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Socioeconomic and Health Impacts of Dust Storms in Southwest Iran

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Abstract: Dust storms are frequent meteorological phenomena in the arid and semi-arid regions of Khuzestan province (KHP) in southwest Iran. These storms result in significant social and economic repercussions that extend beyond mere meteorological and climatic disturbances. Over the past decade, they have become the primary cause of substantial environmental and socio-economic damage in the region. In this study, we aim to assess the economic impacts of sand/dust storms (SDSs) on human health, agriculture (specifically Estamran dates), and migration in KHP. Our findings reveal the following economic consequences: Respiratory diseases incurred a financial loss of approximately USD 14 million, with more than 450 individuals requiring hospitalization at a cost exceeding USD 0.04 million between April and July 2022. In addition, cardiovascular diseases related to SDSs resulted in costs exceeding USD 1.9 million within the same time frame. Cities near the sources of dust storms experienced a cumulative damage cost of approximately USD 6.8 million. The local population in these cities also suffered more significant adverse effects compared to those in cities farther from the influence of dust storms in southwest Iran. We further evaluated the impact of SDSs on the quality of Estamran dates by analyzing 20 samples from key Estamran date production areas in KHP, including Ahvaz, Abadan, Khorramshahr, and Shadegan. The cost of damages (COD) in this sector was estimated at around USD 18.3 million, with Shadegan bearing the brunt of the loss at approximately USD 8.3 million. SDSs also have an important social economic impact due to deterioration of living conditions and migration in KHP. In total, the socio-economic costs of SDSs in these three sectors amounted to about USD 39 million. This is particularly concerning considering that Khuzestan province contributed 14.8% to Iran's Gross Domestic Product (GDP) in 2020, representing 50% of the economic output of southwestern provinces. Therefore, the current findings represent an alarming situation regarding the socio-economic impacts of dust storms in SW Iran.

Keywords: dust storm; economic issues; human health; migration; agriculture; southwest Iran

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1. Introduction

The Middle East is the second largest global dust source, and, unlike North Africa, a large part of the population lives in cities near deserts that are directly affected by dust storms, causing substantial damage to natural and human ecosystems [1–6]. Consequently, around 40 million people in this region, including populations in Iraq, Iran, Kuwait, Saudi Arabia, Qatar, Bahrain, and UAEs, are affected by dust source areas resulting from draining the water within the Mesopotamian Flood Plain and other watersheds and wetlands, as well as due to climate change [7,8]. During the past decade, southwest Iran, particularly Khuzestan province (KHP), has been affected by several intense dust storms and sandstorms (SDSs) [9,10]. Unfortunately, as a result of prolonged droughts, the mismanagement of water, excessive dam construction, and extensive damages from the Iran–Iraq War, SDS phenomena have become a challenging crisis in recent years [11–14]. Khuzestan province is Iran's petroleum hub and accounts for about 15% of the national GDP. This means that dust hazards could highly affect the province's economy and social affairs and, in turn, the country's economy. As a result, socio-economic instability and hydro-climatological drought in the Middle East and the Khuzestan region may exacerbate the land's susceptibility to SDSs [15–17].

Beyond the perturbations in weather, meteorological dynamics, and climate [18–20], several negative effects of sand/dust storms (SDSs) have been reported on the socio-economic life [21–23], human health, such as allergies, respiratory, and cardiovascular diseases and eye irritations [24–29], crime [30], agricultural production [31–33], transportation [34–36], sustainable energy production [23,37,38], migration, and societal changes [39–42]. SDSs not only cause respiratory diseases like asthma [43,44] but also negatively affect the entire community via effects on mental health [45]. In addition, they reduce horizontal visibility (1ess than 1000 m) and increase the number of road accidents (bodily damage/death) during severe dust storm events [46]. It has been reported that, over the past decade, the cost of damages (COD) caused by SDSs in southeastern Iran (Sistan region) was over USD 46.5 million, of which road transport accounted for the highest amount (66%). Dust deposition on the plant leaves also delays the plant's development, reduces the quality and quantity of agriculture production, and significantly increases pests in the dust clouds [31]. On the other hand, vulnerability to dust storms is determined by the soil characteristics, proximity to dust sources, particle size, physical and chemical dust properties, and wind erosion [47–49].

Although more than 77% of the members (total of 151) of the United Nations Convention to Combat Desertification (UNCCD) suffer from adverse impacts of dust storms [50], few studies have been conducted to assess the economic impact of SDSs on national or regional economies. Meanwhile, in some countries such as Iran, Iraq [51], China [52], the USA [53], and South Korea [21], the reported damages caused by SDSs were about USD 1000, 1400, 265, 9600, and 5600 million, respectively. Furthermore, the economic impact of dust storms on oil exports and aviation in Kuwait between 2001 and 2014 was estimated to be USD 9.36 million [54]. Although numerous studies have examined distinct characteristics (chemical, optical, physical) of dust storms in Khuzestan, SW Iran [9,55–60], only a few have dealt with the effects of dust storms in this province [61,62].

To mitigate the consequences and adverse impacts of dust storms on various aspects of human life and the environment, it is imperative to conduct risk assessments across socio-ecological and economic systems. Such assessments are of paramount importance in understanding the vulnerability and resilience of affected communities [63,64]. Despite KHP being one of the regions that are most severely impacted by dust storms in Iran [9,10,65] and experiencing significant detrimental effects on human health [66–68], the socio-economic impacts and costs of dust storms in the province remain inadequately documented. In this context, the present research aims to comprehensively examine the socio-economic effects of SDSs within three key economic sectors in Khuzestan province: (i) human health, (ii) agricultural production, and (iii) migration.

2. Study Area

Khuzestan province (KHP) is the fifth most populated province in Iran, located in the southwest edge of the country. The population of KHP is about 5 million, of whom 75.5% live in cities, while the remaining live in rural areas [69]. The province covers an area of 64,055 km^2, of which 40% is mountainous (Zagros) and 60% is flat terrain (Figure 1a). The primary rivers in the region are Karun and Karkheh, which originate from the Zagros Mountains and flow into the Howeizeh and Shedegan wetlands [70,71]. Climate in the plain is warm and dry; meanwhile, at higher elevations, a warm and semi-arid to semi-humid climate is dominant. The average annual temperature and precipitation are 26 °C and about 250 mm, respectively. The rainy season lasts from October to May, with 49% of precipitation falling between January and March (Figure 1b). The Arabian Sea, Persian Gulf, and the Mediterranean Sea are the main sources of moisture during the wet season [72,73]. Dusty days are very common during the dry season, especially from April to August (Figure 1b), while dust storms may occur throughout the year driven by different mechanisms (Shamal, pre-, and post-frontal dust storms) [10,74]. According to long-term observations, the prevailing wind pattern is from western and northwestern directions (Figure 1c), thus transporting dust mainly from the Iraqi plains [75,76].

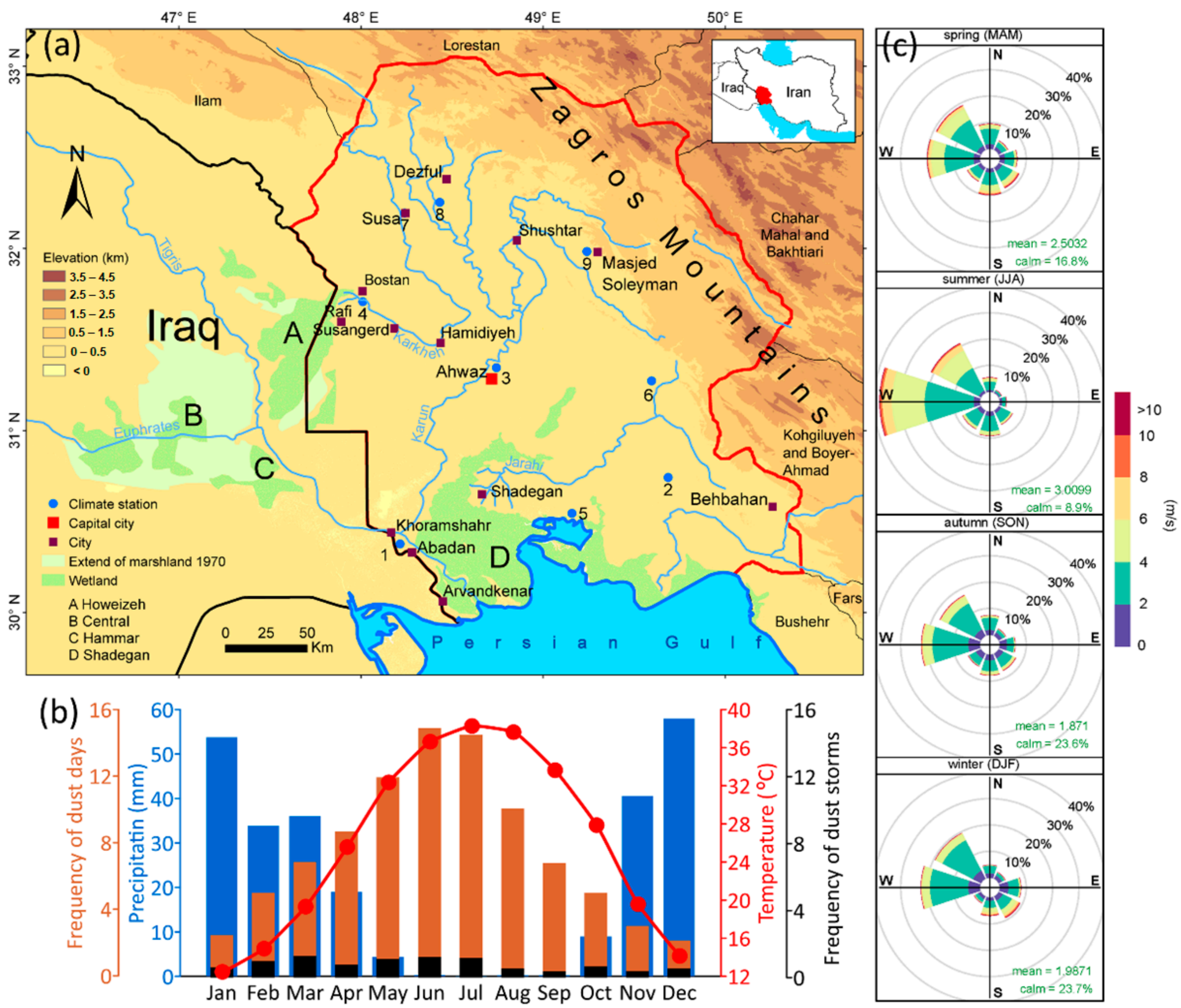

Figure 1. (**a**) Map of the Khuzestan province (separated by the red line) in southwest Iran. Wetlands (A, B, C) are adopted from Rekacewicz (2005), and other vectors are retrieved from Diva GIS portal. (**b**) Frequency of dust days (brown) and dust storms (black) (1963–2021), monthly precipitation (blue) and temperature (red) during the period (1951–2017). (**c**) The wind roses in Ahvaz synoptic meteorological station during the period 1990–2021.

3. Material and Methods

3.1. Data

For the objectives of this paper, multiple data were collected and analyzed in KHP spanning over different periods during the last four decades (1960–2020), regarding temperature changes, droughts, dust activity, population, Date Palm production, crude death, mortality of chronic respiratory (CRD), and cardiovascular diseases (CVD) (see Table 1). Data series of temperature were obtained from (https://psl.noaa.gov/, accessed on 23 December 2024), while those of the standardized precipitation evapotranspiration index (SPEI), which determines the drought, were collected from (https://spei.csic.es, accessed on 23 December 2024).

The population census data and crude death statistics were obtained from the Iran statistics center and civil registration organization (https://www.sabteahval.ir/, accessed on 23 December 2024). To reconstruct crude death data in the province before 2002, the

KHP's share of national crude death over the past 20 years was used. Data on CRD and CVD mortality in Iran during 1990–2019 were obtained from the World Health Organization (https://ncdportal.org, accessed on 23 December 2024), and the CRD and CVD mortality in KHP was estimated based on the province's share of the national crude mortality. The data for Iranian population aged above 65 years was obtained from (https://data.worldbank.org, accessed on 23 December 2024), and KHP's fraction was determined by its proportion to Iran's total population. It should be mentioned that the crude death data during 1994–1997 and 2006–2007 are unreliable due to the inclusion of past unregistered cases. A fitted linear model was used to reconstruct the omitted data of these periods. In addition, the production and the area under Date Palm cultivation in Iran and KHP during 1982–2021 were obtained from the Iranian Ministry of Agriculture (http://www.maj.ir/portal, accessed on 23 December 2024) and Food and Agriculture Organization (FAO) (https://www.fao.org/faostat/, accessed on 23 December 2024). Based on KHP's contribution to the country's Date Palm production over the last 20 years, Date Palm production for the years before 2001 was also estimated.

