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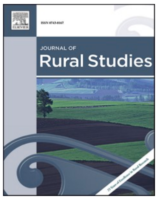

Evaluation of sustainable agriculture and rural development in agro-pastoral ecotone under climate change: A comparative study of three villages in the Shenfu coalfield, China

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ABSTRACT

Sustainable agriculture and rural development (SARD) plays a crucial role in maintaining natural resources, protecting the ecological environment, enhancing global food security, eradicating poverty, and even promoting rural revitalization. To understand the degree of implementation of SARD in the Shenfu coalfield under climate change, three villages that had different levels of energy development were selected. The linear trends and the Mann-Kendall method were used to analyse the climate change characteristics in the study area and a coordinated development model was employed to measure both the SARD coordination and its coordination degree and to analyse the perceptions of farmers, the adaption strategies they have employed, and the factors influencing the success of SARD. The results demonstrate that the climate in the study area has generally become warmer and drier, and this change has increased the vulnerability of the ecological environment and has had adverse impacts on local SARD. Farmers' perceptions of climate change are in line with climate records, but their perceptions of temperature change exhibit a certain time lag. In addition, their adaptation strategies are conducted autonomously, and they vary among the three villages. Based on these results, it is recommended that the local government implement additional policies relating to carbon capture and storage technologies to reduce the adverse effects of climate change. Factors influencing the success of SARD in the three villages are as follows: rapid urbanization; low incomes provided from crop farming; the outflow of primary and middle school students together with the accompanying population; climate warming and the increased frequency of extreme weather events; and environmental pollution and secondary geological disasters caused by coal mining. For all three villages, only by ensuring the synchronization of energy development and environmental protection can SARD be realized in the study area. Countermeasures that can be used to promote SARD in the Shenfu coalfield are proposed in this paper, and they include adjusting the industrial structure in the study area with respect to water conditions, selecting appropriate crop varieties, and accelerating the development of the alfalfa industry in response to national initiatives.

1. Introduction

With respect to the increasing need to ensure agricultural sustainability, the Denbosch Declaration and Programme of Action on sustainable agriculture and rural development (SARD) was issued by the Food and Agriculture Organization of the United Nations in 1991. It combined the concepts of sustainable agriculture development and sustainable rural development for the first time, and proposed the concept, definition, evaluation indicators and strategic objectives of SARD.

In 1992, Agenda 21 of the United Nations Conference on Environment and Development determined SARD as being the top sustainable development priority area, and it incorporated this concept into the 14th chapter of Agenda 21. According to the Denbosch Declaration and Agenda 21, SARD is an advanced development idea that addresses the predicaments facing the agriculture, countryside and farmers. SARD also

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aims to achieve optimum economic, societal and ecological development within rural regions (Chen, 1994; Yang, 1997; Zeng and Luo, 2004). The implementation of SARD may require adaptation to local situations, but it involves fair, appropriate, multilateral and multidimensional modes of development. Although countries may have different understandings and perceptions of SARD, the key ideas must all be aligned and aimed at achieving optimum economic, societal and ecological development within rural regions.

Since the 1990s, the world has faced many problems associated with rapid urbanization and corresponding rural ecological environmental issues, and there has been an ideological trend toward rural reconstruction. Thus, studies have been dedicated to SARD and the SARD-related problems that have emerged across different zones. There are currently six main focuses of SARD research. First, the trans-disciplinary trend is becoming prominent, and SARD-associated studies have focused on the trans-disciplinary perspectives of agricultural economics, agricultural ecology and economic geography (Finnegan, 2011; Wezel et al., 2011; Navabakhsh and Tamiz, 2013; Burandt and Mölders, 2017; Koopmans et al., 2018). Second, studies have become increasingly focused on the important role of multifunctional agriculture (MFA) in SARD, and it is believed that MFA should be used to protect the ecological environment, improve the landscape, inherit native culture, conserve water and maintain biodiversity (Cochrane, 2003; Huylenbroeck and Durand, 2005; Holmes, 2006; Prändl-Zika, 2008; Branca et al., 2013; Guirado et al., 2017; Rivera et al., 2017). Third, some studies consider that the research objectives of the SARD have shifted from focusing on food security and poverty eradication to focusing on the comprehensive SARD objectives: rural sustainable development and rural revitalization (Alagendran et al., 2017; Rivera et al., 2017; Knickel et al., 2018). Fourth, the SARD themes studied have changed from de-localization to re-localization. With the emergence of the MFA, studies have focused on the innovative recurrence of traditional technologies, the rediscovery of local culture and the redevelopment of traditions within rural areas (Cannarella and Piccioni, 2011; Gobattoni et al., 2015; Pandolfini et al., 2016; Scott et al., 2018), which thus involves rediscovering and redeveloping traditions. Fifth, studies were originally conducted on a macro-scale (rural area), but they are increasingly being conducted on a micro-scale (such as farms and community). Many researchers believe that to realize SARD, the most basic and appropriate focuses should be 'the micro-farm' and 'farmers', and their concern is the micro-scale implementation paths of SARD (Varela-Ortega et al., 2011; Todorova and Ikova, 2014; Favilli et al., 2015; Rivera et al., 2017; Escribano et al., 2018), SARD policies (Plieninger et al., 2015; De Roest et al., 2018) and the decision-making behaviour of farmers in response to them (Stojcheskaa et al., 2016; Adjei et al., 2017). Finally, a considerable amount of research has focused on the role of the multi-stakeholder in SARD (Grudens-Schuck et al., 2003; Baig and Straquadine., 2014) (especially on multi-stakeholders who participated under the Common Agricultural Policy (CAP) of the European Union) (Favilli et al., 2015; Santiago-Freijanes et al., 2018; Morén-Alegret et al., 2018), multi-actor governance, and studies focusing on the actor-network theory (Koopmans et al., 2018).

