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Evaluation of Eco-Environmental Vulnerability Using RS and GIS: Case of Ma Keng Iron Mining Area in Fu Jian Province, China

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Abstract: Mining activities are always associated with disturbances and negative eco-environmental changes to the natural ecosystems due to vegetation clearing, soil and water quality degradation and air pollution. Makeng mining is the biggest iron mine in Eastern China. The area has undergone severe eco-environmental changes due increasing anthropogenic activities aiming at exploring the iron ore and other minerals. Mining activities are accompanied by other human activities which include roads and industries construction, clearing of vegetation, construction of workers houses, sedimentation ponds and tailing dams. Soil-water erosion is acute because of the vegetation cover removal and is worsened by the mountainous nature of the area. The aim of this research was to evaluate the eco-environmental vulnerability of Ma Keng mining area for the past 15 years using a numerical environmental evaluation model. Application of GIS and RS technology, assisted by statistical software (SPSS) enabled the extraction and preparation of eco-vulnerability factors and development of the environmental numeric model. This was eventually used to evaluate eco-environmental vulnerability of Ma Keng mining area. Nine eco-environmental vulnerability variables were included in the model namely slope, elevation, soil types, land use, vegetation types, industrial dust pollution, industrial sulfur dioxide gas (SO_2) emission and soil erosion. An Eco-environmental Vulnerability Index (EVI) of the study area for the years 1992, 1998, 2001, 2004 and 2007 were calculated using the environmental numeric model and the results were classified using the cluster principle. The research results showed that the eco-environmental vulnerability integrated index (EVSI) was increasing with time from 1992-2007. The results further revealed that the eco-vulnerability degree is vertically distributed, whereby the low elevation regions are worse than those in higher elevations. To reverse the intensification of eco-vulnerability, improvement in implementation of voluntary and legal environmental protection measures and ecosystem approaches are required.

Key words: Eco-environment, vulnerability evaluation, GIS, RS, principle component analysis

INTRODUCTION

The eco-environment problem is attracting a lot of attention in the new century (Zhoushi and Hongyi, 2007). Rapid economic growth in some developing countries has resulted in widespread and severe environmental degradation, increasing pollution of air, water and land (Niu and Harris, 1996). Destruction of forest vegetation has brought about deterioration of the ecological environment such as increasing soil and water losses and decreasing biodiversity (Qiao *et al*., 2004).

To quantify the degree of eco-environmental changes that has taken place and suggest some restoration measures, eco-environmental evaluation and the degree of vulnerability must be assessed. Several methods for ecological environment evaluation are available.These include a combination of RS, GIS and Spatial Principle Components Analysis (SPCA) (Li *et al*., 2005) comprehensive evaluation method (Goda and Matsuoka, 1986), landscape evaluation method (Antonio *et al*., 2003) and Fuzzy evaluation method (Liem *et al*., 2002). According to Li *et al*. (2005), most of the previously used eco-environmental assessment methods can be used only for quantitative analysis. In addition, there are some difficulties in the process of variables to use in the models. However, advancement in remote sensing, Geographic Information System (GIS) and numerical modeling techniques gives a way to develop powerful tools for eco-environment assessment procedures (Zhang *et al*., 2003; Li *et al*., 2005).

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The main objective of the study presented in this study was to evaluate the eco-environmental vulnerability of Ma Keng mining area using an environmental evaluation numerical model. Specific objectives were: To develop EVI model using GIS and SPCA, To use EVI model to analyze the eco-vulnerability status of Ma Keng area from 1992-2007, To classify the eco-environmental vulnerability by cluster principle and To produce maps showing eco-environmental vulnerability distribution and the index which shows the change of its trends for the past 15 years.

GIS and RS technology played a great role in extraction and preparation of the eco-environmental vulnerability evaluation attributes. Both natural and human induced attributes were considered. The Land use and vegetation cover maps were derived from satellite imageries (TM10 and ETM+7 image data with a resolution ranging from 25-30 m) through classification and interpretation of the land cover features. Terrain characteristics namely slope and elevation were derived from the Digital Elevation Model (DEM). Industrial pollution data (sulfur dioxide gas and dust) were obtained from the industrial emission monitoring data. Demographic data were extracted from social-economic reports in the study area while soil types and soil erosion data were prepared from the available primary data using GIS computer analysis operations.

