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ORIGINAL PAPER

Assessment and management of ecological risk in an agricultural–pastoral ecotone: case study of Ordos, Inner Mongolia, China

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Abstract Ecological disasters have been occurring more frequently in recent years. As a result, ecological risk management has become an area of research focus as governments emphasize risk management and preparedness rather than disaster response. Ordos, China, is a transitional semiarid to arid area characterized by high ecological risk. Using remote sensing and geographic information system technology, we developed a framework for ecological risk assessment and management for this ecologically vulnerable region. Eight sources of ecological risk in six types of ecosystems in Ordos were identified, including soil erosion, desertification, gales, sand storms, floods, droughts, pests, and pollution. Quantitative and qualitative research was conducted to develop spatial distributions of the cumulative degree of ecological risk. The majority of the area is characterized by medium or low risk, while areas northwest and southwest of Dalad Banner have very high risk. The main risk factors for each ecosystem were identified based on the degrees of risks of the different regions. Corresponding countermeasures were developed by taking risk intensity, ecosystem features, and risk distribution into consideration. Moreover, the management of desertification risk was discussed in detail. Such risk assessment and management approach are helpful for providing guidance for local ecological risk management for similar areas.

Keywords Ecological risk · Risk assessment · Risk management · Ecotone · Ordos

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1 Introduction

Ecological risk is the probability of occurrence of an accident or disaster in a certain area, including floods, droughts, earthquakes, landslides, fires, or nuclear releases, that may damage the local ecosystem and its components (Fu and Xu 2001). Recently, ecological disasters have been occurring more frequently in China, particularly floods, geologic disasters, and typhoons. According to statistical data from the Ministry of Civil Affairs (2012), natural disasters in 2012 affected 290 million people in China, with direct economic losses of 418.55 billion yuan. However, the increase in potential threats has not been matched by enhanced community and environmental responses, resulting in inadequate mitigation strategies and measures (Menoni et al. 2012; White et al. 2001). Consistent with the national Twelfth Five-Year Plan (2011), ecological preservation strategies should be reoriented from response to prevention so that ecological deterioration can be controlled at its source. Thus, future study of ecological risk management will focus on before-loss prevention, rather than after-loss recovery (Zhou and Meng 2009a).

Ecological risk management refers to the adoption of positive countermeasures for reducing the frequency and intensity of specific risks, without completely foregoing local human exploitation or other activities (Liu 2011), and is important at a regional scale. Researchers have explored various methods of risk assessments for specific ecosystems, based upon which some governance measures have been proposed (Han and Dai 2001). Early risk assessments focused on a single source of risk or a single receptor with quantitative models that were relatively mature, including physics-based models such as the entropy method and exposure-response method (Hakanson 1980), mathematical models such as probability statistics analysis and mechanistic models (Zheng et al. 2003), and computer simulations such as artificial neural networks (Chen et al. 2005) and Monte Carlo approaches (Chow et al. 2005). As the concept of ecological risk goes to regional one, risk assessments have turned to the superposition of comprehensive spatial information and risk management methods have also tended to be based on integrated frameworks. For example, Hunsaker et al. (1990) constructed a conceptual model of regional ecological risk management at the landscape level. Rosana and Sverker (2004) divided the assessment methods into three stages, primary qualitative analysis, regional semiquantitative analysis, and local semiquantitative analysis. The International Risk Governance Council (IRGC 2005) also proposed an integrated framework for risk assessment and management.

In comparison, ecological risk management research in China is relatively rare, with a few case studies using the above theories and methods. For instance, Xu et al. (2001) emphasized the importance of ecologically based construction in water conservancy projects and established a monitoring and management system for the Yellow River Delta. Shi (2008) constructed a risk assessment model for urban ecosystems, and Zhang et al. (2008) provided risk management countermeasures for Daqing based on the combination of geographic information system, global positioning system, and remote sensing (also known as the 3S technology). Wen (2008) and Wang et al. (2010) studied ecological risk issues associated with basins. Li et al. (2010) developed an ecological risk decision scheme based on the analytical hierarchy process (AHP) for an alpine stocking system in Southern Gansu, and Liu et al. (2012) presented a multi-dimensional forest fire risk index system for northern China. Pan et al. (2012) identified the impacts of oilfield development in Karamay in the Xinjiang Autonomous Region and carried out a comprehensive analysis of ecological sensitivity. Previous research efforts have focused on a specific type of risk or individual organisms or species, and the corresponding preparedness countermeasures focused on a certain ecological process (Ye et al. 2008; Zhang et al. 2005). Thus, they lacked practical significance for regional risk management. In the study, we quantitatively assessed ecological risks in Ordos, a highly degraded area in Inner Mongolia Autonomous Region, and explored pertinent countermeasures to provide effective guidance as well as technical support for regional ecological risk management in an agricultural–pastoral ecotone.

2 The framework for regional ecological risk assessment and management

Ecological risk assessment shifts gradually from single risk to multi-risk assessment and from local to regional scale. Result of multi-risk assessment at regional scale is not equivalent to a simple summation of the results of single risk evaluation at local scale. In a combination of more risk sources, impacts of multi-risk sources would be more complex accordingly due to their diverse and intertwined effects. Moreover, heterogeneity within the region is larger than it is in local area, which leads to more complex effects of multi-risk sources on diverse subareas within a region. Therefore, regional ecological risk assessment requires an integrated framework, which is a combination of integrated spatial information and varieties of risks.

