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Quantitative Analysis of Natural and Human Factors of Oasis Change in the Tail of Shiyang River over the Past 60 Years

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Abstract: The human and natural factors complicit in the driving forces of oasis change have always received considerable interest from the international research community. In this study, we used principal component analysis of natural and socio-economic statistical factors to quantitatively analyze the causal relationships and their contributions to the observed periodic expansion or shrinkage of the Minqin Oasis over almost 60 years. Our results show that human factors were the dominant factors governing expansion or shrinkage, with average contributions of 69.38% and 76.16%, respectively. Moreover, policy decisions have been the pivotal human factors. Under the influence of various policies, we have found that water resource utilization, land reclamation, population explosion, ecological protection and economic development have each played leading roles in different periods. This study provides a scientific basis for modelling the dynamics of an oasis for sustainable management.

Key words: Oasis change, natural factors, human factors, Minqin Oasis

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1 Introduction

The word “oasis” implies a fertile area with a continuous supply of water situated in a desert or dryland (Xue et al., 2015). Many oases, including those in Central Asia, North Africa and northwestern China, are sites of ancient civilizations (Kang et al., 2008). Today, oases with abundant water, vegetation and soil are still the main locations of human habitation and development in arid areas. Taking the area covered by oases in northwestern China as an example, covering merely 4%–5% of national arid land area it supports 90% of the population and creates 95% of social wealth (Wang and Xue, 2010). An oasis is also a unique ecological landscape in an arid area, and one of the most sensitive to the relationship between humans and natural environment (Cao et al., 2016; Zhou and Lei, 2018). Since water resources are limited, oasis ecosystems in arid areas are complex, sensitive and fragile, and easily disturbed by external factors. Under the influence of unsustainable human activities and natural factors such as climate change, an oasis may follow one of two evolutionary processes: expansion or shrinkage. Oasis shrinkage is often accompanied by the occurrence and development of desertification, so people living in the oasis need to rationally regulate their own production and lifestyles. In recent years, with the emerging concept of “ecological civilization” and “green development”, how to effectively curb the shrinking of oases and promote their orderly and healthy development is the key scientific problem in oasis management. In order to assist the reasonable development of oases and management of their ecological environment, we identified the driving factors of oasis change (including natural and human factors) and compared the relative importance of each factor quantitatively.

China, as one of the countries with the largest oasis area, has conducted extensive research on oasis change. Within this, a lot of research has focused on the change of land use / cover of different oases. With the help of remote sensing (RS) and geographic information system (GIS) analysis, the temporal and spatial changes in land use / cover of almost all oases in Northwest China have been extensively studied over the past half century, including oases in Xinjiang (Cheng et al., 2006; Tang et al., 2007; Zhang et al., 2017), the Hexi Corridor (Yang and Eitel, 2016; Xiao et al., 2019), Inner Mongolia (Hu and Li, 2014; Hu et al., 2015), etc. In this context, however, there are few studies on land use / cover in oasis change abroad. Kato et al. (2012) analyzed land use change and crop rotation in the Dakhla oasis of Egypt based on satellite data. Almadini and Hassaballa. (2019) used RS and GIS techniques to quantitatively describe the land surface cover change in the Al-Hassa oasis of Saudi Arabia over the past 32 years. In addition to these studies on identifying oasis change, the impact of oasis change has been a hot topic in China and abroad. Oases in China are mainly distributed in the arid regions of the northwest; therefore, research on the impact of water resources has involved the entire history of oasis research in China. This research has included characteristics of water chemistry, the distribution of water resources, the dynamic relationship between groundwater and soil salinity, etc.

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(Wang et al., 2008; Yu et al., 2017; Zhou et al., 2017). In addition to the study on the influence of oasis change in arid areas, there are also studies on the influence of the evolution of glacial oases, mountain oases and coastal oases abroad. For example, Shrivastava et al. (2019) studied the impact of changes to the Schirmacher oasis on glacial erosional and strategic landforms in East Antarctica. Arizpe et al. (2018) analyzed the social, economic and environmental impact of the evolution of Mexico's Los Cabos' coastal oasis, and provided a restoration strategy. Nagieb et al. (2004) combined hydrology, soil measurement and archaeological investigation methods to study the settlement change history under the evolution of a mountain oasis in northern Oman.

