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Effect of climate change on the vulnerability of a socio-ecological system in an arid area

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ABSTRACT

The vulnerability of arid areas threatens ecosystems and human existence. With climate change and increasing human activities, addressing this vulnerability has become an important concern. To support this objective, we present a complex index system to analyze vulnerability at a regional scale with a 1 km × 1 km resolution. Based on the evaluation framework, which includes natural resources, the natural environment and the social economy, the results indicate that an ecosystem in a mountainous area is more vulnerable than it is in a plain. Land desertification will worsen from 2014 to 2099 under the RCP4.5 scenarios and improve slightly under the RCP8.5 and RCP2.6 scenarios, while the suitable land for agriculture increased slightly under the three scenarios. In addition, a regional sensitivity analysis of vulnerability to climate change shows that the improving region and the worsening region will occupy 1.30% and 74.51%, respectively. In view of this, the socio-ecological system will undergo a worsening trend as a whole. Finally, we simplified how to solve the problem of a socio-ecological system in the future. This research method and results would generate new insights with respect to planning for sustainable development and provide a reference for decision-making.

1. Introduction

Global vulnerability analyses reflect generic processes of socio-ecological systems under climate change and social development (Wei et al., 2013; De Chazal et al., 2008). Since the 1960s, vulnerability has gradually become an important field following the implementation of the International Biological Program (IBP), Man and Biosphere Program (MBP), and International Geosphere-Biosphere Program (IGBP) (Viglizzo et al., 1995; Friedl et al., 2002). Vulnerability research has changed from natural ecosystems, ecological economic systems to social-economic- ecological complex ecosystems (Bardsley and Wiseman, 2012; Abson et al., 2012). Multi-dimensional fields, such as economic (Pérez Agúndez et al., 2014), social (Murphy and Scott, 2014), environmental (Petrosillo et al., 2010) and institutional (Young, 2010) ones, are covered.

Dealing with the social and ecological problem has puzzled many researchers for some time (Tyler et al., 2007). A general framework for analyzing sustainability of a social-ecological system was put forward by Ostrom in 2009, who brought significant attention to social-ecological systems (Ostrom, 2009). Dryland vulnerability at a global scale and sub-national resolution has been classified into poverty, water stress, soil degradation, natural agro-constraints and isolation (Sietz et al., 2011). In the dryland development paradigm, the problem of livelihood and sustainable development are solved in the context of researching desertification, vulnerability, poverty and community development and from the perspective of human environment system (Reynolds et al., 2007). In this paper, the social–ecological system was considered as a complex adaptive system with unpredictability, self-organization, multiple stability, the threshold effect and dependence. These systems are an organic combination of social systems and environmental systems at a particular time and space. Social factors interact with and restrict natural factors.

Climate, landforms, water and heat in arid areas are the main factors that govern the distribution of vegetation, soil and water resources (Hupp and Osterkamp, 1985; Moore et al., 1993). Together, the ecological environment and its ecosystem functions present different diversities and vulnerability levels. In recent years, many studies have focused on the arid area's vulnerability response to global warming (Held and Soden, 2006). According to the Intergovernmental Panel on Climate Change (IPCC) report, tropics and subtropical arid region would enlarge further (Parry, 2007). Additionally, population growth, socioeconomic development and exploitation of soil and water resources have caused many hydrological and ecological environment problems (Stern et al.,

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1996; Evans and Kantrowitz, 2002). Developing adequate responses to the vulnerability of socio-ecological systems to all these changes is a critical challenge for sustainable development of arid areas.

Evaluating the vulnerability of a socio-ecological system must depend on its driving factors, so it is important to analyze the generic processes and formation mechanisms of vulnerability under climate change. In the process of evaluation, most investigations are targeted at ecosystems in the present (Kok et al., 2015). An index system for evaluation of socio-ecological systems is still not sufficient.

2. Background

2.1. Major vulnerability problems in the arid area of Northwest China

An oasis is a functional unit in arid areas with special natural conditions (Zhang, 2002). Individual oases may have different development intensities, which has led to irrational exploitation of their resources (Wang and Zhang, 2012).

First, the spatial distribution of oases is irregular (Liu et al., 2010). At the beginning of exploitation, significant attention was paid to the soil, sun hours and heat, while the water resources were ignored (Ling et al., 2013). After a long time, these activities are no longer coordinated (Shen et al., 2013). Many ecological problems such as land desertification and salinization have become very serious (Wang et al., 2013; Yimit et al., 2011).

Second, water supply and demand is imbalanced (Feng et al., 2000). Extensive management, water waste and economic expansion have led the imbalance between supply and demand for water to become very significant (Cai, 2008). Landscape vulnerability in these oases has also deteriorated seriously (Zhu et al., 2009).

Third, the desert landscape is being destroyed (Qian et al., 2004). With the increase of oases over the last 40 years, the boundaries between oases and the desert has expanded, which qualitatively changed the structure and function of the desert landscape (Zhang et al., 2003). Today, this situation continues.

The aim of this paper is to analyze the vulnerability of socio-ecological systems based on natural resources, the natural environment and economic activities and to evaluate the effect of climate change on a region's vulnerability.

2.2. The study area

The arid area of Northwestern China was selected as a case study and is considered to be representative of a typical arid area. It is located to the west at 106°E and the north at 35°N (Ersi et al., 1999). It is situated in the hinterland of the Eurasian continent and covers a surface area of approximately 1,972,765 km^2 (Fig. 1). The landforms are characterized by a series of undulating mountains ranges sitting parallel to low, broad valleys. This area is dominated by a continental dry climate. The average annual precipitation is no more than 160 mm, and the average annual evaporation is more than 2000 mm in the plain. It is one of the most drought-prone areas of the world and one of the major grain-producing areas of China (Yin et al., 2006). Moreover, the socio-ecological system is very fragile (Deng et al., 2006).

