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Original Article

Investigating the Occurrence of Dust Storms and its Zoning Using GIS During 2018-2021: A Case Study in Ahvaz, Iran

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Abstract
Background: A dust storm is a critical environmental issue and natural hazard in arid and semi-arid regions worldwide. Particulate matters including PM_{10} and $PM_{2.5}$ are of the primary air pollutants, which can adversely affect human health. This research aimed to determine the fine dust concentration spatiotemporally and estimate the suspended particulate matter (PM_{10} and $PM_{2.5}$) during 2018-2021 in Ahvaz.
Methods: An analytical- descriptive method and the data from synoptic weather stations in the studied area were used in this study. The zoning of dust was done using the kriging method by ArcGIS software.
Results: The results indicated that the year 2021 experienced the highest frequency of dusty days, with 54 occurrences, while the year 2019 exhibited the lowest frequency, with only 28 dusty days. Notably, Ahvaz city recorded the highest dust concentration in 2020, reaching an average of 4667 mg/m^3. Based on the findings of PM concentration over the four-year period, it is evident that 2021 recorded the highest PM_{10} concentration (326.14 mg/m^3), while 2020 exhibited the highest $PM_{2.5}$ concentration (148.26 mg/m^3).
Conclusion: The results revealed that there was an increase in dust concentration in the east and north. This is probably attributed to the proximity to dust centers.
Keywords: Dust storm, Zoning, Indoor sources, Concentration of PM

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Introduction

A dust storm is considered as a dominant phenomenon in arid and semi-arid regions of the world. Given their tremendous effects on socio-economic issues, human health, and the environment,[1] it has become a global concern.[2] The researches on the frequency of dusty days in Iran show that central regions of the country have the dustiest days. The western and southwestern regions of the country experience a notable increase in the number of dusty days which are mainly attributed to their proximity to the large deserts of neighboring countries. The majority of dust storms in this area occur during the summer and spring seasons.[3-5]

Based on the definition by the World Meteorological Organization (WMO), dust storms are classified into four categories namely weak, moderate, severe and very severe based on horizontal visibility. Weak dust storms are characterized by visibility from less than 10 km, moderate dust storms from 1 to 10 km, severe storms with visibility ranging from 200 to 1000 meters, and very severe storms with visibility below 200 meters.[6] According to the WMO, a day is classified as having a dust storm when the visibility at a station falls below 1000 meters due to dust.[7]

The reduction in vegetation in deserts and arid regions, particularly in the event of prolonged drought, intensifies wind erosion leads to the occurrence of substantial dust storms and emissions.[8,9] Dust storms can disrupt various aspects, including radiant balance, air temperature, the lifespan, and optical properties of clouds,[10] as well as rainfall patterns, the geochemistry of affected areas,[11] land and marine biogeochemical cycles, hydrological processes, and visual and aesthetic effects. These processes affect the land's ecosystem and human health.[12-15]

Dust storms, as instances of extreme air pollution events, substantially increase the concentrations of particulate matter (PM) with diameters of 10 and 2.5 microns, denoted as PM_{10} and $PM_{2.5}$, respectively, within the impacted regions. High PM_{10} and $PM_{2.5}$ concentrations can adversely affect human respiratory systems and cause bronchitis, chronic cough, and other respiratory illnesses.[12,16-18] Dust increases the oxidative stresses in respiratory epithelial cells, inducing responses in human respiratory and immune systems.[19]

Previous researches have indicated that exposure to dust particles, which can linger in the air for hours or days, may lead to various health problems such as conjunctivitis, meningitis, and valley fever. In rare cases, it can even result in fatalities. Moreover, evidence suggests that frequent exposure to dust storms can amplify adverse health effects across diverse age groups and genders. Individuals with a history of diabetes, hypertension, cerebrovascular, or pulmonary diseases are particularly at higher risk. Numerous epidemiological studies have investigated the health impacts of dust storms by comparing outcomes during dust storm periods with those during non-dust storm periods. Additionally, these studies have assessed the correlation between dust storms or PM_{10} exposure and various health outcomes.[20]

