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The Potential of Integrating Landscape, Geochemical and Economical Indices to Analyze Watershed Ecological Environment

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Abstract:

A river watershed is a complicated ecosystem, and its spatial structure and temporal dynamics are driven by various natural factors such as soil properties and topographic features, human activities, and their interactions. Thus, characterizing the river watershed ecosystem and monitoring its dynamics is very challenging. In this study, we explored the characteristics of the ecosystem and environment of Yalong River watershed in Ganzi Tibetan Autonomous Prefecture, Sichuan Province of China by analyzing and modeling the relationships among economic indices, heavy metal elements and landscape metrics. Landsat 8 data were used to generate a land cover classification map and to derive landscape pattern indices. Governmental finance statistics yearbook data were referred to provide economic indices. Moreover, a total of 9 water samples were collected from the upstream to the downstream to obtain the values of heavy metal concentrations in the water body. Then, both correlation and regression analyses were applied to analyze and model the relationships among these indices. The results of this study showed that 1) The ecological status and process of this river watershed could be explained by analyzing the relationships among the economic indices, heavy metal elements and landscape pattern indices selected based on correlation analysis; 2) Compared with the economic indices, the accumulated economic indices were more significantly correlated with most of the heavy metal elements and should be applied for the integrated assessment of the watershed ecological environment; 3) Landscape pattern indices SHDI and IJI had strong correlations with the important economic indices Population and Population Density and could be used for the integrated assessment of the watershed characteristics; 4) Compared with land cover area, land cover area ratios were more sensitive to the variation of the economic indices. The dominated land cover types Forest and Grassland had strong relationships with the economic indices; and 5) Cu and Zn had significant correlations with the landscape pattern indices. This study implied that analyzing and modeling the relationships among the economic indices, heavy metal elements and landscape pattern indices can provide a powerful tool for characterizing the ecosystem of the river watershed and useful guidelines for the watershed management and sustainable development.

Keywords: Watershed; Geochemistry; Landscape; economic indices; remote sensing; Statistical analysis.

1. Introduction

The challenge of balancing human needs for water with environmental sustainability has come to a head in river systems, where various management plans to conserve and manage the ecosystems have been thrown into a turmoil (Pincock 2010). River ecosystems are mainly influenced by integrated biological, chemical and physical subsystems, which increases uncertainty in ecological assessments, and hampers prediction for the ecological environment changes (Wiley et al. 2010). An in-depth understanding of ecological status and process in river systems is very important for river conservation and management (Wang and Yang 2014). Stream flow and water quality of a river are affected by both natural and anthropogenic factors that exist within a watershed, hence the watershed has been recognized as an appropriate analysis unit for addressing the challenges of water management (Singh et al. 2014; Deng et al. 2014).

There is an urgent demand for sustaining or improving the functions of watersheds to strengthen their roles in supporting human and meeting ecosystem needs simultaneously, because watersheds provide economic goods and ecological services that impact the livelihoods of people (Ingram et al. 2012). Benefiting the economy, community and environment synchronously would realize the sustainable development of a watershed. To achieve this goal, a proactive approach that combines information of economic, social and ecological influence is needed (Randhir and Shriver 2009; Kantamaneni 2016). Thus, the opportunity for sustaining human and their river systems can be enhanced by examining how socioeconomic and ecological processes are integrated at the watershed level (Wolters and Kuenzer 2015; Naiman 1992).

Human activity induced disturbances are one of the most important factors that generate potentially permanent changes to the ecological structure and functions of watersheds (Wang et al. 2015). The pattern and process of land use (or land cover) is one typical manifestation of the interaction between human activities and ecological processes observed in a region (Naiman 1992). Both the extent and depth of transformation are determined by regional land use patterns and processes (Kabat et al. 2004). Understanding how human depends on landscape functions and products, and how land use affects ecological and socioeconomic processes can provide a sound basis for guiding sustainable development of a watershed (Naveh and Lieberman 1984; Zonneveld and Forman 1990).

Landscape ecology is a subsidiary discipline of modern ecology, which deals with the interrelationship between human and landscapes that they live on (Naveh and Lieberman 1990). Landscape ecology focuses on the interactions between landscape patterns and ecological processes, and exploring the impacts of land use patterns on water quality and the spatial scales over which these effects are manifest has become a significant theme of landscape ecological studies (Turner et al. 2001). Digitized land use data stored in a Geographical Information System (GIS) are always used to conduct the analysis of landscape patterns, especially, landscape-level ecosystem status can be credibly estimated through landscape measurements based on land use data obtained from remote sensing imagery (Johnson and Patil 2006). However, as the landscape patterns and ecological processes interact in diverse ways, neither of them can be ignored to grasp the synthetical dynamics of the environment (Fu and Jones 2013). Although various factors including social, economic, and ecological considerations that interactively determine landscape patterns are known abstractly, the quantitative interrelationships among these variables are inadequately recognized. Furthermore, it is difficult to describe the behaviors of a landscape scaling up from ecological systems to communities, thus in-depth exploration of the relationships between landscape patterns and ecological processes is necessary. Because a landscape presents macroscopic and vast scale characters, which cannot be described and studied at a microscopic level, the landscape and geochemistry interaction will be a crucial challenge for studying on the ecological environment assessment in the coming decades. For example, many recent studies have focused on the influence of land use patterns in watersheds on water quality and biological communities in streams (Vrebos et al. 2017; Vaighan et al. 2017; Dzinomwa and Ndagurwa 2017).

Geochemistry is the study of the distribution and migration of elements in the environment where we live in, aiming at exploring the distribution of elements in the earth and interpreting the processes that induce these distribution patterns based on techniques and principles of chemistry and physics (Wainerdi and Uken 1971). Hydro-geochemical investigations of surface water can provide information on the extent and degree of element impacts so as to estimate the level of pollution and identify principal pollutants in surface water (Quercia and Vidojevic 2012). Hydro-geochemical speciation methods can offer a more realistic and reliable measure to identify the degree of migrated water contamination, because they provide fundamental ideas for better understanding of water features and they have a sophisticated and meticulous methodology (Moldan 1992; Reuther 1996). However, the transportation of particulate and dissolved materials in river systems is a complicated action of different biological, chemical and physical processes occurring in the watersheds and in the water (Hedges et al. 1986). Hence, available information on trace elements, including heavy metals in water, is generally inadequate for regional studies of the ecological environment, and little systematic information on the spatial relationships between geochemistry and ecology of water is available (Bowie and Thornton 1985). Thus, a fundamental question concerns whether we can detect, describe and predict the ecological effects at the geochemical level has been proposed (Reuther et al. 1996). Then, applying landscape and geochemistry integrated methods to analyze the ecological environment of a watershed has its theoretical basis and practical need. Furthermore, socioeconomic and ecological processes need to be combined to obtain a sustainable development of a watershed at the landscape level, on which all kinds of analyses utilize land cover types as the basic unit of calculation.

