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Relationship of land use/cover on water quality in the Liao River basin, China

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Abstract

A total of 76 sampling sites were selected in the Liao River basin ($21.9\times10^4 km^2$). During the period of 2009-2010, 58 water samples were collected in 2010 and 42 were collected in 2009, physical-chemical variables were analyzed to investigate their spatial-temporal variability in particular the relationship with land use /cover. The results indicated that physical and chemical properties showed obvious spatial heterogeneity in the Liao River basin. Taizi River and Hun River are located in the southeast of the basin, the water quality for two sub-basins: water quality in upstream is better than that in downstream, water quality level in downstream was classified into IV-V. There were no obvious features in the East Liao River basin, water quality in downstream was classified into III level. West Liao River run for many years, water quality was classified into IV. Big Liao River basin was located in middle and east of the Liao River basin. Water quality was classified into V. Correlation and regression analysis indicated that BOD_5, COD, sediment, hardness and nitrate–nitrogen (NO_3^-–N), total dissolved particular (TDP) were significantly related to land use for forest and agriculture.

Keywords: water quality; land use/cover; Liao River; physical-chemical feature

1. Introduction

In recent years, researches on ecological impacts of land use changes are being strengthened. Studies on ecological effects incurred by land use changes have turned into a prominent subject. With challenges

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of water resources grown into a main constraint for national and regional socio-economic development, impacts of land use changes on water quality, water quantity, and sustainability of water resources have become an important subject of the research [1,2]. Previous researches mainly focus on water quality variables such as dissolved salt, suspended solid particles, and nutrient salt [3-9]. The main conclusion is that with increase of agricultural land, nutrient elements such as nitrogen, phosphorous and suspended particles were washed into the river, causing water pollution and eutrophication. Urban land use changes also significantly affects dissolved salt in the river.

Basin is an integrated body of natural space that encompasses correlation of water, its natural features, along with related movement of elements connected with water resources utilization. Basin is thus the best unit for water related research at the regional scale. Features of water chemistry within a basin scaled water ecology system are subjective to changes of human and natural factors [10,11]. Accordingly, its impacts dynamics on hydrological chemistry are also different. Basin features, including topography and surface geology, could also affect surface water quality [5]. Research of land use changes on water quality first divides the Liao river basin into several sub-basins with the utilization of GIS. By applying SPSS 18.0 software, regression analysis is applied to various sub-basins, investigating related water quality index and land use index.

2. Research area

The Liao River basin is located in northern part of China, covering Jilin, Liaoning, Hebei provinces, and Inner Mongolia Autonomous region (Figure 2). In total, it covers four provinces, 16 municipalities and 65 counties. Geographic scope of the basin is ranged from 116.3 to 125.47 latitude and 39.43 to 45 altitude from south to the north. The basin borders Songhuajiang river basin in the north, and connects the Bohai harbor to the south. The basin covers an area of 21.9×10^4 km^2, with the length of 706 km from south to north, and width of 490 km from east to west. The basin is covered under the temperate and warm temperate belt, subjective to the monsoon climate. Multi-year average temperature in the Liao river basin is ranged between 4 to 9 Celsius with the highest temperature shown in July averaged between 20 to 30 Celsius. The lowest temperature appeared in January with an average between minus 10 to minus 18. Multi year average precipitation amount in the Liao basin is ranged between 350 to 1000 mm, concentrating from June to September. Precipitation runoff in this period counts for more than 70% of annual precipitation amount. Amount of precipitation is reduced from east to west in the basin. The Liao river basin is composed of two independent river systems, one is the East Liao river and West Liao river, both of which merge at the Fude Dian gauge, contributing to mainstream of the Liao River. There is 415.4km total length for this part of the basin. Plus, the Liao river flows into the Bohai sea, 94 Km south to the Fude Dian gauge. In recent years, the West Liao River suffers from continuous droughts, many rivers dried up, certain parts of the river dried up for more than ten years. Based on calculation of data obtained at the river mouth gauge from 1956 to 1979, multi-year average runoff in the Liao river is 126×10^8 m^3, multi-year average stream flow is 400 m^3/s, multi-year average amount of sediment transportation is 2098×10^4 t, height difference along the mainstream is 1200m.

