

Full Paper

Mapping and Assessment of Degraded Land in the Heihe River Basin, Arid Northwestern China

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Received: 13 August 2007 / Accepted: 30 August 2007 / Published: 31 October 2007

Abstract: Land degradation is a great threat in the Heihe River Basin, located in the arid inland of northwestern China and land desertification is one of the main aspects of environmental changes in this basin. Previous studies have focused on water resource utilization and soil erosion, but the status of degraded land in the Heihe River Basin, such as its distribution, extent and precise characteristics is often inadequately known. Based on field observations and TM images from the year 2003, this study provides classification and evaluation information concerning the degraded land in the basin of the Heihe River. There are five types of degraded land types in the Heihe River Basin: water eroded in the southern mountains, sandified and vegetation degraded near the oases, aridized in the low reaches, and salinized in the lowlands. The total degraded area covers 29,355.5 km², 22.58% of the land in the study area. Finally, degraded land in the Heihe River Basin was evaluated according to changes in the physical structure and chemical components of soils, land productivity, secondary soil salt, and water conditions.

Keywords: Degraded land, Heihe River Basin, classification, evaluation, arid northwestern China

1. Introduction

Land degradation is a great threat to the world, not merely as an environmental issue, but also a social and economic problem. Land degradation can be defined as a decrease in either or both the biological productivity and usefulness of a particular place, due to human interference [1]. It is a result of the complex relationships between nature and society on the local, regional, national, and global scales. According to a recent 15 year global assessment study of soil degradation, 15% of the world's land area has been degraded by human activities [2]. There is a little doubt that degraded land is a serious problem at all spatial scales.

China is one of several countries severely affected by desertification. Desertified land covers an area of 3,300,000 km², accounting for 34% of the total territory or 79% of the entire arid land in China [3]. Over 1,000,000 km² of grassland, 77,000 km² of farmland and 100,000 km² of woodland have been affected by degradation [4]. According to Zhu and Wang [5], desertified sandy land increased by some 25,200 km² during 1975-1987, about 40.5% of which distributed in the semi-arid agropastoral regions of northern China. Desertified areas have increased further by 46,740 km² within the 13 years between 1987 and 2000 [6]. It was estimated that the direct economic loss of sandy desertification in China is about 54.1 billion Renminbi (RMB) year⁻¹ [7]. Degraded land is not merely an environmental issue, but has social and economic implications as well [4]. Therefore, it is essential to study land degradation processes in China [8].

Classification, evaluation, and mapping of degraded land are a major issue throughout the world. Some methods to evaluate degraded land have been proposed [9-12]. Remote sensing and GIS techniques have been widely applied to identify and characterize degraded land and monitor the trends of degraded land and desertification. However, due to the lack of perception and information about the environmental state, different physical and social background, no satisfactory evaluation system of degraded land has been adapted to the specific characteristics of each ecosystem [13].

The Heihe River Basin, situated in arid inland of northwestern China, is one of several areas severely affected by land degradation. The problems are particularly serious in the oases along the river basin or in the lower reaches of the Heihe River. The oases administratively lie in Gansu and Inner Mongolia. Details on the hydrological regime and its changes due to overexploitation of surface and ground waters have been published by Qi and Luo [14] and Luo *et al.* [15]. The problem of degraded land and the oases is due to a combination of four factors: (1) over-use of inland river water and/or over-drawing of groundwater leading to the shrinkage of oases, including the decline and death of natural vegetation, the decline of groundwater, drainage of lakes, etc.; (2) poor irrigation management leading to salinization; (3) over-reclamation, over-cutting for firewood, and over-grazing, which lead to grass-degraded land; and (4) failure to maintain shelterbelts in and around the oasis areas, which leads to the invasion by wind-blown sand [16]. Irrational use of water resources is the main cause of land desertification in the lower reaches of basin, Ejina Oasis [17]. However, many studies in this basin were mainly focused on water resource utilization, environmental degradation of water and sandy desertification, and relatively little research has been carried out on the degraded land [6, 14, 15].

The objectives of this study were: (1) to classify, evaluate, and interpret the status of degraded land, based on biological and physical indicators in the Heihe River Basin from satellite imagery and

intensive field investigations; (2) to develop a map of degraded land with recommendations for local land use decision makers.

