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Assessment of the Impact of Land-Use Types on the Change of Water Quality in Wenyu River Watershed (Beijing, China)

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1. Introduction

Land use-land cover (LULC) change is one of the major environmental changes occurring around the globe. Water quality is one of such factors affected by LULC change, since it is a key component of a healthy watershed where it integrates important geomorphic, hydrologic, and some of the biological processes of a watershed (Hem, 1985). Alteration of any one of these processes will affect one or more water quality parameters (Peterjohn and Correll, 1984). Hydrologists and aquatic ecologists have long known that the surface across which water travels to a stream or a lake has a major effect on water quality. Accordingly, the relative amounts of particular types of land use-land cover (LULC) in a watershed will affect water quality as well (Griffith, 2002). Therefore, the change in land-use and management practices will give rise to the considerable impact on water quality.

The importance of the interrelationships between LULC and water quality is reflected by the increased recognition over the past two decades that non-point source (NPS) pollution has come into being the major environmental concern (Loague *et al*, 1998; Sharpley and Meyer, 1994; Griffith, 2002). Pollutants affecting water quality may come from point or nonpoint sources. Point pollution can be easily monitored by measuring discharge and chemical concentrations periodically at a single place. In the past several decades, the major efforts and funding of water pollution control programs focused on the point sources management, and the magnitude of the point source pollution problem has been reduced in many cases. However, NPS pollution presents great challenges because of their dispersed origins and the fact that they vary with the season and the weather, in addition to the fact that non-point inputs are often overlooked by human beings. Land cover influences water quality because land cover determines the type and quantity of NPS pollutants that may enter the water body.

There are a lot of studies examining non-point source pollution focused on the effects from runoff over the agricultural land and concluded that agricultural coverage strongly

influenced water nitrogen (Johnson *et al.*, 1997; Fisher *et al.*, 2000; Ahearn *et al.*, 2005), phosphorus (Hill, 1981), total suspended solids (Ahearn *et al.*, 2005) and sediments (Allan *et al.*, 1997). A number of documents have illustrated the increasing urban areas were another significant contributor to the water quality deterioration, since the impervious surface coverage can alter the hydrology and geomorphology of urban streams and give the negative impacts on urban stream ecosystems (Schueler, 1995; Paul and Meyer, 2001; Morse *et al.*, 2003), and runoff from urbanized surfaces carries greater sources of pollutants, which results in the increasing loading of nutrients (Emmerth and Bayne, 1996; Rose, 2002), heavy metals (Norman, 1991; Callender and Rice, 2000), sediment loadings (Wahl *et al.*, 1997) and other contaminants to the near stream waters.

In recent years, since 1978 when China has initiated her economic reform and open-door policy, rapid urbanization and economic expansion has resulted in massive land alteration. However, people only focus on the economic growth, and always neglect this factor that economy grows at the expense of the environmental destruction. In this study, therefore, we applied Landsat TM data (2000-2008) to examine the changes of land-use and establish the relationship between land-use types and water quality variables, and give the technical support which can help propose the appropriate strategy that will permit the sustainable regional development and protection of the ecological environment, and understand how it important to assess their potential impacts of land-use types on water quality changes in the watershed scale. This study also demonstrates an example of the issue of how LULC change is linked to water quality, one of the most precious resources on earth.

2. Study area

Wenyu River watershed is a key area in Beijing (China), belongs to the water systems of the Beiyun River, which is the most intensive area of human activity in Hai River Basin (Figure 1). Wenyu River, the main stream is 47.5 km, which is originates from the south of Yan Mountain and flows from north to south through Haidian, Changping, Shunyi, Chaoyang and Tongzhou Districts, all of these districts are in the core area of Beijing City. Wenyu River is usually called "the mother river" of Beijing, because of all the main streams in Beijing City, it is the only river which originates in the border and never runs dry.

The total area of Wenyu River watershed is 2,478 km² and the percentage of mountain and flatland area are 40.4% and 59.6%, respectively. The ground elevation in this area is in the region of 15-1000m. And the study area has the terrain characteristics with the high terrain in the northwest and low plain in the southeast. There are many tributaries in this watershed, with the Dongsha, Beisha, and Nansha Rivers in the upper reaches of Wenyu River, meeting in the Shahe Reservoir, and the Lingou, Qing, Ba and Xiaozhong Rivers flowing into the main stream of Wenyu River. The average annual temperature in this watershed is about 11.6 degree Centigrade (for the year 1959-2000). The predominant soil type is cinnamon (53.5%) of the total area. The average annual precipitation is 624.5mm (for the year 1959-2000), more than 80% of a year's total precipitation is concentrated in the flood season from June to September, the average annual water surface evaporation is 1,175mm, and about 42% of a year's evaporation is concentrated from April to June. The average annual runoff is 450 million cubic meters.

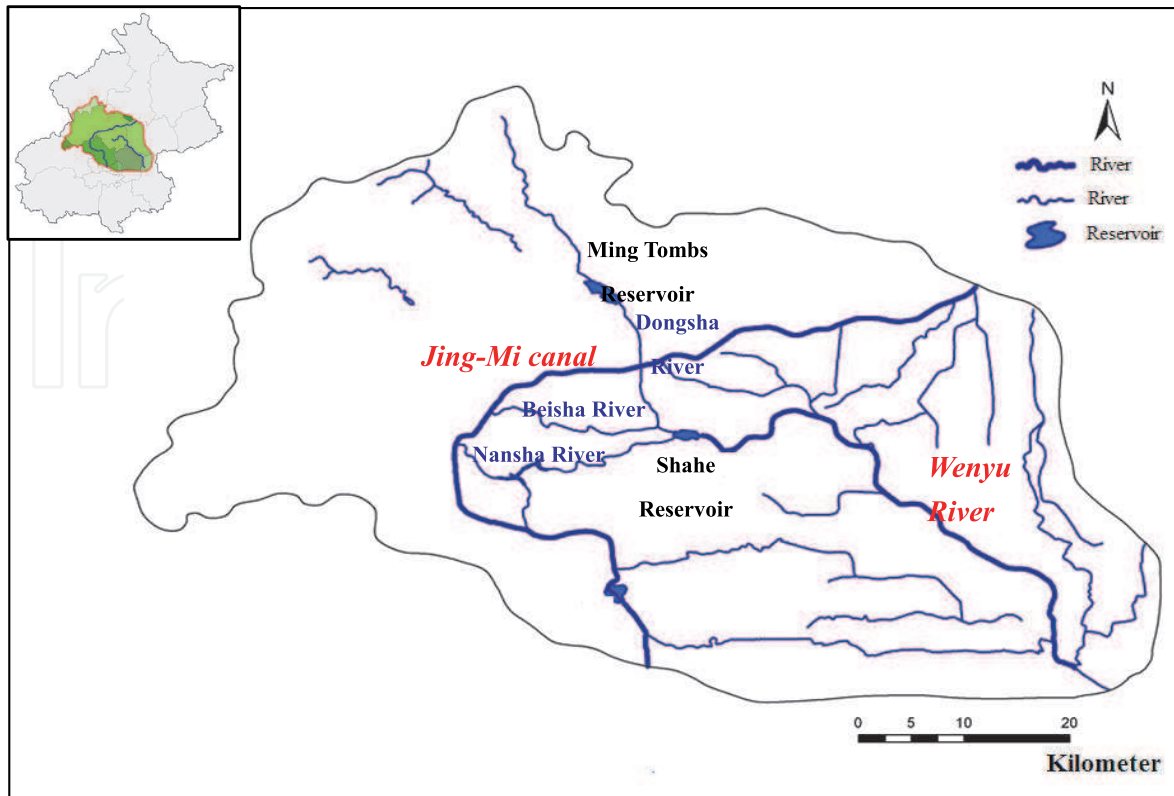


Fig. 1. Map of Wenyu River Watershed in Beijing (China).

