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Present Situations of Dust Storms in Iran for Seeking Numerical Predictions

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Abstract: *Dust storms originate from drylands and bring hazards and dramatic socio-economic impacts. This paper reviews the impacts of this phenomenon on human health, pollution of air, and socio-economic situations by focusing on susceptible areas to dust and sandstorms in Iran. It provides a short review of the dust and sandstorm phenomenon and the process of dust emissions. In addition, it reviews possible sources of dust and sandstorms inside Iran's borders and concludes that it originates from dried bed lakes which are located inside Iran. To consider the countermeasures of the hazardous effects of the dust storms, accurate prediction methods are required to be developed with plausible physical models describing the sand transport phenomenon with the association of mesoscale atmospheric predictions models. Accordingly, case studies employing atmospheric numerical simulation models were discussed. This study highlights the importance of the numerical predictions of dust storms that frequently occur in Iran.*

Keywords: Dust storm; Hazards; Emission; Socio-Economic Impacts

1. INTRODUCTION

Climate is unstable and it always changing. In recent decades it has turned into a concern among countries, and it has been considered as the biggest challenge of the 21st century [1].

Dust and sandstorm are an atmospheric phenomenon that takes place in many regions all around the world, but the frequency of occurrence of dust and sandstorms are high in arid and semi-arid regions, and it has affected life conditions in many arid and semi-arid countries, especially in Asia.[2].

Drivers of dust storms are both natural and anthropogenic. But the fundamental process of dust particle movement is the same in both situations.

Dust storms threaten the economy and environment, and it acts as an impediment, particularly in developing countries. Hazards originate from dust storms impact human-associated issues and affect human society in numerous ways.

To mitigate the negative effects of dust storms, there are several ways to forecast them. In the last decades, several regional atmospheric models have been developed. One of them is the weather research and forecasting model (WRF) which is a mesoscale numerical weather prediction system developed by the national center for atmospheric research (NCAR) and the national center for environmental prediction (NCEP). WRF can simulate atmospheric phenomena based on improved atmospheric models as well as data assimilation contributed by developers.

This paper provides a summary of recent studies about the dust storm, and it contains information about the potential source of dust with focusing on the region of study. The aim of this study is to have an overall picture of this phenomenon for future studies.

2. IRANIAN REGIONAL SITUATIONS

2.1 Geometrical and Meteorological Conditions

Iran, located within a dry belt in the northern hemisphere, is surrounded by several countries having large deserts. For example, the Karakum desert with an area of 350,000 km2 is located in Turkmenistan, the northeast area of Iran. Margo (Dasht-e Margo) and Registan deserts spread in the southeast of Iran with an area of 150,000 km2 in Afghanistan. In addition, the Arabian desert in southwest across the Persian Gulf of Iran consists of three deserts (Rub al Khali, ad-Dahna, and An-Nafud). The area of 2,330,000 km^2 covers not only Saudi Arabia but also Jordan, Iraq, Oman, Yemen, and United Arab Emirates. In Iran as well, there are also deserts such as Dasht-e Kavir and Lut deserts covering the wide ranges of the land of Iran. Since the main problems caused by the dust and sand transports are related to the sands traveling in the air and drifting on the ground from the surrounding deserts, it can be said that Iran is located in susceptible regions influenced by the dust transport and dust storms.

Although Iran spans in vast latitude and is categorized into different types of climate zones, the inland is also affected by morphological conditions. In the east-west and northwest-southeast regions, Alborz and Zagros mountains extend, respectively (Fig. 1). These mountains act as barriers preventing humid air from the Caspian Sea and the Persian Gulf to be introduced into the central parts of the country. Although most parts of Iran lie in sub-tropical regions, annual precipitation is low values of approximately 200-300 mm, especially in the eastern and southeastern part of the country, because of the frequent formation of high-pressure systems.

Due to these synoptical and morphological conditions, the overall land of Ian is considerably dry. According to the DeMarton classification, 64% of the whole country is arid. and 20% semiarid [3]. Accordingly, the Mediterranean to per humid climate type is only limited to 16% [3].

In addition to the sands from the deserts, there are other possible sources for the dust: saline particles. Most lakes in Iran are saline; however, the lakes are droughty due to low precipitation and dry climates. Therefore, Iran is one of the areas exposed to the serious situations of dried lake bed erosions, especially near the edges of the lakes, by winds [4,5]. Zucca [6], analyzed over eighteen lakes all around that are known as dust sources due to desiccation or anthropogenetic activities. Four lakes of them are inside Iran's borders. Desiccation drivers of these lakes are different but the same as mentioned before and concluded that over 80 % of dust storms originate from dried wetlands.

2.2 Drivers of dust events

2.2.1 climatic and terrestrial parameters

Dust storms effect by different factors. Precipitation, temperature, soil moisture, and wind.

