The Effect of Environmental Degradation and Climate on Dust in Khuzestan Province, Iran

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Abstract

Human activities and climate change have resulted in environmental degradation and increased environmental hazards globally. In Khuzestan province, such hazards have included droughts, heat waves, and dust storms occurring more frequently. To understand the factors contributing to the dust storms, this study evaluated changes in rainfall, air temperature maximum and minimum, and soil temperature (1985–2019), as well as land cover, land surface temperature, and water bodies in 2017 (drought) and 2019 (wet year). The findings of the Principal Component Analysis (PCA) indicate a reduction in annual water bodies, spring vegetation, and water bodies in the spring, summer, and autumn seasons. The increase in air and land surface temperature accounts for 95% of the variance in dust in the Khuzestan province. Field surveys suggest that various human activities such as hydro dam building, crude oil drilling, extracting crude oil wells in lagoons, changes in farmland use, and water transfer among water basins have intensified the phenomena in the region under study. To manage this critical issue more effectively, it is recommended to review and assess local policies regarding regional ecology and establish cooperative agreements with regional countries such as Iraq, Turkey, Syria, Jordan, and Saudi Arabia which all experience similar natural disasters.

Introduction

Deserts and semi-arid regions are in the "Arid Lands", which include super-arid, arid, semi-arid, and semi-arid arid regions. Drylands cover about 45–47% of the global land area (Prăvălie, 2016; Koutroulis, 2019) and are home to about 3 billion people who live mainly in semi-arid and semi-humid regions (IPCC, 2022). Drylands host unique, rich biodiversity (Maestre et al., 2015, Al-Hemoud et al., 2020, Norouzi, 2019) and provide important ecosystem services (Bidak et al., 2015; Liu et al., 2020).

The results of the sixth assessment report (IPCC, 2022) indicated the destruction of pastures, soil erosion, reduction of production efficiency, an increase of runoff, and decrease in vegetation index have led to desertification. In the same report, climatic events such as (decreased rainfall, increased temperature, wildfires, floods, heavy rainfall, heat waves, and drought), and human activities such as (changes in land use, urban growth, overgrazing pastures, and destruction of forests) are effective in increasing desertification.

Climate change and human activities in recent years have led to an increase in the frequency and intensity of dust storms (Kok et al., 2021, Wu, 2021). Therefore, it has created important challenges in sustainable development and increased the level of environmental vulnerability. Soil erosion, land use change, dam construction, desertification, increase in temperature, increase in livestock grazing, and destruction of pastures, which are related to socio-economic effects, are effective in the process of increasing and intensity of dust (Engelstaedter et al., 2006, Gholami et al., 2020, 2020, and Emamian et al., 2021, Baltaci H, 2021). The decrease in the level of underground water and the drying up of wetlands and reservoirs significantly affect desertification and dust in Iran (Alizadeh, 2013). The findings indicated that
dust increases with climatic drought, reduction of river hydrological flow, and reduction of vegetation (Hossein Hamzeh et al., 2021, Javan and Teimouri, 2019).

Desertification leads to changes in herbaceous cover, sand and dust storms, water scarcity, and human health. Dust emissions are highly sensitive to changing climate conditions but also to changing land use and management performance (Middleton, 2019). The findings indicated that land degradation, loss of vegetative cover, and drying of water bodies in semiarid and arid areas will contribute to sand and dust activity (Mirzabaev and Stringer, 2022). SDS continues a major worry for desert regions under conditions of climate change and desertification (Middleton, 2017).

In some locations, such as the USA, desert dust can be deposited downwind on snowpacks, hastening snowmelt and altering river hydrology (Painter et al., 2010). Deserts, playas, and salt marshes produced 75–90% of atmospheric dust in the early 21st century, and land use changes and degraded pastures caused by human activities accounted for the remainder (Ginoux et al., 2012; Stanelle et al., 2014).

Recent changes in dust emissions and their proportions vary geographically. In Iran, during the years 1951 to 2013, with the increase in temperature, dust events have increased (Alizadeh-Choobari and Najafi, 2018), the investigation of the performance of dust on the Saccharum officinarum product in the southwest of Iran showed that due to the dust, the photosynthesis process of the plant is disrupted and its efficiency is reduced by 30% (Arvin et al., 2013; Bayat et al., 2016, Malaki et al., 2017), in the southwest of the United States of America, with the increase in drought (2000–2014), dust events have also increased (Hind et al., 2017). The decrease in soil moisture and the drying up of wetlands and reservoirs significantly led to increasing desertification and dust (Ravi et al., 2004, Mahmoodabadi and Rajabpour, 2017; Koochizeh, et al., 2021). The increase in dusty days in the southwest of Iran led to a sharp decrease in the air quality index and an increase in respiratory diseases and a decrease in human health, the standard of living, air quality, and an increase in migration in Khuzestan province, Iran (Shahswani et al., 2013, Amarlui et al. 2013, Khavarian et al., 2019, Hejazi et al., 2022).

