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Exploring the impact of dust storms on pastoralists' livelihoods in West Iran: Social, economic, and environmental consequences

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Abstract

This study investigates the economic, social, and environmental impacts of dust storms on pastoralists' livelihoods in the Chaqakdo rangeland of West Iran. Data was collected through face-to-face interviews with 100 pastoralists in 2019. The research adopts a quantitative approach using Structural Equation Modeling (SEM). The results demonstrate a significant and positive relationship between pastoralists' livelihoods and the three independent variables (environmental, economic, and social), with the strongest correlation observed in environmental factors. The path coefficients indicate positive effects on pastoralists' livelihoods. Additionally, dust storms were found to have detrimental environmental effects, such as plant leaf pollution, reduced grazing, and decreased growth of grassland plants. Therefore, it is crucial to establish adaptive measures to mitigate the impacts of dust storms on pastoralists, considering their heavy reliance on the local pastures.

KEYWORDS
climate incident management, environmental factors, pastoral development concerns, rangeland degradation, socio-economic consequences

1 | INTRODUCTION

By 2100, the world's population is projected to reach 10.9 billion, posing a significant challenge in providing goods and services (FAO et al., 2013; Kumari et al., 2022; Riegels et al., 2019; United Nations, 2013). This necessitates proactive measures to address the growing demands and ensure sustainable development for future generations. Rangeland products and services, encompassing food, fiber production, water resources conservation, biodiversity, and ecosystem services, cater to the needs of about one-third of the global population (Archer et al., 2021; Neely et al., 2009). Given the significance of income generated from natural resources in rural communities (Yang et al., 2018), the deterioration of rangelands and ecosystems assumes a prominent role

in the financial and livelihood needs of pastoralists (Jamil et al., 2022; Ngorima & Shackleton, 2019; Rigg, 2006). Sustaining livelihoods and altering the use of rangeland resources are major pastoral development concerns (Zahed et al., 2022). The drivers behind changes in pastoral systems can be categorized into two main factors, influenced by determinants such as agricultural policies, fluctuations in commodity prices, modifications in land tenure systems, shifts in political and legal frameworks, and advancements in infrastructure development. The first factor revolves around land fragmentation and the subsequent reduction in access to resources (Galvin, 2009; Unks et al., 2019). The second factor involves environmental shocks and variability in arid and semi-arid regions, leading to alterations in vegetation patterns, water availability, and consequently impacting production

systems reliant on climatic conditions (Tan et al., 2017). Dust storms in Iran present a major challenge for the livestock sector by adversely affecting vegetation and agricultural fields (Mesbahzadeh et al., 2022).

Dust storms are hazardous atmospheric events with adverse impacts that pose a significant environmental shock, jeopardizing human livelihood security (Mavhura, 2017; Middleton & Kang, 2017; Nazari et al., 2018). Commonly observed in arid and semi-arid regions, these severe natural disasters transport substantial quantities of desert dust, reducing visibility to less than 1 km (Nabavi et al., 2017; Yassin et al., 2018). Dust storms transport over long distances, affecting temperature, clouds, and convection globally (Mavhura, 2017; Zhang et al., 2019). They damage crops, deplete soil fertility, and pose cardiovascular health risks (Mavhura, 2017). In general, it can be argued that the dust storm affects the livelihoods of pastoralists by contaminating the vegetation and water required for livestock and spreading livestock diseases (Alexander et al., 2018; Chen et al., 2018; Fraser, 2013; Masaguer et al., 2018). Therefore, it is a valid way to manage the dust storms, which increasingly requires initiatives to recognize farmers' attitudes toward this incident (Taheri et al., 2020).

As a result, large parts of the Iranian desert are being destroyed by dust storms (Emami Meibodi1 et al., 2015; Nazari et al., 2018). The produced microbes by dust storms have negative effects on vegetation and morphological and physiological parameters (Prajapati & Tripathi, 2008; Saha & Padhy, 2011; Verma & Singh, 2006). Dust may clog the stomatal openings leading to adverse effects on photosynthesis and leaf temperature (Lin et al., 2019; Zia-Khan et al., 2014). The main sources of dust storms entering Iran are desert areas relatively close to this region, such as the deserts of Syria and Iraq and the desert in the north of the Arabian Peninsula.

