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Eco-environmental vulnerability evaluation in mountainous region using remote sensing and GIS—A case study in the upper reaches of Minjiang River, China

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Abstract

The upper reaches of Minjiang River-valley, located on the eastern edge of Qinghai–Tibet Plain, is characterized by the complex distribution of hills and valleys. It is a typical and key mountainous region with apparent upland ecosystem vulnerability and sensitivity according to National Eco-environmental Renovating Scheme of china. In order to analyze eco-environmental vulnerability, remote sensing (RS) and geographical information system (GIS) technologies are adopted, and an environmental numerical model is developed using spatial principle component analysis (SPCA) method. The model contains nine factors including elevation, slope, accumulated temperature, drought index, land use, vegetation, soil, water-soil erosion, and population density. Using the model, the integrated eco-environmental vulnerability index (EVI) of study area in 1972, 1986, and 2000 are computed. According to the numerical results, the vulnerability is classified into five levels: potential, slight, light, medial, and heavy level by means of the cluster principle. The eco-environmental vulnerability distribution and its dynamic change in the last 30 years from 1972 to 2000 are analyzed and discussed. The results show that the eco-environmental vulnerability in study area is at medial level, and presents apparent vertical-belt distribution, and that driving forcings of dynamic change are mainly caused by human social economic activities and the contribution of late national eco-environmental protection policies, such as Natural Forest Protection and Grain for Green. According to these results, the study area is regionalized into three sub-regions, which may serve as a base for decision-making for eco-environmental recovering and rebuilding. The results of this study indicate that the method that integrates RS, GIS, and the SPCA to evaluate eco-environment vulnerability in mountainous region, cannot only distinctly represent the input subject spatial distribution of mountain vertical-belt feature, but also respect the river-valley as a whole system.

Keywords: Eco-environment; Vulnerability; Spatial principal component analysis (SPCA); Remote sensing; GIS

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1. Introduction

The upper reaches of Minjiang River-valley is a key region for eco-environmental rebuilding according to National Eco-environmental Renovating Scheme of china (http://www.coi.gov.cn/zrbhq/law6.htm). In order to plan a rebuilding project, the first step should be to do an evaluation study on present eco-environmental situation and evolution trend (Aspinall and Pearson, 2000; Rosenberg et al., 1996; Shen et al., 2004). Environmental evaluation may also provide basic data and information for the sustainable development of an eco-sample (Blake and Gentil, 1987; Girardin et al., 2000; Popp et al., 2000; UNCSD, 1996; World Bank, 1997), such as the urban area (Li et al., 1998; Ng and Obbard, 2005; Ogawa et al., 1986) and the river-valley (Eisele et al., 2003; Imbe et al., 1997; Isidori et al., 2004). As a new branch of environmental evaluation, eco-environmental vulnerability trend evaluation has been fast developed in recent years. The previous investigations have developed many method, such as the comprehensive evaluation method (Goda and Matsuoka, 1986), the fuzzy evaluation method (Adriaenssens et al., 2004; Enea and Salemi, 2001), the gray evaluation method (Hao and Zhou, 2002) along with the artificial neural-network evaluation method (Dzeroski, 2001; Park et al., 2004), the osculation value method (Xue et al., 2003), and the landscape evaluation method (Antonio et al., 2003; Kangas et al., 2000). These methods have been used for quantitative analysis, however, the variables used in the model are not always easy to be acquired and operated. For example, the neural-network method needs a number of historical data, which especially is the problem of using existing domain knowledge in the learning process.

Recently, the space technologies, such as remote sensing and GIS, and numerical modeling techniques have been developed as powerful tools for ecological environment assessment (Krivtsov, 2004; MacMillan et al., 2004; Store and Jokimäki, 2003). Combing these technologies cannot only supply a platform to support multi-level and hierarchical integrated analysis on resource and environment, but also integrate the obtained information in a comparative theoretical ecosystem analysis. Meanwhile, Plummer (2000) argued that perspectives of combining ecological models and remotely sensed data focus on estimation accuracy, issues of spatial and temporal scale, long-term comprehensive datasets, etc. The major objective of this study is to evaluate the eco-environmental vulnerability in a typical mountainous region characterized by apparent vertical-belt feature. Under the support of RS and GIS technologies, the study takes the whole river-valley as an integrated system. MSS data (80 m resolution) and TM image with high spatial resolution (30 m) and a long-term comprehension (about 30a) are used to create land-use and vegetation subjects by user-computer interactive interpreting method. And spatial entities based landform is created from digital elevation data (DEM) to support multi-level, hierarchical integrated natural environment inventory. This paper addresses the following specific objectives: (1) an environmental numerical evaluation model is set up supported by GIS. (2) The spatial principal component analysis (SPCA) is developed to build an eco-environmental vulnerability index (EVI) model, and the computed result is classified using the cluster principle. (3) The spatial distribution and its change of eco-environmental vulnerability are analyzed, and driving forcings for change are discussed. (4) The regionalization is worked out as the basis for eco-environmental rebuilding planning.

