A HOLISTIC APPROACH TOWARDS ASSESSMENT OF SEVERITY OF LAND DEGRADATION ALONG THE GREAT WALL IN NORTHERN SHAANXI PROVINCE, CHINA

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Abstract. The farming and grazing interlocked transitional zone along the Great Wall in northern *Shaanxi* Province is particularly vulnerable to desertification due to its fragile ecosystem and intensive human activity. Studies reveal that desertification is both a natural and anthropogenic process. Four desertification indicators (vegetative cover, proportion of drifting sand area, desertification rate, and population pressure) were used to assess the severity of desertification in a GIS. The first three factors were derived from multitemporal remote sensing and land inventory data. 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 last two decades with severely, highly and moderately degraded land accounting for 84.2% of the total area in 1998. While the area affected by desertification has increased, the rate of desertification has also accelerated from 0.74 to 0.87%. Risk of land degradation in the study area has increased, on an average, by 155% since 1985. Incorporation of both natural and anthropogenic factors in the analysis provides realistic assessment of risk of desertification.

Keywords: China, desertification risk, land degradation, sand-blown area, severity assessment

1. Introduction

Land degradation is one of the most serious ecological problems in the world (Al Dousari *et al*., 2000). The most typical and serious form of land degradation in China is desertification. Desertified 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 (Chen *et al*., 1996). Over 100 million ha of grassland, 7.7 million ha of farmland and 0.1 million ha of woodland have been affected by degradation (Sun *et al*., 1998; Liu, 1998). Desertified sandy land increased by 25 200 km^2 between 1975–1987, about 40.5% of which was distributed in the semi-arid agropastoral regions of northern China (Zhu and Wang, 1993). Desertification 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. Desertified 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 (UNDP, 1999; Zhou and Fan, 2000). Hence, it is essential to study land degradation processes in China (Zha and Gao, 1997).

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Land degradation in the farming and grazing interlocked ecotone of southeastern Mu Us Desert is particularly severe for two reasons. First, its ecology is inherently fragile. Lack of precipitation and an abundant supply of sand are conducive to desertification. Due to limited carrying capacity such land can be easily degraded by changes in the ecosystem. Secondly, over-cultivation and grazing by an ever-increasing population are widespread in this predominantly agricultural area. Farmers are forced to cultivate an extensive area in order to generate adequate income under constraining weather conditions. Extensive farming has resulted in land degradation in a large area with implications of long-term destruction to the environment.

In order to bring land degradation in the area effectively under control, severity of degradation and spatial distribution of degraded land have to be assessed realistically. Degradation assessment requires identification and inclusion of various indicators of desertification, both natural and human-made. Mouat *et al.* (1997) identified five indicators, namely, potential erosion, grazing pressure, climatic stress, change in vegetation greenness, and weedy invasives as a percentage of total plant cover. Scoging (1993) identified excessive exploitation of fragile ecosystem by human being, the inherent fragility of the resource system and adverse climatic conditions as causes of desertification. Thus, assessment of degradation severity is realistic only when both natural and anthropogenic factors are taken into consideration.

Some of the significant natural factors that influence the severity of desertification include percentage of existent vegetative cover and the amount of drifting sand. These two parameters have usually been mapped from satellite imagery. For instance, visual interpretation of Landsat MSS images and aerial photographs enabled Gad and Daels (1986) to identify landforms indicative of desertification and to assess desert encroachment along the Nile Valley. Using historical aerial photographs and a Landsat MSS image, Omojola and Ezigbalike (1993) mapped the attendant land degradation processes and actions in the Sokoto-Rima River Basin in northwestern Nigeria. The combination of coarse-resolution satellite data with fine-resolution Landsat MSS satellite data proved ideal for assessment of regional desertification status in the Patagonia region in South America (Del Valle *et al.*, 1998).

The assessment of degradation trend could be realistic only if anthropogenic factors such as population pressure are taken into accountant. Unlike natural factors, anthropogenic factors have not been commonly used in assessing degradation severity. Although Grunblatt *et al.* (1992) proposed to incorporate a human settlement indicator into the scheme of assessment, it was not used to calculate the severity of desertification hazard.

The successful implementation of realistically assessing severity of desertification requires the integration of all identified indicators, which is readily achievable in a Geographic Information System (GIS). By integrating all data layers into a GIS, Mouat *et al.* (1997) identified landscapes having varying levels of land degradation hazard. Use of GIS allowed simple ecosystem models to be included in the assessment process as well.