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There is little empirical evidence to support the long-term effects of dust storms, especially in terms of the impact on widespread livestock mortality and its adverse effects on pastoralists' livelihood. Therefore, the present study focuses on the rangelands of Chaqakdo located in Kermanshah province in the west of Iran. It seems that the influx of dust into the rangelands of Chaqakdo has brought substantial negative externalities at different socio-economic and environmental levels (Doabi et al., 2018). Pastoralists in various fields (including

water and soil pollution and consequently sickness, reduction of forage by livestock, mortality, sale and reduction of livestock, rangelands pollution, income reduction, destruction of natural landscapes, and changes in the occupations) face many problems. These factors have led to changes in rancher livelihoods. To our best knowledge, very little research has been conducted to investigate the effects of dust on the livelihood of pastoralists. We recall that this analysis will not investigate the extent of dust pollution. In fact, this research focuses only on the socioeconomic and environmental effects of dust on the livelihoods of pastoralists. The present study aims to answer the questions of whether Chaqakdo rangelands are affected by the economic, environmental, and ecological consequences of the rainstorm and whether these phenomena are detectable for pastoralists?

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The study contributes to the academic discourse by providing a theoretical framework and empirical evidence on the complex interactions between dust storms, environmental factors, and pastoralists' livelihoods. Through the application of Structural Equation Modeling (SEM), the study establishes and quantifies the relationships between these variables, shedding light on the positive effects of environmental, economic, and social factors on pastoralists' livelihoods. This study also enhances the understanding of the intricate dynamics governing livelihoods in dust-affected regions and serves as a clear way for future research endeavors in similar contexts.

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Furthermore, the identification of adverse environmental effects resulting from dust storms, such as the pollution of plant leaf area, diminished grazing opportunities, and hindered grassland growth, underscores the urgent need for targeted interventions aimed at mitigating the impacts on pastoralist communities. The study advocates for the implementation of measures that facilitate the adaptation of farmers to the challenges posed by dust storms, including the provision of support for alternative livelihood strategies and the adoption of sustainable rangeland management practices. Additionally, the study emphasizes the significance of raising awareness among pastoralist communities regarding environmental risks and advocates for the promotion of adaptive strategies to enhance their resilience. The practical insights derived from this study can inform the development of effective policies and interventions tailored to safeguard the livelihoods of pastoralists in dust-affected regions, thereby contributing to sustainable development and the well-being of these communities. Consequently, this study not only advances academic knowledge but also provides actionable guidance for decision-makers and practitioners working in the field.

1.1 | Literature review

Recent literature has drawn attention to the significant impact of dust storms on various economic and social aspects, particularly in Iran (Broomandi et al., 2022; Namdari et al., 2021). In addition to the well-documented environmental consequences, such as air pollution and landscape changes, dust storms have been found to have severe implications for rangeland grasses, leading to food scarcity and the death of livestock (Hu et al., 2019). This degradation of rangelands not only results in economic losses but also reduces the overall productivity of the land, as livestock heavily depend on these areas for forage (Hu et al., 2019).

Zeidali et al. (2015) established a connection between the growing season and the occurrence of dust storms, highlighting that early-season dust storms can cause severe damage and even destruction of plants. Moreover, pastoralists have observed that the impact of dust on plants is greater during winter, as vegetative growth commonly occurs in tropical areas during this season. Nomadic herders, whose migration patterns are affected by the occurrence of dust storms, tend to migrate to neighboring provinces of Khuzestan, which are highly influenced by this phenomenon.

Studies conducted by Bornette and Puijalon (2011) and Gómez-Amo et al. (2019) emphasized that the deposition of dust and sediment on plant surfaces blocks light penetration, leading to reduced vegetative growth. The presence of dust on leaves hinders the absorption of light necessary for photosynthesis, affecting leaf stomatal conductivity, plant biomass, and photosynthetic rates. Investigations carried out in Iran by Doabi et al. (2017) and Nazari et al. (2018) revealed that dust pollution has detrimental effects on crop production, air quality, leaf surface pollution, and landscape transformation. Similarly, research in China conducted by Yan et al. (2011) demonstrated that dust storms decrease plant photosynthesis and restrict vegetation availability for domestic animals, ultimately leading to plant withering and reduced food resources for livestock.

Furthermore, the role of microorganisms in human health concerns associated with dust storms has been explored. With climate change contributing to desertification and long-term water scarcity, increased dust emissions are predicted, raising public health alarms globally. These studies have identified respiratory problems and mortality as significant consequences of dust exposure (Morman & Plumeele, 2013).

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From a socio-economic perspective, the negative externalities of dust storms encompass floods, temperature changes, soil erosion, heavy rains, and pollution, as observed in Bangladesh (Fang et al., 2018; Rahim et al., 2018). These undesired factors result in crop losses, reduced employment opportunities, decreased livestock activity, and heightened poverty and unemployment rates. Unemployment and migration have been reported as outcomes of resource depletion caused by dust storms among pastoralist communities (Nie et al., 2017; Su et al., 2019; Ullah et al., 2019). To mitigate the socio-economic impacts of dust storms, establishing dust monitoring centers has been suggested to raise awareness among affected communities (Basart et al., 2018).