2. Methods

2.1. Study area

The upper reaches of Minjiang River-valley lies between 31–33°N and 102–104°E, with a length of 340 km and an area of about 23,000 km^2 across Songpan, Heishui, Mao, Li, and Wenchuan Counties in exact correspondence to the governing range of the five counties (Fig. 1). It is a green-reservoir and eco-fence of the Chengdu Plain, and one of the water-resource areas of the Changjiang River. Meanwhile, it is also a typical mountainous region with apparent upland ecosystem vulnerability and sensitivity. Located on the eastern edge of Qinghai–Tibet Plain, the topography of the area is characterized by the complex distribution of hills and valleys, and ranging in elevation from 700 to 6260 m with average elevation difference above 1000 m. Its temperature is obviously related to latitude and altitude with a vertical declining rate of temperature about 0.46 °C/100 m. Its northern area with elevation above 2000 m is extreme cold and has annual precipitation

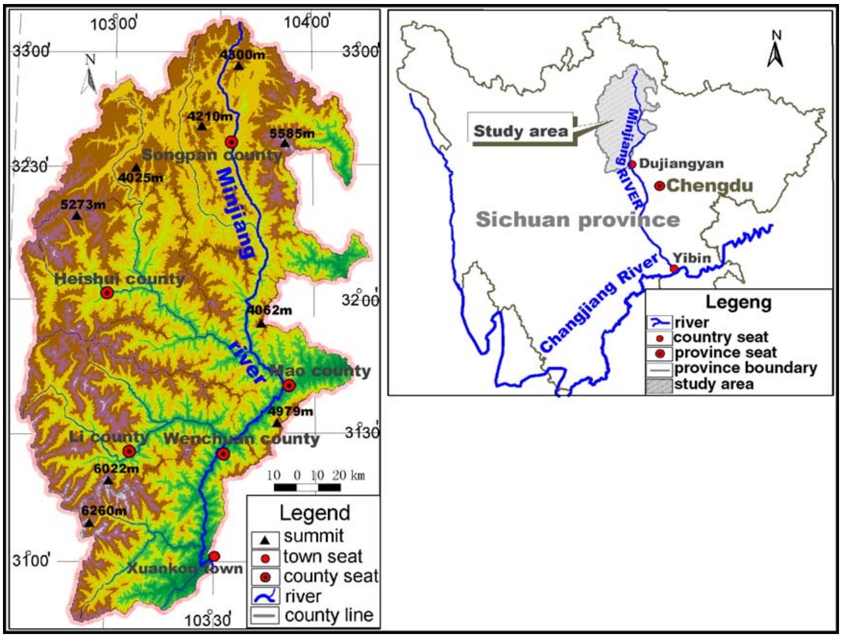

Fig. 1. Location map of the upper reaches of Minjiang River showing the relationship between the study area, Sichuan province, and the Changjiang River, as well as displaying the relief.

730–840 mm; the southern area is drought river-valley with elevation 1200–2000 m and annual precipitation 420–566 mm. More than 80–90% of the annual precipitation falls from May to October. The whole population in this region in 2000 had reached 385,300 and the population is mainly concentrated in river-valley area.

2.2. Data

The basic data used in this study include: (1) remote sensing (RS) data, including MSS data (December 1972) and TM5 data (December 1986 and 2000); (2) data of soil type and water-soil erosion, from national soil-erosion surveying database accomplished by *Remote Sensing Application Institute of Chinese Academy of Sciences* in 1999; (3) DEM data, supplying by *State Bureau of Surveying and Cartography*, which are 1:50,000 standard maps; (4) water-heat meteorological data, from *national eco-environmental background water-heat database* accomplished by *natural resource and agricultural regionalizing research institute of Chinese Academy of Agricultural Sciences* in 1999, including $\geq 10\,^{\circ}$C accumulated temperature, annual average rainfall and drought index; (5) social economic data, from *Annual Statistics of Sichuan Province*.

The three following steps for further processing the source data are: (1) to create subjects for eco-environmental evaluation using original data. The data of land use and vegetation is derived from RS data by user-computer interactive interpreting method, and elevation and slope data are generated from DEM. All spatial data with spatial scale 1:100,000 are requested and social statistic data are designed on base of administrative town. Variables (e.g. land-use) from MSS data can hardly meet the resolution request. However, dynamic change patches can be picked up by comparing the MSS with TM data and combining field survey, which can assimilate the MSS and TM data. (2) To unify the geo-reference of subjects. Coordinate system is Albers Equal Area system with original longitude 103°E, original latitude 0°, double-standard parallel of 27°N and 33°N, Beijing1954 geodetic datum and *Krassovsky* ellipsoid. (3) To grid vector data. Basic data unit adopt 100 m × 100 m, on which spatial logic and algebra computation are worked at each subject layer.