Table 1. Summary of data used in this study.

Type	Class	Usage	Period
Landsat satellites imagery	MSS, TM, ETM+, OLI	Howeizeh wetland surface	1990–2020
Meteorological data	Frequency of dust storms	visibility below 5000 m	1963–2021
Statistical data	Health	Respiratory diseases, cardiovascular patients	2017–2021
	Agricultural	Estamran date	1982–2021
	Migration	Population	2006–2016

3.2. Dust Storms Frequency and Wetland Surface Area

The main sources of SDSs in KHP are the drying wetlands along the Iraq–Iran borders (Figure 1a), the Iraqi plains, and the Syrian–Iraqi Desert [9,13]. We hypothesize that dust storms impact the cities in KHP, namely Ahvaz, Abadan, Khorramshahr, and Shadegan, which are major Estamran date production centers, due to a decrease in the water area in the Howizeh wetland. In this regard, we calculated the water surface area of the Howeizeh wetland using long-term time series imagery over the last three decades (1990–2020) from Landsat satellites (MSS, TM, ETM+, and OLI sensors) (http://earthexplorer.usgs.gov/, accessed on 23 December 2024). The necessary geodatabase infrastructure was generated inArcGIS 10.3, while 20 vector layers were extracted from satellite images. Observational data from the Khuzestan Meteorological Organization was used to calculate the monthly frequency of dust storms (visibility below 5000 m) during 1963–2021, classified as 1000 m, 1000–3000 m, and 3000–5000 m. Date Palm yield data (1997–2021) in Ahvaz, Abadan, Shadegan, and Khoramshahr were collected from (https://pbi.maj.ir/, accessed on 23 December 2024).

Principal component analysis (PCA) was employed to condense the data and identify the predominant patterns of variability (DPV). The input data included changes in surface water levels in the Howeizeh wetland, the seasonal frequency of dust events (DJF, MAM, JJA, SON), mortality rates for cardiovascular diseases (mCVD) and chronic respiratory diseases (mCRD), crude death rates, the fraction of the population aged 65 years and older (above 65), the total population of KHP, and the net migration. The PC scores with the highest eigenvalues were used to establish a connection between DPV and climate change in the region.

The analysis was conducted using R programming and involved the utilization of FactoMineR [77], factoextra [78], and missMDA [79] R packages. The missMDA package was specifically employed to impute missing data in the Howeizeh wetland, net migration, as well as any omitted crude death, CVD, and CRD data.

3.3. Socio-Economic Analysis

The estimated economic damages caused by SDSs in the three examined sectors of health, agriculture, and immigration were calculated in USD based on the following formula:

$$\mathrm{COD} = (\mathrm{Nd} \times \mathrm{CODR})\ \mathrm{i} \times \mathrm{AdvR}/\mathrm{Dvs} \quad (1)$$

In this formula, R is the reference currency, Nd is the number of damage, CODR is the number of damages in the currency of the specified country, AdvR is the average dollar exchange rate in the reference year, Dvs is the dust impact value in the sector, and i is the rate of inflation (if required).

3.3.1. Human Health Cost Analysis

The data of respiratory diseases for the period 2017–2021 were gathered and analyzed, as well as statistics of cardiovascular diseases (35 years and older) and deaths due to dust storms for the period 2020–2021. Related data were provided by the Jundishapur University of Medical Sciences in Ahvaz, Iran. Respiratory patients were divided into three age groups (<16, 16–65, >65 years), and the seasonal distribution of COD in 2020–2021 was calculated. In order to estimate the COD in the human health sector (COD_h), Equation (2) was used, where *NP* is the number of patients and *ACT* is the average cost of treatment [44,47].

$$COD_h = \frac{(NP \ \times ACT)^i}{Adv_R} \times 100 \quad (2)$$

$$COD_{hd} = \frac{(ND \ \times ACW)^i}{\mathrm{Adv}_R} \times 100 \quad (3)$$

More specifically, we also considered the COD_{hd} formula (Equation (3)) for estimating the cost of damages, when human death occurs from cardiovascular and respiratory diseases during dust storms. ND is the number of deaths and ACW is the average cost of wergild, according to Iran's Islamic Sharia laws; ACW costed USD 15,714 in 2020 and USD 16,400 in 2021. Due to the high hospitalization rates for respiratory diseases, this section also assesses the cost of absence from work in the active labor force (COD_{hl}) (Equation (4)).

$$\mathrm{COD_{hl}} = \frac{(\mathrm{Npl} \ \times \mathrm{ACS})^{\mathrm{i}}}{\mathrm{Adv_R}} \times 100 \quad (4)$$

Npl is the number of hospitalized working-age patients (16–65 years old) caused by dust. ACS is the average cost of one day's salary, which is between USD 3 and 3.5 in 2020–2021 (Ministry of Cooperatives, Labor and Social Welfare, Iran).

3.3.2. Agriculture Cost Analysis

Estamran dates are among the major agricultural products in KHP. This variety is planted in approximately 90% of the groves, covering more than 70% of the cultivated area [80]. Twenty Estamran date samples were collected during a dust storm on May 22, 2022. Ten intact Estamran (IE) and ten dusty Estamran (DE) samples were collected in Abadan. Equation (5) was used to estimate the COD incurred by SDSs on Estamran dates (COD_{Ed}).

$$COD_{Ed} = \frac{(E_{pr} \ \times \mathrm{Dv}_E)^i \times MP_t}{\mathrm{Adv}_R} \times 100 \quad (5)$$

E_{pr} is the production rate (Equation (6)) of the Estamran dates that was calculated for the four main Estamran Palm planting areas (Abadan, Ahvaz, Khorramshahr, Shadegan), D_{vE} is the dust impact value in the Estamran (Equation (7)), and MPt is the market price of the Estamran dates in a specified time frame. In addition, D_{vE} was determined by the difference in weight between the IE samples and DE samples:

$$E_{pr} = [(Ec \times EPd) \times APy \quad (6)$$

$$D_{vE} = (IEw - DEw)/Ws \quad (7)$$

E_C is the cultivated area (in hectares), EPd is the distance of the Estamran Palm (8 × 8 square meters), APy is the average yield of each tree in above mentioned regions, while Ws is the weight specified in [81].

3.3.3. Migration Cost Analysis

For the assessment of the migration cost, we compared population change data from Abadan, Rofaeh, Arvandkenar, Sosangerd, Bostan, Shadegan, and Hamedeh cities in KHP, along with cities located far from dust sources such as Ahvaz, Shush, Dezful, and Shushtar, aiming to examine the impact of dust storms on migration in KHP from 2006 to 2016 (available data). Based on three separate census periods, including 1996–2005, 2006–2010, and 2011–2016, the Statistics Center of Iran (SCI) collected migration data (entry/exit). Then, we calculated the COD of the migration sector (CODmig) as

$$COD_{mig} = \frac{(M_n \times Ac)^i \times Dv_{mig}}{Adv_R} \times 100 \quad (8)$$

Mn represents the number of incoming and outgoing immigrants, and Ac represents the average cost of immigration per person in developing countries. It is approximately USD 390 per person, according to [82]. The dust impact coefficient on migration is denoted by Dvmig. According to the IOM (International Organization for Migration), drought is responsible for 12% of household migration in Iraq [83]. In this study, we also used 12% as Dvmig, since the environmental conditions in KHP are very similar to those in Iraq because of the proximity of these areas. Figure 2 shows the flow chart of the methodology and the different datasets used in this study.

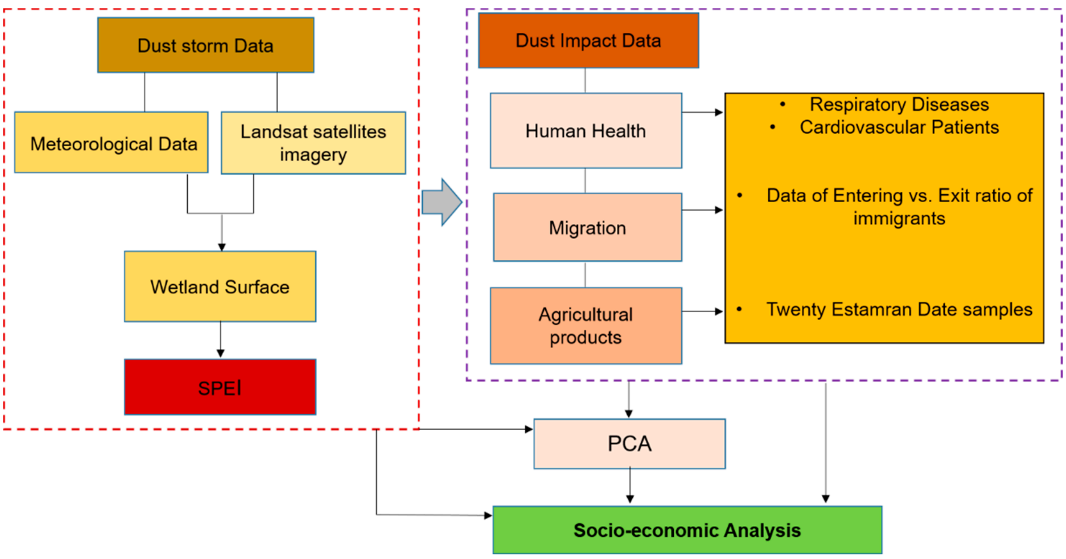

Figure 2. Flow chart of the multiple datasets and methodology used in this study.

4. Results

4.1. Dust Frequency

Two key findings emerged from the analysis of observational data. In the first case, the effects of regional socio-political instability are reflected by a significant increase in dust frequency during the Iran–Iraq war (1980–1988), Iraq's invasion in Kuwait (1990–1991), and the United States' occupation of Iraq (2003–2011), as also stated elsewhere [84] (Figure 3). The second finding is related to the significant warming in the Middle East region during the last three decades, especially after 2000 (Figure 3a), favoring prolonged droughts and desertification [85–87]. It has been reported that sources of dust in Khuzestan include neighboring countries (Iraq, Syria, and Saudi Arabia), as well as local sources, i.e., Khuzestan desert plains and the dried Howeizeh wetland, because of climate change, dam construction, and the increased demand for irrigation [9,60,88–90] (Table 2). Table 3 includes the monthly data of SDS occurrence at meteorological stations in KHP (present study), along with those in neighboring areas, based on observational data and different techniques and criteria for the detection of dust events. So, the main finding is the large frequency of dust events in KHP, which maximizes during the spring and summer months (May to July), in accordance with the monthly variation in dust activity in Kuwait [91]. Long-term analysis and more details about the dust activity in KHP have been documented in previous studies [9,10,92,93]; however, this is beyond the scope of the present work.

The last two decades have been characterized by an increase in moisture deficit in the region and a significant decrease in the water surface area of the Howeizeh wetland (Figure 3b). It is noteworthy that the water area in the Howeizeh wetland has decreased since 2008, mainly due to oil extraction and dam construction projects [56,59], while a dramatic increase in dust activity was observed along the Iraqi plains and KHP during the period 2008–2012 (Figure 3c), following a drought shift in the Fertile Crescent in Iraq [10,85]. Furthermore, the increase in the population of the KHP was associated with an increase in the intensity of the region's moisture deficit, freshwater consumption, and drought conditions (Figure 3b).

In addition, the region's warming trend over the last three decades (Figure 3a) has introduced increasing trends in dust frequency during winter and spring seasons [94,95], whereas the dust frequency started declining after 2012, but remained at higher levels compared to that before the 2000s (Figure 3c). A comprehensive review on climate change in Iran carried out by [96] reported that the mean annual temperature has significantly increased by 0.3 °C/decade, and the annual precipitation decreased monotonically with a mean rate of −7 mm/decade over the last 50 years. Results from several studies showed that abrupt changes in the temperature time series have been happening since the 1970s and 1990s. The ascending trend in temperature is mostly the result of a significant warming trend with different rates in annual Tmin in different parts of the country, i.e., [97–100]. Over the past few decades, climate change in Iran has aligned with the anticipated future conditions for the entire Middle East. This has resulted in various adverse impacts on people's lives, socio-economic activities, ecosystems, and water management. [17,101].

Table 2. Internal and external dust sources affecting Khuzestan plain.

Source	Region	Reference
Local	Howeizeh wetland	Malamiri et al. [59]
	East Zohreh and East Jarrahi sabkha	Rashki et al. (2021) [5]/Abyat et al. (2019) [102]
	Malhe playa	Heidarian et al. (2018) [73]
	Gofer dry land	Malamiri et al. (2022) [6]
	Shlamcheh/Khoramshar desert	Broomandi et al. (2017) [56]
External	Iraq	Zarasvandi et al. (2011) [56]

Kuwait	Hamzeh et al. (2021) [13]
Arabian Peninsula	Hamzeh et al. (2021) [10]
Syria	Salmabadi et al. (2020) [9]
Jordan	Salmabadi et al. (2020) [9]

Table 3. Average annual and monthly frequency of dust events in a regional scale.