2. Materials and Methods

2.1. Study area

The Heihe River Basin is an important commodity grain base in northwestern China due to its relatively abundant water resources, with a mean annual runoff of 3,730,000,000 m³ [18]. It has experienced rapid socioeconomic development and an increase in population density. The Heihe River Basin, located in the middle of the Hexi Corridor of Gansu Province, is a great inland river watershed in the arid zone of northwest China, which lies between 98° and 101°30'E, and 38° and 42°N and covers an area of approximately 130,000 km². Its upper, middle and lower reaches stretch from the middle of the Hexi Corridor in Gansu to Qinghai and western Inner Mongolia. Administratively, the basin includes part of Qilian County in Qinghai Province, several counties and cities of Gansu Province, and part of Ejina Banner in Alxa League of Inner Mongolia [18] (Figure 1).

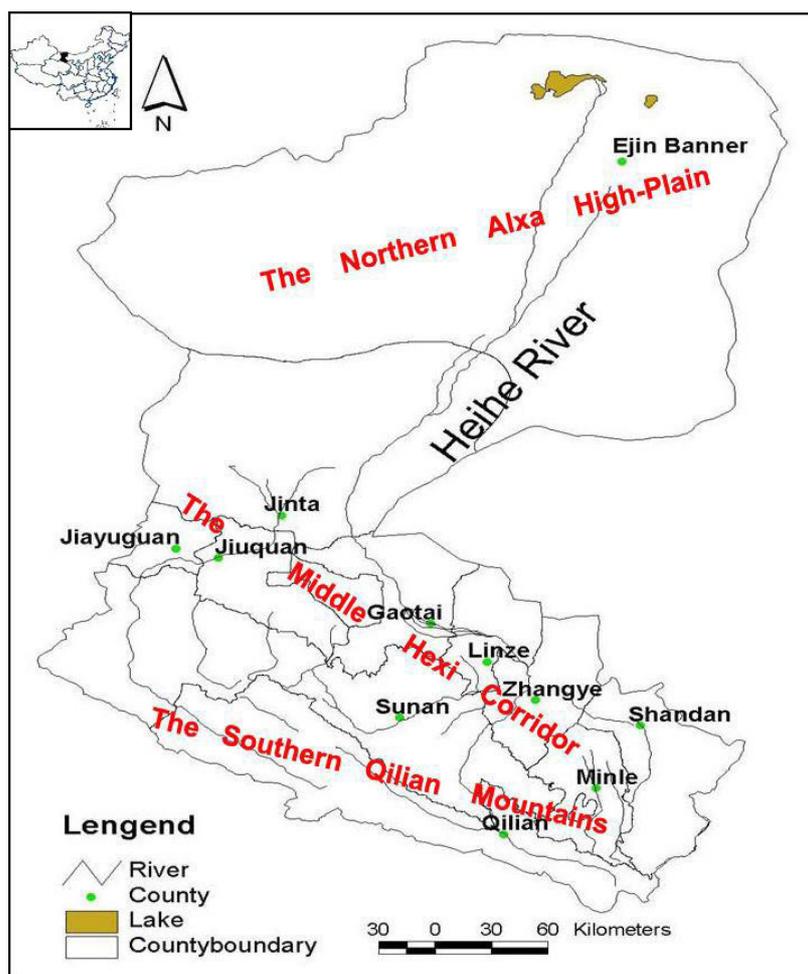


Figure 1. Location map of the Heihe River Basin in arid Northwest China.

The basin comprises three major geomorphologic divisions from the south to the north, namely, the southern Qilian Mountains, the middle Hexi Corridor and the northern Alxa High-plain. The southern Qilian Mountains, with remarkable vertical zonality, is the water source area of the Heihe River, with the elevation ranging from 2,000 to 5,500 m above the sea level and a mean annual precipitation increasing from about 250 mm in the low-mountain or hill zone to about 500 mm in the high-mountain zone. The middle Hexi Corridor, located between the Qilian Mountains and the Beishan Mountains, has elevations from >2,000 m to 1000 m and mean annual precipitation from 250 mm to <100 mm. The northern Alxa High-plain is mainly occupied by the bare Gobi, with mean altitudes of about 1000 m and a mean annual precipitation of <50 mm [19]. Under the influences of landform, climate and vegetation, a zonation of soils, including black, mountain chestnut (Kastanozems), sierozem (FAO, Xerosols), grey desert (FAO, Calcic Yermosols), grey brown desert (FAO, Gypsic Yermosols) and blown sand soils exist sequentially from the Qilian Mountains in the south to the plains region in the north [20, 21]. In addition to the soils showing clear zonal delineations, meadow soils and aquisols occur in the Zhangye and Linze regions. The land types in the study area include mountain meadow grassland, piedmont desert steppe grassland, agricultural land, wetland meadow grassland, Gobi, and desert sandy land [20].