2.3. Evaluation principle and factors

The selection of evaluating criteria plays a key role in a regional eco-environment evaluation, and should be operational, indicative, and representative (Alewell and Manderscheid, 1998; Geraghty, 1993; Zhao, 1999). The eco-environment is a dynamic balanced system caused by energy exchange and materials recycle between natural and cultural environment (Bockelmann et al., 2004; Young et al., 2000). Accordingly, the factors including nature and human activities are crucial to mountainous eco-environment vulnerability with feature of vertical-belt. On the basis of qualitative analysis of eco-environment in study area, an integrated evaluation criteria system is quantitatively set up containing nine factors: elevation, slope, accumulated temperature, drought index, land use, vegetation, soil, water-soil erosion, and population density. The negative impact of each factor on eco-environmental stability is classified into five levels (2, 4, 6, 8, and 10), which are defined as indexes of contribution to vulnerability.

2.4. Evaluation model

How to convert the criteria of water-heat condition, land use, landform, and human interfere into an integrated evaluation index is a key point of environmental evaluation as well as a problem difficult to solve (Munda et al., 1994). At present, there are some methods, such as the indices weight method (IWM) (Diakoulaki et al., 1995; Li et al., 2001) and the analytical hierarchy process (AHP) (Anselin et al., 1989; Klungboonkrong and Taylor, 1998; Liu and Xie, 2003), to be used to achieve the practical success. However, these methods depend on experts' evaluation to weigh the importance of factors, and the level of experts influences the final evaluation results directly. The principal component analysis (PCA), using coefficients of linear correlation offers the possibility to weight the contribution of factors (Parinet et al., 2004; Wotling et al., 2000). This study has developed an eco-environmental vulnerability evaluation (EVE) model by SPCA method, which is a modified PCA approach, whose schematic representation is shown in Fig. 2.

The processes of eco-environmental vulnerability evaluation by SPCA method are explained as follows: (1) to standardize primary data; (2) to establish a covari-

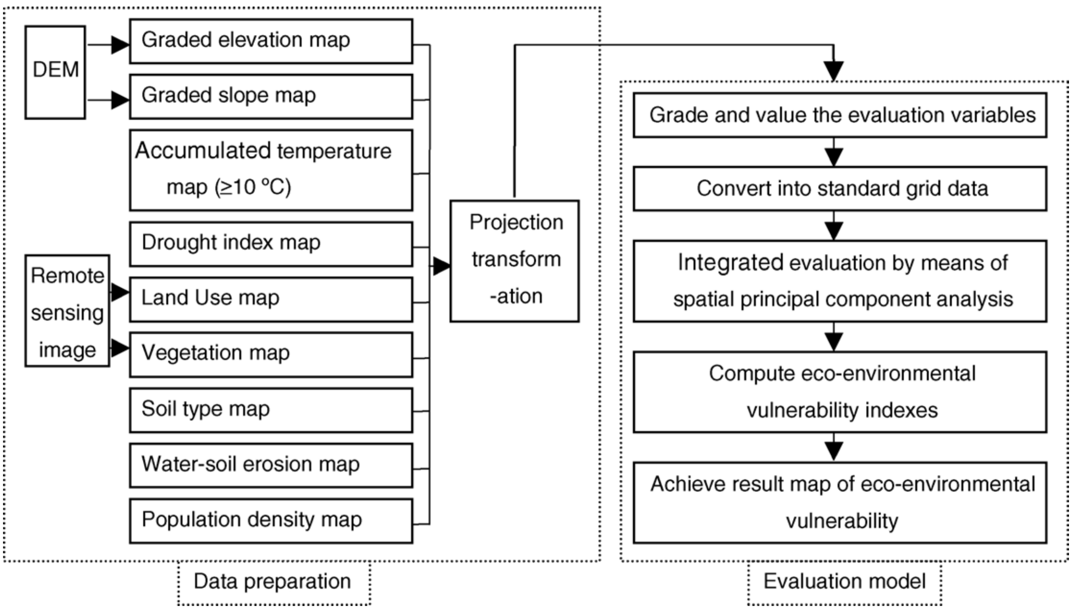

Fig. 2. Schematic representation of numerical model of eco-environmental vulnerability evaluation by means of spatial principal component analysis.