Oasis change and its impacts have both advantages and disadvantages. Historical impacts of oasis change cannot be reversed; however, understanding the driving factors of oasis change in order to prevent further negative impacts is an important contribution to this field. When studying driving factors, most scholars obtain data on oasis land use change using remote sensing techniques, and then use these results to discuss the driving factors of the change observed. For example, Liu et al. (2011) analyzed the spatial expansion characteristics of 17 oasis cities in Xinjiang (Northwest China) over the last 20 years, indicating that resources, population, economy, infrastructure construction and policy planning were the main driving factors. Li et al. (2006) compared changes in cultivated land of oases in the middle and lower reaches of the Shiyang River Basin, and concluded that the amount of surface water is a significant driving force on the middle reaches, while the status of the lower reaches is significantly influenced by meteorological factors. Some studies have examined the driving forces of oasis change on the basis of historical facts or literature. Tang et al. (2018) systematically analyzed the natural and human factors in the evolution of ancient oases in the Heihe River Basin over the past 2,000 years on the basis of historical data. Li et al. (2004), in analyzing the shrinkage of the Ejina Oasis over the last 50 years, found that a warm, dry climate, enhanced wind erosion, excessive development of water and soil resources in the upper and middle reaches, and a large number of vegetation destruction activities in the oasis are the main driving forces for Ejina Oasis desertification. Although these studies have successfully identified the natural or human factors that affect oasis change in their respective areas, most are explained from a qualitative point of view. In contrast, a quantitative study of the relative contributions of both types of factors not only helps to clarify their coupling mechanism for oasis change, but also provides a very important theoretical and practical grounding for the later stages of ecological policy and green development. At present, very few oases have been researched from a quantitative perspective.

The research methods used to determine the relative degree of contribution of natural and human activity on regional eco-environmental change can be divided into three categories. (1) The decisive factors are judged by comparing the correlation between climate, human activities and regional ecological change trend. This method is mostly used in regions where climate and human activities act in opposite directions (Wang et al., 2006). (2) Using remote sensing and GIS, the influence of natural and man-made factors is unified into a comparable index (such as net primary productivity) to determine the relative effect of these factors (Xu et al., 2009). (3) Corresponding mathematical methods—such as regression models and principal component analysis—are used to characterize the differences in driving force by its regression coefficient or variance interpretation rate. Different methods have their own advantages and disadvantages in the evaluation process. For example, methods (1) and (3) mostly take the administrative territorial entity as the minimum research unit. This cannot distinguish differences in the grid scale, but does enable long-term research. Method (2) has a clear mechanism and can be used in different spaces. However, because satellite imaging has only been used recently, there are relatively few long-term data. Most of these methods focus on the quantitative analysis of the natural and human factors in the occurrence and development of desertification in the process of oasis shrinkage, and lack an evaluation of the driving factors of the whole process of oasis expansion and shrinkage. Evaluating the entire process of oasis change is more helpful in understanding the influence of natural and human activities on oasis ecological processes.

The oasis in Shiyang River Basin is in one of the most densely populated areas of China, with a population of more than 2 million. The population density of the oasis is 54.6 people per square kilometer, which is 7.8 times the suitable density of an arid area as stipulated by the United Nations. Since the founding of the People's Republic of China, the rapid increase in population and cultivated land and the acceleration of urbanization has caused the Shiyang River to be over exploited. The water used for production is extracted from the environment that supports the local ecology, resulting in a continuous decline of groundwater level, vegetation degradation, land desertification, salinization and other ecological problems (Su et al., 2017). This is particularly stark in the Minqin Oasis in the lower reaches of the basin. In order to control the ecological and environmental problems of the oasis in the Shiyang River Basin, a series of ecological projects and policies have been implemented by the state and local governments, which have achieved remarkable results. However, due to the ecological sensitivity and local human activities in this arid area, there has been very frequent transformation between oasis and desert over the past 60 years. It is, therefore, vital to study all factors driving the process of oasis change in this area. Minqin County in Gansu Province, the oasis at the end of the Shiyang River, was taken as a typical research area. Firstly, we identified the specific period of oasis expansion or shrinkage based on the progress of the literature and local conditions in the Minqin Oasis. Secondly, we selected the relevant factors that affect the oasis expansion or shrinkage. Finally, we used principal component analysis to quantitatively evaluate the dominant factors determining the period of oasis expansion and shrinkage, and determined the contribution of natural or human factors according to the attributes of the dominant factors. This study provides a formula that can be used for regional development strategies needing to understand these changes.