As the main drainage canal in the Beijing City, the problems of water pollution and water ecosystems degradation in Wenyu River watershed have come along with the economic development in these years. Several documents estimated the pollution status (Wang and Song, 2008; Shi, 2008; You *et al.*, 2009; Hua *et al.*, 2010) of Wenyu River and pointed out that the water environment of this area was under sub-health; additionally, some other authors put forward the reasonable strategies to restore the ecological environment and improve the water quality in Wenyu River Watershed (Zheng *et al.*, 2007; Wang *et al.*, 2008; You *et al.*, 2009). Although there have many studies noted the water quality problems in Wenyu River Watershed, but the studies linking land use to water quality are limited.

3. Methodology

An integrated approach (involving remote sensing, geographic information systems, statistical and spatial analysis, and hydrologic modeling) is used to link the relationship of land use-land cover and water quality in a regional scale. The soft-wares used in this study include ENVI version 4.3, ArcGIS version 9.3, and SPSS version 14.0 for Windows. Figure 2 shows the flowchart of examining the relationship between land-use and water quality.

3.1 Water quality monitoring

Water samples were collected from twenty-four stations within Wenyu River watershed (see Figure 3) from May to August (on May 22, June 9, July 18 and August 18, respectively) in 2009, and each water sample collection was conducted after the rainfall. Most of these stations distribute in the mid-upper stream area of the Wenyu River watershed.

Water quality data are often collected through direct measurement in situ. To some variables cannot be measured in situ, a sample must be taken and then analyzed in a laboratory. In this research, water samples are analyzed to obtain six water quality variables, as Table 1 listed. The variable of DO is in situ measured using Portable Dissolved Oxygen Analyzer, TOC is analyzed in the laboratory using Total Organic Carbon Analyzer, and the other variables are measured according to National standardized water quality detection method (State Environmental Protection Administration of China, 2002).

Variable Name	Chemical Formula or Abbreviation	Unit
Dissolved Oxygen	DO	mg/l
Chemical Oxygen Demand	COD	mg/l
Total Nitrogen	TN	mg/l
Nitrate	NO ₃ - N	mg/l
Total Phosphorous	TP	mg/l
Phosphate	PO ₄ - P	mg/l

Table 1. Water Quality parameters selection in this study.

3.2 Sub-watershed delineation

Because the 24 water sampling points of this study locate across a range of land uses, geology types, and stream orders within the entire Wenyu River watershed. Thus, the sub-watersheds within Wenyu River watershed should be firstly delineated, and Arc Hydro Model is employed to do this job. Arc Hydro Model was developed by a consortium for geographic information systems (GIS) in water resources, integrated by the University of Texas' Center for Research in Water Resources (CRWR) and the Environmental Systems Research Institute (ESRI) during the years 1999-2002. The Arc Hydro data model is a conceptualization of surface water systems and describes features such as river networks, watersheds and channels. The data model can be the basis for a "hydrologic information system", which is a synthesis of geospatial and temporal data supporting hydrologic analysis and modeling (Maidment, 2002). The Arc Hydro tools are a set of utilities developed based on the Arc Hydro data model, and operating in the ArcGIS environment. These tools can be used to process a digital elevation model raster (DEM) to delineate sub-watersheds.

The major data used to delineate the sub-watersheds is the 30 meter DEM (Digital Elevation Model) data set for China, which is a part of ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer) Global 30m DEM topographic data set and available for download free of charge from the NASA's Land Process Distributed Active Archive Center, at URL <https://wist.echo.nasa.gov/api/>. Using Boundary vector of the study area, the DEM for the study area can be obtained. In this process, higher threshold will result in less dense stream network and less internal sub-watersheds; when the value of threshold decrease, a relatively dense stream network and more internal sub-watersheds will be obtained. In this research, the value of 50000 is applied as the threshold value, the resultant stream network and sub-watershed delineation rasters are displayed in Figure 4. It can also be found 42 sub-watersheds are delineated within Wenyu River watershed when 50000 is used as the threshold value.