The purpose of the present study is to devise a methodology for realistically assessing desertification severity and calculating land degradation hazard in the ecologically vulnerable area along the Great Wall in northern *Shaanxi* Province, China. Such a holistic approach to the assessment is an improvement over previous methods as it takes into account both natural and anthropogenic factors. The specific objectives of this study are:

(1) to identify the mechanism and causes of land degradation through field investigation and systematic analysis of the natural settings and socioeconomic background in the study area;
(2) to evaluate and delineate the current status of land degradation using remote sensing and GIS; and
(3) to differentiate regional trends in land degradation hazard.

The article is divided into six sections. This introduction is followed by a description of the study area and land degradation problems there. The next section deals with mechanism of land degradation in the study area, followed by a section on materials and methods. Results are presented in section five. Finally, the article ends with conclusions and a discussion on implications of the findings for desertification control.

2. Study Area

The sand-blown area along the Great Wall in northern *Shaanxi* Province (Figure 1) has been selected as the focus of this study. It encompasses 59 towns/townships distributed in six counties (city). They are *Yulin, Shenmu, Fugu, Hengshan, Jingbian*, and *Dingbian* with a total area of 1.79 million ha. Present population density averages at 45 persons km^{-2}. Over the last decade population in the area has been growing at a rate of 18 200 people per annum. This area is a typical agro-pastoral region and an important energy and mineral base in China. Geographically, the study area is located in the transitional zone between Mu Us Desert and Loess Plateau of northern *Shaanxi* Province. Geomorphologically, it has multiple hierarchical zones dominated by aeolian landforms. Its climate varies from arid and semi-arid to subhumid with dry and windy spring, hot but short summer, autumn full of heavy but short duration rain events, and long, dry and cold winter. It receives an annual precipitation of 392.5 mm. Most rainfall events occur during summer months. Underground water resource is 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.

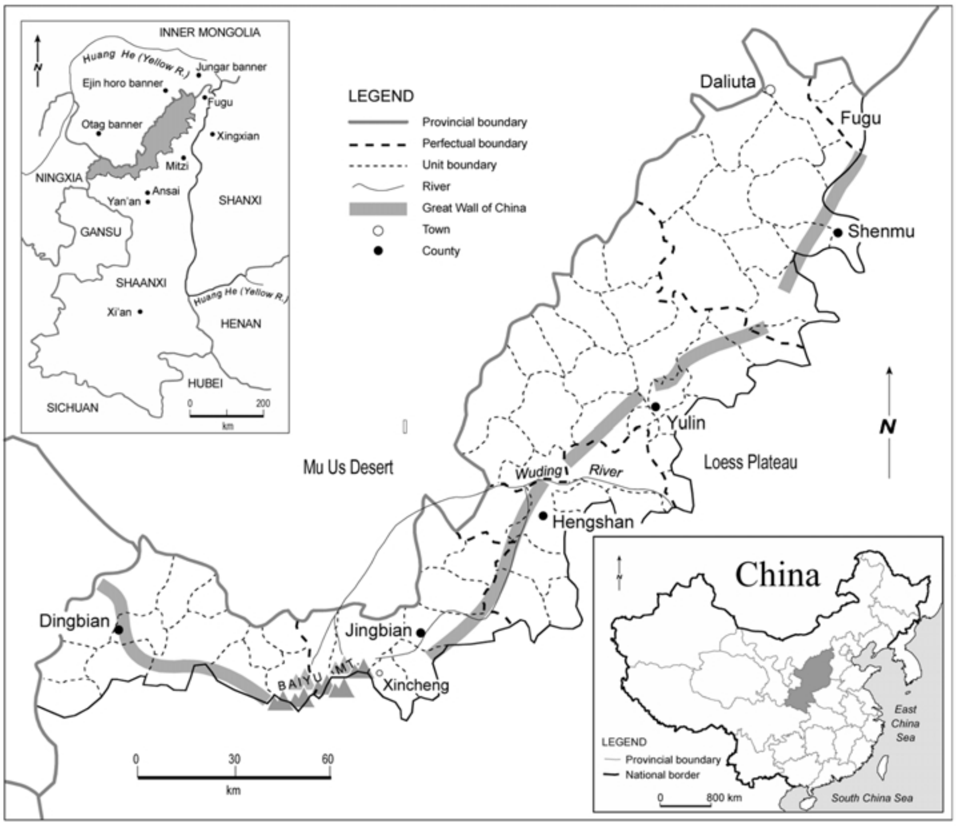

Figure 1. Location of the study area in relation to the Mu Us Desert and the Loess Plateau.