2 Materials and Methods

2.1 Study area

The Shiyang River Basin is located at the intersection of the eastern monsoon region, the Tibetan Plateau and the northwestern arid region of China. Most of the region is semi-desert and arid desert, and has a desert oasis landscape. Minqin Oasis is located in the eastern Hexi Corridor and the downstream area of the Shiyang River Basin (Fig. 1). The geographical coordinates of Minqin Oasis are 38°03′–39°28′ N, 101°49′–104°12′ E. The Tengger Desert surrounds the oasis on the right, and the Badain Jaran Desert surrounds the oasis on the left. Minqin Oasis is an important green barrier to prevent the two deserts from converging. The middle part of the oasis is a long, flat alluvial belt of the Shiyang River. Minqin County has a total area of about 1.6×10^4 km^2, of which the oasis plain accounts for 9%; deserts (including the Gobi) account for 82%. The climate characteristics of a continental desert in this area are very obvious: cold in winter and hot in summer, limited precipitation, high evaporation, sufficient in sunlight and large temperature differences between day and night. There is no runoff except the water from the Shiyang River, which flows into Hongyashan reservoir. Minqin Oasis has historically been rich in water and grass. In recent decades, under the influence of a variety of human and natural factors, it has experienced many periods of transformation between shrinkage and expansion.

By the end of 2015, the gross domestic product (GDP) of Minqin County was 6.956 billion yuan (0.99 billion US dollar), of which the primary, secondary and tertiary industries accounted for 34.08%, 31.55% and 34.37%, respectively. The per capita disposable income of urban residents at that time was 18,661 yuan (2,641 US dollar), and the per capita net income of rural residents was 10,519 yuan (1491 US dollar). By the end of 2015 the area planted with crops in the county was 942.29 km^2, including 547.3 km^2 for grain crops and 260.55 km^2 for main economic crops. The total meat output was 19,000 tons.

2.2 Ecological evolution

The ecological environment of Minqin Oasis has experienced three historical stages: natural ecological period (from about 2000 B.C. to 202 B.C.); artificial farming and animal husbandry ecological period (from about 100 B.C. to 1300 A.D.); and desertification period. The special geographical location and climatic characteristics have determined that the history of Minqin is one of fighting against sandstorms. According to the records of Minqin County, officials and people took the initiative to participate in desertification control to resist sandstorm disasters in the Ming and Qing Dynasties (from about 1368 A.D. to 1912 A.D.). After the founding of the People's Republic of China, an organized campaign of