Several studies have proposed diverse assessment frameworks for ecological risks at regional scales (Hunsaker et al. 1990; Rosana and Sverker 2004; Landis 2005). Taking the nature of semiarid areas into account, we developed an integrated assessment framework based on previous works (Fig. 1). The integration of this framework could be divided into three dimensions: (a) As the study area has risen to local scale, the management objectives should consider both ecosystem protection and the needs of human livelihoods; (b) results of risk assessment should reflect not only the damage due to the presence of risk sources on the region, but also the resistances from the ecosystem and human society; and (c) risk

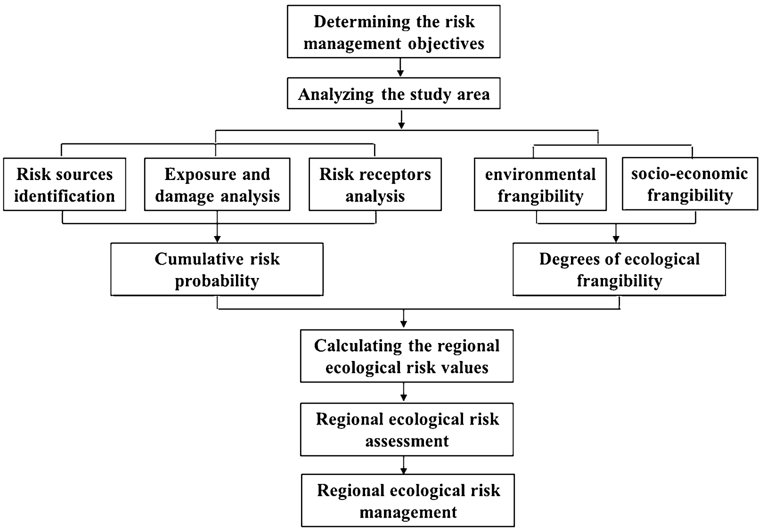

Fig. 1 A conceptual framework for ecological risk management in Ordos

sources identification and exposure analysis are vital in displaying the divergences of risk impacts on each ecosystem, which is the basis of cumulative risk quantification.

Considering the above objectives, the framework of risk assessment and management should include four steps: firstly, determine the objectives of ecological risk management. Arid and semiarid regions are home to several hundred million people. Livelihood conditions of these regions are enabled and constrained by ecosystem services with a pronounced and unpredictable spatial and temporal variability. Therefore, the countermeasures in these areas should effectively coordinate the needs between ecosystem protection and human livelihoods. Secondly, determine the potential affected areas for the following quantification research, including the identification of the boundaries of the region, natural backgrounds, resources conditions, social and economic development, as well as their association with the local ecological risks (such as potential effects of the causes, processes and outcomes). For example, whether the rapid growth of economy in the area is taken up at the cost of quick and primitive processing of local resources, or whether the rapid growth of population in the area has reached the limit of local environment capacity. Thirdly, the quantification and assessment of regional ecological risk. Results of regional ecological risk should integrate two aspects, i.e., the impacts of risk sources on local ecosystem and the inherent resistances and vulnerability of the system. The former is quantified through the comprehensive of risk sources identification, receptors analysis, and exposure and damage analysis, and the latter is calculated by the combination of environmental quality frangibility and socioeconomic frangibility. Since the former takes risk sources as the main part, considering both the possibility of risk occurrences and the losses, while the latter is based on regional development, considering the differences of vulnerability and resilience in dealing with a certain risk, which would exert influences on the degree of risk impacts and the restoring capabilities of the ecosystem. Therefore, a comprehensive risk assessment on the dimensions of risk sources and the regional ecosystem could better reveal the characteristics of regional risk, based on which the cartography of potential risk sources could be made. Fourthly, ecological risk prevention and management based on the previous results, including the monitoring and warning of risks, the construction of emergency systems, the implementation of ecological recovery projects, and the formulation of ecological protection policies, the results of which could provide guidance for the selection of risk sources and areas to be monitored in the future, as well as the scale and scope of ecological recovery projects to be carried out.

3 Study area and data sources

3.1 Study area

Ordos, located in southwest Inner Mongolia (106°42′–111°27′E, 37°35′–40°51′N) and with an area of 86,752 km^2, is an ecotone transiting from agricultural to pastoral areas. The altitude is lower in the east and higher in the west, averaging 1000–1500 m in the central area. A wavy plateau of desert steppes lies to the west, with hill and gully eroded areas and the barren Pisha sandstone area to the east. The Yellow River alluvial plain makes up the north, and the Hobq Desert and the Mu Us Sandy Land lie in the central area (Fig. 2). Ordos has a continental climate with precipitation ranging from 192 to 400 mm and increasing from west to east. Vegetation in this area has uneven distribution. The ecosystem in Ordos is fragile and sensitive, easy to be damaged under external

