Journal of Research and Rural Planning
Volume 15, No. 1, Winter 2026, Serial No. 52, Pp. 75-90
eISSN: 2783-2007 **ISSN: 2783-2791**
http://jrrp.um.ac.ir
Original Article

Vulnerability and Resilience of Rural Livelihoods under Climate Change in Sistan and Baluchestan, Iran

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Abstract
Purpose: This study examines the effects of climate change on the sustainability of rural livelihoods in Sistan and Baluchestan Province, Iran, with particular attention to the vulnerability of agricultural production and food security under changing climatic conditions.
Design/Methodology/Approach: An integrated analytical approach was applied using climatic, agricultural, and socio-economic data. Trends in temperature, precipitation, crop yields, and natural resource availability were evaluated. In addition, survey data were collected from local farmers to assess perceived impacts of climate variability on livelihood conditions.
Findings: The results indicate that rising temperatures and declining precipitation have significantly reduced agricultural productivity in the region. Although the cultivated area of cereal crops increased by about twenty-five percent, yields declined due to insufficient rainfall and increased evapotranspiration. In contrast, cucurbit crops such as watermelon and melon showed relatively improved performance due to higher rainfall during the past seventeen years. Furthermore, depletion of water resources in the Helmand River basin, reduction of inflow to Lake Hamun, and intensification of wind erosion have increased environmental pressure on agricultural systems. Survey results reveal that a large proportion of farmers experienced moderate to severe impacts from drought, resulting in reduced agricultural income and increased migration from rural areas.
Research limitations/implications: The study focuses on a single province, which may limit the generalization of the findings to other regions. Future studies should include multi-regional analyses and long-term socio-economic assessments to support climate adaptation planning.
Practical implications: The findings highlight the need for improved water resource management, adoption of modern agricultural practices, and implementation of targeted climate adaptation programs to strengthen rural livelihood resilience.
Originality/value: This research provides an integrated assessment of climate change impacts on rural livelihoods in an arid and socio-economically vulnerable region by combining environmental and socio-economic perspectives.
Keywords: Adaptation strategies, Climate change, Drought, Resilience, Rural livelihoods, Sistan and Baluchestan Province, Iran.

Use your device to scan and read the article online	How to cite this article:	Date:
	Joojizadeh, Kh., Mozaffari, Gh., Mohammadi Ravari, F., & Kheirolomour, R. (2026). Vulnerability and resilience of rural livelihoods under climate change in Sistan and Baluchestan, Iran. *Journal of Research & Rural Planning, 15*(1), 75-90. http://dx.doi.org/10.22067/jrrp.v15i1.2601-1158	*Received: 05-03-2026* *Revised: 02-05-2026* *Accepted: 24-06- 2026* *Available Online: 26-06-2026*

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1. Introduction

Climate change has become one of the most critical environmental challenges affecting natural resources and human livelihoods worldwide. Increasing temperatures, altered precipitation patterns, and the growing frequency of extreme events such as droughts and floods are intensifying pressure on ecosystems and human systems alike (Ikhuoso et al., 2020; Nyiwul, 2021). These changes reduce water availability, disrupt ecological processes, and threaten biodiversity, while also creating competition over limited natural resources (Shaffril et al., 2018). Such impacts are particularly severe in arid and semi-arid regions where livelihoods are highly dependent on climate-sensitive resources.

Rural livelihoods, especially those based on agriculture, are among the most vulnerable to climate variability and long-term climatic changes. Sustainable rural livelihoods require the capacity to withstand and recover from environmental shocks while maintaining or improving the assets and capabilities necessary for long-term development (Carr, 2020). This adaptive capacity is closely linked to the concept of resilience, which reflects the ability of communities to cope with disturbances while sustaining essential livelihood functions. Previous studies have shown that increased awareness of climate change and its indicators can influence livelihood strategies and adaptation practices among rural populations (Shahraki et al., 2021).

In many developing countries, agriculture remains the primary source of income and food security for rural communities, making it particularly sensitive to climatic fluctuations (Smith & Skinner, 2002). Recurrent droughts, declining water resources, and land degradation have intensified the vulnerability of agricultural systems and rural livelihoods (Speranza et al., 2008; Ellis, 2014). These pressures can lead to declining agricultural productivity, income instability, and in some cases rural out-migration as households seek alternative livelihood opportunities (Mohammadi et al., 2023). Projections indicate that countries located in arid regions, including Iran, will experience increasing temperatures and decreasing precipitation during the twenty-first century, which may further exacerbate food insecurity and resource scarcity (Keshavarz et al., 2013; Waha et al., 2017).

Sistan and Baluchestan Province in southeastern Iran represents one of the country's most climate-sensitive regions. The province is characterized by low and highly variable rainfall, frequent droughts, strong seasonal winds, and severe water scarcity. These environmental pressures, combined with socio-economic constraints, have made rural livelihoods particularly those dependent on agriculture and livestock highly vulnerable to climatic changes. Despite the growing attention to climate adaptation in arid regions, empirical studies that simultaneously examine both vulnerability and resilience of rural livelihoods in this province remain limited.

These challenges are directly linked to several United Nations Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), and SDG 13 (Climate Action). By examining how climate stress affects food production, water scarcity, and livelihood resilience, this study provides evidence that can support researchers, policymakers, regional planners, and development practitioners in designing locally appropriate adaptation and rural development strategies.

Therefore, the main objective of this study is to assess the vulnerability and resilience of rural livelihoods to climate change in Sistan and Baluchestan Province. The study investigates how changes in temperature, precipitation, water availability, and agricultural productivity affect rural livelihood systems and examines the adaptive responses of local communities. The central hypothesis of this research is that increasing climatic stress particularly rising temperatures and declining precipitation has intensified the vulnerability of rural livelihoods in the region, while the level of resilience depends on the adaptive capacity of local communities and the availability of environmental and socio-economic resources.

2. Research Theoretical Literature

A growing body of research has investigated the impacts of climate change on rural livelihoods, particularly in regions where agriculture and natural resources form the foundation of local economies. Global studies indicate that climate change is altering precipitation patterns, increasing temperatures, and intensifying the frequency and severity of extreme events such as droughts and floods (IPCC, 2022; Huang et al., 2023). These changes are especially critical in arid and semi-arid environments, where limited water resources and fragile ecosystems amplify the vulnerability of rural communities. For example, Ayanlade et al. (2018) found that in the Guinea Savannah region of Nigeria, significant temporal and spatial variations in rainfall patterns have disrupted traditional agricultural calendars and increased uncertainty for farmers. More recently, Bobojonov et al. (2022) demonstrated across multiple arid regions that climate-induced water scarcity disproportionately affects smallholder farmers who lack access to supplemental irrigation and financial safety nets.