SPSS capability to produce the weight and the correlation coefficients of the eco-environmental vulnerability attributes helped to develop the numeric model for EVI calculation and the production of EVI maps.

MATERIALS AND METHODS

Study area: Makeng mining area is located between longitude 117° 2' 30"- 117° 6' 04"East and 25° 0'0"- 25° 3'30" North. The area is found in Xin luo district in Long yan city, Fujian province. This mining area is situated in the South East of Long yan basin (Fig. 1). It is about 15 km away from Long yan city. The landform is mountainous, whereby the highest point is Tian Shang ao on the Northeast (1069 m). The lowest elevation is found in the Makeng Village in the Southwest with elevation of 420 m. The elevation difference between the highest and lowest points in the area is 600 m. The main river in Makeng mining is Xi Ma River, flowing from the South to the North where it enters the Long yan basin.

The area lies in subtropical, monsoon climate characterized by warm and humid conditions. There are no extreme temperatures in both summer and winter. Average annual temperature is 19.9°C. The hottest month is July (38.1°C) while the coldest month is January (-5.6°C). The average annual rainfall is 1692 mm. It usually rains in mid May, June, July and August. The rains in July and August are associated with typhoons. The total sun illumination is about 1979.1 h per year.

Data types

Primary data: Primary data in this research included DEM, satellite images (TM and ETM), soil types map, population statistics, industrial dust and sulfur dioxide gas pollution quantitative data. The primary remote sensing images data were obtained from the "3S" (GPS, GIS and RS) laboratory in the school of environment

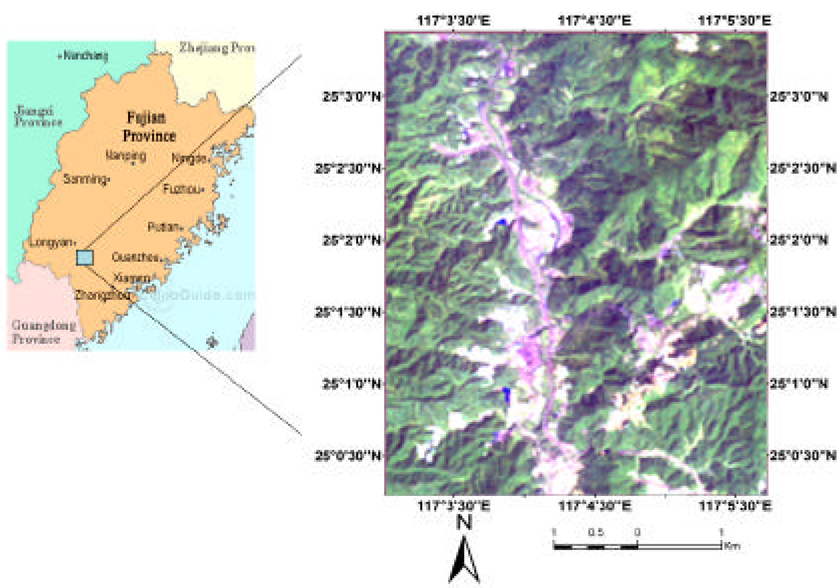

Fig. 1: Location of the study area

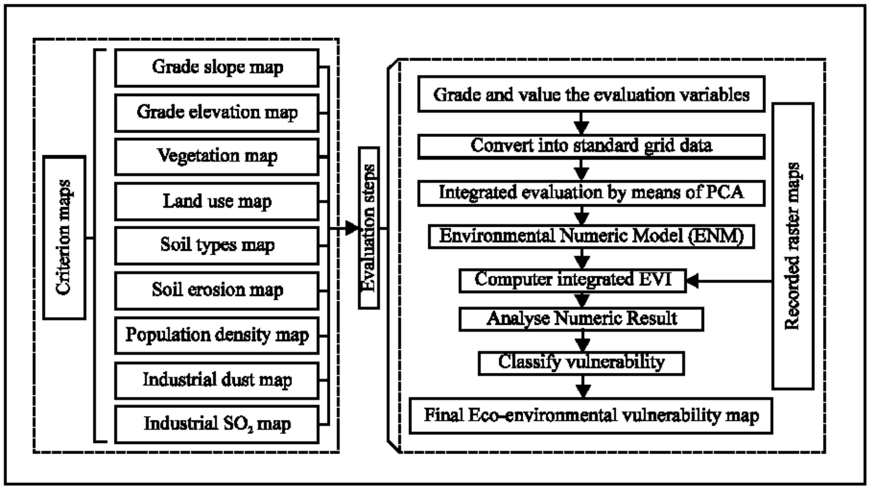

Fig. 2: Flow diagram to show steps of numerical model of eco-environmental vulnerability evaluation by means of principal component analysis coupled with GIS