First of all, landscape pattern indices, characterizing diversified aspects of composition, structure and spatial configuration of landscapes, were introduced to quantitatively describe the correlations between spatial patterns and ecological processes (O'Neill et al. 1988; Remmel and Csillag 2003). One of the most fascinating features of landscape pattern indices is the simplicity: large amount of data can be summarized by a single number (or by a limited set of numbers) without a priori knowledge about the processes and organisms of landscapes (Fortin et al. 2003). Besides, heavy metals are especially dangerous elements and expose potential ecological risks to living organisms, on account of their bioaccumulation, non-degradability and toxicity features (Cai et al. 2015). Heavy metal contamination in aquatic ecosystems is frequently surveyed by evaluating concentrations in sediments, biota and water (Rahman et al. 2014), in which variations of the heavy metal distributions can provide direct information for evaluating the status of pollution and baseline data to help further develop an efficient strategy on their controls (Dong et al. 2015; Yeh et al. 1977). Apart from that, economic indices provide supplementary information on the strength of human activities that give rise to the production of pollutants (Zhou et al. 2012). For example, the Gross Domestic Product (GDP) is commonly used as an index for evaluating the economic health and measuring the living standard of a country. Because the sustainable development of watersheds requires an integration of hydrologic, ecological and socio-economic aspects, relationships among these indices or indicators involving landscape pattern, geochemistry and economy need to be explored to gain an in-depth understanding of ecological processes and properties in a watershed.

The main goals of this study are to: (a) analyze whether and how the relationships among these indices including landscape pattern, geochemistry and economy can be found, and (b) explore the potential of analyzing the ecological environment of a watershed based on a landscape, geochemistry and economy integrated view.

2. Materials and Methods

2.1 Study area and sampling

The study area was Yalong River watershed, within Ganzi Tibetan Autonomous Prefecture, Sichuan Province (Fig. 1). The study area has a total area of 70,366 km^2, and 3/5th of the Yalong River's full length is distributed in the study area. This region is located in the upstream section of the Yalong River, which has an important influence on the water quality and ecological environment. Covering a total of six counties including Shiqu, Dege, Ganzi, Xinlong, Litang and Yajiang in the administrative regions of Ganzi, most of the area is mountainous with steep terrain. In Shiqu County located in the upstream of the basin, the average elevation is 4526.9 m, the average annual temperature is below -1.6 ℃, and the average annual precipitation is 569.6 mm. However, in Yajiang County located in the downstream of the basin, the lowest elevation is 2266 m, the average annual temperature is below 11 ℃, and the average annual rainfall is 650 mm. The regional vertical variations of temperature, precipitation, and vegetation are obvious with the terrain height changes (Shen et al. 2010; 2012).

In total, 9 water samples were collected in the study area in 2014 (Fig. 1). The sampling locations were steadily scattered in the study area from its upstream to downstream to survey heavy metal concentration characteristics in the water body. A hand-held global positioning system (GPS) receiver was used to record the exact locations of the samples for further being imported into ArcGIS. In order to perform the parametric statistical analysis, 30 observation points were obtained through the interpolation of 9 water samples. Furthermore, an identify function of ArcGIS was used to acquire the data of landscape pattern and economy indices for statistical analysis based on the 30 observation points.

2.2 Measuring landscape pattern metrics

2.2.1 Source of data

This study collected and used six multi-spectral bands (band 2-blue, band 3-green, band 4-red, band 5-near infrared, band 6-shortwave channel 1, and band 7-shortwave channel 2) of Landsat 8 images at the spatial resolution of 30 m × 30 m to classifying land cover types of this study area and obtain land cover maps. A total of nine cloud-free leave-on and leave-off images dated from May of 2013 to Jan. of 2014 were acquired by downloading from the website supported by USGS (United States Geological Survey). The radiometric correction and geometric correction of the images were first conducted and then were clipped according to the boundary of the study area with ENVI software.

2.2.2 Land cover classification

The establishment of a scientific land cover classification system according to the regional condition is the primary work needed to obtain the regional landscape data (Anderson et al. 1976; Li and Ma 2000; Bazi and Melgani 2006). Reference for the classification system was made to the land use and land cover classification system for remote sensing data from USGS, the national land classification (For Transition Period) from Ministry of Land and Resources of P. R. China, as well as the regional condition of land cover in the Yalong River watershed, and the requirements for further study. The regional landscape was classified into: forest, river, grassland, lake, marsh land, bare soil, farm land, human habitation, industrial land, glacial and snow, and transportation land.

Based on the Yalong River watershed land cover classification system, a strict description for each type of land cover class was obtained. An object-oriented classification method was applied to extract the land cover information of the study area. Unlike the traditional classification methods that analyze spectral information of land cover types, the object-oriented classification method accounts for the spatial characteristics such as shape and compactness of objects and the relationships between the objects (Sapozhnikova et al. 2006; Kassouk et al. 2014). This method first carried out multi-scale image segmentation, that is, classified the pixels into homogeneous polygons (objects) based on their similarity measured using variances of pixel values, and shape, smoothness and compactness of objects. The classification of land cover types was then conducted using decision tree and nearest neighbor. In order to improve the accuracy of the classification, expert knowledge was applied to conduct the verification and interpretation.

2.2.3 Obtaining land cover map

Based on the above methods, this study obtained the land cover map of the Yalong River watershed (Fig. 2). In accordance with the statistics of the classification results, the areas and proportions of the land cover types of the landscape were obtained, as shown in the Table 1. The statistics showed that the grassland and forest were the major land cover types with their area accounting for 89% of the entire watershed. As shown in Fig. 2, the land cover map of the Yalong River was smooth and compact due to the segmentation of the objects, without the traditional 'salt and pepper' phenomenon formed by isolated pixels. Also, the segments contained information such as shapes, veins, space, and so on, which could be comprehensively utilized in the process of the classification.

In this study, a 30 m spatial resolution image was used in the classification. To ensure the results of the classification accuracy assessment were objective, the samples used for the accuracy assessment were selected from the 1 m spatial resolution image provided by Google Earth. A total of 450 samples were obtained by a simple random sampling method, and these samples were used to calculate the confusion matrix (Foody 2002). The overall accuracy of the classification was 87.11%, and the Kappa coefficient was 0.855. Therefore, the high accuracy could fully meet the demand of this study.

2.2.4 Computing landscape pattern metrics

Landscape pattern indices are easy to understand due to their ecological meanings. The indices also contain certain statistic characteristics and are easily used to analyze and compare the sizes of different patches, and provide important information of landscape patterns, structures and spatial composition to explain the functions of landscapes. Landscape pattern indices have been widely used to describe landscape patterns and changes, and to set up the contact between the patterns and landscape processes (Turner et al. 2001).

Considering the aims of this study and the features of every landscape pattern index, the follow indices were chosen as the indicators to quantify the ecological features: Total Area (TA) represents the area of each landscape type; Total Edge (TE) equals to the sum of the edge lengths of all the segments involved in a corresponding patch type; Edge Density (ED) means the sum of the edge lengths of all segments involving a corresponding patch type and divided by the total landscape area; Contagion (CONTAG) is the negative sum of the proportional abundance of each patch type and multiplied by the proportion of the adjacencies between the cells of this patch type and another patch type; Percentage of Like Adjacencies (PLADJ) is computed as the sum of the diagonal elements of the adjacency matrix and divided by the total number of adjacencies; Interspersion & Juxtaposition Index (IJI) considers all the patch types present on an image to analyze the amount of patch adjacency or fragmentation; Patch Cohesion Index (COHESION) is computed from the information contained in the patch area and the perimeter; Landscape Division Index (DIVISION) is defined as the probability that two animals placed within different areas somewhere in the region of the investigation might find each other; Effective Mesh Size (MESH) simply denotes the size of the patches when the landscape is divided into S areas, with the same degree of landscape division as obtained for the observed cumulative area distribution; Splitting Index (SPLIT) is defined as the number of patches obtained when the total landscape is divided into the patches of equal size, in such a way that this new configuration leads to the same degree of landscape division as obtained for the observed cumulative area distribution; Shannon's Diversity Index (SHDI) is the representative of diversity of a landscape; Number of Patches (NP) reflects the number of all the landscape patch types; Patch Density (PD) measures the heterogeneity of the landscape; Largest Patch Index (LPI) indicates the influencing extent of the largest plaque for the entire landscape; Landscape Shape Index (LSI) reflects the divergence of the shape of landscape patches from the ideal circle; and Aggregation Index (AI) means the percentage of like adjacencies between cells of same patch type (McGarigal et al. 2012).