Experimental studies have provided insights into the ecological consequences of sediment deposition from dust storms. Sediment produced by dust storms has been found to reduce species diversity, pollination, and the energy stored in plant tissues (Perini et al., 2017; Stachiw et al., 2019). These findings highlight the broader ecological ramifications of dust storms and their potential to disrupt ecosystems and biodiversity. Overall, while the recent literature underscores the multifaceted impacts of dust storms on various aspects, including the environment, economy, society, and ecology this study provides valuable insights into the severity of the consequences and the urgent.

2 | METHODS AND MATERIALS

2.1 | Study area

This study focuses on Chaqakdo Rangeland in Kermanshah province located in the west of Iran (see Exhibit 1). The area is approximately 5000 ha and within 30 km of the town of Sarpol-e Zahab, between the eastern longitude 45°13′−34°46′ and the northern latitude 34°13′−34°45′. As shown, the area has an average elevation of 500 m above sea level, and the slope of the area is 17% (Ahmadi et al., 2018). There are 135 pastoralists in this pasture. The management of these rangelands is common (they all jointly exploit rangelands). The forage needed for domestic livestock is obtained from pastures. Therefore, part of the economic status of rangelands relies on rangelands. However, dust on the surface of the plant leaves makes the plant polluted; it pollutes the air, causes diseases, and ultimately affects the landscape of the rangelands (Morman & Plumeele, 2013; Saha & Padhy, 2011; Verma & Singh, 2006).

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Due to proximity to the Iraq boundary, the dust has always affected this region. According to our interview with local people, it is believed that a large amount of dust has been pouring into the Chaqakdo rangelands every year since Iraq has been plagued by war and chaos. There are several consequences mentioned by natives. First, they asserted that the pastoralists have been keen to migrate to the city since the arrival of the dust. Since then, more livestock have died, and pastoralists have paid more money to buy forage. Another effect of the dust that the pastoralists emphasized was the pollution of plants and the reluctance of livestock to eat them. This issue also indirectly threatens the livestock population in the area. On the basis of the aforementioned externalities, it is clear that the storm of dust can substantially impact the socio-economic and environmental factors of rangelands. For this reason, we designed a survey in which we collected pastoralists' views on the effects of dust on socio-economic and environmental factors.

2.2 | Data collection

The methodology employed in this study is based on field surveys and statistical analysis, specifically structural equation estimation. Data and information were collected in July 2019 through face-to-face interviews and questionnaires administered to local pastoralists.

The study's statistical population consisted of 135 pastoralists from the Chaqakdo rangeland, out of which 100 pastoralists were selected as the statistical sample using the Cochran formula. A questionnaire was utilized for data collection. The questionnaire comprised two parts. The first part focused on the personal characteristics of the respondents (see Appendix 1). Variables in this section were measured using rank-scale and distance.