2.2 Methods

The methodology used to obtain and evaluate information on the status of degraded land in the basin was based on Landsat TM images of the year 2003 and field investigations. The primary information for this study was obtained from the false color composites of the whole basin. These composites were made up of bands 4, 3 and 2 (R, G, B) of Landsat TM (Thematic Map) imagery from July 2003. The spatial resolution of the TM images is 30×30 m. The geometrical correction of the images was made by using the Erdas Imagine provided by ERDAS, and accuracy within one pixel (30 m) was achieved. The details of the satellite image processing methodology and procedures were described by Navas and Machin [22], Vasconcelos *et al.* [23], and Bocco *et al.* [24]. Moreover, scanned map of the land resources evaluation in the Heihe River Basin of China (1:1 000000) [25] was used and saved as images and subsequently used in GIS environment for the geometrical correction with TM images and the vector analysis and manipulation. The types and classification system used for degraded land was defined based on the physical and social conditions of the basin. The degraded land was classified into five types in terms of land-use, aeolian landforms (microtopography), vegetation cover, land productivity, landscapes, and soil: water erosion in the southern mountains, sandification and vegetation degradation near the oases, and aridization in the low reaches and salinization in the bottomlands with the help of a set of interpretation indicators from satellite imagery and with recommendations made by relevant researchers in China [26, 27]. Visual interpretation was used to identify the types and extent of degraded land according to a certain image texture, e.g. dense stands of *Sophora alopecuroides* L., vegetation types and formation. The interpretation precision is 30 pixels (about 27,000 m²). With the help of the statistics function of GIS, vector analysis and manipulation were used for the visual interpretation data to analyze and evaluate the degraded land status of the study area.

This classification was also supported by field observations. The field study was carried out along three routes that covered most of the study area. The first one along the upper stream of the Heihe River, aimed at investigating the status of deforestation and water erosion of Qilian Mountains; the second was along the middle stream of the basin, whose aim was to determine the impact of land use types on degraded land. The third route in Ejina Oasis was aimed at studying the desertification status. According to field investigation and analysis, the degraded land in the study area was mainly caused by climate change and human activities. During field investigations, census data were collected from respective counties.

The degraded land map was compiled following the recommendations of Chen and Qu [19] and Xiao [28]. A final map of the degraded land in the Heihe River Basin was finished adopting the following approach: (1) pre-field interpretation and mapping; (2) field checking of different mapping units and modification, if necessary; (3) post-field modification and correlation with existing information and census data collected from respective counties of the basin; and (4) final mapping after field validation. Assessment of degraded land from satellite imagery (Table 1) mainly consisted of results from a classification of levels of degradation. Much information existed on environmental problems, but it is easy to become overloaded with data and to miss key messages [13]. Based on the reference of previous evaluation indicators [19, 29], accompanied with the physical and social conditions of the Heihe River Basin, the physiographic parameters of degraded land in this study were soil characteristics, vegetation cover, grass yield, area of shifting sands and sand dunes, and slope gradient. Four ranks of degraded land were adequate to show intensity: slight, moderate, moderate to severe and severe. The area of each degradation type, level and land-use type was measured using the statistics function of GIS.

Table 1. Classification of land degradation identified by visual interpretation of spectral features and texture types *

Status of degraded land	Texture types	Spectral features
Slight	Smooth, fine, and coarse	High reflectance dominates, with linear and patchy features (homogeneous light-tone pattern)
Moderate	Mixed with fine and coarse and mottled	Moderate reflectance dominates with patchwork type features (associations of patches of light to moderately dark gray-tones, rounded or oval, isolated or connected)
Moderate to severe	Fine, coarse, mixed, mottled, rounded, subdued (blurred), rugged, and peaked divided	Moderate to low reflectance dominates, with patchwork type features (mosaic of intermingled patches of light and dark grey-tones, isolated or partially connected patches)
Severe	Fine, coarse, rough, and peaked divided	Low reflectance dominates with patchy-punctuated features (irregular, rounded or oval, and mostly isolated patches)

* Modified from [29]

