Original Research

Study of Environmental Change Detection Using Remote Sensing and GIS Application: A Case Study of Northern Shaanxi Province, China

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Abstract

This research focuses on the environmental change indicators in the northern part of Shaanxi Province, China. Remote sensing and GIS software were used to classify Landsat TM of 1987 and Landsat ETM+ of 2002 imagery into five land use and land cover (LULC) classes. Supervised classification and change detection techniques were adopted in this research and used, respectively, to retrieve its class boundary. The results showed that 7,867.3 Km^2 (28.4%) of land had high environmental change, 9,474.1 Km^2 (34.2%) had moderate, and 1,0360.6 Km^2 (37.4%) of land had low environmental change. In conclusion, the study location is exposed to a high risk of environmental change.

Keywords: environment, change detection techniques, classification, RS, GIS

Introduction

Environmental change is facing a critical problem due to several factors such as increasing population, demolished natural resources, environmental pollution, land use planning, and others. Presently, unplanned changes of land use have become a major problem. Most land use changes occur without clear and logical planning, nor with any attention to environmental impact. Major flooding, air pollution in large cities, deforestation, urban growth, soil erosion, and desertification are all consequences of mismanaged planning without considering environmental impacts. Environmental change is a common consequence of improper land use change [1-9].

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Reviewing the causes of environmental change indicators in arid and semi arid areas, we found, that this process may take many forms, depending on soil type, soil erosion, natural vegetation, salinization, soil water-logging, and the means of deploying grazing animals in the landscape [10-12]. According to a literature review [13] there are three main types of environmental change indicators: changes in landscape topography, changes in topsoil composition, and changes in vegetative cover composition (land use/cover change). All these indicators are closely related to impact from intensive human activity. Considering changes in the composition of vegetative cover as a possible indicator applicable to the study location case, in relation with other studies, vegetation cover in China, where each animal shared 3.33 ha of grassland and which has decreased within 20 years to 1.11 ha, shows quantitative and qualitative degradation of steppe pastures. Considering the above-

mentioned three types of environmental change indicators proposed by [13], the relationship of current indicators with induced causes in northern Shaanxi Province show that:
1. Changes in lakes' surface levels in the study location could be related to changes in topography, which may be due to long-term climatic changes. This was illustrated in [14-16].
2. Study of vegetation dynamics in northern Shaanxi Province done by researchers concluded that denudation and soil formation processes influence current processes.

The changes in composition of the topsoil and vegetative cover compositions trigger each other. Therefore, the concept of land use/cover changes will be further analyzed for applicability in arid and semi-arid environmental change indicators to which northern Shaanxi Province belongs.

The objective of this study is assessing, monitoring, and mapping environmental change in northern Shaanxi province using RS and GIS technologies and change detection techniques at a county-level GIS environment.

Materials and Methods

Materials

Study Location

The study area, located in northern Shaanxi province, lies within longitude 108º33′ to 111º24′ E and from latitude 36º97′ to 39º58′ N with a total area of 27,702 km^2, accounting for 17.5% of total Shaanxi province (Fig. 1). In order to study the development of land degradation, the counties of Jingbian, Hengshan, Mizhi, Jiaxian, Yuyang, Shenmu, and Fugu have been selected as a study location. This area is a typical agro-pastoral region and an important energy and mineral base in China. Geographically, the study location is located south and east of the Mu Su Desert (Inner Mongolia). Geomorphologically, it has multiple hierarchical zones dominated by aeolian landforms. Its climate varies from arid and semi-arid to sub-humid with dry and cold winter. Underground water resources are relatively rich. Natural vegetation transforms from desert and desert steppe to forest steppe. This transitional nature of its ecology implies that the environment in the region is diverse, complex, and vulnerable. Presently, severe land degradation occurs mainly in the form of desertification. Overall, 88.5% of land has been desertified to varying levels, Yulin County being most desertified (96%) [15].