The second part of the questionnaire examined the economic, social, and environmental effects of dust on the livelihood of pastoralists. To evaluate Iranian pastoralists' experiences with dust storms, criteria for each indicator were defined. A five-point Likert scale ranging from
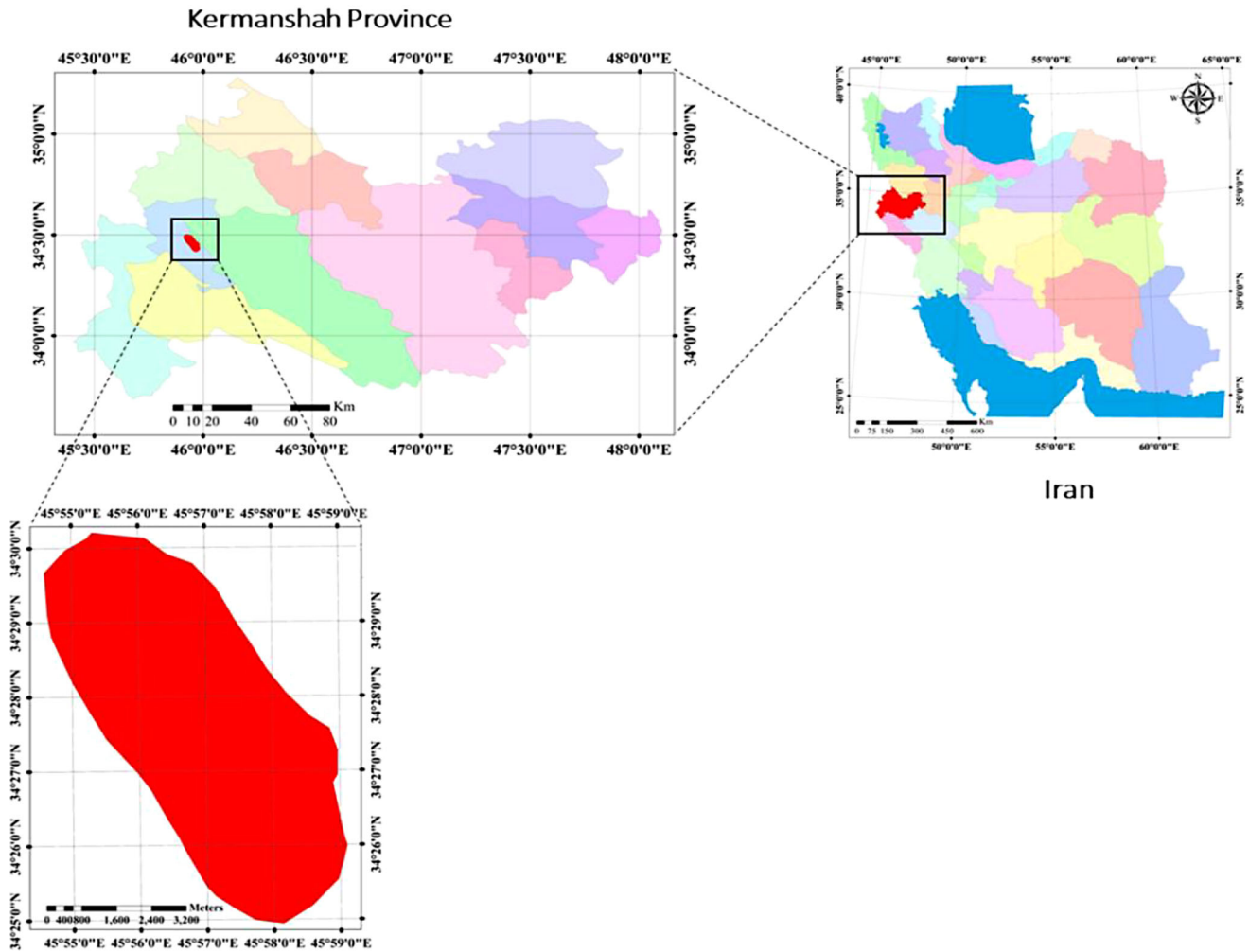
EXHIBIT 1 Location of case study: Chaqakdo Rangeland. Reference: Own presentation. [Color figure can be viewed at wileyonlinelibrary.com]

one (very low) to five (very high) was employed to measure the items. The content and validity of the research instrument and criteria were assessed through expert evaluations and relevant literature (Kalantari et al., 2008).

Furthermore, to ensure the validity of the analysis, Cronbach's alpha was calculated, resulting in values of 0.7, 0.74, and 0.76 for the economic, social, and environmental factors of dust, respectively, as well as 0.7 for the dependent variable (livelihood of pastoralists). The average of each item influencing the livelihood of pastoralists was assessed using the Kendall Tau-b test, while the Spearman correlation test was employed to examine the correlation between independent variables and the livelihood of pastoralists. These tests were conducted using SPSS software version 22.

2.3 | Data analysis

A hypothetical model was developed, taking into account the expert opinions and research background provided (Exhibit 2). Then, the

Structural Equation Modeling (SEM) was performed using the partial least squares (PLS) method which is a statistical technique commonly used for predictive modeling and structural equation modeling. It aims to establish linear relationships between variables by identifying latent factors that explain maximum covariance (Esposito Vinzi et al., 2010). PLS is widely applied in various fields such as marketing, finance, and social sciences (Henseler et al., 2009; Esposito Vinzi et al., 2010). Two important outputs, including 1-T-statistic and 2-Path coefficients (factor loads), are obtained from this software. In fact, the value of the T statistic is the main criterion for confirming or rejecting the assumptions. If this statistic value is greater than 1.64, 1.96, and 2.58, we conclude that the hypothesis is confirmed at the 1, 2, and 2% levels. Furthermore, if the path coefficient value between the independent variables and the dependent variable is positive, we conclude that by increasing the independent variable, we will have an increase in the dependent variable and counter (Azar & Gholamzadeh, 2016). This study is not seeking to assess how the dust storm impacts rangelands; instead, the study aims at exploring the dust impact on the livelihood of pastoralists from their point of view.
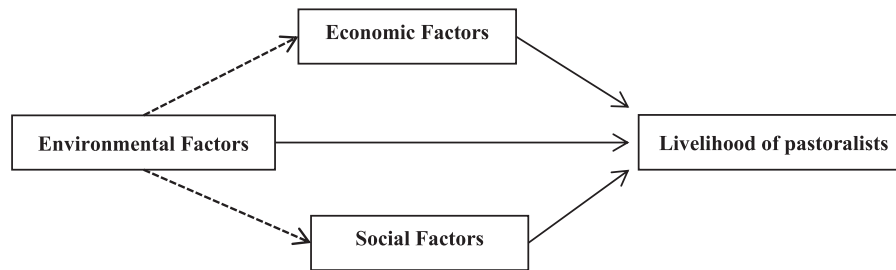
EXHIBIT 2 How independent variables affect (consequences related to dust) the livelihood of pastoralists.