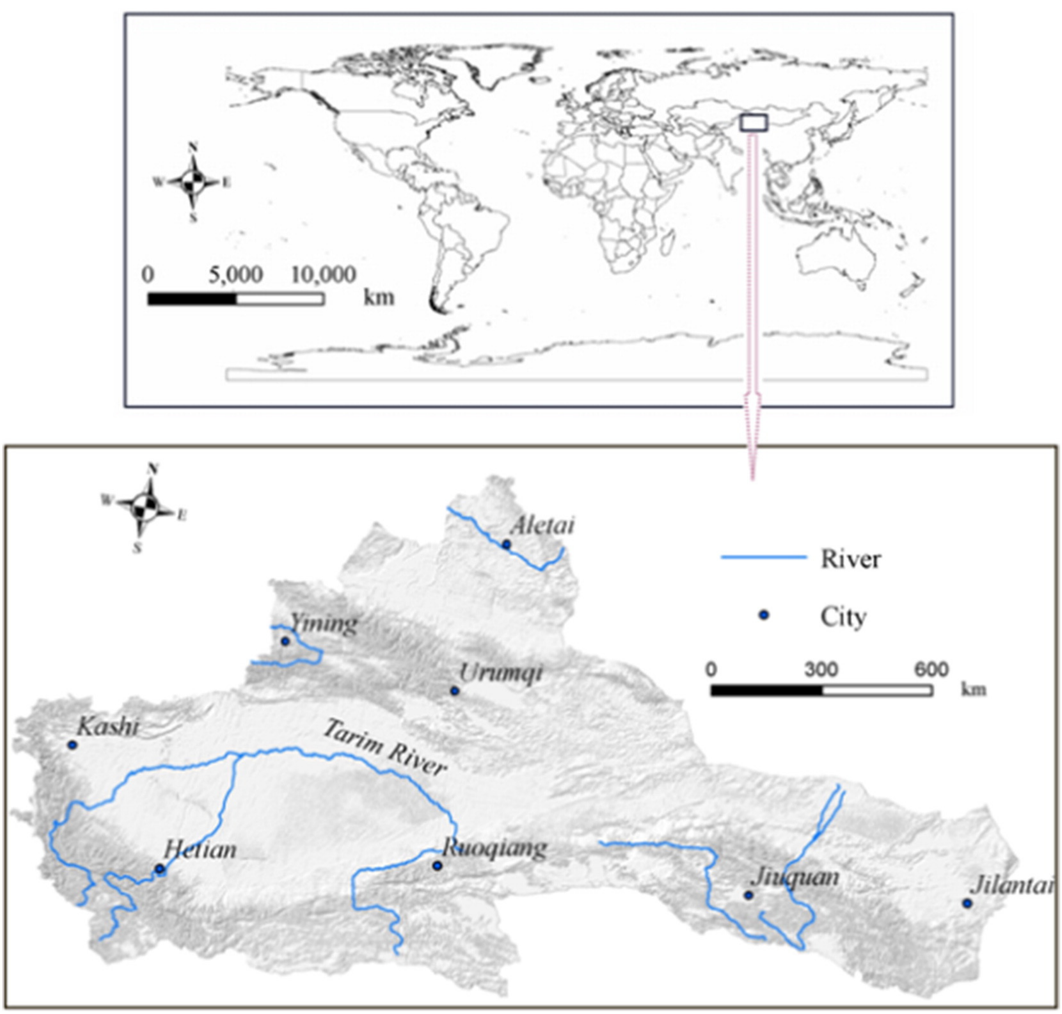

Fig. 1. Location of the arid area of Northwestern China.

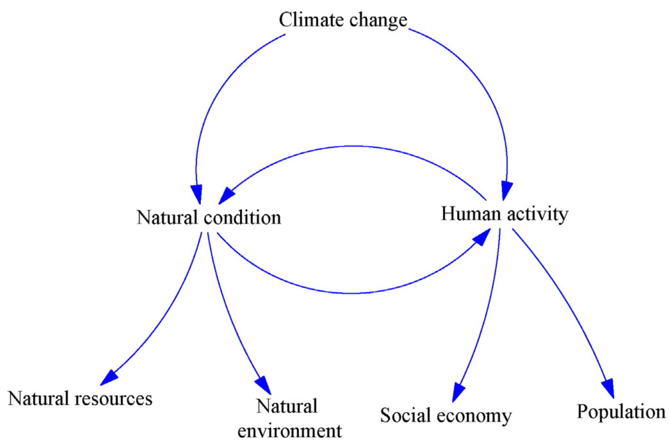

Fig. 2. Effect of climate change on the vulnerability of a socio-ecological system.

3. Data and methods

3.1. Conceptual framework

Human community and the natural and social environments correlated with people's survival are the main elements of a socio-ecological system (Ostrom, 2009). The effect of climate change on the vulnerability of a socio-ecological system mainly impacts the change in the natural environment and social environment. We try to establish a conceptual framework based on their relationships (Fig. 2).

3.2. Quantitative indicator of vulnerability

Evaluating an indicator system for vulnerability of socio-ecological systems involves diverse fields (Adger, 2006; Sietz et al., 2011). To foster a convenient analysis, the indicator system is required to be scientific, complete, dominant, independent and regional. The indicator system in this paper is based on the investigation of natural conditions and the social economic factors which are listed in Table 1.

The calculation of each indicator is a composite process. The main methods are as follows.