In Iran, several studies have examined the relationship between climate variability and rural livelihood vulnerability. Zareei et al. (2017) analyzed drought patterns in southeastern Iran and reported that many meteorological stations frequently experience conditions ranging from normal to severe drought, with a high likelihood of transitions from wet to dry periods. At a more localized scale, Ashtab and Sharifzadeh (2016) investigated the vulnerability of farmers in Hirmand County, a key agricultural area in Sistan and Baluchestan Province, finding that farmers in the Qorqori sector face higher levels of vulnerability across social, economic, and environmental dimensions compared to those in the central sector. Complementing these findings, Erfanian et al. (2021) examined the long-term consequences of water stress in southeastern Iran and highlighted how groundwater depletion and soil degradation compound the livelihood insecurity of rural populations over successive drought cycles. Similarly, Savari et al. (2019) emphasized the importance of livelihood diversification and complementary economic activities as effective strategies for stabilizing the livelihoods of small-scale farmers under drought conditions. Building on this, Nazari et al. (2022) further documented that rural households with diversified income sources in arid Iranian provinces demonstrated significantly lower vulnerability indices during prolonged dry spells, underscoring the protective role of non-farm employment and off-farm income.

Recent studies have also explored practical strategies for strengthening agricultural resilience in the region. Karimi et al. (2024) identified several barriers to the adoption of climate-smart agriculture in the Sistan Plain, including financial constraints, weak institutional support, limited technical capacity, and insufficient farmer training, and highlighted the importance of targeted training programs, pilot projects, improved infrastructure, and supportive policies to facilitate the adoption of climate-adaptation practices. Likewise, Alavizadeh et al. (2023), in a study of rural households in Rostaq Dehestan, found that modern irrigation systems represent one of the most effective measures for improving drought resilience, emphasizing the importance of locally tailored solutions. Rezaei-Moghaddam and Karami (2023) further argued that participatory extension approaches where farmers are actively engaged in designing adaptation interventions yield more durable and context-appropriate outcomes than top-down technology transfer models. Additionally, Meinzen et al. (2021) demonstrated at the global level that secure land tenure and collective resource management significantly amplify farmers' willingness and capacity to invest in climate-adaptive technologies, a finding with direct relevance to the communal resource systems prevalent in Sistan and Baluchestan.

Beyond empirical assessments, theoretical research has expanded the understanding of vulnerability and resilience within rural livelihood systems. Scholars argue that vulnerability should not be viewed solely as a physical outcome of environmental change but rather as a dynamic process shaped by socio-economic conditions, political structures, and unequal access to resources (Adger, 2006; Turner et al., 2003). From this perspective, adaptive capacity varies across communities and social groups depending on their access to assets, knowledge, and institutional support. Ferdous et al. (2022) refined this argument by demonstrating that within the same agro-ecological zone, intra-community differentiation in social capital and prior exposure to shocks can produce markedly divergent adaptive trajectories. Studies within the framework of political ecology further emphasize that social inequalities including differences in gender roles, economic status, and power relations can significantly influence vulnerability and the ability to respond to environmental stress (Sultana, 2014; Tschakert et al., 2021). In this regard, Rao et al.

(2020) provided systematic evidence that gender-responsive adaptation programs substantially improve household resilience outcomes in rain-fed agricultural systems, as women's access to resources and decision-making is closely linked to food security and livelihood stability (UN Women, 2021).

Despite these contributions, research focusing specifically on the vulnerability and resilience of rural livelihoods in Sistan and Baluchestan Province remains limited. Many previous studies have primarily examined drought patterns, agricultural productivity, or adaptation strategies in isolation, without integrating both vulnerability and resilience perspectives within a comprehensive analytical framework. Moreover, the region's distinctive combination of chronic water scarcity, ethnic marginalization, and weak institutional infrastructure calls for context-specific inquiry that goes beyond generalizations drawn from other arid zones. Therefore, further research is required to provide a more integrated analysis that simultaneously considers climatic, environmental, and socio-economic dimensions. Such an approach can contribute to a deeper understanding of how rural communities in this arid region respond to climate stress and which factors enhance or constrain their adaptive capacity, ultimately informing more effective and equitable policy interventions.

3. Research Methodology

3.1 Geographical Scope of the Research

Sistan and Baluchestan Province, located in southeastern Iran, has a distinctive geographical configuration. It is bounded to the south by the Oman Sea, with an extensive coastline of approximately 300 km. To the east, it shares international borders with Pakistan and Afghanistan over a distance of about 1,800 km, while its northern and western boundaries adjoin the Iranian provinces of South Khorasan, Kerman, and Hormozgan. The geographical extent of Sistan and Baluchestan Province is 25°03′–31°29′N and 58°49′–63°20′E; the map of the province and the elevation data sources are presented in Figure 1.

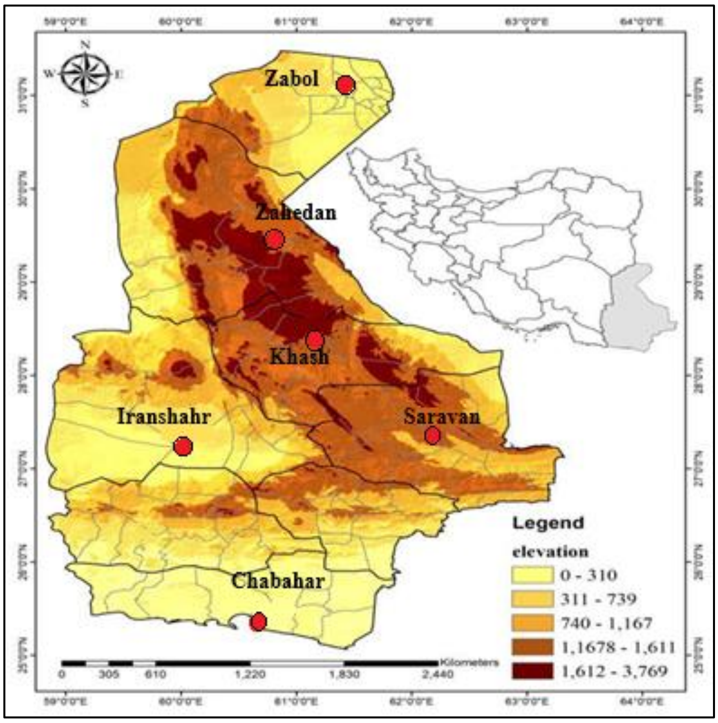

Figure 1. Geographical location of the study area with elevation characteristics

Climatically, the region is influenced by four dominant systems: Mediterranean, monsoonal, Oman Sea air masses, and Siberian high-pressure systems, with an overall predominance of arid desert conditions. Major climatic controls include the seasonal dominance of subtropical high-pressure systems, the presence of extensive interior deserts, its position along the Alpine–Himalayan orogenic belt, and internal depressions such as the Jazmourian Basin. Together, these factors generate pronounced spatial and temporal climatic variability across the province.