Location	Reference	Monitoring Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total SDS
West Iran	Present study	18	0.5	3.2	5.2	4.9	7.8	8.5	7.1	2.2	2.2	1.1	0.4	0.4	43.5
Kuwait	Alshemmari et al. 2013 [91]	19	0.9	1.4	2.1	3.3	3.7	4.5	4.6	1.9	0.6	1.4	0.3	1.1	25.8
Bahrain	Al-Dousari et al. 2020 [20]	33	0.1	0.3	0.5	0.6	0.5	1.4	1.5	0.2	0.3	0	0.1	0.1	5.6
Qatar	Subramaniam et al. 2015 [12]	15	0.4	0.5	0.7	0.7	0.4	1.7	1.4	0.2	0.1	0.3	0.4	0.1	7.1
Abu Dhabi	Al-Ghadban et al. 1999 [11]	6	0.4	0.3	0.6	0.1	0.4	0.4	0.7	0	0.1	0	0.2	0.7	3.9

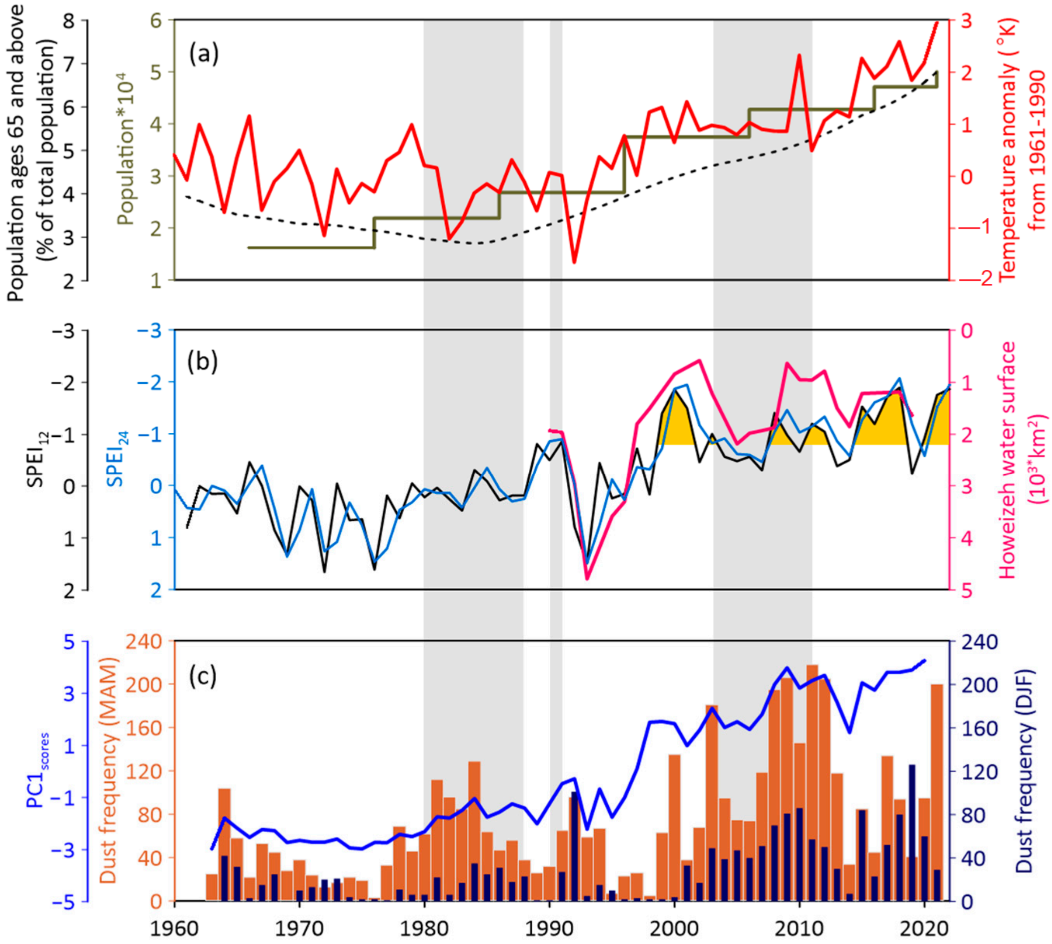

Figure 3. (**a**) Monthly anomaly of the HadCRUT5 2 m air temperature (red) (https://psl.noaa.gov/, accessed on 23 December 2024), step line of population data (olive), along with the percentage of population aged 65 years and above (dashed black) in KHP. The population number in 2021 was estimated based on the population growth rate during 1996–2016. (**b**) The standardized precipitation evapotranspiration index annual timeseries (SPEI12and24) (black and smalt blue), for which data below near normal moisture are highlighted with yellow color, and Howeizeh wetland water surface area (neon red). (**c**) Observations of dust frequency (in bar plots) in spring (red brown) and winter (dark navey blue) in Ahvaz station (1963–2022). The blue line is PC1scores. The gray areas depict the Iran–Iraq war (1980–1988), Iraq invasion in Kuwait (1990–1991), and US occupation of Iraq (2003–2011).

The analysis of the principal components revealed that the first two PCs explain approximately 76% of the data variance. PC1 is responsible for about 57.3% of the variance of all data (Figure 4). Population-related parameters exhibit a strong connection with PC1; however, the water surface area of Howeizeh wetland exhibits a negative correlation with PC1. Winter and spring dust events both exhibit a moderate connection to PC1, whereas summer and fall dust frequencies are mostly connected to PC2. Finally, migration is negatively connected to PC2, but this correlation is moderate.

The results of the simple linear regression indicated that the SPEI24 and SPEI12 explained 67% and 59% of the variation in PC1scores [$F(1,57) = 119.1$, $p = 1.391 \times 10^{-15}$; $F(1,57) = 81.9$, $p = 1.28 \times 10^{-12}$], respectively. These results were statistically significant at the 99th confidence level ($p < 0.01$). The strong negative (positive) association of the water surface area (frequency of dust in spring and winter) in the PC1 led us to suggest that the decline in water coverage in the Howeizeh wetland was one of the factors contributing to the increase in the frequency of dust storms in spring and winter over Khuzestan, as was also reported by [58,102]. In addition, [103] highlighted the Howeizeh marshes as the main SDS local source area in southwestern Iran. In a similar way, previous studies [5,102] have indicated that the desiccation of the Hamoun lakes played a significant role in the dust activity in Sistan, east Iran.

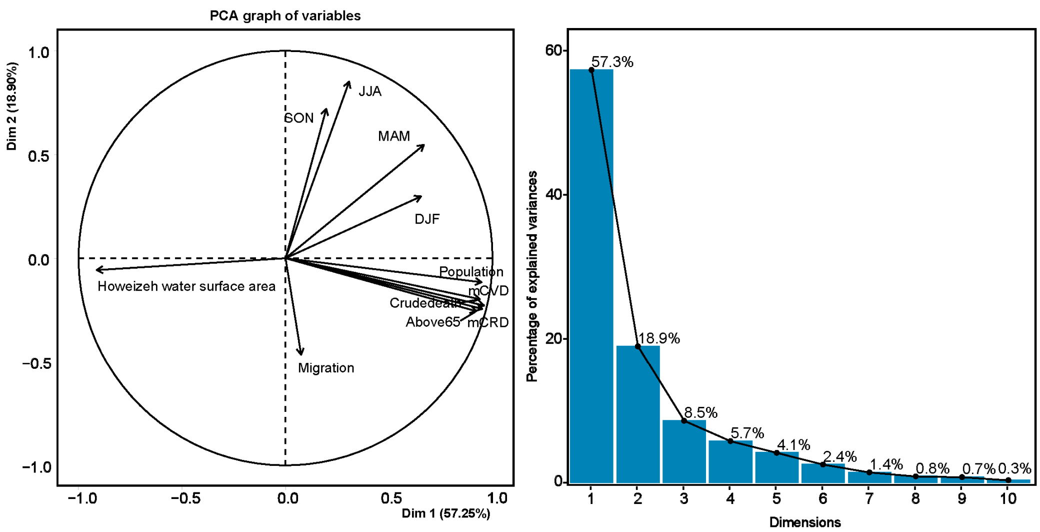

Figure 4. (**left panel**) The PCA graph of variables for the first and second principal components (PCs) or dimensions (Dim); (**right panel**) the scree-plot displaying the distribution of explained variance across all PCs.

4.2. Socio-Economic Impacts

The economic effects of dust on the global economy have not been comprehensively studied, and the analyses have focused more on the local (national) economies. SDSs in various regions of the world have diverse economic and social effects depending on the vulnerability of the country, the economic indices, exposed population density, etc., [1,104,105]. Frequent and severe SDSs could lead to poverty, damage to the agricultural economy, the overwhelming of the health system, tourism interruptions, disruptions of the transportation system (road, rail, and aviation), decreases in the performance of organizations, and the closing of schools and universities [9,46,106]. Ref. [107] reported that a daily increase of 10 $\mu g\ m^{-3}$ in the coarse particle ($PM_{10–2.5}$) concentrations during Saharan dust days in Barcelona, Spain, increased the daily mortality by 8.4% (95% confidence interval: 1.5–15.8%). In the Middle East and North Africa (MENA) region and southwest Asian (SWA) countries, there are some estimates showing that the economy is subjected of shrinking by about USD 13 billion because of dust storms every year [108]. The estimated economic costs and the main impacts on economy sectors caused by SDSs in different parts of the MENA region are summarized in Table 4, while other studies reported high economic costs for the removal of dust and sand from buildings and infrastructure in Middle Eastern countries [34,109,110].

Table 4. Economic damage cost of dust storms in Iran and other countries in the MENA region.

Region	Cost (USD)	Impacts	Reference
MENA	13 billion		UNEP et al. [108]
Kuwait	824,311 per oil tanker 28,180 daily tactical airline	Oil exports, delays in air travel, traffic accident,	Al-Hemoud et al. (2019) [54]
Iraq	1.4 < million	Health, transportation, agriculture	Meibodi et al. (2015) [44]
Iran	1 < million	Health, transportation, agriculture	Meibodi et al. (2015) [44]
Khuzestan (southwest) Sistan and Baluchistan (southeast) Kermanshah (west) Illam (west) South Khorasan (northeast) Hormozgan (southwest)	375 million 250 million 105 million 44 million 69 million 125 million	Health, transportation, agriculture, closure of educational centers, industries, power outages, families	Iran Environment protection office (2020) [111]
Yazd (central)	6.8 million	Cleaning, health, electronics, car accidents, airline delay, signs, posts, irrigation	Ekhtesasi and Sepehr (2009) [104]
Ardakan (central)	~8.1 million	Treatment, agriculture, air pollution, animal husbandry	Qanavati et al. (2018) [105]
Zabol (southeast)	99.1 million	Physical damage and loss of production	Pahlavanravi et al. (2012) [32]
Khuzestan	~39 million	Agriculture	Yazdani et al. (2024) [106]

4.2.1. Human Health

The KHP population, crude death, and mortality rate of CRD and CVD showed strong positive associations with PC1 (Figure 4). During the initial three decades, from 1960 to 1990, the crude death rate was around 110 people per year, but between 1990 and 2021, this tripled to 330 people per year, coinciding with the increasing aridity and dust activity in the region since 1990 (Figure 3a,b). Estimated CVD and CRD mortality rates in KHP indicated an increase of 40% and 70%, respectively, between 2000 and 2019 (Figure 5a).

