESION	Cohesion index

1. Introduction

Non-point source (NPS) pollution resulted from the agricultural production threatened the water quality and aquatic ecosystems [1-3]. In the factors caused the non-point source, land use and land cover are predominated and numerous studies have been conducted the relationships between land uses and water quality within watersheds [4-7]. However, there is a growing demand for large-scale land transformation, which affects stream in a variety of ways across numerous spatial and temporal scales [8-12].

Recently, scientists in hydrology, ecology, geography, pedology, environmental sciences are concerned about the changes in landscape composition of watershed, their cumulative impaction on water quality, and emerges hundreds of water quality models on non-point source pollution mechanism and nutrient migration and transformation. Of particular concern is the degree to which landscape conditions at watershed scales influence nitrogen, phosphorus, and sediment loadings to surface waters [13,14]. High levels of nutrients and sediment in water can pose significant human health and ecological risks [13]. In watershed scales models, there are the mechanism models based on hydrological processes and empirical models based on the correlative regression analysis between landscape and water quality [15-21]. However, it often occurs that parameters of these models have undefined ecological significance when we models landscape and water quality using these methods, which is the one reason that leads to the limited applying of empirical models.

At present, Allometric models, which also named multiple power exponent regression models and originated from the relationship between the biomass, metabolic and growth character in different organs of organism, has increasingly wide application [22-24], and could afford to a new idea for evaluating the relationship between landscape and water quality. Extensive studies have shown that the Allometric relationship is simulated in different tributaries connection of watershed [25-27], many of which are about the relationship between hydrographic geometry character and water quantity. So, it is important to explain ecosystem character and evaluate ecological security in regional landscape [28]. Few have directly addressed the question of whether there is the Allometric relationship between water quality and landscape parameters in the basin scale. Actually, the hydrographic geometry characters of watershed are included in landscape characters. It is possible to obtain the Allometric relationship and the scale value between the hydrographic geometry characters and water quality through that of water quantity and the hydrographic geometry characters.

2. Materials and methods

2.1. Study site

Sihu Basin lies in Jianghan Plain, Hubei Province, China (29°26′-31°02′N, 111°57′-114°05′E). South of the basin is the Yangtze River, and the north is Han River and Dongjin River, the east is the Xintan entrance that is the Dongjin River enters the Yangtze River, the northeast is the Main Ditch and the third sub-ditch of Zhanghe Reservoir. It is the subtropical monsoon climate and covers an area more than 11547.5 km^2, which comprises about 80 % land and 20 % water [29]. The total yearly radiation is 440.0-460.9 KJ/cm^2, the yearly average sunshine is 1800-2000 h, the accumulated temperature above 10 ℃ is 5000-5350 ℃, the yearly average atmosphere temperature is 15.9-16.6 ℃, and the yearly precipitation is 1100-1300 mm. Due to the complex hydrographic network, this wetland agricultural basin could be divided into three parts. The upper reach is the hilly country and the area is 3240 km^2, which includes the Chang Lake, Tianguan River and the upper of them. The middle area is 5980 km^2 between the below of the Chang Lake, Tianguan River and the upper of the Hong Lake, Xiaxin River. The lower reach is 1155 km^2 included the lower of the Hong Lake, Xiaxin River. There are 33 irrigating water gates, 4 drainage gates, 17 first pump stations and 754 second pump stations in the selected basin. Soil type is the yellow and brown earth and the paddy soil of the hilly country and the plain is the alluvial paddy soil.

2.2. Selection of hydrological units and sampling sites

The upper reach of the basin is out of the study because its terrain is the hilly country and has not the characteristic of wetland agriculture. Sampling sites were located at the middle and the lower reaches along the Main Channel, Pailao River, West Channel, Luoshan Channel, 17 of which were the middle reach (ID01-ID17) and others were the lower reach (ID18-ID24). Meantime, the boundary of 24 hydrological units was accurately defined by digital elevation model (DEM) data and field research (shown in Fig.1). Water samples were collected from the outlet sites of the 24 hydrological units in August, 2010. A 600 ml plastic bottle was used for sampling at 0.5 m below the surface water and 5 replications were conducted. At the same time, the longitude and latitude of the sampling sites were situated accurately by GPS (GARMIN GPS72). Nine physical and chemical indices in the sampled water, electric conductivity (*EC*), pH, suspend solids (*SS*), dissolve oxygen (*DO*), chemical oxygen demand (*COD*), total nitrogen (*TN*), total phosphorous (*TP*), nitrate nitrogen (NO_3^--*N*), ammonium nitrogen (NH_4^+-*N*), respectively, were measured. The portable dissolve oxygen analyzer (JPB-607) was used in the analysis of *DO*. *EC* was determined by the conductivity meter (DDS-001A). The *pH* value was measured with the electric potential method. *COD* was analyzed by the potassium permanganate oxidation. *TN* and *TP* were measured from a persulfate-digested split of unfiltered sample on a UV spectrophotometer and molybdenum antimony colorimetry. NO_3^--*N* was measured on a UV spectrophotometer. NH_4^+-*N* was analyzed by Nessler's reagent colorimetry. *SS* was determined by drying method. These methods can be seen in the environmental quality standards for surface water (GB3838-2002), China.