Remote Sensing Data

Multi-temporal Landsat (WRS2: 127/33, 127/34, and 128/34) TM (dated October 1987) and ETM+ (dated September 2002) imagery remotely sensed dataset were assembled and analyzed for land use as an environmental change indicator analysis in the study location. The spatial resolution of one pixel of TM and ETM images were 28.5 m by 28.5 m.

Ancillary Data and Software Packages

County-level topographic map, geological map, socio-economic data, meteorological data, and all the thematic layers were generated in GIS environment at a scale of

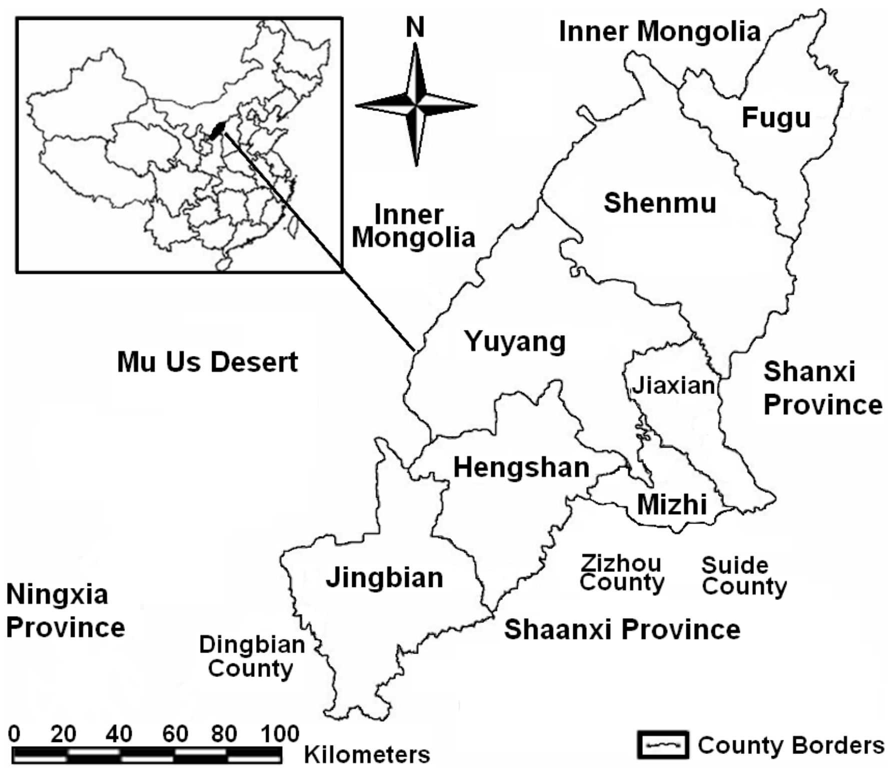

Fig. 1. General location of study location in the northern part of Shaanxi province.

1:250,000. The software packages used for this study were ERDAS for image processing and Arc-GIS for analyzing and presenting the results; Statistical Graphics, NCSS, and Microsoft Excel were used.

Methods

Data Preparation

Multi-resolution/multi-temporal TM and ETM data were used in this study with the acquisition dates for 15 September 2002 and 24 October 1987, respectively. Correction of TM data with 28.5 meter resolution was done by 1:25,000 scale topographic map using 30 control points (GCP) with a RMSE as 0.36. The ETM image with 28.5 meter resolution was registered by a corrected TM image using 30 control points with RMSE as 0.35. The remotely sensed dataset were geometrically corrected in the datum WGS84 and projection UTM N49 using the first order (linear) of polynomial function and Nearest Neighbor rectification re-sampling, which was chosen in order to preserve the radiometry and spectral information in the imagery [17].