Table 1: Types of remote sensing images data

Satellite ID and Instrument	Acquisition date	Resolution
Landsat-5,TM 10	1992-10-20	30.00 m
Landsat-5, TM 10	1998-12-08	25.00 m
Landsat-7, ETM+7	2001-11-22	28.50 m
Landsat-5, TM 10	2004-10-05	25.00 m
Landsat-5, TM 10	2007-09-12	25.00 m

of China University of Geosciences. Table 1 summarizes the RS data information.

Soil types and DEM data were already available in the above mentioned laboratory. Industrial sulfur dioxide gas and dust emission for the five cement and iron industries were extracted from the industries annual emission monitoring records.

Secondary data: Nine maps for eco-environmental vulnerability evaluation were prepared by processing the primary data. Soil types were digitized from the existing soil types map. Soil erosion maps in each year were prepared by performing GIS weighted overlay of slope, land use, vegetation types and soil types maps. The population density map was prepared by expressing the population figures into the polygons, where the whole area was divided into 4 watersheds. The area under influence of dust and sulfur dioxide gas pollution from each industry was delineated by creating voronoi polygons and a buffer of 1000 m from each industrial location. Vegetation cover and landuse maps were derived from the TM10 and ETM+7 data by performing image classification. All maps were georeferenced using UTM projection whereby WGS 84 spheroid and WGS 84 datum were specified.

Assessment of eco-environmental vulnerability: In order to assess the vulnerability structure of the eco-environment, there is a need to determine the factors which pose some negative impacts on the ecosystem and hence make the ecosystem prone or sensitive or vulnerable to degradation. The factors can be determined on the basis of an analysis of existing knowledge base. The use of the judgments made by different experts from different fields is of great importance. Vulnerability inducing factors are used as criterion separately. A criterion is a basis for a decision that can be measured and evaluated (Eastman *et al*., 1995). Layers representing the criteria are referred to as criterion maps. The criterion maps for this eco-environmental vulnerability evaluation were: Slope, Elevations, Soil types, Population density, Land use, Soil erosion intensity, Vegetation index, Dust and Sulfur dioxide gas.

In this research, the steps in Eco-vulnerability evaluation were grouped in two broad categories namely: Data preparation for EVI calculation model and Calculation of EVI and grading the vulnerability. The EVI calculation model data preparation involved: Standardizing maps, Reclassifying and RECODING each raster map. Raster to vector data conversion, Overlaying the vector maps and Performing factor analysis using PCA based on the overlaid map in SPSS. Calculation of the integrated EVI and grading vulnerability involved: Calculating the EVI using the eigenvalues and principle components from SPSS and then use the cluster principle to grade the eco-vulnerability. Figure 2 summarizes the steps involved in development of numeric model for evaluation of eco-environmental vulnerability using PCA.

During vector-raster map conversion, the grid size was limited to 25×25 m. It is also, on this spatial unit that all map algebra on this evaluation was based. In the process of standardizing the maps, each factor was classified into levels ranging from 1-10 based on its negative contribution to eco-environmental stability.

Table 2: Principle component analysis results from SPPS

Year		Retained principle components				
		1	2	3	4	5
1992	Eigenvalues (β)	3.194	2.078	1.222	0.819	0.651
	Contribution ratio (%)	35.486	23.092	13.581	9.102	7.233
1998	Eigenvalues (β)	3.417	1.435	1.183	0.928	0.689
	Contribution ratio (%)	37.966	15.950	13.147	10.315	7.660
2001	Eigenvalues (β)	3.292	1.480	1.252	0.810	0.729
	Contribution ratio (%)	36.583	16.449	13.914	9.003	8.098
2004	Eigenvalues (β)	3.460	1.934	1.064	0.946	0.589
	Contribution ratio (%)	38.450	21.491	11.825	10.506	6.541
2007	Eigenvalues (β)	3.767	1.739	1.117	0.715	0.529
	Contribution ratio (%)	41.859	19.323	12.406	7.948	5.876

Factor analysis using PCA in SPSS retained 5 out of the original 9 factors whose cumulative percentage were 88.50, 88.04, 85.05, 88.81 and 87.41% for 1992,1998, 2001, 2004 and 2007, respectively. Deciding the number of components to extract is a great challenge. Li *et al*. (2005) demonstrated that the components to be extracted should have the cumulative contribution lying between 85-95%. On the other hand, Landau and Everitt (2004), suggests retaining just enough components to explain some specified large percentages of the total variation of the original variables. Values between 70 and 90% are usually suggested.