SARD studies relating to climate change include interviewed farmers' perceptions (Ochieng et al., 2016; Shameem et al., 2018), their adaption strategies and corresponding influencing factors (Seo and Mendelsohn, 2008; Deressa et al., 2009; Bryant et al., 2010; Arimi, 2014; Brottem and Brooks., 2018); regional SARD adaptation strategies based on a frame model and its application (Sposito et al., 2010); bio-energy utilization and regional SARD (Mol, 2007; Sharma et al., 2016); the protective development of bio-cultural heritage in rural communities based on rural resiliency (Sayre et al., 2017); and SARD in poor areas (Dasgupta and Baschieri, 2010; Nkomwa et al., 2014). Furthermore, the impacts of climate change on agricultural production, food security, the rural social economy and farmers' income have also become the focuses of climate change research (Lake et al., 2012; Shindell et al., 2012; Bobojonov and AwHassan, 2014; Reidsma et al., 2015). In this respect, it has been established that local dry farming in Chinese farming-pastoral ecotones will be severely affected when the mean annual precipitation is less than 400 mm and the climate change tendency rates of annual mean temperature are greater than 0.1 °C/per 10-yr (Leng and Liu, 1999; Lv and Wang, 2003).

SARD has been implemented by the Chinese government since the 1990s, and it has become an important thrust for transforming Chinese agricultural and rural development patterns and for promoting the balanced development of regional economies and rural revitalization. Compared with international research, research conducted in China has focused more on assessing the SARD situation and the optimal regulations that can be applied in different regions under rapid urbanization, and such studies have included evaluations of SARD on different scales (Wang and Hao, 2001; Tan and Wang, 2005; Liu and Feng, 2001), SARD development models (Luo et al., 2001; Wang, 2002; Zhang et al., 2012) and SARD optimization paths (Sun and Yang, 2005; Li, 2006; Wang et al., 2012). Both Chinese and international research relating to SARD under climate change have focused on agricultural vulnerability and the adaptation strategies used by farmers on different scales. However, a limited number of studies have investigated SARD under both climate change and energy development in the farming-pastoral ecotone, and it is thus necessary to conduct more research on associated adaptation strategies and to evaluate the coordinated development degree of village-scale SARD, particularly with respect to coalfield villages.

This study investigates the SARD situation in rural areas of a farming-pastoral ecotone and the factors influencing this under climate change, energy development and other stresses, and then proposes adaptation strategies. Three villages that have different scales of energy development in the Shenfu coalfield are considered as case studies, and climate change and farmers' perceptions of climate change are analysed. The factors influencing SARD are then explored by evaluating the degree to which SARD is being coordinated and its associated development within these three villages. Adaptation strategies are subsequently designed to address the SARD problems in the three villages. The research results can be used as a reference for cultivating alternative industries and promoting SARD in the Shenfu coalfield and similar areas under climate warming.

2. Study area and data processing

2.1. Study area

The Shenfu coalfield is located in the transitional zone between Mu Us Sandy Land, the Loess Plateau and the Inner Mongolia plateau (108°36′-110°3′E, 37°20′-40°16′N). Wulansetai village, Min'gaitu village, and Shanzigou village were selected as the case study areas (Fig. 1), and they are all located within the Shenfu coalfield northwest of Shenmu City (Fig. 1) in an agro-pastoral ecotone. The primary geomophology types are loess and aeolian, and the area is seriously affected by soil erosion and aeolian erosion. Typical vegetation types are psammophytes and xerophytes. The area hosts a typical temperate continental climate; the annual mean temperature and precipitation from 1957 to 2015 were 9.2 °C and 408.9 mm, respectively, and precipitation from July to September accounted for approximately 65% of all annual mean precipitation. The primary crops grown within the area include potato, corn, and millet, and farmers grow jujube, polygala, and other Chinese traditional medicines as cash crops. At the end of 2016, these villages contained 640 households and had a population of 1930 people. The rate of migrant workers exceeded 70%, and per capita cultivated land area was 0.153 ha, while per capita income was measured at around 12,000 yuan. Wulansetai, Min'gaitu and Shanzigou villages have three, one and zero coal mines, respectively, and because there is no coal mine in Shanzigou village, its agricultural scale, investments and income are higher than those of the other two villages.