Data Post-Processing (Change Detection Technique)

In spectral change detection, images of two dates were transformed into a new single-band or multi-band image that contains the spectral changes. The resultant image was further processed to assign the changes to specific land cover types [18]. Since these methods are based on pixel-wise or scene-wise operations, they are sensitive to image registration and co-registration accuracy. Discrimination of change and no-change pixels is of the greatest importance in successful performance of these methods. A common method for discrimination is the use of statistical threshold [18]. In this method a careful decision is required to place threshold boundaries to separate the area of change from no-change [19]. Spectral change detection methods are as follows:

- <u>Image Differencing</u>: In this method, two co-registered image dates are subtracted pixel by pixel in each band to produce a new change image between two dates [18-20].
- <u>Change Vector Analysis</u>: Sujatha [21] defined a change vector of a pixel as the vector difference between the multi-band digital vectors of the pixel on two different dates. A spectral change vector describes direction and magnitudes of change from date one to date two. The output encompasses two images, one containing the magnitude of the change vector, the other its direction. Comparison of magnitude of changes with a specified threshold determines the change (if exceeded) and direction of change vector represents the type of change [19].
- <u>Vegetation Index Differencing</u>: In vegetation studies the ratio (known as vegetation indices) is used to enhance the spectral differences between strong reflectance of vegetation in the near-infrared part of the spectrum and chlorophyll-absorption band (red part) of the spectrum [22]. Typical vegetation indices include: ratio vegetation index, normalized vegetation index, and transformed vegetation index.
- <u>Post-classification Technique</u>: In the post-classification approach, images belonging to different dates are classified and labeled individually. Later, the classification results are compared directly and the area of changes extracted [23-18]. Supervised and unsupervised classifications are used in this approach. Individual classification of two image dates minimizes the problem of normalizing for atmospheric and sensor differences between two dates [19].

Accuracy dependency of the classification's results is the main disadvantage of this method. Poor classification accuracy of individual classification leads to propagation of uncertainties in the change map, which results in inaccurate information of land-use changes. Wessels [18] described the uncertainty sources in change detection as error of the source image, classification methods, and determination of changes. They explained three main error sources in Maximum Likelihood (ML) classification-based change detection:

(1) the process of training data collection is subjective
(2) the ML classifier assumes that the probability distribution of each class is normal
(3) method used to determine changes (based on the amount of uncertainties)

Confusion matrix (error) is the common method to describe the uncertainty in a classified remote sensing image. Several error indicators can be derived from the confusion matrix, such as error of commission.

Statistical Analysis

Analyzing impacts of urban, sand, and bare lands expansion on land use/cover change using the statistical data of north Shaanxi Province in recent years affects classes' expansion on environmental change.

Results and Discussion

Vegetation change Assessment

Fig. 2 shows the main land use/cover types occurring in the study location. Where we noted that 9,399.3 km^2 contributed 33.9% of the studied area was vegetation cover in 2002, followed by the desert or sand area, which represent 30.0% of the study location 8,310.6 Km^2. The unused land coverage constitutes 15.1% of the study location, the water bodies and urban areas, which represent 12.5% and 8.5% of the study location, respectively. When these changes are aggregated over 15 years there is clearly a large increase in sand cover in the image. From 1987 to 2002, bare sandy soil cover increased from 26.1% to 30.1% over 8,310.6 Km^2 of the study location. It can be seen from the study provided by the ERDAS software that the overall accuracy of classification of 1990 and 2003 reached 87.9 and 85.3, respectively.

Table 1. Drifting sand coverage percentages and its increasing rates in the study location, 1987 to 2002.

County	County Area	Drifting Sand 1987		Drifting Sand		Drifting Sand 1987~2002		Drifting Sand Rate
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	$km^2 \cdot yr^{-1}$
Jingbian	5,040.6	1,239.7	24.5	1,616.9	32.1	377.2	7.5	31.42
Hengshan	4,237.1	859.8	20.3	1,142.5	26.9	282.7	6.7	23.51
Mi zhi	842.7	45.9	5.4	49.4	5.8	3.5	0.4	0.30
Yuyang	5,816.7	1,414.1	24.3	1,912.7	32.8	498.5	8.5	41.54
Jiaxian	1,123.6	29.1	5.5	51.7	4.6	22.6	2.0	1.88
Shenmu	7,464.7	1,430.8	19.1	1,739.2	23.2	308.3	4.1	25.69
Fugu	3,176.6	51.2	1.6	55.4	1.7	4.1	0.1	0.34
Total	27,702	5,070.6	18.3	6,567.8	23.7	1,497.2	5.4	