3.2.1. Water resources carrying capacity

To establish the evaluation model of water resource carrying capacity, we assume that the water resources carrying capacity is a compound system of society, economics, ecology and water resources and then set up a comprehensive evaluation model that includes seven categories and 31 indicators. A standardized processing method was used. These details were introduced by Liu (Du et al., 2011).

3.2.2. Land desertification

The drought index has been used for judging arid regions by the Food and Agriculture Organization (FAO) since 1977 (FAO, 1977). It is defined as the ratio of precipitation to potential evapotranspiration (P/E). The potential evapotranspiration E is calculated using the Thornthwaite method (Thornthwaite, 1948).

3.2.3. Natural disaster

Drought and flood are the main natural disasters in an arid area. The Z index has typically been used for quantifying the degree of drought and flood (Karl, 1986). Precipitation during some periods could be

Table 1
Evaluating indicator system of vulnerability of socio-ecological system.

Vulnerability dimension	Indicator	Spatial resolution	Indicator range	Data source
Natural resource	Water resources carrying capacity	1 km × 1 km	1–5	China water resources bulletin
Natural environment	Land desertification	1 km × 1 km	1–5	the Cold and Arid Regions Sciences Data Center
	Natural disaster	1 km × 1 km	1–5	ECMWF
Social economy	Agricultural suitable region	1 km × 1 km	1–6	CMIP5; USGS
	population density	1 km × 1 km	1–5	

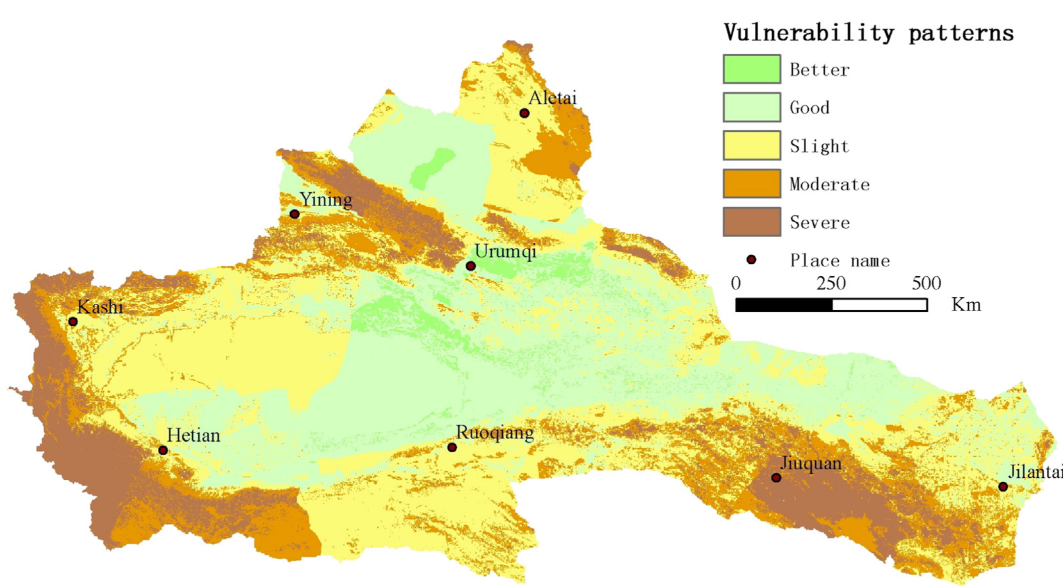

Fig. 3. Spatial distribution of the vulnerability of the socio-ecological system in the arid area of Northwest China.

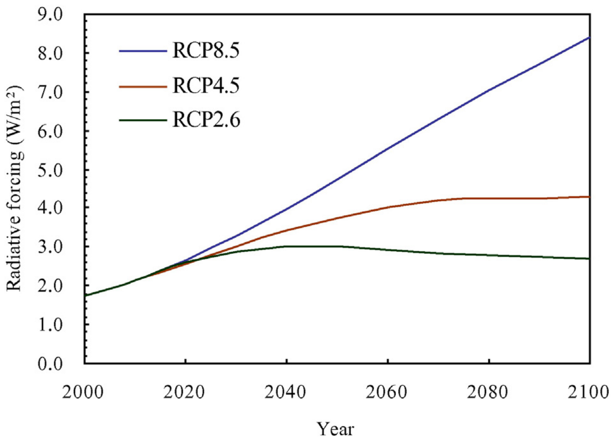

Fig. 4. Radiation forcing of RCP2.6, RCP4.5 and RCP8.5.

assumed to follow a Pearson-III distribution. After normal processing for precipitation, the Pearson-III probability density function can be transformed into standard normal distribution. The Z index responses to drought and flood were quicker than other statistical parameters. The calculation method can be found in the references (Wu et al., 2001).

$$Z_i = \frac{6}{C_s}\left[\frac{C_s}{2}X_i + 1\right]^{\frac{1}{3}} - \frac{6}{C_s} + \frac{C_s}{6} \tag{1}$$

where X_t is standardized variable of precipitation; C_s is coefficient of skewness, which is calculated using the sample numbers (n) of precipitation and its mean square deviation(S); i is ordinal number of data. C_s was calculated by the following equation:

$$C_s = \frac{\sum_{i=1}^{n}\left(R_i - \overline{R}\right)^3}{nS^3} \tag{2}$$

3.2.4. Agricultural suitable region

Oasis agriculture is the economic foundation for the arid area. This region has the advantage of sunlight and heat that can be used for agriculture plants in arid areas. Water and surface irrigation are the dominant factors influencing suitability besides landform and soil texture (GAEZ, 2000). Therefore, climate change has an important effect on the agricultural structure. The standards followed are in Table 3:

3.2.5. Population density

Population density is a measurement of the population per unit area or unit volume. It is frequently applied to living organisms and particularly to humans (Donald et al., 2001). Here, we adopted the density of the agricultural population per unit of cultivable area.