There is 4.95×10^4 km^2 agricultural land in the Liao river basin, mainly allocated in the mid and downstream areas (2.27×10^4 km^2). Among the land, 5.49×10^3 km^2 is paddy fields, concentrating in the downstream of Liao river and East Liao river. There is 5.45×103 km2 water irrigated land, 8.29×10^4 km^2 grassland and 4.29×10^4 km^2 forestry land. Annual food production in the basin is 1.695×10^7 t. Major population is allocated in towns and cities located in this area. By 2005, there is total population of 3500×10^4 in the basin with GDP production of 6,000 billion Yuan. Per capita GDP level in the basin is higher than the national average level.

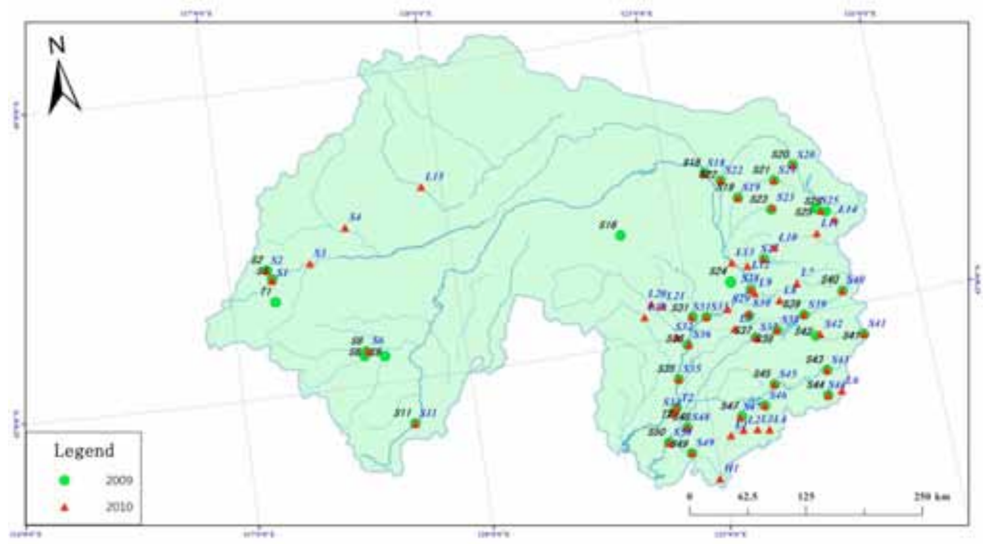

Fig. 1. The location of sampling sites and river network in the Liao River basin

3. Data source and methodology

3.1. Water quality sampling

In both August 2009 and June 2010, chemical and physical features of water environment, along with aquatic species in the Liao river basin are tested based on 80 sampling stations. As mainstream of the river in Inner Mongolia are within an interrupted status for long time, actual water sample stations were 42 in 2009 and 58 in 2010. In total, principles of allocating the stations are to select 1 to 2 representative stations for each tributaries and mainstream. Distance between sampling stations along the mainstream is 30km.

Portable multi-function water quality testing appliance, such as Ph-B-1 acidity testing appliance and YSI-85-25 testing appliance, is applied to measure on site value of pH, water temperature, dissolved oxygen. In accordance to the national standard on land surface and water environment quality (GHZBI-121999), parameters such as solidity, NO_2^-N, NH_4^+-N, NO_3^-N, TN, TP, PO_4^{3-}, DO, $COD_{Mn,}$are measured. Orientation and altitude were also measured on site with GPS tools.

3.2. Land use/cover analysis

The 2007 Landsat TM 15 image was selected as reference for remote sensing. Based on the requests of National Guideline for Land Use Status Investigation, six category I land use types were identified, including agricultural land, forestry land, grassland, water body, urban-rural residential land, and bare land. Allocation of the land use types is shown in the figure below.

Fig. 2. Land use/cover in the Liao River basin in 2007

3.3. Statistical analysis

Based on the area of the Liao River basin, the basin was divided into one hundred and two sub-basins. Considering positions of sampling stations at respective sub-basins, as well as area of the basin, 24 sub-basins including all sampling stations was selected to analyze land use/cover pattern and water quality. Among the sub-basins, calculation on water quality is based on average value of all sampled sub-basins.

SPSS18.0 software was utilized to cluster analyze water quality data collected at all sampling stations. Regression analysis is also applied in various sub-basins to identify correlation between water quality and land use patterns. This has resulted in Spearman correlation index and regression formula. Dual variable analysis approach is applied in analyzing Spearman correlation index, when analyzing statistics results of Spearman correlation index, accompaniment rate reaches $p \leq 0.05$, this has shown statistics relevance.