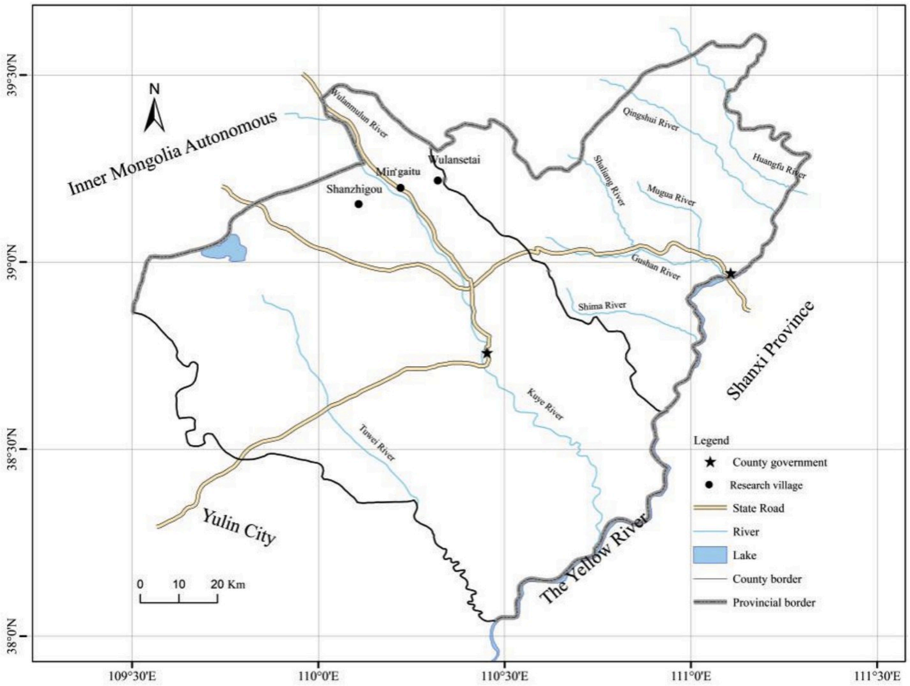

Fig. 1. Location of study area and its vicinity.

2.2. Data sources

This study predominantly employs climate and statistical data. Climate data were derived from the National Meteorological Information Centre (http://data.cma.cn/site/index.html), and monthly temperature and precipitation data were obtained from the Wulidun meteorological station in Shenmu City. All data cover the period from January 1, 1957 to February 28, 2016. Other statistical data were acquired from the *Shenmu City Statistical Yearbook*, and the statistical data of the village communities in the study area. Field survey data were collected in the study area from January to February 2017 and May to June 2017 using the results of 151 valid and returned questionnaires.

In the analysis of climate change, the seasons were categorized as follows: spring from March to May, summer from June to August, autumn from September to November, and winter from December to February. To reduce seasonal variation in the climate series, anomalies were identified and filtered out. In accordance with the relevant regulations of the World Meteorological Organization (WMO), the annual and seasonal mean temperature and the annual and seasonal mean precipitation anomalies of the study area were calculated separately.

2.3. Methodology

2.3.1. Statistical methods used to determine climate change

The linear tendency and moving average methods were used to fit the trends of annual and seasonal mean temperature and precipitation. These two methods are the simplest and most effective for fitting the climate series change trend. The former uses linear regression to determine the trends of annual and seasonal mean temperature and precipitation, while the latter uses low-pass filtering to determine the trends of annual and seasonal mean temperature and precipitation. The Mann-Kendall test and cumulative anomaly analysis were selected to diagnose sites of mutations within the seasonal and annual climate series. The Mann-Kendall test is a nonparametric statistical test method widely used in climate change mutation tests (Wei, 2007); it does not require a sample to follow a certain distribution, and it can avoid any interference resulting from a few outliers. Accumulative anomaly analysis was used to visually evaluate the climate change trends by analysing the curves of anomaly values (Wei, 2007).

The Z-index method was used to determine drought and waterlogging events that had occurred in the study area. It assumes that annual mean precipitation conforms to a Pearson III type distribution, and it then converts its distribution into a standard normal distribution with Z as the variable. In this respect, the occurrence levels of drought and waterlogging were determined according to the calculated Z value and local conditions (Song et al., 2011; Lei, 2005; Qin, 2016).

Principal Component Analysis (PCA) was used to moderately reduce the indicators used in the evaluation index system employed to evaluate SARD in the three villages. The improved entropy method was employed to weight the evaluation indicators, and as only three villages were studied, the linear proportional method was used to nondimensionalize the evaluation indicator (Zhu and Wei, 2015).

2.3.2. Coordinated development model (CDM)

2.3.2.1. Efficacy function. The efficacy coefficient (EC) characterizes the contribution of order parameters (selected variables) to the system order, and its value is between 0 and 1. When EC = 1, the order parameters are considered to be optimal and their contribution to the coordination of system is the greatest, but EC = 0 shows a poor contribution (Yang et al., 2008). Given U_i is the orderly efficiency coefficient for the SARD evaluation system in the study area, the calculation formula for the efficiency coefficient is as follows.

When U_i has positive effects:

$$EC(x_i) = \frac{(x_i - MIN(x_i))}{(MAX(x_i) - MIN(x_i))}, MIN(x_i) \le x_i \le MAX(x_i),$$

When U_i has negative effects:

$$EC(x_i) = \frac{(x_i - MAX(x_i))}{(MIN(x_i) - MAX(x_i))}, MIN(x_i) \le x_i \le MAX(x_i)$$

where x_i is the order parameter of the system, and $MAX(x_i)$ and $MIN(x_i)$ represent the maximum value and the minimum value, respectively, of the order parameters when the SARD evaluation system is in a steady state.