This clearly indicates a significant desertification effect in this area. It may be interesting to compare these areas with maps showing prior land uses, indicating which land contributes to large rates of desertification. A further complication with this analysis is that urban areas generally have

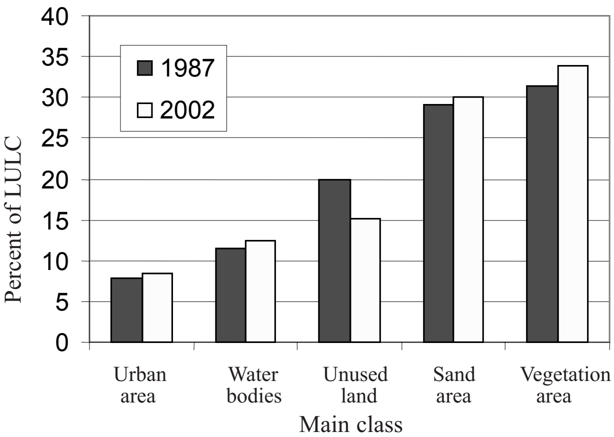

Fig. 2. (LULC) classes monitored from satellite image for the study location.

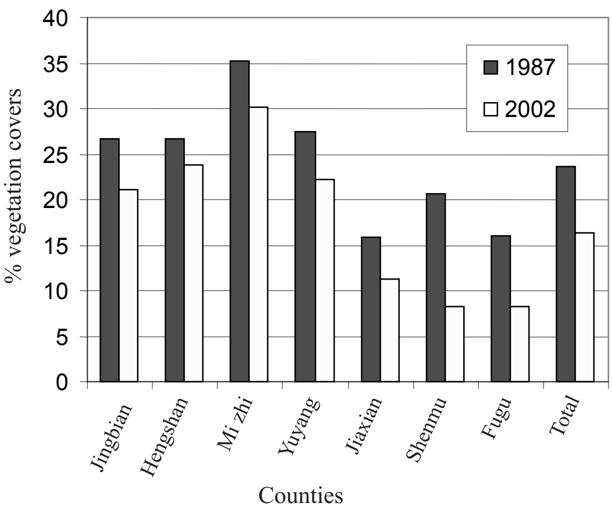

Fig. 3. Percentage of vegetation covers areas for each county in 2002 compared with 1987 in the study location.

spectral characteristics similar to those of sand soil, and therefore some image interpretation is needed to separate the various effects being observed.

Although the comparison between the two images showed the variation in the vegetation decreased over the past 15 years, this was shown more clearly in Fig. 3. During this 15-year period, however, it was clear that the farmland had decreased; in the study location the farmland areas in 2002 were less than those in 1987. Meanwhile, in Jingbian, Hengshan, Yuyang, Shenmu, and Fugu the decline in vegetation coverage was conspicuous in 2002. As shown in Fig. 3, the total area in study location with declining vegetation in both 1987 and 2002 was 23,833 km^2. Such a remarkable decline in vegetation was exceptional.

For the vegetation change assessment the main indicator was considered to be the percentage of vegetation cover. The decrease of vegetation cover percentage was strongly related to the NDVI utilizing for the two periods of 1987 and 2002, when decreases in percentage of vegetation cover images were calculated and combined to produce an overlapping vegetation change map. This result revealed potentially high-risk land degradation areas for further investigation. Results also suggested that enhancements to this method could help monitor the condition, and extent, of salinization cover areas on the margins of vegetation areas. In Fig. 3, the general estimation for vegetation cover change in the study location is detailed. The entire area was presumed to be subject to vegetation change, mainly by anthropogenic activities and climatic variation. Thus, 13.9% of the land area had vegetation cover in 2002, while 19.1% had vegetation cover in 1987, revealing the gravity of vegetation cover change problem in this study area.