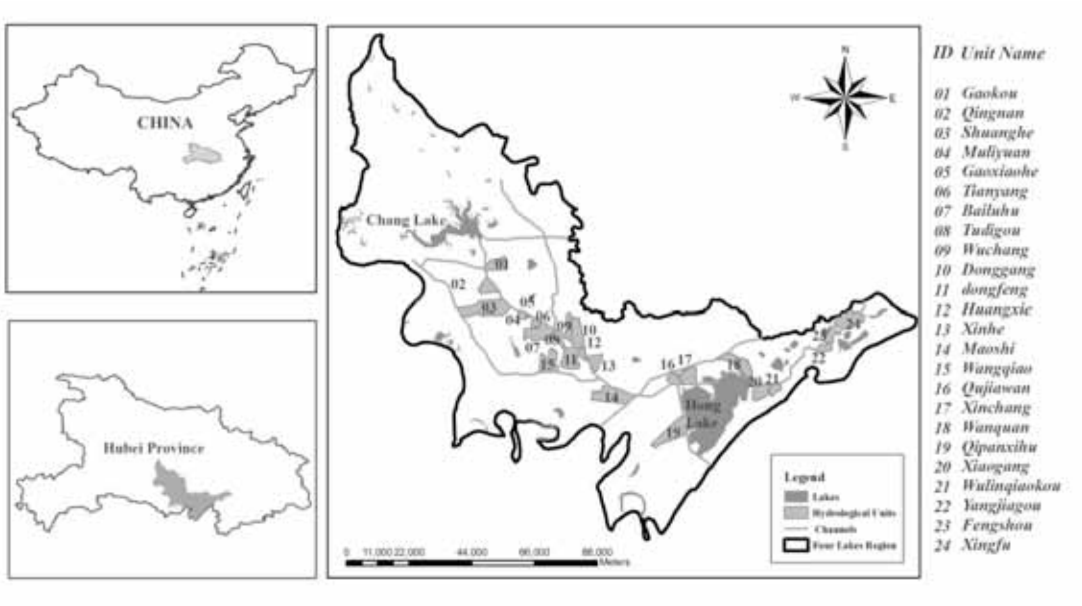

Fig.1 Study area and hydrological units

2.3. Analysis of land use and landscape metrics

The satellite data of HJ-1AB (30 m resolution) in 2010 was collected from the network platform of resource satellite application center of China for evaluating the land use of the basin, which was analyzed by supervised classification and manual visual judgment in ENVI 4.5 (The Environment for Visualizing Images) and ArcGIS 9.3, then land use pattern of 24 hydrological units were dominated by residential point (RP), road (R), ditch (D), fish pond (FP), dry farm land (DL), paddy field (PF) and forest land (FL), according to the current situation classification of land use (GB/T 2001-2007) and the characteristic of land cover (shown in Fig.2).

We used FRAGATATS software (version 3.3) to calculate 18 landscape metrics at class level, including *PLAND*, *NP*, *PD*, *TE*, *ED*, *LSI*, *LPI*, *AREA_MN*, *AREA_SD*, *AREA_CV*, *PARA_MN*,

SHAPE_MN, *SHAPE_AM*, *FRAC_MN*, *FRAC_AM*, *AI*, *IJI*, *COHESION*, which showed the area and quantity, shape, distribution and structure, and diversity of the class in the basin, respectively.

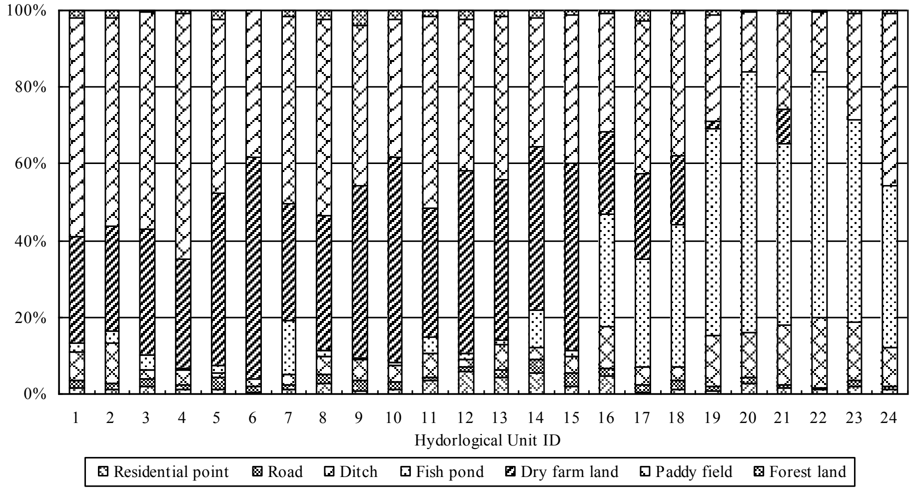

Fig.2 Composition of land uses in Sihu Basin, Hubei Province, China

2.4. Statistical analysis

Allometric model and multiple linear regression model were used to explain the relationships of water quality indices and landscape metrics in 24 hydrological units of the basin. Two kinds of models take the following forms:

$$WQI= a_0+a_1L_1+a_2L_2+\ldots+ a_nL_n \quad (1)$$

where *WQI* (water quality indices) is the dependent variables, $L_{1,2\ldots n}$ (landscape pattern metrics) are the independent variables, $\alpha_{1,2\ldots n}$ *a*re the coefficients and *n* is the number of variables.

$$WQI = AL_1^{\alpha_1}L_2^{\alpha_2}\cdots L_n^{\alpha_n} \quad (2)$$

Where $\alpha_{1,2\ldots n}$ are the relative growth weight factors, *n* is the number of variables and *A* is an undetermined coefficient which would represent the management level.