As the second-largest province in Iran by area, Sistan and Baluchestan contains more than 10% of the country's inhabited villages, comprising 6,553 rural settlements. According to the 2016 National Population and Housing Census (Statistical Center of Iran, 2016), the province is administratively divided into 19 counties, 37 cities, 48 districts, 112 rural districts, and 9,839 settlements. In recent decades, the region has experienced notable climatic disturbances, including shifts in temperature and precipitation patterns, a marked reduction in the Helmand River's inflow, and prolonged severe droughts, resulting in a critical environmental situation.

3.2 Data Sources

Socio-economic data, including literacy and unemployment rates disaggregated by county, were extracted from the 2016 provincial statistical yearbooks. In addition, agricultural production data for six counties (Zabol, Zahedan, Khash, Saravan, Iranshahr, and Chabahar) over the period 2002–2019 were obtained from the Agricultural Jihad Organization. These data were grouped into three main categories: cucurbit crops, grains, and other field crops, as relevant.

A key limitation of this study is the reliance on a 17-year time series (2002–2019). This constraint reflects the lack of longer-term, integrated datasets for all required variables across the study counties. Nevertheless, this specific timeframe is particularly suitable for capturing recent accelerations in climate trends and extreme events (such as recurrent severe droughts) that may not be clearly visible in longer, smoothed historical records. Consequently, while the period restricts the analysis of centennial-scale trends, it provides a relatively high-resolution perspective on contemporary climate impacts that are most relevant to current rural livelihood strategies.

This study employs a multi-method analytical framework to investigate the complex, multi-scalar relationships between climate variability, agricultural production, and rural livelihood vulnerability in the Sistan and Baluchestan Province. The integrated approach combines trend analysis, econometric modeling, composite index construction, and structural equation modeling to provide a robust, triangulated assessment from climatic drivers to socio-economic outcomes (Figure 2).

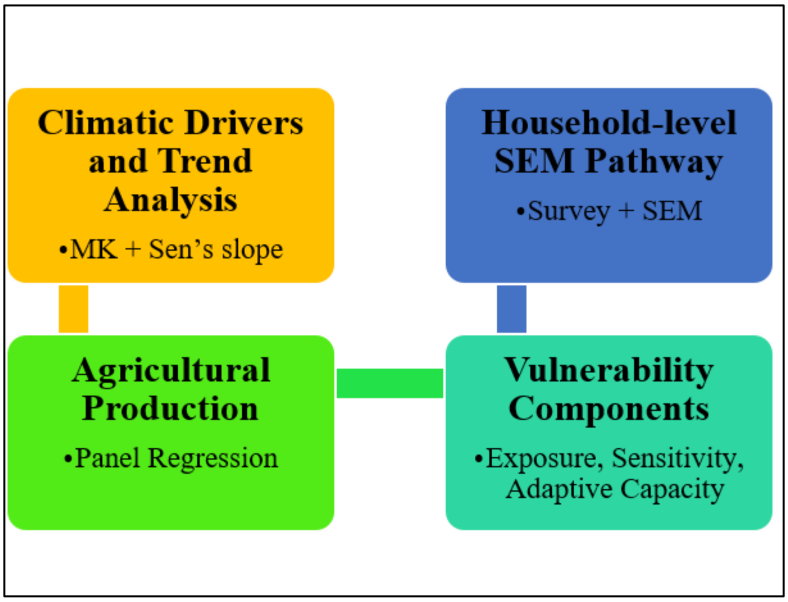

Figure 2. Conceptual model of the research

3.3 Trend Analysis

To detect and quantify long-term monotonic trends in key climatic variables (e.g., temperature, precipitation, evaporation) and agricultural yields, the non-parametric Mann–Kendall (MK) test was employed (Mann, 1945; Kendall, 1975). This method is preferred in hydro-climatological studies due to its robustness against non-normally distributed data, missing values, and outliers, which are common in environmental time series (Hamed & Rao, 1998; Yue et al., 2002). The test statistic (Z)indicates the direction and significance of a trend: a positive Zsignifies an increasing trend, while a negative Zindicates a decreasing trend. To estimate the magnitude of identified trends, Sen's Slope Estimator (Sen, 1968) was applied, providing a non-parametric median rate of change. This combined approach is a standard for robust climatic trend detection, as validated in arid region studies (Tabari & Hosseinzadeh Talaee, 2011).

3.4 Panel Regression Analysis

To econometrically isolate the impact of climate variability on agricultural production, a panel regression model was estimated using data from the six selected counties over the study period. The dependent variable $(Y_{sn})$is the total volume of agricultural production (aggregating grains, legumes, vegetables, melons, and forage) in county $s$and year n. The core independent variables (X_{sn})comprise a suite of climatic factors: maximum wind speed, number of frost days, annual mean minimum and maximum temperatures, total annual precipitation, relative humidity, pan evaporation, and sunshine hours. To control for confounding factors, a vector of socio-economic variables (L_{sn})such as irrigated area, fertilizer use, and rural population was included (Lobell & Field, 2009).

The general form of the model is:

$$Y_{sn} = \alpha + \beta X_{sn} + \gamma L_{sn} + u_s + v_{sn}$$

where $u_s$represents county-specific fixed effects (capturing time-invariant heterogeneity like inherent soil quality or topography), and $v_{sn}$is the idiosyncratic error term. The choice between a fixed-effects and random-effects specification was determined using the Hausman test (Hausman, 1978), which tests for correlation between the unobserved effects $(u_s)$and the regressors.