KMO test values for 1992, 1998, 2001, 2004 and 2007 were 0.681, 0.780, 0.699, 0.728 and 0.753, respectively. These values justified the ability to conduct factor analysis since the distribution of the values of the factors was adequate. For factor analysis to be acceptable, the KMO value must be not less than 0.5. Bartlett's test significance value was 0.00 for all factor analysis performed. A significant value ($p<0.05$) indicates that the data do not produce an identity matrix and thus approximately multivariate normal and acceptable for factor analysis (George and Mallery, 2006).

Calculation of the integrated EVI and grading vulnerability: The eigenvalues (β) and principle components (α) played a great role in formulation of the integrated model for EVI calculation for each particular year. Consider Table 2 showing the eigenvalues and the contribution ratio for the 5 retained components (PC).

Based on the eigenvalues and the coefficients of the component matrices in Table 2, the EVI for the respective years were calculated based on the following function:

$$EVI = \beta_1 PC1 + \beta_2 PC2 + \ldots \beta_5 PC5 \tag{1}$$

where, β stands for the eigenvalues (percentage variance for each component) and PC is the principle component (α).

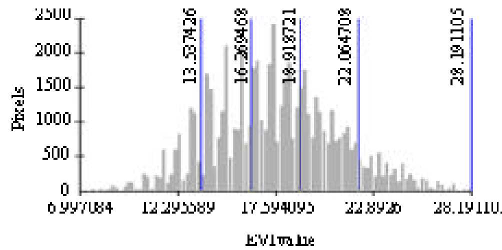

Fig. 3: EVI data distribution histogram in 2007

Table 3: EVI value classification results

Vulnerability evaluation level	Grade number	EVI value range
Potential	1	<13.54
Slight	2	13.54-16.27
Light	3	16.27-18.92
Medial	4	18.92-22.06
Heavy	5	>=22.06

Taking PC1 as an example, individual PC (1-5) was calculated using the following expression:

$$PC1 = \alpha_1 M1 + \alpha_1 M2 + \alpha_1 M4 + \ldots + \alpha_1 M9 \tag{2}$$

where, α is the coefficient of the component matrix tables, extracted by Principle components analysis. M1 to M9 are the 9 RECODED raster maps.

The same numeric function (1) above was used to calculate the EVI for 1992, 1998, 2001, 2004 and 2007. The coefficients of linear correlation offered the possibility to weigh the contribution of factors, which were later used for environmental evaluation using integrated evaluation index.

Gradation of vulnerability using cluster principle: The EVI obtained by integrated vulnerability index calculation was a continuous value. To quantify the vulnerability, the value was classified using the cluster principle. The histogram showing distribution of the EVI values was used as a tool to make the breaks among the vulnerability classes. Five classes were specified, these are Potential, Slight, Light, Medial and Heavy. The histogram of 2007 EVI map (Fig. 3) was used as the standard to cluster into grades the EVI data of the remaining years' EVI maps. The same grading approach was used by Li *et al*. (2005) to grade the degree of eco-environmental vulnerability. Figure 3 shows the histogram of EVI data distribution in 2007.

The resulting vulnerability evaluation levels and vulnerability grades from the cluster principle in Fig. 3 above are presented in Table 3.

Analysis of vulnerability change trend: The trend of eco-vulnerability change was analyzed using 2 approaches. The first one was a qualitative approach in which the eco-vulnerability degree value was divided qualitatively into grades: 1-Potential vulnerability, 2-Slight vulnerability, 3-Light vulnerability, 4-Medial vulnerability and 5-Heavy vulnerability. The analysis of vulnerability change trends for different years based on the grades of vulnerability was based on the area (ha) and area percentage (%ha) occupied by each vulnerability grade. Secondly, a quantitative approach was the application of the weighted sum of vulnerability value. The value obtained by calculating the total integrated vulnerability index (EVSI) for each year using the function given by Li *et al*. (2005) as shown in Eq. 3:

$$EVSI = \sum_{i=1}^{n} Pi X \frac{Ai}{Sj} \tag{3}$$

where, n is the number of valuation grade, P_i is the eco-environmental vulnerability grade i (1-5), A_i is the area occupied by eco-environmental vulnerability grade i and S_j is the total area under analysis unit j.