Presently, severe land degradation occurs mainly in the form of desertification. Overall, 88.5% of land has been desertified to varying levels, *Yulin* City being most desertified (96%) (Liu, 1996a). 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 (Li, 1998). Systematic study of land degradation on a regional scale is significant not only for demonstrating the feasibility of rehabilitating degraded land into productive use, but also for improving the living standard of local inhabitants.

3. Mechanism of Land Degradation

Land degradation starts with wind and water erosion that may occur naturally and/or be triggered by human activity. It refers to deterioration in the physical, chemical, and biological characteristics of soil, and the long-term loss of natural vegetation (UNEP, 1992). Its main manifestations include decrease in land productivity, decline in land output potential, loss of land resources, and emergence of surface conditions unfavourable for production (Zhu, 1994). The degradation process may be everlasting, gradual, continual, and localised (Liu *et al.*, 1997).

The mechanism of land degradation was determined through analysis of natural settings in the study area and their evolution, and through field investigation. The objective of field study was to identify and evaluate the present characteristics and processes of desertification. Field study was carried out along three transacts that covered most of the study area. The first route along the Great Wall aimed at investigating the status of desertification to the south and north of the Wall. The second route was along the upper stream of the *Wuding* River and in the northern piedmont of the *Baiyu* Mountain. The aim of this transact was to determine the impact of land use types (farming versus grazing) on desertification. The third route between the capital of *Shenmu* County and *Daliuta* was aimed to study the impact of mining on desertification.

Analysis of change in land use trends through historical times indicates that the study area was known as 'fertile land of million hectares' with advanced farming and grazing as early as the *Qin* and *Han* Dynasties (221 BC–220 AD). This favourable setting still remained intact in the *Ming* Dynasty (1368–1644 AD) during the construction of the Great Wall. By mid-*Qing* Dynasty (1644–1911 AD), the policy of 'provide for people with other lands' led to the conversion of naturally vegetated land to agricultural land. Massive stripping of natural vegetation initiated desertification. By the time the People's Republic of China was founded in 1949, only 40 000 ha of natural forest remained, covering two percent of the land. Later large-scale preventive efforts such as afforestation and grass planting enhanced vegetative coverage and helped reverse the trend of desertification within certain localities. Nevertheless, the overall trend of land degradation continues as a consequence of inappropriate land use practice, particularly destruction of vegetative cover and denudation of soil. Soil erosion initiated by strong wind averages 3800 t km^{-2}. Wind erosion has depleted soil layer, degraded land quality, reduced land productivity, and accelerated desertification (Liu, 1999).

Rapid growth of population during the last decade has intensified the process of degradation of the already fragile ecosystem, resulting in the degenerative succession of many environmental factors (Table I). This analysis conclusively establishes that desertification, the principal form of land degradation in the study area, stems from an imbalance between the fragile environment and human economic activity, among many other factors. In other words, desertification in this ecologically vulnerable region is the outcome of unsustainable land use and resource mismanagement. Inappropriate land use practices in conjunction with poor land management have resulted in visible destruction to the fragile ecosystem (Liu *et al.*, 1997; Yang and Bi, 1996; Liu, 2001). The process of land degradation is illustrated in Figure 2, according to which both natural and anthropogenic factors play a critical role in the initiation and exacerbation of desertification in the study area.

TABLE I

Succession of degradation characteristics of environmental factors

Stage of land degradation		Initial eco-environment	Subsequent surface/soil degradation	Resultant land degradation	Manifestation of desertification
Environmental factors	Vegetation	Initial vegetation	Damaged vegetation	Grass and shrub	Xerophytic vegetation
	Soil	Initial soil	Soil deflation	Wind-eroded soil	Aeolian sandy soil
	Surface material	Fluvial and lacustrine deposits	Loosened land surface	Sandy soil	Emergence of sand dune
	Climate	Semi-arid	Drastic change	Arid and windy	Many gales
Induced human activities	Intensity	Harmonious	Predatory	Exploitation combined with rehabilitation	Restricted negative impact
	Mode	Agriculture and forestry	Agriculture, forestry and animal husbandry	Forestry and animal husbandry	Difficult to utilize
Characteristics of major evidences		Landscape of farmland and forest	Vegetation reduction	Development of drifting sand	Intensive sand dunes