Table 1
The results of spatial principal component analysis in the study

	Selected principal components					
	I	II	III	IV	V	VI
1972a						
Eigenvalue λ_i	7.7357	4.0959	3.0406	2.0873	1.4426	1.2647
Contribution ratios (%)	34.930	18.495	13.730	9.425	6.514	5.711
Cumulative contribution (%)	34.930	53.425	67.155	76.580	83.094	88.805
1986a						
Eigenvalue λ_i	7.7340	4.0959	3.0413	2.0877	1.4444	1.2649
Contribution ratios (%)	34.908	18.487	13.728	9.423	6.520	5.709
Cumulative contribution (%)	34.908	53.396	67.123	76.546	83.066	88.775
2000a						
Eigenvalue λ_i	7.7326	4.1025	3.0310	2.1186	1.4435	1.2744
Contribution ratios (%)	34.666	18.392	13.588	9.498	6.471	5.713
Cumulative contribution (%)	34.666	53.058	66.646	76.144	82.615	88.328

ance matrix R of each variable; (3) to compute an eigenvalue λ_i of matrix R and its corresponding eigenvectors α_i; (4) to group α_i by linear combination and put out m principal components. In the software environment of the GRID module in geographical information system software ARC/INFO, the function PRINCOMP is used to transform the data in a stack from the input multivariate attribute space to a new multi-variate attribute space whose axes are rotated with respect to the original space. The axes in the new space are uncorrelated. According to the cumulative contribution of principal components, the number of components is affirmed 6 and SPCA is accomplished. The corresponding results are shown in Table 1. Then, an evaluation function can be set up to compute an integrated evaluation index on the basis of selected components.

Index E is defined as sum of a couple of weighted principal components shown as below:

$$E = \alpha_1 Y_1 + \alpha_2 Y_2 + \cdots + \alpha_m Y_m \tag{1}$$

In the formula, Y_i is no. i principal component, while α_i is its corresponding contribution.

According to each component's weight and generated stack, the algebra computation is worked out and evaluation indexes are put out pointing the situation of regional eco-environmental vulnerability, defined in this paper as eco-environmental vulnerability index. The higher the EVI value, the more vulnerable eco-environment is.

Derived from Table 1 and formula (1), the linear formulas for computing EVI is created as follows:

$$\begin{aligned}
\mathrm{EVI}_{1972} &= 0.3493 \times A_1 + 0.1850 \times A_2 + 0.1373 \\
&\quad \times A_3 + 0.0943 \times A_4 + 0.0651 \\
&\quad \times A_5 + 0.0571 \times A_6 \\
\mathrm{EVI}_{1986} &= 0.3491 \times B_1 + 0.1849 \times B_2 + 0.1373 \\
&\quad \times B_3 + 0.0942 \times B_4 + 0.0652 \\
&\quad \times B_5 + 0.0571 \times B_6 \\
\mathrm{EVI}_{2000} &= 0.3467 \times C_1 + 0.1839 \times C_2 + 0.1359 \\
&\quad \times C_3 + 0.0950 \times C_4 + 0.0647 \\
&\quad \times C_5 + 0.0571 \times C_6
\end{aligned}$$

In the formula, EVI is eco-environmental vulnerability index, A_1–A_6 are six principal components sorted out from nine initial spatial variables in 1972. Similarly, B_1–B_6 are principal components in 1986, and C_1–C_6 are the ones in 2000. The cumulative contribution of the six components is 88.80% (1972a), 88.77% (1986a) and 88.33% (2000a), respectively. Each of them lays in 85–95%, which accord with the convention of choosing factors by PCA method with a high reliability. However, there is still an information loss of about 11.00% when the number of selected components reaches six, which shows that the initial factors have relatively independent function on evaluation.

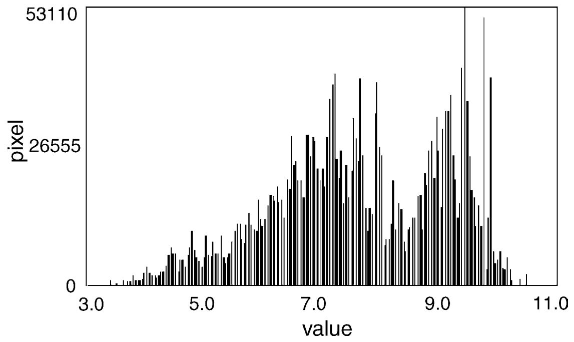

Fig. 3. Data distribution histogram of the integrated index of eco-environmental vulnerability in 2000a.

2.5. Vulnerable gradation

The result computed from EVE model is a continuous value, which should be classified into several levels standing for different eco-environmental vulnerability. The classification is crucial to evaluation, so it should be objective and logical. Histogram is a graphical tool to explore the statistical distribution of the classes and clusters in the attribute space (Apan, 1997). This study applies the cluster principle to discrete the computed result through analyzing the histogram of index distribution to line out the dividing points between "cluster" and "cluster". Taking year 2000 as an example, the average value of EVI is 7.585 and standard error is 1.305, which can be looked as polarized normal distribution ranging from 3.2 to 10.1 and there appear obvious "vale" at 4.7, 6.1, 7.8, and 9.2 (Fig. 3). Under the supervized by this standard, eco-environmental vulnerability in the study is graded into five levels defined as potential, slight, light, medial, and heavy levels, and each level is characterized by typical feature, shown in Table 2.