3.3. Data sources

We obtained data from the European Centre for Medium-Range Weather Forecasts (ECMWF; http://www.ecmwf.int/), and daily temperature, precipitation, sunshine duration and evaporation were used during the period from Jan. 1, 1960, to Dec. 31, 2013. Data were from the ERA-40 dataset (1960–1978) and the ERA-Interim dataset (1979–2013). The size of the grid cells was 0.25° × 0.25°. The simulated monthly precipitation and temperature data (2014–2100) were obtained from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) (http://cmip-pcmdi.llnl.gov/cmip5/). The monthly runoff data in this period were from the China water resources bulletin (http://www.mwr.gov.cn/zwzc/hygb/szygb/). The social economy and ecological environment data from 2000 to 2013 were from China's statistical yearbook (http://www.stats.gov.cn/tjsj/ndsj/). Land use and land cover data were provided by the Cold and Arid Regions Sciences Data Center at Lanzhou (http://westdc.westgis.ac.cn). The digital elevation model (DEM) (90 m × 90 m) and vegetation data were provided by United States Geological Survey (USGS) (http://earthexplorer.usgs.gov).

Table 2
Classification index of arid area.

Drought grade	Drought index
Extreme arid region	<0.05
Arid region	0.05–0.2
Semi-arid region	0.21–0.5
Semi-humid region	0.51–0.65
Humid region	>0.65

3.4. Vulnerability evaluation

Principal component analysis (PCA) is a quantitative analysis tool used for correlation analysis among multiple quantitative variables.

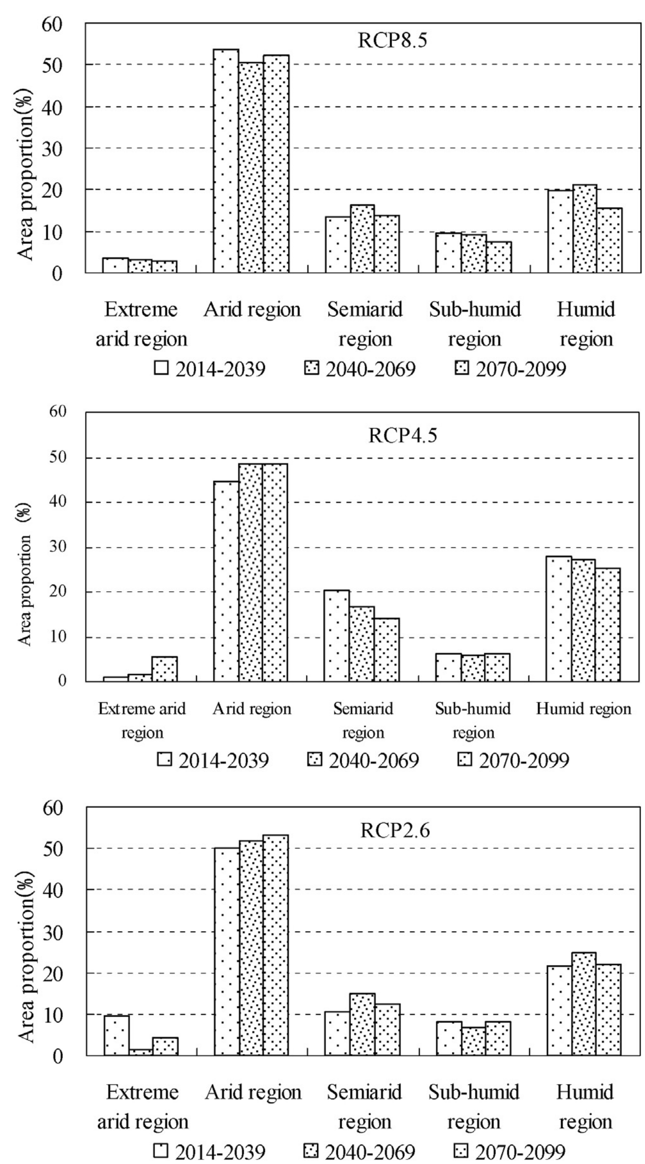

Fig. 5. Change of land desertification with climate change under different climate scenarios.

Table 3
Climate, soil and terrain constraints for rain-fed crop production.

Factor	Condition and constraints					
Annual accumulated temperature(≥5 °C)	0	1–60	60–119	120–179	180–269	270–365
Constraints	Severe	Moderate	Moderate	Slight	Slight	Non
Terrain slopes	0–3%	3–7%	7–15%	15–25%	25–30%	> 30%
Constraints	Non	Slight	Moderate	Moderate	Severe	Severe
Soil drainage	Good	Poor				
Constraints	Non	Moderate				
Soil texture	Medium/fine		Sandy/stony	Cracking clay		
Constraints	Non		Slight	Moderate		