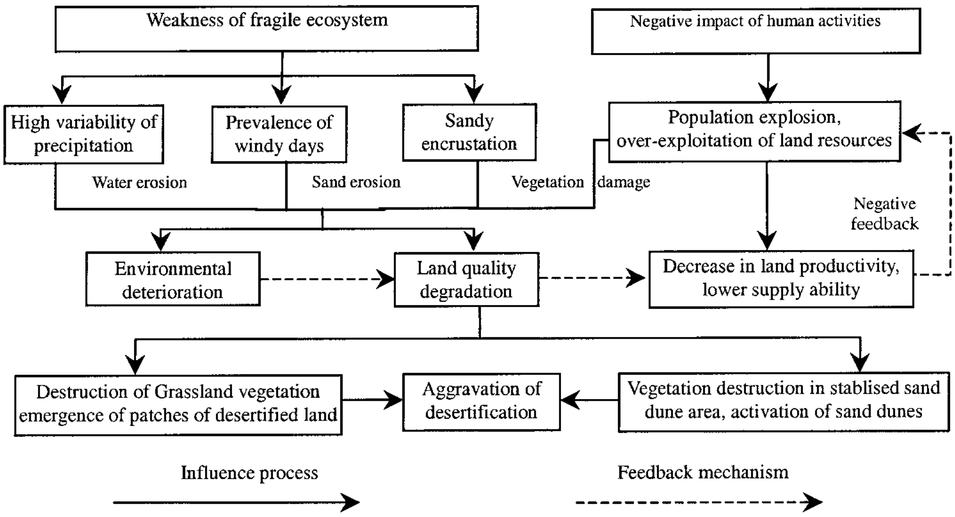

Figure 2. Mechanism of land degradation in the case study area.

4. Assessment of Degradation Severity

4.1. Degradation Indicators and Their Weighting

Realistic assessment of desertification severity relies, first and foremost, on the identification of pertinent indicators (Rubio and Bochet, 1998). Four indicators have been identified as critical to assessment of desertification severity in the study

TABLE II
Indices and weights for factors used in the assessment of land degradation

Indicators	Severity level				Weight
	I – severe	II – high	III – medium	IV – low	
Vegetation cover (%)	<10	10–25	25–40	>40	0.40
Drifting sand coverage (%)	>65	15–65	5–15	<5	0.25
Annual desertification rate (%)	>5	2–5	1–2	<1	0.15
Population pressure (%)	>50	30–50	0–30	–30–0	0.20

area: vegetative cover, extent of drifting sand, desertification rate, and population pressure (Table II). The first two factors are prime indicators of land degradation and directly derivable from satellite imagery. Population pressure and expansion rate of desertified land are indirect, dynamic indices. They are critical indicators of land degradation hazard and its pattern of spatial-temporal change.

Realistic assessment is possible only with assignment of appropriate weighting to the identified indicators. It was decided to categorise desertification severity in the study area into four levels: severe, high, medium, and low (Table II). The threshold for each rank of a given indicator was set in accordance with the United Nations' indices for desertification assessment (UNEP, 1992), with recommendations made by other relevant researchers in China (Dong, 1996; Liu, 1996b; Zhang and Wang, 1998; Lu, 1999), and with actual field observations. Each indicator was weighted through a few pilot studies of small sample areas. The largest weight of 0.4 was assigned to vegetative cover because of its dominant role in desertification. A similar weight was allocated to coverage of drifting sand and population pressure. A lower weight of 0.15 was given to the expansion rate of deserts; adding up to a weight of 1.

4.2. Material and Methods

Three types of data were used to undertake this study, namely, census data of 1982 and 1998, a detailed 1985 land inventory map, and remote sensing data. Census data enumerated at the township level were collected from respective counties. Primary information for this study was gathered from a 1:100 000 false colour composite made from bands 4, 7 and 3 (R, G, B) of Landsat TM (Thematic Mapper) imagery of 30 October 1998. Additional information included 1:50 000 colour infrared aerial photographs of 1978 and 1998. The colour composite was geometrically rectified using six ground control points whose ground coordinates were read from a topographic map of the same scale. Accuracy of geometric correction was achieved within one pixel.