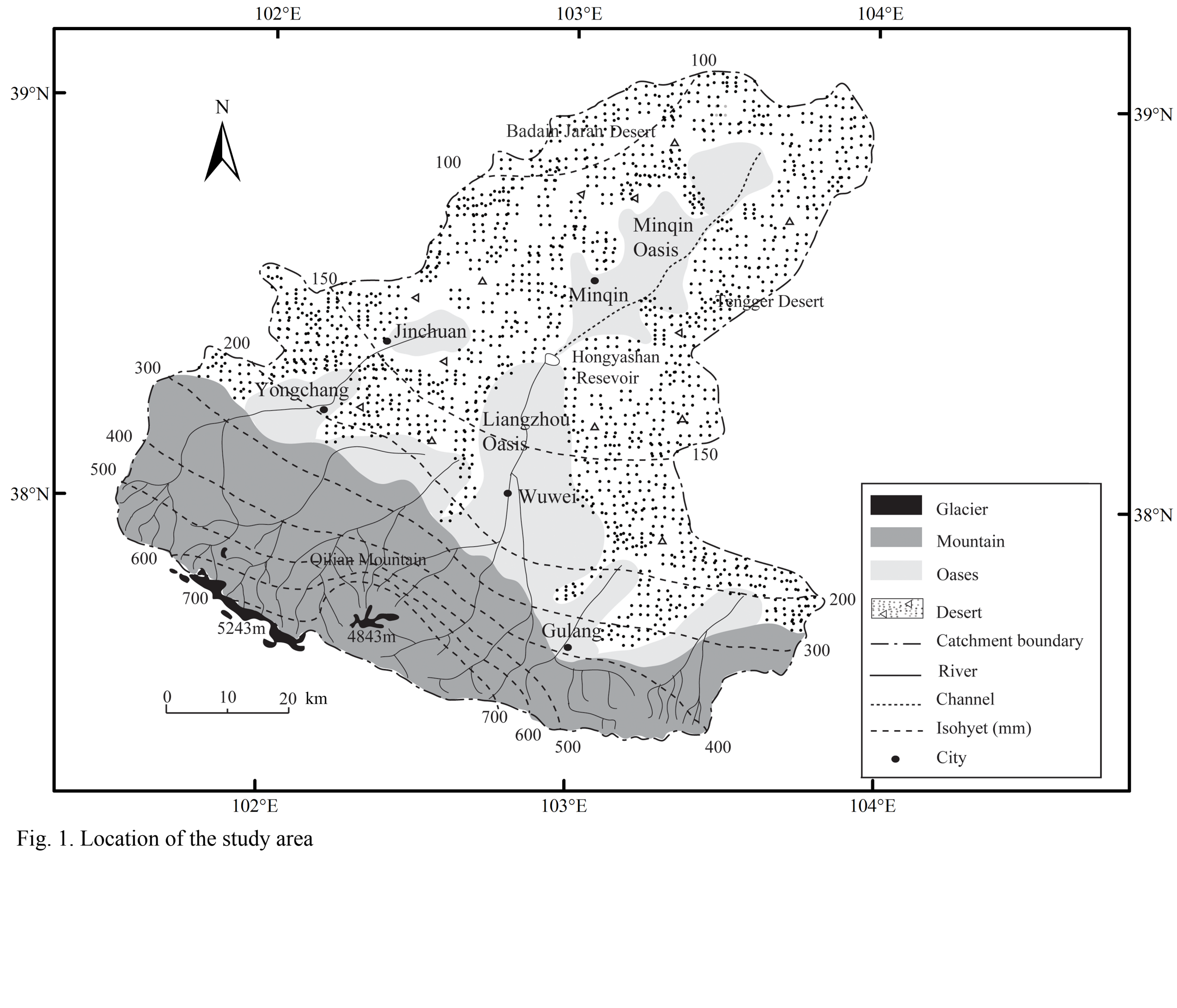

Fig. 1. Location of the study area

sand control and ecological improvement was gradually launched. From 1949 to 1958, the county completed a total of 947 km^2 of afforestation and 2,350 km^2 of cultivation of grass and hardy plants in the sand (Huang et al., 2014). Although ecological construction has been carried out in Minqin County, the influence of differences in national development priorities, unreasonable human activities and climate fluctuations has meant that there is great uncertainty in the quality of the ecological environment. In 2000, the desertification land area of Minqin County accounted for 83.09% of its total area (Wang et al., 2004). In 2001, Prime Minister Wen Jiabao stated that "Minqin should not be allowed to become the second Lop Nor"[1]. Since then, Minqin County has implemented the strategy of establishing the county on an ecological basis, and set up key projects in ecological construction and protection, such as returning farmland to forests, closing wells to farmland and constructing nature reserves. From 2005 to 2015, the desertification of Minqin County was clearly reversed, and the reversed desertification area was 4.23 times that of the development area (Chen, 2017). With the evolution of ecological environment for decades, the scale of Minqin Oasis has also undergone expansion or shrinkage.

2.3 Data and methods

Oasis change is a dynamic process determined by the joint actions of human and nature in arid region. The main driving factors of oasis evolution cannot be separated from the local climate conditions, ecological conditions, resource background characteristics and human activities. Combined with the current literature on (Hao et al., 2008; Zhang et al., 2008; Li et al., 2017; Yang and Zhu, 2018) and field characteristics of the study area, this study identifies the main factors affecting the change of the Minqin Oasis from the aspects of climate, population, resource conditions, ecological governance behavior, industrial development, etc. In order to carry out the principal component analysis scientifically, we first performed a correlation analysis on the selected indicators, and selected the 15 most highly-relevant indicators.

The indicators reflecting natural factors include temperature, precipitation, evaporation, and number of sandstorms. The indicators reflecting human factors consist of water inflow from upstream, number of wells, afforestation area, cultivated land area, number of livestock, total population of the county, natural growth rate of population, per capita GDP, total agricultural output value, total industrial output value, and total retail sales of social consumer goods. The selection of indicators are in accordance with the principles of science, generality and operability. The indicator data used in the study were all from the "Digital Minqin 1949–2009" and the Minqin County Statistical Yearbook from 2010 to 2015.

According to the previous research by Xie and Chen (2008) and Lu et al. (2017) on oasis space-time change in Minqin County, we divided the changes in the Minqin Oasis area into an expanding period (1959–1973, 1987–2005, 2010–2015) and a shrinking period (1973–1987, 2005–2010). We analyzed all the data within these five periods with SPSS 19.0 software, and all passed the Kaiser -Meyer-Olkin (KMO) test. The main factors in each period were extracted according to the principle of cumulative variance contribution ≥ 80% (Table 1).

