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Design a Dynamic Monitoring System of Land Degradation Using Geoinformation Technology for the Northern Part of Shaanxi Province, China

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Abstract: Northern part of Shaanxi Province is particularly vulnerable to decertification due to its fragile ecosystem and intensive human activity. Studies reveal that decertification is both a natural and anthropogenic process. Four decertification indicators (vegetative cover, proportion of drifting sand area, decertification rate and population pressure) were used to assess the severity of decertification in the region with Geoinformation technology (Remote Sensing, Geographical Information System 'GIS' and Global Positioning System 'GPS'). The first three factors were derived from multitemporal remote sensing. The last factor was calculated from census data. It was found that the overall severity of land degradation in the study area has worsened during the study period (twelve years) from 1987 to 1999 with severely, highly and moderately degraded land accounting for 88.9% of the total area in 1999. While the area affected by decertification has increased, the rate of decertification has also accelerated to reach 71.1 km^2 yr^{-1}. Risk of land degradation in the study area has increased, on an average, by 46.6% since 1987. Incorporation of both natural and anthropogenic factors in the analysis provides realistic assessment of risk of decertification. A dynamic monitoring system of land cover changes and land degradation was developed in Arc/View GIS. The county level soil resources data and pattern maps; land use, land cover changes and land degradation maps for the study area during the study period and their corresponding data are integrated in the monitoring system.

Key words: Land degradation risk, severity assessment, geoinformation technology, monitoring system, shaanxi

INTRODUCTION

According to the definition in UN convention to Combat Decertification, "Decertification" means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variation and human activities[1]. It is a significant task to monitor decertification status and dynamic changes timely and efficiently, to provide evidence for executives and planning sectors to assist them in making macro-decisions for combating decertification.

Land degradation is a process, which implies a reduction of potential productivity of the land[2]. The most typical and serious form of land degradation in China is the decertification. Decertified land covers an area of 3.3 million km^2, accounting for 34% of the total territory or 79% of the entire arid land in China[3]. Decertification has resulted in a direct economic loss estimated at between 0.2-0.25 billion US dollars while indirect losses may be two to three times higher. Decertified areas are currently expanding by 2460 km^2 annually, which is 1.58 and 1.17 times the rate recorded in the 1960s and 1970s, respectively[4,5].

The objectives of this study are:

1. Assess the decertification severity and calculating land degradation risk in the ecologically vulnerable area in the Northern part of Shaanxi Province, China.
2. Evaluate and delineate the current status of land degradation using Geoinformation technology.
3. Differentiate regional trends in land degradation hazard and
4. Develop a dynamic monitoring system of land cover changes in GIS environment at county level.

Study area: The Northern part of Shaanxi Province has been selected as the focus of this study. It includes four counties; Fugu, Shenmu, Yulin, Jiaxian and Yijin Huo Luo Qi county as well, which is located in Inner Mongolia Autonomous Region with a total area of 20,866.7 Km^2. The study area extends between latitude N 38°03' to N 39°45' and longitude E 109°19' to 110°29'.

Present population density averages at 45 persons Km^{-2}. Over the last decade population in the area has been growing at a rate of 18,300 people per annum. This area is a typical agro-pastoral region and an important energy and mineral base in China. It receives an annual

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precipitation of 392.5 mm. Most rainfall events occur during summer months. Underground water resource is relatively rich.

Presently, severe land degradation occurs mainly in the form of decertification. Overall, 88.5% of land has been decertified to varying levels, Yulin City being most decertified (96%)[6]. As an important coal base, the region will continuously be exploited for its natural resources in the future, worsening the degradation situation. Evidently, land degradation is not merely an environmental issue, but has social and economic implications as well[7].

MATERIALS AND METHODS

Data and pre-processing

Remote sensing data: A Landsat-5 thematic mapper (TM) imagery remotely sensed dataset was assembled for this study, the period analysed was 1987 and 1999, the pre-processing of this dataset included geometric corrections. All images were geometrically corrected not only to eliminate geometric distortions present in the images but also to register the satellite images to ground data. Ground Control Points (GCP) were extracted from vector files for the same region, using geographic features such as big and small rivers. Polynomials of first order were used in each registration. The nearest neighbor resampling method was used in datum WGS84 and projection UTM (49N). All images were resampled to a 30 m pixel grid. Crust index, NDVI and Tasseled Cap transformation[8] were applied on the TM images. The TM composites, vegetation cover, drifting sand images were interpreted and statistically analyzed to produce a decertification severity maps based on the vegetation cover and extent of drifting sand. Preliminary results of this task were verified in the field investigation by using GPS receiver.