3.5 Vulnerability Index Assessment

Regional agricultural vulnerability was assessed by constructing a composite vulnerability index (CVI) grounded in the Intergovernmental Panel on Climate Change (IPCC) conceptual framework, where vulnerability $(V)$is a function of Exposure (E), Sensitivity (S), and Adaptive Capacity (AC)(IPCC, 2022). The operationalization is expressed as:

$$V = f(E, S, AC)$$

- Exposure (E): Quantified using drought severity and frequency metrics derived from the Standardized Precipitation Index (SPI) (McKee et al., 1993) calculated from the climatic dataset.
- Sensitivity (S): Measured as the coefficient of variation in county-level crop yields, reflecting the system's inherent responsiveness to climatic shocks (Antwi-Agyei et al., 2012).

Indicators were normalized, and component weights were assigned using the Analytical Hierarchy Process (AHP) (Saaty, 1980), a multi-criteria decision-making tool. The weighting scheme was reviewed by an expert panel drawn from the Agricultural Jihad Organization, the Natural Resources Organization of Sistan and BaluchFestan Province, and the Khuzestan Water Organization (n =10); the pairwise-comparison consistency ratio (CR = 0.06) should be reported in the manuscript or supplementary material to improve reproducibility and transparency.

The final analytical stage employed primary data to examine the psychosocial and behavioral pathways linking climate stress to livelihood outcomes. The target population was farming households in the six counties. A stratified random sampling design ensured proportional representation across distinct agro-ecological zones. The sample size $(n)$was determined using Cochran's formula for large populations (Cochran, 1977):

$$n = \frac{Z^2 \cdot p \cdot (1 - p)}{e^2}$$

where $Z$is the z-score, $p$is the estimated proportion, and $e$is the desired margin of error.

The survey data were analyzed using Structural Equation Modeling (SEM), a multivariate technique ideal for testing complex networks of direct and indirect relationships among latent constructs (Kline, 2015). The SEM assessed hypothesized pathways, for instance, how perceived climate risk influences adaptation intentions, which in turn affect livelihood diversification strategies and, ultimately, household well-being (Grothmann & Patt, 2005; Savari et al., 2019). Model fit was evaluated using standard indices: Comparative Fit Index (CFI > 0.90), Tucker-Lewis Index (TLI > 0.90), and Root Mean Square Error of Approximation (RMSEA < 0.08).

4. Research Findings

The survey population consisted of farmers residing in six selected counties of Sistan and Baluchestan Province. A stratified random sampling method was employed, and the sample size was calculated using the standard formula for determining sample size in infinite populations. Prior to conducting the survey, informed consent was obtained from all participants, who were assured that their information would remain confidential. This research was carried out with the approval of the Ethics Committee of the University of Yazd.

Summary statistics for climatic variables influencing agricultural production in Sistan and Baluchestan Province (2002–2019) are presented in Table 1. Due to regional data constraints, the analysis is restricted to this 17-year period. To enhance robustness given the relatively short time series, data were aggregated at the provincial scale. By combining observations across seven spatial units, a panel dataset comprising 119 observations was constructed. The "Groups" in Table 1 correspond to these seven spatial units.

Table 1. Descriptive Statistics of Selected Climatic Variables

Variable	Observations	Groups	Mean	Standard Deviation	CV (%)	Minimum	Maximum
Precipitation (mm)	119	7	90.5	82.2	90.83	0.0	513.1
Mean Annual Temperature (°C)	119	7	23.11	2.81	12.16	17.6	28.1
Mean Annual Evaporation (mm)	119	7	3549.9	985.15	27.75	821.5	5663.4
Mean Humidity (%)	119	7	50.42	15.22	30.19	32.0	90.08

Note: "Groups" refers to seven spatial units used in the climatic dataset. CV = coefficient of variation (SD/Mean × 100).

Cucurbits (watermelon, muskmelon, cucumber) rank among the province's most important agricultural products. Between 2002 and 2019, mean production reached 472,820 tons, accounting for approximately 24% of total agricultural output, with an average cultivated area of 22,619 hectares.

Figure 3 illustrates the spatial distribution of cucurbits Production Rankings in Sistan and Baluchestan Province, identifying Zabol (194,358 tons) and Chabahar (142,897 tons) as the leading producers, while Zahedan and Khash recorded markedly lower outputs (5,299 and 15,997 tons, respectively).

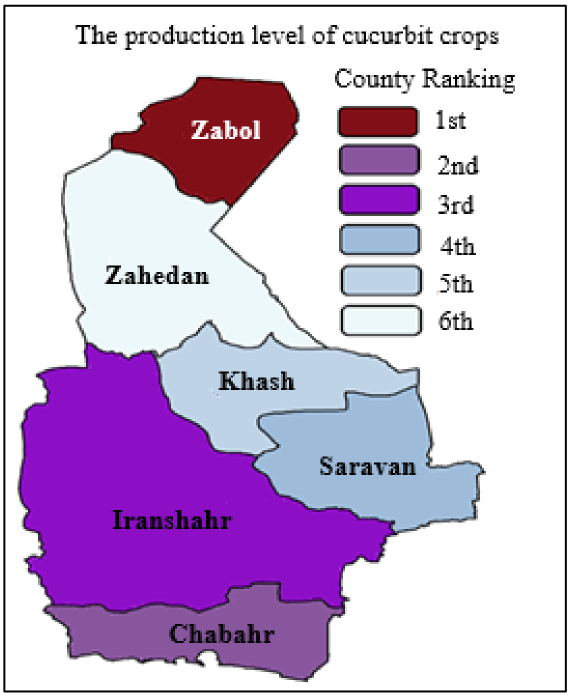

Figure 3. Spatial Distribution of Cucurbits Production Rankings in Sistan and Baluchestan Province

Mann-Kendall trend analysis (Figure 4) indicates a clear increasing trend in cucurbit and vegetable production at the provincial level. However, panel regression results (Table 2) demonstrate that this increase is strongly conditioned by climatic factors. Among the variables tested, only annual precipitation exhibited a positive and statistically significant effect ($\beta=0.88, p<0.05$), implying a yield increase of approximately 0.88 tons per hectare per unit increase in rainfall. Conversely, mean annual maximum temperature ($\beta=-14.34, p<0.05$) and annual evaporation ($\beta=-5.70, p<0.05$) had significant negative effects. These results suggest that despite overall production growth, yields remain highly sensitive to temperature extremes and evaporative water losses, increasing farmer vulnerability during low-rainfall years.