4. Result analysis

4.1. Distribution of land use/cover pattern

In the analyzed 24 sub-basins (as is shown in figure 4), forestry, agricultural land and water body are the main landscape types. Percentage of forestry land is ranged from 13.95% (upstream of Taizi river) to 82.07% (downstream of Liao river), concentrating on mid and downstream areas of the Taizi river, upstream area of the Laoha river, mid and downstream areas of the east Liao river, and downstream area of the West Liao river. Water body is another major landscape type. It is ranged from 84.15% (upstream of the Taizi river) to 0.58% (downstream of the Taizi river), concentrating on upstream areas of the Taizi river, Xila'Mulun river, and Hun river. Among the 24 sub-basins where sampling stations are setup, there are half sub-basins with 50% or higher forestry land, and 10 with water area more than 50%. Within the Liao river basin, grassland area is smaller with the largest shown in upstream areas of Xila'Mulun River, counting for 16.76%. Area of agricultural land is ranged from 17.48% (upstream of Xila'Mulun River) to

0.33% (area of the Xi River). Rural and urban residential land is ranged from 5.79% (downstream area of the Liao River) to 0.47% (Haicheng River). Area of unutilized land counts for 1.61%, which is located in the Yingjin River. Most of the sub-basins are utilized by 100%.

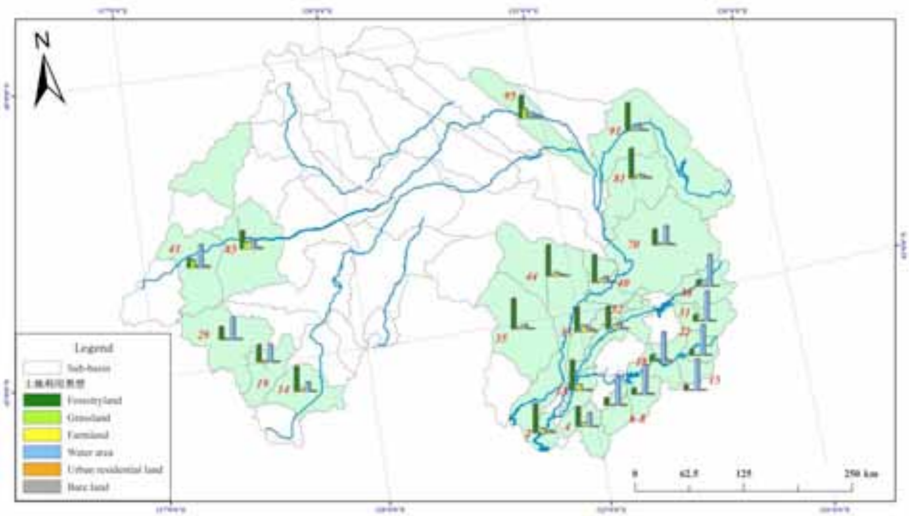

Fig. 3. The Composition of land use/cover in the Liao River basin

4.2. Physical and chemical indicators of water quality

The Liao river basin consists with the following tributaries including East Liao River, West Liao River, Taizi River, Hun River, Xila'Mulun River, Laoha River and mainstream of the Liao River. Spatial distribution of water quality was investigated in this paper.

Cluster analysis was applied to 58 water quality indicators including Dissolved Oxygen, COD, total phosphorous, total NOx, geographic location and habitat evaluation (figure 5). From figure 5, it can be seen that the entire Liao river basin is classified based on geographic locations. Taizi River and Hun River are located in the southeast of the basin. Physical and chemical features of the two rivers are quite similar as geographic distance between them is small. As a result, general water quality of the two rivers is bad. Water quality is better in the upstream of the rivers, and the quality at some parts is category III. Due to industrial pollution, water quality in mid and downstream of the rivers is worse, and mostly are worse V category. Xila'Mulun and Laoha River are located in the northwest part of the Liao river basin. This area is severely short of water. At some sections, river drying up lasted for more than six years. Due to smaller geographic distance between the two rivers, physical and chemical features of the two rivers are similar. Water quality of these two rivers are at the above section of figure 5. Total water quality in these two rivers is evaluated as IV and V category. Water quality is generally worse in these two rivers. Most parts of the west Liao river are dried up. Samples collected from its downstream areas can be classified as the same category with Liao river basin area. Water quantity is rich in mainstream part of the Liao river. The mainstream part is located in the mid and east of the Liao River basin. This area is classified in the lower part of figure 5. Most of the physical and chemical indicators of the mainstream area are at worse V category with serious water pollution. There are large number of mining plant, sand plant, petroleum refinery, brick factories located along the mainstream, resulting in industrial wastewater discharge.