EXHIBIT 3 Frequency distribution of pastoralists according to individual characteristics.

Variable	Variable levels	Abundance (%)	Percentage	Cumulative percentage
Age (year)	Less than 40	5	5	5
	40–49	30	30	35
	50–59	35	35	70
	60–69	23	23	93
	70 and above	7	7	100
Household dimension (number)	Less than 3	31	31	31
	3–5	35	35	66
	5–7	20	20	86
	7 and above	14	14	100
Exploitation experience (year)	Less than 35	32	32	32
	35–45	45	45	77
	45–55	10	10	87
	55–65	10	10	97
	Above 65	3	3	100
Number of livestock available (number)	Less than 40	32	32	32
	40–60	42	42	74
	60–80	10	10	84
	80–100	10	10	94
	100 and above	6	6	100

Reference: Own.

3 | RESULTS

Exhibit 3 provides a summary of our data. The average age of pastoralists in this study was 58 years. The highest percentage of pastoralists (35%) fell within the age range of 50–59 years, indicating that the majority of pastoralists in this area are middle-aged or older. In terms of household dimension, the highest percentage (35%) was observed in the range of 3–5 members. The objective of our analysis is to assess the potential effects of dust storms on the livestock sector from the perspective of pastoralists themselves, rather than relying solely on expert opinions. Therefore, the data were collected through face-to-face interviews and questionnaires administered to local pastoralists. Accordingly, we included indices that adequately cover various aspects of the associated indicators (social, economic, or environmental) and

are familiar to pastoralists. Nevertheless, the content and validity of the research instrument and criteria were assessed through the input of experts and relevant literature. Furthermore, the average years of exploitation experience among pastoralists were 38 years, with a significant proportion (45%) having a record of 35–45 years. The average number of livestock owned by pastoralists was 46 (Exhibit 1).

In this section, we provide an elaboration on the correlation of sub-variables with the dependent variable. The results of the Kendall Tau-b correlation test revealed that among economic factors, the decline in livestock production and livestock sales items exhibited the highest correlation with the livelihood of pastoralists. Conversely, the items related to mortality and livestock decline, as well as increased treatment costs for local people diseases, showed the least correlation with the livelihood of pastoralists.

Furthermore, the analysis of social indicators demonstrated that the increasing tendency to migrate from the village to the city and the rise in unemployment displayed the highest correlation with the livelihood of pastoralists. On the other hand, items related to increased conflict among local people and increased crime exhibited the least relationship with the livelihoods of pastoralists.

Lastly, among environmental factors, the pollution of the leaf area of plants, the reduction of livestock grazing, and the growth of rangeland plant items showed the highest correlation with the livelihood of pastoralists. Conversely, increases in the pollution of water resources and springs displayed the least correlation with the livelihood of pastoralists in the study area (Exhibit 4).

Next, we discuss the correlation of variables with the dependent variable using the Spearman correlation test. The results of the Spearman correlation coefficient indicate a positive and significant relationship between the livelihood of pastoralists and all three independent variables. Among these variables, the highest correlation was observed with environmental factors, specifically dust-related impacts. Thus, the environmental impacts of dust demonstrate the most significant relationship with the livelihood of pastoralists. Following that, economic and social factors were ranked in descending order of correlation strength (Exhibit 5).