RESULTS AND DISCUSSION

The main objective of the research was to evaluate eco-environmental vulnerability of Makeng mining area

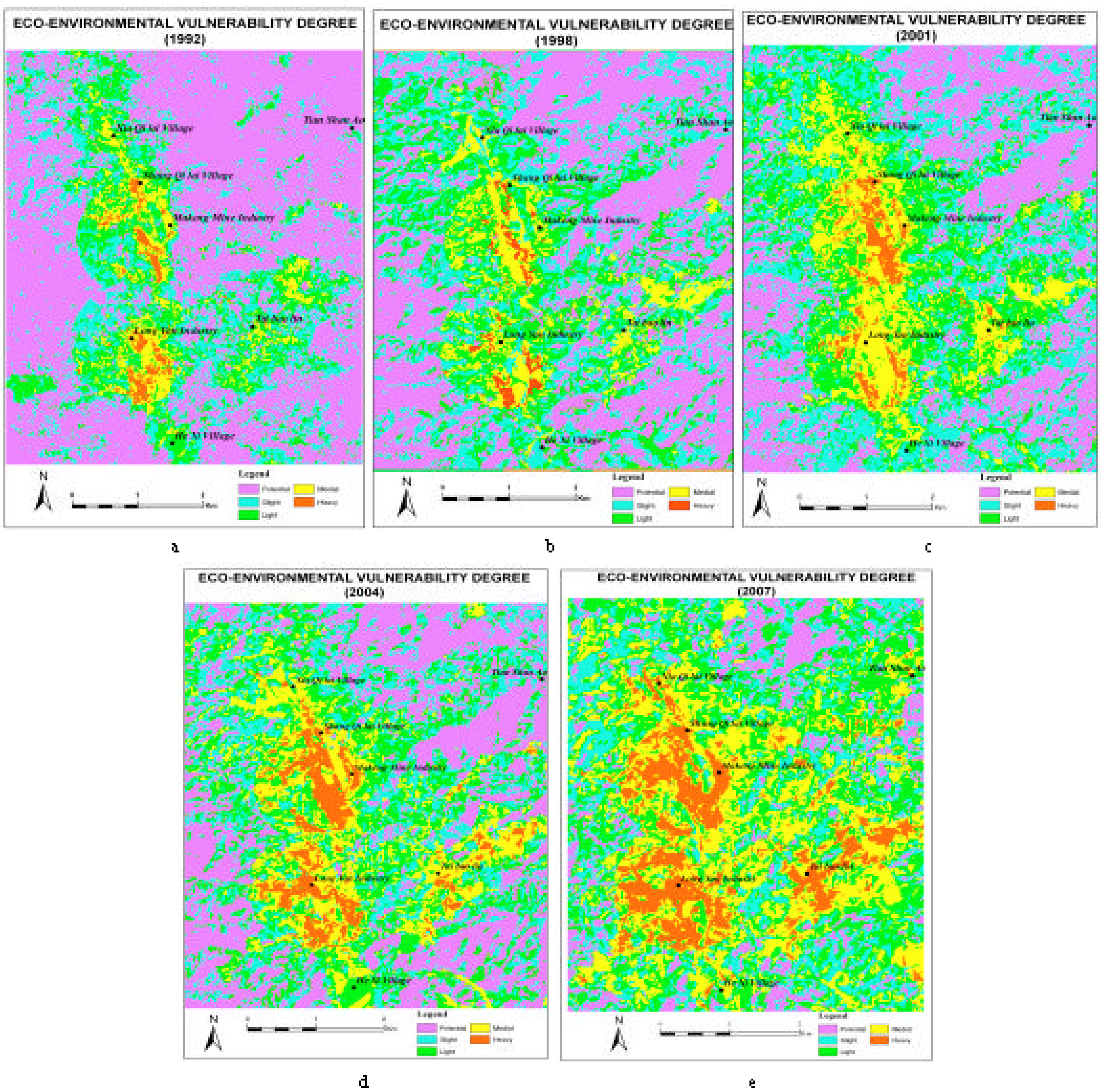

Fig. 4: Maps to show the eco-environmental vulnerability grades and their distribution for 1992, 1998, 2004 and 2007. Key: red = Heavy, yellow = Medial, green = Light, cyan = Slight and purple = Potential

for the years 1992, 1998, 2001, 2004 and 2007 using a numeric evaluation model. The application of the EVI Eq. 1 and the cluster principle for vulnerability gradation (Fig. 3) facilitated the production of the 5 maps for the aforementioned years, which show the spatial distribution of the eco-environmental vulnerability and their grades. The maps are shown in Fig.4 a-e.