Industrial wastewater has polluted water quality and left sulfurized elements at the riverbed, which brings down further water quality.

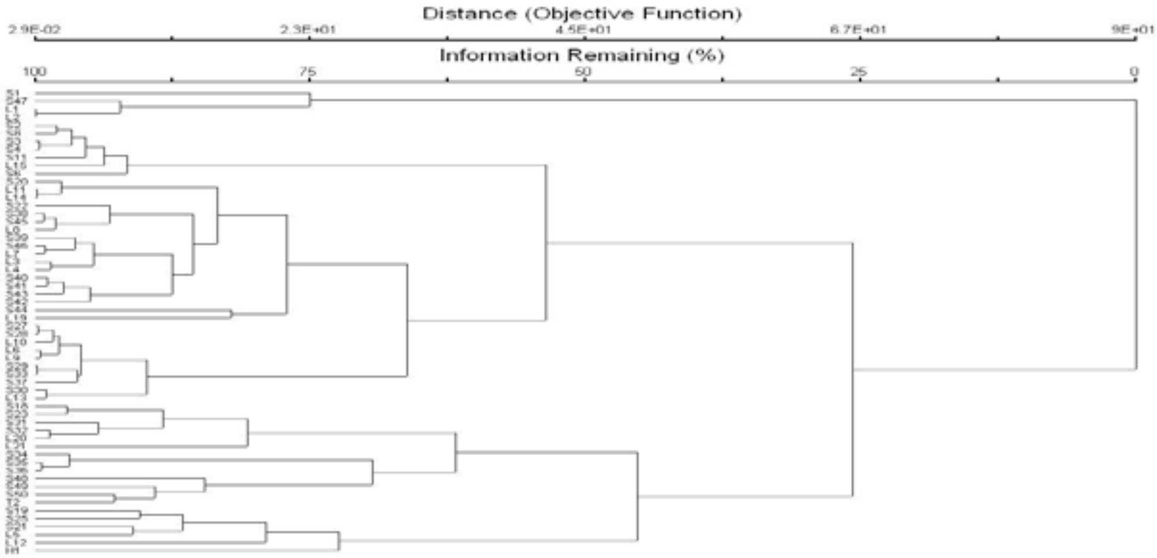

Fig. 4. Classification of physical and chemical indictors in the Liao River basin

Generally speaking, source area of the Liao river basin is least polluted. Water quality is the best in this area. Nevertheless, the mid and downstream areas of the basin suffer from severe water pollution and worse water quality. As the Liao River basin is a major industrial base of the Liaoning province, COD and NH_4^+-N are two main pollutants in the basin. They are also the main chemicals under control. River pollution study in the region has important pratical significance.

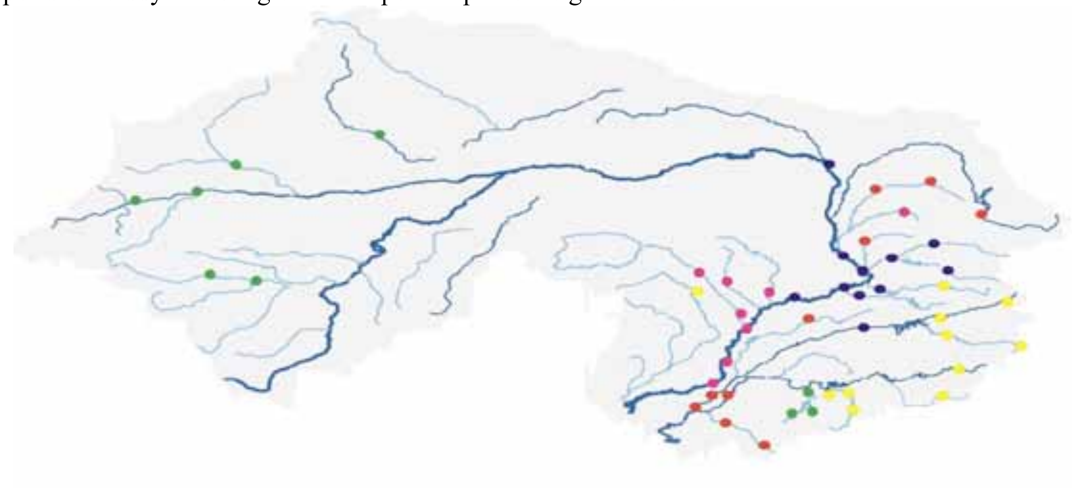

Fig. 5. Classification of physical and chemical indictors in the Liao River basin