Also, dust storms affect many segments of an economy, either directly or indirectly. Direct effects refer to the immediate consequences of the events. There are some examples such as the shutdown of marine terminals, airline delays, road accidents, detrimental health effects (such as respiratory diseases), reduced commercial activities (e.g., a low number of customers in shops), loss of agricultural production due to crop damage and livestock deaths, cleaning and landscaping in residential premises, as well as damage to road signs and posts. Indirect effects are secondary outcomes that may occur following the direct effects. For instance, a decline in commercial and transport activities can lead to a reduction in the availability of products in retail stores. Similarly, airline delays and cancellations may result in a decrease in the number of guests staying in hotels, while delays in construction work can extend the time required for project completion. Less apparent indirect effects also encompass opportunity costs. For instance, these may include the delayed shipment of exports (via air, land, or marine routes) or the postponed delivery of products to commercial stores. The economic impact of dust storm also depends on the level of economic activity within an economy. Regions or locations with a significantly higher level of economic activity, such as cities with major infrastructure or transport hubs, will be more affected by dust storm than locations with less infrastructure or populations.[21,22]

In crowded areas, many contaminants are found in dust particles, including metals, herbicides, digoxin, and nuclear particles. Thus, quantification of the dust source and estimating its concentrations are essential in air quality studies.[23] Iraq, Syria, Saudi Arabia, Iran, Jordan, and Turkey contribute to producing dust storms in the Middle East by 39.2, 23, 14.5, 13.8, 5.7, and 3.8 percent, respectively. Iraq and Syria produce more than 60% of the dust in the Middle East region. These centers serve as the primary sources of dust entering the western and southwestern regions of the country.[24] Figure 1 illustrates the domestic origins of dust centers in Khuzestan province.

Implementing strategies and operational approaches to control land surface issues and address root causes necessitates the precise identification of local dust production sources. This is crucial because the physical and chemical properties of dust are primarily determined by the characteristics of the land surface origin.[26] Given the significance atmospheric phenomenon, numerous researchers have dedicated the origin, characteristics, movement paths, compounds within these storms, as well as the effects and consequences of micro dust over the years.

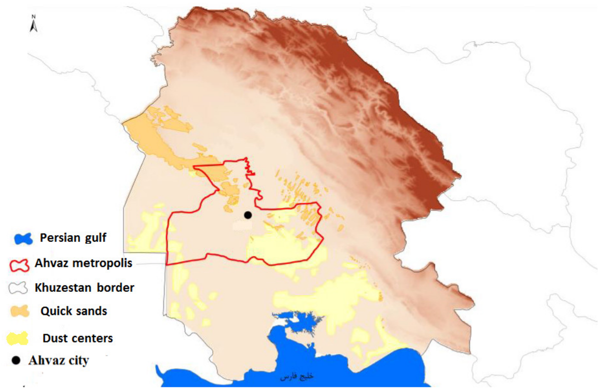

Figure 1. Location of Dust Centers in the Khuzestan Province[25]

Hahnenberger and Nicoll conducted a research on the characteristics of dust occurrences in the eastern part of Utah, United States. The results revealed that the highest frequency of dust events was observed during the spring season, particularly in the afternoons when wind speeds reached their maximum.[27] O'Loingsigh et al monitored wind erosion using meteorological data from 1965 to 2011 in Australia. The findings indicated a significant correlation between precipitation and dust occurrence, with a notable increase during years with decreased precipitation. [28] Goodarzi et al[29] explored the temporal and spatial distribution of days with dust in the western and southwestern regions of Iran, encompassing the provinces of Ilam, Khuzestan, and Kermanshah. For this purpose, the National Meteorological Organization provided statistics on days with dust from 1986 to 2008. The results revealed that the highest number of dusty days occurred at Dehloran, Ahvaz, and Dezful stations, with the most critical conditions observed in the southern parts of Khuzestan and Ilam provinces. The frequency of dusty days demonstrated an increasing trend from the northern to the southern regions of the area. Additionally, the findings highlighted variations in the distribution of this phenomenon influenced by regional climate systems, owing to the diverse conditions and altitude levels in the western part of the country. Notably, the southwest of Khuzestan province recorded the highest number of days with dust.