2.6. Analysis of change trend

For quantitative analysis of change trend on eco-environmental vulnerability, an integrated index standing for vulnerable situation should be given. According to the vulnerability, every grade is granted a quantified value, respectively, which is as follows: potential vulnerability is graded I, slight vulnerability is II, light vulnerability is III, medial vulnerability is IV, and heavy vulnerability is V (shown in Table 2). The formula for defining Eco-environmental Vulnerability Integrated Index (EVSI) is shown as below:

$$\mathrm{EVSI}_j = \sum_{i=1}^{n} P_i \times \frac{A_i}{S_j} \qquad (2)$$

In this formula, n is the number of valuation grade, EVSI_j the EVSI in unit j, A_i the occupied area of grade i in analysis unit j, S_j the area of analysis unit j, and P_i is the graded value of grade i.

In general, the whole change trend can be worked out from change of EVSI value. This paper analyses the change trend through comparing the EVSI value of each period and the distribution of each level.

3. Results

3.1. Vulnerability grade

According to the standard mentioned above, the integrated evaluation indexes in 1972, 1986, and 2000

Table 2
The result of eco-environmental vulnerability classification in the upper reaches of Minjiang River-valley

Evaluation level	Number	EVI	Feature description
Potential vulnerability	I	<4.7	Stable ecosystem, great anti-interference ability, rich soil, and relatively low altitude
Slight vulnerability	II	4.7–6.1	Relatively stable ecosystem and anti-interference ability, rich soil, and relatively low altitude
Light vulnerability	III	6.1–7.8	Relatively unstable ecosystem and poor anti-interference ability, bad-quality soil, and complex vegetation distribution type
Medial vulnerability	IV	7.8–9.2	Unstable ecosystem, poor anti-interference ability, deteriorated soil, and dominated by alpine shrub grassy marshland
Heavy vulnerability	V	≥9.2	Extremely unstable ecosystem and poor anti-interference ability, deteriorated soil, and sparse vegetation dominated by extreme-coldness plants

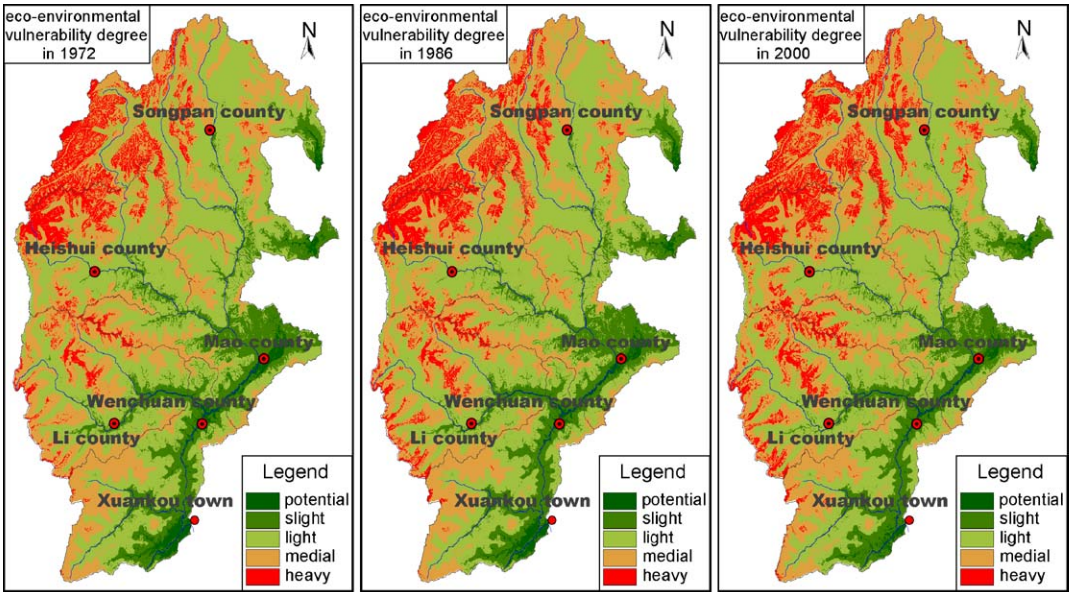

Fig. 4. Distribution of eco-environmental vulnerability in study area, showing the eco-environmental vulnerability level in 1972, 1985 and 2000, respectively, as well as a general change trend since the red region standing for "heavy" is expanding gradually from 1972, 1986 then to 2000.

are classified to generate corresponding results shown in Fig. 4. Taking the year of 2000 as an example, it can be seen from Table 3 that the light vulnerable zone lies within average-value range with the largest area proportion accounting for 42.08%, the medial vulnerable zone account for 33.12%, the slight vulnerable zone account for 12.08%, and the heavy vulnerable zone accounts for 11.28% while potential vulnerable zone only accounts for a very small proportion of 1.44%. The profile of index shows an asymmetry normal distribution and the center of profile lean to "heavy" level, shown in Fig. 5.