Sandy Land Degradation Detection

Although the comparison between the two images shows that the variation in the aeolian deposits was increasing over the past 15 years, the values in Table 1 exhibit the variation more clearly. During this 15-years period, however, it is clear that the aeolian deposits had rather extended toward the cultivated land areas; the aeolian deposit areas in 2002 are larger than those in 1987: the Jingbian (31.42 $km^2 \cdot yr^{-1}$), Hengshan (23.51 $km^2 \cdot yr^{-1}$), Yuyang (41.54 $km^2 \cdot yr^{-1}$), and Shenmu (25.69 $km^2 \cdot yr^{-1}$) areas are more than Mi zhi (0.30 $km^2 \cdot yr^{-1}$), Jiaxian (1.88 $km^2 \cdot yr^{-1}$), and Fugu (0.34 $km^2 \cdot yr^{-1}$). The declining vegetation is conspicuous in 2002 and larger than that in 1987 in the Jingbian, Hengshan, Yuyang, and Shenmu areas.

In this area, however, extended aeolian deposits were clearly found in the study location. Thus, the comparison between two values obtained in 1987 and 2002 (Table 1) suggests that large-scale aeolian deposit change in cover has occurred in this area, at least during the 15 years of study, but the vegetation area has increased as the result of irrigation and plantation. In fact, many canals and water reservoirs are found, in the images presented here in 2002, but not in 1987 for the study area. Accordingly, a possible decrease in the vegetation of the barren soil may be found, although there is no available data to support this. The result in Table 1 exhibits remarkable indications of aeolian deposit changes in cover, although the declining vegetation is exceptionally found in Jingbian, Hengshan, Yuyang, and Shenmu. On the other hand, increases in vegetation in the Mizhi, Jiaxian, and Fugu areas are found, indicating the results of the efforts to develop the farmlands.

Detection of Water Bodies and Bare Land Change

Supervised classification and change detection techniques were used to investigate the situation of surface water bodies in the study area. The results (Fig. 4) revealed that there was a significant decrease in the surface water bodies area that happened during the study period. Initially Jinbian County has the biggest surface water area among the studied counties; consequently, it gained a significant diminution in its water body area from 9.87 to 9.12% in 1987 and 2002, respectively. The highest and the lowest change rates were 12.50 and 9.10% in Mizhi and Yuyang counties, respectively. That decrease, coupled with the decrease in the vegetation cover area of the seven counties

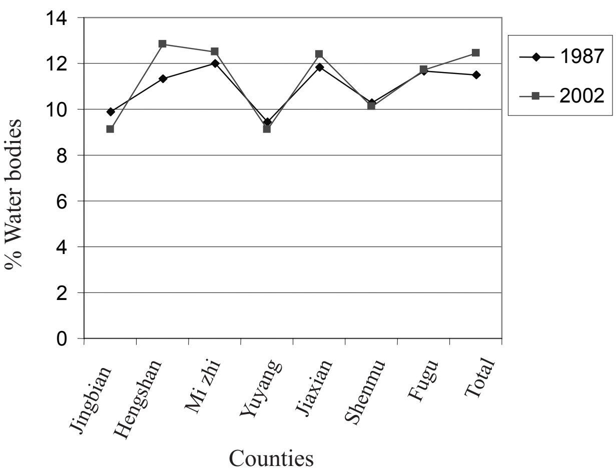

Fig. 4. Percentage of water body areas for each county in 2002 compared with 1987 in the study location.

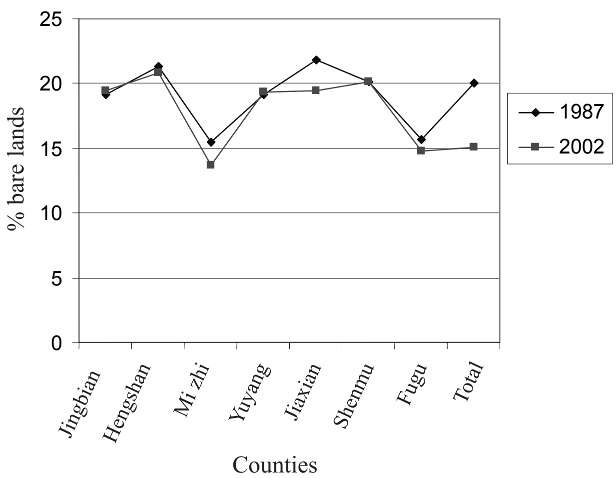

Fig. 5. Percentage of bare lands for each county in 2002 compared with 1987 in the study location.