Ancillary data: Set of land use maps, topographic maps, meteorological data and population census data for the study area were used in this study. Population pressure was calculated from census data of 1987 and 1998[9] on the basis of critical population density threshold of 20 persons km^{-2} for semi-arid regions as given by the United Nations[10].

Soil and vegetation indices

Crust index: A spectral crust index (CI) based on the normalized difference between the RED and the BLUE spectral values:

$$CI = 1-(RED-BLUE)/(RED+BLUE)$$

Applying the index to a sand dune and sand lands environment, it has been shown that the CI can be used to detect and to map, from remote sensing imagery[11].

NDVI: The normalized difference vegetation index (NDVI) was initially proposed by Rouse *et al.*[12]. NDVI derived from the ratio of band 3 and band 4 in Landsat TM images data was applied for monitoring vegetation changes in the study area within the years of 1987 and 1999.

$$NDVI = (TM4-TM3)/(TM4-TM3)$$

Thresholding was used to make a mask for separating the drifting sand and vegetation cover and then produce the degradation maps of the study area for the years 1987 and 1999.

Assessment of degradation severity

Degradation indicators and their weighting: Realistic assessment of decertification severity relies, first and foremost, on the identification of pertinent indicators[13]. Four indicators have been identified as critical to assessment of decertification severity in the study area: vegetative cover, extent of drifting sand, decertification rate and population pressure. The first two factors are prime indicators of land degradation and directly derivable from satellite imagery. Population pressure and expansion rate of decertified land are indirect, dynamic indices. They are critical indicators of land degradation hazard and its pattern of spatial-temporal change.

Degradation risk index: Land degradation risk is indicative of the overall degree of difficulty in rehabilitating degraded land in a given region to productive use. The higher value of this index has, the more severe the level of land degradation is. The following formulae is proposed for its calculation:

$$D_j = \sum_{i=1}^{n} P_{ij} \; C_i^{-q}$$

where, D_j ($0 \le D_j \le 1$) represents the risk of land degradation in the region j; C_i is the rank at which land in an assessment unit has been degraded; P_{ij} refers to the areal percentage of land having a rank I in relation to the total area of unit j; n stands for the number of degraded ranks; and q denotes the exponent of rank. An empirical value of 7.1, 5.9 and 0.6 were adopted for q after experimentation in this study for vegetation cover, drifting sand coverage and annual decertification rates, respectively. The calculation was carried out with county as the unit. D_j was calculated through a computer program for the individual counties.

RESULTS

Severity of land degradation: Figure 1 depict spatial distribution of the drifting sand coverage in the study area within 1987 and 1999, while Table 1 provides the related statistics. The results indicated that the vegetation cover percentage in Fugu and Shenmu declined from 15.3% in 1987 to 6.9% in 1999, are designated as severely degraded land (Table 1, 2 and Fig. 1).

Spatial pattern of land degradation: Figure 2 a, b show the vegetation degradation severity for the study area during the study period for 1987 and 1999, table 2 indicates the related statistics. On one hand all of the counties except Yijin Huo Luo Qi have more than 80% of their areas decertified at high level, while Yijin Huo Luo Qi County has more than 70% of its territory medium decertified. Comparison of the vegetation cover and the drifting sand coverage images which produced by applying Crust index and NDVI algorithms (Fig. 1) reveals that the extent of degraded land within the study area has expanded from Northwest toward Southeast, while the overall severity of land degradation has worsened. This has been confirmed by field investigation.

Decertified areas have advanced in a linear manner towards the southeast (Fig. 1). The highest vegetation degradation rate was in Shenmu; it was 62.7 km^2 yr^{-1}, while the highest drifting sand coverage expansion rate was 71.1 km^2 yr^{-1} in Yulin. Evidently, the rate of decertification has accelerated during the study period in the study region.

Water body decrease by an area of 79.9 km^2, distributes mainly in Yijin Huo Luo Qi, west of Shenmu and west of Yulin. This change suggests that the precipitation was likely to be declined and evaporation increased in the past twelve years in those areas. Urban and built-up area had both increased. From remote sensing data, urban built-up area increase by an area of 46.9 km^2 (Fig. 3 and Table 3).