Table 2. Panel Regression Results for Cucurbit Crops in Sistan and Baluchestan Province

Variable	p value	Coefficient	t statistic
Annual Precipitation	0.001	0.8821	3.26
Annual Evaporation	0.001	−5.0741	−3.45
Annual Average Maximum Temperature	0.074	−14.3411	−1.80
Average Relative Humidity	0.001	−5.9413	−3.52

Note: The model is estimated using fixed effects; therefore, the intercept is absorbed by the unit-specific effects and is not reported separately. Multicollinearity diagnostics (VIF) should be reported in supplementary material.

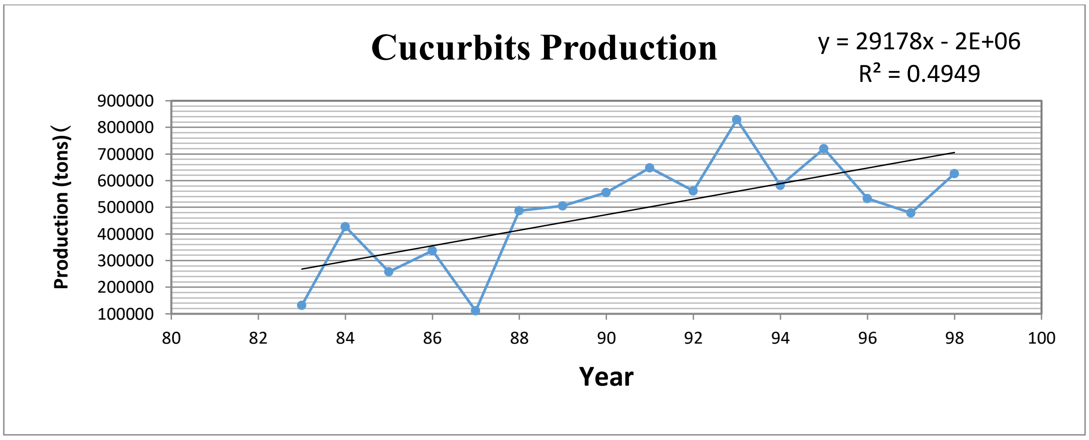

Figure 4. Trend of Cucurbits Production (in tons) in Sistan and Baluchestan Province

The vulnerability index (Figure 7) highlights pronounced spatial heterogeneity in climate risk across the province. A key vulnerability driver in the Sistan region is its dependence on the Hirmand River basin. Multiple interacting challenges including transboundary water disputes, desiccation of the Hamun wetlands, and erosion from the “120-day wind” create a compound hazard regime. These processes have precipitated an agricultural crisis, amplified migration, poverty, and unemployment, with broader implications for border security. Additionally, calcareous and marine sediments inhibit stable aquifer formation, rendering groundwater unreliable.

Mann-Kendall analysis (Figure 6) revealed a slight upward trend in provincial grain production over the 17-year period, though a notable decline occurred after 2014—the year of the largest recorded wheat cultivated area. Panel regression results (Table 3) indicate that mean annual minimum temperature ($\beta=7.15$, $p<0.05$), annual precipitation ($\beta=0.42$, $p<0.05$), and mean annual minimum relative humidity ($\beta=0.39$, $p<0.05$) positively and significantly affected cereal production. In contrast, the strongest statistically significant negative effects were associated with mean annual maximum temperature ($\beta=-23.09$, $p<0.05$), annual absolute minimum temperature ($\beta=-3.06, p<0.05$), and annual evaporation ($\beta=-2.42, p<0.05$).

Table 3. Panel Regression Results for Grains Crops in Sistan and Baluchestan Province

Variable	p value	Coefficient	t statistic
Annual Precipitation	0.004	0.4298	2.94
Annual Evaporation	0.012	−2.4300	−2.57
Annual Average Maximum Temperature	0.000	−23.0962	−4.11
Annual Average Minimum Temperature	0.044	7.1506	2.04
Average Minimum Relative Humidity	0.000	0.3989	4.00
Annual Absolute Minimum Temperature	0.033	−3.0695	−2.16

Note: The model is estimated using fixed effects; therefore, the intercept is absorbed by the unit-specific effects and is not reported separately. Multicollinearity diagnostics (VIF) should be reported in supplementary material.

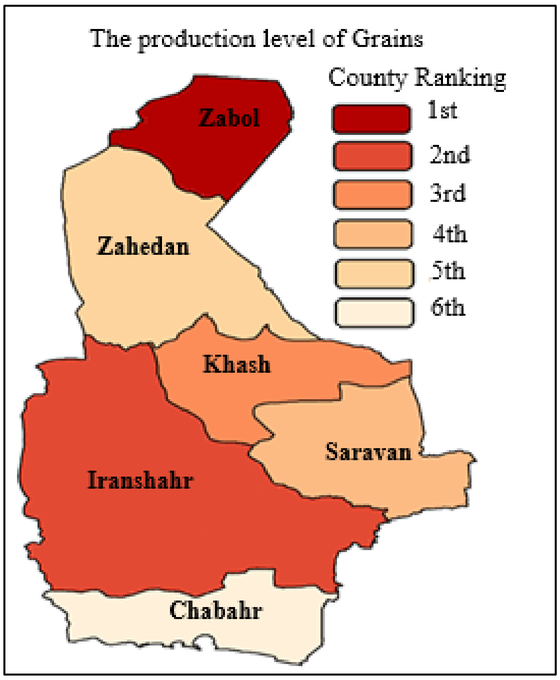

Figure 5. Spatial Distribution of Grains Production Rankings in Sistan and Baluchestan Province

The vulnerability index (Figure 7) highlights pronounced spatial heterogeneity in climate risk across the province. A key vulnerability driver in the Sistan region is its dependence on the Hirmand River basin. Multiple interacting challenges including transboundary water disputes, desiccation of the Hamun wetlands, and erosion from the "120-day wind" create a compound hazard regime. These processes have precipitated an agricultural crisis, amplified migration, poverty, and unemployment, with broader implications for border security. Additionally, calcareous and marine sediments inhibit stable aquifer formation, rendering groundwater unreliable.

Table 4. Descriptive Distribution of Farmers' Perceived Responses Regarding the Impacts of Climate Change on Livelihood Resilience Dimensions

Livelihood component	Decreased (%)	Increased (%)	Others (%)
Economic	11.25	36.25	52.50
Social	15.00	25.00	60.00
Environmental	17.50	15.00	67.50
Quality of life	20.00	20.00	60.00

Note: Table 4 presents descriptive frequencies and percentages only. It summarizes farmers' perceptions of climate change impacts and does not include inferential statistical testing; therefore, p-values, confidence intervals, and chi-square statistics are not reported.