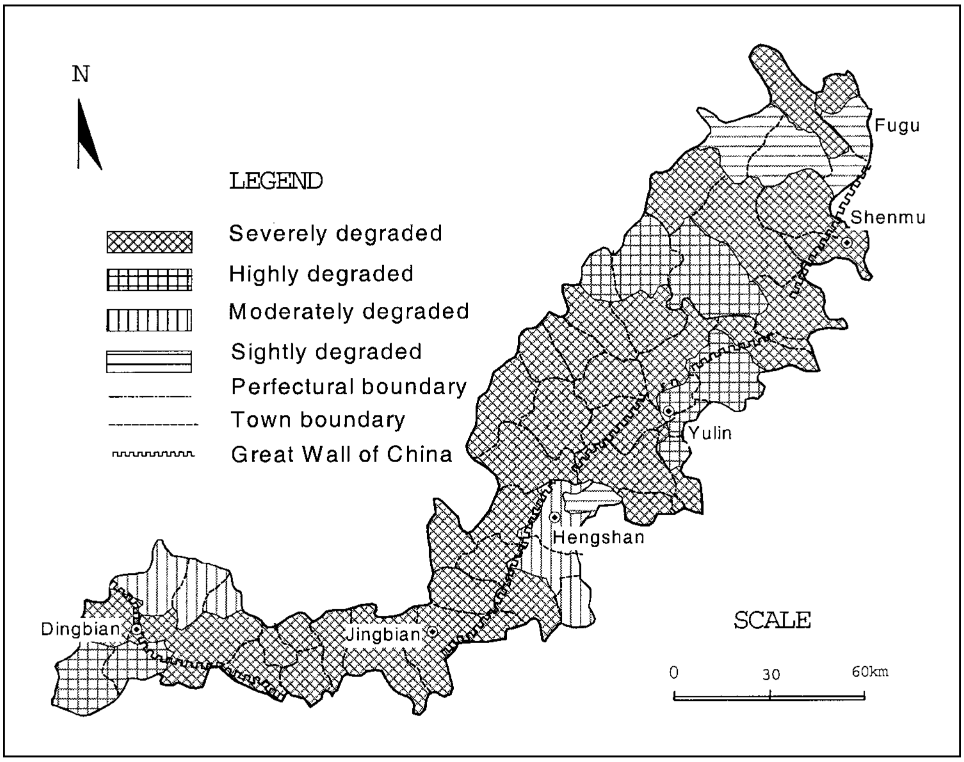

Figure 3. Land degradation zones in the study area.

The composite image was visually interpreted to produce a desertification severity map based on vegetation cover and extent of drifting sand in a sequence of steps. Woodland and grassland patches were directly delineated from the image. These polygons were assessed for their density of vegetation cover directly, and the extent of drifting sands indirectly. Preliminary results of this exercise were verified in the field and inconsistency reconciled. In the field vegetative cover and extent of drifting sand were determined in a sample area of 50 m by 50 m in some typical sites. Each of the land cover patches was assigned one of the four severity ranks as indicated in Table II. Following this procedure, the entire map was delineated into various assessment units of four levels of degradation severity.

The boundary of each assessment unit was slightly adjusted to ensure that it followed the administrative boundaries as closely as possible because most socioeconomic data were collected on the basis of these boundaries (Figure 3). Adjustments were made largely in accordance with boundaries of smaller towns. Thus, the 59 administrative regions were sub-divided into 65 assessment units. Each indicator was assigned an upper and lower threshold, corresponding to a severity rank of I to IV. It was appended with a look-up table showing the observed values and the thresholds for a particular rank.

TABLE III

Degraded land within the study area by area (Unit: 10^4 ha)

County/City	Area studied		I		II		III		IV	
	Area	%	Area	%	Area	%	Area	%	Area	%
Yulin	57.51	32.10	43.28	75.30	14.23	24.70	–	–	–	–
Shenmu	44.64	24.90	26.65	59.70	5.69	12.70	–	–	12.3	27.60
Fugu	3.87	2.20	2.05	53.00	–	–	–	–	1.82	47.00
Hengshan	19.02	10.60	15.37	80.80	–	–	2.43	12.78	1.22	6.42
Jingbian	21.07	11.70	14.57	69.20	3.53	16.80	–	–	2.97	14.10
Dingbian	33.25	18.50	9.11	27.40	16.51	49.70	3.99	12.00	3.64	10.90
Total	179.3 6	100	111.03	61.90	39.96	22.28	6.42	3.58	21.95	12.24

Determination of desertification rate was based on comparison of colour infrared photographs of 1978 with 1998, and with the land inventory map of 1985. The rate was calculated for each of the 65 assessment units and expressed as percentage. Population pressure was calculated from census data of 1982 and 1998 (SBSP, 1999) on the basis of critical population density threshold of 20 persons km^{-2} for semi-arid regions as given by the United Nations (Ci and Liu, 2000).