Mehrabi et al[30] investigated the relationship between climatic parameters and the occurrence of fine dust in Khuzestan. Their findings suggest that the occurrence of a dust storm in summer at various stations indicates the potential for local and intra-provincial origins of storms in this region. In a related study, Kandakji et al[31] employed remote sensing and GIS to identify and characterize dust point sources in the southwestern United States. This study confirms playas' importance as a dynamic source of dust in the southwestern U.S. Moreover, it suggests that anthropogenic factors are prominent in dust emissions within the southwestern U.S. However, bare lands are not subjected to anthropogenic factors (e.g., the white sands dune field) which emit the dust.

In another study, Hojati et al identified influencing factors on the subsidence rate and other characteristics of dust. They introduced climatic conditions in the subsidence area, the distance from the source of dust production, and the distinction between local and international sources of dust production as crucial elements.[32] Overall, the settling rate of dust can be regarded as a complex response to the interplay of atmospheric parameters, including rainfall and seasonal precipitation, wind, temperature, and relative humidity.

Given its geographical location, the Ahvaz metropolis experiences the influence of both internal dust centers and dust from external sources in different seasons. Notably, 65% of dust events occur in the Ahvaz city, possibly attributed to its closer proximity to micro dust centers both within and outside the country.[33] Understanding the sources and distribution of dust in this metropolis is crucial for planners and decision-makers. This knowledge facilitates the development of operational plans to combat and control fine dust while effectively managing and mitigating its effects.

Given the significance of the dust phenomenon, the associated challenges, and its widespread occurrence in various parts of Iran in recent years, this research aims to examine the spatial distribution of dust and PM concentration in Ahvaz city from 2018 to 2021. The study employs the innovative techniques of Geographic Information System (GIS) and geostatistics to enhance the understanding of these patterns.

Materials and Methods

The research was conducted in Ahvaz city, situated in the central area of Khuzestan province, covering an area of 20 000 hectares (Figure 2). Ahvaz city is situated at 31 degrees and 20 minutes north latitude and 48 degrees and 40 minutes east longitude in the plains of Khuzestan. The soils of Ahvaz city are predominantly sedimentary, with some areas exhibiting characteristics such as salinity, alkalinity, and brown litho-cell formations.[34] In terms of climate, Ahvaz experiences sweltering and prolonged summers, along with short and mild winters. The average relative humidity in this area is approximately 43%. According to Dumarten's classification, based on average rainfall and temperature, the region falls into the dry climate group. With most of the area situated at a low altitude relative to sea level, the maximum altitude is 161 meters in the east, while the minimum altitude is -12 meters in the southwest (Figure 3). The northern and eastern parts of the studied area feature higher altitudes, characterized by mountains that are barren and non-agricultural. Residential areas are predominantly situated in the central part, while a substantial portion of the city is covered by agricultural lands.[35]

The research employed a statistical-descriptive method, utilizing the synoptic weather station data from the study area to achieve the defined objectives. The required statistics were obtained from the country's Meteorological Organization and Environment Organization which were transferred to Excel software. The dusty days were presented in a graph based on the average concentrations of suspended particles below 2.5 and 10 microns in the air for the entire duration at each station, with a total of 37 samples collected from the study area. The sampling locations are shown in Figure 4. GIS was employed to