3. Results and Discussion

3.1. Types and distributions of degraded land in the Heihe River Basin

The maps in Figures 2 and 3 show the spatial distribution and different types of degraded land, and the corresponding statistical results are listed in Table 2. In the study area (130,000 km²), 29,355.5 km² (22.58% of the land) had experienced different types of degradation. This land degradation was mainly due to water erosion, aridization, salinization, sandification and vegetation degradation, respectively. Sandification of the degraded land caused by overgrazing and over-cultivation, was the most common type of degraded land in the study area, mainly situated in the middle and lower reaches of Heihe River Basin, especially in the latter (Figure 2). This area includes shifting sands, sand dunes, and some sandy deserts formed in the historic period. The intensive exploitation of the water resources in the middle reaches of Heihe River Basin has led to a sharp decrease of such resources to the lower reaches, thus resulting in the development and spread of sandy desertification of this basin [15]. Water erosion was mostly confined to the southern mountains, mainly caused by over-farming and over-grazing. Aridization resulting from changing of the water resources' course appeared on the beaches of rivers and lakes in part of the plain. Salinized land, the secondary type of degraded land in the study area, was mainly distributed in the bottomlands, beaches and edges of flood fans. This type of land degradation was caused by drought, which induced accumulation of salts on the surface soil. Vegetation degradation resulting from climate change and overgrazing was apparent almost on the whole basin and the degradation intensity was indicated by the great decrease in biological productivity.

As seen in Figure 3 and Table 2, desertified land is the most typical form of degraded land. The desertified area reached 10,571.8 km², 36.49% of the degraded land. Salinized (10,391.4 km²) and water eroded (5,932.6 km²) are the secondary forms of degraded land, accounting for 35.86 and 19.16% of the degraded land, respectively. The rest of degraded land, including vegetation degraded, with area of 1,290.4 km² and aridized, with an area of 1,169.4 km² are the minor types, accounting for 4.45 and 4.04% of the degraded land, respectively.

Table 2. Classification of degraded land in the Heihe River Basin of arid northwestern China.

Categories (Geomorphic position-Vegetation-Soil)	Area (km ²)	Percentage of degradation land	Percentage of basin area
Water erosion	5932.6	19.16	4.3
Sub-alpine-Crops-Mot-Ustic Cambisols	428.0	0.15	0.03
Middle mountain-Crops- Mot-Ustic Cambisols	39.4	0.14	0.03
Middle mountain-Stipa,Salsola passerine-Hap- Orthic Aridisols	1292.9	4.46	1.00
Middle mountain-Crops-Cal-Ustic Isohumisols	107.1	0.37	0.08
Middle mountain-Caragana stenophylla,Stipa krylovii-Hap- Ustic Isohumisols	245.3	0.85	0.19

Table 2. Cont.

Middle mountain-Stipa spp., Sympegma regelii- Cal- Orthic Aridisols	2133	0.74	0.17
Low mountain- Crops-Cal-Ustic Isohumisols	1302	0.45	0.10
Middle mountain Crops-Hap-Ustic Isohumisols	3452	1.19	0.27
Middle mountain-Agropyron cristatum, Stipa spp.- Cal-Ustic Isohumisols	1914.4	6.61	1.48
Middle mountain- Stipa spp., Artemisia frigida, Caragana spp.- Hap-Ustic Isohumisols	1216.8	4.20	0.94
Aridization	1169.4	4.03	0.90
Bottomland-Phragmites communis, Achnatherum splendens, Glycyrrhiza inflata- Mot- Ustic Cambisols	829.5	2.86	0.64
Wet Bottomland-Populus euphratica, Elaeagnus angustifolia, Tamarix spp.-Och-Aquic Cambisols	339.9	1.17	0.26
Salinization	10391.3	35.86	8.05
Artificial oasis-Crops-Pas-Sil-Orthic Anthrosols	302.2	1.04	0.23
Wet Bottomland-Phragmites communis, Achnatherum splendens-Mot-Ustic Cambisols	911.9	3.15	0.71
Wet Bottomland-Phragmites communis, Tamarix spp., Sophara alopecuroides, Lycium ruthenicum-Pas-Gen-Aquic Cambisols	2830.6	9.77	2.19
Artificial forest-Elaeagnus angustifolia, Populus spp.-Pas-Sil-Ustic Cambisols	67.7	0.23	0.05
Wet Bottomland- Tamarix spp., Phragmites communis, Elaeagnus angustifolia, Populus euphratica-Pas-Och-Aquic Cambisols	433.0	1.49	0.34
Bottomland-Phragmites communis, Tamarix spp., Populus euphratica-Aqu-Orthic Halosols	1436.3	4.96	1.11
Bottomland-Kalidium gracile, Lycium ruthenicum, Orthic Halosols alostachys belangeriana, Tamarix spp.-Ari- Orthic Halosols	362.0	1.25	0.28
Loam flat-Karelinia caspica, Glycyrrhiza inflata, Tamarix spp., Phragmites communis, Aqu- Orthic Halosols	2554.4	8.82	1.98
Bottomland- Ari- Orthic Halosols	1493.2	5.15	1.16
Sandification	10571.8	36.49	8.19
Stabilised dune-Tamarix spp. Haloxylon ammodendron, Nitraria spp.-Ari-Sandic Entisols	1084.0	3.74	0.84
Semi- Stabilised dune-Haloxylon ammodendron,	1264.1	4.36	0.98

Reaumuria soongorica-Ari-Sandic Entisols

Table 2. Cont.