From figure 5, it can be seen that distribution of physical and chemical indicators of water quality can be divided into five major zones, which is upstream area of the Liao river basin, downstream area of the Liao river basin, Taizi and Hun river basin area, downstream of Taizi river, along with Xila'Mulun and Laoha river area.

4.3. Relations between water quality and land use types

The regression and correlation analysis between water quality and land use patterns shows that forestry land percentage is closely related with BOD5, COD, sediment amount, habitat evaluation, electricity conductivity, hardness ($p<0.01$), forestry is related with total dissolved particle($p<0.05$) , and forestry land percentage is negatively related with habitat evaluation and sediment amount; grass percentage is positively related with sand amount($p<0.05$); agriculture land percentage is closely related with BOD5, COD, sediment amount, habitat evaluation, electricity conductivity, total nitrogen hardness ($p<0.01$), agriculture land percentage is related with NO3-N、NO2-N、NH3-N($p<0.05$), and agriculture land percentage is negatively related with NO3-N and habitat evaluation; water body percentage is closely related with BOD5, COD, sediment amount, habitat status, electricity conductivity ($p<0.01$), water body percentage is related with hardness and total dissolved particle($p<0.05$), and water body percentage is positively related with habitat evaluation. Multiple regression analysis showed BOD_5、COD、electricity conductivity and hardness may be respectively expressed with agriculture land percentage、forestry land percentage、water body percentage、agriculture land percentage, sand amount、habitat evaluation、NO_3-N、 total dissolved particle can be expressed by multiple land use/cover; sand amount can be expressed with grass land and agriculture land percentage; habitat evaluation can be expressed with water body land 、grass land 、urban land and bare land percentage; NO_3-N can be expressed with grass and agriculture land percentage; total dissolved particle can be water body and agriculture land percentage.

Table 1. Pearson correlation coefficient between LUCC and water quality parameters in the Liao River basin

Physico-chemicals	forestry	grass	agriculture	Water body	Urban land	Bare land
T	-0.025	-0.150	0.213	0.005	0.248	-0.308
BOD_5	0.733[b]	0.096	0.726[b]	-0.714[b]	0.079	0.050
COD	0.836[b]	0.279	0.698[b]	-0.841[b]	0.186	0.198
Sediment	-0.745[b]	-0.468[a]	0.653[b]	-0.796[b]	0.254	-0.156
Habitat	-0.667[b]	-0.412	-0.581[b]	0.714[b]	0.075	-0.210
EC	0.804[b]	0.344	0.659[b]	-0.819[b]	0.237	0.021
TP	0.141	-0.118	0.253	-0.109	-0.383	-0.143
TN	0.471[a]	-0.361	0.605[b]	-0.384	-0.016	-0.101
Hardness	0.602[b]	-0.215	0.581[b]	-0.533[a]	0.164	0.206
pH	0.367	0.330	0.340	-0.397	-0.022	-0.003
TSM	0.093	-0.018	0.241	-0.092	-0.388	0.037
NO_2-N	0.293	-0.214	0.465[a]	-0.270	0.192	-0.098
NO_3-N	-0.327	0.648[b]	-0.500[a]	0.211	-0.062	0.264
NH_3-N	0.341	-0.091	0.472[a]	-0.309	-0.259	-0.115
PO_4-3	0.142	-0.092	-0.309	-0.126	-0.344	-0.065
TDP	0.552[a]	0.390	0.260	-0.567[a]	0.245	0.134

a. Correlation is significant at the 0.05 level (2-tailed).

b. Correlation is significant at the 0.01 level (2-tailed).