Risk of land degradation: The risk for all counties became significantly higher with an annual average increment of 1.75%. In 1999, Yulin had the highest risk value at 0.82. Shenmu (0.72) and Yijin Huo Luo Qi, Fugu (0.70) had the medium level of risk while Fugu (0.60) and Jiaxian (0.58) and Jiaxian faced relatively lower risk.

In this study the land cover changes data (dependents) and land degradation index (independent) were incorporated and inputted in STATGRAPHICS plus 5 for regression modeling. The relationship between land degradation index and percentages of drifting sand and vegetation cover are shown in the following equation:

$$Ldi = 0.694105+0.0118028 (S)-0.020271 (V) [R^2= 0.886]$$

Fig. 1: Location map of the study area

Where:
LDi is the land degradation index,
S is the drifting sand cover percentage and
V is the vegetation cover percentage.

The statistical analysis also showed that the correlations between the land degradation index and the sand cover percentage and vegetation cover percentage was 0.57 and (-0.52), respectively.

Design of the dynamic monitoring system: Based on the above procedures, a dynamic monitoring system of land cover changes was developed in Arc/View GIS. The county level soil resources data and pattern map, land cover changes in the recent decades and their corresponding data are integrated in the monitoring system. The monitoring system includes he following thematic layers: Vegetation cover and drifting sands layers for the years 1987, 1999; Water bodies decrease; Urban extension; Coal Mining extensions; County boundary; Landsat TM composite 741 for the years 1987 and 1999. Figure 3 shows the all layers for the study area.

DISCUSSION

The results of this study indicated that land degradation is a result of natural and anthropogenic factors. Overlay of decertification severity layers interpreted from multi-temporal remotely sensed materials in a GIS, in conjunction with field investigation, revealed that the spatial extent of decertified land in the area has

Table 1: Drifting sand coverage percentages and its increasing rates of the study area for the period from 1987 to 1999

		Drifting sand 1987		Drifting sand 1999		DS_1999-DS_1987		
Countries	County area (km²)	(km²)	(%)	(km²)	(%)	(km²)	(%)	Drifting sand rate km²/yr
Fugu	3176.62	50.45	1.588	54.99	1.73	4.54	0.14	0.37
Shenmu	7464.70	1122.06	15.032	1278.49	17.12	156.42	2.09	13.03
Yulin	5816.78	1180.98	20.303	2034.39	34.97	853.40	14.67	71.11
Jiaxian	1123.61	28.38	2.526	50.30	4.47	21.92	1.95	1.82
Yijin Huo Luo Qi	3284.98	677.99	20.639	871.86	26.54	193.86	5.90	16.15
	20866.69	3059.88	14.664	4290.04	20.55	1230.16	5.89	

Table 2: Vegetation cover percentages and vegetation degradation rate for the study area for the period from 1987 to 1999

		Vegetation cover 1987		Vegetation cover 1999		V.C._1999-V.C._1987		
Countries	County area (km²)	(km²)	(%)	(km²)	(%)	(km²)	(%)	Vegetation degradation km²/yr
Fugu	3176.62	437.00	13.75	228.64	7.19	208.35	6.55	17.36
Shenmu	7464.70	1267.52	16.98	514.31	6.89	753.21	10.09	62.76
Yulin	5816.78	851.01	14.63	648.06	11.14	202.96	3.48	16.91
Jiaxian	1123.61	152.04	13.53	116.72	10.38	35.32	3.14	2.94
Yijin Huo Luo Qi	3284.98	943.00	28.70	654.59	19.92	288.40	8.78	24.03
	20866.69	3650.59	17.49	2162.32	10.36	1488.26	7.13	

Table 3: Urban extension water body decrease and coal residues extensions areas in the study area of the period from 1987 to 1999

		Urban extension		Water bodies decrease		Coal extension	
Countries	County area (km²)	(km²)	(%)	(km²)	(%)	(km²)	(%)
Fugu	3176.62	8.74	0.27	0.00	0.00	9.12	0.28
Shenmu	7464.70	17.09	0.22	13.83	0.18	8.38	0.11
Yulin	5816.78	12.09	0.20	18.09	0.31	1.12	0.01
Jia Xian	1123.61	0.11	0.01	0.10	0.00	0.02	0.00
Yijin Huo Luo Qi	3284.98	8.89	0.27	47.84	1.45	3.65	0.11
	20866.69	46.93		79.88		22.30	