Semi- Stabilised dune-Artemisia spp., Populus euphratica, Tamarix spp.- Ari-Sandic Entisols	1450.7	5.01	1.12
Sandy flat-Ari-Sandic Entisols	350.3	1.21	0.27
Mobile dune-Ari-Sandic Entisols	6422.7	22.17	4.98
Vegetation degradation	1290.4	4.45	1.00
Middle mountain-Stipa spp., Sympegma regelii, Reaumuria soongorica-Hap-Orthic Aridisols	907.9	3.13	0.70
Loam flat- Sympegma regelii, Salsola passerine, Artemisia spp.-Hap-Orthic Aridisols-Loam flat	254.7	0.88	0.20
Middle mountain river valley-Carex Montana, Kobresia spp., weeds-Mot-Udic Cambisols	36.8	0.13	0.03
Alluvial flood plain-Stipa spp., Salsola passerine, Artemisia spp.-Cal-Orthic Aridisols	64.5	0.22	0.05
Wet bottomland-Phragmites communis, Achnatherum splendens, Aneurolepidium dasystachys, Calamagrostis spp.-Gen-Aquic Cambisols-Wet bottomland	26.5	0.09	0.02
Total	29355.5	100.00	22.58

Figure 2. Spatial distribution of degraded land in the Heihe River Basin (Note: In the study area, no degraded land includes lakes, forests, oases, undegraded grasslands and residential areas etc.)

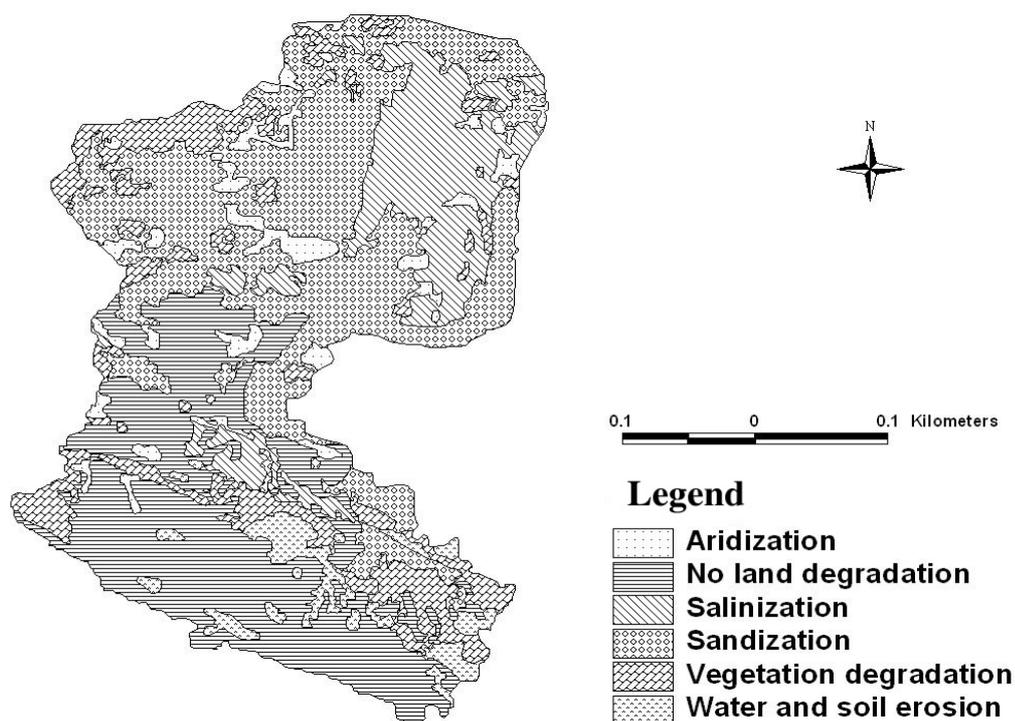
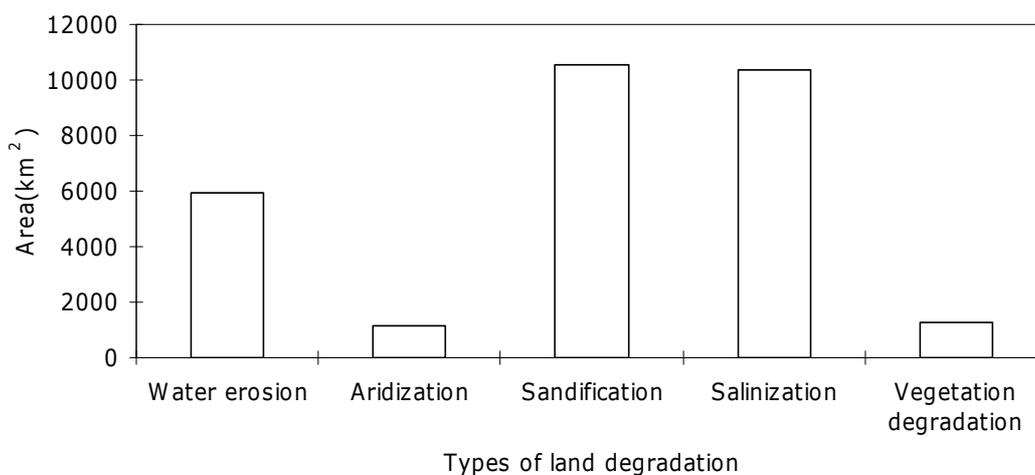