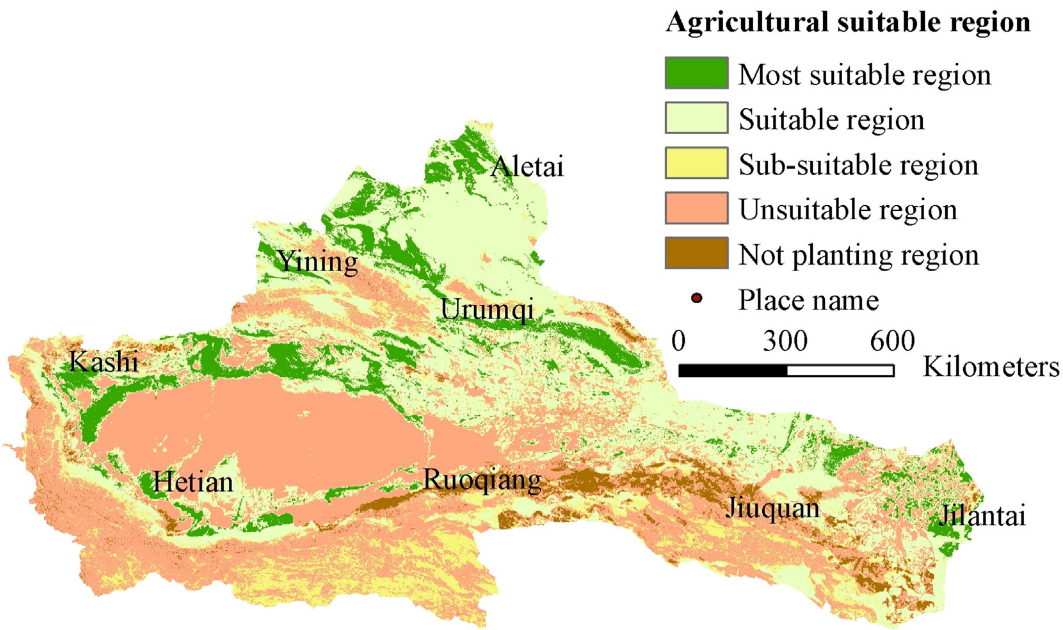

Fig. 6. Distribution of agricultural suitable region in 2014.

According to orthogonal transformation, a set of uncorrelated principal components with the original variable information can be obtained. Principal components are usually used to construct a comprehensive index and explain any underlying rules (Wold et al., 1987). In this paper, PCA was used to reduce the dimension of the evaluation indicators.

Entropy is a measure uncertainty in information theory. Higher uncertainty means higher entropy (Zou et al., 2006). Thus, entropy can be used to measure the degree of dispersion of the principal component factors. In this case, entropy has been used to determine the weight of principal component factors for forming a comprehensive index. Finally, the Jenks natural breaks optimization method (Jenks, 1967) was used to determine the threshold values of evaluation types in the first period. The method seeks to minimize the variance within classes and maximize the variance between classes. Calculations are repeated until the sum of the within class deviations reaches a minimal value. When the evaluation was based on climate change scenario data, the threshold values of evaluation types adopted the same values obtained by the Jenks natural breaks optimization method in the first period.

The evaluation process includes six steps: (1) standardizing the raw data for eliminating the influence of quantities and dimensions; (2) calculating the correlation coefficients of evaluation indices; (3) extracting feature vectors from a matrix; (4) determining the principal components based on the contribution rate and accumulated contribution rate; (5) calculating the comprehensive index according to the weights of principal component factors; and (6) classifying evaluation types using the Jenks natural breaks optimization method.

3.5. Simulation of the effect of climate change on vulnerability

According to the Fifth Assessment Report (AR5) released by the Intergovernmental Panel on Climate Change (IPCC) in 2014, three Representative Concentration Pathways (RCPs), RCP2.6, RCP4.5 and RCP8.5 were chosen as the input data for climate (Van Vuuren et al., 2011).

RCP8.5 is characterized by increasing greenhouse gas emissions over time and is representative of scenarios in the literature that lead to high greenhouse gas concentration levels. The rising radiation forcing pathway leads to 8.5 W/m^2 in 2100. RCP4.5 is a stabilization scenario in which the total radiation forcing does not exceed 4.5 W/m^2 and is stabilized before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions. RCP2.6 is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels, and the peak in radiation forcing at 3 W/m^2 appears before 2100 and then declines (Parry et al., 2009).

Table 4
Statistics of vulnerability classification.

Vulnerability pattern	Area(km^2)	Area share(%)
Better	55,751	2.82
Good	630,916	31.89
Slight	694,106	35.08
Moderate	348,629	17.63
Severe	248,969	12.58

Table 5
Change rate of vulnerability factors with climate change.

Factor	Change rater(%)						
Change direction	−2	−1	0	1	2	3	4
Water resources carrying capacity	–	–	16.86	28.04	43.79	11.31	-
Land desertification	–	14.38	66.57	18.03	1.02	-	-
Natural disaster	–	–	–	81.34	14.83	3.53	0.30
Agricultural suitable region	0.86	26.06	66.33	6.20	0.56	–	–
Population density	–	–	–	32.42	39.82	19.43	8.33

The precipitation and temperature data from 2014 to 2100 were simulated using the MIROC ESM model. The gridded data are at a 50 km × 50 km resolution.

4. Results and discussion

4.1. Characteristics and spatial distribution of vulnerability patterns

According to the methods introduced in the previous section, the vulnerability of socio-ecological systems in the northwest arid area was evaluated.

4.1.1. Statistics of vulnerability

The vulnerability has been classified into five patterns. The results are listed in Table 4.

Table 4 indicates that the socio-ecological system is very weak in the arid area of Northwest China. The non-fragile area occupies 34.71%,while the fragile area reaches 65.29%. We note that almost one third of the area is subject to very severe fragility.

4.1.2. Spatial distribution of vulnerability

We can obtain the spatial distribution map of vulnerability using the spatial analysis model in ArcGIS 10.1 (Fig. 3).

Fig. 3 shows that the better and good vulnerability patterns are mainly distributed in the artificial oasis and desert hinterland. Most of the areas with a slight vulnerability are located in the transition zone between the artificial oasis and natural oasis. The severe vulnerability regions are distributed in high altitude areas and around the basin edge. This indicates that water resources have been redistributed because of human activity, but land desertification has been controlled by agriculture vegetation. However, the fragile ecosystem in the high mountain area has become more vulnerable. This is consistent with distribution of the vulnerability profiles in drylands worldwide by Kok (Kok et al., 2015).