Patterns of eco-vulnerability distribution: Through the visual interpretation of Fig. 4 above, the heavy vulnerability grade seem to extend outwards all directions from the center of the Makeng mining area, especially around Makeng mine and Long yan industries. As time lapsed, there was a kind of crawling and outward extension of the percentage land area accounted by heavy vulnerability. Figure 5 shows that in 1998, the environment was a bit resilient, where the percentage of land area under heavy vulnerability decreased to 0.9% compared with 6.6% in 1992 and that of potential vulnerability in 1992 increased from 34.7-40.7% in 1998. In 2004 and 2007, the heavy and medial levels of eco-environmental vulnerability spread and became more apparent in the eastern parts of the study area, especially in areas around Tai bao lin. The phenomenon was a result of increased mining activities around Tai bao lin which in turn led to clearing of vegetation covers and exposed the soils to erosion agents.

Change of eco-vulnerability distribution pattern: The eco-vulnerability status of the area has been shifting from Potential-Slight to Light-Medial as from 1992 through 1998, 2001, 2004 to 2007. Figure 6 shows the nature of the eco-environmental vulnerability distribution curves for the targeted years.

As demonstrated in Fig. 6, the curves for the years 1992 and 1998 are generally placed above those of 2004 and 2007 in the area under slight vulnerability grade zones. The curves for 2001, 2004 and 2007 lie above others in the medial vulnerability zone. The 2007 curve appeared to be polarized to the right of the vulnerability grades distribution graph and above other curves in medial and heavy vulnerability zones. This gives an indication that a large percentage of land in the study area is shifting from better to worse eco-environmental status.

Time based quantitative variations of eco-vulnerability degree: Ecological stability of the study area was observed to be very dynamic. The area is under the influence of different land use activities namely agriculture, infrastructure development, mining and industries. Based on the influence of these activities, the sizes of the area characterized by each degree of eco-vulnerability in each year have also been changing in a

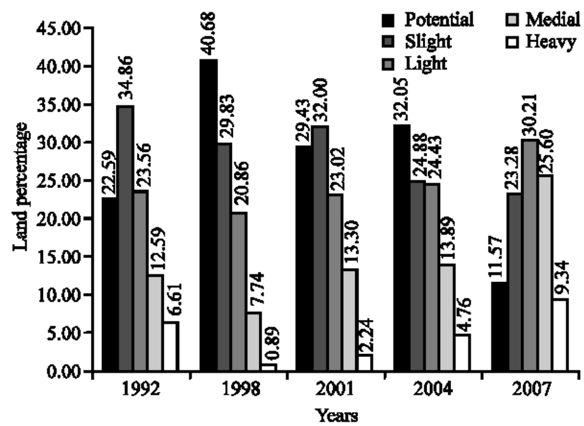

Fig. 5: Eco-environmental vulnerability grades dynamics expressed in percentage of land they cover against time

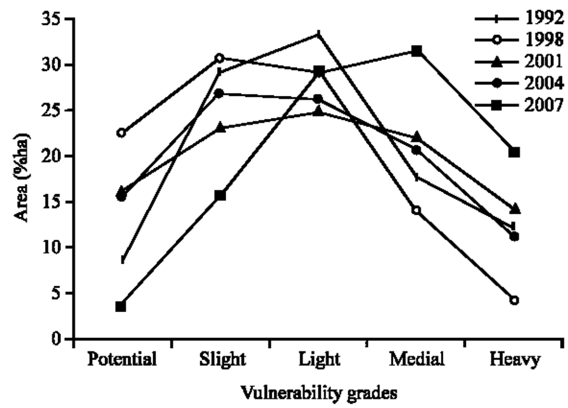

Fig. 6: Distribution pattern of vulnerability grades for the selected years of study