After the natural logarithm transformation of dependent and independent variables, Allometric model convert into multiple linear regression model:

$$Ln(WQI)=Ln(A)+a_1Ln(L_1)+a_2Ln(L_2)+ a_3Ln(L_3)+\ldots+ a_nLn(L_n) \quad (3)$$

Before modeling, the normal distribution of landscape metrics in the class levels was tested by Kolmogorov-Smirnov method [30]. Results indicated that nine variables, R_{NP}, D_{SHAPE_MN}, FP_{PLAND}, DL_{LPI}, DL_{PARA_MN}, DL_{SHAPE_MN}, DL_{FRAC_MN}, DL_{FRAC_AM} and $DL_{COHESION}$ did not meet the normal distribution ($p<$

0.05). After converting the natural logarithm, these indices were presented the preferable normal distribution. Statistical analysis was carried out by SPSS 17.0.

3. Results

3.1. Allometric model between landscape metrics and water quality indices

The Allometric model was used to establish the relationship between landscape variables and water quality variables, as shown in Eq.(4) to Eq.(12).

$$Ln(SS) = 2.909 + 0.871Ln(PF_{ED}) - 1.386Ln(PF_{PARA\_MN}) - 0.051\,Ln(DL_{IJI}) + 0.375\,Ln(PF_{PLAND}) \tag{4}$$

Where *SS* is suspend solids (mg/L), PF_{ED} is *ED* of paddy field (m/hm^2), PF_{PARA_MN} is *PARA_MN* of paddy field, DL_{IJI} is *IJI* of dry farm land (%), PF_{PLAND} is *PLAND* of paddy field (%). Eq. (4) was the simulated model for SS by the Allometric model. It was showed that 80.5% of the total variation could be explained by PF_{ED}, PF_{PARA_MN}, DL_{IJI} and PF_{PLAND}. Significantly positive correlation was found between the proportion of the paddy field and the concentration of *SS* in the water of ditch, and there was a negative correlation between DL_{IJI} and the concentration of *SS*, that meant, the concentration of *SS* was decreased when the dry farm land patches were dispersed in the other patches.

$$Ln(DO) = 2.290 + 0.93Ln(FP_{SHARE\_AM}) + 0.504Ln(D_{IJI}) + 0.18\,Ln(FP_{AREA\_MN}) - 0.551\,Ln(FL_{IJI}) \tag{5}$$

Where *DO* is dissolve oxygen (mg/L), FP_{SHARE_AM} is *SHARE_AM* of fish pond, D_{IJI} is *IJI* of ditch (%), FP_{AREAMN} is *AREA_MN* of fish pond (hm^2), FL_{IJI} is *IJI* of forest land (%). In Eq. (5), 77.7% of the variation of *DO* could be explained by FP_{SHAPE_AM}, D_{IJI}, FP_{AREA_MN} and FL_{IJI}. With the mean patch area of fish pond increasing, the shape of fish pond regulating, and the ditch patch dispersing, the concentration of *DO* in the hydrological units was the higher. A negative correlation was found in both FL_{IJI} and *DO*, which suggested that forest land acted as the sink could be improved water quality to some extent.

$$Ln(TN) = 1.093 - 0.292Ln(D_{AREA\_MN}) \tag{6}$$

Where *TN* is total nitrogen (mg/L), D_{AREA_MN} is *AREA_MN* of ditch (hm^2). In the Allometric model for *TN*, D_{AREA_MN} was served as explanatory variable after stepwise regression. When the D_{AREA_MN} increased, the concentration of *TN* was decreased, which was benefit for water quality.

$$Ln(TP) = -0.568 - 0.427Ln(D_{AREA\_MN}) - 0.069\,Ln(D_{AREA\_SD}) \tag{7}$$

Where *TP* is total phosphorous (mg/L), D_{AREA_MN} is *AREA_MN* of ditch (hm^2) and D_{AREA_SD} is *AREA_SD* of ditch (hm^2). Eq. (7) showed that D_{AREA_MN} and D_{AREA_SD} in landscape metrics could explain the variation of *TP*. That is, the larger of D_{AREA_MN} and D_{AREA_SD}, the concentration of *TP* in water of ditch was the lower, which implied that ditch was the key landscape composition for regional water quality.

$$Ln(NH_4^+\text{-}N) = -0.235 - 0.502Ln(D_{AREA\_MN}) - 0.666\,Ln(FL_{AREA\_MN}) \tag{8}$$