**The Study Area:**

This area is located at the longitude of 29° 57′ to 33° 4′ of North latitude and 47° 38′ to 50° 32′ of East longitude, it is located in the Southwest of Iran and the northwest of the Persian Gulf (Statistical yearbook of Iran, 2020), (Fig. 1). It is in the southwest of Iran, bordering Iraq and the Persian Gulf. The Khuzestan province can be divided into two regions; the rolling hills and mountainous regions North of the Ahvaz Ridge, and the plains and marshlands to its South. In the South part province, there is wind erosion (Ahvaz, Abadan, and Mahshahr), (Brown Color, Fig. 1)). These areas are the internal source of dust in Khuzestan province.

**Data:**
The South of Ahvaz ridge is the internal source. Therefore, our focus for station data analysis is on meteorological stations in this region. The analyzed data includes rainfall, air temperature, dust, and soil temperature in meteorological stations (1985–2019) (Fig. 2). In addition, Landsat 8 satellite images in the seasons (winter, spring, summer, and autumn) were used to investigate and change the environment in the dry year (2017) and wet year (2019). Using these images, changes in land surface temperature(LST), and normalized land cover index(NDVI) have been investigated. The study focuses on two years, a drought year (2017) and a wet year (2019), for evaluating environmental degradation. The data recorded in meteorological stations were daily, and these data were analyzed monthly and annually.

**Methodology**

This study employs geostatistical and spatial analysis methods to analyze meteorological and dust data. Due to the homogeneity of data in meteorological stations, the data are studied regionally using the Co-Kriging model (Equ.1) as shown below:

\[
\text{Equ.1 } z = \sum w_i z(x_i)
\]

Which: \( z^* \) is the estimated spatial variable, \( z(x_i) \) is the observed spatial variable and \( w_i \) is the weight of the variable given to the observations’ count.

The study examines the impacts of changes in rainfall, drought, minimum and maximum air temperatures, land cover, land surface temperature, and land use dust. In this study, an attempt is made to evaluate the environmental degradation impact by assessing the observed data trends through the anomaly(normalize), Pettitt’s test, LST, NDVI, SM(Soil Moisture), and Principal Component Analysis (PCA). For calculation normalzation the equation.2 is applied as shown below:

\[
\text{Equ.2 } Z\text{-value}=\left(\frac{p_i - \mu}{\delta}\right)\text{,Which : } p_i = \text{ value for annual, } \mu = \text{ Average, } \delta = \text{ Standard Deviation.}
\]

Pettitt's test is a nonparametric test that requires no assumption about the distribution of data (Pettitt A.N., 1979). For the detection of changes in variables Eq. 3 applied to Pettitt’s test(95%) as shown below(Equ.3):

\[
\text{Equ.3 } K_T \max |U_{t,T}|, U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{sgn}(X_i - X_j) p \simeq 2 \exp\left(\frac{-6K^2}{T^3 + T^2}\right) \text{ Which :}
\]

\( U_{t,T} \): Turningpoint, \( K_T \): Significancelevel.

For calculation NDVI the equation.4 applied as shown below(Equ.4):

\[
\text{Equ.4 NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}, \text{That value is between } -1 \text{ and } +1. \text{ Values of this index between } +1 \text{ are used for dense vegetation cover and } -1 \text{ for the water body.}
\]

For calculation LST the equation.5 is applied as shown below Equ.5:
Equ. 5 $LST = \frac{BT}{(1 + (0.00115 * BT / 1.4388) * \ln(\varepsilon))}$, Which: $\varepsilon = 0.004 * P_v + 0.986$, Brightness Temperature $BT = \frac{1321.0789}{\ln \left(\frac{774.8853}{\%TOA\%} + 1\right)} - 273.15$

Finally, principal component analysis has been used to determine the factors affecting dust.

**Results and Discussion**

Since 2003, the occurrence of dust has increased in the southwest of Iran. The dust has led to a decrease in air quality and agricultural production efficiency, an increase in respiratory diseases, road accidents, cancellation of flights, drying of forests, and closure of educational centers (Local Government Report, 2019). The increase in dust is related to environmental destruction, drought, climate change, and human activities. To evaluate the effect of environmental degradation and climate change on dust, changes in rainfall, air temperature, land surface temperature, and land cover were investigated.