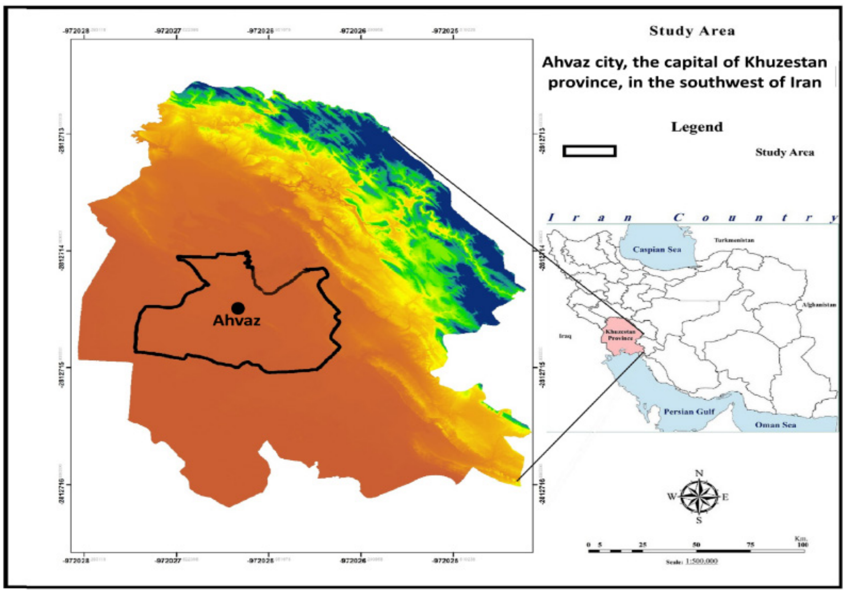

Figure 2. Geographical Location of the Studied Area

explore the spatial distribution of dusty days. In this regard, dust zoning from 2018 to 2021 was determined using ArcGIS 10.2 software and the ordinary kriging interpolation method. The Kriging technique is a basic geostatistical approach that provides the best linear unbiased estimation for spatially dependent variables. The Kriging technique weights the surrounding measured values to derive a prediction for an unmeasured location. The data collection tool was based on the occurrence of fine dust and the pollution of suspended particles below 10 and below 2.5 microns from environmental and meteorological organizations. We gathered pertinent data through fieldwork and statistics from environmental and meteorological organizations. The collected data were then analyzed using SPSS and Excel software. Excel was utilized for creating graphs and curves, while ArcGIS 10.2 software was employed to generate dispersion maps of suspended particles.

Results and Discussion

To provide an overview of the dust situation in Ahvaz, we estimated the number of dusty days and their average particle concentrations in different months from 2018 to 2021 (Table 1). The results indicate that the highest number of dusty days per year was recorded in 2021, totaling 54, while the lowest occurred in 2019, with 28 days. The highest dust concentration was recorded in Ahvaz city in 2020, with an average of 4667 micrograms per cubic meter. Figure 5 shows the average number of dusty days in different months from 2018 to 2021 in Ahvaz city. According to this figure, the days with the most dust were in June and July, with 14 and 13 days, respectively.

The results illustrating the variations in PM_{10} and $PM_{2.5}$ pollutant concentrations in the Ahvaz city over a four-year period (2018-2021) are presented in Table 2 and Figure 6. According to the results, 2021, with a concentration of 326.14 μ/m^3, and 2020, with 148.26, have the highest PM_{10} and $PM_{2.5}$ concentrations, respectively. Moreover, the lowest concentration of PM_{10} and $PM_{2.5}$ was seen in 2018, with 102.44 and 44.01 μ/m^3, respectively.

The results of those days with PM_{10} concentrations outside the standard range (< 3150 $\mu g/m^3$) indicated that 2021 recorded the highest frequency as 24.8%, whereas 2018 had the lowest, with 16.08% (Table 3). Furthermore, the highest and lowest percentages of days exceeding the standard of $PM_{2.5}$ concentration were observed in 2020 and 2018, accounting for 17.04% and 10.8%, respectively.

Spatial Zoning of Dust Concentration

Figure 7 shows the spatial distribution of dust concentrations using ordinary kriging interpolation methods from 2018 to 2021. The results of zoning show