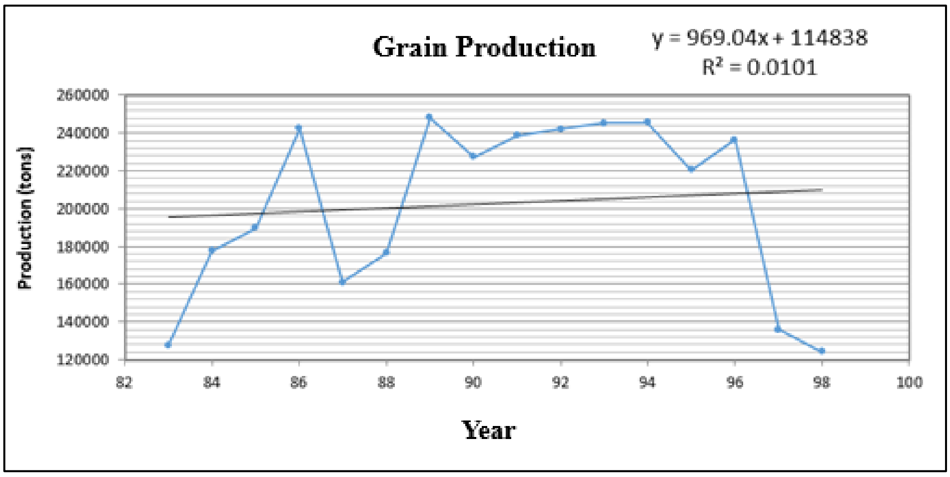

Figure 6. Trend of Grains production (in tons) in Sistan and Baluchestan Province

As Figure 7 indicates, Zabol (Index = 1.67) exhibits high vulnerability, consistent with the strong negative temperature effects identified earlier. Iranshahr and Khash also face serious vulnerability due to extensive, often unregulated groundwater exploitation. Limited surface water access has forced heavy reliance on groundwater, critically depleted in recent years. Overall, Chabahar (Index = 2.0), Khash (1.79), and Zabol (1.67) fall into the high-vulnerability category, while Zahedan (Index = 1.09) displays relatively lower vulnerability, though still considerable stress.

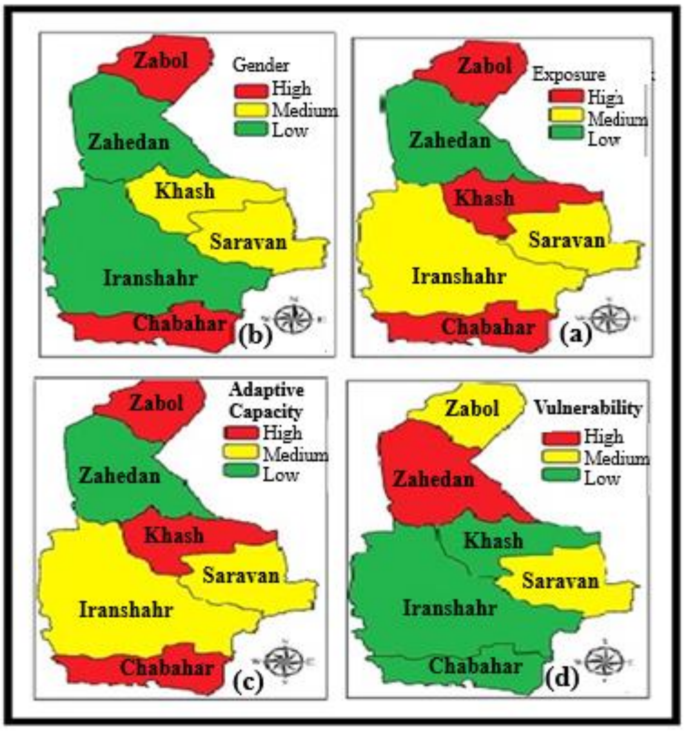

Figure 7. Results of Indices: (a) Exposure Index, (b) Gender Index, (c) Adaptive Capacity Index, (d) Vulnerability Index

Following the spatial vulnerability assessment, a household survey was conducted in the high-vulnerability districts of Chabahar and Khash, using a questionnaire validated by an expert panel.

The demographic profile revealed that 45% of respondents were over 60, 45% were illiterate, and 60% lived in households with >5 members, reflecting socio-economic challenges facing an aging farming population.
Table 5 summarizes the distribution of households across three livelihood resilience categories derived from the composite resilience index: Fully Suitable, Nearly Suitable, and Fully Unsuitable. The results show that 33.5% of households fell into the Fully Suitable category, 41.5% into the Nearly Suitable category, and 25.0% into the Fully Unsuitable category, indicating that most households were concentrated in the moderate-to-high resilience range.

Table 5. Distribution of Rural Households by Livelihood Resilience Category

Resilience category	Operational definition	Percentage of total sample (%)
Fully Suitable (High resilience)	Households with strong adaptive capacity, effective risk management, and diversified livelihood options, allowing them to cope effectively with drought.	33.50
Nearly Suitable (Moderate resilience)	Households with moderate adaptive capacity that can cope with some drought impacts but still face important resource and livelihood constraints.	41.50
Fully Unsuitable (Low resilience)	Households with limited adaptive capacity, high vulnerability, and substantial difficulty responding to drought conditions.	25.00

Note: Percentages represent the proportion of the total sample in each mutually exclusive category and therefore sum to 100%.