2.3.2.2. Coordination function. Coordination involves benign associations between two or more systems, and the coordination degree is a quantitative indicator of the coordination status between the systems or the internal elements of the systems. The coordinated development state of the compound system can be obtained via a coordination function that is constructed based on the order parameters of the system, and the obtained function value is the coordination degree. Generally, the geometric mean method and the linear weighted summation method are used to obtain this degree of coordination: in this study, the latter method is used to calculate the degree to which SARD has been coordinated in the three villages. Given that *f(x)* and *g(y)* are functions of the comprehensive economic benefits and comprehensive environmental benefits of the three villages, respectively, the comprehensive economic and environmental benefits of the three villages can be calculated as follows,

$$\mathrm{f(X)} = \sum_{i=0}^{n} \alpha_i \times EC(\mathrm{X_i}); f(x) = \sum_{i=0}^{n} a_i \times EC(x_\mathrm{i}); g(y) = \sum_{i=0}^{m} \beta_i \times EC(y_\mathrm{i}),$$

where *x* represents the standardized values of the evaluation indicators of the comprehensive economic benefits; *y* represents the standardized values of the evaluation indicators of the comprehensive environmental benefits; α_i and β_i are the indicator weights (obtained via the entropy method); $EC(x_\mathrm{i})$ and $EC(y_\mathrm{i})$ are the efficiency coefficients of the comprehensive economic benefits and the comprehensive environmental benefits evaluation indicator layer, respectively; *n* and *m* are the numbers of evaluation indicators of comprehensive economic benefits and comprehensive environmental benefits, respectively.

The coordination degree of the regional economy-environment compound system depends on the deviation of *f(x)* and *g(y)*; when the deviation is smaller, the compound system is more coordinated, and vice versa (Yang, 1994; Liao, 1996). Therefore, the variation coefficient was used to calculate the coordination degree between the ecological environment and the economic development of the three villages in Shenfu coalfield as follows,

$$C = \left\{ \frac{f(x) \times g(y)}{\left[\frac{f(x)+g(y)}{2}\right]^2} \right\}^k,$$

where *C* is the coordination degree of economic development and environmental conservation in the study area; *k* is the adjustment coefficient ($k \geq 2$), and the actual *k* value is 2 according to the situation within the study area. The above formula illustrates that the coordination value *C* is between 0 and 1: when the *C* value is higher, the overall coordination of the system is better. With respect to the actual situation of the study area, the SARD coordination degree can be divided into eight categories (Li et al., 2007; Yang et al., 2008) (Table 1).

2.3.2.3. Coordinated development degree function. According to system theory and synergy theory, the coordinated development of a compound system is an aggregation that focuses on the comprehensive development of a system. Although the coordination degree can adequately reflect the degree of coordination between economic development and environmental systems in the study area, it cannot reflect the level of their overall coordinated development. To further reflect the synergy between these two systems, the following function is used to calculate the coordinated development degree among the three villages (Liao, 1996; Ding and Wen, 2010):

$$D = \sqrt{C \times T}$$

$$T = \alpha f(x) + \beta g(y)$$

where *D* is the coordinated development degree, *C* is the coordination degree, *T* is the comprehensive evaluation index of economic and environmental benefits, and α and β are the undetermined weights, which are determined by the importance of the system. As the Shenfu coalfield is located within the national soil and water conservation zone, the values of α and β are determined as 0.4 and 0.6, respectively.

3. Results and analysis

3.1. Statistical characteristics of climate change

3.1.1. Trend analysis

The change in the annual mean temperature anomaly demonstrates that annual mean temperatures increased significantly from 1957 to 2015, at a climate change tendency rate of 0.286 °C/per 10-yr (Fig. 2a). In conjunction with the result of the Mann-Kendall trend test (4.27), which demonstrates a clear warming trend, the change in the annual mean precipitation anomaly shows a decrease in the amount of precipitation within the study area since 1957, with a climate change tendency rate of annual mean precipitation of −5.926 mm/per 10-yr (Fig. 2a). This decrease in annual mean precipitation is also confirmed by the value of the Mann-Kendall trend test (−0.399). In addition, the climate change tendency rates of spring, summer, autumn and winter temperatures over the 59 years were 0.286 °C/per 10-yr, 0.098 °C/per 10-yr, 0.236 °C/per 10-yr and 0.526 °C/per 10-yr, respectively, and the climate change tendency rates of spring, summer, autumn and winter precipitations were 0.392 mm/per 10-yr, −9.543 mm/per 10-yr, 2.68 mm/per 10-yr and 0.544 mm/per 10-yr, respectively. Over this period, winter and spring temperatures increased significantly, while summer precipitation showed a decreasing trend.

The changes in annual mean temperature and precipitation anomalies in the study area differed from decade to decade over the 59-yr period (Fig. 2a), and the climate changed gradually from being cold-wet to warm-dry. The climate from 1957 to the 1970s was much colder and wetter than that in the 1980s; the climate continued to warm and dry significantly between the late 1990s and 2010s; and from 2011 to 2015, the climate warming trend weakened but the climate humidifying trend strengthened, and changes in daily precipitation data demonstrate that extreme precipitation events were a major contributor to increased amounts of annual mean precipitation.

The changes in annual mean precipitation and annual mean temperature cumulative anomalies show a weak decrease of the former, but the latter can be roughly divided into two stages with respect to the value of 1993: annual mean temperature has been increasing significantly since 1993 (Fig. 2b). In summary, annual mean temperature and annual mean precipitation in the study area are negatively correlated on a decadal scale, the regional climate is warming and drying, and the reverse symmetry of climate change has been more pronounced since the late 1990s.

Table 1
Coordination division and associated standard grade.