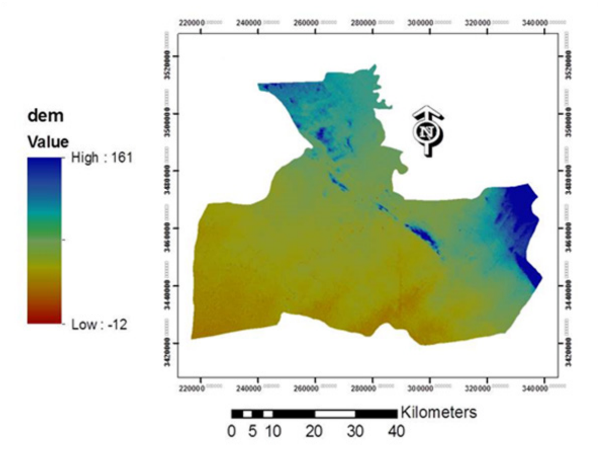

Figure 3. Digital Elevation Model Map of Ahvaz City

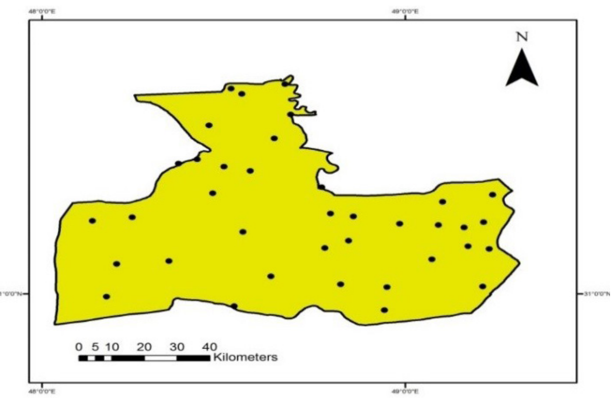

Figure 4. Locations of Sampling Points

Table 1. The Mean and Standard Deviation of Particles Concentration and their Durability During the Dust Phenomenon From 2018 to 2021

Year	Number of Days of Dust	Particles Concentration (μg/m³)	Dust Durability (h)
		Mean ± Standard Deviation	
2018	31	3440 ± 87.6	392
2019	28	3798 ± 100.4	374
2020	42	4667 ± 177.4	422
2021	54	4274 ± 64.7	456

Table 2. Average and Standard Deviation of PM_{10} and $PM_{2.5}$ Concentration During 2018-2021

Year	PM_{10}		$PM_{2.5}$	
	Mean	Standard Deviation	Mean	Standard Deviation
2018	102.44	14.1	44.01	4.3
2019	114.87	9.44	74.36	9.42
2020	244.8	11.54	148.26	8.14
2021	326.14	6.42	140.01	11.14

Table 3. The Percentage of Days Outside the Standard Threshold of PM Concentration

Year	The Percentage of Days Outside the Standard PM_{10} Concentration	The Percentage of Days Outside the Standard of $PM_{2.5}$ Concentration
2018	16.08	10.8
2019	21.25	7.22
2020	14.4	17.04
2021	24.8	10.37

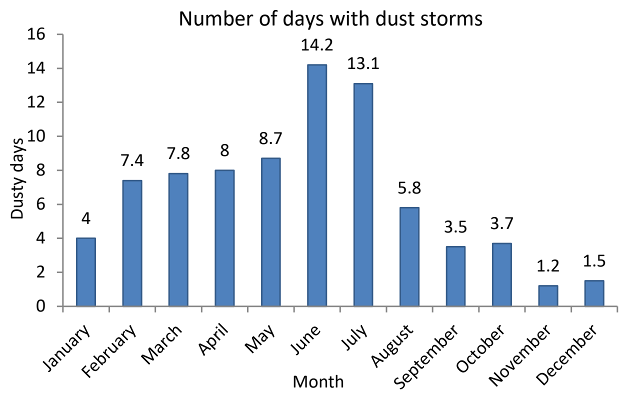

Figure 5. The Average Occurrence of Dust in Different Months Between 2018-2021 (General Department of Meteorology of Khuzestan Province)