Table 2. Linear regression models for physic-chemicals and LUCC in the Liao River basin

Physico-chemicals	Independent variables	Regression equations	R^2	Adjusted R^2	P
BOD_5	Agriculture	0.226agriculture+3.031	0.423	0.397	0.001
COD	forest	0.267forest+2.350	0.663b	0.439	0.000
Sediment	Grass agriculture	-0.027grass+0.032agriculture+0.101	0.548b	0.505b	0.004
Habitat	Water urban bareland grass	0.470water-0.627grass-14.221bareland+6.945water -260.361	0.798a	0.755a	0.049
EC	Wate	-5.501water+680.887	0.455b	0.430b	0.000
Hardness	Agriculture	0.122agriculture+2.633	0.309b	0.277b	0.005
NO_3-N	Grass agriculture	0.016grass-0.016agriculture+0.364	0.560b	0.518b	0.003
TDP	Water agriculture	-4.515water-22.793agriculture+528.225	0.531b	0.478b	0.006

5. Discussions

Based on the investigation in 2005, it showed that Phosphorous is the major pollutant in the Liao River basin, with concentration amount from 0.21 to 6.98 mg/L. Such concentration has exceeded criteria of category III water quality by 33.9 times. The second major pollutant is COD with concentration amount of 21.5-402mg/L. The third is suspended particles with concentration amount of 82-6040 mg/L. This study shows that concentration amount of Phosphors in the Liao river basin is 0.0001-3.2541mg/L, and is not any more the major pollutant. COD has become the major pollutant with concentration amount reached 2.01-61.3781mg/L. This indicates that, even COD amount is decreasing at the basin scale, it remains at a higher level.

BOD_5 and COD concentration is higher in cities such as Anshan, Liaoyang, Fushun and Shenyang. These areas are industrial base. Fast industrialization has resulted discharge of large amount organic pollutants into the river, severely affecting water quality. In the basin of Taizi river, where cities such as Benxi, Anshan and Liaoyang, chifeng, siping are located, in which urban land percentange are more, concentration of TN、NH_4^+-N、NO_3^--N、NO_2^--N、TP is also high. which has resulted in increased discharge of nutrient element and suspended particles into river runoff, leading to water pollution such as eutrophication.

There are already researches indicating that total amount of nitrogen and phosphor is the highest in forestry areas which were followed by agricultural land and urbanized land [12-13]. Urbanization has led to the increase of nitrate particles. This research is conducted at the basin scale to analyze relations between land use patterns and physical and chemical features of water body. The research shows that, concentration of BOD_5, COD, EC (Electricity Conductivity) and hardness were varied in different sub-basins. Amount of such chemicals is positively related to area of forestry and agricultural lands, which means their amount shall increase when forestry and agricultural lands increase. Nevertheless, amount of the variables is negatively related to area of water body, which means concentration shall decrease when the area of water body increases. Amount of sedimentation contained is positively related with area of agricultural land, but negatively related with area of forestry, agricultural and water areas. Status of river habitat is negatively related with both agricultural and forestry lands, but positively related with area of water body. This means status of habitat shall improve when area of agricultural and forestry lands increase. Total nitrogen concentration is positively related with area of forestry and agricultural lands. Nitrate concentration is positively related with area of grasslands but negatively related with agricultural lands. This means nitrate amount shall increase with grassland areas but decrease with increase of agricultural land. Amount of total dissolved particles is also positively related with area of forestry land but negatively related with area of water body. This means total amount of suspended particles shall increase with increase of forestry land but decrease with increase of water body. Amount of NH_4^+ is positively related with area of agricultural land, and shall increase when agricultural land increase.

In multi-variable regression equations, there is high correlation reflected between BOD_5, COD, and forestry, agricultural lands. This demonstrates these two land cover types are major source of organic pollutants. Similar strong correlations are found between nitrate, sediment and grass land, agricultural land, these reflected these two types of land cover are major sources of water-borne nitrate and sedimentation. EC can be expressed with ratio of water body, which shows area of water body has direct link with concentration of EC. Status of water habitat is strongly related with the ratio of water body, urbanized lands, unutilized lands and grasslands, which shows the four types of land covers are main affecting sources to habitat status. It was also found in the regression model that hardness is largely correlated with ratio of agricultural lands, water areas. Moreover, ratio of water area and agricultural lands is the main affecting source to Total Dissolved Particles (TDP). Contribution of agricultural land to the concentration of TDP is the highest.