2.3 Measuring chemical concentration

The chemical parameters (Al, Fe, Cr, Ni, Cu, Zn, Cd, Pb) were measured according to the industry standard (DZ/T0064-93) (Figs. 3-6), conducted by Ministry of Geology and Mineral Resources of P. R. China. All these elements were measured with a method of ICP-MS (Inductively Coupled Plasma Mass Spectrometry). The results are listed in Table 3.

2.4 Measuring economic variables

The GDP and Population are commonly used as the indicators for measuring the economic health and living standard in a country. In addition to these two indices, other indices are also used to observe the effects of human disturbances on water quality. Data pertaining to spatial distribution of economic indices (Population, Accumulated Population, Population Density, Accumulated Population Density, GDP, Accumulated GDP, Per Capita GDP, Accumulated Per Capita GDP, Gross Output Value of Agriculture, and Accumulated Gross Output Value of Agriculture) were generated through the spatial analysis methods, to identify the relationships between economic indicators and other indices (Table 2). As examples, Fig.7 and Fig. 8 respectively showed the spatial distributions of GDP and its accumulation values. The accumulated indicators were calculated by summing the local values of the corresponding indicator along the river from the upper reach and implied the impacts of accumulated values.

2.5 Statistical analysis

The relationships between ecological, hydrologic and socio-economic factors, respectively, were analyzed by calculating Pearson product moment correlation coefficients among the landscape pattern, geochemistry and economy indices (Pearson 1895). Moreover, a significance test was conducted to determine whether the coefficients were statistically significantly different from zero at the significant level of 0.05. Linear and nonlinear relationships between the economic indices, heavy metal elements and landscape pattern indices were then tested and quantitatively explored through various linear and non-linear regression models. In addition to linear models, the potential nonlinear equations include exponential, growth, logistic, S-curve, compound, power, cubic, quadratic, inverse, and logarithmic models. The most appropriate models were obtained through the comprehensive analysis of coefficient of determination (R^2) and statistical significance (Sig.). Finally, principal component analysis (PCA) is a widely used method to reduce the dimensions of variables. In this study, PCA was carried out to reduce the number of the original variables (Polit and Beck 2012). At the same time, PCA was also used to identify the interrelationships among the landscape pattern, heavy metal elements and economic indices, and to determine whether and how the relationships among them could be presented by specific representative factors.

3. Results and discussion

3.1 Distribution characteristics of elements in water samples

Figures 3-6 show the values of water quality parameters for the upper, middle, and lower main channels. The contents of Cr, Ni, Cu, Zn, Cd, and Pb were all below the guideline values for Drinking-water Quality defined by World Health Organization and the Environmental Quality Standards for Surface Water by the Ministry of Environmental Protection of P. R. China. However, the contents of Al and Fe were significantly higher than the guideline values. Spatially, the contents of the elements in the river water generally increased from the upper to downstream. Table 3 summarized the mean values of the water quality parameters for counties from the upstream to the downstream. The average values of Al, Fe, Ni, Zn and Pb continuously increased as the water flew to the downstream. The spatial pattern is somewhat alike to that gained in the study of the Fuji River in Japan, in which high-pollution regions were mainly located in the downstream (Shrestha and Kazama 2007). However, the spatial distributions of Cr, Cu, and Cd values fluctuated from the upstream to the downstream.

3.2 Analysis of landscape pattern

Based on the land cover classification results, the landscape pattern indices of the study area were obtained using Fragstats 4.2 software, which are shown in Table 4. The results indicated that the values of the indices were diversified from the upstream to the downstream except PLADJ, AI, COHESION and MESH. Among the indices, TA, LPI, CONTAG, PLADJ, COHESION, MESH and AI showed the highest values, while PD, ED, LSI, DIVISION, SPLIT and SHDI had the lowest values in Shiqu county located in the upstream, implying that a health ecological condition was observed in the upstream. In Xinlong county located in the midstream, there were highest values for NP, PD, TE, ED, LSI, DIVISION, SPLIT and SHDI, and lowest values for LPI, PLADJ, IJI and AI, demonstrating that the ecological environment was disturbed and landscape fragmentation was observed. The landscape indices LPI, PD and DIVISION showed a turning point in the midstream Xinlong County. In Litang county that had a smallest area, the values of TA, NP, TE, CONTAG, COHESION and MESH were lowest, while the value of IJI was highest, indicating that the ecological environment needed to be paid attention to.

The AI in all the counties had the values of above 91.5, indicating that the landscape of the study area showed a high degree of aggregation, that is, the ecological environment was still in a good condition. The differences of LPI between the counties were very obvious. All the high values were distributed in the upstream, which meant the large patches dominated the landscape of the region. LSI had the higher values in the downstream, which indicated that the landscape structure was complicated in this region. In addition, by combining the values of CONTAG, PLADJ, COHESION, DIVISION, MESH, SPLIT and SHDI indices in the table, it was found that the upstream had a better but weaker ecological condition than the downstream.

3.3 Correlations among landscape pattern, geochemistry and economy indices

3.3.1 Economic indices and heavy metal elements

The Pearson correlation coefficients between the economic indices and heavy metal elements were calculated. The Al, Fe, Ni and Pb elements were significantly correlated with the economic indices at the significant level of 0.05 except Population, Population Density and Gross Output Value of Agriculture. The Cr had weak relationships with the economic indices except GDP. The Cu element had a significant correlations with the economic indices except Population, Population Density, Per Capita GDP and Gross Output Value of Agriculture. The Zn was significantly correlated with the economic indices except Population Density, GDP and Gross Output Value of Agriculture. There were significant correlations between Cd element and the economic indices except Population Density, Accumulated Population Density, Per Capita GDP and Gross Output Value of Agriculture. In summary, GDP and its relevant indices showed significant correlations with most of the heavy metal elements; and all the accumulated indices were also significantly correlated with most of the heavy metal elements because of the assembling characteristics of elements from the upstream to the downstream.

3.3.2 Economic and landscape pattern indices

The correlation coefficients between the economic indices and landscape pattern indices were calculated. PD is a fundamental manifestation of landscape patterns and can provide the information on the degree of landscape fragmentation. A significantly negative correlation between PD and Population looked like inexplicable and controversial because an increased population potentially resulted in landscape fragmentation. The limitation of PD index emerged when it was used for expressing the number of patches to assist the comparisons among the varying size landscapes. SHDI is a popular measure of diversity in ecology. In this study, it had a significantly negative correlation with Population, which is very intelligible because the human activities have negative influence on the ecological environment. TE is a gauge of the total edge length of a specific patch type. Its limitation was also observed because it showed the same distribution features with PD. IJI is based on patch adjacencies and provides a measure of the interspersion or intermixing of patch types. In this study, there was a significant correlation between IJI and Population Density, which is understandable because a high intensity of human disturbances makes the regional landscape structure more complicated. All these relationships proved that population was complex and integrated with many social activities, which affected the landscape patterns and structures. At the same time, some limitations of the landscape pattern indices were also observed.