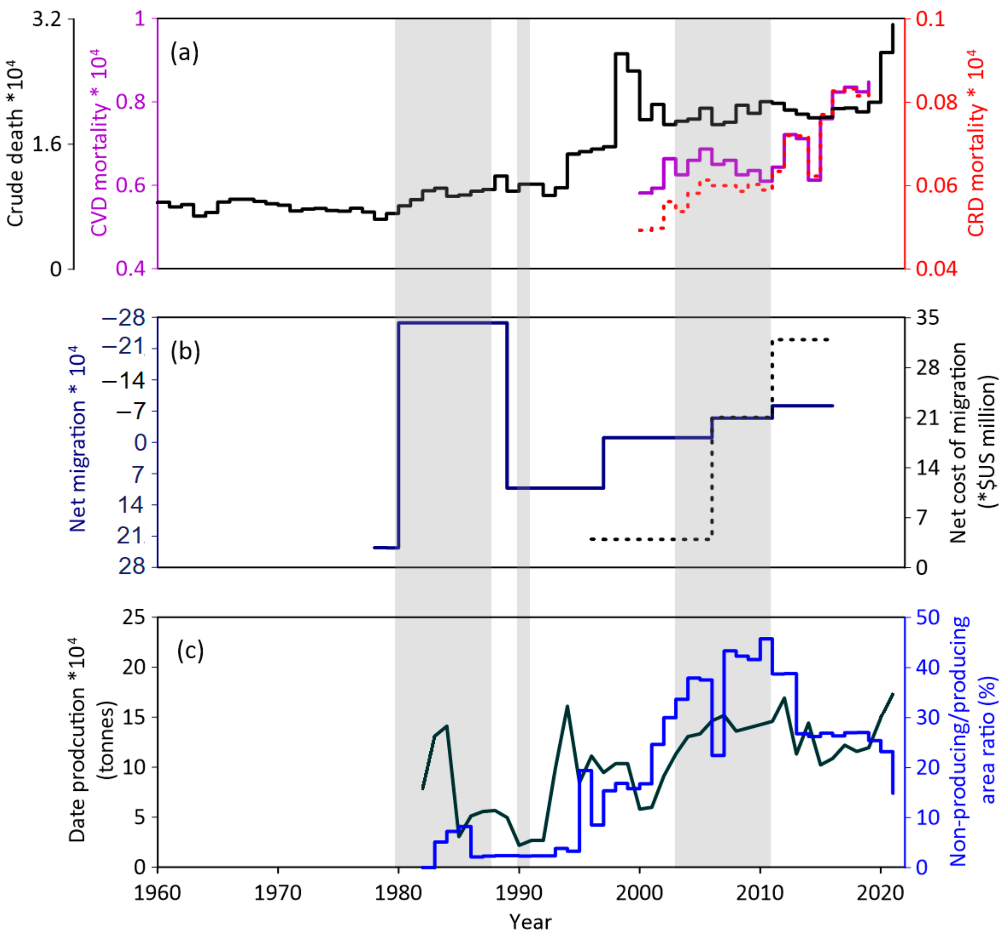

Figure 5. (**a**) Step plot of recorded (2002–2021) and estimated (1960–2002) crude death in KHP (black), mortality of CVD (purple) and CRD (red). (**b**) Step plot of net migration (1978–2016) (dark blue) and estimated cost of migration (1996–2016) (dashed black line). (**c**) Line plot of recorded (1982–2021) date production (dark green) and ratio of non-producing to producing area (blue). Gray bars are similar to Figure 2.

The inhalation exposure to dust aerosols and the related health effects are sensitive to several factors like the dust chemical composition and adhesion of potential toxic elements (PTEs), the dust particle size and shape, the duration of exposure, and the physiological (lung and immune system) characteristics of a person [112]. Airborne dust particles in Saudi Arabia and Iraq were found to contain aeroallergens, fungal spores, antigens, and organic detritus, which may cause a variety of allergies and respiratory diseases [113,114]. Furthermore, several human pathogens like Bacillus, Brucella, Coxiella, and Mycobacterium can be adhered to and transported with dust, as was also found in Iraq and Kuwait [115]. In this work, the respiratory (asthma) patients during dust events, analyzed according to age and season in 2020 and 2021, revealed that the number of patients increased during the warm season (Figure 6a,b). The economic-active population group (16–65 age) exhibited the highest number of hospital visits in 2020 and 2021 (814 and 683 persons, respectively). The total COD_h for a one-day absence from work caused by a respiratory illness was approximately USD 15,000 (COD_{hl} = USD 8000 in 2020 and USD 7000 in 2021) (Table 5). During 2017–2021, the number of respiratory disease cases has dramatically increased in KHP. The highest number of cases (10,948 people) reported in 2019. During this course, COD_h was calculated at around USD 1.9 million (Figure 6c). Also, a positive association was found between dust concentrations and hospital emergency room patients from April to July 2022, since the highest dust concentrations on 18 and 22 May were closely followed by increased cases of respiratory patients (Figure 6d). During this time period, 7901 people visited hospitals with respiratory problems and symptoms in KHP, and approximately 450 people were hospitalized, with an estimated COD_h at about USD 40,000. In this respect, ref. [116] analyzed the time series of dust storm events, along with daily emergency hospital admissions for asthma and respiratory diseases in Kuwait, spanning for a period of 5 years. They found a statistically significant association between dust storm events (~34% of total days) and hospital admissions for asthma and respiratory issues at the same day, which was notably higher for children.

Table 5. Number of deaths due to respiratory diseases with estimated COD_{hd} and COD_{hl} in KHP in 2020/2021.

Season	Respiratory (Death)		COD_{hd} (USD ×1000)		COD_{hl} (USD×1000)	
	2020	2021	2020	2021	2020	2021
Spring	8	5	125.7	82	2.44	1.97
summer	14	11	219.9	180.4	1.82	2.41
Autumn	4	4	62.8	65.6	1.67	1.45
Winter	8	7	125.7	114.8	1.94	1
Total	34	27	534.1	442.8	7.87	6.92

Overall, KHP faced a COD_{hd} of approximately USD 4.4 to USD 5.3 million for cardiovascular diseases between 2020 and 2021 (Table 6). The results of the cardiovascular damage (for people over 35 years old) showed that the winter and summer seasons had the highest number of cases (646 in 2020 and 841 in 2021) and, consequently, the highest COD_h (USD 0.22 in 2020 and USD 0.34 million in 2021). In general, during 2020–2021, dust-related COD_h in KHP was more than USD 1.9 million. Deaths from cardiovascular diseases were higher during summer (85 in 2020 and 104 in 2021), followed by winter and spring.

Table 6. Number of cardiovascular patients and deaths of cardiovascular sickness, along with COD_h and COD_{hd} (above 35 years old) in KHP in 2020/2021.

Season	Cardiovascular (35 ≤ Old)		Cost of Cardiovascular USD*1000		Cardiovascular (Death)		Cost of Cardiovascular (Death) USD*Million	
	2020	2021	2020	2021	2020	2021	2020	2021
spring	500	528	172.14	214	64	71	1	1.1
summer	633	841	217.93	340.9	85	104	1.3	1.7
autumn	554	670	190.73	271.64	54	58	0.848	0.951
winter	646	700	222.40	283.80	64	75	1	1.2
Total	2333	2739	803.2	1110.34	267	308	4.148	4951

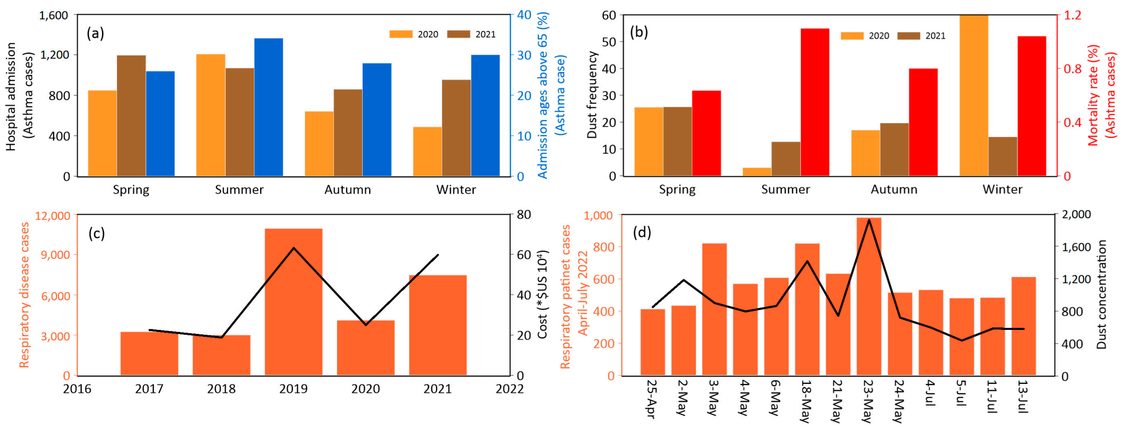

Figure 6. (**a**) Bar plot of seasonal asthma-related hospital admissions in 2020 and 2021 (orange and brown), along with percent of admissions for ages above 65 (smalt blue) in Ahvaz. (**b**) Bar plot of seasonal dust frequency in 2020 and 2021 (orange and brown) and reported rate of mortality in asthma patients (red). (**c**) Bar plot of annual respiratory diseases cases and related damage cost (COD_h) (orange) in KHP during 2017–2021. (**d**) Number of respiratory patients who visited the hospital emergency in Ahvaz in dusty days of April–July 2022 (orange), associated with line plot of dust concentration (in μg m^{-3}) (black).

4.2.2. Migration

KHP was an open province for immigrants before the Iran–Iraq war (1980–1988), which caused massive emigration [117]. Towns of Abadan and Khorramshahr were highly drained from population (Figure 5b). After the war, due to the strategic importance of the province, immigration increased during 1989–1996 and the large city of Ahvaz was formed, along with a large number of smaller cities contributing to the increase in the KHP population [118]. Since 1996, the region has also experienced an increase in dust frequency and an intensification of the drought; since then, the immigration face has been replaced by a slow emigration rate (Figure 5b), and in the mean time, the KHP's population has been steadily increasing since 1990 (Figure 3a).

Migration exhibited a weak negative correlation with PC2, but no association with PC1 (Figure 4). Also, PC2 scores revealed no link with the SPEI or temperature anomalies in the KHP area. Likely, dust has a negative effect on net migration, to some extent. In other words, factors other than droughts and dust played an indirect role in net migration. Because the abundance of dust in the summer season is strongly related to this PC, a seasonal migration just to avoid the heat and dust in this season may be a likely scenario as well. However, increased spring and winter dust [95] has accelerated migration in recent years (Figure 5b).

The analysis of the economic impacts of migration revealed that during 2006–2016, about 135,831 people emigrated, which is about 13 times higher than that during 1996–2005. Both decades were characterized by increases in aridity in KHP (Figure 3b), while the dust frequency during 2006–2016 was higher compared to 1996–2005 (Figure 3c). Our estimates show that between 1996 and 2016, the total migration damage cost (COD_{mig}) in KHP exceeded USD 6.8 million (Table 7). Due to climate change impacts (increase in temperature and drought) and several human activities that deteriorate the environment and quality of life in SW Iran, more people leave than enter the Khuzestan Provide. This wave of emigration away from the province progressively increased from 1996–2005 to 2011–2016, as the balance of immigrants increased from about 10 to 146 thousand (Table 7), indicating that people are pessimistic about future living conditions and the worsening quality of life (economic, social, etc.) in Khuzestan. Furthermore, a linear regression with $R^2 = 0.99$ was established between immigration variance and the total cost of migration damage.

Table 7. Data of entering vs. exit ratio of immigrants in three censuses periods with the amount of CODmig in Khuzestan province.

Census	Enter	Exit	Immigration Variance	Cost of Migration Damage (USD*Million)
1996–2005	58,854	69,025	−10,171	0.476
2006–2010	60,521	114,493	−53,972	2.5
2011–2016	53,632	135,491	−81,859	3.8
Total	173,007	319,009	−146,002	6.576

4.2.3. Agricultural Products

Dust deposition on plants was recognized to affect many of their physiological processes, such as weakening photosynthesis, a loss of chlorophyll, decreases in stomata conductance, a loss of plant tissue due to sandblasting, the possible deposition of PTEs, among others [119–122]. In addition, wind erosion and SDS emissions reduce soil fertility through the removal of soil particles that are rich in nutrients and organic matter, thus contributing to desertification [123]. Climate change and natural hazards cause immense vulnerability in different dimensions of the agricultural part and, therefore, food production [124,125]. The significant dependence of rural economy and livelihoods of farmers on agricultural activities in Iran has escalated the vulnerability to natural hazards, particularly droughts and dust storms [126–129].

The date, or the tree of life, is a backbone of rural subsistence agriculture in most of the arid/desert lands in the MENA region [130,131]. KHP contributes approximately 14% to Iran's date production, which is concentrated by 85% in the Abadan and Shadegan districts. The date production in KHP has followed two major trends over the last four decades, since it decreased prior to 1990 and then reversed. In the mean time, the ratio of non-producing to yielding areas increased from about 5% in 1990 to 50% in 2010, and then dropped to around 30% (Figure 5c). The ratio of non-producing to date yielding areas showed a moderate correlation with PC1. The results of the linear regression showed that the PC1 explains about 60% of the variation in this ratio [$F(1,38) = 56.81$, $p = 4.668 \times 10^{-9}$], with the results being statistically significant at the $p < 0.01$ level.