Where NH_4^+*-N* is the content of ammonium nitrogen (mg/L), D_{AREA_MN} is *AREA_MN* of ditch (hm^2), FL_{AREA_MN} is *AREA_MN* of forest land (hm^2). In landscape metrics, D_{AREA_MN} and FL_{AREA_MN} were contributed to the concentration of NH_4^+*-N*. With the D_{AREA_MN} and FL_{AREA_MN} increasing, the concentration of NH_4^+-N was decreased. It was concluded that ditch, a typical artificial wetland, played an important role to reduce the eutrophication of the surface water. In addition, forest land acted as a kind of sink landscape could withhold the pollutant in the water.

$$Ln(EC) = 5.266 + 0.324Ln(PF_{PLAND}) - 0.099Ln(FP_{AREA\_CV}) \quad (9)$$

Where EC is electrotic conductivity (us/cm), PF_{PLAND} is $PLAND$ of paddy field (%), FP_{AREA_CV} is $AREA\_CV$ of fish pond. There is correction relationship among EC and the content of inorganic acid, alkali and salt in the water body, the more of the content of these ions, the higher is the electronic conductivity. Eq. (9) showed that EC could be explained by PF_{PLAND} and FP_{AREA_CV} in the landscape variables. When the percentage of paddy field area decreased and the difference among the fish pond patches increased, EC is decreased.

$$Ln(NO_3^-\text{-}N) = 0.004 + 0.175Ln(PF_{PD}) - 0.062\, Ln(PF_{NP}) \quad (10)$$

Where NO_3^--N is the content of nitrate (mg/L), PF_{PD} is FD of paddy field (Number per 100 hectares), PF_{NP} is NP of paddy field. In Eq. (10), the independent variable was dominated by paddy field. With the PF_{PD} and PF_{NP} increased, the concentration of NO_3^--N was increased and water was contaminated.

$$Ln(pH) = 1.975 + 0.011Ln(D_{LPI}) \quad (11)$$

Where D_{LPI} is LPI of ditch (%). When the linkage of pH and landscape metrics was simulated by the Allometric model, the independent variable was only D_{LPI}. That meant, largest patch index was responsible for pH.

$$Ln(COD) = 1.414 - 0.144Ln(FP_{AREA\_MN}) \quad (12)$$

Where COD is chemical oxygen demand (mg/L), FP_{AREA_MN} is $AREA\_MN$ of fish pond (hm^2). Eq. (12) showed that the variation of COD was dominated by FP_{AREA_MN}. The larger of FP_{AREA_MN}, the concentration of COD in water was the higher.

3.2. Multiple linear regression models between landscape metrics and water quality indices

Multiple linear regression model was usually used to specify the relationships in both land use and water quality. So, we also used these models to simulate the linkages of the landscape metrics and water quality indices, presented in Eq.(13) to Eq.(21).

$$SS =0.371 - 0.017FP_{PARA\_MN} \quad (13)$$

Where SS is suspend solids (mg/L), FP_{PARA_MN} is $PARA\_MN$ of fish pond (hm^2). In Eq. (13), the variation of SS was dominated by FP_{PARA_MN}, with the mean perimeter-area ratio of fish pond increasing, the concentration of SS was reduced.

$$DO = 4.921 – 0.151FP_{LPI} \quad (14)$$

Where DO is dissolve oxygen (mg/L), FP_{LPI} is LPI of fish pond (%). Eq. (14) showed that a negative correlation was found between DO and FP_{LPI} in linear regression model. The lower of FP_{LPI}, the concentration of DO was the higher, which was benefit for improving water quality.

$$TN = 11.417 - 0.105D_{COHESION} \tag{15}$$

Where TN is total nitrogen (mg/L), $D_{COHESION}$ is $COHESION$ of ditch (%). In multiple linear regression model for TN, $D_{COHESION}$ was the key independent variable for TN. The larger of $D_{COHESION}$, the concentration of TN was the higher, which meant that the better connection among the ditches could improve water body.

$$TP =0.090 + 0.009DL_{LPI} \tag{16}$$

Where TP is total phosphorous (mg/L), DL_{LPI} is LPI of dry farm land (%). From Eq. (16), with the DL_{LPI} increasing, TP in water was improved. There was a negative effect in both DL_{LPI} and TP.

$$NH_4^+\text{-}N = 0.019 + 0.679D_{PD} + 0.014DL_{LPI} \tag{17}$$

Where $NH_4^+\text{-}N$ is the content of ammonium nitrogen (mg/L), D_{PD} is PD of ditch (Number per 100 hectares) and DL_{LPI} is LPI of dry farm land (%). $NH_4^+\text{-}N$ is the important factor resulting in eutrophication of river and lake. In Eq. (17), D_{PD} and DL_{LPI} were contributed to the variation of $NH_4^+\text{-}N$. Positive corrections were presented between the concentration of $NH_4^+\text{-}N$ and D_{PD} and DL_{LPI}.

$$EC = -2382.268 +3.755PF_{PLAND} +2453.833PF_{FRAC\_CV} \tag{18}$$

Where EC is electrotic conductivity (us/cm), PF_{PLAND} is $PLAND$ of paddy field (%), PF_{FRAC_CV} is $FRAC\_CV$ of paddy field. Modelling the linkage of EC and landscape metrics by multiple linear regression equation, the independent variables were PF_{PLAND} and FP_{FRAC_CV}. With the PF_{PLAND} and PF_{FRAC_MN} increasing, EC was improved.