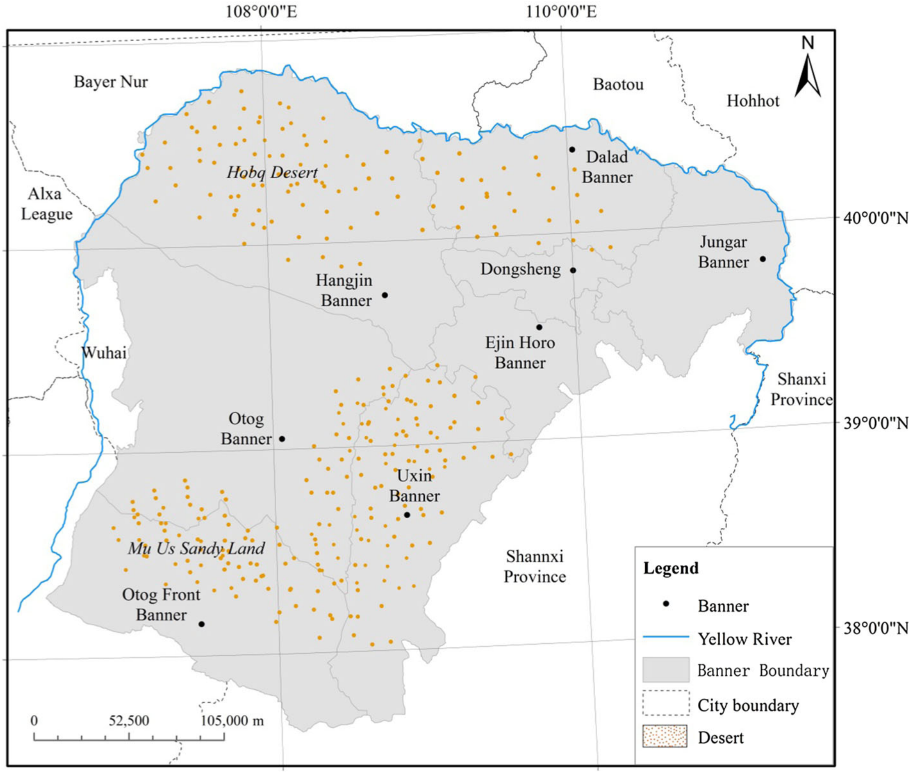

Fig. 2 Location of Ordos

disturbances, and relatively difficult to be restored, so natural elements such as geology, landforms, climate, biology, soil, and human factors, particularly land use, are variable and in transition and the vulnerability of the ecosystem remains high (Meng et al. 2011). In recent decades, the economy in Ordos has been growing rapidly, becoming one of the most active economic regions in Inner Mongolia. With an increasing urbanization rate of 72 % in 2012, the GDP rose to 370 billion yuan, 97 times larger than that of 1988. However, the conflict between rapid economic growth and high ecological vulnerability has become increasingly severe, resulting in land degradation and the increase in other ecological risks.

3.2 Data sources

Landsat Thematic Mapper (TM) images in 2008 were used to derive the basic land-use data. By visual interpretation and other conventional image preprocessing techniques, land use in Ordos was divided into eight types, including cultivated land, forest, grassland with low coverage (5–20 %), grassland with medium coverage (20–50 %), grassland with high coverage (>50 %), water, developed land, and desert. Then, these eight types were further combined into six ecosystems: farmland, forest, grassland, water, urban, and desert. The classification accuracy was more than 90 %. Basic geographic information data, including administrative divisions, roads, rivers, railways, were obtained from the National Geometrics Center of China at a 1:250,000 scale. Soil, vegetation, and hydrology data were digitized from maps using ArcGIS. The digital elevation model (DEM) was obtained from the Global Land Cover Facility of the University of Maryland.

Daily temperature and precipitation data from nine standard meteorological stations from 1960 to 2007 were obtained from the Meteorological Administration of China. Statistical data on hazards were obtained from the Disaster Reduction Center of the Civil Administration Department and the chronicles of the Ikh Juu[1] League and related banners. Other social and economic data were obtained from the Year Book of Ordos (1999–2008), the Year Book of Inner Mongolia (1999–2008), the Statistical Bureau, the Forestry Bureau, the Environmental Protection Agency, and the Agricultural Bureau.

Data processing tools included ArcGIS 9.3 Desktop and SPSS 13.0. Since some data, like geographic information, are in high resolution, while the precision of hazard statistics is on local scale, we resampled all the source data to 30×30 m^2 grid cells, so that the assessment model can be processed in the ArcGIS platform.

4 Ecological risk assessment for Ordos

According to Costanza et al's study (1997), a health ecosystem has the characteristics of stability, sustainability, vitality, the ability to keep regulated and self-managed, and the resilience to the outside pressure. The words of "vitality, regulatory status, and resilience" are used to describe the characteristics and function of different ecosystems, which are also recognized as the universal ecosystem assessment indices. Specifically, vitality means the energy or activities, revealing the function of ecosystem. Regulatory status refers to the complexity of ecosystem structure, and resilience means the gradual restoring capability after the disappearance of outside pressure. In this study, the characteristics of the six ecosystems are analyzed in the aspects of vitality, regulatory status, and resilience in Sect. 4.2. Then, the quantification method is explained through the theory and calculation process of exposure coefficients in Sect. 4.3; the concepts of ecosystem service value and exposure analysis are introduced to quantify the characteristics and function of different risk receptors.

4.1 Risk sources identification

As a typical transitional zone from semiarid to arid areas in northern China, multiple risk factors exist within the fragile environment of Ordos, which can be divided into natural sources, anthropogenic sources, and a combination of the two. Natural sources refer to the phenomena that impact the structure and function of ecosystems, such as floods, droughts, hail, and pests. Anthropogenic sources include activities such as overgrazing, pollution, and biological invasion that damage ecosystems. Combined sources refer to mixed factors. Since the absolute happening probability of the risk can hardly be determined due to the complexity of regional ecological warnings, we used the frequency, intensity, or extent of natural disasters to represent the occurrence probability of various risks. As for meteorological disasters such as drought, flooding, gale, sandstorm, we defined their risks as the occurrence times in a given period. As regards pest disaster, the risk can be defined as the ratio of area impacted by pest to area of pest prevention. As for the desertification, the risk can be defined by combined degree and extent of desertification in a specific region.

[1] The old name of Ordos.

4.2 Risk receptors analysis

The receptors for Ordos are six types of ecosystems (Table 1), i.e., grassland, forest, farmland, urban, water, and desert, among which desert and grassland (mainly low coverage grassland) have occupied 93.32 % of the total area. Water, forest and urban are distributed scatteredly, accounting for 2.28 % of the region, which are chiefly affected by the factor of micro-topography and microclimate. Farmland is mainly distributed in the northeastern part of the Yellow River, which is closely related to irrigation facilities.