Since 1990, the KHP has experienced an increase in date output, as a result of rising minimum temperatures and the growing aridity in the area. The KHP's booming business sector has been offset by the downward trend in the water surface of the Howeizeh wetland, rising dust frequency, and all associated environmental problems. We consider the production of agricultural products to be a process in which labor, particularly in the rural economy, plays a crucial role. As stated in the methodology section, the SDS impact on the quality of the Estamran dates was studied by analyzing 20 date samples at different production regions in the KHP. The total cost of damages (COD) was estimated at about USD 18.3 million, while the Shadegan district contributed most to this damage cost (with an amount of about USD 8.3 million) due to higher date production. We contend that the production of dates contributes a negligible beneficial contribution to the region's economy and that both migration and mortality are having a detrimental effect on the workforce in rural areas. Therefore, we may conclude that the region's agricultural products are primarily impacted by the total harms brought on by migration and human loss. A previous study [132] reported that the income of farmers in Iran decreased by about USD 0.36 in irrigated agricultural lands and by USD 0.08 in rainfed lands, per hectare, due to increases in dust events, thus increasing the concern of farmers on disastrous natural phenomena such as SDSs. The estimated total annual cost of the dust damage to the agriculture sector in KHP is about USD 39 million, while the whole cost of the dust damages to province's economy is up to USD 375 million (Table 4).

5. Discussion

Apart from the estimated SDS-related damage costs in the three economic sectors of public health, migration, and agriculture in KHP that are analyzed here, the economic impacts of dust storms may also include other sectors like aviation, transportation, the closing of organizations, shops, etc. As reported by [133], 232 and 172 flights were canceled in 2008 and 2009, respectively, in KHP, due to a high reduction in visibility as a direct consequence of increased dust events. The cancelation of flights, disturbances in airport operations, mechanical failures in aircraft turbines, and possible passenger compensations all contribute to high costs in the aviation sector. Furthermore, in 2008 and

2009, due to increased dust activity in Khuzestan and in all of SW Iran [10], increased road accidents were also reported, highlighting the role of dust storms in poor visibility.

The good association between PC1scores and the SPEI indicated that droughts and population growth have likely increased the frequency of dust events in winter and spring over the last 20 years (Figure 3b,c). Furthermore, the relationship between droughts and crude death in KHP showed that the increase in temperature or in the severity of drought exhibited a positive trend in the increase in annual mortality, while the difference in dust frequency between wet and dry years is intriguing. As a result of several wars and political conflicts in the Middle East region, the dust frequency in KHP increased due to human and military intervention, leading to land degradation and the deterioration of environment [133].

We suggest that increasing aridity associated with long periods of unrest in the region has increased dust frequency. It has been reported that dust storms have significantly increased asthma attacks, cardiovascular diseases, and associated costs, particularly among children and the elderly, in different parts of the globe [112,134–138]. Also taking into consideration the lack of economic development and poverty [139,140], an aging population, and long-term exposure to high temperatures, particularly in summer, that increase the heat stress, e.g., [17,141,142], the increasing dust activity has contributed to an increase in CVD hospitalization and mortality. As a result, CVD and CRD have recently emerged as major causes of mortality in the elderly and premature population in KHP, which are strongly related with dust weather.

Several factors have contributed to Khuzestan's higher unemployment rate and poverty over the years, including an increasing population [143], a lack of economic development [144,145], and harsh climatic conditions. Previous studies [146,147] reported that unemployment, low income, and climate change were the main reasons for emigration from villages to cities or from KHP to other provinces during 2006–2016. Because of the high vulnerability of KHP to desertification [148,149], it is likely that drought intensification and population growth in the province have significantly decreased wetlands and vegetation areas, while desertification due to climate change has also been accelerated. Furthermore, as a result of mismanagement and socio-political unrest in the neighboring regions, desertification in the province's western parts has increased, and this area has since become a dust source [148,150].

Therefore, during the last two decades, desertification not only has amplified dust storms in the KHP but has also resulted in poverty and unemployment, a phenomenon that accelerated the immigration. It is worth noting that desertification and the mismanagement of water resources is a result of poverty and the lack of economic development on the one hand, while its outcomes aggravate poverty on the other [151]. In general, climate change and its economic and social consequences may be sufficient reasons for the recent decade's migration from southwest Iran [152]. McLeman [40] and Wu et al. [153] believe that human migration is a normal behavior during severe environmental challenges. However, ascribing migration from KHP to the dust frequency requires extensive census data, especially when censuses are not conducted continuously. We suggest that in the past few decades, climate change has likely exacerbated desertification and indirectly exacerbated dust storms in the KHP, which, in turn, have increased immigration.

Since the 1990s, there has been an upward trend in date production, which coincided with a positive temperature anomaly in KHP. The date can grow even in the absence of rain and withstand high temperatures during summer [130]. The date harvest has increased due to warmer conditions and, of course, due to population growth and more working hands since the 1990s in KHP. The date crop showed a stable trend until 2010, but it has been gradually declining since then, posing a significant threat to the region's rural economy. The main reasons for the decrease in date production during this period (after ~2010) can be attributed to extensive dam construction and a decrease in the level and quality of groundwater [154], while the large increase in dust activity during 2008–2012 [10] may also contribute to the decreased date production that occurred in the following years. As date crop production is centered in rural areas, the increase in date production might be a positive sign of development for the unstable rural economy, but it is a warning sign triggered by the recent droughts. The latter is a major driver of migration from villages to larger cities in the province, also posing a long-term threat to the region's ecosystem and excessive poverty.

The environmental issue of land degradation and desertification in the Middle East is especially important and is projected to be exacerbated by climate change in the coming decades [17,92]. The expected increase in air temperature beyond the current increase of about 1.5 °C, the decline in precipitation, and the higher intensity and frequency of droughts and dust storms will significantly affect the natural and artificial ecosystems, thus contributing further to land deterioration, biodiversity loss, the intensification of desertification, socio-economic damages, and increased costs of resilience and adaptation [101,155,156]. Although dust is the dominant component of air pollution in the Khuzestan province, urban/anthropogenic emissions due to petrochemical industries, oil refineries, power plants, traffic, and any combustion process highly contribute to the deterioration of air quality in this area [6,9]. Therefore, mitigation strategies and actions are needed at least from local authorities to limit the urban emissions that greatly contribute to atmospheric deterioration and hospitalization costs, as also observed in megacities across the globe [157,158]. The current analysis provides useful insights for policymakers and local authorities, as well as a scientific basis for mitigation strategies to meet the United Nations Sustainable Development Goals (SDGs) for resilient cities, better lifetimes, and less costs for health impacts.

6. Conclusions

Khuzestan province in southwest Iran has suffered from significant economic and social damages caused by the dust and sand storms. Multiple statistical data were used to calculate the cost effects of dust (COD) on health, agriculture, and migration. Current results indicated a positive relationship between the frequency of dust occurrence and economic losses. COD amounts were estimated to be around USD 39 million in the three sectors. Using data analysis, the health COD was approximately 14 million between 2017 and 2021. The economic-active population group (16–65 years) exhibited the highest number of respiratory patients, and the highest cost, during summer. Over USD 1.9 million was spent on damages associated with dust-related cardiovascular patients in 2020 and 2021. In addition, migration data analysis revealed that dust caused a loss of USD 6.8 million and ethnic changes in the Khuzestan province between 2006 and 2016. Last but not least, we believe that dust contributed to a significant loss for farmers in the Estamarn date harvest (COD_{Ed} = USD 18.3 million).

Droughts in recent decades have caused irreparable damage in southwest Iran. The region's ecosystem has been deteriorated by the lack of economic development, poverty, as well as an increase in urban population. Political and social unrest in the western neighbor (Iraq) has also hastened desertification in recent decades. An obvious consequence of this phenomenon is an increase in the frequency of dust activity, even during the cold season, which contributed to short- and long-term threats to the cardiovascular health and economic wealth of the region's residents. Desertification-induced poverty has also accelerated the migration process over time. Overall, dust storms constitute a major economic loss for Khuzestan province, and the future climatic projections of increased temperatures and decreased moisture and precipitation over the Middle East will be a real threat to the province's and nation's economy. Regional scientific cooperation and land-restoration projects are the real solutions to controlling the main source areas of dust and reducing its socioeconomic effects.

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References

1. Goudie, A.S. Desert dust and human health disorders. *Environ. Int.* **2014**, *63*, 101–113.
2. Doronzo, D.M.; Al-Dousari, A.M.; Folch, A.; Waldhauserova, P.D. Preface to the Dust Topical Collection. *Arab. J. Geosci.* **2016**, *9*, 468. https://doi.org/10.1007/s12517-016-2504-9.
3. Doronzo, D.M.; Al-Dousari, A. Preface to dust events in the environment. *Sustainability* **2019**, *11*, 628.
4. Soleimani, Z.; Teymouri, P.; Darvishi-Boloorani, A.; Mesdaghini, A.; Middleton, N.; Griffin, D.W. An overview of bioaerosol load and health impacts associated with dust storms: A focus on the Middle East. *Atmos. Environ.* **2020**, *223*, 117187. https://doi.org/10.1016/j.atmosenv.2019.117187.
5. Rashki, A.; Middleton, N.; Goudie, A. Dust storms in Iran—Distribution, causes, frequencies and impacts. *Aeolian Res.* **2021**, *48*, 100655.
6. Malamiri, N.; Rashki, A.; Hosseinzadeh, S.R.; Kaskaoutis, D.G. Mineralogical, geochemical, and textural characteristics of soil and airborne samples during dust storms in Khuzestan, southwest Iran. *Chemosphere* **2022**, *286*, 131879.
7. Sufiyan, I.; Magaji, J.I.; Zaharadeed, I. Simulation of Sediment Yield and Supply on Water Flow in Different Subbasins of Terengganu Watershed from 1973–2017. *Water Conserv. Manag.* **2020**, *4*, 1–6. https://doi.org/10.26480/wcm.01.2020.01.06.
8. Al-Dousari, A.; Omar, A.; Al-Hemoud, A.; Aba, A.; Alrashedi, M.; Alrawi, M.; Rashki, A.; Petrov, P.; Ahmed, M.; Al-Dousari, N.; et al. A success story in controlling sand and dust storms hotspots in the middle east. *Atmosphere* **2022**, *13*, 1335. https://doi.org/10.3390/atmos13081335.
9. Salmabadi, H.; Khalidy, R.; Saeedi, M. Transport routes and potential source regions of the Middle Eastern dust over Ahvaz during 2005–2017. *Atmos. Res.* **2020**, *241*, 104947.
10. Hamzeh, N.H.; Kaskaoutis, D.G.; Rashki, A.; Mohammadpour, K. Long-Term Variability of Dust Events in Southwestern Iran and Its Relationship with the Drought. *Atmosphere* **2021**, *12*, 1350.