4.2. Change trends in the most vulnerable areas

4.2.1. Climate change scenarios

As stated in the previous section, RCP2.6, RCP4.5 and RCP8.5 represent three typical emission scenarios. Based on the fifth phase of the Coupled Model Intercomparison Project (CMIP5) recommended data, the radiation forcing simulations are listed in Fig. 4.

Based on the anthropogenic emissions, precipitation and temperature data from 2014 to 2100 could be simulated using the MIROC ESM model.

4.2.2. Effect of climate change on land desertification

Based on the climate scenario data, the drought index was calculated and classified into five climatic regions according to Table 2. The change of climatic regions reflects the effect of climate change on land desertification (Fig. 5).

Fig. 5 shows that the areal percentages of each sub-region under the three climate scenarios are: Arid region (44.74–53.75%) > Humid region (15.60–27.72%) > Semiarid region (10.71–20.45%) > Sub-humid region (5.99–9.45%) > Extreme arid region (0.84–9.58%). The areal proportion in each scenario is similar. The sum of the three sub-regions of extreme arid, arid and semiarid region is approximately 70%. Under RCP4.5 scenarios, the extreme arid and arid region increases from 2014 to 2099, and the semiarid region decreases in this period. The humid region fluctuates slightly. All three categories of arid regions will continue to expand slightly in the future.

Under the RCP8.5 scenarios, a small change occurs in the extreme arid area. The areal extent follows a drop followed by an upward trend for the arid region and an upward followed by downward trend for the semiarid region. Under RCP2.6 scenarios, the arid region will decrease from 2014 to 2099.

Consequently, land desertification increases under the RCP4.5 scenarios and decreases slightly under the RCP8.5 and RCP2.6 scenarios from 2014 to 2099. The proportion of arid area ranges from 0.8% to 2.2%.

4.2.3. Effect of climate change on agricultural suitable region

We evaluated the present agricultural suitable region based on the average temperature recorded over the last 40 years, terrain slopes, soil drainage and soil texture data. The classification rules are listed in Table 3. The results are shown in Fig. 6.

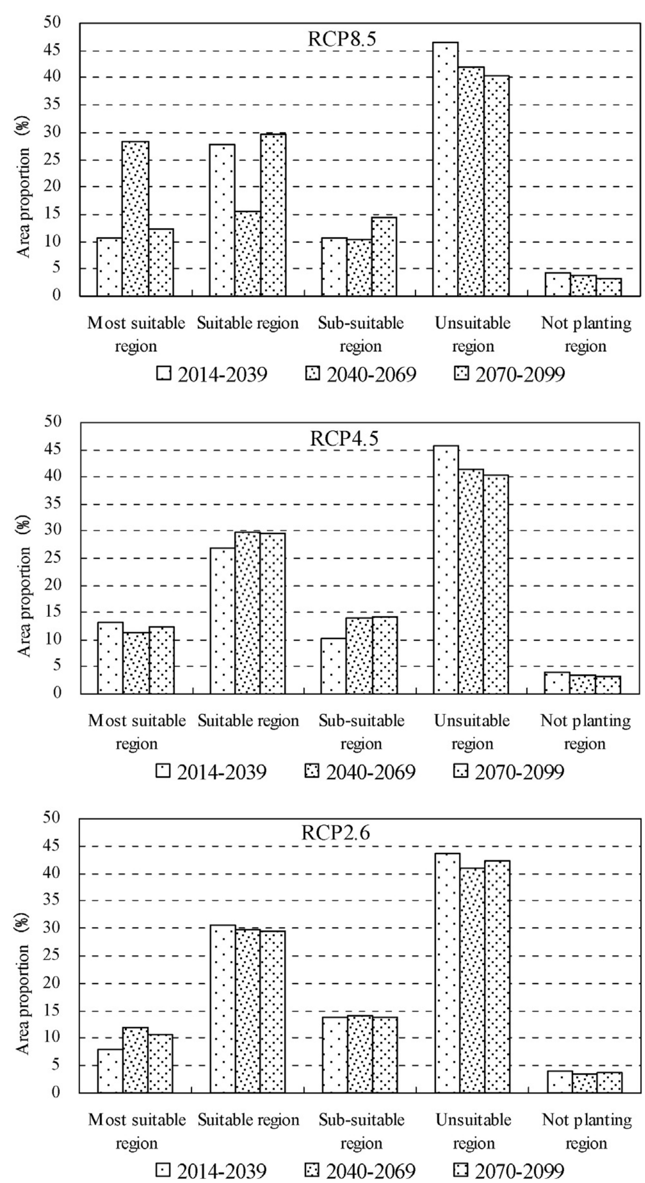

Fig. 7. Effect of climate change on agricultural suitable region.