3.3.3 Economic indices and land cover area/area ratios

The Pearson correlation coefficients between the economic indices and land cover area/area ratios showed that three main land cover types: Forest, Grassland and Transportation Land had significant correlations with the economic indices, and land cover area proportions or ratios were more sensitive to the variation of economic indices. Transportation Land was highly correlated with the economic index Population because the traffic condition was one key factor for supporting the local human activities. Forest had a significantly negative correlation with Population, which is intelligible because of the demand for woods and other indirect impacts on the forest ecological system by human activities. However, GDP and Gross Output Value of Agriculture, usually applied as the indicators of the economic health and living standard in a country, almost do not have any relationships with the land cover types, which seems inexplicable and controversial. This implies that a connection between economic development and landscape structure is unable to be established with a simple index.

3.3.4 Heavy metal elements and landscape pattern indices

The correlation coefficients of both Cu and Zn with CONTAG were -0.82 and -0.84, respectively, showing significant negative correlations at the significant level of 0.05. CONTAG is influenced by both the dispersion and interspersion of patch types and its negative correlation with the heavy metal element Zn is understandable because one disaggregated and interspersed landscape pattern may release more Zn. Both PD and DIVISION can provide fragmentation information for a regional landscape. The significantly positive correlations of 0.82 were found between Zn and PD and DIVISION, respectively. This is intelligible as the same reason with CONTAG. However, no significant correlations were observed between all the other heavy metal elements and landscape pattern indices, which indicates the limitation of analyzing the relationships between the heavy metal elements and the landscape pattern indices to explore the ecological status and process, and a more complicated and comprehensive approach is needed.

3.3.5 Heavy metal elements and land cover area/area ratios

The Pearson correlation coefficients between the land cover area/area proportions and the heavy metal elements showed that land cover area proportions were more sensitive to the variations of the heavy metal elements than the land cover areas. Forest showed significantly positive correlations with all the heavy metals, except Cr. Grassland showed strongly negative correlations with all the heavy metals except Cr although the correlations were not statistically significant at the significant level of 0.05. The moderately negative correlations between Transportation Land and all the heavy metals except Cr and Cd could also be observed. River showed negative correlations with the heavy metals. No strong correlations were observed between other heavy metal elements and the land cover area proportions. The negative correlations between the river and the heavy metals can be explained by a vast water body that has a powerful ability to dilute the elements. However, the strong positive correlations between forest and heavy metals, especially, the strong negative correlations between transportation land and heavy metals are inexplicable and controversial. There must be some profound causes for this paradoxical phenomenon. For example, the features of the natural background were the main factors that control the immigration process of geochemistry. These kinds of problems could not be simply accounted for by analyzing the relationships between the heavy metal elements and the land cover area/area proportions.

Overall, the above results showed that the regional ecological status and process of the river watershed could be, to a certain extent, explained using the correlation analysis among the hydrologic, ecological and socio-economic indices. However, the ecological problems of the watershed are complex due to the interactions of the hydrologic, ecological and socio-economic factors and could not be accounted for through the simple correlation analysis. The sustainable development of the watershed requires a comprehensive evaluation of the factors to gain an in-depth understanding of the ecological processes and properties in the watershed.

3.3.6 The functional relationships between the indices

The functional relationships among the hydrologic, ecological and socio-economic indices were analyzed using the indices that had statistically significant correlations (Table 5). The results showed that the functional relationships were diverse. It was found that as the indicators of the economic health in a country and the references for quantifying the intensity of human activities, the economic indices had significantly linear or nonlinear relationships with the heavy metal elements and landscape pattern indices at the significant level of 0.05. The accumulated economic indices such as accumulated population, accumulated population density, accumulated GDP, etc., were more involved in the regression models that were statistically significant than the economic indices themselves. Being a sensitive indicator for water pollution, the variation of the heavy metal concentrations in the river water was linearly or nonlinearly dependent on the economic and landscape pattern indices.

The relationships of Forest, Grassland and Transportation Land with the heavy metals were strong. Especially, the grassland can be considered as an intermediate and disturbance dependent ecosystem (Pretelli et al. 2015) and provide various ecological services, including soil and water conservation, carbon storage, and habitats for animals and recreation (Sivanpillai and Shroder 2016). The grassland also plays an important role in controlling the atmospheric greenhouse gases through carbon storage and sequestration (O’Mara 2012; Gang et al. 2016). In addition, many studies have proved that the correlations exist between grassland and heavy metals in diverse ways or at different scales (Babalonas et al. 1997; Klessa and Desira-Buttigieg 1992; Aitken 1997). As the dominant landscape type in this region, grassland accounted for 61.22 % of the study area, showing a strong correlation between the grassland landscape and the heavy metal elements is intelligible and understandable.

Cu and Zn are crucial elements for both animals and plants, but they have also been identified as possible specific pollutants in many countries (Comber et al. 2008; Jensen et al. 2016). Cu and Zn account for the highest inputs of the trace elements in agricultural soils (Tella et al. 2016), and many studies have proved that the distribution patterns of Cu and Zn have significant correlations with certain landscape patterns and processes (Stone and Droppo 1996; Lindström 2001; Morse et al. 2016). This was supported by the results of this study.

All the heavy metals, landscape pattern and socio-economic indices listed in Table 5 were selected to calculate the principal components of PCA (Table 6). The results showed that there were three main components, and the top two accounted for above 88% of the original variances, indicating principal component one and two were enough for explaining the variability of the original and correlated variables. Principal component one had large correlation coefficients with all the indices except Population Density and IJI that showed great correlation coefficients with principal component two. The results indicated that the interrelationships among the landscape pattern, geochemistry and economy indices existed and were diverse, and could be identified by the selected and representative factors. Moreover, some of the indices involving in the analysis were important and could not be neglected, but should be selected and integrated to analyze the characteristics of the ecological environment of the river watershed.

4. Conclusions

In this study, the relationships between the economic indices, heavy metal elements and landscape pattern indices were explored and used to analyze and characterize the ecosystem and environment of Yalong River watershed within Ganzi Tibetan Autonomous Prefecture, Sichuan Province, using water samples collected in the field and an image derived land cover classification. In summary, this study led to following findings: 1) The ecological status and process of the watershed could be explained by analyzing the relationships among the economic indices, heavy metal elements and landscape pattern indices selected based on correlation analysis; 2) The accumulated economic indices than the economic indices themselves were more significantly correlated with most of the heavy metal elements and should be applied to the integrated assessment of the watershed ecological environment. This conforms to the assembling characteristics of the elements in the river from the upstream to the downstream (Cortecci et al. 2009; Li and Zhang 2010; Taylor et al. 2012; Yang et al. 2014; Bu et al. 2016); 3) Some landscape patterns indices such as SHDI and IJI could be used to the integrated assessment of the watershed ecological environment because of their strong correlations with the important economic indices, i.e., Population and Population Density; however, some limitations of using the landscape pattern indices were also observed, indicating that the selection of the landscape pattern indices was essential; 4) Compared with land cover area, land cover area proportions were more sensitive to the variation of the economic indices. As the dominated land cover types in the study area, Forest and Grassland had strong relationships with the economic indices. Transportation Land also had a close relationship with Population because transportation and mobility were vital constituents of socio-economic development in any country (Gentile and Noekel 2016; Alam et al. 2016); and 5) Cu and Zn were the main elements that showed significant correlations with the landscape pattern indices and this was also supported by previous studies (Stone and Droppo 1996; Lindström 2001; Morse et al. 2016). The conclusions will play a fundamental role in establishing the synthetic models for management of watersheds.