3 Results

3.1 Relative contributions of natural and human factors to oasis change

The load matrix of orthogonal rotation (Table 1) indicates that three common factors were extracted from the influencing factors of Minqin Oasis expansion from 1959 to 1973. The first common factor imposed a relatively high load on the number of water wells, the total population of the county and the upstream inflow (the absolute value was above 0.7, the same below), indicating

Table 1 The loading of each principal component after rotation of influencing factors of Oasis change

Variable	1959–1973			1973–1987			1987–2005			2005–2010			2010–2015		
	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3	C_1	C_2	C_3
Average annual temperature	−0.025	0.314	0.598	0.487	0.000	0.123	0.006	0.621	0.061	−0.393	0.581	0.459	0.662	−0.008	0.702
Annual precipitation	0.509	−0.267	−0.272	−0.032	−0.249	0.238	−0.085	0.105	0.813	−0.391	0.074	0.801	0.087	−0.003	0.979
Annual evaporation	−0.462	0.312	0.786	0.327	−0.065	0.602	−0.547	0.028	−0.606	0.212	−0.175	0.919	−0.245	0.058	−0.882
Annual sandstorm frequency	0.091	0.169	0.784	−0.572	0.163	0.717	−0.588	0.012	0.271	−0.063	0.014	−0.827	−0.215	−0.946	−0.176
Water inflow from upstream	0.711	0.463	−0.653	−0.524	−0.756	-0.113	−0.620	−0.639	−0.114	0.496	0.859	−0.056	0.225	0.560	0.551
Number of wells	0.887	−0.141	0.252	0.994	0.634	0.070	0.430	0.727	0.192	−0.360	−0.786	0.429	−0.252	−0.924	−0.147
Afforestation area	0.101	0.873	0.118	0.176	−0.109	-0.537	0.439	0.220	0.716	0.939	0.130	−0.089	0.903	0.298	−0.292
Cultivated land area	−0.438	0.767	0.074	0.722	0.518	0.345	0.519	0.887	0.142	−0.781	−0.392	−0.431	−0.680	−0.025	−0.184
Number of livestock	0.372	−0.674	−0.109	0.899	−0.047	0.201	0.578	0.351	0.172	0.165	0.924	0.311	0.937	0.226	0.106
Total population of the county	0.739	0.052	−0.066	0.538	0.510	−0.006	0.751	0.681	0.126	0.429	0.224	0.859	−0.310	−0.907	−0.139
Natural growth rate of population	0.028	0.915	−0.132	−0.210	−0.644	0.079	0.664	−0.508	−0.191	−0.278	−0.597	−0.673	−0.755	−0.208	0.206
Per capita GDP	0.623	−0.266	−0.232	0.664	0.206	−0.011	0.241	0.444	0.191	0.664	0.697	0.138	0.778	0.571	−0.215
Total agricultural output value	0.577	−0.415	0.765	0.925	0.246	−0.053	0.837	0.469	0.116	0.789	0.610	0.019	0.807	0.529	−0.230
Total industrial output value	0.066	0.562	0.098	0.080	0.943	0.064	0.847	0.374	0.310	0.814	0.456	0.185	0.809	0.521	−0.192
Total retail sales of social consumer goods	0.624	0.038	0.232	0.335	0.919	−0.002	0.880	0.409	0.150	0.833	0.338	0.092	0.904	0.419	−0.083
Eigenvalues	6.747	2.934	1.255	8.009	2.468	1.728	9.976	1.483	1.283	8.243	3.221	1.980	8.574	3.290	1.843
Contribution rate	50.005	24.583	13.393	56.416	19.476	14.541	66.508	9.890	8.556	54.952	21.476	13.202	57.157	21.932	12.289
Cumulative contribution rate	50.005	74.588	87.981	56.416	75.891	90.432	66.508	76.398	84.954	54.952	76.428	89.630	57.157	79.089	91.377

1 Lop Nor is located in the eastern part of the Tarim Basin in Xinjiang, China (39°58′–40°40′ N, 90°10′–90°40′ E), and was once the final catchment center of the basin's water system. Before 220 A.D., the water area of Lop Nor reached 5350 km^2. With the increase of human activities, the area of Lop Nor gradually shrinks. However, there were still 1900 km^2 in Lop Nor from 1921 to 1952. After 1962, the distribution of surface runoff was changed with unreasonable human activities (excessive water diversion in the upper and middle reaches), resulting in the downstream cutoff and the drying up of Lop Nor (Duan et al., 2013; Liu et al., 2015).

that the first common factor comprehensively carries the above three index information. These three indexes mainly reflect human activities, so the first main factor can be regarded as a human factor. The natural growth rate of population, afforestation area and cultivated land area imposed a relatively high load on the second common factor. In the second common factor, the index with a higher load was also reflect human activities, so the main factor was also regarded as a human factor. The third main factor had a relatively high load on annual evaporation, the number of sandstorms and the value of total agricultural output. There were both natural and human indexes with high load in the third common factor, and so this can be regarded as the comprehensive effect of natural and human factors.

The principal component factors indicated that the proportions of the total variance that could be explained by the three common factors were 50.005%, 24.583% and 13.393%, respectively. Combined with the above analysis of natural and human factors, the contribution of human factors in the expansion of the Minqin Oasis from 1959 to 1973 was 74.588%, and the contribution of natural and human factors was 13.393%.