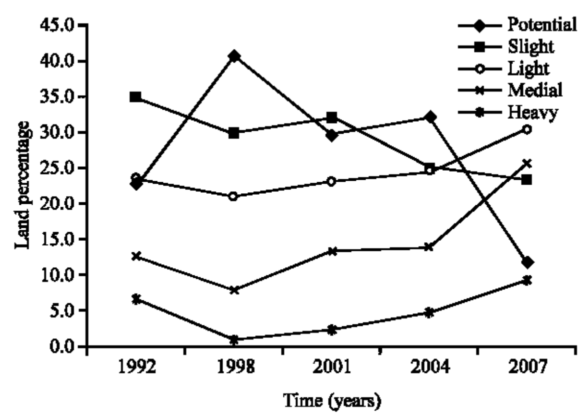

Fig. 7: Land percent characterized by different eco-environmental vulnerability grades at different years

fluctuating pattern. There is neither continuous increase nor decrease of a particular vulnerability grade. Figure 7

Table 4: Variation in integrated EVI with time

Year	EVSI	Change in EVSI	EVSI change (%)
1992	1.70		
1998	1.98	0.28	16.58
2001	2.27	0.29	14.42
2004	2.34	0.08	3.31
2007	2.98	0.63	27.06

and 5 stresses on the trends and the comparison the quantities of land (ha%) under different vulnerability grades at different time, respectively.

To be noted from Fig. 7, the increase in the percentage of land under potential vulnerability (22.6-40.7%) as from 1992 to 1998, led to the slight decrease in percentage of land occupied by other vulnerability grades in the period between the same years. As from 1998-2007, the percentage of land under heavy vulnerability has been increasing noticeably. There is a complex substitution of the percentage of land under different eco-vulnerability grades observed between 2004 and 2007. However, the percentage of land under potential and slight vulnerability grades in these 2 years decreased from 32.0-11.6 and 24.-23.3%, respectively. The area under heavy, medial and light vulnerability shot up from 4.8-9.3, 13.9-23.6 and 24.4-30.2% as from 2004-2007.

Eco-vulnerability integrated index change: The desire to explain the totality of the annual eco-environmental vulnerability status of a particular geographic location requires a single and integrated index. The index is usually used for comparison of the eco-vulnerability status of a given eco-environment for different times. Vulnerability index is a dimensionless measure of vulnerability to be used as a tool for monitoring and expressing the degree of vulnerability.

Equation 3 was used to calculate EVSI for the selected years under this study. Table 4 shows the EVSI and the change trends in both magnitude and percentage between the successive selected years. To be noted also, all changes are positive in view of the fact that EVSI data was increasing with time.

Although, Fig. 5 shows that the percentage of land area under heavy vulnerability grade decreased from 6.6-0.9% between 1992 and 1998, it does not mean that the eco-environment status was better in 1998 than that of 1992 as shown in Table 4. In general, the total eco-vulnerability status of the study area follows the order 1992<1998<2001<2004<2007 based on the eco-environment vulnerability integrated index values. The smallest difference in increase of the EVSI value was observed between 2001 and 2004 despite an increase in industrial dust loading from Ma Keng Mine industry in 2000. The reason for such observation could be a slight decrease of the forest land and small increase in the land converted into agriculture and grassland. During this period there was a slight natural recovery of the parts which were cleared for roads to the mining tunnels and other infrastructures. Major constructions (increase in urban features), decrease in forest land and expansion of agriculture/grasslands were observed between 2004 and 2007, hence can account for the great change in EVSI value (27.06%) as shown in Table 4.