However, it was found that the connection between the economic development and the landscape structure was unable to be established with a simple index analysis. Moreover, analyzing the relationships between the heavy metal elements and the landscape pattern indices to explore the ecological status and process had their limitations. The ecological problems of a watershed could not be revealed through simply analyzing one kind of indices and the sustainable development of the watershed requires an integrated evaluation of hydrologic, ecological and socio-economic factors. A more complicated and comprehensive approach is needed to get an in-depth understanding of the ecological processes and properties of the watershed. Although, at the present, an increasing number of theories and methods for integrated watershed management have been developed, the exploration of quantitative relationships among the driving factors still requires a significant effort and multivariate statistical methods based on sufficient sampling data in the future work could be an alternative.

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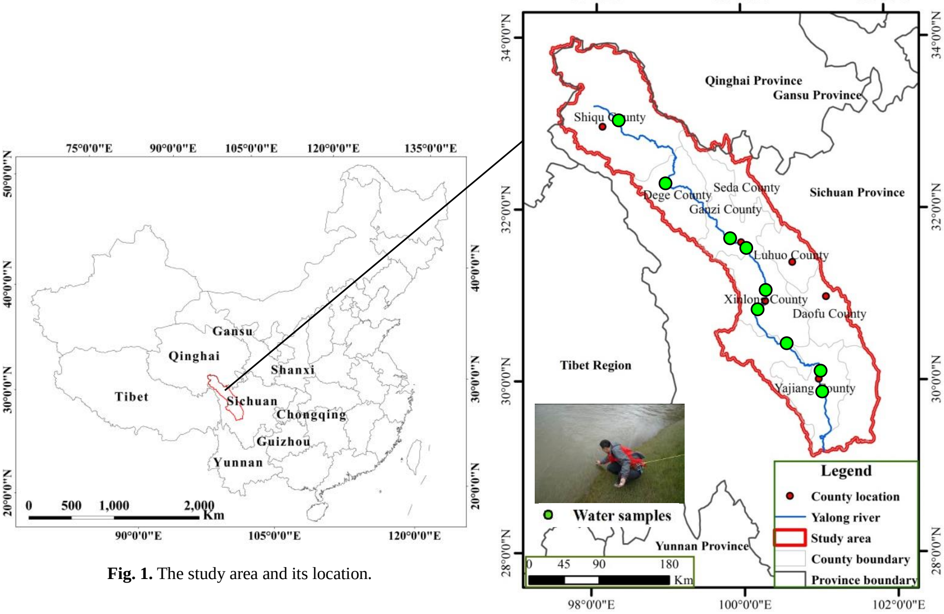

Fig. 1. The study area and its location.

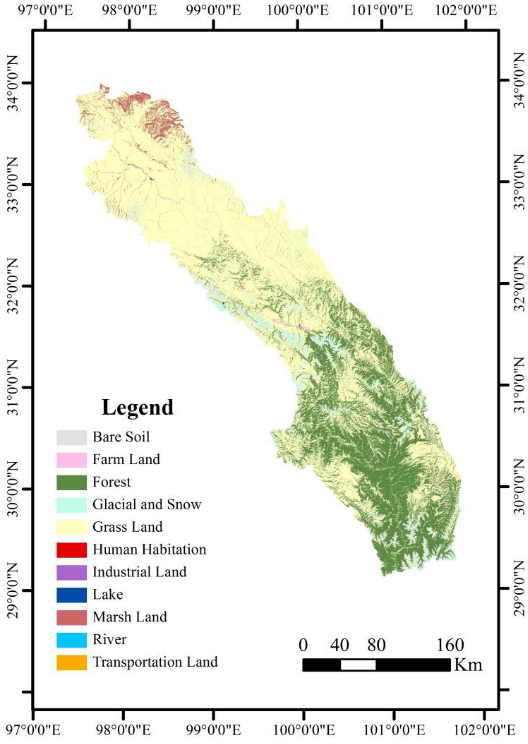

Fig. 2. Land cover classification map.

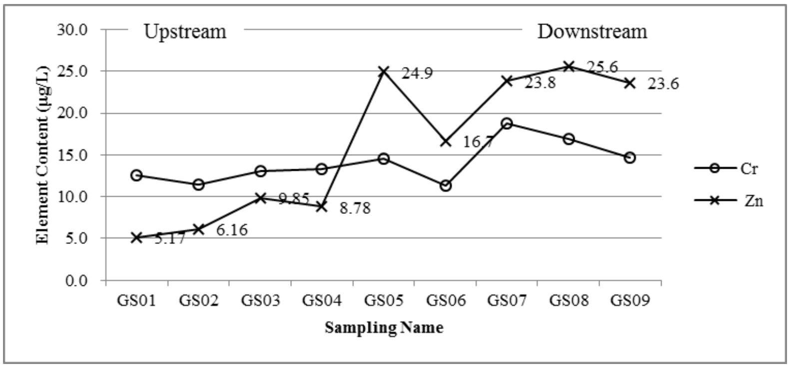

Fig. 3. The values of Cr and Zn elements from water samples along the river from upstream to downstream (µg/L)

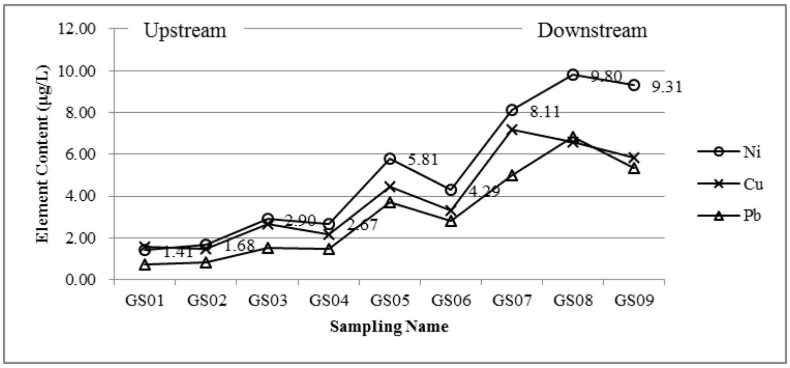

Fig. 4. The values of Ni, Cu and Pb elements from water samples along the river from upstream to downstream (µg/L)