**The Trend of Dust Annually:**

The temporal distribution of dust frequency (1985–2019) indicated that 19 years of this period occurred in $\geq 100$ days per year. The frequency of this event is 7 times in the first period (1985–2002), and 12 times in the second period (2003–2019) (Fig. 2). In the second period, 71.5% of the years had $\geq 100$ days of dust. The spatial distribution of dust (1985–2019) also indicated that the probability of its occurrence is higher in the Southern parts than in the northern parts (South 48.27% (5990 days)) and (Northern parts 20% (2516 days)). These findings were also confirmed in the Mann-Kendall test (an increase in the southern parts (Ahwaz ($Z = 1.37$), Abadan ($Z = 1.53$) and Mahshahr ($Z = 1.68$), but there is no trend in the northern parts). The findings of the monthly dust anomaly indicated that the month with dust has increased since 2003. In addition, the results of the Pettitte test at the 95% confidence level indicated that dust days have increased since 2003. The comparison of two periods (1985–2003) and (2003–2019) indicated that it has increased from 149 days to 195 days at Ahvaz station, from 95 to 132 days at Abadan station, and from 88 to 129 days at Mahshahr station (Fig. 3).

**The trend of rainfall:**

The variability of rainfall greatly influences other environmental factors like soil moisture, vegetation cover, water body, and temperature. The rainfall pattern in this region has differential temporal and spatial paradigms. Rainfall varies between 750 mm in the northeast (mountain part (North)) and 160 mm in the south (the plain part (South)). The findings indicated that spatial paradigm in rainfall depends on altitude changes as shown in the equation below:

$$P = 0.34 (H) + 219.5, \text{ (Which : } P \text{ is annual precipitation, and } H \text{ is Hight).}$$

Therefore, precipitation increases from south to north in Khuzestan province. The temporal variation of rainfall in this region is high (STDV = 74.5, and SKEW = 0.31).
The annual rainfall anomaly table of the province (1985–2019) shows that 61% of the years have negative anomalies and 39% have positive anomalies. 21 years of statistical drought have happened. But the most important event is the long-term drought (2007–2017), which has had devastating environmental effects.

The timing of this drought period coincides with the increase in dust (Fig. 4). This long-term drought has been recorded in almost the whole of Iran. The continuation of this drought has had a great effect on vegetation, and water bodies.

The results of Pettitt’s test indicated that there were no significant changes in the 95% confidence level of the annual rainfall of the sample stations. The finding of Sen’s slope shows that the rainfall has a decreasing trend, but it is not confirmed at the significant level of 95% (Fig. 5).

**The Annual trend of Temperature**

The air temperature change indicates that the air temperature is subject to spatial and temporal changes. The ELR (Environmental lapse Rate) is 6.4°C in this region (Equ.1).

\[ T = 25.7 - (0.064) (H) \]

Which: \( T \) is air temperature, and \( H \), is Height (m).

Analyzing change in the min and max air temperature of the region in this period reveals the temporal change at a 95% confidence level, with an ascending trend. Anomaly and Pettitt’s test were used to evaluate the minimum and maximum air temperature changes.

The results of the anomalies showed that the minimum and maximum air temperatures were increasing and the frequency of months with positive anomalies (more than mean temperature) has increased since 1997.

From 1997–2019, the air temperature minimum increased by 1.5°C in the South part of Khuzestan province (Ahvaz from 18.38 to 19.73, Mahshahr from 18.3 to 19.7, and Abadan from 19.36 to 19.94 °C) (Fig. 6). Air temperature maximum has increased almost 2 °C in the South part of Khuzestan province (Ahvaz from 32.4 to 34.15, Mahshahr from 31.8 to 33.2, and Abadan from 32.8 to 34.18 °C), since 1997 (Fig. 7).

The minimum and maximum temperature increase in a period of 34 years (1985–2019) is between 1.5 and 2 °C. Compared to the trend of global warming in 100 years (1920–2020), which is between 0.5 and 1 °C, it is very high. The south of Khuzestan province has become 3 times warmer than the global average. This intensity of temperature increase has created harmful environmental effects such as increasing dust.

**Change of Land Surface Temperature**

Land surface temperature (LST) is an essential factor in studying environmental degradation because it reflects radiation and heat balance changes. To evaluate soil temperature changes, stations (Ahvaz,
Mahshahr, and Abadan) were used in the period from 1992–2019, and Landsat 8 satellite images in 2017 (drought), and 2019 (wet year).