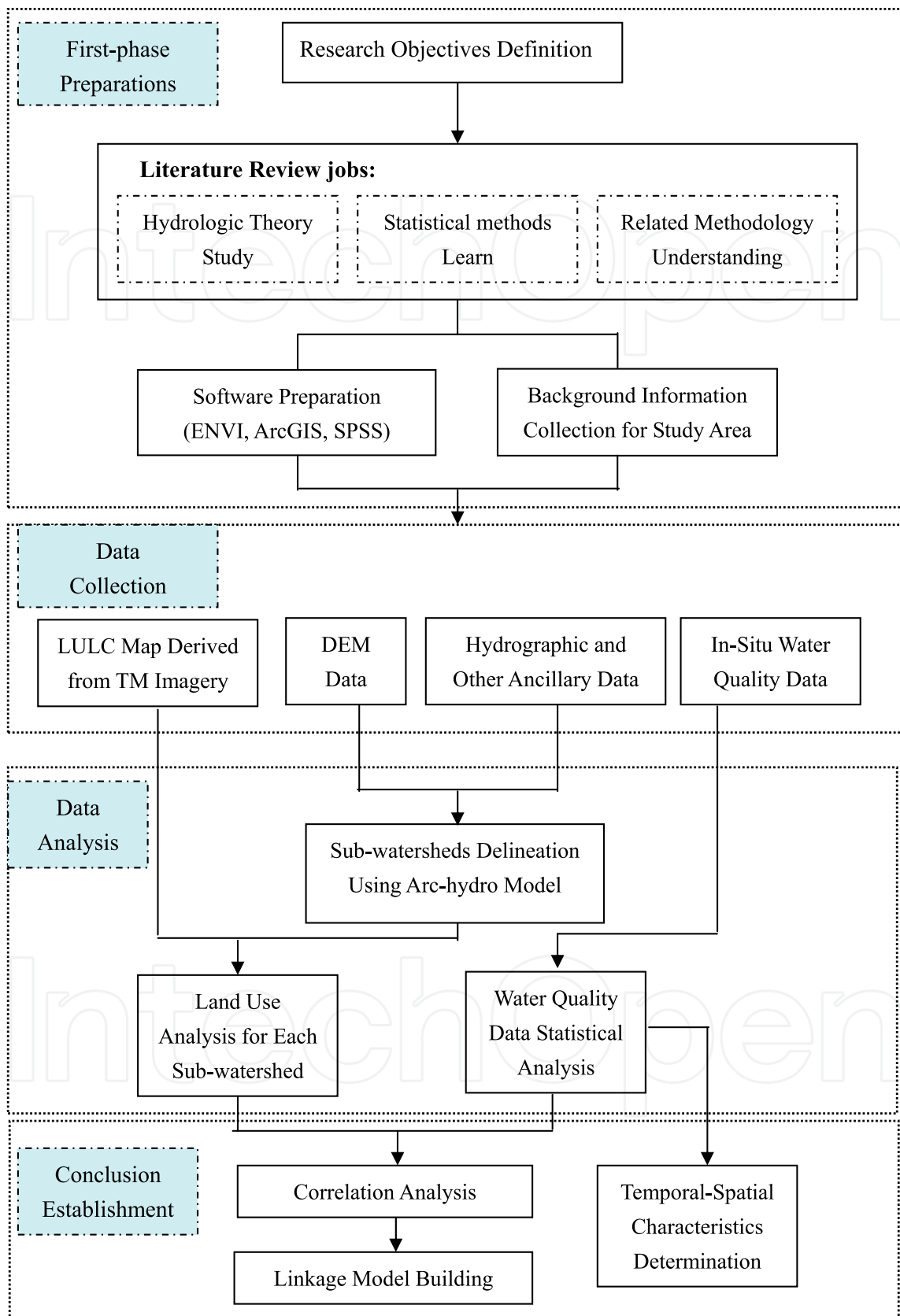


Fig. 2. The flowchart of examining the relationship between land use-land cover and water quality.

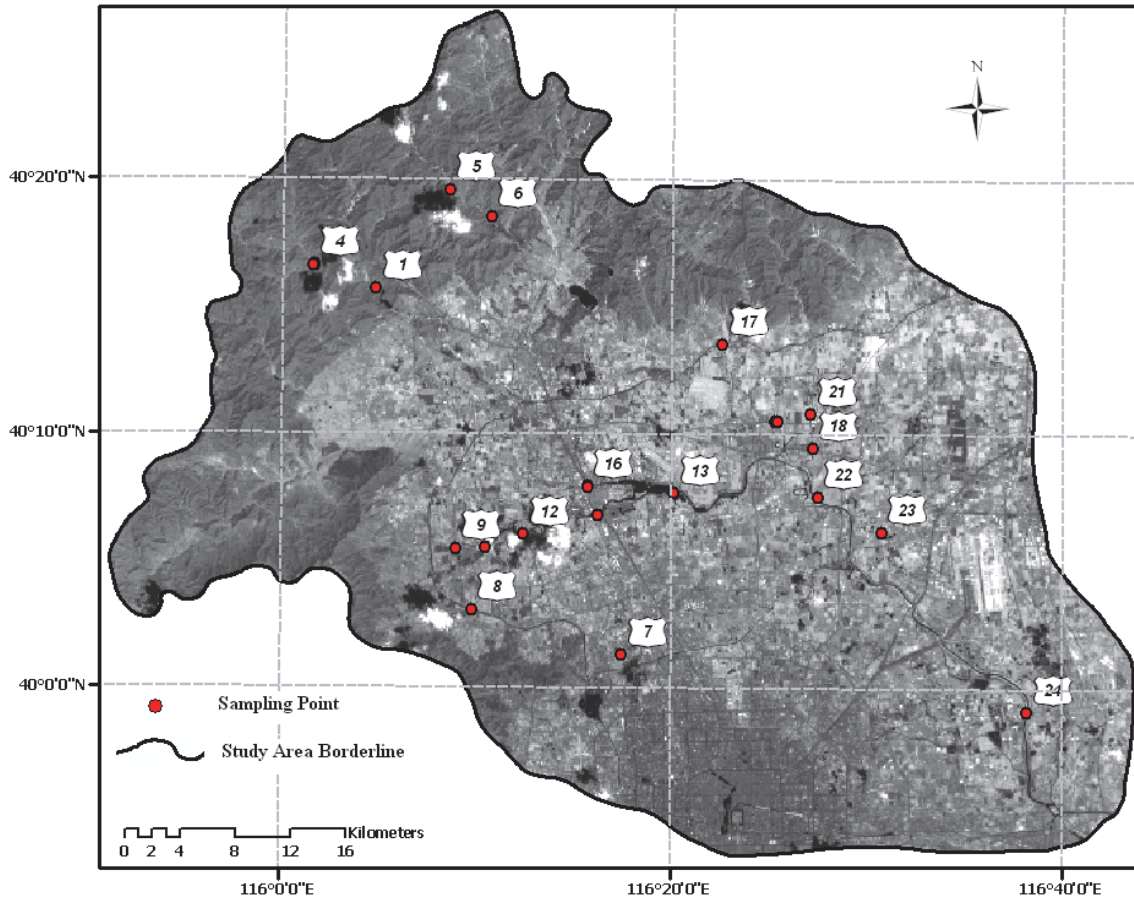


Fig. 3. Water Quality Sampling Points in Wenyu River Watershed (Landsat TM5 image).

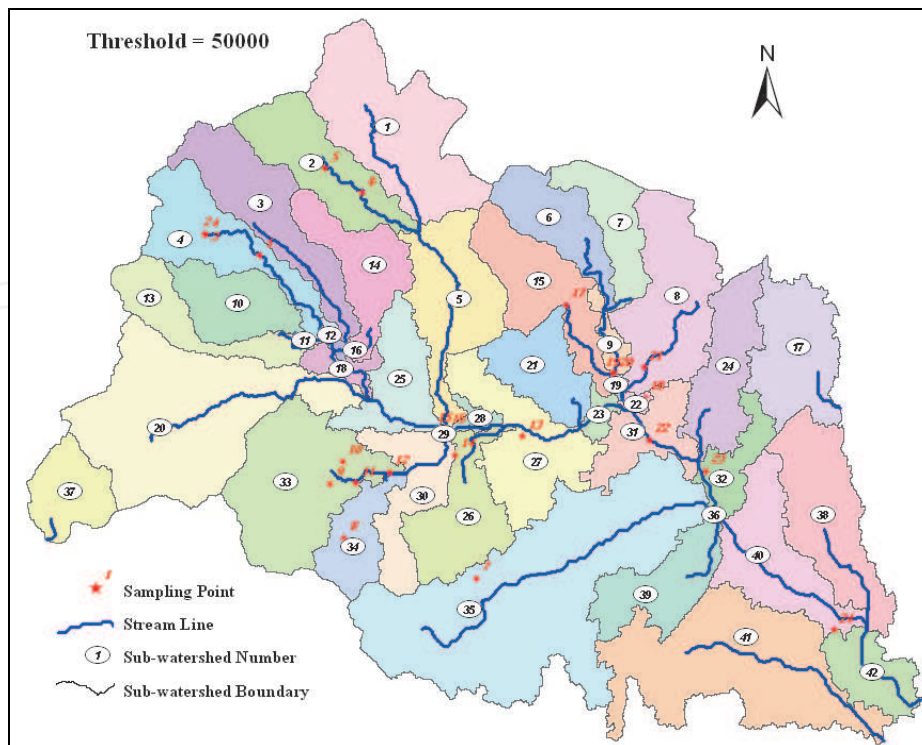


Fig. 4. The sub-watersheds delineation results generated by using the threshold value of 50000.