$$NO_3^-\text{-}N =2.216 - 0.013PF_{AI} -7.575\times10^{-7} D_{TE} \tag{19}$$

Where $NO_3^-\text{-}N$ is the content of nitrate nitrogen (mg/L), PF_{AI} is AI of paddy field (%) and D_{TE} is TE of ditch (m). $NO_3^-\text{-}N$ is one of the important factors resulting in the pollution of ground water. For $NO_3^-\text{-}N$ simulated by multiple linear regression model, PF_{AI} and D_{TE} were severed as the variation of $NO_3^-\text{-}N$. There were positive effects between the concentration of $NO_3^-\text{-}N$ and PF_{AI}, D_{TE}.

$$pH = 7.306 + 0.013D_{AREA\_MN} – 0.042\ PF_{SHAPE\_AM} +0.0005\ PF_{AREA\_CV} \tag{20}$$

Where D_{AREA_MN} is $AREA\_MN$ of ditch (hm^2), PF_{SHARE_AM} is $SHARE\_AM$ of paddy field and PF_{AREA_CV} is $AREA\_CV$ of paddy field. There were positive effects between the pH and D_{AREA_MN}, PF_{AREA_CV}, while PF_{SHARE_AM} was opposite.

$$COD = 4.076 - 0.029FP_{ED} + 0.069\ D_{LPI} + 1.535\ FL_{LPI} \tag{21}$$

Where COD is chemical oxygen demand (mg/L), FP_{ED} is ED of fish pond (m/hm^2), D_{LPI} is LPI of ditch (%) and FL_{LPI} is LPI of forest land (%). Eq. (20) and Eq. (21) showed that D_{AREA_MN}, PF_{SHAPE_AM}, PF_{AREA_CV} and FP_{ED}, D_{LPI}, FL_{LPI} in landscape metrics were served as pH and COD in linear regression models, respectively. The *pH* was increasing with the D_{AREA_MN} and PF_{SHAPE_AM} improving and the PF_{AREA_CV} decreasing. There were positive corrections in both the concentration of *COD* and D_{LPI}, FL_{LPI}.

3.3. Comparison between Allometric models and multiple linear regression models

The relationships between landscape metrics and water quality indices were established in the above equations. Compared the determination of coefficients (R^2) in Allometric models and multiple linear regression models (shown in Fig. 3 to Fig. 11), the results showed that, Allometric model was more suitable for *SS*, 80.5% of the total variation could be explained by PF_{ED}, PF_{PARA_MN}, PF_{PLAND} and DL_{IJI} (Fig.3). And *DO* took the second place, 77.7% of the variation could be explained by FP_{AREA_MN}, FP_{SHAPE_AM}, D_{IJI} and FL_{IJI} (Fig.4). Compared with the multiple linear regression model, Allometric models were more suitable for *TP*, *TN* and NH_4^+-*N*, in which landscape pattern metrics could explain the 58.2%, 43.9%, 67.6% of total variation respectively (Fig.5, 6, 7). In the models of *TN* and *TP*, the independent variables were dominated by ditch, which could eliminate and purify the pollutant in the water body, such as the nutritional salts of nitrogen and phosphorus.

Fig.8 and 9 showed that the multiple linear regression models had the similar determination of coefficients (R^2) with the Allometric models for *EC* and NO_3^--*N*. The coefficients were 0.575, 0.534 and 0.406, 0.387, respectively. Applying two kinds of models to predict NO_3^--*N* would have been inefficient because the R^2 of models were less than 0.5, which demonstrated that there was not sufficient proofs for explaining the variation of NO_3^--*N* using the metrics at patch class level within hydrological units.

From Fig.10 and 11, the multiple linear regression models were better than Allometric models for predicting *pH* and *COD*. 72.0% of the variation in *pH* could be explained by D_{AREA_MN}, PF_{SHAPE_AM} and PF_{AREA_CV}. The result is similar to that of modelling at the Chugoku district in the west of Japan by Bahman, which 74.0% of the variation was explained by water and urban indices in multiple linear regression model [31]. In our study, 40.1% of *pH* variable could be explained by D_{LPI} in the Allometric model, which suggested that there was a linear correlation among pH and landscape metrics.

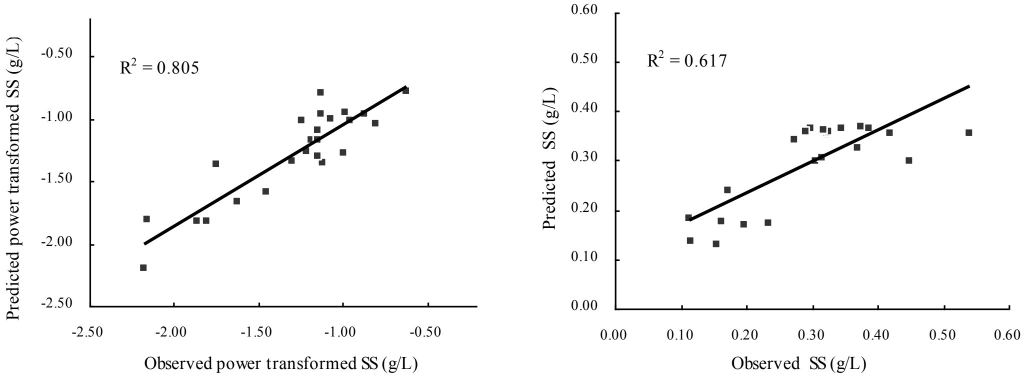

Fig.3 Comparison of observed and predicted values for *SS* in Allometric model and multiple linear regression model