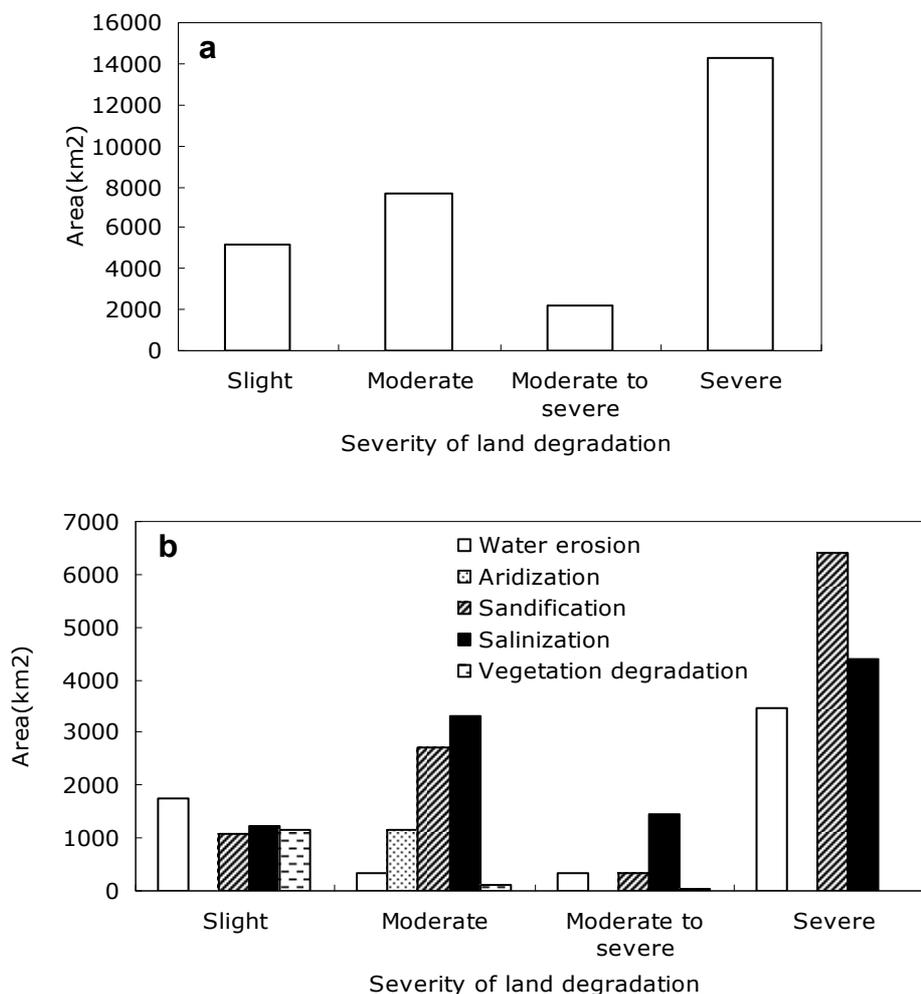
Figure 3. Area of different types of degraded land in the Heihe River Basin