To those sub-watersheds containing in-situ measured water quality data, it is very clear about the water quality status there and obtain the mean values of each water quality parameters of these sub-watershed through the statistical computing process.

3.3 LULC classification in the study area

Landsat TM data are used to extract the land use-land cover information of the Wenyu River watershed. Landsat TM is appropriate for the purpose in this research because it is free online and can be downloaded easily. Its spatial resolution is 30 meter which will be appropriate to conduct land use analysis of the watershed of Wenyu River. One nearly cloud-free Landsat 5 TM image covering the study area is acquired from the USGS website, <http://glovis.usgs.gov>. Table 2 describes the general information of this downloaded image.

Landsat Scene Identifier	LT51230322009201IKR00
WRS Path/ROW *	123/032
Data Acquired	2009/07/20
Cloud Cover	3.58%
Corner Upper Left	41°16'19"N/ 115°53'07"E
Corner Upper Right	40°57'24"N/118°02'53"E
Corner Lower Left	39°41'38"N/115°24'26"E
Corner Lower Right	39°23'08"N/117°31'21"E

* WRS means The Worldwide Reference System, which is a global notation used in cataloging Landsat data; both Landsat 5, 7 follow the WRS-2, and Landsat 1,2,3,4 follow the WRS-1.

Table 2. The general information of downloaded Landsat 5 TM scene.

To extract land covers of Wenyu River watershed from Landsat TM 5 data, the supervised classification method is adopted in this research, which is the procedure most frequently used for quantitative analysis of remote sensing data, and the maximum likelihood algorithm is employed to detect the land cover types in ENVI software. Based on the priori knowledge of the study area and additional information from previous research in Wenyu River watershed, a classification system concerned with six land classes has been established for this study area, including forest, farmland, urban, village, bare land and the water bodies, the description of these land cover classes are presented in Table 3.

No.	Land Cover Type	Description
1	Forest land	Coniferous & deciduous forest, trees covers, shrubs with partial grassland
2	Farmland	Cropland and pasture, Orchards, other agriculture land
3	Urban area	Residential, commercial, industrial, transportation, and communications facilities; the area of intensive use with much of the land covered by structures and high population density, usually located in the center of a city
4	Village area	Located in the rural areas, surrounding the urban area and has a relatively low population density
5	Bare land	Areas with no vegetation cover, stock quarry, stony areas, uncultivated agricultural lands
6	Water body	Seas, lakes, reservoirs, rivers and wetland

Table 3. Land use-land cover classification scheme used in TM data.

During the process of supervised classification, the collection of training sites constitutes a very critical stage and it is essential that all the required classification classes are sampled. The quality of a supervised classification depends on the quality of the training sites. In order to select the accurate training sites, different band combinations are used to identify the different land categories, according to Landsat TM Band spectral characteristics. Figure 5 displays the generated land use-land cover map of Wenyu River watershed in 2009.

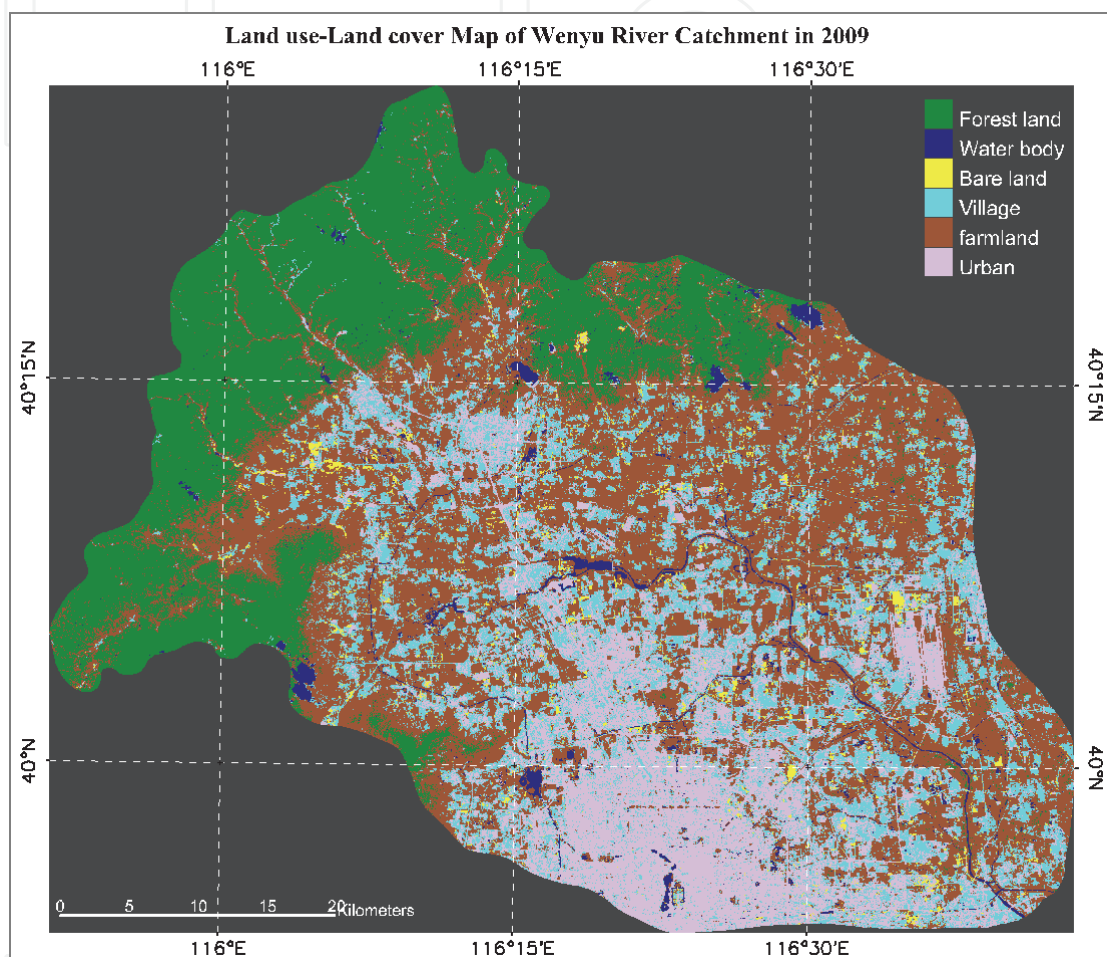


Fig. 5. Land use-land cover map of Wenyu River watershed in 2009 from Landsat TM 5 data.