One of the major factors that play important role in inducing dust storms is wind. Temperature and precipitation affect wind erosion through their effect on soil moisture. Humidity increases soil particle cohesion which helps to resist wind erosion [7].

The vegetation factor has a crucial role. Low coverage of vegetation on the surface makes it susceptible to wind erosion. Therefore, the height and density of vegetation should be considered effective factors.

The dry climate also worsens the situation. Since Iran is located in a semi-arid and arid region, many parts of the country's soil have a low level of moisture. Thus, the wind has unpleasant consequences in most regions. Besides, surface durability is dependent on the erodibility of the surface material and their size. The low-weight soil textures like sand and loams are the most susceptible to wind erosion. Wind lifts up light particles and picks them up from the surface and transports them long distances.

2.2.2 anthropogenic parameters

Anthropogenic dust sources can be known as poor land management such as the building of dams, deforestation, impropriate use of water sources, increase in population, and dried wetlands. Since most of them are linked to the hydrological cycle, thus they are affected by climate variability.

In a study about the distribution of dust storms in Iran Raski [8], found that it has increased in the west of Iran induced by human activity and changes in landforms such as building dams which are in agreement with Adib & Akhzari [9]. Hamzeh [10] studied the effects of drought on dust storms in the western part of Iran and found that Syria and Iraq are centers of dust production and indicate the variation of climatic parameters has effects on dust storms. Miri [11], studied dust storms in Zabol city which has a high record of dust storms among other cities in Iran. They concluded that dusty days have been increased and horizontal visibility has been decreased in the summer season after 1999 regarding drying of Hamoun lake near to city and reduction of visibility. Karegar [12] analyzed the same region as Miri and found that the dried bed of Hamoun lake is the main source of dust emission which is transport dust to the southern part of Iran up to the Oman sea.

Rashki [13], studied the frequency of dust storms in southeast Iran, south Turkmenistan, west Afghanistan, and Pakistan during 2010-2016. It has been revealed that at some stations such as Zabol, Sukar, Mary, and Khandehar dust days have been reached to 30 days per month and found that June and July are characterized by dust activities. Baghbanan [14], studied the frequency occurrence of dust storms in southeast and south of Iran During 1984-2013. He recognized 1168 days with dust storms with the highest days for Zabol and lowest for Bandar abbas, besides, the number of dust storms has increased. Araqizadeh & Masoudian [15], had analyzed the frequency of occurrence of dust and sandstorms in the northeast of Iran. They found that Sabzevar city has experienced a high frequency of dust storms since it is near to Kavir desert.

2.3 Potential Source of Dust Particles

Dust particles within dust storms are thought to be both sands from surrounding deserts as well as salts and saline particles originating from saline lakes. Because saline particles can be deposited on the ground, salinize soil, and cause damage to vegetation, the identification of the possible saline source particle source is required. Table 1. listed the possible saline particle sources in Iran due to the droughts or other factors. To scrutinize the relationship between dust transport and meteorological conditions, Fig. 2 represents wind speeds and directions at selected stations in Iran during 1951-2021.

One of the lakes that play important role in dust emission is Hamoun lake and marshes located in the north-northwest part of Zabol city (the down triangle in Fig. 1), near the Iran and Afghanistan border. Hamoun lake is naturally dry in the summer season. The desiccation period of Hamoun lake coincides with the beginning of the activation of Levar winds which is also known as the “120-days wind“ because the strong wind lasts approximately for four months from June to September [16]. The north-southern wind is caused by the pressure difference between the Caspian Sea and Hindu Kush mountains, and it covers the east of Iran, west of Afghanistan, and Turkmenistan where it starts [17]. In addition, decreasing of precipitation during summer intensifies the drought in the lake. Because of the dried bed of Hamoun lake, and the strong winds for the same reason, saline particles from the lake are thought to be the major sources of the dust storm in the area [18].

In Fig.1, at Zabol station, the average wind speed is higher than 5 m/s, and in summer average exceeds 8 m/s. At Zabol station, the prevailing wind direction is from north and northwest which corresponds to the location of Hamoun lake.

Hawr-al-Azim is the largest wetland in Iran. The area is 3000 km2 and is fed by two rivers Karkheh and Tigris. Construction of a dam on the Karkheh and Tigris rivers and activities associated with oil production has reduced its area and dried part of it has turned into a source of dust storm [19]. Adib [20] has concluded that the highest dust discharge originated from the Hawr-al-Azim wetland happened in June and July and the direction of dust scattering toward the northwest of Iran and overcrowded areas.

Urmia lake with an area of 5200 km2 is located in the northwest of Iran and it is known as the largest hypersaline lake and the biggest lake in Iran. Urmia lake is located east of Urmia city which is a highly populated city in northwest Iran. Desiccation of the lake has increased from 2005 to 2013. The result showed particle concentration of dust has been increased not only in Urmia city but also in Igdir Turkey [21].