5. Discussion and Conclusion

This study assessed climate change vulnerability and resilience of rural livelihoods in Sistan and Baluchestan Province, examining how temperature, precipitation, water availability, and agricultural productivity affect livelihood systems. The central hypothesis that increasing climatic stress, particularly rising temperatures and declining precipitation, intensifies vulnerability, with resilience dependent on adaptive capacity and resource availability is largely supported, with important nuances across crops, space, and social groups. By integrating 17 years of climatic and agricultural data with spatial vulnerability indices and household surveys, this research provides a needed integrated empirical analysis for the province. Consistent with global and national projections (Keshavarz et al., 2013; Waha et al., 2017; IPCC, 2022), the province experiences rising maximum temperatures, high rainfall variability, and elevated evaporation. Panel regressions confirm these trends exert measurable pressure: grain yields (wheat, barley) declined despite expanded cultivated area, primarily due to thermal stress and water deficits, mirroring patterns in other stressed systems (Bobojonov et al., 2022). Cucurbit production increased, but this growth is precipitation-dependent, indicating contingent gains. These findings confirm earlier work on drought in southeastern Iran (Zareei et al., 2017; Erfanian et al., 2021) while extending it in three key ways. First, it integrates climate, production, and livelihoods within a single framework considering climatic exposure, agricultural outcomes, and livelihood impacts simultaneously. Second, the spatially explicit county-level vulnerability index reveals pronounced intra-provincial differences: Chabahar, Khash, and Zabol emerge as high-vulnerability hotspots due to combined climatic stress, transboundary Hirmand basin dependence, and critical groundwater depletion, aligning with localized evidence (Ashtab & Sharifzadeh, 2016) but providing systematic province-wide comparison. Third, household surveys link biophysical pressures to perceived impacts. High shares reporting moderate-severe drought impacts, income decline, and increased migration align with studies highlighting income instability, diversification, and migration as climate responses in arid regions (Savari et al., 2019; Nazari et al., 2022; Mohammadi et al., 2023). The results align with vulnerability frameworks emphasizing dynamic, socially mediated processes (Turner et al., 2003; Adger, 2006), showing similar climatic hazards yield differentiated outcomes based on local socio-economics and institutions. Reliance on the transboundary Hirmand River and Hamun wetlands, combined with water disputes, weak institutional support, and limited infrastructure, creates “compound vulnerability” beyond climate alone. Wetland desiccation and intensifying “120-day wind” reduce water availability and soil quality while eroding ecosystem services and cultural landscapes integral to resilience, echoing political ecology perspectives on multi-level vulnerability drivers (Sultana, 2014; Tschakert et al., 2021). Household-level demographic characteristics high shares of older farmers, illiteracy, large households reveal constraints on adaptive capacity, consistent with studies highlighting assets, knowledge, and social capital in resilience (Carr, 2020; Ferdous et al., 2022). Limited education and aging populations hinder adoption of climate-smart practices and new opportunities, underscoring needs for targeted capacity-building (Rezaei-Moghaddam & Karami, 2023). Findings also resonate with research showing diversification into non-/off-farm activities reduces vulnerability (Savari et al., 2019; Nazari et al., 2022), suggesting broader livelihood portfolios enhance shock absorption.

This study provides robust, multi-method evidence that climate change is actively undermining the foundation of rural livelihoods in Sistan and Baluchestan Province. The integration of climatic, agricultural, spatial, and survey data confirms that rising temperatures and water scarcity are not future threats but present crises, exerting measurable negative pressures on grain yields and rendering apparent gains in other crops precariously dependent on rainfall. Crucially, vulnerability is not uniform; it is spatially concentrated in counties like Chabahar, Khash, and Zabol, where climatic stress intersects with transboundary water dependencies and groundwater depletion to create compound hazards. The research moves beyond merely diagnosing exposure to reveal the nuanced architecture of resilience. The counter-intuitive survey finding where higher reported resilience correlated with higher perceived drought impact challenges linear assumptions and underscores that resilience is a multidimensional construct, shaped by perception, expectation, and context as much as by material assets. This implies that effective policy must look beyond generic, top-down solutions. Ultimately, securing a viable future for the province requires a fundamental transformation from crisis response to proactive, systemic adaptation. This transformation must be anchored in the three pillars demonstrated as essential: climate-smart agricultural restructuring, equitable and cooperative water governance, and diversified economic foundations. Embedding these context-specific strategies within national development plans and international frameworks (e.g., SDGs 2, 6, 13) is imperative. The time for incremental adjustment has passed; the findings of this study constitute a clear call for decisive, evidence-based action to invest in the adaptive capacity of Sistan and Baluchestan’s communities before existing vulnerabilities escalate into irreversible human and environmental insecurity.

Acknowledgments

This article is derived from a thesis supported by the Iran National Science Foundation (INSF). The authors gratefully acknowledge this support. The authors also wish to express their sincere gratitude to the Meteorological Organization and the Agricultural Jihad Organization of Sistan and Baluchestan Province for providing the necessary statistics and data. In addition, the authors thank the farmers and local residents of the region for their patient cooperation during the fieldwork phase of this research.

Authors′ contributions

K. Joojizadeh: Data collection, analysis, and writing of the original draft; G. Mozaffari: Conceptualization, supervision, and methodology; F. Mohammadi Ravari: Writing, review, and editing; R. Kheirolomour: Writing, translation, and fieldwork, and All authors read and approved the final manuscript.

Conflict of interest

The authors declare no conflict of interest.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Journal of Research and Rural Planning
Volume 15, No. 1, Winter 2026, Serial No. 52, Pp. 75-90
eISSN: 2783-2007 ISSN: 2783-2791
http://jrrp.um.ac.ir

Original Article

آسیب‌پذیری و تاب‌آوری معیشت‌های روستایی در برابر تغییرات اقلیمی در استان سیستان و بلوچستان، ایران

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چکیده مبسوط

۱. مقدمه

پژوهش حاضر به بررسی یکی از بحرانی‌ترین چالش‌های زیست‌محیطی قرن حاضر، یعنی تغییر اقلیم، و پیامدهای مستقیم و غیرمستقیم آن بر پایداری معیشت روستایی در استان سیستان و بلوچستان می‌پردازد. تغییر اقلیم نه تنها به عنوان یک پدیده هواشناسی، بلکه به عنوان یک عامل تهدیدکننده امنیت غذایی و ساختار اجتماعی-اقتصادی در مناطق خشک و نیمه‌خشک عمل می‌کند. با توجه به پیش‌بینی‌های جهانی مبنی بر افزایش ۱/۵ تا ۴/۵ درجه‌ای دمای زمین تا سال ۲۱۰۰ و کاهش ۲۰ تا ۲۵ درصدی بارش‌ها در ایران، استان سیستان و بلوچستان به دلیل موقعیت جغرافیایی و وابستگی شدید به منابع آب برون‌مرزی (حوضه هیرمند)، در وضعیت آسیب‌پذیری مضاعف قرار دارد. این مطالعه با هدف واکاوی پیوند میان متغیرهای اقلیمی و پایداری معیشت، تلاش دارد تا ابعاد مختلف این بحران را در سطوح محلی و منطقه‌ای تبیین نماید.