The LULC map shows that, upper region of Wenyu River has significantly more forest land with higher elevation, while the middle region of the research watershed has a higher percentage of urban area and the major land types in the lower region are village and farmland. The different regions in Wenyu River watershed differ significantly in terms of percentage of forest, urban, village and farmland covers.

3.4 Spearman's rank correlation

Since most of the water quality variables do not distribute normally, the statistical analyses are confined to non-parametric statistical tests, spearman's rank correlation analyses are used to explore the relationships between land use types and water quality indicators in Wenyu River Watershed. And this statistical analyses are performed using SPSS 14.0 for Windows.

In statistical researches, Spearman's rank correlation coefficient is a non-parametric measure of statistical dependence between two variables, which allows us to easily identify the strength of correlation within a data set of two variables, and whether the correlation is positive or negative. The absolute value of the correlation coefficient, with the range from 0 to 1, indicates the strength, with larger absolute values indicating stronger relationships. The significance level (also termed as p-value) is the probability of obtaining results as extreme as the one observed. If the significance level is very small (p value is less than 0.05), the correlation is significantly related at 95% confidence level, and the two variables are linearly related. The data set, which are used in the Spearman's rank correlation process to determine the relationships between land use cover and water quality in this research, includes the land use-land cover variables (%) and the water quality variables (mg/L) of the delineated sub-watersheds.

3.5 An exponential model

Delivery of non-point source pollutants from discrete upstream contributing zones to a particular downstream point is a multi-step, often episodic, process (Phillips, 1989). During the rainfall event, the pollutants released from different land use types will flow through various land covers with the surface runoff, continuing to be absorbed, deposited and released, and eventually enter the nearest stream water. A first-order rate equation can be used for modeling nutrient attenuation in flow through various land uses to the nearest stream (Phillips, 1989). Thus in most cases, the concentration of nutrients or total suspended solids (NPS_i) at a sample point received from a basin i , can be described in the form of an exponential model (Fetter 1994; Basnyat *et al.*, 1999; Basnyat *et al.*, 2000) as follows:

$$NPS_i = \alpha e^{(\beta_1 \text{Forest}_i + \beta_2 \text{Farmland}_i + \beta_3 \text{Urban}_i + \beta_4 \text{Village}_i + \beta_5 \text{Bare}_i + \beta_6 \text{Water}_i)} \quad (1)$$

Where NPS_i is the dependent variable, α is the intercept β_1 , β_2 , β_3 , β_4 , β_5 and β_6 are parameters that specify the direction and strength of the relationships between each land use type and NPS_i .

Based on the linkage model, multiple regression models were applied to each of water quality variables: total nitrogen, nitrate, total phosphorous, phosphate, chemical oxygen demand and dissolved oxygen, respectively. A backwards stepping approach is employed to isolate a final model with only significant independent variables included. In Backward approach, all the predictor variables will go into the model firstly. The weakest predictor variable is then removed and the regression re-calculated. If this significantly weakens the model, the predictor variable will re-entered, otherwise it will be deleted. This procedure will repeated until only useful predictor variables remain in this model.

The purpose of multiple regression process is to predict a single variable (dependent variable) from one or more independent variables. For each model, the initial fixed independent variables are LULC variables (forest, farmland, urban, village, bare and water). The dependent data of water quality parameters and the independent data of land use variables will be natural log transformed to meet the assumptions of normality, as determined via graphical evaluation of standard diagnostic graphs. Finally, goodness-of-fit of final significant statistical models will be evaluated by scatter plot to compare the observed data against equivalent model prediction.

4. Results and discussion

4.1 Water quality temporal and spatial characteristics

The 24 water sampling points of this study were located across a range of land uses, geology types, and stream orders within the entire Wenyu River watershed (Figure 6). Thus, the Wenyu River watershed was firstly delineated into 42 sub-watersheds using DEM raster. According to the in-situ water quality measured data, water quality status of certain sub-watershed can be obtained.