11. Al-Ghadban, A.N.; Saeed, T.; Al-Dousari, A.M.; Al-Shemmari, H.; Al-Mutairi, M. Preliminary assessment of the impact of draining of Iraqi Marches on Kuwait's northern marine environment. Part I. Physical manipulation. *Water Sci. Technol.* **1999**, *40*, 75–87. https://doi.org/10.1016/S0273-1223(99)00586-7.
12. Subramaniam, N.; Al-Sudairawi, M.; Al-Dousari, A.; Al-Dousari, N. Probability distribution and extreme value analysis of total suspended particulate matter in Kuwait. *Arab. J. Geosci.* **2015**, *16*, 12650. https://doi.org/10.1007/s12517-015-2008-z.
13. Hamzeh, N.H.; Karami, S.; Kaskaoutis, D.G.; Tegen, I.; Moradi, M.; Opp, C. Atmospheric dynamics and numerical simulations of six frontal dust storms in the Middle East region. *Atmosphere* **2021**, *12*, 125.
14. Papi, R.; Attarchi, S.; Attarchi, S.; Darvishi-Boloorani, A.; Samani, N.N. Characterization of Hydrologic Sand and Dust Storm Sources in the Middle East. *Sustainability* **2022**, *14*, 15352. https://doi.org/10.3390/su142215352.
15. Gholami, H.; Kordestani, M.D.; Li, J.; Telfer, M.W.; Fathabadi, A. Diverse sources of aeolian sediment revealed in an arid landscape in southeastern Iran using a modified Bayesian un-mixing model. *Aeol. Res.* **2019**, *41*, 100547. https://doi.org/10.1016/j.aeolia.2019.100547.
16. Gholami, H.; Mohammadifar, A.; Pourghasemi, H.R.; Collins, A.L. A new integrated data mining model to map spatial variationin the susceptibility of land to act as a source of aeolian dust. *Environ. Sci. Poll. Res.* **2020**, *27*, 42022–42039. https://doi.org/10.1007/s11356-020-10168-6.
17. Zittis, G.; Almazroui, M.; Alpert, P.; Ciais, P.; Cramer, W.; Dahdal, Y.; Fnais, M.; Hadjinicolaou, P.; Howari, F.; Jrrar, A.; et al. Climate change and weather extremes in the Eastern Mediterranean and Middle East. *Rev. Geophys.* **2022**, *60*, e2021RG000762. https://doi.org/10.1029/2021RG000762.
18. Jin, Q.; Yang, Z.-L.; Wei, J. Seasonal responses of Indian summer monsoon to dust aerosols in the Middle East, India, and China. *J. Clim.* **2016**, *29*, 6329–6349.
19. Kaskaoutis, D.G.; Houssos, E.E.; Solmon, F.; Legrand, M.; Rashki, A.; Dumka, U.C.; Francois, P.; Gautam, R.; Singh, R.P. Impact of atmospheric circulation types on southwest Asian dust and Indian summer monsoon rainfall. *Atmos. Res.* **2018**, *201*, 189–205.
20. Schepanski, K. Transport of Mineral Dust and Its Impact on Climate. *Geoscience* **2018**, *8*, 151. https://doi.org/10.3390/geosciences8050151.
21. Jeong, D.Y. Socio-economic costs from yellow dust damages in South Korea. *Korean Soc. Sci. J.* **2008**, *35*, 1–29.
22. Tozer, P.; Leys, J. Dust storms–what do they really cost? *Rangel. J.* **2013**, *35*, 131–142.
23. Al-Dousari, A.; Al-Nassar, W.; Ahmed, M. Photovoltaic and wind energy: Challenges and solutions in desert regions. In Proceedings of the International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF 2020), E3S Web of Conferences, Kryvyi Rih, Ukraine, 20–22 May 2020; Volume 166, p. 04003, https://doi.org/10.1051/e3sconf/202016604003.
24. Khaniabadi, Y.O.; Daryanoosh, S.M.; Amrane, A.; Polosa, R.; Hopke, P.K.; Goudarzi, G.; Mohammadi, M.J.; Sicard, P.; Armin, H. Impact of Middle Eastern Dust storms on human health. *Atmos. Pollut. Res.* **2017**, *8*, 606–613.
25. Al-Dousari, A.M.; Ibrahim, M.I.; Al-Dousari, N.; Ahmed, M.; Al-Awadhi, S. Pollen in aeolian dust with relation to allergy and asthma in Kuwait. *Aerobiologia* **2018**, *34*, 325–336. https://doi.org/10.1007/s10453-018-9516-8.
26. Goudie, A.S. Dust storms and human health. In *Extreme Weather Events and Human Health*; Springer: Cham, Switzerland, 2020; pp. 13–24.
27. Soleimani, Z.; Boloorani, A. D., Khalifeh, R., Teymouri, P., Mesdaghinia, A., & Griffin, D. W. (2019). Air pollution and respiratory hospital admissions in Shiraz, Iran, 2009 to 2015. Atmospheric Environment, 209, 233-239.
28. Aghababaeian, H.; Ostadtaghizadeh, A.; Ardalan, A.; Asgary, A.; Akbary, M.; Yekaninejad, M.S.; Stephens, C. Global health impacts of dust storms: A systematic review. *Environ. Health Insights* **2021**, *15*, 11786302211018390.
29. Nkosi, V.; Mathee, A.; Blesic, S.; Kapwata, T.; Kunene, Z.; du Preez, D.J.; Garland, R.; Wright, C.Y. Exploring meteorological conditions and human health impacts during two dust storm events in Northern Cape Province, South Africa: Findings and lessons learnt. *Atmosphere* **2022**, *13*, 424.
30. Jones, B.A. Dust storms and violent crime. *J. Environ. Econ. Manag.* **2022**, *111*, 102590.
31. Stefanski, R.; Sivakumar, M.V.K. Impacts of sand and dust storms on agriculture and potential agricultural applications of a SDSWS. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2009; Volume 7, p. 012016.
32. Pahlavanravi, A.; Miri, A.; Ahmadi, H.; Ekhtesasi, M.R. The impacts of different kinds of dust storms in hot and dry climate, a case study in sistan region. *Desert* **2012**, *17*, 15–25.
33. Gross, A.; Tiwari, S.; Shtein, I.; Erel, R. Direct foliar uptake of phosphorus from desert dust. *New Phytol.* **2021**, *230*, 2213–2225.

34. Al-Dousari, A.; Al Saleh, A.; Ahmed, M.; Misak, R.; Al Dousari, N.; Al-Shatti, F.; Elrawi, M.; William, T. Off-Road vehicle tracks and grazing points in relation to soil compaction and land degradation. *Earth Syst. Environ.* **2019**, *3*, 471–482. https://doi.org/10.1007/s41748-019-00115-y.
35. AlKheder, S.; AlKandari, A. The impact of dust on Kuwait International Airport operations: A case study. *Int. J. Environ. Sci. Technol.* **2020**, *17*, 3467–3474.
36. Miri, A.; Middleton, N. Long-term impacts of dust storms on transport systems in south-eastern Iran. *Nat. Hazards* **2022**, *114*, 291–312.
37. Kosmopoulos, P.G.; Kazadzis, S.; El-Askary, H.; Taylor, M.; Gkikas, A.; Proestakis, E.; Kontoes, C.; El-Khayat, M.M. Earth-Observation-Based Estimation and Forecasting of Particulate Matter Impact on Solar Energy in Egypt. *Remote Sens.* **2018**, *10*, 1870. https://doi.org/10.3390/rs10121870.
38. Gholami, A.; Ameri, M.; Zandi, M.; Ghoachani, R.G.; Eslami, S.; Pierfederici, S. Photovoltaic Potential Assessment and Dust Impacts on Photovoltaic Systems in Iran: Review Paper. *IEEE J. Photovolt.* **2020**, *10*, 824–837. https://doi.org/10.1109/JPHOTOV.2020.2978851.
39. Castañeda, I.S.; Mulitza, S.; Schefuß, E.; Lopes dos Santos, R.A.; Sinninghe Damsté, J.S.; Schouten, S. Wet phases in the Sahara/Sahel region and human migration patterns in North Africa. *Proc. Natl. Acad. Sci. USA* **2009**, *106*, 20159–20163.
40. McLeman, R. Developments in modelling of climate change-related migration. *Clim. Change* **2013**, *117*, 599–611.
41. Hornbeck, R. Dust Bowl Migrants: Environmental Refugees and Economic Adaptation; Working Paper 27656; University of Chicago and National Bureau of Economic Research: Cambridge, MA, USA. 2020.
42. Zanganeh, Y.; Boroughani, M. The Analysis of the Relationship Between Dust Phenomenon and Rural Population Changes in Sistan Region. *Geogr. Res.* **2021**, *36*, 115–123. (In Farsi)
43. Griffin, D.W. Atmospheric movement of microorganisms in clouds of desert dust and implications for human health. *Clin. Microbiol. Rev.* **2007**, *20*, 459–477.
44. Meibodi, A.E.; Abdoli, G.; Taklif, A.; Morshedi, B. Economic modeling of the regional polices to combat dust phenomenon by using game theory. *Procedia Econ. Financ.* **2015**, *24*, 409–418.
45. Darvishi-Boloorani, A.; Papi, R.; Soleimani, M.; Karami, L.; Amiri, F.; Samany, N.N. Water bodies changes in Tigris and Euphrates basin has impacted dust storms phenomena. *Aeolian Res.* **2021**, *50*, 100698, https://doi.org/10.1016/j.aeolia.2021.100698.
46. Miri, A.; Maleki,S.; Middleton, N.An investigation into climatic and terrestrial drivers of dust storms in the Sistan region of Iran in the early twenty-first century. *Sience of The Total Environment*, **2021**, *757*, 143952.
47. Miri, A.; Ahmadi, H.; Ekhtesasi, M.R.; Panjehkeh, N.; Ghanbari, A. Environmental and socio-economic impacts of dust storms in Sistan Region, Iran. *Int. J. Environ. Stud.* **2009**, *66*, 343–355.
48. Parajuli, S.P.; Stenchikov, G.L.; Ukhov, A.; Kim, H. Dust emission modeling using a new high-resolution dust source function in WRF-Chem with implications for air quality. *J. Geophys. Res.* **2019**, *124*, 10109–10133. https://doi.org/10.1029/2019jd030248.
49. Darvishi-Boloorani, A.; Soleimani, M.; Neysani Samany, N.; Bakhtiari, M.; Qareqani, M.; Papi, R.; Mirzaei, S. Assessment of Rural Vulnerability to Sand and Dust Storms in Iran. *Atmosphere* **2023**, *14*, 281.
50. Middleton, N.; Kang, U. Sand and dust storms: Impact mitigation. *Sustainability* **2017**, *9*, 1053.
51. Eshghizadeh, M. Determining the critical geographical directions of sand and dust storms in urban areas by remote sensing. *Remote Sens. Appl. Soc. Environ.* **2021**, *23*, 100561.
52. Jiang, C.; Wang, Y.; Yang, Z.; Zhao, Y. Do adaptive policy adjustments deliver ecosystem-agriculture-economy co-benefits in land degradation neutrality efforts? Evidence from southeast coast of China. *Environ. Monit. Assess.* **2023**, *195*, 1215. https://doi.org/10.1007/s10661-023-11821-6.
53. Pimentel, D.; Harvey, C.; Resosudarmo, P.; Sinclair, K.; Kurz, D.; McNair, M.; Crist, S.; Shpritz, L.; Fitton, L.; Saffouri, R.; et al. Environmental and economic costs of soil erosion and conservation benefits. *Science* **1995**, *267*, 1117–1123.
54. Al-Hemoud, A.; Al-Dousari, A.; Misak, R.; Al-Sudairawi, M.; Naseeb, A.; Al-Dashti, H.; Al-Dousari, N. Economic impact and risk assessment of sand and dust storms (SDS) on the oil and gas industry in Kuwait. *Sustainability* **2019**, *11*, 200.
55. Zarasvandi, A.; Carranza, E.J.M.; Moore, F.; Rastmanesh, F. Spatio-temporal occurrences and mineralogical–geochemical characteristics of airborne dusts in Khuzestan Province (southwestern Iran). *J. Geochem. Explor.* **2011**, *111*, 138–151.
56. Broomandi, P.; Dabir, B.; Bonakdarpour, B.; Rashidi, Y. Identification of dust storm origin in South–West of Iran. *J. Environ. Health Sci. Eng.* **2017**, *15*, 1–14.
57. Ahmady-Birgani, H.; McQueen, K.G.; Mirnejad, H. Characteristics of mineral dust impacting the Persian Gulf. *Aeolian Res.* **2018**, *30*, 11–19.