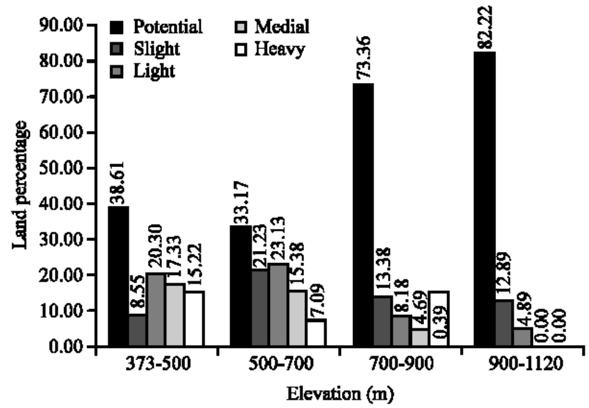

Fig. 8: Distribution of vulnerability grades along the elevation ranges in 2004

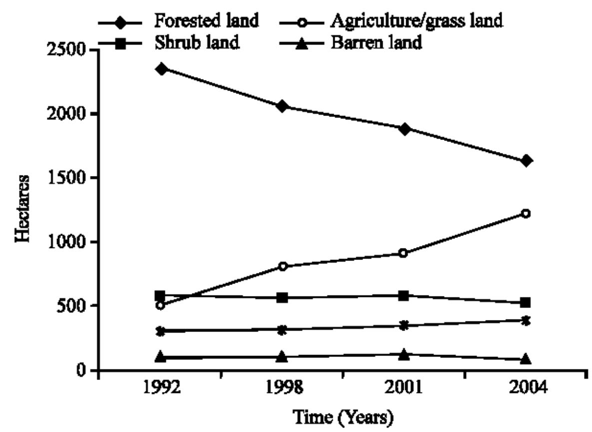

Fig. 9: The graph to show Land use change trends against time in the study area

Geographical distribution of eco-vulnerability: The study area terrain is “V” shaped, the central part being the lowest in elevation. The eastern and western parts are higher than the central parts. The elevation is directly and inversely proportional to the vulnerability grades. Taking the year 2004 for example, the percentage of land accounted for by heavy vulnerability is inversely proportional to elevation. It decreases with altitude, from 15.2, 7.1, 0.4-0% on elevations between 373-500 m, 500-700 m, 700-900 m and 900-1120 m, respectively. The slight and light vulnerability grades follow the similar trend as heavy vulnerability as shown in Fig. 8.

The reason for the above observed trend is due to the fact that human activities that put eco-environment into stress like agriculture (paddy fields), iron and cement industries, settlement and roads are concentrated on low elevations (373-500 m) and their intensity decreases with altitude. Only one big industry-Tai bao lin is located on elevations above 500 m. The areas between the elevations 700-900 m high have less human activities; most of the land in these elevations is covered by both thick and less dense vegetations and grasslands. These areas are found in the northeast, east and west zones of the study area. The highest elevation is found in Tian Shan ao (900-1120 m), the top of the area has flat to gentle slopes, free from human activities and largely covered by vegetation, as a result, the land percentage characterized with the lowest vulnerability (0%) and the highest potential vulnerability (82.2%) are found in the highest elevations. The potential vulnerability has a direct proportional relationship with elevation as from 1998-2007, whereby it increased from 33.2, 73.4 to 82.2% across the elevation ranges as shown in Fig. 8.

Driving forces of eco-environmental vulnerability: Nine factors are put into consideration in this study. They include both natural and human induced eco-environment stressors. Slope, population density and elevation parameters did not change during the vulnerability analysis. Soil erosion intensity was a function of land cover and land use changes for each particular year of study. There was a slight addition of dust pollution as from 2001 because Ma Keng Iron mine industry started its operation in the year 2000. Hence; it can be concluded that land use and vegetation cover changes are the main driving forces for the eco-environmental vulnerability in the study area. Consider the two figures below (Fig. 9) showing the land use types in terms of land percentage occupied each year of investigation.

CONCLUSION

This research was carried out to evaluate the eco-environmental vulnerability of the typical mountainous mining area of Ma Keng. The adoption of RS and GIS technologies and PCA played a great role in the development and scaling of the eco-vulnerability factors. They also facilitated the derivation and application of the numeric eco-vulnerability evaluation model. At the inception of the research, based on the Ma Keng project reports reviewed and the field survey undertaken, it was expected that the eco-environmental vulnerability would be found to be increasing from 1992-2007. Despite the fluctuations and dynamics in the land percentage accounted for by different vulnerability grades, the EVSI showed that the eco-vulnerability status of the study area was increasing with time although at different magnitude. The Increase was a function of the intensification of human activities year after a year. The distribution of the vulnerability grades respects the vertical and horizontal belts. Eco-environmental health status based on the eco-vulnerability degrees was found to be worse in the low elevations where most of the human activities are concentrated and better at high elevations. The major factors that led to the magnification of the eco-vulnerability in the study area were human activities namely mineral exploitation associated with construction of tailing dams. The presence of 20 local open-pit mines of limestone and iron has degraded the natural vegetation resulting in accelerated soil erosion, especially by water.

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