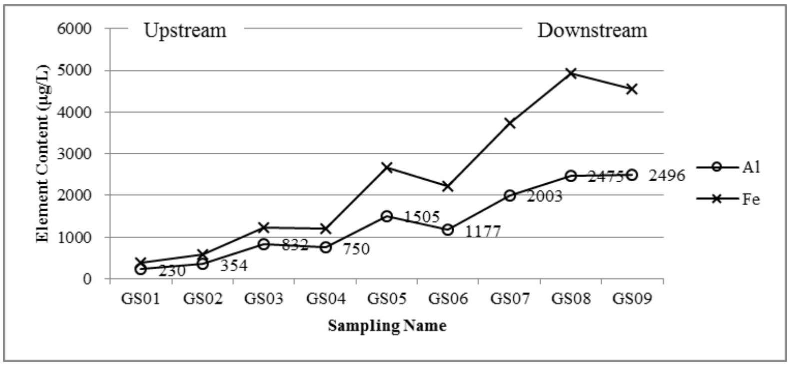

Fig. 5. The values of Al and Fe elements from water samples along the river from upstream to downstream (µg/L)

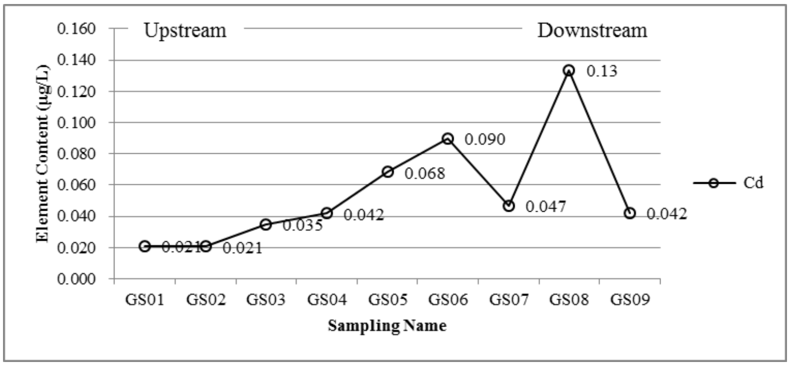

Fig. 6. The values of Cd element from water samples along the river from upstream to downstream (μg/L)

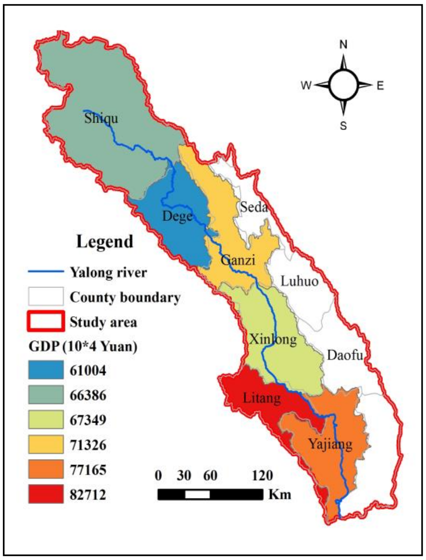

Fig. 7. Map showing the GDP of the counties that the river goes through

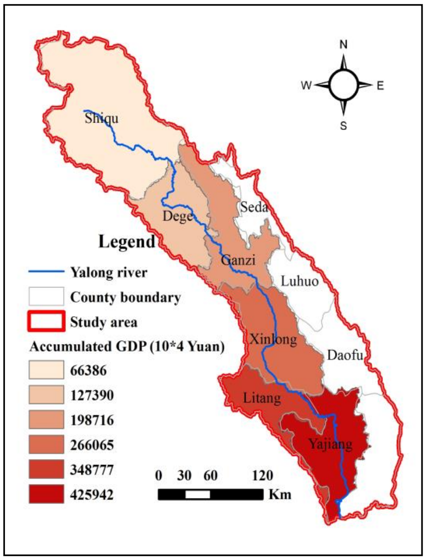

Fig. 8. Map showing the accumulated GDP of the counties that the river goes through

Table 1. Area and proportion of each land cover type.

Land cover classes	Shiqu		Dege		Ganzi	
	Area(km^2)	Proportion (%)	Area(km^2)	Proportion (%)	Area(km^2)	Proportion (%)
Bare Soil	561.77	3.12%	398.24	6.18%	309.39	4.22%
Farm Land	4.81	0.03%	22.86	0.35%	80.18	1.09%
Forest	1.10	0.01%	644.45	10.00%	774.57	10.56%
Glacial and Snow	131.10	0.73%	286.03	4.44%	285.20	3.89%
Grassland	15428.98	85.68%	4997.31	77.57%	5793.54	78.96%
Human Habitation	1.45	0.01%	2.65	0.04%	7.66	0.10%
Industrial Land	0.45	0.00%	0.23	0.00%	0.19	0.00%
Lake	9.48	0.05%	5.18	0.08%	0.19	0.00%
Marsh Land	1693.74	9.41%	36.08	0.56%	23.84	0.32%
River	143.26	0.80%	38.94	0.60%	55.63	0.76%
Transportation Land	32.26	0.18%	10.68	0.17%	6.86	0.09%

Table 1 (Continuous). Area and proportion of each land cover type

Land cover classes	Xinlong		Litang		Yajiang	
	Area(km^2)	Proportion (%)	Area(km^2)	Proportion (%)	Area(km^2)	Proportion(%)
Bare Soil	451.32	5.64%	191.70	4.11%	363.59	4.80%
Farm Land	38.69	0.48%	15.72	0.34%	38.01	0.50%
Forest	3540.41	44.22%	2274.36	48.78%	4868.50	64.29%
Glacial and Snow	330.76	4.13%	104.38	2.24%	81.37	1.07%
Grassland	3581.73	44.74%	2062.01	44.23%	2181.47	28.81%
Human Habitation	1.00	0.01%	0.00	0.00%	0.98	0.01%
Industrial Land	0.37	0.00%	0.00	0.00%	0.11	0.00%
Lake	13.62	0.17%	0.00	0.00%	1.02	0.01%
Marsh Land	5.77	0.07%	0.00	0.00%	0.00	0.00%
River	39.59	0.49%	14.16	0.30%	37.88	0.50%
Transportation Land	2.89	0.04%	0	0.00%	0	0.00%

Table 2. Statistics of economic indices for counties along the river.

Counties	Population (10^4 Persons)	Accumulated Population (10^4 Persons)	Population Density (Persons/km^2)	Accumulated Population Density (Persons/km^2)	GDP (10^4 Yuan)	Accumulated GDP (10^4 Yuan)	Per Capita GDP (Yuan)	Accumulated Per Capita GDP (Yuan)	Gross Output Value of Agriculture (10^4 Yuan)	Accumulated Gross Output Value of Agriculture (10^4 Yuan)
Shiqu	9.77	9.77	4.18	4.18	66386	66386	6795	6795	45252	45252
Dege	8.26	18.03	12.13	16.21	61004	127390	7385	14180	36568	81820
Ganzi	6.94	24.97	8.17	24.38	71326	198716	10278	24458	44344	126164
Xinlong	5.12	30.09	5.66	30.04	67349	266065	13154	37612	36489	162653
Litang	7.01	37.10	12.6	42.64	82712	348777	11799	49411	39616	202269
Yajiang	5.12	42.22	6.13	48.77	77165	425942	15071	64482	27692	229961

Table 3. Statistics of heavy metal elements for counties along the river.

Counties	Al	Cr	Fe	Ni	Cu	Zn	Cd	Pb
	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Shiqu	230	12.5	377	1.41	1.57	5.17	0.021	0.74
Dege	354	11.4	586	1.68	1.49	6.16	0.021	0.82
Ganzi	791	13.2	1218	2.78	2.41	9.32	0.038	1.51
Xinlong	1341	12.9	2447	5.05	3.89	20.80	0.079	3.28
Litang	2003	18.8	3732	8.11	7.21	23.80	0.047	4.99
Yajiang	2485	15.8	4742	9.56	6.20	24.60	0.088	6.11

Table 4. Landscape pattern indices of the study area.