58. Malamiri, N.; Rashki, A.; Hosseinzadeh, S.R.; Gahadi Toroqh, M. Identification of desert dust sources in the West Khuzestan Province using of brightness temperature algorithms. *J. Geogr. Environ. Hazards* **2019**, *8*, 97–110. (In Farsi)
59. Malamiri, N.; Hosseinzadeh, S.R.; Rashki, A.; Gahadi Toroqhi, M. Evaluating the Capability of Various Types of Geomorphological facies in supplying dust sources in the west of Khozestan province-Iran. *Res. Earth Sci.* **2020**, *11*, 19–34.
60. Mohammadpour, K.; Sciortino, M.; Saligheh, M.; Raziei, T.; Boloorani, A.D. Spatiotemporal regionalization of atmospheric dust based on multivariate analysis of MACC model over Iran. *Atmos. Res.* **2021**, *249*, 105322.
61. Khaledi, K.S. Economic loss of dust storms in Iran west provinces case study of Ilam, Khuzestan and Kermanshah. *Econ. Model.* **2013**, *7*, 105–125. (In Farsi)
62. Monjezi, N.; Roknedineftekhari, A. Evaluation of Economic Losses of Dust phenomenon on Agricultural Sector (Case Study: Masjed Soleiman County, Khuzestan Province). *J. Nat. Environ. Hazards* **2021**, *10*, 145–158. (In Farsi)
63. Duniway, M.C.; Pfennigwerth, A.A.; Fick, S.E.; Nauman, T.W.; Belnap, J.; Barger, N.N. Wind erosion and dust from US drylands: A review of causes, consequences, and solutions in a changing world. *Ecosphere* **2019**, *10*, e02650, https://doi.org/10.1002/ecs2.2650.
64. Barzaman, S.; Shamsipour, A.; Lakes, T.; Faraji, A. Indicators of urban climate resilience (case study: Varamin, Iran). *Nat. Hazards* **2022**, *112*, 119–143. https://doi.org/10.1007/s11069-021-05174-x.
65. Shahsavani, A.; Tobías, A.; Querol, X.; Stafoggia, M.; Abdolshahnejad, M.; Mayvaneh, F.; Guo, Y.; Hadei, M.; Hashemi, S.S.; Khosravi, A.; et al. Short-term effects of particulate matter during desert and non-desert dust days on mortality in Iran. *Environ. Intern.* **2020**, *134*, 105299. https://doi.org/10.1016/j.envint.2019.105299.
66. Goudarzi, G.; Alavi, N.; Geravandi, S.; Idani, E.; Behrooz, H.R.A.; Babaei, A.A.; Alamdari, F.A.; Dobaradaran, S.; Farhadi, M.; Mohammadi, M.J. Health risk assessment on human exposed to heavy metals in the ambient air PM10 in Ahvaz, southwest Iran. *Intern. J. Biometeor.* **2018**, *62*, 1075–1083. https://doi.org/10.1007/s00484-018-1510-x.
67. Najmeddin, A.; Keshavarzi, B. Health risk assessment and source apportionment of polycyclic aromatic hydrocarbons associated with PM10 and road deposited dust in Ahvaz metropolis of Iran. *Environ. Geochem. Health* **2019**, *41*, 1267–1290. https://doi.org/10.1007/s10653-018-0209-6.
68. Nazarpour, A.; Watts, M.J.; Madhani, A.; Elahi, S. Source, Spatial Distribution and Pollution Assessment of Pb, Zn, Cu, and Pb, Isotopes in urban soils of Ahvaz City, a semi-arid metropolis in southwest Iran. *Sci. Rep.* **2019**, *9*, 5349. https://doi.org/10.1038/s41598-019-41787-w.
69. Statistical Yearbook of Iran. Statistical Center of Iran. 2016. Available online: https://nnt.sci.org.ir/sites/Apps/yearbook/Lists/year_book_req/Item/newifs.aspx (accessed on 23 December 2024). (In Farsi)
70. Malamiri, N.; Hossenzadeh, S.R.; Khosroshahabadi, R. Assessing the theory of spatial stability of Ergs in Iran, using remote sensing data. *J. Arid. Reg. Geogr. Stud.* **2017**, *7*, 23–35. (In Farsi)
71. Adib, A. Effects of the Karkheh Dam construction on haze generation due to geomorphological changes (in the Khuzestan Province, Southwest of Iran). *Water Supply* **2022**, *22*, 2338–2350. https://doi.org/10.2166/ws.2021.376.
72. Rezaei, M.; Farajzadeh, M.; Mielonen, T.; Ghavidel, Y. Analysis of spatio-temporal dust aerosol frequency over Iran based on satellite data. *Atmos. Pollut. Res.* **2019**, *10*, 508–519.
73. Heidarian, P.; Azhdari, A.; Joudaki, M.; Khatooni, J.D.; Firoozjaei, S.F. Integrating remote sensing, GIS, and sedimentology techniques for identifying dust storm sources: A case study in Khuzestan, Iran. *J. Indian Soc. Remote Sens.* **2018**, *46*, 1113–1124.
74. Karami, S.; Kaskaoutis, D.G.; Kashani, S.S.; Rahnama, M.; Rashki, A. Evaluation of Nine Operational Models in Forecasting Different Types of Synoptic Dust Events in the Middle East. *Geosciences* **2021**, *11*, 458. https://doi.org/10.3390/geosciences11110458.
75. Goudarzi, G.; Sorooshian, A.; Maleki, H. Local and Long-range transport dust storms over the city of Ahvaz: A survey based on spatiotemporal and geometrical properties. *Pure Appl. Geophys.* **2020**, *177*, 3979–3997.
76. Rashki, A.; Kaskaoutis, D.G.; Francois, P.; Kosmopoulos, P.G.; Legrand, M. Dust-storm dynamics over Sistan region, Iran: Seasonality, transport characteristics and affected areas. *Aeolian Res.* **2015**, *16*, 35–48.
77. Lê, S.; Josse, J.; Husson, F. FactoMineR: An R package for multivariate analysis. *J. Stat. Softw.* **2008**, *25*, 1–18.
78. Kassambara, A.; Mundt, F. factoextra: Extract and Visualize the Results of Multivariate Data Analyses, R package v. 1.0. 7. 2020. Available online: https://cran.r-project.org/web/packages/factoextra/readme/README.html (accessed on 23 December 2024).
79. Josse, J.; Husson, F. missMDA: A package for handling missing values in multivariate data analysis. *J. Stat. Softw.* **2016**, *70*, 1–31.
80. Ahmadizadeh, S.; Moghaddasi, R.; Mostaan, A. Determination of economic life of varieties of palms" Sayer" in Ahwaz. *J. Agric. Econ. Res.* **2018**, *10*, 221–240. (In Farsi)

81. Department of Environment of Iran (2020), Estimation of damages to biological and economic resources caused by dust. 11 pages (In Farsi)
82. Cazabat, C.; Yasukawa, L. *Unveiling the Cost of Internal Displacement: 2020 Report*; IDMC: Castle Hill, NSW, Australia, 2020
83. Hafeznia, M.R.; Taheri, A.; Farajzadeh Asl, M. Political Effects resulting from dust storms in Tigris and Euphrates basins. *Geopolit. Q.* **2016**, *12*, 13–38.
84. Chudnovsky, A.; Kostinski, A. Secular Changes in Atmospheric Turbidity over Iraq and a Possible Link to Military Activity. *Remote Sens.* **2020**, *12*, 1526. https://doi.org/10.3390/rs12091526.
85. Notaro, M.; Yu, Y.; Kalashnikova, O.V. Regime shift in Arabian dust activity, triggered by persistent Fertile Crescent drought. *J. Geophys. Res. Atmos.* **2015**, *120*, 110–229. https://doi.org/10.1002/2015jd023855.
86. Yu, Y.; Notaro, M.; Liu, Z.; Wang, F.; Alkolibi, F.; Fadda, E.; Bakhrjy, F. Climatic Controls on the Interannual to Decadal Variability in Saudi Arabian Dust Activity: Toward the Development of a Seasonal Dust Prediction Model: Saudi Arabian Dust Prediction. *J. Geophys. Res.* **2015**, *120*, 1739–1758.
87. Nasreen, S.; Ashraf, M.A. Inadequate Supply of Water in Agriculture Sector of Pakistan Due to Depleting Water Reservoirs and Redundant Irrigation System. *Water Conserv. Manag.* **2021**, *5*, 13–19. https://doi.org/10.26480/wcm.01.2021.13.19.
88. Attiya, A.A.; Jones, B.G. Assessment of mineralogical and chemical properties of airborne dust in Iraq. *SN Appl. Sci.* **2020**, *2*, 1614.
89. Neelamani, S.; Al-Dousari, A. A study on the annual fallout of the dust and the associated elements into the Kuwait Bay, Kuwait. *Arab. J. Geosci.* **2016**, *9*, 1–11.
90. Nabavi, S.S.; Moradi, H.; Shrifikia, M. Evaluation of dust storm temporal distribution and the relation of the effective factors with the frequency of occurrence in Khuzestan Province from 2000 to 2015. *Sci.-Res. Q. Geogr. Data* **2019**, *28*, 191–203. (In Farsi)
91. Alshemmari, H.; Al-Dousari, A.M.; Talebi, L.; Al-Ghadban, A.N. Mineralogical characteristics of surface sediment in Sulaibikhat Bay, Kuwait. *Kuwait J. Sci.* **2013**, *40*. Available online: https://journalskuwait.org/kjs/index.php/KJS/article/view/122 (accessed on 23 December 2024).
92. Mahmoudi, L.; Ikegaya, N. Identifying the Distribution and Frequency of Dust Storms in Iran Based on Long-Term Observations from over 400 Weather Stations. *Sustainability* **2023**, *15*, 12294. https://doi.org/10.3390/su151612294.
93. Masoumi, A.; Moradhaseli, R. Spatio-temporal classification of dust source activities affecting the Khuzestan region, based on CALIPSO-CALIOP data and atmospheric models. *Atmos. Res.* **2023**, *287*, 106702, https://doi.org/10.1016/j.atmosres.2023.106702.
94. Shaheen, A.; Wu, R.; Yousefi, R.; Wang, F.; Ge, Q.; Kaskaoutis, D.G.; Wang, J.; Alpert, P.; Munawar, I. Spatio-temporal changes of spring-summer dust AOD over the Eastern Mediterranean and the Middle East: Reversal of dust trends and associated meteorological effects. *Atmos. Res.* **2023**, *281*, 106509, https://doi.org/10.1016/j.atmosres.2022.106509.
95. Yousefi, R.; Wang, F.; Ge, Q.; Shaheen, A.; Kaskaoutis, D.G. Analysis of the Winter AOD Trends over Iran from 2000 to 2020 and Associated Meteorological Effects. *Remote Sens.* **2023**, *15*, 905. https://doi.org/10.3390/rs15040905.
96. Rahimi, J.; Malekian, A.; Khalili, A. Climate change impacts in Iran: Assessing our current knowledge. *Theor. Appl. Climatol.* **2019**, *135*, 545–564.
97. Rahimzadeh, F.; Nassaji Zavareh, M. Effects of adjustment for non-climatic discontinuities on determination of temperature trends and variability over Iran. *Int. J. Climatol.* **2014**, *34*, 2079–2096.
98. Ghasemi, F.F.; Mohammadi, A.; De-la-Torre, G.E.; Saeedi, R.; Dobaradaran, S. Occurrence of polychlorinated biphenyls in indoor dust of different buildings in Bushehr port, Iran. *Air Qual. Atmos. Health* **2024**, *17*, 1479–1490.
99. Shirvani, M.; Sherkat, Z.; Khalili, B.; Bakhtiary, S. Sorption of Pb (II) on palygorskite and sepiolite in the presence of amino acids: Equilibria and kinetics. *Geoderma*, **2015**, *249*, 21–27.
100. Balling, R.J. A Car-Free, Polycentric City, with Multi-Level Skybridges and Inter-Building Atria. *CTBUH J.* **2016**, *3*, 28–33.
101. Nyika, J.; Dinka, M. Managing Water Scarcity in an Era of Climate Change in Developing Countries: The Case Study of Kenya. *Water Conserv. Manag.* **2023**, *7*, 77–82. https://doi.org/10.26480/wcm.01.2023.77.82.
102. Abyat, A.; Azhdari, A.; Almasi Kia, H.; Joudaki, M. Khuzestan plain continental sabkhas, southwest Iran. *Carbonates Evaporites* **2019**, *34*, 1469–1487.
103. Cao, H.; Liu, J.; Wang, G.; Yang, G.; Luo, L. Identification of sand and dust storm source areas in Iran. *J. Arid. Land 2015*, *7*, 567–578.
104. Ekhtesasi, M.R.; Sepehr, A. Investigation of wind erosion process for estimation, prevention, and control of DSS in Yazd–Ardakan plain. *Environ. Monit. Assess.* **2009**, *159*, 267–280. https://doi.org/10.1007/s10661-008-0628-4.
105. Ghanavati, H.; Fatahi Ardakani, A.; Neshat, A. Economic evaluation of environmental dust phenomenon damage (case of study: Ardakan city). *Environ. Sci.* **2018**, *16*, 141–158.