Coordination level	Extreme disorder	High disorder	Moderate disorder	Low disorder	Basic coordination	Low coordination	Moderate coordination	High coordination
Coordination degree	0–0.19	0.2–0.29	0.3–0.39	0.4–0.49	0.5–0.59	0.6–0.69	0.7–0.79	0.8–1

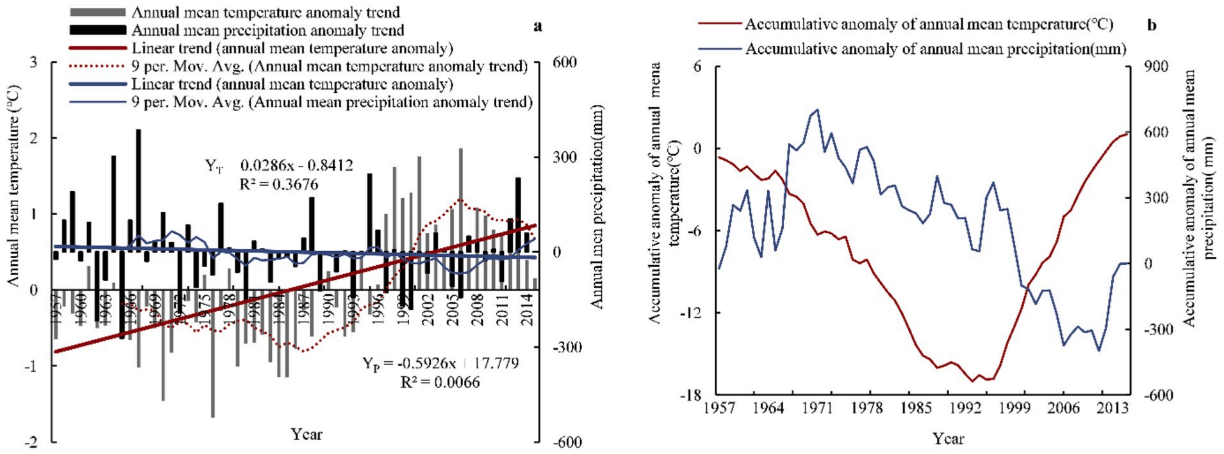

Fig. 2. Trends and accumulative anomalies of temperature and precipitation changes at Wulidun Meteorological Station from 1957 to 2015.

3.1.2. Mutational analysis

As seen in Fig. 3a, the change in the UF curve illustrates that annual mean temperatures in the study area have undergone a significant warming trend since 1980s: the UF curve exceeds the significant level at a value of 0.05 ($U_{0.05} = \pm 1.96$), which indicates that annual mean temperatures have increased significantly since the 1980s. According to the Mann-Kendall test, as the intersection of the curve UF and the curve UB is located between the critical lines (Fig. 3a), the warming mutation began in 1994. Similarly, the warming mutation sites of mean spring, summer, autumn and winter precipitation relate to 1996, none, 1997, and 1989, respectively (Fig. 3b–e). As show in Fig. 3f–j, the changes in the UF curve illustrate that the changes in annual and seasonal mean precipitation in the study area differ, and mean precipitation increased in all seasons except summer. As the change in the UF curve in Fig. 3f–j does not exceed the 0.05 significance level (or even the 0.01 significance level), this indicates that there has been no mutation in the annual and seasonal mean precipitation series.

#: two straight dotted lines indicate a significance level of $\alpha = 0.05$; solid line represents a positive sequence and dotted line an inverse sequence.

3.2. Climate change and SARD of study area

3.2.1. Analysis of drought and waterlogging

Relevant research has reported that spring drought, early summer drought and corresponding waterlogging are the primary meteorological disasters occurring during the crop growing period in the study area, and of these, spring drought occurs much more frequently than the others. The sowing and harvesting periods occur in the three villages at around the time of the Ching Ming Festival and mid-October, respectively. As a result, the crop growing period of the study area is from April to September, and the meteorological disasters that have occurred are calculated here based on this crop growing period. According to the Z index calculation results, disasters falling within the crop growing period can be categorized into 7 levels (Table 2): extreme waterlogging, heavy waterlogging, waterlogging, drought, heavy drought, and