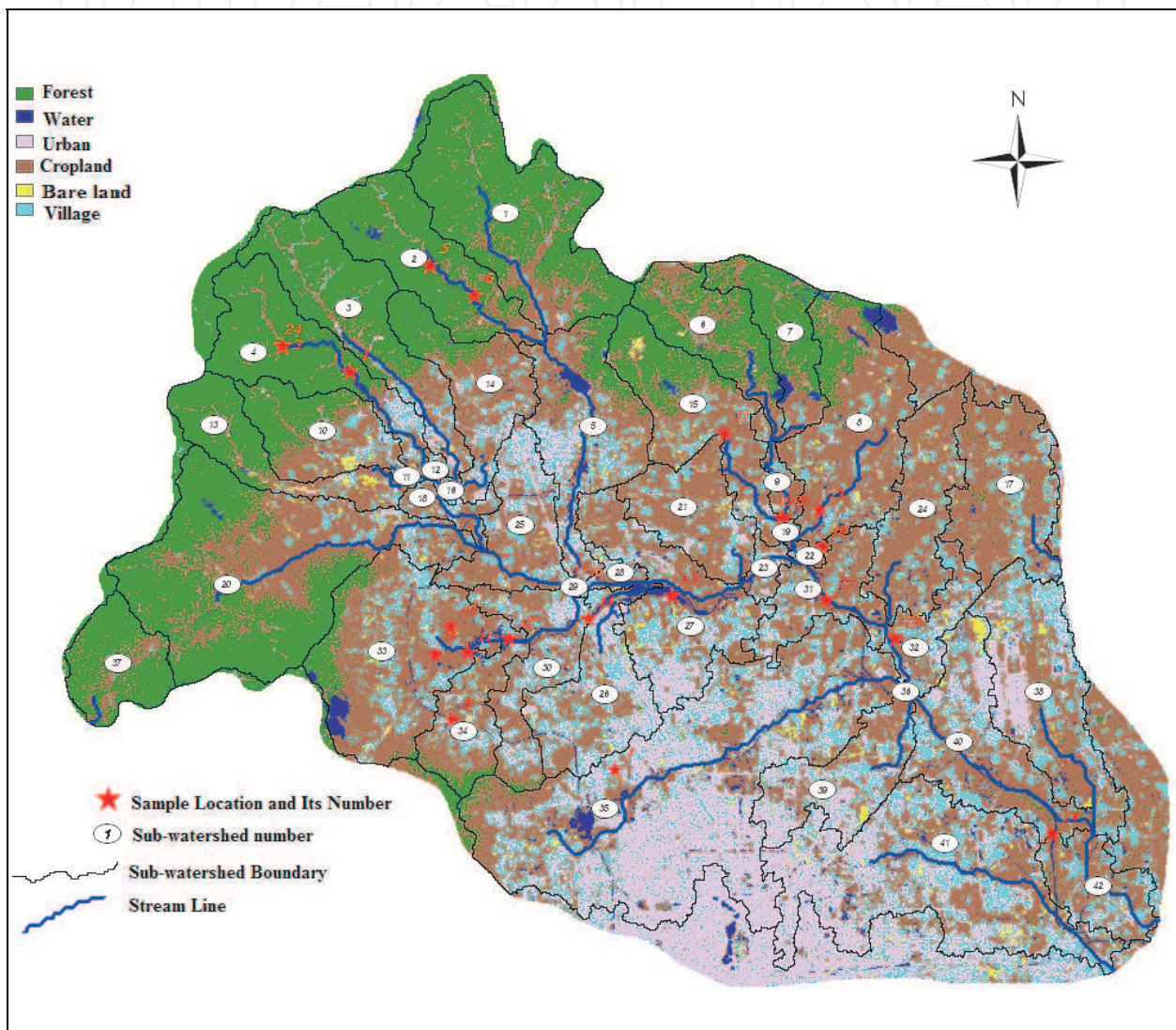


Fig. 6. There different spatial areas definition within the Wenyu River Watershed.

Considering their similarity of geographic location, topographic characteristic, land use-land cover, and human activities, the delineated sub-watersheds were generally clustered into three types in which they located (see Figure 6): Upstream Mountain Area, Midstream Urban Area, and Downstream Plain Area. Table 5 summarizes the characteristic information of these three different spatial areas within Wenyu River watershed. And only those sub-watersheds containing in-situ water quality data were considered in this research.

Different Spatial Areas	Sub-watershed Number	Water Sampling Sites	Area Characteristics
Upstream Mountain Area	w2	Sites 5, 6	<ul style="list-style-type: none"> Lying in the upstream of Wenyu River Watershed and with the higher elevation; With the only significant land use of forest; Sparse human population; Less influence on water quality from human activities.
	w4	Sites 1, 2, 3, 4	
Midstream Urban Area	w26	Site 14	<ul style="list-style-type: none"> Lying in the midstream of Wenyu River Watershed; With gently sloping surface; With the notable land use of Urban and village; High density of population; Considerable influence on water quality from human activities.
	w27	Site 13	
	w28	Site 15, 16	
	w33	Sites 9, 10, 11, 12	
	w34	Site 8	
	w35	Site 7	
Downstream Plain Area	w8	Site 21	<ul style="list-style-type: none"> Lying in the downstream of Wenyu River Watershed; With gently sloping surface; With the dominant land use of production agriculture; Relatively low density of population; Certain influence on water quality from agriculture activities.
	w9	Site 20	
	w15	Sites 17, 19	
	w22	Site 18	
	w31	Site 22	
	w32	Site 23	
	w42	Site 24	

Table 4. Three different spatial areas definition within Wenyu River Watershed.

Through the statistical computing process, water quality information in Upstream Mountain Area, Midstream Urban Area and Downstream Plain Area can be obtained based on the measured water quality data at total 24 water sampling sites. These water quality statistical information include the mean value (the sum of all observations divided by the number of observations) and the standard error of the mean (SEM, calculated by dividing the standard deviation by the square root of the sample size) of six water quality parameters' concentration, including TN, NO₃-N, TP, PO₄-P, COD and DO.

4.2 Water quality comparison between different land-use types

In order to conduct the further analysis of the relationship between land use and the water quality within Wenyu River watershed, in this section, the sub-watersheds are divided into

different classes according to their different land-use structures. And the results of water quality comparison between different land-use structures tell us that land use types are significantly correlated to water quality variables in Wenyu River Watershed.

Here the total nitrogen (TN) is an example of water quality parameters to be monitored from May to August in 2008. Figure 7 illustrates that, between the four different land-use structures, the TN concentration of class III has the largest value, while the TN concentration of class I is the smallest. And the total nitrogen counts produced from class III is about three times greater than that from class I. The sub-watersheds belonging to the class III have three mixed dominant land use types, village, urban and farmland, and all of these sub-watersheds are located in the midstream urban area of Wenyu River watershed, where have the high density of population and the human activities must give rise to the considerable influence on the water quality. The sub-watersheds of w2 and w4 belonging to the class I, they locate in the upstream mountain area with the single significant land use of forest and sparse human population. The result indicates that contribution from forest is the smallest to the total nitrogen loading compared with those from farmland, urban and village.

The water quality parameters of $\text{NO}_3\text{-N}$ concentration was also monitored in the months of May, July and August. Figure 8 shows that, between the four different land-use structures, $\text{NO}_3\text{-N}$ concentration of class IV has the largest value, while the value of class I is the smallest. Both class I and class IV are the land-use structures with single dominant land use; the dominant land use of the former is forest while the latter is farmland cover. It is clear that the contribution from the farmland is larger than the forest to the nitrate loading in the surface water within Wenyu River watershed.

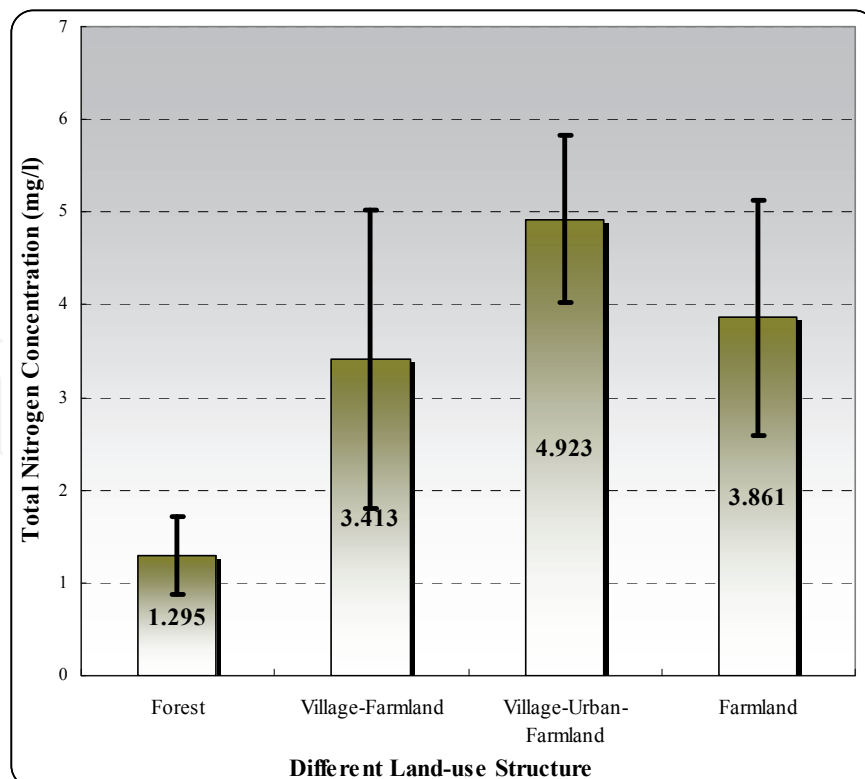


Fig. 7. TN concentration (mean \pm SEM) comparison between different land-use structures.