4.3 Exposure and damage analysis

Exposure and damage analysis refers to the research of risk sources distribution, flow direction and their interaction and exposure effects with risk receptors, which can reflect the form and extent of risk impact on each ecosystem, thus helping to quantify the type and degree of each risk source. Apart from the direct negative impact on a certain receptor, some risk sources also exert indirect impacts on other receptors, resulting in ecological and socioeconomic loss. These indirect effects were also considered in exposure and damage analysis.

In this paper, the exposure coefficients are calculated by the impact proportion that risk receptors bear under each risk source, which further served as weights for each of the risk sources (Hunsaker et al. 1990; Ma et al. 2011). And the theory of ecosystem services function was introduced to calculate the exposure coefficients.

Ecosystem service refers to the natural environment conditions and utility functions for human survival in the ecological processes. Costanza et al. (1997) have grouped the ecosystem services into 17 aspects. Xie et al. (2003) developed the equivalent factor of ecosystem service value for the terrestrial ecosystem in China, and Li (2007) further modified for its universality. Considering the actual situation, the services in Ordos were classified into four areas: provisioning, such as the production of food and water; regulating, such as the control of climate and disease; supporting, such as nutrient cycles and crop pollination; and cultural, such as spiritual and recreational benefits, and the total value of each ecosystem, as well as the value of each ecosystem under the impact of each source, is calculated according to Li's results (Table 2).

Then, the exposure coefficient for risk source j to ecosystem i was calculated using the following formula:

$$E_{ij} = \frac{\sum_j V_{ij}}{V_i} \quad (i = 1, 2 \ldots, 6; \quad j = 1, 2, \ldots, 8) \tag{1}$$

where E_{ij} is the exposure coefficient for risk source j to ecosystem i, V_i is the total value of ecosystem i, and V_{ij} is the value of ecosystem i under the impact of source j. The exposure coefficients for the 8 risks to the 6 ecosystems are shown in Table 3.

4.4 Cumulative risk probability

4.4.1 Probability of each risk source

To determine the absolute probability of a particular outcome is challenging due to the complexity of regional ecological risks. Here, the frequency of natural disasters and the data on agricultural and industrial development were used to calculate the risk of

Table 1 Ecosystem type in Ordos

Ecosystem type	Characteristics	Distribution
Farmland	Irrigation agriculture, distributed in the areas with relatively abundant water supply	Along the river in the northwest, north, and northeast of the region
Forest	Shrubs, open forests, and natural forests, degraded	Distributed along roads and around cities
Grassland	Widely spread in the region, mainly secondary successional grassland with low level of coverage	Mostly in pastoral areas, and grassland with high coverage distributed in the middle and southwest
Urban	Including all the construction land, some comes from farmlands and forests due to rapid urbanization	Concentrated in the northeast and central area of Dongsheng District
Water	Lakes, whose area, and quantity are reducing	Scattered in the humid eastern part
Desert	The major ecosystem type in the region, and the area varies depending on the implementation of sand prevention project	Concentrated in the north (the Hobq Desert) and the south (the Mu Us Sandy)

Table 2 The equivalent factor of ecosystem service value in China

Ecosystem function	equivalent factors	Farmland	Forestland	Grassland	Urban	Water	Desert
Provisioning function	Food	1.00	0.57	0.30	0	0.10	0.31
	Materials	0.10	3.52	0.05	0	0.01	0.07
Regulating function	Climate	0.89	4.20	0.90	0	0.46	17.10
	Gas	0.50	5.10	0.80	0	0	1.80
	Erosion	1.46	6.34	1.95	0.00	0.01	1.73
	Water	0.60	4.73	0.80	−7.74	20.38	15.53
	Pollution	1.64	2.73	1.31	−11.68	18.18	18.19
Cultural function	Recreation	0.01	1.72	0.04	0	4.34	5.55
Supporting function	Bio-diversity	0.71	4.95	1.09	0	2.49	2.84
	The total value	6.91	33.86	7.24	−19.42	45.97	63.12

Table 3 Exposure coefficients for the eight sources of risk to the six ecosystems

Ecosystem	Droughts	Floods	Gales	Sand storms	Pests	Pollution	Desertification	Soil erosion
Farmland	0.689	0.603	0.559	0.826	0.690	0.449	0.763	1.000
Forestland	0.773	0.563	0.815	0.405	0.769	0.423	0.665	0.769
Grassland	0.709	0.703	0.584	0.703	0.739	0.739	0.819	1.000
Urban	1.000	1.000	1.000	1.000	0.399	0.601	0.399	0.399
Water	0.602	0.604	0.159	0.604	0.056	1.000	0.604	0.604
Desert	0.618	0.138	0.589	0.544	0.682	0.316	0.677	0.682

environmental and ecological disasters. The probabilities of droughts, floods, gales, and sand storms were estimated by the use of meteorology risk frequency data (meteorology risk refers to disaster caused by meteorological factors, including floods, droughts, gale, hail, frost, snow disaster, and ice run) for each Banner in Ordos (Table 4). The probability of pest infestations was estimated using the ratio of pest prevention area to occurrence area. The area of pest prevention in a certain region could reflect the risk preparedness capability of local residents, while the area of pest occurrence represents the actual damage in the area. Thus, the ratio can better reflect the probability of pest risk with higher ratio value indicating better prevention and smaller loss and lower value reflecting poor prevention and higher pest risk. Pollution was calculated using environmental quality indices including releases of chemical oxygen demand, SO_2, and solid wastes. Because desertification and soil erosion are combined (environmental as well as anthropogenic) sources, their quantification should consider the current condition of risk and driving forces. We used indices of the current desertification condition and the underlying driven forces to characterize desertification risk probability. The former refers to the degree of current desertification (light, moderate, serious, and acute), and the latter includes indices of average wind velocity, gale days, precipitation, evaporation, duration of sunshine, population density, and livestock density. The integration of all the factors approximated to the occurrence probability of desertification.