The degradation severity map derived from the satellite image was digitised and edited in Arc/Info. Other derived attribute data, viz., population pressure and desertification rate, were incorporated into the GIS database using FoxPro® . Final tally of degradation severity for each of the 65 assessment units was determined by merging all four ranks of severity associated with the four indicators. Prior to the merging, each rank level was converted into a numerical value according to an established linear and continuous mathematical equation. The area of degradation at each overall level of severity within each county/city was ascertained by overlaying the final degradation severity map with the administrative boundary map using Arc/Info GIS (Table III).

4.3. Calculation of Degradation Hazard

Land degradation hazard is indicative of the overall degree of difficulty in rehabilitating degraded land in a given region to productive use. The higher value 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 $D_j (0 \leq D_j \leq 1)$ represents the risk of land degradation in 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 1.5 was adopted for q in this study after experimentation. The calculation was carried out with county/city as the unit. D_j was calculated through a computer program for both the entire study area and for individual counties (city).

In order to study the temporal dynamics, degradation risk was calculated for each county/city in 1985. Data used for this assessment were vegetative cover and extent of drifting sand, both of which were derived from the land inventory map of 1985. D_j in 1985 was derived in a manner similar to that in 1998. For instance, both were based on the same weighting and had the identical assessment units. Thus, the two indices are directly comparable.

5. Results of Assessment

5.1. Severity of Land Degradation

Figure 3 depicts the spatial distribution of land degradation severity while Table III provides the related statistics. Covering 61.9% of the area, mobile sand dunes, with a height ranging from 3 to 5 m, and occasionally as high as 10–20 m, are designated as seriously degraded (I) land. Over half of their extent is under the influence of drifting sand and wind erosion, with a vegetative cover of <5%. Indicative vegetation species of degradation include *Psammochloa vallosa, Corispermum hyssopifolium, Agriophyllum squarrosum*, *Pugionium cornutum, Hedysarum scoparium*, and *Artemisia sphaerochphala*. The majority of land encrusted with sand dunes is unsuitable for productive use. Only a small portion of interdunal land can be used for grazing.

Highly degraded (II) land has a high degree of severity caused mainly by drifting sand that accounts for 15% in areal proportion. A quarter of the study area (399 600 ha) is subject to the impact of drifting sand and/or wind erosion. Sand dunes inside this category are semi-stabilised and have a wave-like appearance. Mobile sand dunes are 2–5 m high while vegetative cover is only 5–15%. Typical vegetative species include *Artemisia ordosica, Caragana intermedia*, and *Salix psanmmophyla*, all of which are not economically valuable. Some psammophyte and salinity-tolerant species are relatively well established in interdunal plains without dominance by a single species. This land is suitable for animal husbandry.

Moderately degraded (III) land has an intermediate level of severity, encompassing the smallest proportion (3.58%) of the study area at only 64 200 ha among the four levels of severity. Most of the sand dunes in this category have been stabilised or partially stabilised with 5–25% of the land subject to encroachment by shifting sand. Mobile sand dunes are less than 3 m in height, and are distributed in small patches in confined sites. Its vegetative cover of 15–30% comprises mostly of unproductive grass and sparse shrubs. There is a more diverse range of psammophyte species, which include *Pycnostelma lateriflorum* and *Oxytropis psammocharis* in hilly areas, and *Sophora alopecuroides* and *Glycyrrhiza uralensis* in flat terrain when compared with the two previous classes. Suitable usages of this land include forestry and animal husbandry while farming is a distinct possibility.

Degradation has not occurred in the low risk (IV) land that accounts for 12.24% of the study area. Land surface under this category still resembles the original undisturbed state with localised pockets of thinly layered sand. Vegetation species commonly found are *Stipa breviflora* and *Thymus mongolicus* in arid grassland and *Carix spp* in pasture. Most of the vegetative cover (30–60%) in this category consists of grass, low shrubs and bushes. Other species such as *Corispermum hyssopifolium* and *Agriophyllum squarrosum* have also invaded this fragile land of limited carrying capacity. When human activity exceeds its inherent ecological tolerance level, land degradation could be triggered.