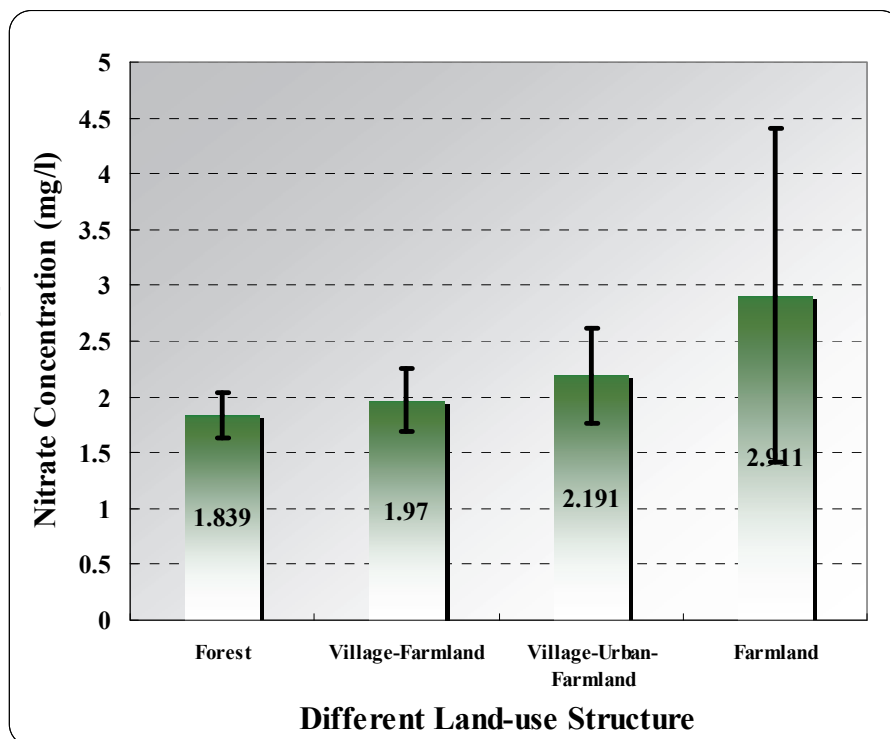


Fig. 8. Nitrate (NO₃-N) concentration (mean ± SEM) comparison between different land-use types.

4.3 Spearman’s rank correlation analysis

The result from Spearman’s rank correlation analysis between land use-land cover variables (%) and the water quality variables (mg/L) is shown in Table 5, which indicates that land use types are significantly correlated to many water quality variables within Wenyu River Watershed. For example, the water quality variables of total nitrogen, total phosphorous, phosphate and chemical oxygen demand have strong positive relationships with urban and village lands, while they are all present the negative correlation with the forest land use. Except for dissolved oxygen, forest is negatively correlated with the other five variables. In comparison, farmland, urban and village have the negative relationship with dissolved oxygen, while urban and village have the strong positive relationship with five variables.

Water quality Indicators	Land use types						N
	Forest	Farmland	Urban	Village	Bare	Water	
TN	-0.401	0.181	0.456	0.462	0.187	0.632*	13
NO ₃ - N	-0.055	-0.209	0.181	0.033	0.275	-0.242	13
TP	-0.412	0.198	0.560*	0.681*	0.681*	0.352	13
PO ₄ - P	-0.725**	0.357	0.533	0.621*	0.302	0.714**	13
COD	-0.297	-0.346	0.676*	0.720**	0.187	0.22	13
DO	0.082	-0.291	-0.28	-0.396	-0.385	-0.341	13

Notes: ** indicates significance $p < 0.01$ while * indicates $p < 0.05$; Absolute coefficient value of 1.0 is a perfect fit.

Table 5. Correlations analysis between land use types and water quality indicators based on Spearman’s rank correlation coefficient.

The above results can provides insight into the linkage between land use types and stream water quality, which is just in line with the comparison results (as Table 6 listed) of water quality variables between different land-use structures.

Water Quality Variables	Order for different land-use structure
Total Nitrogen (TN)	Village- urban-Farmland > Farmland > Village-Farmland > Forest
Nitrate (NO ₃ - N)	Farmland > Village- urban-Farmland > Village-Farmland > Forest
Total Phosphorous (TP)	Village- urban-Farmland > Village-Farmland > Farmland > Forest
Phosphate (PO ₄ - P)	Village- urban-Farmland > Farmland > Village-Farmland > Forest
Chemical Oxygen Demand (COD)	Village-Farmland > Village- urban-Farmland > Forest > Farmland
Dissolved Oxygen (DO)	Village- urban-Farmland < Farmland < Village-Farmland < Forest

Table 6. The order of water quality variables for different land-use structures.

Three water quality variables including total nitrogen, total phosphorous and phosphate, have strong positive relationships with urban and village lands, while are negatively related to the forest land. This means that the observed concentration values of the three variables would increase if the percentage area of urban or village land cover increases, whereas the concentration values would decrease if the percentage area of forest land increases. Therefore, the same order exists of the three variables for different land-use structures: Village- urban-Farmland > Village-Farmland > Forest. In comparison, dissolved oxygen has the negative relationships with urban, village and farmland, so the order represents as Village- urban-Farmland < Farmland < Village-Farmland < Forest.

4.4 The linkage model

Based on the exponential model, separate multiple regression models are developed to estimate the contributions of different land types on six stream water quality variables, including TN, NO₃- N, TP, PO₄- P, COD and DO, in Wenyu River watershed. The resulted models are identified to well explain the water quality variables using land use types. And the goodness-of-fit of these models are reasonably satisfactory. Table 7 presents the examples of regression models developed for TN and NO₃-N in this case study, in which each model is selected with the highest R and R^2 , which indicates the significant level of using land use types to explain the water quality of the watershed.

For this land regression analyses, the concentration data of total nitrogen and nitrate are respectively natural log-transformed. The use of predictive equations allows city planners to model various scenarios of landscape alterations and observe the effects on water quality. From the table, it is determined that the regression models have a reasonably high degree of "goodness of fit", i.e., the R^2 values > 0.65, but the result of total nitrogen is less than 0.65. The observed and predicted data for total nitrogen and nitrate are compared using scatter plots in Figure 9. In the figure, most data distribute around the 45 degree lines, indicating a strong linear relationship between the two concentrations. The further investigation will be performed with more water samples of *in situ* measurements in the near future.

Water Quality Parameters	Regression Equations	R Value	R Square	Std. Error of the Estimate
Total Nitrogen (TN)	<p><i>Predictors:</i> Forest, Urban, Village and Water</p> <p><i>Equation:</i> $Ln(TN) = -0.086Forest - 0.057Village + 0.301Urban + 0.7Water + 0.954$</p>	0.729	0.531	0.639
Nitrate (NO ₃ -N)	<p><i>Predictors:</i> Forest, Urban, Village and Bare</p> <p><i>Equation:</i> $NO_3-N = -0.083Forest - 0.240Village + 0.794Urban + 1.209Bare + 2.819$</p>	0.828	0.685	0.857

Note: The independent variables of %Forest, %Urban and %Water were natural log-transformed because their normality assumptions were not met

Table 7. Regression equations developed for TN and NO₃-N in Wenyu River Watershed.