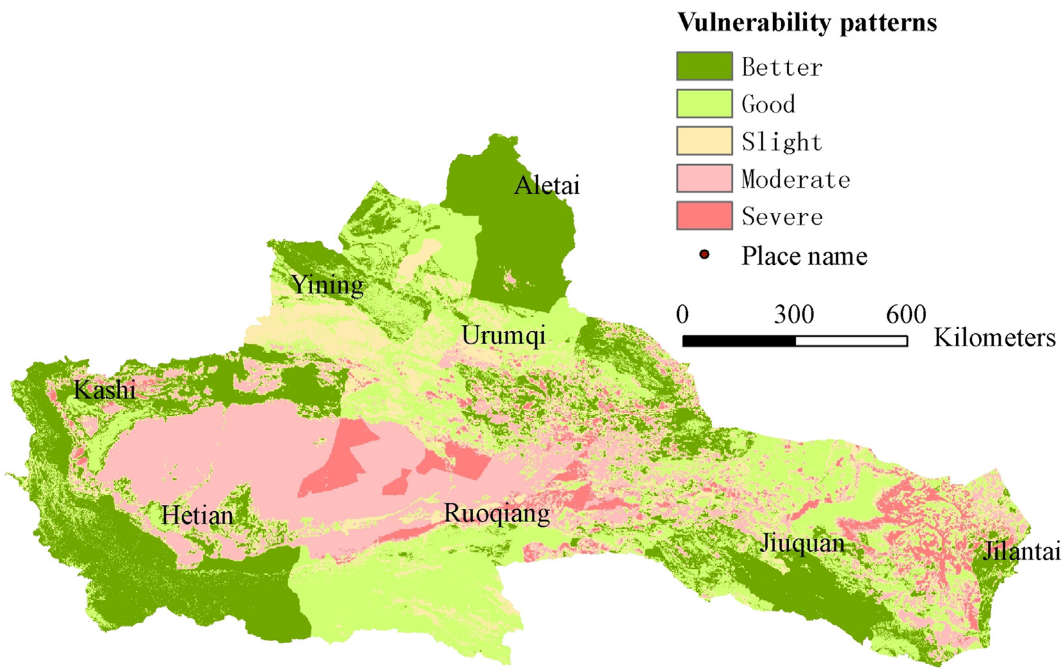

Fig. 8. Distribution of vulnerability of socio-ecological systems.

Fig. 6 indicates that the most suitable and suitable regions are mainly distributed around the periphery of basin. This is in accordance with the actual situation. The area of the most suitable region, suitable region, sub-suitable region, unsuitable region and not planting region occupy 9.64%, 33.45%, 12.25%, 40.95% and 3.72%, respectively. Without considering water conditions in the evaluation rules, the areal percentage occupied by the suitable region is much larger than the present oasis area.

To analyze the effect of climate change on agricultural suitable regions, the simulated climate data from 2014 to 2099 were used for evaluation (Fig. 7).

Fig. 7 shows that the suitable region will increase in area and the unsuitable region will shrink by the end of the 21st century. Under the RCP4.5 scenario, the most suitable region has a slight decreasing trend of 0.88–1.85%, whereas the suitable and sub-suitable region has a larger increasing trend of 2.97–4.20%. The areal extent of the unsuitable region drops from 45.61% to 40.33%. The no planting region decreases 4.05% to 3.26%.

Under the RCP8.5 scenario, there is an obvious increase in the most suitable region and decrease for the suitable region from 2040 to 2069, with 17.62% and 12.11% of amplitude of fluctuation, respectively. The unsuitable and no planting regions drop with time.

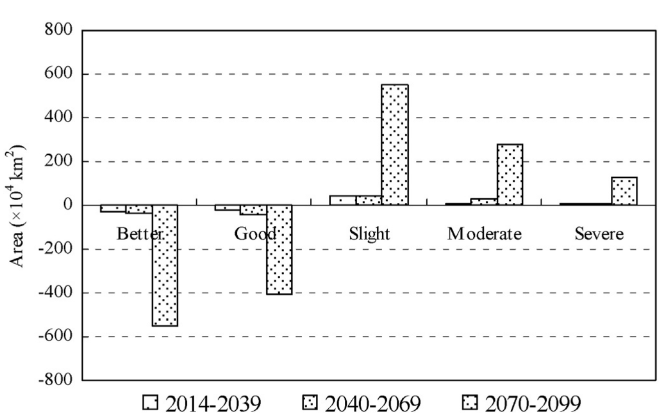

Fig. 9. Change trend of vulnerability of socio-ecological system to climate change.

Under the RCP2.6 scenario, the change is significant. There is some increase in the most suitable region and decrease for the suitable region. Throughout the entire study period, the proportion of these sub-regions remains stable.

4.2.4. Effect of climate change on the vulnerability of the socio-ecological system

4.2.4.1. The distribution of present vulnerability. The vulnerability of a socio-ecological system was evaluated based on water resources carrying capacity, land desertification, natural disaster, agricultural suitable region and population density using PCA. The spatial distribution of the current vulnerability is shown in Fig. 8.

Fig. 8 indicates that the socio-ecological system in the northwestern arid area is highly vulnerable. The percentage of the area for each of the five types, better, good, slight, moderate and severe type is 28.99%, 30.70%, 13.34%, 21.61% and 5.36%, respectively. The low vulnerability region is mainly distributed in the desert region, while the high values region is along the periphery of the basin.

4.2.4.2. Change of vulnerability with climate change. By comparing the values of vulnerability in the future, we find that vulnerability increases from 2014 to 2099, and thus the socio-ecological system is negatively impacted by the climate change. The change rate fluctuates significantly especially from 2070 to 2099. The better type and good type decrease by 24.88–39.71% during 2014–2069 and by 410–551% from 2070 to 2099. The slight type, moderate type and severe type increase by 4.85–44.88% from 2014 to 2069 and by 130–552% from 2070 to 2099. The areal extent is reduced for the better type category, which is larger than the good type. The highest increasing rate is observed in the slight type category, with the moderate type following in second place. The lowest areal extent is observed in the severe type (Fig. 9).

4.2.4.3. Sensitivity analysis of vulnerability. By overlaying the change map of vulnerability on the climate change map in Arcgis, the response relationship could be analyzed (Fig. 10).