of northern Shaanxi Province. The results (Fig. 5) showed a general decrease in the bare lands in the study location: 4,180.23 km^2, accounting for 15.09% of the total study location. The highest decrease rate in bare lands during the study location was 13.65% in MiZhi County, while the lowest decrease rate in the bare lands area was 14.75% in Fugu County. The highest increase in the bare lands was in Jinbian and Yuyang Counties (19.49 and 19.31%, respectively). Henshan, Jiaxian, and Shenmu county values had appeared as a low decrease in the bare lands area despite its increase in the built-up area, which can refer to the increase of the vegetation area in the district during the study period. When these changes were aggregated over 15 years, there was clearly a large increase in bare land. From 1987 to 2002, although vegetation change had reversed in some areas, vegetation cover generally increased by 30.47 to 33.93%. This clearly indicates no strong soil conservation planning effect in this area. These areas could also be compared to maps showing prior land use to indicate which land use contributed to the large rates of vegetation change. However, a complication for this analysis was that water bodies generally had spectral characteristics similar to those of bare land, requiring some image interpretation to separate the various effects being observed.

Urbanization Expansion Detection

Urbanization process in northern Shaanxi Province, China, has been accelerated after the government put up with a strategy of fast development of urban economic and transportation grigs about 20 years ago, which has caused the loss of farmland in the urban periphery. By analyzing the urban boundaries of Shaanxi Province counties in 1987 and 2002 resulting from supervised classification and change detection techniques, we can find that during 15 years the study location has witnessed a rapid urban expansion. From 1987 to 2002, the urban area has added 160.68 km^2, from 2,196.76 km^2 to 2,357.44 km^2. The average increase rate was 1.2% per year and the rate of increase ranged from 0.7% to 1.5% (Fig. 6). The causes of urban expansion in the center and northern Shaanxi Province was the high and new technological industry zone, Shaanxi province economical, and technological the development zone which are newly located in these regions, respectively. Because of large-scale construction of the development zone, large-scale constructions of infrastructures have made urban expansion develop rapidly.

The statistical data of the census showed a general increase in the population of the whole study location. Population in the region increased from 7.95% in 1987 to 9.25% in 2002, with an accompanying increment in population density from 18 to 43 persons·km^{-2}. One of the direct consequences of population growth is a decrease in the availability of arable lands, necessitating the expansion of agriculture into ecologically fragile land. The results of the statistical analysis showed that the urban area has a significant correlation with increasing population positive change (0.90). It was a clear indication of the great danger to the northern, very fertile cultivated land, part of Shaanxi Province. This pattern of increase was mostly related to socio-economic conditions. People tend to live where the administrations are concentrated. Also, where rural life is associated with a distinctive location strategy, as in study location, these trends are always on account of the fertile cultivated land. Hence, redistribution of administration and work opportunities must be considered in establishing new urban societies. These conditions might have their influence on people's education and mentality, which may help in following a civilized population policy.

Analysis of Change Detection Results

According to statistics of land use/cover thematic map, the total study location is 27,702 km^2. There the area of high environmental change is about 7,867.3 km^2 of total area, medium is about 9,474.1 km^2, and low environmental change is 10,360.6 km^2 (Table 2). In Table 2 we calculated areas affected by various levels of environmental change in the northern part of Shaanxi Province. It is supposed that