In the same way, we obtained the contribution of natural and human factors in the expansion and shrinkage of the oasis in Minqin County from 1973 to 1987. The contributions of natural factors and human factors to oasis shrinkage in this period were 14.541% and 75.891%, respectively. From 1987 to 2005, the combined contribution of natural and human factors to oasis expansion was 8.556%, and the contribution of human factors was 76.398%. From 2005 to 2010, the human contribution to oasis shrinkage was 76.428%, and the combined contribution of natural and human factors was 13.202%. From 2010 to 2015, the human contribution to oasis expansion was 57.157%, and the combined contribution of natural and human factors was 34.221%.

3.2 Analysis of factors influencing oasis expansion

From 1959 to 2015, the Minqin Oasis experienced three periods of expansion: 1959–1973, 1987–2005 and 2010–2015 (Fig. 2). Water conservancy construction was the main cause of the expansion in 1959–1973. The completion of the Hongyashan Reservoir, the Yuejin Main Canal and the integration of the internal and external rivers, as well as channel reconstruction and groundwater extraction, brought great benefits during this period. Against the background of a government grain-production policy, a rapid increase in population gradually expanded the scale of land reclamation; and the "moving into the desert" policy during this period made remarkable strides in artificial afforestation, and many forest belts and sands that had been destroyed in the past were restored and managed.

From 1987 to 2005, the population of Minqin increased from 252,000 to 3,013,000, a net increase of 49,300. The large increase in population was one of the main factors for oasis expansion during this period. The inflow of water from the upper stream of the Minqin Oasis (upstream of the Shiyang River) continued to decrease from the previous period (1973–1987), but the digging of wells to extract groundwater continued throughout the county, alleviating the shortage of surface water sources to a certain extent. As reform and opening up continued to be promoted, the planned economy of the past gradually weakened, and the socialist market economy steadily became established. During this period, the primary, secondary and tertiary industries all experienced considerable development. At the same time, the prices of agricultural products continued to be high, and land management benefited a great deal, leading to accelerated development of the reclamation movement. The large-scale reclamation of the upstream dam area and the Quanshan area resulted in continued expansion of the oasis, and the area of reclamation was larger than the area abandoned in the previous period (1973–1987). However, owing to the limited water resources in the original oasis and its surrounding areas, the potential for reclamation was limited. During this period, people also focused on the area between hills in the desert, making the expansion of the oasis no longer a spatially continuous, but scattered to the hinterland of the desert.

The expansion in 2010–2015 benefited from various ecological governance policies. Under a series of ecological protection measures such as afforestation, grazing prohibition and water-saving transformation of the irrigated area, the vegetation coverage in the Minqin Basin increased by 20% to 30%; and Qingtu Lake, which had been dry for 51 years, found itself with a surface water cover of 25.16 km^2. Although a lot of people left the region during this period, urban development was relatively fast. Compared with the 11th Five Year Plan period (2006–2010), the primary, secondary and tertiary industries increased by 6.25%, 10.1% and 9.95% annually, respectively. At the same time, owing to the influence of climate warming, the average temperature of the Minqin Oasis increased by 14.16%, the average precipitation increased by 6% and the average evaporation decreased by 11.3%, which lead to relative improvement in oasis ecology.