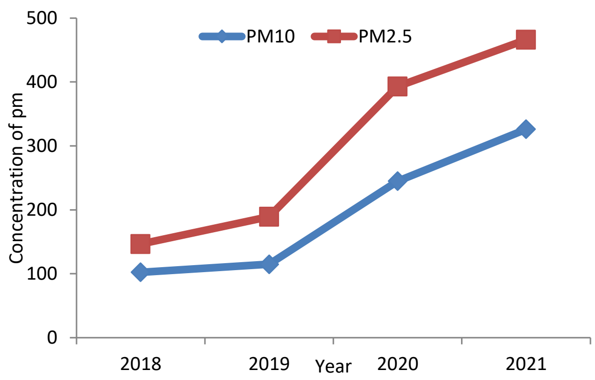

Figure 6. Changes in the Concentration of PM_{10} and $PM_{2.5}$ in 2018-2021

that the dust concentration is higher in the eastern and northern parts of the city than in the central and southern. The concentration of the pollution decreases from the west to the center and east of Miroim city. Regions with the highest concentrations are typically associated with residential areas and dust centers, particularly in the central and western parts characterized by agricultural activity. Due to the abundance of vegetation in these areas, dust concentration is comparatively lower.

Several climatic factors affect the internal dust storms occurrence originating from the station and outside of the station with external origin. In any given location and timeframe, certain climatic factors may be more dominant than others. Therefore, the occurrence of dust storms is not solely influenced by one factor; rather, it is the result of a combination of variables such as temperature, precipitation, drought events, and other climatic parameters. Human factors, particularly in the form of mismanagement, also play a crucial role. In instances of mismanagement during dust storms, this phenomenon becomes a fundamental challenge with wide-ranging environmental, economic, and social consequences. The severity and prevalence of these challenges are expected to increase due to forthcoming climate conditions.

In examining the relationship between climatic parameters and the occurrence of fine dust in Khuzestan province and Ahvaz city, a study focused on temperature, humidity, and wind direction and speed.[29] A decline in the