3.2. Change trend of vulnerability

According to the formula (2), the value of EVSI of whole study area and each county can be worked out, shown in Tables 3 and 4. The general change trend of eco-environmental vulnerability is analyzed from Table 3, which is the situation in 1972 with an EVEI 3.3116 is better than in 1986 with an EVEI 3.3729, and the latter is better than in 2000 with an EVEI 3.4027. The bigger the value of EVSI means the more serious eco-environmental vulnerability. In sequence of time, change of area occupied by each evaluation level is sur-

Table 3
The results computed from formula (2) and the proportion of each level in whole study area

Eco-environmental vulnerability level	1972			1986			2000		
	Grid number	Percentage	EVSI	Grid number	Percentage	EVSI	Grid number	Percentage	EVSI
I	58569	2.38	3.3116	46434	1.89	3.3729	35470	1.44	3.4072
II	323693	13.17		312759	12.73		296755	12.08	
III	1077523	43.85		1025427	41.73		1033933	42.08	
IV	788422	32.08		823369	33.51		813881	33.12	
V	209090	8.51		249307	10.15		277250	11.28	

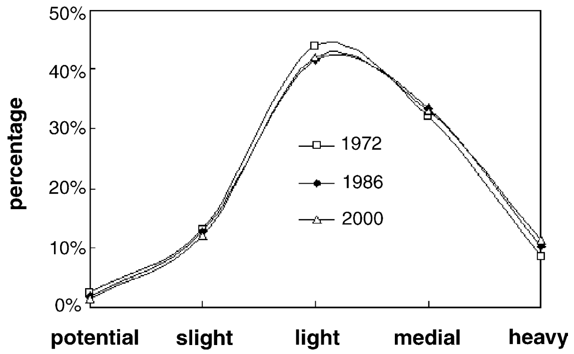

Fig. 5. Eco-environmental vulnerability index profiles in 1972, 1986, and 2000, respectively. It shows an asymmetry normal distribution.

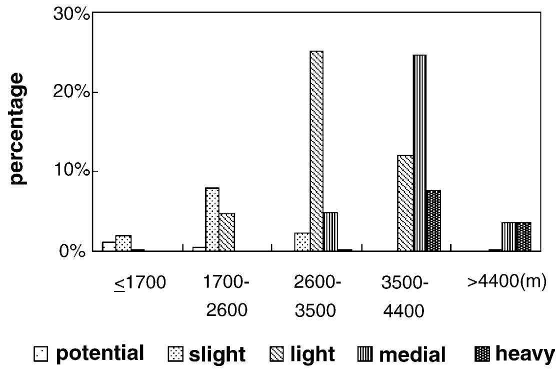

Fig. 6. Distribution of each eco-environmental vulnerability level in each elevation belt in 2000a.

veyed as follows: (1) from the year of 1972 to 1986, levels I–III are decreased 0.34, 0.44 and 2.12%, respectively, correspondingly, levels IV and V are increased 1.43 and 1.64%, respectively; (2) from 1986 to 2000, levels I and II are decreased 0.45 and 0.65% continuously on the basis of year 1986, while level III is increased 0.35%, level IV decreased 0.39%, and level V increased 1.13%. Fig. 5 further shows a degradation trend of eco-environmental vulnerability, which is shown that the asymmetry normal distribution center of index profiles has been transferring towards heavy vulnerability during late 30 years, yet the transferring speed slowing down in latter half stage.

3.3. Geographical distributional pattern

Eco-environmental vulnerability in study area presents distinct vertical-belt distribution. As is shown from Fig. 6, the vulnerability is related to altitude obviously, in which levels III and IV are most widely distributed and mainly in elevation belt ranging from 2600 to 4400 m, levels I and II distributed below the elevation 2600 m, and level V distributed above the elevation 3500 m. Similarly, eco-environmental vulnerability in this region also has clearly geographical horizontal-belt distribution. In general, the vulnerability is heavy in the north while it is relatively light in the south. It is shown from Table 4 that the situation (e.g. 2000a) in Wenchuan (with EVSI 2.9187) and Mao (with EVSI 2.9505) County are better than the average of the whole area (with EVSI 3.4072), while Li, Heishui, and Songpan County are worse than the average. Through the comparison between counties, the order from best to worst is: Wenchuan, Mao, Li, Songpan, and Heishui County, which is exactly corresponding to the latitude of each county from south to north.

Table 4
EVSI of each county in upper reaches of Minjiang River-valley in 2000a

EVSI	
Wenchuan	2.9187
Mao	2.9505
Li	3.5400
Songpan	3.6309
Heishui	3.7268
Total area	3.4072

3.4. Eco-environmental vulnerability regionalization

To make study results effectively serve as a base of local eco-recovery, it is necessary to regionalize the eco-environmental vulnerability so as to further plan the eco-rebuilding in order of importance and urgency. Hall and Arnberg (2002) argued that the environment regionalization should focus on the natural boundaries evolved from a long period of natural environment changes more than the administrative boundaries. This study uses EVI as an integrated index to regionalize study region, considering the regional characteristics and practical needs of eco-recovery work. Eco-environmental vulnerability in study area is spatially divided into the following three sub-regions, shown in Fig. 7.