	TA	NP	PD	LPI	TE	ED	LSI	CONTAG
Shiqu	1800824	22492	1.25	82.39	38454870	21.35	73.64	85.28
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	96.75	36.98	99.96	0.32	1223736.26	1.47	0.56	96.79
Dege	**TA**	**NP**	**PD**	**LPI**	**TE**	**ED**	**LSI**	**CONTAG**
	644263	17027	2.64	71.40	24016890	37.28	76.85	77.48
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	94.33	41.11	99.91	0.49	328937.41	1.96	0.84	94.40
Ganzi	**TA**	**NP**	**PD**	**LPI**	**TE**	**ED**	**LSI**	**CONTAG**
	733726	19702	2.69	62.68	25446540	34.68	77.08	78.44
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	94.70	42.94	99.89	0.59	298410.58	2.46	0.80	94.76
Xinglong	**TA**	**NP**	**PD**	**LPI**	**TE**	**ED**	**LSI**	**CONTAG**
	800609	32222	4.02	21.15	42916860	53.61	121.78	70.40
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	91.90	35.34	99.81	0.90	79176.66	10.11	1.09	91.96
Litang	**TA**	**NP**	**PD**	**LPI**	**TE**	**ED**	**LSI**	**CONTAG**
	466235	16748	3.59	31.13	21566220	46.26	82.39	65.07
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	92.91	46.34	99.77	0.85	69570.70	6.70	0.96	92.98
Yajiang	**TA**	**NP**	**PD**	**LPI**	**TE**	**ED**	**LSI**	**CONTAG**
	757294	24862	3.28	58.83	28723440	37.93	85.03	73.96
	PLADJ	**IJI**	**COHESION**	**DIVISION**	**MESH**	**SPLIT**	**SHDI**	**AI**
	94.22	37.34	99.89	0.64	270170.13	2.80	0.89	94.28

Table 5. The functional relationships between the economic indices, heavy metal elements and landscape pattern indices

Indices A (y)	**Indices B (x)**	**Functional Relationships**	**Indices A (y)**	**Indices B (x)**	**Functional Relationships**
Population	Zn	$y = 4.608 + 24.537/x$, (R^2=0.82 , Sig.= 0.013)	Population	SHDI	$y = 5.868 – 6.669\ln(x)$, (R^2=0.71 , Sig.= 0.035)
Population	Cd	$y = 1.92*x^{-0.401}$, (R^2=0.94 , Sig.= 0.002)	Population	Forest	$y = 5.834 – 0.458\ln(x)$, (R^2=0.71 , Sig.= 0.035)
Accumulated Population	Al	$y = -57.216 + 12.449\ln(x)$, (R^2=0.98 , Sig.= 0.000)	Population	Grassland	$y = 3.923*2.529^x$, (R^2=0.72 , Sig.= 0.032)
Accumulated Population	Fe	$y = -58.167 + 11.644\ln(x)$, (R^2=0.98 , Sig.= 0.000)	Population	Transportation Land	$y = 5.528 + 1885.276x$, (R^2=0.71 , Sig.= 0.035)
Accumulated Population	Ni	$y = 7.845 + 14.654\ln(x)$, (R^2=0.96 , Sig.= 0.001)	Accumulated Population	Forest	$y = 14.057 + 43.765x$, (R^2=0.90 , Sig.= 0.004)
Accumulated Population	Cu	$y = 45.469 – 48.523/x$, (R^2=0.89 , Sig.= 0.005)	Accumulated Population	Grassland	$y = 55.491 – 47.437x$, (R^2=0.86 , Sig.= 0.007)
Accumulated Population	Zn	$y = \exp(3.957 – 7.731/x)$, (R^2=0.92 , Sig.= 0.003)	Accumulated Population	Transportation Land	$y = 38.563 –14416.564x$, (R^2=0.94 , Sig.= 0.002)
Accumulated Population	Cd	$y = 45.414 – 0.661/x$, (R^2=0.80 , Sig.= 0.016)	Population Density	IJI	$y = 37.061 – 1146.586/x$, (R^2=0.70 , Sig.= 0.037)
Accumulated Population	Pb	$y = -17.376 + 12.821\ln(x)$, (R^2=0.95 , Sig.= 0.001)	Accumulated Population Density	Forest	$y = 42.965*x^{0.261}$, (R^2= 0.94, Sig.= 0.002)
Accumulated Population Density	Al	$y = -87.047 + 16.957\ln(x)$, (R^2= 0.96, Sig.= 0.001)	Accumulated Population Density	Grassland	$y = 66.465 – 64.604x$, (R^2= 0.85, Sig.= 0.009)
Accumulated Population Density	Fe	$y = -88.422 + 15.871\ln(x)$, (R^2= 0.96, Sig.= 0.001)	Accumulated Population Density	Transportation Land	$y = 43.393 – 19612.577x$, (R^2=0.92 , Sig.= 0.003)
Accumulated Population Density	Ni	$y = 1.450 + 20.054\ln(x)$, (R^2=0.96 , Sig.= 0.001)	Accumulated GDP	Forest	$y = 90556.374 + 500358.573x$, ($R^2$= 0.93, Sig.= 0.002)
Accumulated Population Density	Cu	$y = 52.751 – 65.911/x$, (R^2=0.87 , Sig.= 0.007)	Accumulated GDP	Grassland	$y = 565231.417 – 543935.249x$, ($R^2$= 0.90, Sig.= 0.004)
Accumulated Population Density	Zn	$y = 50.735 – 232.723/x$, (R^2= 0.88, Sig.= 0.006)	Accumulated GDP	Transportation Land	$y = 367785.493 – 161132699.387x$, ($R^2$= 0.92, Sig.= 0.002)
Accumulated Population Density	Pb	$y = 14.535 + 17.489\ln(x)$, (R^2=0.93 , Sig.= 0.002)	Per Capita GDP	Forest	$y = 7291.924 – 11655.492x$, ($R^2$= 0.88, Sig.= 0.006)
GDP	Al	$y = 62402.308 + 7.153x$, (R^2=0.68 , Sig.= 0.042)	Per Capita GDP	Grassland	$y = 18459.936 – 12855.251x$, ($R^2$=0.87 , Sig.= 0.006)
GDP	Cr	$y = 116487.741 – 623994.562/x$, ($R^2$=0.98 , Sig.= 0.000)	Per Capita GDP	Transportation Land	$y = \exp(9.543 – 376.266x)$, (R^2=0.91 , Sig.= 0.003)
GDP	Fe	$y = 63101.817 + 3.612x$, (R^2= 0.66, Sig.= 0.048)	Accumulated Per Capita GDP	Forest	$y = \exp(9.264 + 2.993x)$, (R^2=0.86 , Sig.= 0.008)
GDP	Ni	$y = 61830.678 + 1922.278x$, ($R^2$= 0.70, Sig.= 0.037)	Accumulated Per Capita GDP	Grassland	$y = 86235.996 – 89024.133x$, ($R^2$=0.92 , Sig.= 0.002)
GDP	Cu	$y = 59807.595 + 2946.703x$, ($R^2$= 0.83, Sig.= 0.011)	Accumulated Per Capita GDP	Transportation Land	$y = \exp(10.956 – 1006.639x)$, (R^2=0.93 , Sig.= 0.002)
GDP	Pb	$y = 62721.265 + 2843.233x$, ($R^2$= 0.67, Sig.= 0.046)	Accumulated Gross Output Value of Agriculture	Forest	$y = 64329.161 + 259835.845x$, ($R^2$= 0.92, Sig.= 0.003)
Accumulated GDP	Al	$y = 61810.012 + 147.475x$, (R^2= 0.98, Sig.= 0.000)	Accumulated Gross Output Value of Agriculture	Grassland	$y = 310675.857 – 282212.324x$, ($R^2$= 0.89, Sig.= 0.005)
Accumulated GDP	Fe	$y = 74776.315 + 75.15x$, (R^2=0.97 , Sig.= 0.000)	Accumulated Gross Output Value of Agriculture	Transportation Land	$y = 209902.565 – 85686748.466x$, ($R^2$= 0.96, Sig.= 0.001)
Accumulated GDP	Ni	$y = 22056.352 + 165621.016\ln(x)$, (R^2= 0.97, Sig.= 0.000)	CONTAG	Zn	$y = \exp(9.051 – 0.087x)$, (R^2=0.74 , Sig.= 0.028)