5.2. Spatial pattern of land degradation

Analysis of Table III indicates that not all counties are equally desertified. On the one hand, all of them except *Dingbian* have over half of their areas desertified at the severe level while *Hengshan* and *Yulin* have over three quarters of their territory severely desertified. On the other, many of the counties have a large proportion of land with low degradation risk. Therefore, the pattern of desertification severity appears to be polarised.

Comparison of the recent satellite image with historical aerial photographs reveals that the extent of degraded land within the study area has expanded while the overall severity of land degradation has worsened. This has been confirmed by field investigation; for instance, the desert front in the vicinity of *Xincheng, Jingbian* County has advanced forward by over 10 km. The sand-topped loess topography incised by gullies has crawled southwards by 10 to 30 km. In the worst affected region between *Yulin* and *Hengshan*, the encroachment is as far as 40 km. Because of the expansion of the Mu Us Desert and the impact of sandstorms, the Great Wall is no longer the divide between sandy land and the Loess Plateau.

In addition, desertified land is neither evenly distributed across the study area nor is its extent constant. Desertification is severe in northeastern *Shenmu*, the upstream area of *Wuding* River, and in the northern piedmont region of *Baiyu* Mountain in *Dingbian* and *Jingbian* counties. Desertified areas have advanced in a linear manner towards the southeast. Desertification rate has increased from 0.74 to 0.87% between 1978–1985 and 1985–1998. Evidently, the rate of desertification has accelerated in the last 20 yr. Mounting population pressure, which is the direct cause of over-cultivation and overgrazing, has been identified as the driving force behind desertification (Guo, 1995). Population in the region increased from 571 000 in 1978 to 807 000 in 1998 with accompanying increment in population density from 31.8 to 45 persons km^{-2}. One of the direct consequences of population growth is the decrease in availability of per capita arable land from 0.38 (1978)

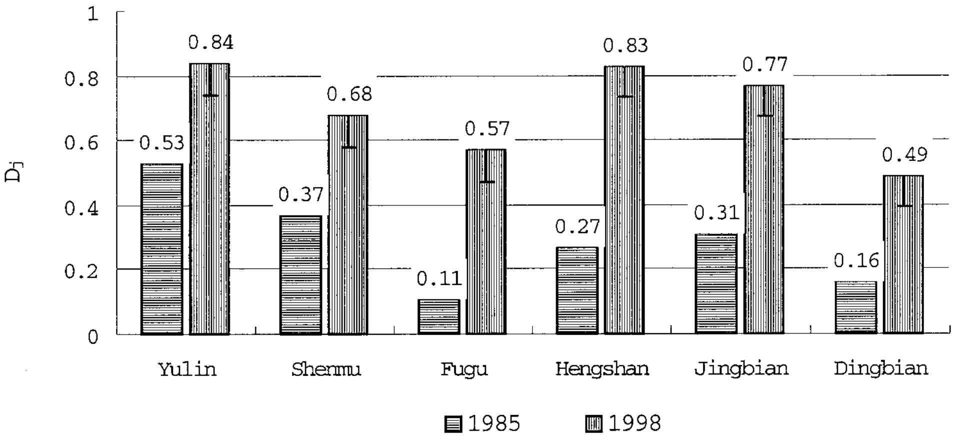

Figure 4. Comparative chart of land degradation degree by county.

to 0.13 ha (1998), necessitating expansion of agriculture into ecologically fragile land.

Severely degraded land has quadrupled near the *Daliuta* region, *Shenmu* County as a consequence of intensified mining activities and mine spills. Massive stripping of natural vegetation for mining activity has induced the rapid expansion of mobile sand dunes into adjoining areas. It is estimated that the *Shenmu-Dongshen* coalmine alone will increase desertified area by 129.6 km^2, 1.5–2 times higher than naturally occurring desertification (Wu, 1996). Understandably, desertification in this coalfield region of China will worsen as exploitation of natural resources continues. Such severe degradation near *Shenmu* lies in juxtaposition with a low level of degradation thanks to the higher moisture supply by the *Wulanmulum* River and the *Beiniu* River in this valley region. This rich supply of water by the rivers enables a relatively dense cover of bushes to become established over an extended area.