Based on those absolute statistical indices for each risk factor, maximum difference normalization was used to standardize the indices. The minimum and maximum levels of a certain index were defined as 0 and 100, respectively, and the remaining data were distributed on the 0–100 scale. Then, all the values were standardized into four grades—25, 50, 75, and 100—in direct proportion to the probability of that source of risk, which indicates low risk, medium risk, high risk, and very high risk, respectively.

4.4.2 Cumulative risk probability

Cumulative risk probability means the integration of the above eight single risk sources. Due to the heterogeneity of risk sources and receptors, as well as their interaction and intertwined effects, result of cumulative risk probability is not equivalent to a simple

Table 4 Meteorology risk probability statistics in Ordos

Disaster type	Droughts		Floods		Gales (day/year)	Sand storms (day/year)
	Occurrence times/year	Frequency	Occurrence times/year	Frequency		
Dongsheng District	16/41	0.390	38/47	0.809	14	23
Dalad Banner	25/40	0.625	36/47	0.766	17	27
Jungar Banner	16/20	0.800	45/47	0.957	10	17
Otog front Banner	11/24	0.458	11/47	0.234	17	21
Otog Banner	15/35	0.429	27/47	0.574	32	17
Hanggin Banner	19/32	0.594	26/47	0.553	30	27
Uxin Banner	16/22	0.727	41/47	0.872	16	17
Ejin Horo Banner	29/40	0.725	43/47	0.915	3	17

summation of the results of single risk evaluation. Specifically, we assigned weights to the different sources of risk using exposure coefficients, which can be expressed as follows:

$$\mathrm{ER}_i = E_{ij} \times R_j \quad (i = 1, 2\ldots, 6; \quad j = 1, 2\ldots, 8) \tag{2}$$

where ER_i is the cumulative risk probability for ecosystem i, E_{ij} is the exposure coefficient for risk source j to ecosystem i, and R_j is the grade of risk source j.

After calculating the cumulative risk probabilities of all the six ecosystems, we overlaid them in ArcGIS and got the cumulative risk probability distribution of the whole region, i.e., the value of regional cumulative risk probability (ER).

4.5 Ecological frangibility

Ecological frangibility refers to the sensitivity reaction and restoring capability of the ecosystem under outside disturbances in a certain scale. As it is the co-effects of natural attributes and human activities, the quantification of ecological frangibility should consider both the two aspects. Based on an existing ecological evaluation index system (Meng et al. 2011), the degree of ecological frangibility in this paper was measured by integrating ecological–environmental and socioeconomic frangibility indices. Environmental indices, representing the characteristics of the ecosystem and its restoring capability, were calculated according to the "ecological environment evaluation of technical specifications" (2006) issued by the Environmental Protection Administration of China (Table 5). Socioeconomic vulnerability, revealing the positive and negative disturbances of human activities, was calculated by disaster preparedness capability index (including the production values of first, second, and third industry), disaster response capability index (including grain productions and revenues per land, capital construction investment, and the number of beds per unit area), pasture pressure index (livestock density), and economic pressure index (including per capita GDP and per capita food production) (Wang et al. 2006). Then, the scores of those indices were standardized and graded using SPSS13.0, and the degrees of ecological frangibility for banners in Ordos were calculated using the following formula:

$$\mathrm{EV}_m = 0.5 \times \mathrm{EI}_m + 0.5 \times \mathrm{SV}_m \quad (m = 1, 2\ldots, 8) \tag{3}$$

where EV_m is the score for ecological frangibility for banner m, EI_m is the score for environmental quality frangibility, and SV_m is the score for socioeconomic frangibility.

4.6 Ecological risk degree

Methods for evaluating the degree of risk vary with different analytical perspectives for ecological risk. Maskrey (1989) used the integration of hazard and vulnerability to quantify ecological risk. Smith (1996) used the multiple of probabilities and damages. Tobin and Montz (1997) used the integration of probabilities and vulnerability. Deyle et al. (1998) used the multiple of hazards and vulnerability. Cheng et al. (2004) used the multiple of probabilities, ecological index, and ecological frangibility. Based on the risk assessment framework in Sect. 2, we take the aspects of risk sources in local ecosystems and the inherent ecological frangibility into consideration (Wang et al. 2006). The former reveals the pressure the ecosystem bears, and the latter represents the resistance and reaction capabilities under those risk attacks. And the integration of the two indicators could reflect

Table 5 Weights of Environmental Indices in Ordos

Biological abundance index[a]		Vegetation coverage index[b]		Land deterioration index[c]		Environment quality index[d]		Environment condition index	
Index	Weights	Index	Weights	Index	Weights	Index	Weights	Index	Weights
Farmland	0.11	Farmland	0.19	Light erosion	0.05	SO_2	0.4	Biological abundance index	0.25
Forestland	0.35	Forestland	0.38	Medium erosion	0.25	COD	0.4	Vegetation coverage index	0.2
Water	0.28	Water	–						
Urban	0.04	Urban	0.07					River density index[e]	0.2
Desert	0.01	Desert	0.02	Heavy erosion	0.7	Solid waste	0.2	Land deterioration index	0.2
Grassland with high coverage	0.13	Grassland with high coverage	0.2					Environment quality index	0.15
Grassland with medium coverage	0.06	Grassland with medium coverage	0.1						
Grassland with low coverage	0.02	Grassland with low coverage	0.04						

[a] The quantity divergences in biology species of different ecosystem types, revealing the abundance degree of biological resources in a certain area

[b] The area percentage value of forestland, grassland, farmland, construction land and unused land in a certain area, reflecting the vegetation coverage degree

[c] The area percentage of wind erosion, water erosion, gravity erosion, freeze thawing and engineering erosion in a certain area, reflecting the land deterioration degree

[d] The pollutant burden in a certain area, revealing the environmental pollution pressure

[e] The length percentage of river, lake and water in a certain area, revealing the water resources abundance

the characteristics of regional risks. In this study, the following formula was used to calculate the degree of ecological risk (Wang et al. 2006):

$$WV = ER \times EV \quad (4)$$

where WV is the degree of ecological risk, ER is the cumulative risk of the whole region, and EV is the degree of ecological frangibility.