۲. روش تحقیق

این تحقیق با اتخاذ یک رویکرد توصیفی-تحلیلی و با بهره‌گیری از داده‌های ثانویه و پیمایشی انجام شده است. پایگاه داده‌های اقلیمی شامل آمار ۱۷ ساله (۱۳۸۱-۱۳۹۸) از ۸ ایستگاه سینوپتیک استان (مانند زاهدان، زابل، خاش، ایرانشهر و چابهار) است که متغیرهایی نظیر میانگین دمای سالانه، بارش، رطوبت نسبی و تبخیر را پوشش می‌دهد. در بخش تحلیل آماری، از آزمون ناپارامتری «من-کندال» برای شناسایی روند تغییرات و از مدل رگرسیون پانل برای تخمین اثرات متغیرهای اقلیمی بر تولیدات کشاورزی استفاده شده است. همچنین، برای سنجش آسیب‌پذیری، مدل VSD به کار گرفته شده که از ترکیب سه مؤلفه اصلیِ «مواجهه»، «حساسیت» و «ظرفیت انطباق‌پذیری» به دست می‌آید. در بخش کیفی نیز از طریق پرسشنامه، ادراک ذهنی کشاورزان از پایداری معیشت مورد سنجش قرار گرفته است.

۳. یافته‌های تحقیق

یافته‌های حاصل از تحلیل داده‌ها نشان می‌دهد که میانگین بارش سالانه در دوره مورد مطالعه تنها ۹۰.۵ میلی‌متر بوده، در حالی که میانگین تبخیر سالانه رقم بسیار بالای ۳۵۴۹/۹ میلی‌متر را نشان می‌دهد که این ناترازی شدید هیدرولوژیک، پایداری منابع آب را از بین برده است. در بخش محصولات جالیزی (که ۲۴ درصد تولیدات استان را شامل می‌شود)، تحلیل رگرسیون نشان داد که افزایش هر واحد در بارش، منجر به افزایش ۰/۸۸ تنی در عملکرد می‌شود، اما تأثیر مخرب دمای حداکثر با ضریب ۱۴/۳۴- بسیار چشمگیرتر است. در مورد غلات که بیش از ۵۵ درصد اراضی زراعی (معادل ۱۰۰,۰۰۹ هکتار) را اشغال کرده‌اند، وضعیت بحرانی‌تر گزارش شده است؛ به طوری که علی‌رغم افزایش ۲۵ درصدی در سطح زیرکشت طی برخی دوره‌ها، تولید نهایی به دلیل تنش‌های حرارتی و خشکسالی با افت جدی مواجه شده و دمای حداکثر با ضریب ۲۳/۰۹- اثر کاهنده بر تولید داشته است. در مجموع، تغییرات اقلیمی باعث کاهش ۱۰ تا ۱۵ درصدی در کل بازده تولیدات کشاورزی استان شده است.

۴. بحث و نتیجه گیری

تحلیل شاخص آسیب‌پذیری در سطح شهرستان‌های استان حاکی از توزیع ناعادلانه ریسک‌های اقلیمی است. شهرستان چابهار با نمره ۲ و خاش با ۱/۷۹ در بالاترین رده‌های آسیب‌پذیری قرار دارند، در حالی که شهرستان زاهدان با نمره ۱/۰۹ آسیب‌پذیری کمتری را تجربه

می‌کند. این تفاوت‌ها عمدتاً ناشی از نرخ‌های متفاوت تبخیر و دسترسی به منابع آب پایدار است. در بخش پیمایشی، ۸۰ درصد از جامعه آماری روستایی، تأثیر تغییر اقلیم و خشکسالی بر معیشت خود را در سطح «زیاد و خیلی زیاد» ارزیابی کرده‌اند. کاهش ۳۰ درصدی ورودی آب حوضه هیرمند و خشک شدن تالاب هامون نه تنها کشاورزی، بلکه معیشت‌های جایگزین مانند صیادی و صنایع دستی وابسته به نیزار را نیز نابود کرده است. این وضعیت منجر به کاهش شدید درآمد ۶۵ درصد از خانوارها و افزایش نرخ مهاجرت‌های اجباری از روستا به حاشیه شهرها شده است. نتایج این پژوهش تأیید می‌کند که تغییر اقلیم در سیستان و بلوچستان از یک پدیده زیست‌محیطی به یک بحران معیشتی و امنیتی تبدیل شده است. ناپایداری تولید در دو بخش غلات و محصولات جالیزی، که ستون‌های اصلی اقتصاد روستایی منطقه هستند، ضرورت بازنگری در سیاست‌های مدیریت منابع آب و خاک را دوچندان می‌کند. برای مقابله با این روند، پیشنهاد می‌شود که دولت و نهادهای ذی‌ربط بر «دیپلماسی فعال آب» برای احقاق حقابه هیرمند، «تنوع‌بخشی به معیشت‌های غیرکشاورزی» (نظیر گردشگری و تجارت مرزی)، «ترویج الگوهای کشت مقاوم به خشکی» و «توسعه سیستم‌های گلخانه‌ای» تمرکز کنند. همچنین تقویت صندوق‌های بیمه محصولات کشاورزی و آموزش روش‌های نوین سازگاری به روستاییان، می‌تواند ظرفیت انطباق‌پذیری جامعه محلی را در برابر تکانه‌های اقلیمی آینده افزایش دهد.

کلیدواژه‌ها: استان سیستان و بلوچستان، استراتژی سازگاری، تغییر اقلیم، خشکسالی، شاخص آسیب‌پذیری.

تشکر و قدردانی

این مقاله با حمایت مالی صندوق حمایت از پژوهشگران و فناوران کشور (بنیاد ملی علم ایران) انجام‌پذیرفته است و مراتب سپاسگزاری از این بنیاد، به‌پاس حمایت مالی، ابراز می‌شود. همچنین از سازمان هواشناسی و جهاد کشاورزی استان سیستان و بلوچستان به‌خاطر ارائهٔ آمار و داده‌های مورد نیاز، و نیز از تمامی کشاورزان و ساکنان بومی منطقه که در بخش میدانی این پژوهش همکاری نمودند، صمیمانه قدردانی می‌شود.

Use your device to scan and read the article online	**How to cite this article:**	**Date:**
	Joojizadeh, Kh., Mozaffari, Gh., Mohammadi Ravari, F., & Kheirolomour, R. (2026). Vulnerability and resilience of rural livelihoods under climate change in Sistan and Baluchestan, Iran. *Journal of Research & Rural Planning, 15*(1), 75-90. http://dx.doi.org/10.22067/jrrp.v15i1.2601-1158	*Received: 05-03-2026* *Revised: 02-05-2026* *Accepted: 24-06- 2026* *Available Online: 26-06-2026*