3.3 Analysis of factors influencing oasis shrinkage

From 1973 to 1987, the main reason for oasis shrinkage

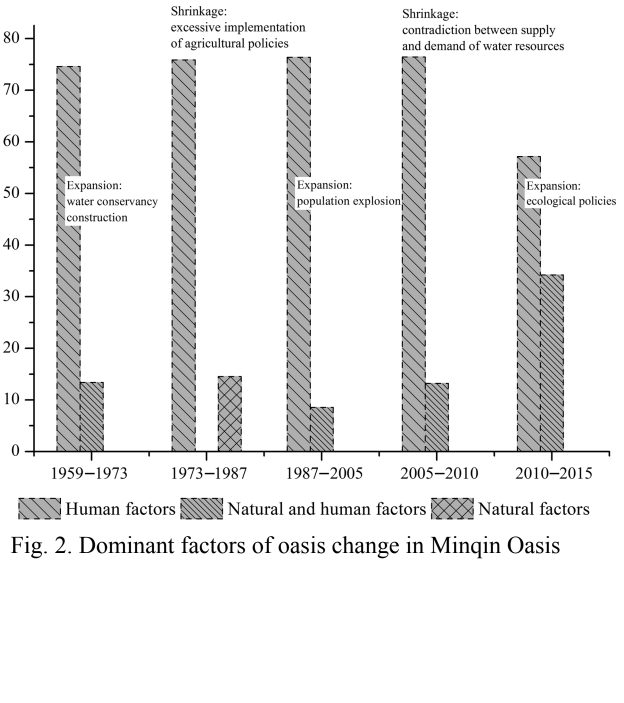

Fig. 2. Dominant factors of oasis change in Minqin Oasis

was the over-implementation of agricultural policies and the contradiction between supply of and demand for water resources. The first half of this shrinking period was still during the era of people's communes, and land reclamation and unilateral expansion of cultivated land continued. However, the amount of water coming from the upper streams reduced significantly, while water consumption did not. This imbalance between supply and demand lead to a large deficit in water resources for the Minqin Oasis. To combat this, there was a county-wide move to dig wells to extract groundwater, which partially alleviated the shortage of surface water sources. Nevertheless, this imbalance was considerable, and a large area of abandoned land began to appear in the Northern Lake area. Also, during this time the upstream water flow reduced further, particularly after the 1980s, and the increase in the number of mechanical and electrical wells started to fall, exacerbating the problem of insufficient supply of and demand for water resources. As a result, the edge of deserts on the east and west sides of the dam and Quanshan areas encroached on the oasis, and the vegetation of the original natural river course declined, leading to the oasis shrinking.

From 2005 to 2010, the imbalance between supply and demand continuously grew, and the groundwater level continued to decline as the cost of drilling wells rose. In addition, the government strictly controlled the number and scale of wells, leading to further water shortages. The continuous decline in the prices for agricultural products during this period resulted in famers' enthusiasm for farming waning. At the same time, owing to the serious deterioration of the ecological environment in the northern part of the basin, the government also strengthened the management of desert land reclamation. Under these circumstances, the trend of oasis expansion was curbed, and the area of the oasis declined.

4 Discussion

Taking the Minqin Oasis as an example, this study conducted a quantitative analysis of the main driving forces of oasis expansion or shrinkage based on the principal component analysis method. From this, we have proposed a preliminary clarification of the contribution of the natural and human factors, and identified specific influencing factors acting during the periods of expansion or shrinkage of this oasis. This study provides a scientific basis for modelling the dynamics of an oasis for sustainable management.

The results show that the contribution of natural factors was relatively small among the factors driving oasis change in Minqin County. This is most likely because the Minqin Oasis is located in an arid region and annual precipitation is very low. Although precipitation has increased in recent years, it is still part of an annual cycle, and has little impact on the Minqin Oasis which is characterized by irrigation agriculture. In contrast to this result, some other studies have shown that climate factors have a very significant positive impact on oasis changes in arid regions. For example, Song and Zhang (2015) studied the change of the Heihe agricultural oasis in China from 1986 to 2011 and concluded that changes in the annual temperature and precipitation have significant positive effects on oasis changes; however, they also confirmed that the proportion of irrigated agricultural oases has significant negative effects on agricultural oasis expansion. This indicates that human activities in arid regions have always been the dominant driving factor of oasis changes, regardless of whether climate factors have played a role. The specific human driving factors of Minqin Oasis change include water resource utilization, land reclamation, population explosion, ecological protection and economic development. This result is consistent with most existing studies. Ma et al. (2007) showed that overgrazing and over exploitation of water resources in the upper reaches are the main causes of desertification in the Minqin Oasis. Following comprehensive analysis of the natural and human-induced driving factors, Han et al. (2015) found that population pressure and irrational use of water resources were key factors in oasis change. According to Diao et al. (2019) and Yang et al. (2002), in addition to the impact of over exploitation of water resources, the expansion of cultivated land brought by population growth was the main factor in the decline of the Minqin Oasis.

However, although these specific indicators have driven changes in the oasis, these indicators have not changed autonomously. Many studies have shown that human activities in arid regions are easily disturbed by mainstream policies (Hao et al., 2008; Zhang et al., 2008; Hao et al., 2017). For example, under the guidance of grain-oriented policies, such activities as building reservoirs and digging wells solved the problem of agricultural irrigation water supply. However, they also produced a serious negative spillover effect, which manifested in more serious environmental problems, such as insufficient ecological water use, groundwater over exploitation and soil salinization (Truelove et al., 2014; Ba et al., 2020). These ecological protection policies directly affected oasis ecology through measures such as returning farmland to forests and prohibiting grazing, which effectively curbed the development of desertification (Xue et al., 2015). In addition, the perception of policy actors also had a certain impact on the effect of policy implementation through their actions, which then affected change in the oasis. For example, ecological compensation policies such as returning farmland to forest and grassland, which are conducive to the reversal of desertification, often failed to meet the living needs of farmers and herdsmen due to inadequate compensation. This issue lead directly to insufficient participation and acceptance of policies by farmers and herdsmen, and therefore, an unsuccessful campaign (Hou et al., 2018).