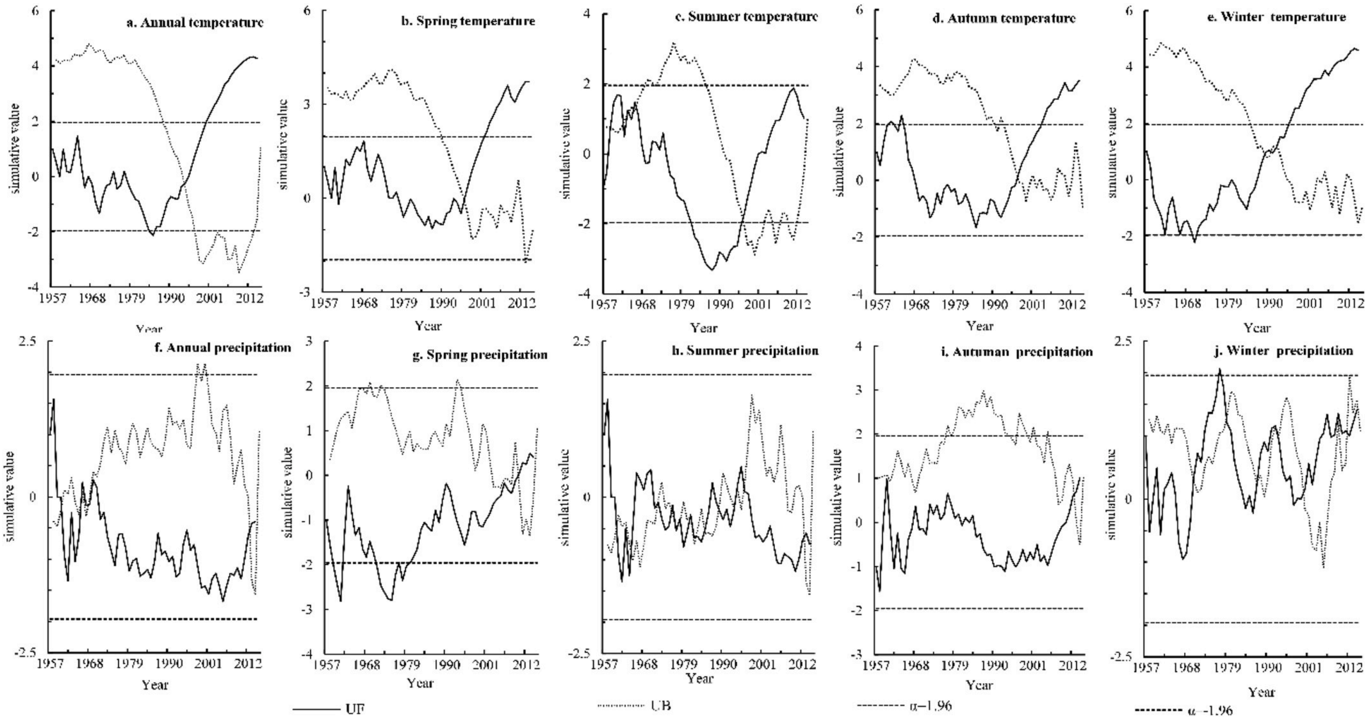

Fig. 3. Mann-Kendall mutation test for annual and seasonal mean temperature and precipitation in the study area.

Table 2
The occurrence frequency of drought/waterlogging in crop growing period from 1957 to 2015.

Time	Waterlogging	Heavy waterlogging	Extreme Waterlogging	Drought	Heavy drought	Extreme drought
1957–1960	0	1	1	0	0	0
1960s	1	1	3	2	0	2
1970s	1	0	1	3	1	2
1980s	0	0	1	0	2	0
1990s	1	0	1	1	0	4
2000s	2	0	0	0	2	0
2011–2015	1	2	0	0	0	1
Total	**6**	**4**	**7**	**6**	**5**	**9**

extreme drought.

Over the 59-yr period, drought and waterlogging occurred during the crop growing period 20 and 17 times, respectively (Table 2), and severe disasters occurred more frequently than other disaster types. The 1960s witnessed the highest numbers of waterlogging occurrences that accounted for 8.48% over the 59 years, and waterlogging occurred every two years on average over the 59 year period. Droughts occurred relatively frequently in the 1960s; but more frequently in the 1970s (accounting for 10.17%), and drought occurred every 1.67 years over the 59 years. In the 1980s, drought and waterlogging occurrence remained relatively low, but in the 1990s, drought occurrence rose again to a level just below that in the 1970s (accounting for 8.48%) and drought occurred every two years over the 59-yr period. In the first decade of the 21st century, there was a decrease in the frequency and intensity of drought and waterlogging occurrence, especially drought; but from 2011 to 2015, the frequency and intensity of waterlogging occurrences were higher than in the previous decades.

3.2.2. *Perception analysis of the farmers towards climate change and factors influencing SARD*

In their answers to questionnaires, farmers admitted they were aware of the climate warming. They were also aware of a significant decrease in mean spring and summer precipitation; particularly that of summer. They also acknowledged an increase in the occurrence of extreme weather events, such as droughts, and 86% of respondents reported that climate mutation began in around the mid-1990s. This perception aligns with the results of the climate mutation analysis, albeit with a slight delay of approximately two years, thereby indicating a certain time lag between actual climate changes and those perceived by farmers. The period from seedtime to harvest time in the three study villages had generally been postponed in the last few years of the study period because of drought occurring during seeding time and increased precipitation during harvest time (the delay time of this depends on actual climate change). In addition, farmers also reported that there has been a significant decrease in the occurrence of hail in the most recent years, but there had been a significant increase in the incidence of severe frost during the crop growing period and waterlogging during harvest time.

At the end of the study period, there were only 258 individuals residing in Wulansetai village, Min'gaitu village and Shanzigou village, and most were over 50 years old. The employment ratio of migrant workers in the three villages was calculated as 60.34%, 82.79%, and 78.17% respectively, and rural hollowing remained serious. The farmers who were interviewed believed that the factors influencing the SARD of the three villages were as follows: (1) rapid urbanization; (2) low income provided from crop farming; (3) the outflow of primary and middle school student together with the accompanying population; (4) climate warming and the increasing frequency of extreme weather events such as droughts and waterlogging and (5) environmental pollution and secondary geological disasters caused by coal mining. Owing to these five factors, most of the arable land in the study area had been abandoned, and the commercialization rate of agricultural products was extremely low. Although 92% of farmers reported that the dominant reasons for agricultural decline and rural hollowing were rapid urbanization and the low income provided from crop farming, 87% also acknowledged that climate change did have certain impacts on SARD in the study area. This demonstrates that the impacts of climate change on local SARD in the agro-pastoral ecotone cannot be ignored.