106. Yazdani, S.; Khorami, S.; Salami, H.; Saleh, I. Economic Evaluation of Dust Damage on the Performance of Agricultural Products in Khuzestan Province. *Iran. J. Agric. Econ. Dev. Res.* **2024**, *55*, 149–167. https://doi.org/10.22059/ijaedr.2022.283683.669103.
107. Pérez, L.; Tobias, A.; Querol, X.; Künzli, N.; Pey, J.; Alastuey, A.; Viana, M.; Valero, N.; González-Cabré, M.; Sunyer, J. Coarse particles From Saharan dust and daily mortality. *Epidemiology* **2008**, *19*, 800–807.
108. UNEP; WMO; UNCCD. *Global Assessment of Sand and Dust Storms*; United Nations Environment Programme: Nairobi, Kenya, 2016.
109. Rashki, A.; Kaskaoutis, D.G.; Mofidi, A.; Minvielle, F.; Chiapello, I.; Legrand, M.; Dumka, U.C.; Francois, P. Effects of Monsoon, Shamal and Levar winds on dust accumulation over the Arabian Sea during summer–The July 2016 case. *Aeolian Res.* **2019**, *36*, 27–44.
110. Opp, C.M.; Groll, H.; Abbasi, M. Ahmadi Foroushani, Causes and Effects of Sand and Dust Storms: What Has Past Research Taught Us? A Survey. *J. Risk Financ. Manag.* **2021**, *14*, 326. https://doi.org/10.3390/jrfm14070326.
111. Albozahr, A. (2005). Quantitative and qualitative study of date palm waste. National Conference on Agricultural Product Wastes (In Farsi). https://sid.ir/paper/809013/fa
112. Behrooz, R.D.; Kaskaoutis, D.G.; Grivas, G.; Mihalopoulos, N. Human health risk assessment for toxic elements in the extreme ambient dust conditions observed in Sistan, Iran. *Chemosphere* **2021**, *262*, 127835.
113. Kwaasi, A.A.A.; Parhar, R.S.; Al-Mohanna, F.A.A. Aeroallergens and viable microbes in sandstorm dust—Potential triggers of allergic and non-allergic respiratory ailments. *Allergy* **1998**, *53*, 255–265.
114. Al-Dabbas, M.; Ayad Abbas, M.; Al-Khafaji, R. The mineralogical and microorganisms effects of regional dust storms over Middle East region. *Intern. J. Water Resour. Arid Environ.* **2011**, *1*, 129–141.
115. Leski, T.; Malanoski, A.P.; Gregory, M.J.; Lin, B.; Stenger, D. Application of a broad-range resequencing array for detection of pathogens in desert dust samples from Kuwait and Iraq. *Appl. Environ. Microbiol.* **2011**, *77*, 4285–4292. https://doi.org/10.1128/AEM.00021-11, 4285–4292.
116. Thalib, L.; Al-Taiar, A. Dust storms and the risk of asthma admissions to hospitals in Kuwait. *Sci. Total Environ.* **2012**, *433*, 347–351. https://doi.org/10.1016/j.scitotenv.2012.06.082.
117. Beik Mohamadi, H.; Mokhtarei, R. A Geograplical Analysis on Migration Processin Khoozestan Province. *Geogr. Dev.* **2003**, *1*, 21–36. https://doi.org/10.22111/gdij.2003.3812.
118. Ahmadi, R.; Amanpour, S.; Monfared, S.; Torabi, Z. An Investigation of Primate City Formation Process in Khuzestan Province in 1956–2011. *Pažuheš-Nâme-Ye Târix-E Ejtemâ'i Va Eqtesâdi (Socio Econ. Hist. Stud.)* **2013**, *2*, 19–50.
119. Luis, M.; Igreja, A.; Casimiro, A.P.; Joao, S.P. Carbon dioxide exchange above Mediterranean C3/C4 grassland during two climatologically contrasting years. *Global Change Biol.* **2008**, *14*, 539–555.
120. Ibrahim, M.M.; El-Gaely, G.A. Short-term effects of dust storm on physiological performance of some wild plants in Riyadh, Saudi Arabia. *Afr. J. Agric. Res.* **2012**, *7*, 6305–6312.
121. Javanmard, Z.; Kouchaksaraei, M.T.; Hosseini, S.M.; Pandey, A.K. Assessment of anticipated performance index of some deciduous plant species under dust air pollution. *Environ. Sci. Poll. Res.* **2020**, 27, 38987–38994. https://doi.org/10.1007/s11356-020-09957-w.
122. Ahmadzai, H. The impact of sand and dust storms on agriculture in Iraq. *Middle East Dev. J.* **2023**, *15*, 50–65.
123. Shao, Y.; Wyrwoll, K.H.; Chappell, A.; Huang, J.; Lin, Z.; McTainsh, G.H.; Mikami, M.; Tanaka, T.Y.; Wang, X.; Yoon, S. Dust cycle: An emerging core theme in Earth system science. *Aeol. Res.* **2011**, *2*, 181–204.
124. Madani, K.; AghaKouchak, A.; Mirchi, A. Iran's socio-economic drought: Challenges of a water-bankrupt nation. *Iran. Stud.* **2016**, *49*, 997–1016.
125. Soliman, M.M.; Al-Khalaf, A.A.; El-Hawagry, M. Effects of Climatic Change on Potential Distribution of Spogostylum ocyale (Diptera: Bombyliidae) in the Middle East Using Maxent Modelling. *Insects* **2023**, *14*, 120. https://doi.org/10.3390/insects14020120.
126. Maleki, T.; Sahraie, M.; Sasani, F.; Shahmoradi, M. Impact of dust storm on agricultural production in Iran. *Intern. J. Agric. Sci. Res. Technol. Ext. Educ. Syst. (IJASRT EES)* **2017**, *7*, 19–26.
127. Nazari, B.; Liaghat, A.; Akbari, M.R.; Keshavarz, M. Irrigation water management in Iran: Implications for water use efficiency improvement. *Agric. Water Manag.* **2018**, *208*, 7–18.
128. Ahmadi, H.; Baaghideh, M.; Dadashi-Roudbari, A. Climate change impacts on pistachio cultivation areas in Iran: A simulation analysis based on CORDEX-MENA multi-model ensembles. *Theor. Appl. Climatol.* **2021**, *145*, 109–120. https://doi.org/10.1007/s00704-021-03614-z.

129. Bazzi, F.; Hoseyni, S.; Turki, M.A. Investigating the effects of dust on the livelihood of villagers (Case study: Nimroz city). *J. Rural. Dev. Strateg.* **2021**, *8*, fa367–fa379.
130. Abdelouahhab, Z.; Arias-Jimenez, E.J. Date palm cultivation. In *FAO Plant Production and Protection Paper*; FAO: Rome, Italy, 1999; Volume 156.
131. Mihi, A.; Tarai, N.; Chenchouni, H. Can palm date plantations and oasification be used as a proxy to fight sustainably against desertification and sand encroachment in hot drylands? *Ecol. Indic.* **2019**, *105*, 365–375.
132. Gholizadeh, H.; Zoghipour, M.H.; Torshizi, M.; Nazari, M.R.; Moradkhani, N. Gone with the wind: Impact of soil-dust storms on farm income. *Ecol. Econ.* **2021**, *188*, 107133.
133. Shirkhani-Ardehjani, S.I.R. of Iran National Report on Regional Action Plan to combat dust and sand storm. In Proceedings of the International Cooperative for Aerosol Prediction (ICAP) 4th Workshop: Aerosol Emission and Removal Processes, ESA/ESRIN, Frascati, Italy, 14–17 May 2012.
134. Zucca, C.; Fleiner, R.; Bonaiuti, E.; Kang, U. Land degradation drivers of anthropogenic sand and dust storms. *Catena* **2022**, *219*, 106575.
135. Alshawaf, M.; Poudineh, R.; Alhajeri, N.S. Solar PV in Kuwait: The effect of ambient temperature and sandstorms on output variability and uncertainty. *Renew. Sustain. Energy Rev.* **2020**, *134*, 110346.
136. Goudarzi, G.; Hopke, P.K.; Yazdani, M. Forecasting PM2.5 concentration using artificial neural network and its health effects in Ahvaz, Iran. *Chemosphere* **2021**, *283*, 131285.
137. Middleton, N.; Kashani, S.S.; Attarchi, S.; Rahnama, M.; Mosalman, S.T. Synoptic causes and socio-economic consequences of a severe dust storm in the Middle East. *Atmosphere* **2021**, *12*, 1435.
138. Raphael, D.; Farrell, E.S. Beyond medicine and lifestyle: Addressing the societal determinants of cardiovascular disease in North America. *Leadersh. Health Serv.* **2002**, *15*, 1–15.
139. Škare, M.; Družeta, R.P. Poverty and economic growth: A review. *Technol. Econ. Dev. Econ.* **2016**, *22*, 156–175.
140. Jones, C.A.; Perera, A.; Chow, M.; Ho, I.; Nguyen, J.; Davachi, S. Cardiovascular disease risk among the poor and homeless-what we know so far. *Curr. Cardiol. Rev.* **2009**, *5*, 69–77.
141. Zafeiratou, S.; Samoli, E.; Dimakopoulou, K.; Rodopoulou, S.; Analitis, A.; Gasparrini, A.; Stafoggia, M.; De' Donato, F.; Rao, S.; Monteiro, A.; et al. A systematic review on the association between total and cardiopulmonary mortality/morbidity or cardiovascular risk factors with long-term exposure to increased or decreased ambient temperature. *Sci. Total Environ.* **2021**, *772*, 145383.
142. Klompmaker, J.O.; Laden, F.; James, P.; Sabath, M.B.; Wu, X.; Schwartz, J.; Dominici, F.; Zanobetti, A.; Hart, J.E. Effects of long-term average temperature on cardiovascular disease hospitalizations in an American elderly population. *Environ. Res.* **2023**, *216*, 114684.
143. Torabi Kahlan, P.; Navvabpour, H.; Bidarbakht Nia, A. Missing Aspects of Poverty: The Case of Multidimensional Poverty in Iran. *J. Poverty* **2022**, *26*, 424–437.
144. Hosseini, G.; Khani, S. Trend Changes and Migration Patterns in the Border Provinces of Iran. *Natl. Stud. J.* **2019**, *20*, 93–114.
145. Savari, M.; Damaneh, H.E.; Damaneh, H.E. Drought vulnerability assessment: Solution for risk alleviation and drought management among Iranian farmers. *Int. J. Disaster Risk Reduct.* **2022**, *67*, 102654.
146. El Rafei, M.; Sherwood, S.; Evans, J.P.; Ji, F. Analysis of extreme wind gusts using a high-resolution Australian regional reanalysis. *Weather. Clim. Extrem.* **2023**, *39*, 100537.
147. Shahpari, D.; Hazbavi, A. Study of Immigration Impacts on Population Growth in Khuzestan Province during (1996–2011). *Q. J. Soc. Dev. (Previously Hum. Dev.)* **2019**, *13*, 145–162. https://doi.org/10.22055/qjsd.2018.14565.
148. Noroozi, A.; Shoaei, Z. Identifying areas with dust generation potential in the southwest of Iran, case study: Khuzestan Province. *Watershed Eng. Manag.* **2018**, *10*, 398–409.
149. Mohammadi, Z.; Rahimi, D.; Najafi, M.R.; Zakerinejad, R. The impact of environmental degradation and climate change on dust in Khuzestan province, Iran. *Nat. Hazards* **2024**, *120*, 1–20. https://doi.org/10.1007/s11069-023-06368-1.
150. Hejazi, S.J.; Sharifi, A.; Arvin, M. Assessment of social vulnerability in areas exposed to multiple hazards: A case study of the Khuzestan Province, Iran. *Int. J. Disaster Risk Reduct.* **2022**, *78*, 103127.
151. Zhu, G.; Yong, L.; Zhao, X.; Liu, Y.; Zhang, Z.; Xu, Y.; Wang, L. Evaporation, infiltration and storage of soil water in different vegetation zones in the Qilian Mountains: A stable isotope perspective. *Hydrol. Earth Syst. Sci.* **2022**, *26*, 3771–3784. https://doi.org/10.5194/hess-26-3771-2022.
152. Eskandari Damaneh, H.; Khosravi, H.; Habashi, K.; Eskandari Damaneh, H.; Tiefenbacher, J.P. The impact of land use and land cover changes on soil erosion in western Iran. *Nat. Hazards* **2022**, *110*, 2185–2205.

153. Wu, X.; Deng, H.; Huang, Y.; Guo, J. Air pollution, migration costs, and urban residents' welfare: A spatial general equilibrium analysis from China. *Struct. Change Econ. Dyn.* **2022**, *63*, 396–409.
154. Jalali, L.; Zarei, M.; Gutiérrez, F. Salinization of reservoirs in regions with exposed evaporites. The unique case of Upper Gotvand Dam, Iran. *Water Res.* **2019**, *157*, 587–599.
155. Barua, P.; Rahman, S.H.; Barua, S.; Rahman, I.M.M. Climate Change Vulnerability and Responses of Fisherfolk Communities in The South-Eastern Coast of Bangladesh. *Water Conserv. Manag.* **2020**, *4*, 20–31.
156. Abbasi-Kangevari, M.; Malekpour, M.R.; Masinaei, M.; Moghaddam, S.S.; Ghamari, S.H.; Abbasi-Kangevari, Z.; Rezaei, N.; Rezaei, N.; Mokdad, P.A.H.; Naghavi, P.M.; et al. Effect of air pollution on disease burden, mortality, and life expectancy in North Africa and the Middle East: A systematic analysis for the Global Burden of Disease Study 2019. *Lancet Planet. Health* **2023**, *7*, 358–369.
157. Santana, J.C.C.; Miranda, A.C.; Rosa, J.M.; Berssaneti, F.T.; Ho, L.L.; da Silva Ferreira, L.L.; Gomes, R.A.; de Araújo, S.A.; Belan, P.A. A neuro-fuzzy model to predict respiratory disease hospitalizations arising from the effects of traffic-related air pollution in São Paulo. *Clean Technol. Environ. Policy* **2024**, *27*, 191–204.
158. Santana, J.C.C.; Miranda, A.C.; Souza, L.; Yamamura, C.L.K.; Coelho, D.d.F.; Tambourgi, E.B.; Berssaneti, F.T.; Ho, L.L. Clean production of biofuel from waste cooking oil to reduce emissions, fuel cost, and respiratory disease hospitalizations. *Sustainability*, **2021**, *13*, 9185.