The monthly temperature anomaly shows that since 2008, there has been an increasing trend in the soil temperature (depth of 5 cm). The number of months with positive soil temperature anomalies is more than the months with negative anomalies (Fig. 8). The findings of the non-parametric Pettitt’s test showed that the soil temperature has increased in Abadan and Mahshahr by more than 1 °C since 2008. The comparison of soil temperature indicates the soil temperature has increased in the stations of Abadan (from 16.1 to 17.3° C), Mahshahr (from 15.8 to 16.8° C) and Ahvaz station by about 16° C in the period (2008–2019) compared to the previous period. (1992–2007) (Fig. 8).

Landsat 8 satellite images were selected to evaluate LST in 2017 (drought) and 2019 (wet year). The findings of calculating the LST indicated there is a big difference between the LST in different seasons. In winter 2017, the air temperatures maximum and minimum are 4 and 2 °C, in spring, 4 and 5 °C, in summer, 3 and 5 °C, and in autumn, 3 and 10 °C, respectively; in the same year, the average Land surface temperature is 4.5 °C warmer than that in 2019 (Fig. 9).

Land use and Land cover (LU/LC):

Wind erosion is the process by which soil particles are moved by the wind. Reducing soil moisture, vegetation and land management lead to an increase in wind erosion. Land use and land cover are two effective factors in the dust. The land use of Khuzestan province shows that about 4000 km² of Khuzestan province includes sand dunes, salt fields, bare lands, and dry farming (Fig. 10). These uses have a high potential to create dust. The occurrence of drought, increase in air temperature, decrease, and water body of these lands are sources of dust.

Landsat 8 satellite images were selected to evaluate land cover in 2017 (drought) and 2019 (wet year). The findings of calculating the NDVI indicated there is a big difference between the NDVI in different seasons. Changes in land cover can better reflect the causation of environmental and human factors. The NDVI index is applied to determine the changes in land cover. This index is reviewed in 2017 for drought and 2019 for wet years, as it is shown in Fig. 10. The NDVI index findings indicate that the area of vegetation has increased from 23,755 Km² in 2017 as a dry year to 29,952 Km² in 2019 as a wet year. Changing the area of water bodies is another change in land cover (Fig. 11).

Water Bodies and Wet land:

Drying and decreasing soil moisture leads to increased wind erosion even at low speeds. Drought, increase in temperature and decrease in the area of wetlands and water areas are the reasons for the increase in wind erosion and dust in Khuzestan province.

Fine-grained clays and sediments in the dried-up parts of wetlands lead to dust in low-speed winds. Shadgan wetlands (Abadan and Mahshahr), Huvizeh (shared with Iraq) in the West of Ahvaz, Bamdej (North of Ahvaz) with an area of 3030km² are the largest wetlands in Khuzestan province. Shadgan
Wetland is supplied with water through the Karuon and Jahre rivers, Huvizeh Wetland through the Karkheh River in Iran and Tigris and Euphrates in Iraq, and Bamdej Wetland through the Shavor rivers (Fig. 12).

Construction of Karun1-4 Dams, Maruon and Mashrageh (Shadgan wetland), South Anatolia Project (GAP) in Turkey and Karkheh Dam in Iran (Huvizah wetland) and Shavor Dam (Bamdej wetland), agricultural development, long-term droughts (2007–2017) were effective in reducing water body and wetlands since 1990 (Fig. 13). The implementation of these projects and long-term droughts (2007–2017) have led to changes in the area of water bodies. During this period, the frequency of dust has increased. The area of water body was 1966 Km2 (in 2017) in drought and 4310 Km2 (in 2019) during a wet year. The findings indicated that dust of 2017 (N = 117) are more than 2019 (N = 43).

The results obtained from assessing the effects of dust on environmental degradations in two sample years of 2017 (drought) and 2019 (wet) reveal that, there exists an inverse relation between environmental variables and dust. For example, in 2017, when a drought occurred (SPI = -1.5), with a decrease in water body, an increase in air temperature, a decrease in vegetation index, and an increase in the recorded Land surface temperature, the number of dusty days increased to 117 days. In 2019, a wet year with 324 mm of rainfall and (SPI = +0.7) with more water areas, more vegetation index, and lower air temperature, the recorded dusty was 43. Table 4.

Table 4

<table>
<thead>
<tr>
<th>Year</th>
<th>Rainfall (mm)</th>
<th>Air temperature</th>
<th>Water body</th>
<th>Number dust days</th>
<th>SPI</th>
<th>Meadow, forest(km(^2))</th>
<th>(LST)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max</td>
<td>Min</td>
<td>Km(^2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>139.3</td>
<td>34.7</td>
<td>19.9</td>
<td>1966</td>
<td>117</td>
<td>-1.5</td>
<td>23755</td>
</tr>
<tr>
<td>2019</td>
<td>324.3</td>
<td>33.6</td>
<td>19.7</td>
<td>4310</td>
<td>43</td>
<td>0.7</td>
<td>29952</td>
</tr>
</tbody>
</table>

Principal Component Analysis:

Assessment of environmental degradation due to dust, the spatial and temporal changes of pasture, forest, water areas (seasonal and annual), rainfall, temperature, and drought (17 variables) was analyzed using Principal Component Analysis.