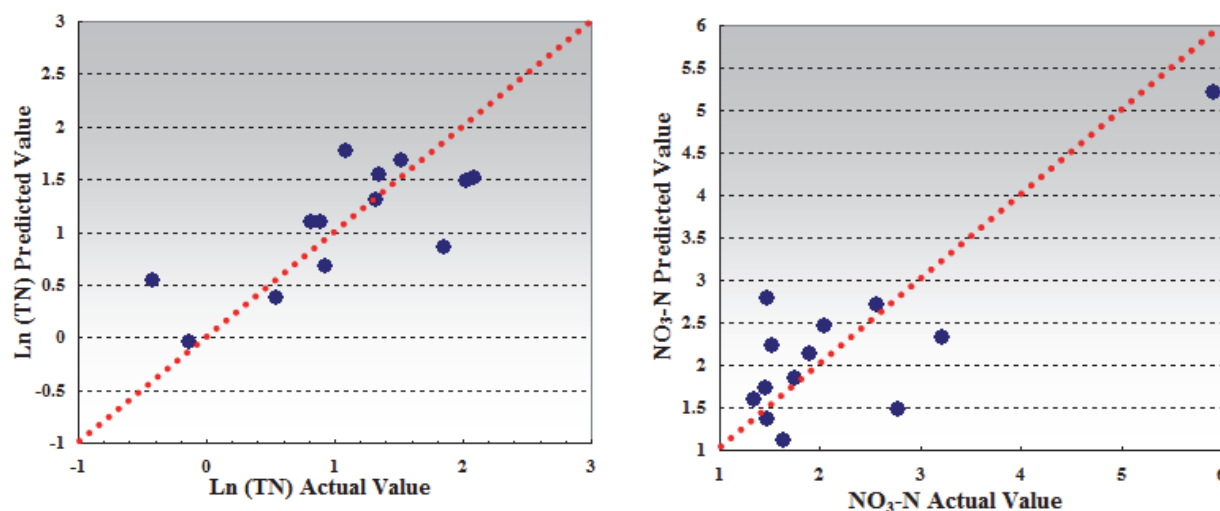


Fig. 9. Goodness-of-fit of statistical models for six water quality variables prediction.

The results can provide insight into the linkage between land-use types and stream water quality. The regression models have used in several ways by environmental planners and others interested in watershed management. The models can help examine the relative sensitivity of water quality variables to alterations in land-use types within a watershed. If the pattern of land-use changed, the levels of contaminants should be changed accordingly. Only with a better land-use planning, it is able to reduce the water quality deterioration.

4.5 Water quality changes with land-use types

In the study, we also examined the changes of water quality in relation to the changes of land-use types in the Wenyu River watershed. It is very clear that most of water quality variables were degraded from 2000 to 2008. For example, both TN and TP increased

relatively high in farmland, urban and village areas, but very little change in forest areas. Since urban areas are dramatically increasing from 2000 to 2008, their impacts on TN and TP are quite obvious. These results not only provide the linkages between land-use types and stream water quality, but also show the high correlation of land-use types and water quality variables. The results indicate that water quality improvement and ecological restoration have great effects on the regional sustainable development. Thus, if the sustainable development is pursued, land management should consider the potential impacts of land-use on water quality changes in the watershed scale.

5. Conclusion

Land use-land cover (LULC) change is one of the major environmental changes occurring around the globe. Water quality is such one factor affected by LULC change. In this study, an integrated approach, involving remote sensing technology, geographic information system (GIS), statistical and spatial analysis, and hydrologic modeling, is used to conduct a comprehensive study on the relationship between land-use types and water quality in the Wenyu River watershed. Landsat TM data is used to extract the land-use information in the study area. The result suggests that this model is indeed an useful tool in hydrologic research and management. The results of water quality comparison with different land-use types show that land use types are significantly correlated to water quality variables. The Spearman's rank correlation analyses confirmed the change of water quality is impacted by land-use changes. Based on an exponential model, multiple regression models were applied to estimate the contributions of different land types on six stream water quality variables, including TN, NO₃- N, TP, PO₄- P, COD and DO, in Wenyu River watershed. The obtained results are identified well to explain the water quality variables using land-use types, with the reasonable satisfactory in the goodness-of-fit of the models.

The results can provide insight into the linkages between land-use types and stream water quality. The study offers the supporting evidence for the previous studies to serve as a reference to similar studies estimating the response of water quality to the land-use change. The models can help examine the relative sensitivity of water quality variables to alterations in land-use types within a watershed. The predicted values are close to the actual monitored values, which indicates that with little calibration and validation, the regression model can be applied in other watersheds under a different geographical scale in a different region with variable landscapes.

The results also indicate that with the integration of GIS and ecological modeling, a decision-making support system can be developed to manage land development and control non-point sources pollution at the watershed scales. This study also suggests that if a sustainable development is pursued, land management should consider the impacts of land-use types on water quality change in the area. The study provides a technical support for the water quality improvement and ecological restoration in the Wenyu River watershed, which has the great significance for the sustainable economic development of Beijing City.

However, in the study, only land-use related variables are considered in the models. In fact, there are other factors would be related to water quality levels in a sub-watershed, such as population characteristics, waste water treatment plants, soil types, average precipitation

and other physical or biological variables. Nevertheless, the models in this study fail to reflect these variations for the sake of discussion. Hence, in the near future, other characteristics as the research background information will be helpful in the identification of the problems and developing a more rigorous linkage models between land-use types and water quality.

Several previous studies argued that the significant influences from land-use on water quality only exist within a shorter distance of the receiving water body. Hence, estimating the relationship between the buffer landscape and stream water quality will be another subject of the future study.

Estimating the links between land-use types and water quality over an extended period is crucially important task in the future works. The further study can help understand the response of water quality change to the change of land-use types, and give the environmental planners more information for the decision-making in land management. Furthermore, persistent water quality monitoring is useful to assist in identifying how land-use planning brings help in the control of water quality change in the watershed scale. This study also demonstrates an example of the issue of how LULC change is linked to water quality, one of the most precious resources on earth.

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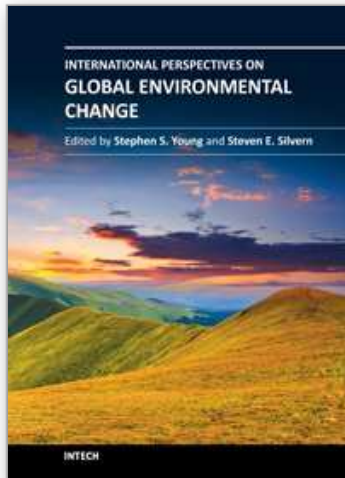
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