Our research findings suggest that all three variables, namely environmental, economic, and social factors of dust, have positive path coefficients (factor loads) that significantly affect the dependent variable, the livelihood of pastoralists. Among these variables, the strongest correlation was found with environmental factors (0.484), followed by economic factors (0.225) and social factors (0.220). This implies that the livelihoods of pastoralists are primarily influenced by the environmental consequences of dust storms. Notably, in the structural model, the path from ecological factors to economic factors emerged as the most crucial factor, surpassing even the impact of environmental factors on the livelihood of pastoralists. Furthermore, the highest factor loadings among the independent variables of environmental, economic, and social factors were observed in contaminating the leaf area of the plant and reducing livestock grazing (c2), reducing livestock production (b1), and the decrease in participation in rangeland restoration and rehabilitation projects (d1) (Exhibit 2). The results of the T-test confirmed all

the research hypotheses. Specifically, all five hypotheses were supported: (1) the impact of environmental factors on economic factors, (2) the impact of environmental factors on livelihood, (3) the impact of environmental factors on social factors, (4) the impact of economic factors on livelihood, and (5) the impact of social factors on livelihood.

In the structural model, environmental factors exhibited the strongest relationship with economic factors (149.280). The hypotheses regarding the relationship between environmental and economic factors, as well as the relationship between environmental and social factors, were significant at the 1% level. Moreover, the hypotheses concerning the relationship between environmental factors and the livelihood of pastoralists, the relationship between economic factors and the livelihood of pastoralists, and the relationship between social factors and the livelihood of pastoralists were significant at the 5% level (Exhibit 6).

4 | DISCUSSION

The insights shared by pastoralists in this study highlighted the adverse effects of dust storms, prompting us to further explore the consequences through an extensive review of relevant literature. It is evident that pastoralists possess a strong awareness of the significant outcomes associated with dust storms

The insights shared by pastoralists in this study highlighted the adverse effects of dust storms, prompting us to further explore the consequences through an extensive review of relevant literature. It is evident that pastoralists possess a strong awareness of the significant outcomes associated with dust storms. They specifically identified issues such as air pollution, the deposition of dust on plants' surfaces, livestock mortality, reduced palatability, and the detrimental impact on rangeland landscapes resulting from dust phenomena. These findings align with the research conducted by Taheri et al. (2020), who also observed that farmers possessed adequate knowledge about the

EXHIBIT 4 Correlation between the consequences of dust storm and the livelihood of pastoralists.

Indicators	Items and their priority	Kendall Tao *b* correlation coefficient	P-value
Economic consequences related to dust from the pastoralists' viewpoint	Reducing livestock production (b1)	0.854**	0.000
	Sale of livestock (b3)	0.732**	0.000
	Increased treatment costs for animal diseases (b6)	0.660**	0.000
	Crop reduction (b7)	0.655**	0.000
	Reducing the use of rangelands sub-products (b4)	0.550**	0.000
	Mortality and livestock reduction (b2)	0.464**	0.000
	Increasing treatment costs for local people's diseases (b5)	0.385**	0.000
Social consequences related to dust from the pastoralists' viewpoint	Increased tendency to migrate from village to city (d2)	0.630**	0.000
	Unemployment increase (d5)	0.615**	0.000
	Decreasing collaboration among people in rural activities (d7)	0.570**	0.000
	Reducing motivation among pastoralists (d3)	0.485**	0.000
	Reduced participation in rangeland restoration and rehabilitation projects (d1)	0.216**	0.004
	Increased strife and conflict among local people (d4)	0.210**	0.006
	Increased crime (d6)	0.155*	0.024
Environmental consequences related to dust from the pastoralists' viewpoint	Pollution of leaf area of plants and reduction of livestock grazing (c2)	0.671**	0.000
	Decrease in growth of grassland plants (c1)	0.660**	0.000
	Inappropriate ecotourism aspect of rangelands (c4)	0.655**	0.000
	Landscape change and destruction of the natural landscape (c3)	0.500**	0.000
	Decrease in palatability of grassland plants (c6)	0.424**	0.000
	Increased air pollution (c7)	0.412**	0.000
	Water and springs pollution (c5)	0.185*	0.021

*Significant at 5% level; **Significant at 1% level.
Source: Research findings.

EXHIBIT 5 Correlation between independent variables and the livelihood of pastoralists.

Factors affecting the livelihood of pastoralists	Spearman correlation coefficient "*r*"	P-value	Priority
Economic consequences related to dust from the pastoralists' viewpoint	0.909**	0.000	1
Social consequences related to dust from the pastoralists' viewpoint	0.900**	0.000	2
Environmental consequences related to dust from the pastoralists' viewpoint	0.706**	0.000	3

**Significant at 1% level.
Source: Research findings.

understandable consequences of dust storms. Furthermore, farmers expressed concerns regarding the far-reaching negative effects of dust storms on crop production and marketing, creating difficulties in selling their products. The following section delves into the economic, social, and environmental consequences of dust storms:

4.1 | Economic effects

The findings from the Kendall Tau-b Correlation Test revealed that the primary economic impact of dust on the livelihoods of pastoralists in the Chaqakdo region is a decline in livestock production.