The findings indicated that the highest eigenvalues of the principal components included in the area of the water bodies (2.57), the coverage of meadows in the spring season (2.11), water body the spring season (1.49), the summer season (1.32), and autumn (1.04) (Fig. 14). The findings of the PCA indicated the reduction of annual water bodies, spring vegetation, spring, summer and autumn water bodies,
drought, and increase in air temperature and land surface temperature account for 95% of the dust variance in the Khuzestan province (Fig. 15).

The PCA indicated that 39% of dust storms are related to annual water body changes. Also, the vegetation and wetlands are reduced due to long-term droughts, land use changes, and improper management of water resources (construction of a dam and water transfer). These changes have led to desertification and the creation of dust sources in this region. The continuation of these conditions also leads to an increase in environmental temperature, land surface temperature, land use, and local dust production (Fig. 16).

**Conclusion**

Human activities and improper use of environmental resources such as fossil fuel, water resources, forests, meadows, and soil have caused the degradation of the environment and climate change. The increase in the emission of greenhouse gases, long-term droughts, and the increase in temperature have led to a decrease in soil moisture and vegetation and an increase in the LST and air temperature. The analysis of annual precipitation and temperature trends (1985–2019) indicated an increase in annual precipitation ($Z = -2.13$), maximum temperature ($Z = 2.72$), minimum temperature ($Z = 5.11$), and mean temperature ($Z = 4.48$) have increased. The evaluation of land cover and elements of climate indicated vegetation cover and water body decrease and air temperature and soil temperature increase in drought. But in wet years, (2019), vegetation and water bodies increase, and LST and air temperature decrease. So, drying forests, increasing forest fires, and pastures decreasing water bodies, and decreasing soil moisture led to the increasing frequency of dusty days in 2017, drought, is 117 dust days, and the same for 2019 wet year 43 dust days.

The findings of the PCA indicated the reduction of annual water bodies, spring vegetation, water bodies in spring, summer, and autumn, drought, and increase in the air temperature, and land surface temperature account for 95% of the dust variance in the Southwest of Iran.

Non-scientific and non-governed human activities have led to a direct effect on this phenomenon. Construction of Karkheh and Karun 3 and 4, Masjed Soleiman, Godar, Gotevand, Takab, Meshrageh, and Zohre hydro dams with about 15000 ml. m³, drilling for oil in the lagoons, mega agricultural projects, water transition from Karun, Karkheh, and Dez tributaries, destruction of plantation constitute some of the Anthropogenic factors promoting dust.

A dry and very hot climate in the summer season (more consumption of energy and fossil fuels) and flares of oil and gas sources lead to more emission of greenhouse gases and regional warming. These conditions lead to an increase in temperature (in the air and LST), water demand, decrease in vegetation cover, and ultimately further degradation of the environment and increase in dust. In addition, the number of sources of dust production and air pollution increased from the years (2005–2019) due to the drying of wetlands for easier oil extraction. Climate change (global warming, drought) and human activities (deforestation, wetland drying, and mismanagement) have led to an increase in dusty days.
It should be noted that dust from climate conditions and environmental degradations in the Arab regions in the Middle East which affects a significant part of Iran, is different from dust from a local source. Cooperation with the regional countries (Iraq, Turkey, Syria, Jordan, and Saudi Arabia) and the Euphrates and Tigris rivers’ flow patterns would establish an efficient measure in confronting the environmental risks.

**Declarations**

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**Research Data Policy and Data Availability Statements**

The authors declare that data supporting the findings of this study are available and were cited within the article. Data is available and provided to the journal whenever needed.

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Dariush Rahimi contributed to the study’s conception and design. Zahra Mohammadi performed material preparation, data collection, and analysis. Zahra Mohammadi and Dariush Rahimi wrote the first draft of the manuscript, and Mohammad Reza Najafi and Reza Zakerinejad commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

**Ethics declarations:**

**Conflict of interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Consent to participate**

The data of this research were not prepared through a questionnaire.

**Consent for publication**

There is no conflict of interest regarding the publication of this article. The authors of the article make sure that everyone agrees to submit the article and is aware of the submission
Ethical approval

Not applicable, because this article does not contain any studies with human or animal subjects.

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