Fig. 10 illustrates that there is a strong sensitivity of the vulnerability of the socio-ecological system to climate change. Most of the area is very sensitive to climate change. The insensitive regions are mainly

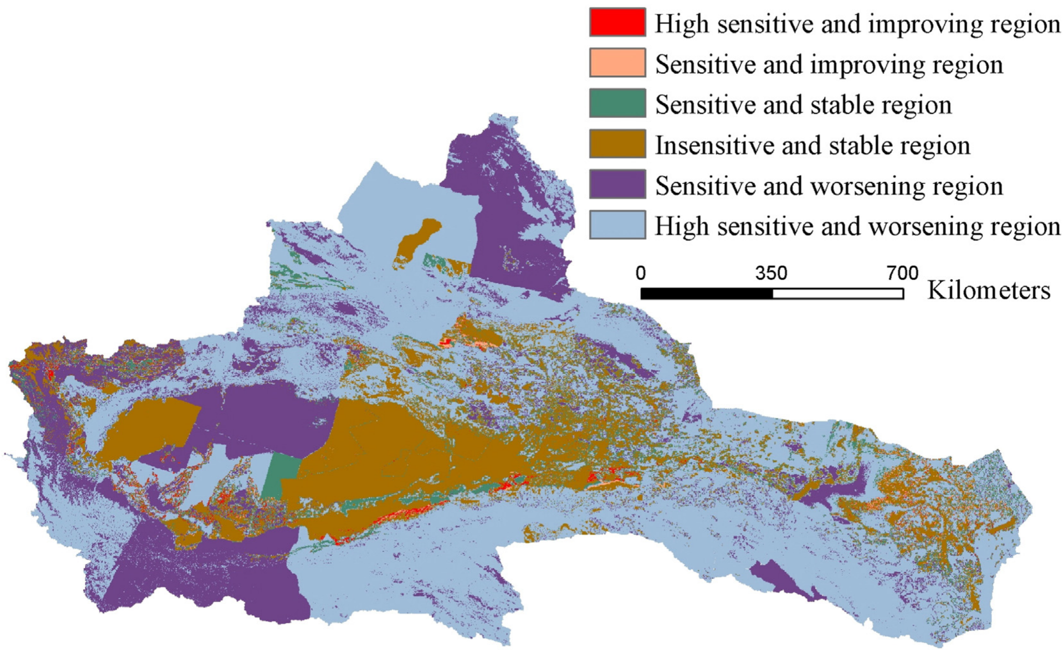

Fig. 10. Sensitivity and stability of socio-ecological system with climate change.

distributed in the desert hinterland. 81.87% of the area is in a highly sensitive or sensitive region, and 24.19% of the area belongs to the insensitive region. The improving region only occupies 1.30%, and the worsening region occupies 74.51%. This indicates that the socio-ecological system as a whole will follow a worsening trend when climate change is considered.

5. Conclusions and suggestions

According to a case study in a typical arid area, we found that severe vulnerability is distributed in high altitude areas around the basin edge. The results indicate that water resources have been redistributed in the area because of human activity (Feng et al., 2000), and land desertification has also been controlled by agricultural vegetation (Zhang et al., 2003). At the same time, the fragile ecosystem in high mountain areas became more vulnerable. This distribution characteristic of socio-ecological vulnerability could be found in Southern Africa (Abson et al., 2012).

The land desertification increases under the RCP4.5 scenarios and decreases slightly under the RCP8.5 and RCP2.6 scenarios from 2014 to 2099. The regions suitable for agriculture increase slightly under the three scenarios. The socio-ecological system worsens with climate change from 2014 to 2099. The main reason for the evolution is that the climate changes from warm dry to warm wet pattern in the arid area of Northwestern China (Wang et al., 2013; Wu et al., 2001).

The socio-ecological system presents a worsening trend as a whole. Finally, taking into account the variability rate of vulnerability factors with climate change, adjusting the water utilization structure, optimizing water resources projects, and controlling the appropriate population scale would be the most efficient mechanisms for mitigating the problems in socio-ecological systems in the future (Sietz et al., 2011). To investigate solutions for reducing vulnerability in an arid area, variation of factors was analyzed based on the mean of three climate models at the end of 2099 (Table 5).

Table 5 shows the change rater of each cluster for every factor. We can see that the pressure of the water resources carrying capacity, natural disasters and population density will increase by the end of this century. More than 80% of the area will face water resources carrying capacity problems, while population growth constitutes a significant challenge on the other hand. With the increase of precipitation and temperature, land desertification would decrease and the regions that are suitable to agricultural would enlarge. Improving the utilization efficiency of water resources and controlling human activities would be the best way to address problems related to the socio-ecological system in the future (Abson et al., 2012).

5.1. Adjusting water utilization structure

Currently, more than 80% of water is used for agriculture. Research indicates that irrigation water would increase by 8.2–9.1% for use in saline-alkali soils if the temperature increase by 0.5–3.0 °C(Li et al., 2013). Climate warming would also make the irrigation demand increase, intensifying the demand for and quantity of agricultural water further. Industrial and domestic water demands are also projected to develop widely, which would aggravate the shortage of water resources. Adjusting the water utilization structure and decreasing the water use quota would be helpful strategies.

5.2. Optimizing water resources project

The reservoirs and other water conservation projects in Northwestern China have played an important role in water use. Now, many water conservation projects are distributed around large cities and irrigated areas in arid regions (Gleick, 2000). Judiciously planning water conservation projects would directly affect the spatial distribution of water resources and could also relieve the regional imbalance between supply and demand.

5.3. Controlling the appropriate population scale

Because of the pressure of water resources and the ecological environment, there is less population capacity in arid areas than in other regions (Chandel and Malhotra, 2006). Preventing population overload would not only control the excessive development of agriculture and husbandry but also industry and the service industry.

These aspects are also important beyond an analysis of global change, and they should be considered in the sense of reducing their barriers to implementation.

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