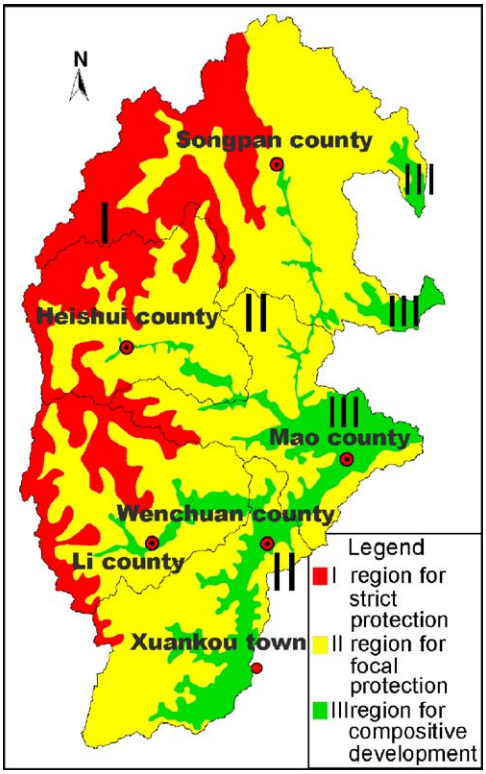

Fig. 7. Regionalization of ecological environmental vulnerability.

I. Heavy vulnerability region for strict protection. It is mainly concentrated in northwestern parts of Li, Heishui, and Songpan County and a small distribution in edge belts of Wenchuan and Mao Counties lying in the borders of three counties, with an area of 601,200 km^2 accounting for 24.32% and a low population density below 10 person/km^2. The landform is characterized by high mountains and hilly lands, of which ecosystem is composed of alpine coniferous forest, alpine scrub, and plateau meadow.

II. Light and medial vulnerability region for focal protection. It is distributed in five counties with an area of 1,495,067 km^2 accounting for 60.47% of the whole study area and low population density below 20 person/km^2 in most area. The landform is medial and low mountains, of which the main ecosystem types are middle-mountain shrub meadow, alpine evergreen broadleaf forests, alpine coniferous forests, plateau meadow, plateau shrub meadow, and plateau coniferous-shrub mixed forest. It is obvious that the ecosystem is complex and diversiform with the highest vegetation coverage.

III. Slight vulnerability region of comprehensive developing medial-and-low-mountain valleys. It is distributed in five counties with an area of 376,079 km^2 only accounting for 15.21% of study area which is a core of economic development, the most densely populated area as well as a main concentrated region of farmlands, but mainly distributed in the two counties of Wenchuan and Mao. It is a middle-and-low mountain valley, of which the main ecosystem types are middle-low-mountain shrub meadow, middle-mountain evergreen forest, middle-mountain coniferous-broadleaf mixed forest, and valley shrub meadow.

4. Discussions

4.1. Evaluation of result

In general, eco-environment in study area is at medial level for that the light vulnerability level occupies the largest area proportion accounting for 42.08%, which is in agreement with the results obtained by Doctor Ye (2004) by applying the landscape ecology theory. Meanwhile, the EVI presents apparent geographical distribution. Since the EVI ingests the information of all input variables, which have evolved from natural environmental development along with regional geographical distribution. The study area is characterized by typical middle-high mountainous area with landforms rising and falling violently. Mountain spread, slope direction and degree, and vertical changing climate cause great difference in natural resources and obvious identity of human activities. It shows that the results strictly represent regional feature.

4.2. Analysis of eco-environment vulnerability change driving forces

The eco-environmental vulnerability is changing during study period, and its' change trend shows in accordance to woodland coverage change. In past 30 years, comparatively stable eco-factors, such as landform, water-heat condition and soil type have very limited influence on eco-environmental vulnerability changes in this region (Bao and Wang, 2000). Correspondingly, the driving forcings for the changes is mainly related to the impact of social economic, resulting in increasing pressure of human on land, which lead to rapid changes of land use (Li, 2003). Thus, the coverage of land is cutting down, and soil erosion is intensified eventually, resulting in a further degradation of eco-environment.