Table 5 (Continuous). The functional relationships between the economic indices, heavy metal elements and landscape pattern indices

Indices A (y)	**Indices B (x)**	**Functional Relationships**	**Indices A (y)**	**Indices B (x)**	**Functional Relationships**
Accumulated GDP	Cu	y = 20939.671 + 189845.505ln(x) , (R^2= 0.91, Sig.= 0.003)	PD	Zn	y = 1.974*1.879^x, (R^2=0.75 , Sig.= 0.025)
Accumulated GDP	Zn	y = exp(13.205 – 10.03/x) , (R^2= 0.94, Sig.= 0.001)	DIVISION	Zn	y = 28.513*x$^{1.623}$, (R^2= 0.77, Sig.= 0.022)
Accumulated GDP	Cd	y = exp(13.282 – 0.038/x) , (R^2=0.83 , Sig.= 0.012)	CONTAG	Cu	y = exp(7.239 – 0.081x) , (R^2=0.70 , Sig.= 0.038)
Accumulated GDP	Pb	y = 129601.73 + 145130.698ln(x) , (R^2= 0.96, Sig.= 0.001)	Grassland	Al	y = 2.143 – 0.228ln(x) , (R^2= 0.86, Sig.= 0.008)
Per Capita GDP	Al	y = 1168.75*x$^{0.322}$, (R^2=0.93 , Sig.= 0.002)	Grassland	Fe	y = 2.191 – 0.217ln(x) , (R^2=0.89 , Sig.= 0.005)
Per Capita GDP	Fe	y = 1148.026*x$^{0.3}$, (R^2= 0.93, Sig.= 0.002)	Grassland	Ni	y = 0.966 – 0.279ln(x) , (R^2= 0.91, Sig.= 0.003)
Per Capita GDP	Ni	y = exp(9.664 – 1.211/x) , (R^2=0.94 , Sig.= 0.001)	Grassland	Cu	y = 0.966 – 0.319ln(x) , (R^2=0.84 , Sig.= 0.010)
Per Capita GDP	Zn	y = exp(9.699 – 4.621/x) , (R^2= 0.94, Sig.= 0.002)	Grassland	Zn	y = 0.98 – 0.025x, (R^2= 0.95, Sig.= 0.001)
Per Capita GDP	Cd,	y = exp(9.779 – 0.019/x) , (R^2= 0.98, Sig.= 0.000)	Grassland	Cd	y = 1.098exp(-13.854x) , (R^2= 0.83, Sig.= 0.012)
Per Capita GDP	Pb	y = exp(9.626 – 0.591/x) , (R^2= 0.95, Sig.= 0.001)	Grassland	Pb	y = 0.957exp(-0.186x) , (R^2= 0.93, Sig.= 0.002)
Accumulated Per Capita GDP	Al	y = exp(11.026 – 520.961/x) , (R^2=0.96 , Sig.= 0.001)	River	Cu	y = exp(-4.723 – 0.128x) , (R^2=0.76 , Sig.= 0.025)
Accumulated Per Capita GDP	Fe	y = 6106.918 + 12.235x, (R^2=0.99 , Sig.= 0.000)	River	Zn	y = 0.011 – 0.002ln(x) , (R^2= 0.68, Sig.= 0.045)
Accumulated Per Capita GDP	Ni	y = exp(11.286 – 3.26/x) , (R^2= 0.97, Sig.= 0.000)	Accumulated Gross Output Value of Agriculture	Fe	y = -362084.406 + 68803.725ln(x) , (R^2=0.99 , Sig.= 0.000)
Accumulated Per Capita GDP	Cu	y = exp(11.434 – 3.377/x) , (R^2=0.88 , Sig.= 0.006)	Accumulated Gross Output Value of Agriculture	Ni	y = 27500.489 + 86966.779ln(x) , (R^2=0.98 , Sig.= 0.000)
Accumulated Per Capita GDP	Zn	y = exp(11.37 – 12.32/x) , (R^2=0.95 , Sig.= 0.001)	Accumulated Gross Output Value of Agriculture	Cu	y = 251600.739 – 290115.347/x, (R^2=0.92 , Sig.= 0.003)
Accumulated Per Capita GDP	Cd	y = exp(11.473 – 0.048/x) , (R^2=0.85 , Sig.= 0.009)	Accumulated Gross Output Value of Agriculture	Zn	y = exp(12.609 – 8.952/x) , (R^2= 0.95, Sig.= 0.001)
Accumulated Per Capita GDP	Pb	y = 15169.098 + 23446.004ln(x) , (R^2=0.96 , Sig.= 0.001)	Accumulated Gross Output Value of Agriculture	Cd	y = exp(12.679 – 0.034/x) , (R^2=0.83 , Sig.= 0.011)
Accumulated Gross Output Value of Agriculture	Al	y = -355759.007 + 73460.738ln(x) , (R^2= 0.99, Sig.= 0.000)	Accumulated Gross Output Value of Agriculture	Pb	y = 83902.099 + 76300.297ln(x) , (R^2=0.97 , Sig.= 0.000)

Table 6. Component matrix

Indices	Components		
	1	2	3
Accumulated Gross Output Value of Agriculture	.990	-.014	.053
Per Capita GDP	.933	-.323	-.015
Accumulated Per Capita GDP	.977	-.086	.149
Accumulated GDP	.982	-.040	.120
GDP	.786	.332	.449
Accumulated Population Density	.979	.052	.064
Population Density	.156	.877	-.304
Accumulated Population	.983	.005	.034
Population	-.842	.366	.302
River	-.840	-.342	.220
Forest	.976	-.151	.024
Grassland	-.963	.195	-.005
Transportation Land	-.981	.003	-.027
SHDI	.763	-.007	-.646
IJI	.134	.947	.050
PD	.839	.008	-.541
CONTAG	-.855	-.344	.350
DIVISION	.815	.082	-.488
Al	.975	-.048	.207
Fe	.969	-.060	.220
Ni	.965	-.010	.243
Cu	.944	.200	.217
Zn	.986	-.069	.009
Cd	.838	-.539	-.070
Pb	.966	-.053	.229
Cr	.783	.449	.373