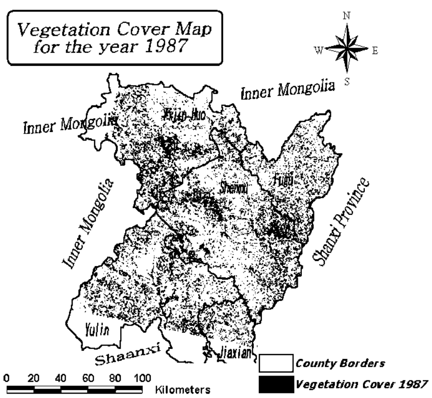

Fig. 2a: County level vegetation cover map for the study area for the year 1987

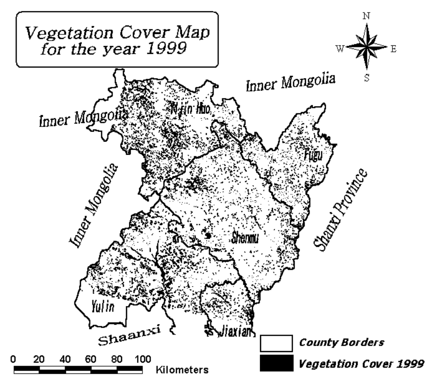

Fig. 2b: County level vegetation cover map for the study area for the year 1999

drastically expanded during the twelve years study period (1987-1999).

It was found that most of the counties studied were highly decertified. The overall severity of land degradation has worsened during the study period with degraded areas accounting for 88.9% of the total area in 1999. There is a clear trend in the spatial distribution of the decertification direction within the study area; it was from the Northwest toward the Southeast.

Decertification risk was 0.68 in 1999, a figure indicative of a worsening situation in the study area. The risk has risen considerably, on an average, by 44% for all counties between 1987 and 1999. In particular, the risk has increased considerably for those counties not previously considered highly vulnerable to degradation. Mining activity has been the sole cause of accelerated pace of decertification in the coalfield region.

Implications of reduction of decertification risk: The findings in this study have profound implications on how to reduce the s everity of decertification risk in the study area. In accordance with[14-16] who indicated to the

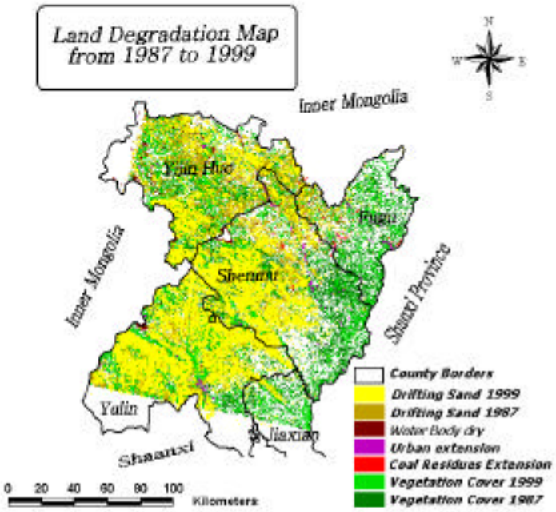

Fig. 3: County level land cover change map for the study area from 1987 to 1999

importance of soil conditioners for fixation of mobile sand dunes in Iraq and[17], who developed a model for rehabilitation of decertified land in which experimental demonstration was combined with popularization processes, successful solutions to the problem require a combination of mechanical, biological, ecological, engineering and legislative measures. Mechanical measures, such as bundling and deployment of straw grid fences, Clayey blocks barriers, Cane branches barriers and dry planting of Tamarix (*tamarix articulata*) cuttings in flat sandy areas, aim at stabilizing mobile sand dunes while biological measures intend to reduce wind velocity by erection of windbreaks[18,19]. Ecological measures include diversification of traditional farming activities to include animal husbandry and forestry.

Improved irrigation conditions would enhance farmland productivity and hence reduce over-cultivation and grazing. If the reasonably rich water resource in the area could be adequately utilized through engineering projects, it would be feasible to gradually revegetate this area.

In summary, no single means can work effectively in isolation. Only concerted measures can reduce the severity of decertification in the study area and reverse the trend of decertification. Rehabilitation efforts must be directed towards both severely degraded areas and also those counties that are not at high risk in order to reduce the overall risk of decertification.

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