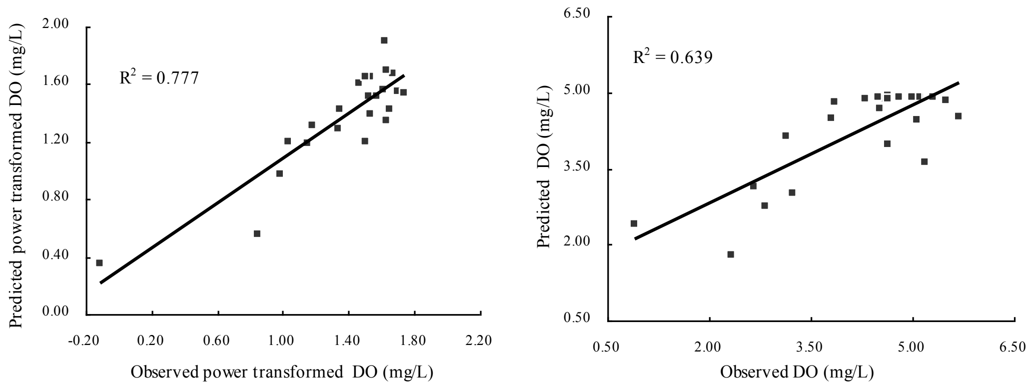

Fig.4 Comparison of observed and predicted values for *DO* in Allometric model and multiple linear regression model

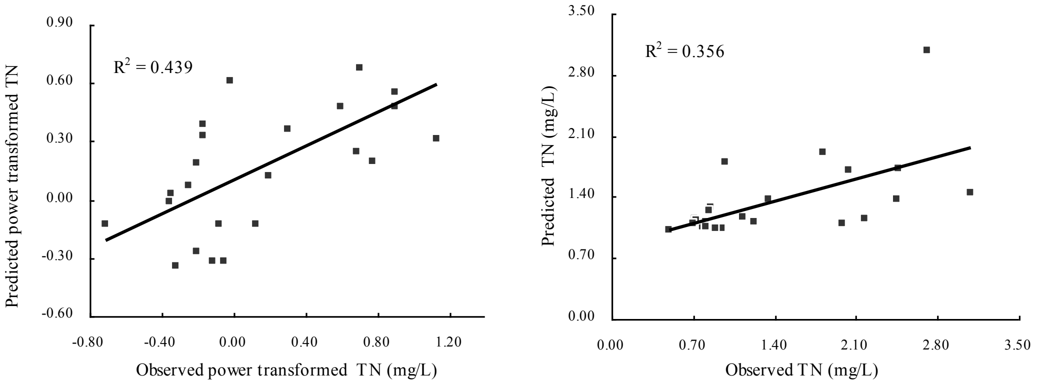

Fig.5 Comparison of observed and predicted values for *TN* in Allometric model and multiple linear regression model

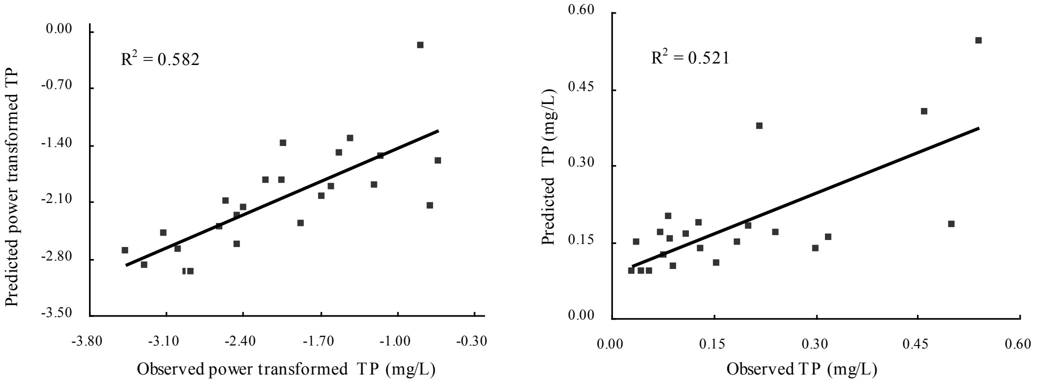

Fig.6 Comparison of observed and predicted values for *TP* in Allometric model and multiple linear regression model