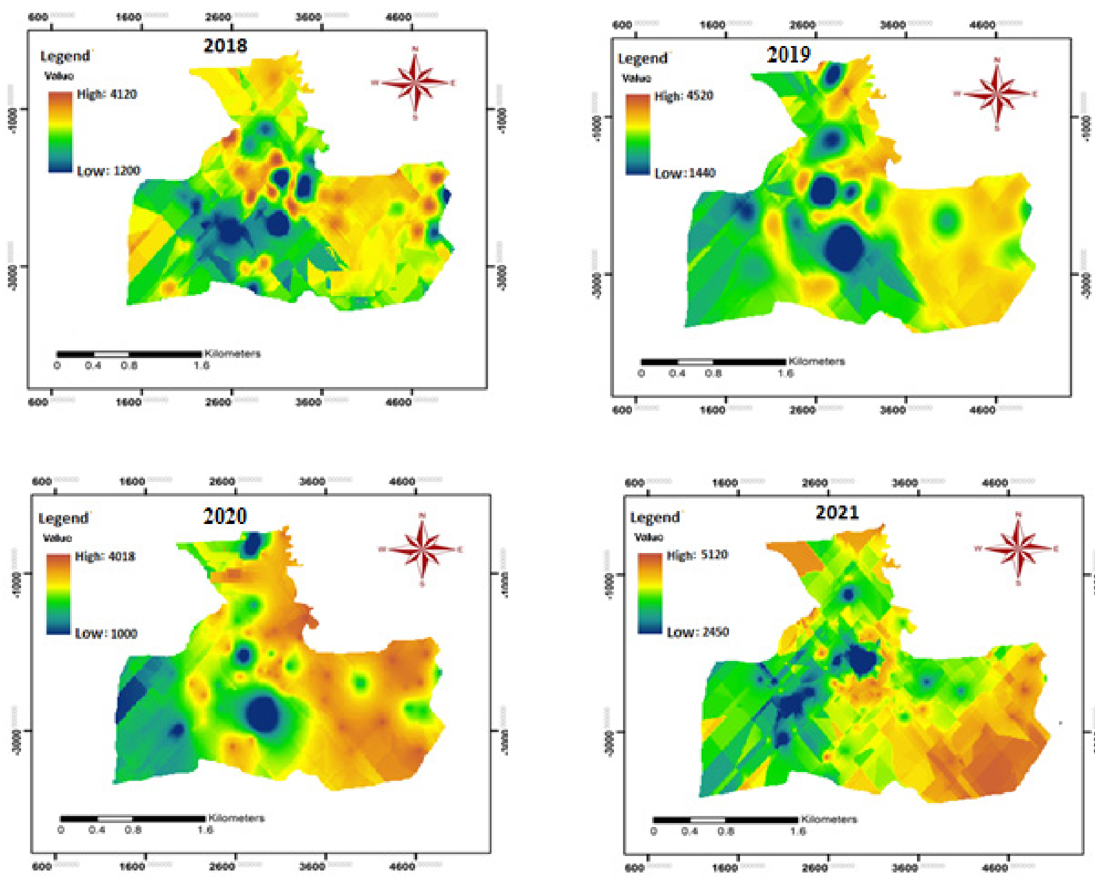

Figure 7. Dust Zoning Maps in Ahvaz City in 2018-2021

frequency of days with precipitation contributes to soil drying and reduction in vegetation. Consequently, the soil becomes more susceptible, and fine-grained sediments in the interior regions are poised to be lifted from the ground, even at wind speeds below the erosion threshold of six meters per second in the area.

Hence, the climatic conditions of Ahvaz city, coupled with its proximity to dust centers, constitute the most significant factors contributing to dust occurrences in the region. Essentially, the city's proximity to internal dust centers and the inflow of sands from all directions results in the accumulation of dust particles throughout various seasons. During events originating externally, the city, situated along the primary trajectory of incoming dust from the northwest-southeast, southeast-northwest, and the north of the area, experiences particle settlement due to a reduction in wind speed.[36]

Reshno[36] investigated and analyzed the dust phenomenon in Khuzestan province statistically using remote sensing and divided the causes of dust in the region into two categories namely human and natural factors. He mentioned the recent droughts as one of the most critical natural reasons for the increase in dust storms. The imposed war, agriculture, dam construction, and the policy of transferring water from water-rich to low-water areas as human factors were also influential. Mohammadiha et al studied dust storm formation case-by-case using Moderate Resolution Imaging Spectroradiometer (MODIS) sensor images.[37] They stated that the dust originated from Iraq's deserts. Goherdoost et al conducted a review and analysis of synoptic maps of peak dusty days in Khuzestan province, revealing that over a 10-year period, the majority of dust waves in Khuzestan predominantly occurred during summers, particularly in July.[38] This observation aligns with the findings of the present study.

Rasouli et al confirmed that the production of fine particles is due to the decrease in air humidity, the drought phenomenon, excessive use of water resources, and the construction of dams on the Tigris and Euphrates rivers.[39] Similar studies have indicated that there exists a correlation between the rise in particle concentration and elevated environmental temperatures, leading to a reduction in rainfall and relative humidity. Moreover, a noteworthy association has been observed between increased air humidity and a decline in dust concentration. An analysis of air humidity across various seasons demonstrated a consistent pattern, wherein an increase in this parameter resulted in a proportional decrease in dust particle concentration. This phenomenon can be attributed to particles absorbing moisture, thereby increasing in weight and settling.[40]

Conclusion

This study investigated the spatial and temporal zoning of dust in Ahvaz from 2018 to 2021. For this purpose, the dust data were obtained from the Meteorological Organization of the country. The findings indicate that the highest number of days with dust in Ahvaz city was documented in 2021, while the lowest was recorded in 2019. The highest dust concentration was recorded in Ahvaz city in 2020. The average changes in the number of dusty days in different months from 2018 to 2021 showed that June and July have the highest number of dusty days. The maximum dust duration was recorded in 2021 as 456 hours. The maximum PM_{10} and $PM_{2.5}$ concentrations were in 2021 and 2020, respectively. During the four years (2018-2021), the concentration of PM_{10} was higher than $PM_{2.5}$. Furthermore, the lowest PM_{10} and $PM_{2.5}$ concentrations were observed in 2018. The dust zoning maps showed that the maximum concentration of dust was in the eastern, northern, and northeastern parts. As these surfaces lack vegetation and remain barren, they serve as internal sources of dust. Consequently, the primary factors contributing to dust in the region are climatic conditions, proximity to domestic dust centers, and the location along the primary path of dust originating from neighboring countries.

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Competing Interests

The author declares no conflict of interest.

Ethical Approval

There were no ethical considerations to be considered in this research.

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