3.2. Assessment of degraded land in the Heihe River Basin

Realistic assessment of degradation intensity relies, first and foremost on the identification of pertinent indicators [13]. Degraded land is associated with long-term changes in ecosystem function, and results in changes of physical structure and chemical component of soils, reduced soil nutrients, declining land productivity and biodiversity and diminished economic viability. Therefore, this evaluation mainly considered the indirect changes of soil salt, soil moisture, time of water logging, direct changes of vegetation cover and area of shifting sands and sand dunes, grass yield, and slope gradient. The former three indicators come from the previous research [19, 20, 26] and the latter four indicators from the Landsite TM imagery [29] and the field observations. The evaluation indicators for degraded land are shown in Table 3 and the evaluation results are shown in Table 4 and Figure 4.

In the study area (130,000 km²), 29,355.5 km² (22.58% of the land in the Heihe River Basin) displayed to a different extent land degradation. The area of slightly degraded, moderately degraded, moderately to severely degraded, and severely degraded was 5,221.0, 7,669.2, 2,156.6, and 14,308.7 km², accounting for 17.79, 26.13, 7.35, and 48.73% of the total degraded area, respectively. This indicates that about 16,465.3 km², including the moderately to severely and severely degraded land, or 12.67% of the total land resource in the study area, of which shifting sands, sand dunes, and some sandy deserts are main parts, is difficult to use or unusable under the current technical conditions,.

Figure 4 shows the assessment results and status of degraded land in the Heihe River Basin, which illustrates that the largest proportion was severely degraded (Figure 4a). The severe degradation covered 14,308.7 km², making up 48.73% of the degraded land or 11.0% of the study area. The severe degradation mainly includes three types of degraded land: water eroded, sandified and salinized (Figure 4b), of which the largest area and proportion (6,422.7 km², and 44.89%, respectively) corresponded to sandification. Moderate degradation, including all five types of degraded land, covered 7,669.2 km², occupying 26.13% of the degraded land. Slight and moderate to severe degradation, mostly comprising water erosion, sandification, salinization, and vegetation degradation, accounted for proportions of 17.79% and 7.35%, respectively, with the latter occupying the smallest proportion.

Figure 4. Status of different types of degraded land in the Heihe River Basin**Table 3.** Evaluation indexes of degraded land in the Heihe River Basin

Assessment factors	Slight	Moderate	Moderate to severe	Severe
Soil salt in 0-30 cm (%)	0.5~1	1.0~1.5	1.5~2.0	>2.0
Soil moisture in 0-100 cm (w %)	5~12	2~8	0.1~5	< 0.1
Time of water logging (months)	<2	2~4	4~6	> 6
Area of shifting sands and sand dunes (%)	10~20	20~30	30~50	> 50
Coverage of vegetation (%)	> 60	60~40	40~20	< 20
Grass yield (Dry kg ha ⁻¹)	800~600	600~500	500~400	< 400
Slope gradient	10~15	15~20	20~25	> 25

Table 4. Evaluation of degraded land in the Heihe River Basin

Ranks	Categories	Land-use types	Area (km ²)	
Slight (5,221.0 km ²)	Vegetation degradation	Middle mountain-Stipa spp., Sympegma regelii, Reaumuria soongorica-Hap-Orthic Aridisols	907.9	
		Loam flat- Sympegma regelii, Salsola passerine, Artemisia spp.-Hap-Orthic Aridisols-Loam flat	254.7	
	Water erosion	Sub-alpine-Crops-Mot-Ustic Cambisols	428.0	
		Middle mountain-Crops- Mot-Ustic Cambisols	39.4	
		Middle mountain-Stipa,Salsola passerine-Hap-Orthic Aridisols	1,292.9	
	Salinization	Artificial oasis-Crops-Pas-Sil-Orthic anthrosols	302.2	
		Wet Bottomland-Phragmites communis, Achnatherum splendens-Mot-Ustic Cambisols	911.9	
	Sandification	Stabilised dune-Tamarix spp. Haloxylon ammodendron, Nitraria spp.-Ari-Sandic Entisols	1,084.0	
	Moderate (7,669.2 km ²)	Vegetation degradation	Middle mountain river valley-Carex Montana, Kobresia spp., weeds-Mot-Udic Cambisols	36.8
			Alluvial flood plain-Stipa spp., Salsola passerine, Artemisia spp.-Cal-Orthic Aridisols	64.5
Water erosion		Middle mountain-Crops-Cal-Ustic Isohumisols	107.1	
		Middle mountain-Caragana stenophylla,Stipa krylovii-Hap- Ustic Isohumisols	245.3	
Aridization		Bottomland-Phragmites communis, Achnatherum splendens, Glycyrrhiza inflata-Mot- Ustic Cambisols	829.5	
		Wet Bottomland-Populus euphratica, Elaeagnus angustifolia, Tamarix spp.-Och-Aquic Cambisols	339.9	
Salinization		Wet Bottomland-Phragmites communis, Tamarix spp., Sophara alopecuroides, Lycium uthenicum-Pas-Gen-Aquic Cambisols	2,830.6	

Table 4. Cont.