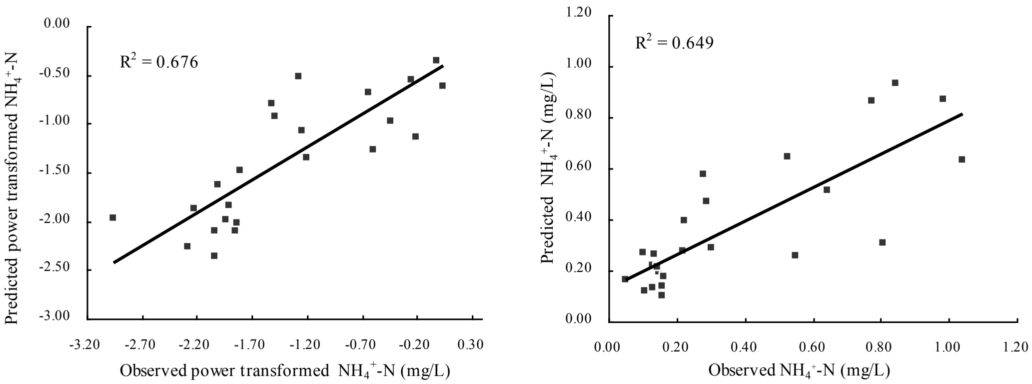

Fig.7 Comparison of observed and predicted values for *NH_4^+-N* in Allometric model and multiple linear regression model

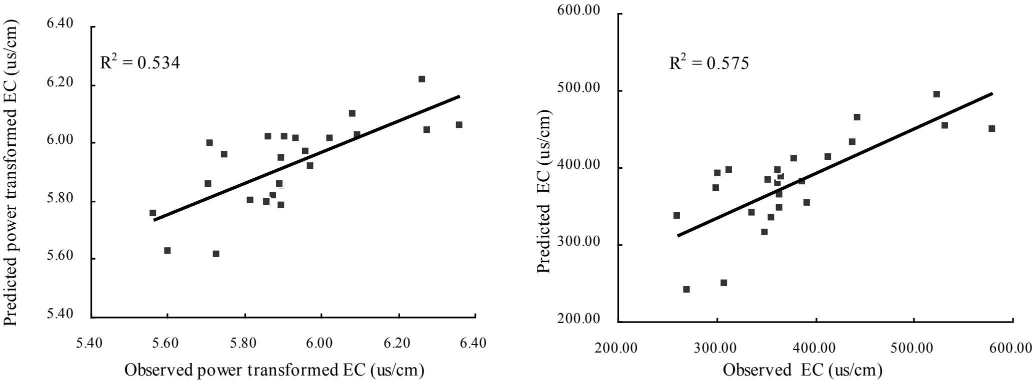

Fig.8 Comparison of observed and predicted values for *EC* in Allometric model and multiple linear regression model

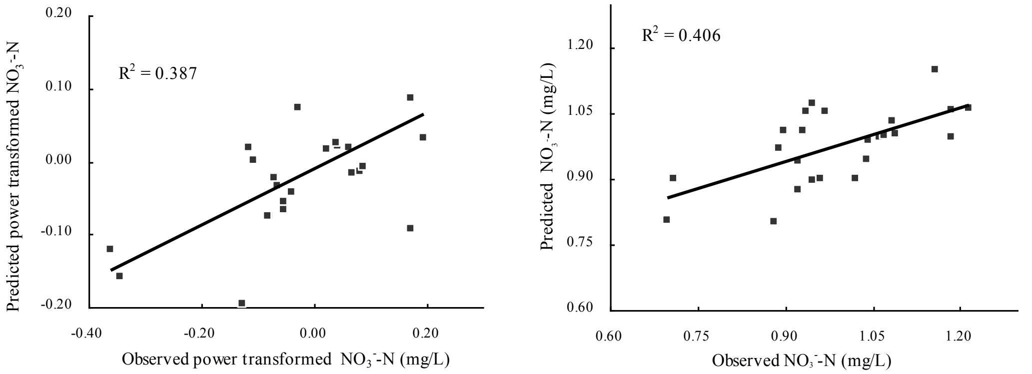

Fig.9 Comparison of observed and predicted values for *NO_3^--N* in Allometric model and multiple linear regression model

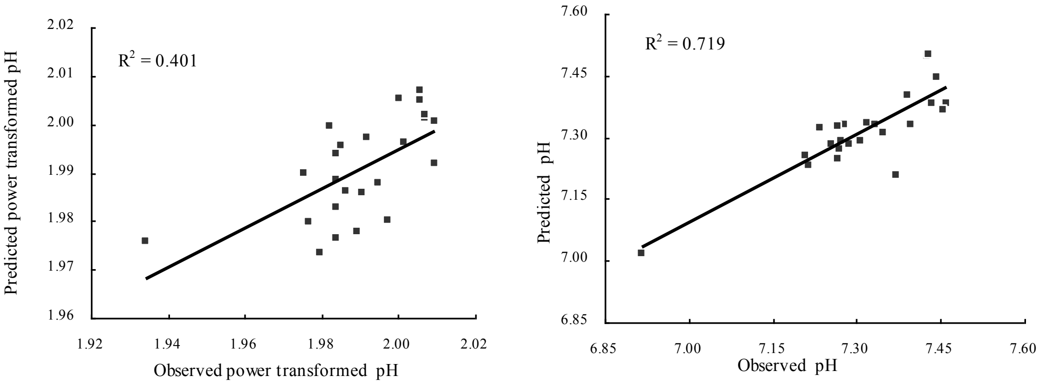

Fig.10 Comparison of observed and predicted values for *pH* in Allometric model and multiple linear regression model