EXHIBIT 6 Results of the path coefficients and *T* statistics.

Interaction paths of variables	Path coefficients	T stat.	P-value
Environmental-economic	0.987	149.280	0.000
Environment-livelihood	0.484	2.570	0.020
Environmental-social	0.881	40.136	0.000
Economic-livelihood	0.225	2.416	0.027
Social-livelihood	0.207	2.144	0.033

Source: Research findings.

According to pastoralists, the deposition of dust on vegetation leads to plant infections, resulting in reduced consumption by livestock. Given the low income levels of pastoralists in the area, who heavily rely on rangelands, they face challenges in affording supplemental forage such as alfalfa, barley, straw, and concentrate. Consequently, their livestock continue to graze on contaminated grasslands, ultimately leading to a decrease in livestock production. These results are consistent with the findings of Fang et al. (2018) and Morman and Plumeele (2013), who also observed that dust-related pollution negatively affects livestock health and productivity. Pastoralists further mentioned that domestic animals avoid consuming infected plants, which leads to malnutrition and a decrease in body size. To improve the livelihoods of pastoralists, it is recommended that government assistance be provided to facilitate the purchase of forage during periods of air pollution. Interestingly, these findings contradict the conclusions of Taheri et al. (2020), who suggested that the impact of dust on animal production is minimal, resulting in low livestock production losses.

4.2 | Social effects

Among the social consequences associated with dust storms, the strongest correlation with the livelihoods of pastoralists is the increased inclination towards migration from rural areas to urban centers. As livestock production declines and pastoralists are compelled to sell their livestock, they often choose to migrate to cities. Since their livelihoods are closely tied to livestock and rangelands, the contamination of grazing areas with microorganisms and subsequent reduction in grazing opportunities weaken their means of sustenance. Consequently, pastoralists are more inclined to seek employment in major cities, engaging in occupations such as construction, painting, travel, and security. These findings are consistent with the research conducted by Nie et al. (2017), Su et al. (2019), and Ullah et al. (2019), which demonstrated that sociological phenomena, including increased migration, unemployment, and addiction, are linked to dust storms. Rashki et al. (2012) and Ghaljahi et al. (2019) also highlighted the significance of dust storm sediments in the Zabol region, particularly their high salinity, leading to a wide range of social and economic effects that ultimately result in decreased agricultural and livestock production.

4.3 | Environmental effects

The results of the Kendall Tau-b correlation test revealed that environmental effects, such as leaf area pollution, reduction in livestock grazing, and diminished forage growth, exhibit the strongest correlation with the livelihoods of pastoralists. Dust pollution negatively impacts plant growth by obstructing light penetration to the leaf surface, leading to reduced photosynthesis (Gómez-Amo et al., 2019). These findings are consistent with the research conducted by Gómez-Amo et al. (2019), Prajapati (2012), and Zia-Khan et al. (2014). Some pastoralists have proposed the idea of storing enough forage in warehouses to ensure availability during times of need. Others have suggested that government support should be provided to facilitate the purchase of forage when plants are polluted by dust storms. However, Middleton's study (2018) indicated that various human activities, including logging, fire-use, urban development, road clearance, and intense domestic livestock grazing, can contribute to vegetation degradation and reduction in vegetation cover, potentially leading to increased wind erosion. The Spearman correlation results indicated that environmental factors associated with dust exhibit the strongest correlation with the livelihoods of pastoralists. Furthermore, the structural model results revealed that among the three independent variables, the environmental factors associated with dust exhibited the highest factor loadings. Additionally, the path factor (factor load) with the highest value was related to the path of environmental-economic factors, suggesting that environmental factors directly influence the livelihoods of pastoralists and have the strongest association with economic factors (factor value of 0.987). The pastoralists in the Chaqakdo area expressed their belief that the negative effects of dust on vegetation in the region have significantly impacted the livestock sector, ultimately reducing their income derived from rangelands. Rahim et al. (2018) and Fang et al. (2018) have also noted that unfavorable natural factors contribute to crop losses, decreased livestock activity, employment reduction, and increased poverty and unemployment. To mitigate these losses, some pastoralists have suggested the implementation of livestock insurance programs to compensate for livestock losses in case of perishing.

This study specifically focuses on assessing the impact of dust on livestock livelihoods, without investigating the quantity of dust present. As the primary occupation of most pastoralists in the area is livestock and their livelihoods are reliant on rangelands, it is recommended that relevant agencies take necessary measures, particularly

during days of heavy dust pollution, to ensure the provision of required forage. By doing so, the environmental impacts of dust on pastoralists' livelihoods can be mitigated, reducing vulnerability and minimizing the need for rural migrants to relocate to larger cities.