		Artificial forest- <i>Elaeagnus angustifolia</i> , <i>Populus</i> spp.-Pas-Sil-Ustic Cambisols	67.7
		Wet Bottomland- <i>Tamarix</i> spp., <i>Phragmites communis</i> , <i>Elaeagnus</i> <i>angustifolia</i> , <i>Populus euphratica</i> -Pas-Och- Aquic Cambisols	433.0
	Sandification	Semi- Stabilised dune- <i>Haloxylon</i> <i>ammodendron</i> , <i>Reaumuria soongorica</i> - Ari-Sandic Entisols	1,264.1
		Semi- Stabilised dune- <i>Artemisia</i> spp., <i>Populus euphratica</i> , <i>Tamarix</i> spp.- Ari- Sandic Entisols	1,450.7
	Vegetation degradation	Wet bottomland- <i>Phragmites communis</i> , <i>Achnatherum splendens</i> , <i>Aneurolepidium</i> <i>dasystachys</i> , <i>Calamagrostis</i> spp.-Gen- Aquic Cambisols-Wet bottomland	26.5
Moderate to severe (2,156.6 km ²)	Water erosion	Middle mountain- <i>Stipa</i> spp., <i>Sympegma</i> <i>regelii</i> -Cal- Orthic Aridisols	213.3
		Low mountain- Crops-Cal-Ustic Isohumisols	130.2
	Salinization	Bottomland- <i>Phragmites communis</i> , <i>Tamarix</i> spp., <i>Populus euphratica</i> -Aqu- Orthic Halosols	1,436.3
	Sandification	Sandy flat-Ari-Sandic Entisols	350.3
		Middle mountain Crops-Hap-Ustic Isohumisols	345.2
	Water erosion	Middle mountain- <i>Agropyron cristatum</i> , <i>Stipa</i> spp.- Cal-Ustic Isohumisols	1,914.4
		Middle mountain- <i>Stipa</i> spp., <i>Artemisia</i> <i>frigida</i> , <i>Caragana</i> spp.- Hap-Ustic Isohumisols	1,216.8
Severe (14,308.7 km ²)	Salinization	Bottomland- <i>Kalidium gracile</i> , <i>Lycium</i> <i>ruthenicum</i> , Orthic Halosols <i>alostachys</i> <i>belangeriana</i> , <i>Tamarix</i> spp.-Ari- Orthic Halosols	362.0
		Loam flat- <i>Karelinia caspica</i> , <i>Glycyrrhiza</i> <i>inflata</i> , <i>Tamarix</i> spp., <i>Phragmites</i> <i>communis</i> , Aqu-Orthic Halosols	2,554.4
		Bottomland- Ari- Orthic Halosols	1,493.2
	Sandification	Mobile dune-Ari-Sandic Entisols	6,422.7
Total degraded land			29,355.5

4. Conclusions

These data have provided, for the first time, an overview of the extent of environmental damage and degraded land across the Heihe River Basin. The map shows the general locations where land degradation problems exist. Human activities such as misuse of land, water and biological resources are important causes of degraded land in the basin. To prevent further land degradation, population control and improvements in management practices and production techniques are prerequisite approaches. For example, it is imperative that we set up an authoritative water management organization, design and implement a unified plan distribution and protection of water resources in order to avoid overuse of water in the upper and middle reaches of Heihe River Basin, increase water supply to the lower reaches of the basin, limit use of the water extracted from water courses for agricultural irrigation and provide much more water for grasslands and woodlands, followed by protection and proper expansion of existing natural oases in the middle and lower reaches of Heihe River Basin, prohibition of overgrazing and uncontrolled harvesting of fuel-wood and medicinal herbs. There is also a need to prevent sand drift and encroachment and spread of deserts and desertification from deteriorating the basin. In a word, working out a reasonable land use plan and scientific-based policies are very essential for this purpose.

Acknowledgements

The study in this paper was sponsored by the Doctoral Foundation of Shandong Normal University, Shandong Province of China (Grant No. 304010).

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