In addition to the influence of regional characteristics, policies and the cognition of policy actors, other factors such as the market, population scale and economic development level also played an important role in the change of oases. (Zhang et al., 2003; Robinson et al., 2016; Fan et al., 2017; Jing et al., 2020) (Fig. 3). With respect to the market, the price of agricultural products had an impact on change in the oasis. Price rises or falls directly determined whether the farmers reclaimed or

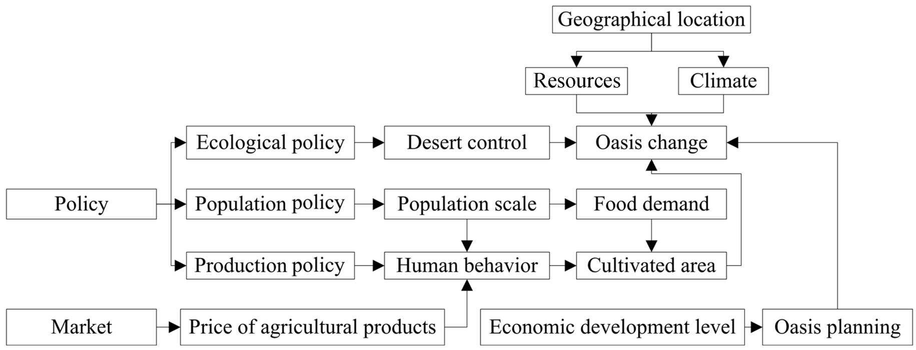

Fig. 3. Main driving factors of oasis scale change

abandoned the land. Population growth was accompanied by increases in demand for food, which then resulted in a change in area of cultivated land, but this change was mostly manifested as a simple increase in quantity. The level of economic development affected the scientific and orderly planning of oasis development to a certain extent.

This paper evaluates the relative contribution factors of oasis change over time, however, restricted by the availability of data, it is unable to analyze spatial change. Comprehensive analysis at the joint space level is more conducive to the formulation of an oasis management model in accordance with local conditions. Research into the complex coupling of factors through time and space should be the focus of future research on oasis management. In addition, the oasis changes discussed are limited to expansion and shrinkage of the oasis area. These changes in spatial extent also trigger changes in the landscape, and environmental factors such as biology, soil, meteorology and hydrology. The magnitude and speed of change of these factors are affected by both human activities and climate change. In the future, the comprehensive contribution of all factors should be fully considered.

5 Conclusions

Our analysis has shown that changes in the Minqin Oasis over the last 60 years have been caused by a variety of factors, and that different factors dominated different periods. Quantitative evaluation of the natural or man-made contributions to the expansion or shrinkage of the Minqin Oasis at different stages can provide a scientific basis for the construction of an oasis regulation and management model. We conclude:

(1) Human factors were the main drivers during the expansion periods of the Minqin Oasis (average contribution 69.381%), followed by the coupled effect of nature and human factors (contribution 18.723%). The contribution factors for the two shrinking periods (1973–1987, 2005–2010) were slightly different, but were still predominantly human-caused, with an average contribution of 76.16% for human factors. In addition, natural factors contributed 14.541% to total change over the 1973–1987 period. In 2005–2010, natural and human factors contributed 13.202%. It can be seen from the comprehensive analysis of the influencing factors during the period of expansion and shrinkage of the Minqin Oasis that human activities were the primary driving factors of oasis change in this area: their direct influence was 72.092%, and the combined influence with natural factors was 17.343%.

(2) Among the human factors driving the expansion or shrinkage of the Minqin Oasis, the exploitation, utilization and changes in water resource reserves played an important role in the whole process of oasis change. Reclamation behavior, population, ecological protection and economic development played leading roles at different stages. All human factors were driven by policies which had different effects on oasis change. In general, they were important in the orderly expansion of oases, but were also culpable in the shrinkage of oases. Scientific planning by policy makers is clearly needed.

(3) According to the research results, we put forward the following suggestions for the future development of the Minqin Oasis. First, we suggest continuing to implement ecological protection measures. Alongside ensuring sufficient reserves for ecological water use, rationally allocate water for various industries. Second, scientifically evaluate the ecological carrying capacity of the Minqin Oasis and rationally plan the scale of urban development. Third, adjust crop planting structure and restrict land reclamation. Fourth, use measures such as diversion of water from the outside and cooperation with shutting down wells to alleviate water shortages. Finally, it is recommended to set up an authoritative water resources management institution throughout the Shiyang River Basin. Surface and groundwater resources should be uniformly planned, managed, and deployed.

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