In this study, it is acknowledged that there may be some overlap or repeatability between indicators used. Specifically, the term "productivity" has different meanings in economics and ecology. However, in this research, the focus is primarily on "economic productivity," which refers to higher production levels achieved with a specific amount of input. This perspective may result in positive environmental externalities, such as reduced pollution. For instance, the pollution of plant leaf surfaces and reduced livestock grazing can hinder the growth of grassland plants. It is important to note that this study also examined socio-economic dimensions since the technical aspects of productivity were not widely understood by most participants, which represents one of the main limitations of the research.

5 | CONCLUSION

This study reveals significant environmental effects resulting from dust storms, including pollution of plant leaf area, reduced livestock grazing, and decreased growth of grassland plants. These effects have substantial economic and social implications for livestock farmers, as highlighted by the responses from pastoralists in the Chaqakdo pastures. The Spearman correlation coefficient analysis demonstrates a positive and significant relationship between livestock and the independent variables of environmental, economic, and social factors, with environmental factors related to dust exhibiting the highest correlation. The path coefficients obtained from the PLS intelligent software indicate that all three variables positively influence the dependent variable of pastoralists' livelihoods. These findings underscore the strong influence of environmental, economic, and social factors on pastoralists' livelihoods.

This study reveals significant environmental effects resulting from dust storms, including pollution of plant leaf area, reduced livestock grazing, and decreased growth of grassland plants. These effects have substantial economic and social implications for livestock

farmers, as highlighted by the responses from pastoralists in the Chaqakdo pastures.

Assessing the economic damage caused by dust storms plays a crucial role in policy development, particularly in the context of risk reduction. However, our study reveals a notable lack of comprehensive assessments of the economic losses attributed to dust storms, particularly in relation to transboundary impacts such as reduced crop yields, plant tissue loss, seedling burial, and increased soil erosion. It is essential to develop policies that address the broader effects of dust storms, with a specific focus on transboundary regions. Given the significant increase in wind erosion and dust storms worldwide, there is a pressing need for the widespread implementation of policies and practices aimed at mitigating these impacts. The study contributes valuable insights that can inform the development of policies to improve farmers' livelihoods and serve as a reference for reducing the socio-economic and environmental consequences of dust storms at regional and global levels.

While the study has provided important contributions, it also has limitations. The relatively small sample size and limited availability of medical history data for livestock pose constraints on the generalizability of the findings. Future studies should consider incorporating additional socioeconomic attributes, such as the economic status of herders' households, education and training of young herders, behavior of ethnic groups, and livestock diseases and malnutrition. Furthermore, exploring the role of new information technologies in shaping pastoralists' perspectives on dust storms and obtaining expert opinions from local state authorities could enrich future research. Additionally, it is essential to engage technical experts in conjunction with farmers to conduct more comprehensive studies on the impacts of dust storms. This study has generated practical information that can serve as a basis for formulating hypotheses and guiding follow-up studies.

While the study has provided important contributions, it also has limitations. The relatively small sample size and limited availability of medical history data for livestock pose constraints on the generalizability of the findings.

Considering that the livelihood of farmers in the study area is closely tied to the availability of pastures, it is imperative to create conditions that enable adaptation to dust storms. Currently, dust incidents pose significant biological and social challenges in the region, affecting various aspects of life and causing harmful effects on farmers' livelihoods. The current study underscores the need for government support and intervention to address the consequences of dust incidents, reduce the dependency of ranchers on rangelands, and explore alternative income-generating activities. Proper management of water resources, environmental protection, and the development of green spaces are crucial strategies to prevent dust incidents. Compensation for dust damage, better livestock insurance services, cultivation of dust-resistant forage in rangelands, and providing training for pastoralists on managing livestock in dusty conditions are also recommended. Furthermore, addressing the economic needs of rural communities through diverse job opportunities and income generation methods is essential for improving the living standards and economic security of pastoralists.

In future research, it is suggested to explore other sources of income for pastoralists beyond rangelands to gain a more comprehensive understanding of the impact of dust storms on their livelihoods. Collaborative studies involving rural sociologists can aid in identifying and defining the social problems faced by local communities. Lastly, ecologists should evaluate adaptable and resistant species to dust and encourage pastoralists to cultivate them. These recommendations can contribute to the development of holistic strategies and policies that enhance the resilience and well-being of pastoralist communities in dust-affected regions.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.