At different scales of rivers, relation between water quality and land use types could be different [14-15]. At different timing scales, varied water quality could increase uncertainties of the correlation. However, through analysis of correlation between water quality variables and different land use patterns, various land use types that could affect water quality can be identified. What can also be reached are land use types, as source of water pollution at various time and spatial scales. The correlations identified shall be useful for the planning and construction of water protection projects and wastewater treatment plants, along with ecological restoration works. Water quality changes in the river are quite a complex process. In addition to land use changes, amount of runoff along with agricultural and industrial pollution sources on both banks of the river are important factors affecting water quality at the basin scale. This research is expected to investigate correlation between land use types and water quality at the basin scale, from a quantitative perspective.

6. conclusions

- First point Water physical and chemical features in the Liao River basin demonstrate strong geographic zoning features. Upstream areas of the Taizi and Hun rivers receive least water pollution, but their mid and downstream areas are polluted. Water in downstream areas of the two rivers are mostly within the worse V category. General water quality in the Xila'Mulun and Laha rivers is ranged from IV to V category. Water quality is bad in these rivers. Water quality in the East Liao River is dearth of rhythm, but most water in this river is below category III. West Liao River is largely dried out, and water collected at sampling stations along the West Liao River is IV category. Water quality in mainstream area of the Liao River is V category.
- Second point Regression and correlation analysis shows that agricultural and forestry lands in the Liao River basin are directly linked with pollutants concentration, particularly BOD_5, COD, sediment amount, hardness, nitrate, TDP
- Third point This research is financed by the Major Special Science and Technology Projects on Water Pollution Control and Management (2008ZX07526-001-001). The authors appreciate the tutor and classmate for analyzing the water quality data.

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References

[1] Fu BJ, Chen LD, Wang J, Meng QH, Zhao WW. Land Use Structure and Ecological Processes. *Quaternary Sciences* 2003;**23**:247-55 (in Chinese).

[2] Yu XX, Yang GS, Wang Y. Advances in Researches on Environmental Effects of Land Use/Cover Change. *Scientia Geographica Sinica* 2004;**24**:627-33 (in Chinese).

[3] Hill AR. Stream phosphorus exports fromwatersheds with contrasting land uses in southern Ontario. *Water Resources Bulletin* 1981;**17**:627-34.

[4] Allan JD, Erickson DL, Fay J. The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology* 1997;**37**:149-61.

[5] Johnson LB, Richards C, Host GE, Arthur JW. Landscape influences on water chemistry in Midwestern stream ecosystems. *Freshwater Biology* 1997;**37**:193-208.

[6] Osborne LL, Wiley MJ. Empirical relationships between land-use cover and stream water-quality in an agricultural watershed. *Journal of Environmental Management* 1988;**26**:9-27.

[7] Smart RP, Soulsby C, Neal C, Wade A, Cresser MS, Billett MF, et al. Factors regulating the spatial and temporal distribution of solute concentrations in a major river system in NE Scotland. *The Science of the Total Environment*, 1998;**221**:93-110.

[8] Hu JL, Liu GC, Cai QH, Hu ZHY. Investigation on the Phytoplankton of Spring from Three gorges Reservoir in Chongqing. *Acta Hydrobiologica Sinica* 2006;**30**:116-9 (in Chinese).

[9] Sliva L, Williams DD. Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Research* 2001;**35**:3462-72.

[10] Ahearn DS, Sheibley RS, Dahlgren RA, Anderson M, Jonson J, Tate KW. Land use and land cover influence on water quality in the last free-flowing riverdraining the western Sierra Nevada, California. *Journal of Hydrology* 2005;**313**:234-47.

[11] Sliva L, Williams DD. Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Research* 2001;**35**:3462-72.

[12] Ngoye E, Machiwa JF. The influence of land use patterns in the Ruvu river watershed on water quality in the river system. *Physics and Chemistry of the Earth* 2004;**29**:1161-6.

[13] Turner RE, Rabalais N. Linking landscape and water quality in the Mississippi River Basin for 200 years. *Bioscience* 2003;**53**:563-72.

[14] Tian YM, Li X. Review of Researches on Environmental Effects of Land Use/Cover Change. *Environmental Science and Management* 2006;**31**:60-4.

[15] Zhao MJ, Xu T. Research on the Environmental Impacts of Land Use and Land Cover Change. *Research of Soil and Water Conservation* 2005;**12**:43-6 (in Chinese).