The degree of ecological risk was classified using ArcGIS into low risk, medium risk, high risk, and very high risk (Fig. 3). Because grasslands and deserts occupy large areas of Ordos, the risk distribution is patchy. The majority of Ordos has medium (41 %) or low (56 %) risk. Areas with high and very high risks comprise <3 % of the total and are mainly distributed in the northwest of Dalad Banner along the Yellow River, in southern Otog Banner, i.e., the Mu Us Sandy Land, and in central and southwest Hangjin Banner, i.e., the Hobq Desert and along the boundaries with Dongsheng and Ejin Horo Banners.

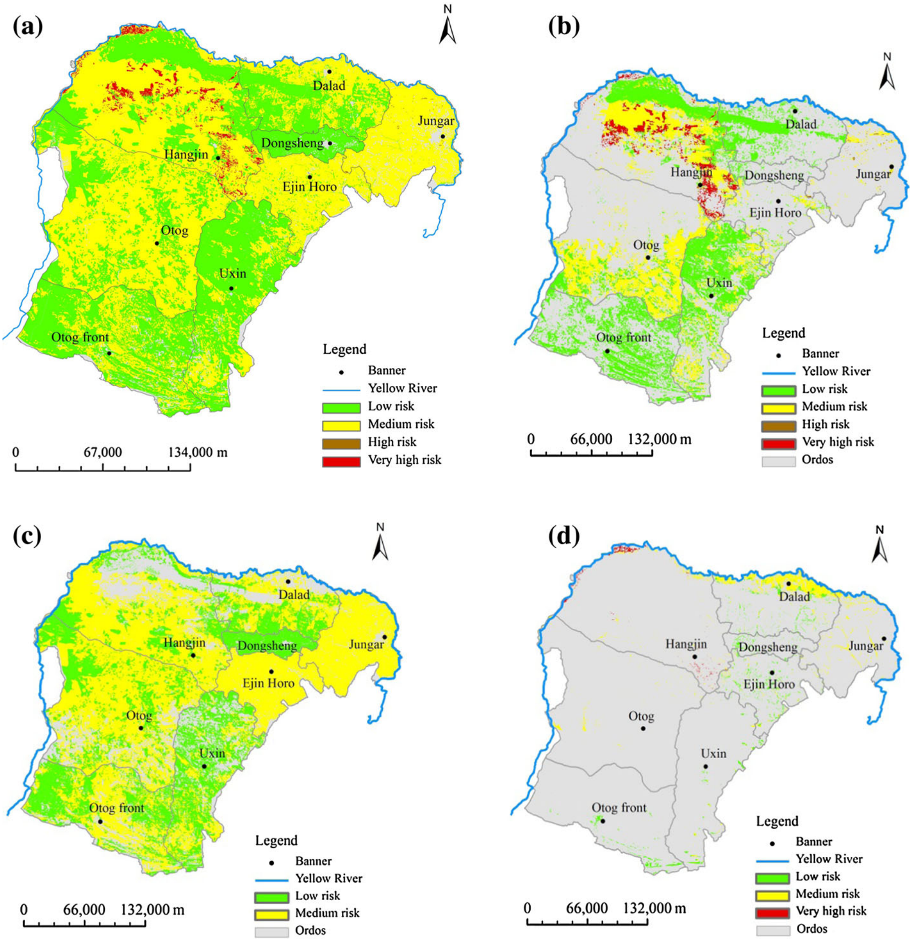

Fig. 3 Spatial distribution of ecological risk degree for Ordos

5 Ecological risk management in Ordos

Considering the characteristics of spatial diffusion and continuous occurrence of regional ecological risk, corresponding management procedures which vary with both places and risk degrees should be established to allocate and integrate regional resources. Thus, corresponding precautionary measures in Ordos were proposed for different degrees of risk (i.e., low, medium, high, and very high), different ecosystems (i.e., grassland, forest, farmland, urban, desert, and water), and different regions with specific risk sources (i.e., soil erosion, desertification, gales, sand storms, floods, droughts, pests, and pollution).

5.1 Countermeasures for varying degrees of risk

Based on the above regional risk assessment results, possible governance measures are proposed to develop a program for resource allocation and integration (Table 6).