5.3. Hazard of land degradation

Desertification hazard at the county/city level ranged from 0.11 for *Fugu* to 0.53 for *Yulin* in 1985. Apart from these two extremes, all the remaining counties had a hazard index of <0.3 with a mean of 0.29. Fourteen years later the hazard had increased considerably to 0.71 in the entire study area. The risk for all counties became significantly higher with an average increment of slightly over a quarter percent. As a result, the smallest risk of 0.49 (*Dingbian*) in 1998 was highly comparable to the highest of 0.53 (*Yulin*) in 1985. In 1998, *Yulin* and *Hengshan* had the highest risk value at 0.84 and 0.83, respectively. *Jingbian* (0.77) and *Shenmu* (0.68) had the medium level of risk while *Fugu* (0.57) and *Dingbian* (0.49) faced relatively lower risk.

Figure 4 illustrates the change in desertification risk for all counties. Those with a low risk value previously recorded maximum risk. For instance, *Fugu* experienced 400% increase in its risk value whereas *Hengshan* and *Dingbian* registered an increase of 207%. This phenomenon demonstrates that while desertification hazard has been growing in severely desertified counties despite rehabilitation measures, counties not considered vulnerable earlier suffered much more. Thus, they should receive more attention in the future in order to contain the overall risk of degradation.

6. Conclusions and Discussion

6.1. Conclusions

Temporal study of natural settings of the sand-blown area along the Great Wall in northern *Shaanxi* Province indicates that land degradation is a result of natural and anthropogenic factors. Overlay of desertification severity layers interpreted from multi-temporal remotely sensed materials in a GIS, in conjunction with field investigation, revealed that the spatial extent of desertified land in the area has drastically expanded during the 20 yr study period (1978–1998).

Severity of desertification was assessed through consideration of both natural (vegetative cover, drifting sand, desertification rate) and anthropogenic (population pressure) factors in the study. It was found that most of the counties/city studied were highly desertified. The overall severity of land degradation has worsened during the last two decades with degraded areas accounting for 84.2% of the total area in 1998. There is no clear trend in the spatial distribution of the desertified land within the study area.

Desertification hazard was 0.71 in 1998, a figure indicative of a worsening situation in the study area. The risk has risen considerably, on an average, by 155% for all counties between 1985 and 1998. In particular, the risk has increased considerably for those counties not previously considered highly vulnerable to degradation. Consequently, the disparity of desertification hazard among the six counties has shrunk as all of them are at a higher risk in 1998 than ever before.

The accentuation of desertification is attributed to conflicts among human interest, increasing population pressure, limited land resource, and fragile ecosystem. Inappropriate human activities such as excessive exploitation of natural resource and mismanagement of land, to a certain extent, have contributed to the environmental destruction. Mining activity has been the sole cause of accelerated pace of desertification in the coalfield region.

6.2. Implications of reduction of desertification hazard

The findings in this study have profound implications on how to reduce the severity of desertification hazard in the study area. As the cause of this problem is both natural and anthropogenic in origin, any measure must deal with problems of rural economic development, especially development of agriculture and animal husbandry. In accordance with Zhu and Wang (1993), who developed a model for rehabilitation of desertified land in which experimental demonstration was combined with popularisation 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 in flat sandy areas, aim at stabilising mobile sand dunes while biological measures intend to reduce wind velocity by erection of windbreaks. Ecological measures include diversification of traditional farming activities to include animal husbandry and forestry. A systematic approach would include establishment of effective vegetation cover composed of forest belts, windbreak networks, and scattered patches of orchards and grassland. Engineering measures such as water conservancy projects or watershed development would aim at improvement of conservation of rainwater for facilitating survival and growth of vegetation, thus stabilising mobile dunes. A well-established vegetative cover, in turn, is conducive to the retention of rainwater locally. 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 utilised through engineering projects, it would be feasible to gradually revegetate this area.

Legislative efforts have dual components, strict enforcement of existent laws and, enactment of new laws. The former refers to those laws governing the exploitation and management of natural resources such as coal. Coal resource should be exploited rationally, and mining sites should be properly planned to minimise damage to the environment. A mechanism should be established to compensate for farmers whose income has dropped as a consequence of diminished land productivity caused by mining-induced degradation in the vicinity. Secondly, environmental laws aimed at managing desertification and protecting the environment should be passed to mitigate the detrimental influence of human economic activities on land. For instance, in severely degraded, poverty-stricken regions scattered small villages must be shifted to areas with relatively richer water resource so as to enable natural vegetation to recover, thus reversing the trend of desertification.

In summary, no single means can work effectively in isolation. Only concerted measures can reduce the severity of desertification in the study area and reverse the trend of desertification. 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 desertification.

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