3.2.3. *Adaptation strategies of farmers under climate change*

In the study area, increased winter and spring temperatures and decreased summer precipitation have had adverse effects on the SARD of three villages. By the end of the study period, 86% of farmers in the three villages had adopted autonomous adaption strategies, such as expanding the planting of drought-tolerant crop species like millet and miscellaneous beans on high-quality cultivated land, and covering poor-quality cultivated land with corn and potatoes. Other adaption strategies include the use of multiple cropping techniques, such as early-maturing potatoes and multiple-cropping autumn cabbages. The proportion of interviewed farmers who had adopted adaption strategies in Shanzigou village was higher than those in Min'gaitu village and Wulansetai village. However, the farmers in the three villages have received a low level of education, and no other active strategies have been adopted in response to climate change. The local government has encouraged farmers to plant water-saving, drought-tolerant crop species; however, although these measures can only temporarily alleviate the impact of climate change, they can neither guarantee stable input-output benefits nor cultivate alternative industries to realize SARD in the Shenfu coalfield area. In summary, therefore, adaptation strategies are required that are more comprehensive and policy guided.

3.3. *Evaluation on coordination degree of SARD in study area*

Given the actual socio-economic conditions and ecological environment of the study area, and based on an analysis of factors affecting and restricting SARD in the three villages, an evaluation index system based on PCA was constructed (Table 3). The entropy method and coordination degree model were used to evaluate the SARD of the three villages in 2016.

The degrees to which SARD had been coordinated in Wulansetai village, Min'gaitu village, and Shanzigou village in 2016 were 0.599, 0.366, and 0.531, respectively. Thus, the degrees can be categorized as low coordination, moderate disorder, and basic coordination (Table 1), respectively.

Wulansetai village has three coal mines and is more seriously affected by energy development than the other two villages. Fewer villagers are engaged in crop planting activities, but their annual incomes are the highest among the three villages because of land rent and year-end coal mine bonuses. It has the lowest amount of vegetation coverage, a low gross agricultural output per hectare, a low amount of per capita arable land, low total investment in pollution abatement and a low agricultural productive input. Its SARD coordination degree is thus inadequate and falls within the low coordination category. In contrast, Min'gaitu village has only one coal mine and is less affected by energy development, but it has the highest investment in pollution abatement because it has the lowest per capita area of arable land, the lowest gross agricultural output per hectare, the least amount of large-scale agricultural machinery and equipment, and the highest rate of migrant

Table 3
Evaluation index indicator system of SARD coordination degree in three villages.

Target layer	System layer	Criteria Layer	Indicator	Efficacy
Coordination degree of SARD in three villages	Economic sustainability Social sustainability Environmental sustainability Support ability of science & technology	Level of agricultural development Capacity for agricultural development Quality of life Level of social security Bearing capacity of resources and environment Environmental pollution and pollution abatement Level of Agricultural technology	Total value of farm output (10,000 Yuan) Per hectare total value of farm output (10,000 Yuan/ha) Agricultural productive input (10,000 Yuan) Rate of immigrant laborers (%) Engel coefficient (%) Minimum living allowance (Yuan/year) Rate of pension fund (%) Per capita arable land (ha) Vegetation coverage (%) Use of fertilizer and pesticide (t/ha) Total investment in pollution abatement (10,000 Yuan) Percentage of agricultural technicians (%) Large-scale agricultural machinery and equipment (set)	Positive Positive Positive Negative Negative Positive Positive Positive Positive Negative Positive Positive Positive

labours. However, the SARD coordination degree in Min'gaitu village is the lowest of all three villages and it falls within the moderate disorder category. Shanzigou village has no coal mine and is the least affected by energy development. Its per capita arable land, agricultural productive input, and large-scale agricultural machinery are the highest of the three villages. Although the Shanzigou villagers use the largest amounts of fertilizer and pesticide, the village has the highest vegetation coverage and lowest Engel coefficient; therefore the SARD coordination degree of Shanzigou village is higher than that of Min'gaitu village, and it falls within the basic coordination category.

3.4. Evaluation of SARD coordinated development degree in the study area

The coordination degree can only demonstrate the coordinated development of each subsystem in the compound SARD system instead of comprehensively reflecting the overall coordinated development level of the compound SARD system or the level of its comprehensive environmental economic benefits. To discern the coordinated development degree and restraining factors of SARD in three villages, the function of the coordinated development degree was used to calculate the coordinated development degree of the resources, environment and the economy in each village. In calculating the coordinated development degree of SARD, the social sustainability and technology support indicators in Table 3 were classified within the layer of economic sustainability. The results show that the coordinated development degrees of SARD in Wulansetai village, Min'gaitu village and Shanzigou village are 0.474, 0.356, and 0.373, respectively. According to relevant research, the coordinated development degree of SARD in Wulansetai village falls within the economic loss-making type of the over-development category, and the coordinated development degrees of SARD in both Min'gaitu village and Shanzigou village fall within the dysfunctional development category, but their specific types of development differ: the former is classified as environmental loss-making and the latter is classified as economic loss-making.

Although intensive energy development has brought significant economic benefits to Wulansetai village, the village has not made sufficient investments in agricultural development or in pollution abatement. With this misalignment between economic development and ecological protection, the village's environmental conservation practices lag behind its economic development level; therefore, the coordinated development degree of SARD in this village is moderately impaired due to ecological degradation. Min'gaitu village is less affected by energy development, its investment in pollution abatement outpaces that in Wulansetai village but is still not enough to remedy environmental pollution and vegetation damage. As a result, the coordinated development degree of SARD in Min'gaitu village is the lowest. Shanzigou village has no coal mine and its agricultural productive input and vegetation coverage are the highest. However, it is hindered by climate change and its excessive usage of chemical fertilizers and pesticides; therefore the coordinated development of SARD in this village is slightly damaged and is lower than that of Wulansetai village.