Areas marked with very high or high risk usually indicate a severe environment deterioration leading to the degradation of ecosystem services. Eliminating these risks confronts a series of technical difficulties. Even such elimination is technically feasible, high costs put them out of the reach of local budgets. Therefore, administrative approaches for protecting livelihoods in these areas from ecological risks might be limited. Monitoring the status of risk sources, setting up an emergency system, and developing a compensation

Table 6 Countermeasures for different degrees of risk in Ordos

Degree of risk	Description	Possible action
Very high-risk region	The ecological environment is under severe deterioration and ecological disasters frequently occur. The structure of the ecosystem is damaged and very difficult to restore	Timely action and administrative approaches for protecting livelihoods are needed as soon as possible; investigation measures like monitoring the status of risk sources, setting up an emergency system, and developing a compensation mechanism are needed. Financial and strategic support from upper-level governments
High-risk region	The ecological environment is under serious damage and loss of function. Ecological disasters sometimes occur. The structure of the ecosystem is damaged and somewhat difficult to recover	
Medium risk region	The ecological environment is under a significant interference although its structure and function are still intact. Ecological challenges are not severe	Action may be needed and responsible. Efforts should be made to manage the trade-offs between livelihoods and eco-conservation. Attentions should be paid to promote the efficiency of resource utilization and reduce the ecological pressure from human activities
Low risk region	The ecological environment is relatively unspoiled and the structure and function of the ecosystem are still complete with strong restoration possibilities. Ecological challenges are not severe	Restoration is not needed at present, and existing measures are sufficient

mechanism would help guarantee the livelihoods of local residents in short term. In the long run, relocation of settlements and stipulation of ecological conservation projects are necessary in these areas, which generally require the financial and strategic support from upper-level governments.

Areas with moderate risk level suggest a significant interference to ecosystems. Livelihoods in these areas confront potential losses resulted from degradation of ecosystems. Moreover, the degradation could be ascribed to various impacts of human activities. Therefore, coping with the moderate ecological risks in these areas is essentially managing the trade-offs between livelihoods and eco-conservation. Attentions should be paid to promote the efficiency of resource utilization and reduce the ecological pressure from human activities. With regard to the countermeasures, efforts should be made to position local development toward a sustainable way, involving diversifying the sources of livelihoods, upgrading local industries, stipulating conservation policies, etc.

5.2 Countermeasures for different ecosystems

The dominant risk source for each ecosystem differed as indicated by the exposure coefficients (Table 3). Considering the current situation in Ordos (Fig. 4) and the characteristics of different ecosystems, such as their vitality, regulatory status, and resilience, corresponding prevention measures should be taken for different types of ecosystems taking into account the characteristics of each source of risk.

The areas classified as high and very high risks within each ecosystem were not particularly large, but their spatial distributions were distinct. Most desert ecosystems had low risk (Fig. 4a), while 5 % of deserts had very high risk, unusual among other ecosystem types. Since 2000, the local government has implemented a series of sand stabilization measures to improve the function of desert ecosystems. Future development should not only focus on increasing individual income, but also focus on improving awareness and preventing adverse impacts caused by local farmers and grazing.

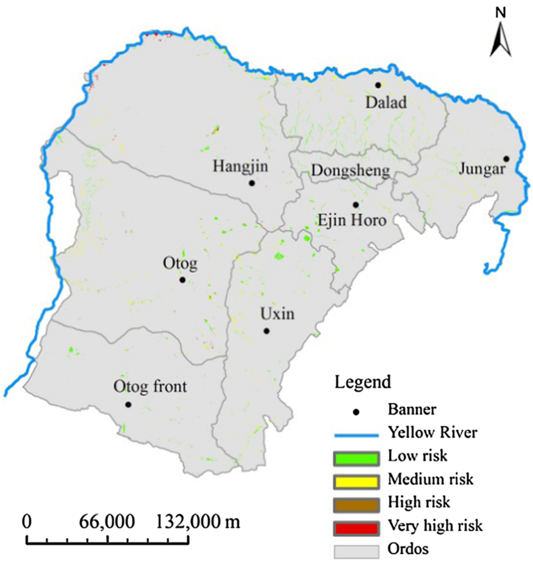

Fig. 4 Degrees of ecological risk for **a** desert, **b** grassland, **c** farmland, and **d** water in Ordos

The overall risks of forest and grassland ecosystems were low (Fig. 4b). All of the grassland in Ordos were medium or low risk, as was 99 % of forest. These areas are recommended for a series of ecological restoration measures, particularly reforestation and grassland restoration. Other approaches may include implementation of fenced farming; agricultural modifications such as banning, delaying, or rotational grazing; and combining ecosystem protection measures with farmers' cultivation practices to improve their incomes and optimize the industry structure.

The majority (60 %) of the farmland was at medium risk (Fig. 4c), which was closely related to the spatial distribution of farmland in Ordos. Most farmland is in the alluvial plain along the Yellow River, with naturally fertile soil and abundant water. However, 11 % of the farmland was classified as very high risk. Because the arable land in some regions is characterized by alluvial, saline, or sandy soils, which have high risk of erosion, policies of Grain for Green Project and facility and irrigated agriculture should be implemented further. Additionally, the growth of population should be controlled reasonably, to reduce the occupation of farmland caused by urban expansion and mining exploitation.

As for the water areas, 30 % were at high risk and 10 % were at very high risk (Fig. 4d). Considering the small area of water resources in Ordos and their vital significance in meeting the demands of the ecosystems and local socioeconomic development, emphasis should be placed on improving the supervision of lakes and rivers to protect the current natural wetlands. The scales of population and livestock should be controlled within the limit of regional water resources capacity, by the measures of reducing water consumption quota and promoting low water consumption industries.

5.3 Countermeasures for different sources of risk

Based on the analysis of risk sources and receptors, the typical ecological risks in the different regions of Ordos were identified and corresponding preparedness measures were listed (Table 7). As limited by the scope of this paper, we took the management of desertification as an example in the following part.

Apart from the natural drivers such as arid climate, sandy landscape, and sparse vegetation, the occurrence of desertification is closely related to local human activities, such as overgrazing, deforestation, reclamation, and mining. So the following measures can be taken to manage the risk.

(a) Continuing to implement ecological construction measures. Future management should attach more importance to improve the conservation awareness of local residents, arousing their initiatives to participate in the control of desertification. Moreover, the local government should establish advanced desertification monitoring and forecasting systems, for more scientific decision-making and real-time information releasing.