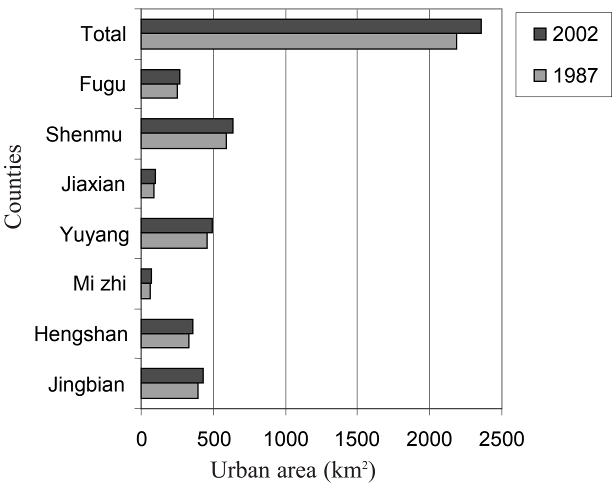

Fig. 6. Urban area values in the study period from 1987 to 2002.

Table 2. The categories of environment change and the proportion of each category.

Class	Environment change detection	
	Area (km^2)	Proportion (%)
Slight environment change	10,360.6	37.4
Moderate environment change	9,474.1	34.2
High environment change	7,867.3	28.4
Total land area	27,702	100.0

the whole area is subject to environment degradation, as we mentioned previously, mainly by anthropogenic activities and climatic variation. The overall results were 37.4, 34.2, and 28.4% for slight, moderate, and high environmental change risk class, respectively. This study examines the temporal and spatial pattern of environmental degradation as a consequence of five prominent environment degradation processes, namely: sandy desertification, bare lands, urbanization, vegetation degradation, and loss of wetlands. Using a combination of the techniques of remote sensing and GIS, the study clearly identifies a temporal pattern of land use change within northern Shaanxi Province, characterized by a substantial loss of plain dry land and a phenomenal expansion of urban construction land.

This study has looked into the possibility of applying data collected by the land use variation survey to study the anticipated relationship between land uses/cover changes and environmental degradation in northern Shaanxi Province, China. The various databases were linked through GIS; the spatial distribution of land use changes produced realistic description of environment degradation in the study location. The research shows that northern Shaanxi Province is quickly going through land use changes; the environment is adversely affected. Land degradation appears to be worsening; recently, Shaanxi Province experienced the most drastic undesirable changes in land use. These undesirable land use/cover changes might have been furthered by inadequate policy measures that encouraged land degradation. For example, large areas of cultivated land became occupied by nonagricultural users as a result of a sharply increased demand for real estate, economic development areas and high-tech industrial parks. However, the China Government has recognized that land degradation obstructs further sustainable development in the future. Although some fundamental strategies as well as practical and economic practices have been implemented to combat land degradation, and although achievements have been reached, under increasing population pressures and natural resource demand for rapid economic development, the situation is far from satisfactory. Attempts should be made to adopt powerful approaches to control and rehabilitate negative changes to vegetation cover. Therefore, monitoring of the environmental change and regional planning in this region should become a priority.

Conclusion

Remote sensing data and GIS technique is very useful for extraction of information like proportion of drifting sand areas, open green space, loss of wetlands, and urban land use mapping that are important for assessing the environmental change quality for a big arid and semi-arid region and the northern part of Shaanxi province in China that was taken as a case. These maps were then used to generate land use, land cover change, vegetation degradation, and land degradation maps for the study location during the study period, and their corresponding data were integrated into a systematic analysis. Results showed that the overall severity of environment degradation in the study location worsened during the study period from 1987 to 2002 with highly and the moderately degraded environment accounting for 62.6% of the total area. Incorporation of both natural and anthropogenic factors in the analysis provided realistic assessment of the risk of environmental degradation. The study location, in general, is exposed to a high risk of environmental degradation. This study recommended that there is a need to establish a professional arid environment center, which can be coordinated with government sectors and different universities in Shaanxi Province to solve the various environmental problems. It is also necessary to compare the case of Shaanxi Province with other important cities in other developing countries that are experiencing similar forces of degradation processes. It is hoped that our application of the techniques of remote sensing and GIS to environmental research as demonstrated in this study can open up a new arena of comparative research so that a broad and full picture can eventually be unfolded to shed light over the pattern and processes of land use transformation in China under environmental degradation processes.

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