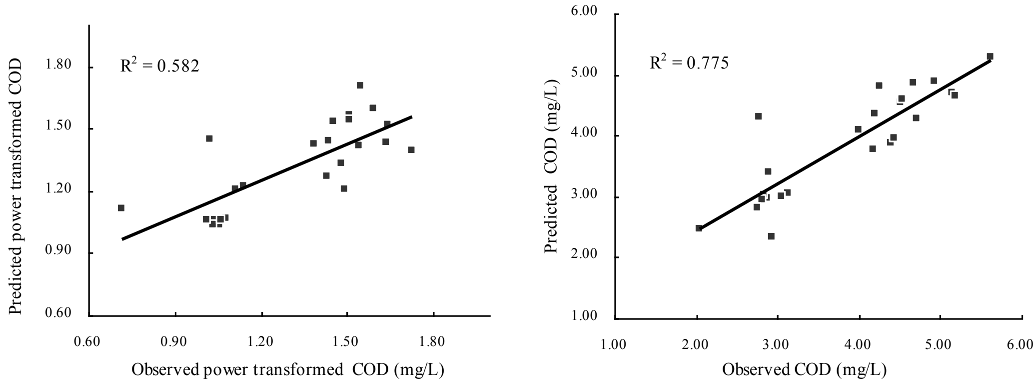

Fig.11 Comparison of observed and predicted values for *COD* in Allometric model and multiple linear regression model

4. Discussion

Studying quantitative relationships between landscape metrics and water quality indices is a fundamental step to assess the impacts of non-point source pollution. Many hydrological models with multi-functionality have been developed as useful tools to study several key mechanisms in non-point source pollution. In landscape ecological studies, however, the empirical modelling approaches have been dominated with emphasis on the relationships between the landscape metrics and water quality. The main techniques for developing those models of landscape-water quality are statistical regression analysis based on linear models. Whether there is the non-linear relation in both landscape and water quality variables is not clear. The Allometric scaling relationships defined as the power exponent relation that describes variation in population density with body size in ecological communities, such as the thinning law in plant ecology, can be explained in terms of how individuals use resources as a function of their size. These relationships usually take the form of power laws $M = bB^{\alpha}$, where M is body mass, B is the biological property of interest and b and α are constants specific to the relationship [32]. Generally, the parameters in the Allometric model have more clear meaning than those of the other regression equations.

So, it is often used to evaluate variation in population density with body size in ecosystem. *Maritan A. et al*. [27] have been studied how the basic scaling features change to variations in network shape of river basins using Allometric model, and derived a new Allometric law for loopless networks. It is also believed that using Allometric model to link geometrical features of landscape and water quality may potentially provide a new way. In our research, the Allometric model and the multiple linear regression model were used to model the linkage of landscape-water quality. The Allometric model was more suitable for 5 of the selected 9 water quality indices, *SS*, *DO*, *TN*, *TP*, NH_4^+-*N*, respectively, than multiple linear regression equation. Two kinds of models had the similar simulation determination of coefficients (R^2) for *EC* and NO_3^--*N*. Although the R^2 of the Allometric model was not as strong as that obtained for the multiple linear regression model for *COD*, the variation of *COD* explained by landscape variables was over 50%. The results reveal that the majority of landscape and water quality indices are the non-linear relationship. Hence, modelling the linkage of landscape and water quality by the power exponent equation is feasible. *Banavar et al.* [33] have shown that directed networks would yield exactly $\alpha = (D + 1)/D$, where D is the dimension of the underlying space ($D = 2$ for planar networks, and $D = 3$ for a network in space) in plants and living organisms. They also showed that arbitrary loopless networks have $\alpha \geqslant (D + 1)/D$ hence suggesting that the purported ubiquity of the value $\alpha \sim 4/3$ in nature. *Dreyer O.* [34] has concluded that the Allometric scale was two-thirds between area and water quantity of watershed, and half between mid-length stream and water quantity. That is, the Allometric scale of regional water variables resulted from landscape pattern changes can be gained by the Allometric model analysis, which is a very useful method for regional water quality management. Further research should closely examine the Allometric scale in both landscape metrics and water quality indices.

5. Conclusion

In this paper, we used two kinds of models, Allometric model and the traditional multiple linear regression model, to estimate the linkage of landscape metrics and water quality of 24 hydrological units in Sihu Basin, Hubei Province, China. The results suggested that, compared with the traditional multiple linear regression models, the Allometric models were more suitable for *SS*, *DO*, *TP*, *TN*, NH_4^+-*N*, in which landscape pattern metrics could explain the 80.5%, 77.7%, 58.2%, 43.9%, 67.6% of total variation of the water quality indices, respectively. There had little difference between multiple linear regression models and Allometric models for *EC* and NO_3^--*N*. The coefficients of determination in the Allometric models were not as strong as that obtained in the multiple linear regression models for *pH* and *COD*. The above results indicated that using Allometric model may potentially provide a new way to study the linkage between landscape metrics and water quality indices, which will help protect our regional water resources.

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