(b) Strengthening the protection, restoration, and reconstruction of desert ecosystem. The expansion of desert should be attributed to the continuously increased human disturbances in the region. Their excessive utilization of land and biological resources has destroyed the internal stability and balance of the ecosystem. As can be seen from Fig. 4a, the highest risk of desert ecosystem is mainly distributed in the Hobq Desert and the Mu Us Sandy Land. Therefore, more rigorous prevention strategies and biological measures should be taken to restore the local natural

Table 7 Risk management for different risk sources

Sources of risk	Region	Risk management
Floods	Dongsheng District, Jungar Banner, Uxin Banner, Ejin Horo Banner	Build monitoring, forecasting, and warning systems for rainstorms. Improve water retention capacity and put in place effective defensive measures
Droughts	Jungar Banner, Uxin Banner, Ejin Horo Banner	Strengthen drought forecasting and early warning systems. Adjust industrial uses considering local conditions such as climate, soil, geology, and crop type. Improve utilization of water resources to promote water-conserving agriculture. Develop crops with low water consumption, strong benefits, and drought tolerance
Soil erosion and desertification	Dongsheng District, Hanggin Banner, Uxin Banner, Ejin Horo Banner, Jungar Banner, Dalad Banner	Continue implementation of reforestation, returning farmland to forest, grassland protection, small watershed management, and construction of water conservation facilities. Control land degeneration and desertification by exploring the best and most efficient methods of land use under local conditions. For areas experiencing water loss, soil erosion and desertification, plant forests to stabilize dunes and prevent new damage. Take measures to revitalize forests and grasslands
Gales and sand storms	Otog Banner, Hanggin Banner, Dalad Banner	Continue with projects modifying land use and replacing cropland with pasture. Research land surface conditions and obtain data on soil water to reduce bare surfaces, reduce water loss and soil erosion, and control damage done by insects and mice to decrease the effects of dusty weather
Pollution	Ejin Horo Banner, Jungar Banner, Uxin Banner, Dongsheng District	Improve the human and ecological environment of industrial parks, reduce energy loss and environmental pollution, and promote scientific and technological innovations, including independent innovation
Pests	Otog Banner, Hangjin Banner, Uxin Banner	Establish and refine monitoring and warning systems for insects and rodent damage. Improve forecasting of grassland conditions to reduce damage and increase productive uses

vegetation. Only after reconstructing the desert ecosystem could the trend of desertification be effectively restrained.

(c) Making sand prevention and control plans. Based on the current natural condition of Ordos, the characteristics of driving factors, and the requirements of socioeconomic development, an environmentally friendly ecological security pattern for Ordos should be built. Specifically, building the system of farmland, pastures and villages shelterbelts for different sand source areas, taking prevention measures like sand barrier-fixing, chemical sand-fixing, configuring land-use patterns according to the results of land ecological suitability assessment, to keep the regional land resources within the capacity of ecology.

(d) Combing the process of exploitation and reclamation in the mining area. Ordos has always been the important energy mineral base in China, but the durative open-pit mining has resulted in a wide range of ecological destruction, causing a large area of mine land and slag dumping grounds, which is a considerable source of ecological risk. Therefore, a comprehensive mining and reclamation plan should be compiled to ensure the land remediation measures. Future mining activities should be strictly under the geological environment-governance-deposit system as well as environment access system, following the rule of "Who destroyed, who control," to reduce the destroy on the local environment.

6 Conclusions

Due to the heterogeneity of risk sources and receptors, as well as their interaction and overlay effects, regional risk assessment is far more complex than risk assessment. Through the review of previous methods, the paper has developed a conceptual framework for ecological risk assessment and management in Ordos, including the determination of management objectives, risk sources identification, exposure and damage analysis, frangibility analysis, risk degree quantification and risk management. The paper emphasizes the establishment of a novel conceptual model for ecological risk assessment and management at the regional scale, and the inclusion of natural hazards and human disturbances into such model.

Through analysis of local physical and human demographic characteristics as well as historic statistical data, eight primary sources of risk were identified (soil erosion, desertification, gales, sand storms, floods, droughts, pests, and pollution) and four degrees of risks were assigned (i.e., low, medium, high, and very high) and presented using GIS to visualize the cumulative degree of ecological risk and its distribution. The results showed that overall risk of Ordos was generally low to moderate, with 97 % of the area being classified as having low or medium risk. At the same time, the distribution of risk among the ecosystems varied. Specifically, the risk in forest and grassland was relatively low, as a result of the ecological protection measures taken by local government. A considerable portion of the desert and farmland was at very high risk, mainly due to the fragile natural background conditions of these regional ecosystems. A large percentage of the water areas were also at high risk, reflecting increasing conflicts between socioeconomic development and clean water supplies.

Future study of ecological risk management should focus on the whole stage of risk development, including before-risk prevention, in-risk reaction, and after-risk recovery (Zhou and Meng 2009b). Based on the spatial distribution of cumulative risk, corresponding preparedness countermeasures were developed considering the degree of risk, the ecosystem, and driving risk factors, among which the sources of risk and their intensity were crucial factors in establishing the management measures. Due to the limitation of space, the paper mainly discussed the management of desertification in the region.

The research is based on a method using relative degrees of risk rather than absolute risks. More studies are needed to make systematic research on temporal and spatial variations and coupling effects among all the sources of risk. There are still various sources of uncertainty include incomplete data, variability in the natural environment, and the complexity of ecological processes and mechanisms. Moreover, analysis of the functions of different sources of risk in different zones is not embedded. Presentation of the effects on different ecosystems with multiple risk sources is a topic worthy of further research to provide effective guidance for ecological risk management.

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