As was recorded in *Marco Polo Travel Notes*, 600 years ago the main stream and branches of Minjiang River were covered by boundless forests with a coverage of 50%, however, in the early 1950s, there was only a forest coverage of about 30% (Expedition of Minjiang River, 1980), which revealed a general degradation trend of eco-environment in this region. Nevertheless in 1960s, with sprang of the mass steel-making movement and the great leap forward,[1] woodlands suffered a complete destroy, resulting in a rapid decrease of forest coverage down to 18.80% in 1980 (Nu, 1999). In late 1980s, forestation came to be regarded as an important forestry eco-industry, however, since the financial income of Songpan, Li, and Heishui Counties in upper reaches mainly come from wood industry, and thus wood overexploitation cannot be stopped basically. According to the study of author (Li, 2003), the flow in Minjiang River is well correlative with woodland coverage. When woodland coverage is below 18.46%, the mainstream of Minjiang River perhaps dries up with blocks the flow during dry season, while peak flew will turn bigger in flood season. In fact, in late 1990s, there continuously appeared the cut-off streams in Minjing River (Ding, 2001). After super flood in 1998, the execution of the policies of Natural Forest Protection and Grain for Green[2] was beneficial to the restoration of forest in the upper reaches of Minjiang River, whether the degradation trend can be reversed completely requests a further supervision in that eco-environment is also closely related to other natural geographical aspects together with human activities.

[1] The mass steel-making movement and the great leap forward are two economic movements occurred in late 1950s and early 1960s in china without respect to sustainable development, in which a great of natural resource including trees was consumed.

[2] The Natural Forest Protection and Grain for Green are two eco-environmental protection policies, which direct that lumbering be prohibited in natural forests and the cultivated scarp land should be return to grassland and woodland.

4.3. Function of sub-regions

As mentioned above, the study area is planned into three sub-regions to direct the eco-recovery work. Each sub-region has its' own function, which is addressed as follows:

1. Region I is the main fountainhead in the upper reaches of Minjiang River. Mitsh and Day (2004) augured that river is a whole ecosystem with unsymmetrical features between upper and lower reaches, and the upper reaches of a river should be a key region for environmental protection. And this sub-region is located at high altitude area, there is great difficulty in recovering vegetation once they are destroyed (Bao and Wang, 2000). Therefore, this region should be strictly protected from lumbering and pasture while strengthening eco-recovery building at the same time.
2. Region II has a wide distribution and is a buffer zone in the upper reaches of Minjiang River, which is particularly important for decreasing soil erosion. In addition, the elevation and water-heat conditions in this region are suitable to restoring destroyed vegetation. Therefore, it is a key recovery region in study area, in which should be stop lumbering, carry out a scheme of large-scale forestation, return farmland to grassland and woodland, and plan a reasonable project for pasture resources utilization.
3. Region III is an industrial base for whole study area. Wenchuan and Mao counties are the second-line vegetable base of Chengdu, besides they lie in the golden-travel route from *Chengdu* to *Jiuzhaigou* and *Huanglong*; thus, making their economy far ahead of other counties. In 2000, the total agricultural and industrial gross product of the two counties had reached US$ 228,825,000, accounting for 77.82% of whole study area. The most area in this sub-region is a well-known drought center in china owing to foehn effect, and characterized by a specific drought valley shrub landscape. However, according to study result, it can be predicted that further degradation will not appear. Therefore, regional economic development should be limited to a certain extent. It is very important and necessary to establish an eco-environmental economic compensation mechanism, which should be used to adjust human activities, so as to develop

middle-and-low valleys comprehensively. The practical measures are that build multi-functional mixed eco-forest with the focus on an agriculture-forest mixed ecosystem, and afforest uncultivated mountains and lands.

5. Conclusions

This study focuses on an idea about eco-environmental vulnerability in a typical mountainous valley, and evaluates the situation and its change in eco-environmental vulnerability in the upper reaches of Minjiang River. A numerical evaluation model is developed to analyze eco-environmental problem in mountainous region under the support of RS and GIS. And the SPCA method is used to determine the variables and their weights. From the study, we draw the following conclusions:

1. Eco-environmental vulnerability in study area is at medial level, and its distribution is of apparent vertical and horizontal zonal nature. In recent 30 years, the situation has been transferring towards heavy vulnerability yet with a slow-down speed in the last 15 years, for which the driving forcings have been mainly due to the pressure caused by unrational rapid development of social economy and the contribution of environmental protection policies, such as Grain for Green and Natural Forest Protection implemented since 1998. The results indicate it is urgent that, besides the improvement and reinforcement of compensation mechanism construction, the work of eco-environmental recovering and rebuilding should be carried out according to regionalization.
2. The results of this study also indicate that the method that integrates the technologies, such as RS and GIS, and the SPCA mathematical approach to evaluate eco-environment vulnerability in mountainous region, cannot only distinctly represent the input subject spatial distribution of mountain vertical-belt feature, but also respect the river-valley as a whole system.

Additionally, there is not too much combination between eco-environmental vulnerability study and regional environmental eco-mechanism, and the focus is put on large-and-medial scale (1:100,000 spatial scale and 14-year temporal span) with little involvement of small-scale especially micro-temporal-spatial scale. As proved by previous studies, scale has a great influence on the analysis results (Burnett and Blaschke, 2003; Store and Jokimäki, 2003), which leaves a vast exploration space for next-step research.

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