4. Discussion

The climate change tendency rate of the study area is 0.286 °C/per 10-yr, which is lower than that of the northwest region (0.037 °C/per 10-yr), higher than that of overall China (0.21–0.25 °C/per 10-yr) and globally (0.07 °C/per 10-yr) over the 50 years (The Committee of the Third National Assessment Report on Climate Change, 2015). This value illustrates a clear climate warming trend in the study area, and the annual mean temperature and precipitation trends of the study area are aligned with the climate change observed in Yulin city (Liu et al., 2017). In addition, the mutation time of the annual mean temperature series (1994) in the study area is similar to that of Yulin city (1996) (Liu and Liu, 2006).

As annual mean precipitation in the study area is 408.876 mm, the base line of 400 mm for a stable dry farming harvest has not yet been fully met (Leng and Liu, 1999). However, the rate of climate warming (0.286 °C/per 10-yr) far exceeds that of 0.1 °C/per 10-yr, which is the threshold of the ecological system (Lv and Wang, 2003). In response to accelerating adjustments to the agricultural industrial structure under climate change in the study area, it is considered that the following principles should be applied: the development of agricultural guiding principles for grain self-sufficiency; prioritization of pasture husbandry and then a forestry economy; and advancements in miscellaneous grain production. Thus, we recommend that Shenmu City seize the opportunity of being listed as a key alfalfa county and apply for special funds to encourage farmers in Shenfu coalfield to plant alfalfa. The development of an alfalfa industry should occur in combination with the cultivation of new-type management entities in rural areas (irrigation could be obtained from the adjacent Nalingou and Niudinghao reservoirs. In addition). The three villages should actively develop special crops that provide significant economic benefits, such as millet, potatoes and buckwheat. These drought-tolerant, water-saving, and suitable miscellaneous crops, together with the alfalfa industry, would align the crop varieties grown with the original vegetation of the study area and reduce the adverse impacts of drought and waterlogging. Furthermore, such strategies could increase the accumulation of organic carbon in the soil, decrease carbon dioxide release and perhaps alleviate the effect of climate change in the study area. Moreover, in addition to the construction of the Nalingouand Niudinghao reservoirs, Shenmu city could accelerate the construction and maintenance of water conservancy establishments in Shenfu coalfield villages, thereby ensuring effective irrigation for alfalfa and miscellaneous crops. In consideration of climate change, drought and waterlogging in the study area, improvements in the Shenmu Agriculture Network should be accelerated by local government, and distance learning should be provided (including on-line consultations and classes for locals that include climate change lectures, thematic videos and real-time sharing of agricultural product information). Furthermore, it is necessary to provide information services relating to monitoring and early warnings of agricultural disasters (especially drought, waterlogging, and frost disasters), in addition to providing corresponding preventive measures. All the above-listed measures would enhance the area’s adaptation to climate change.

Increased winter and spring temperatures and decreased summer precipitation have had adverse impacts on the local crops, such as corns, potatoes, and millet. Owing to the different scales of energy development, the adaption strategies of farmers vary among the villages, and their autonomous adaption strategies cannot effectively alleviate these adverse impacts. Therefore, local governments need to develop and implement policies related to carbon capture and storage technology that will reduce the adverse effects of climate change on the SARD of these three villages.

In addition, over 60% of interviewed farmers want the government to establish a platform that leases middle- and small-scale agricultural machinery to them. The Shenmu government should thus utilize ecological compensation funds to establish rental companies managed by the local agriculture bureau to lease ploughs, reapers, planters and UAVs, which would then alleviate the shortage of production machinery in the Shenfu coalfield area.

5. Conclusion

Over the 59 years studied, the annual mean temperature increased while annual mean precipitation decreased, and the characteristics of climate change varied from decade to decade within the study area. In addition, drought and waterlogging occurred frequently during the crop growing period over the 59 years, but there were obvious differences in their occurrences between decades and seasons.

Farmers’ perceptions about climate change are in basic agreement with climate records, although their perception of the temperature mutation slightly lags behind the one recorded. Farmers have adopted several autonomous adaptation strategies, which vary among the studied villages; however, none are capable of effectively alleviating climate change. In response to this situation, the government needs to implement policies employing carbon capture and storage technology to reduce the adverse effects of climate change.

The interviewed farmers believe that the primary factors influencing the SARD of the study area are rapid urbanization, low income provided from crop farming, the outflow of primary and middle school students together with the accompanying population and climate change. These findings indicate that the adverse effects of climate change on the SARD of these three villages should not be ignored.

The coordination degrees and coordinated development degrees of the three villages are low, which demonstrates that energy development has an adverse effect on the SARD of the ecological fragile zone; hence SARD can only be realized in the study area if energy development and environmental protection are synchronized.

A village-scale evaluation of the coordination degree and coordinated development degree of SARD throughout the Shenfu coalfield area further would enrich our knowledge about the application of SARD in typical regions of China under multiple stresses (such as climate change and intensive energy development).The results of this paper can be used as a reference when considering the nurture of alternative industries and SARD in the Shenfu coalfield and similar areas under climate change. However the ability to generalize the conclusion made in this article (that energy development does not align with the coordination degree and coordinated development degree of SARD) remains uncertain, and further studies are required to determine whether it can be extended throughout the entire Shenfu coalfield area or to other similar areas. Subsequent research should focus on the factors and obstacles influencing farmers’ adaption strategies in the agro-pastoral ecotone under climate change. In addition, it would be useful to conduct research on the coordination mechanism and institutional innovation of SARD in the Shenfu coalfield under climate change based on Actor network theory (ANC).

Declaration of competing interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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