Jazmurian lake is located between Kerman, Sistan, and Baluchestan. Its area is over 6900 km2. Precipitation is low in this area and evaporation is high. The east, west, and south part of lakes tend to erosion. Dust generated by this lake mainly affects southeastern Iran, southern Pakistan, and Oman. The dust storm has increased in Iranshahr city near the lake.

In recent years main water bodies inside of Iran have been shrunk. As consequence, dried and desiccated part of them has negative effects on humans and the environment.

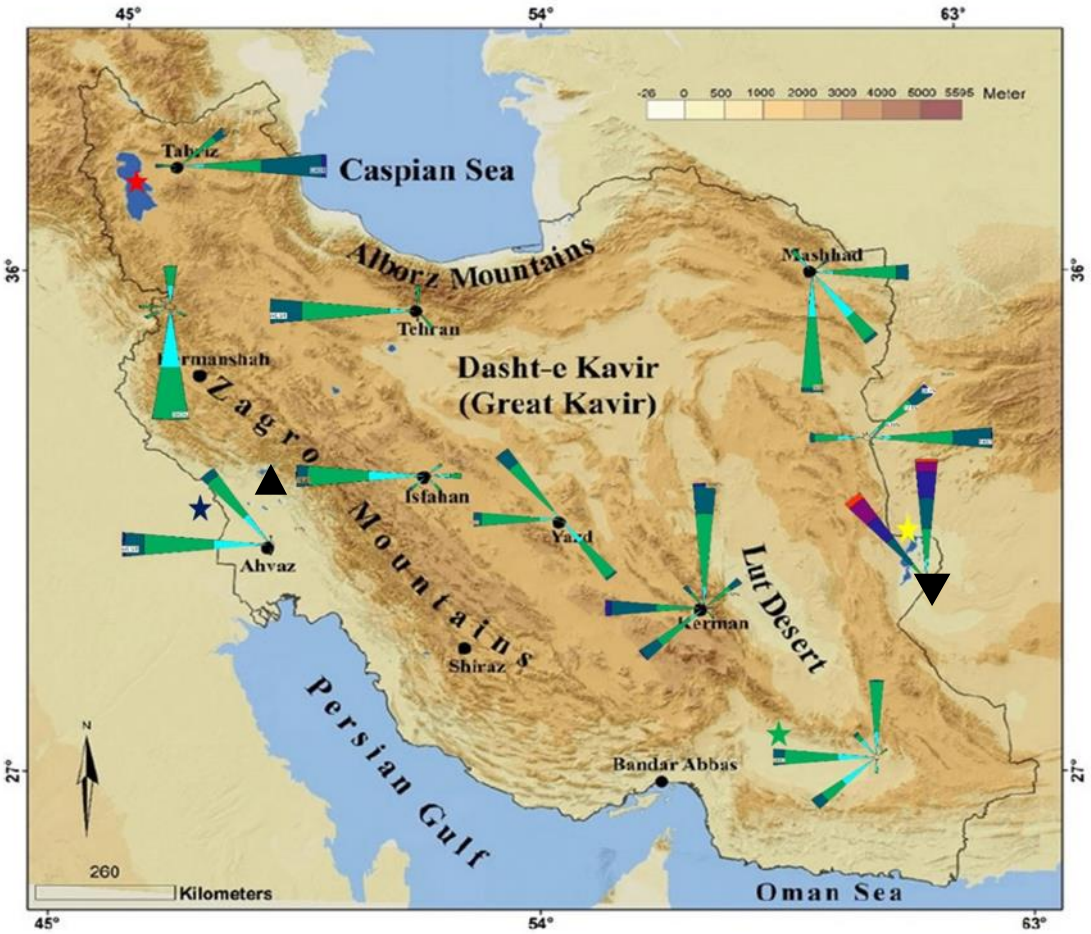

Fig. 1. Wind speeds and directions in major cities in Iran. The star symbols in the figure indicates the cities listed in Table 1.

Table 1. Possible sources of dust and sandstorm near Iran areas

Name	Country	Position on map	Description
Hamoun Lakes and Marshes	Iran-Afghanistan	★	Desiccation of Hamoun lakes is related to the use of water in upper watersheds, mostly dry in summer. Interaction of drying lake beds with strong local winds causes the formation of dust storms in the area.
Hawr-al-azim	Iran-Iraq borders	★	Annual discharge capability of 2.5 tons per second.
Urmia Lake	Iran	★	Used to be the biggest hypersaline lake, has lost 80% of its water in the past decades. The southern and eastern parts of the lake are exposed to severe desertification.
Jazmurian Lake	Iran	★	Two rivers flow into Jazmurian lake but they are diverted for agriculture. Thus, the lake remains almost dry for the last 15 years except for the spring season. characteristic of dust events in this region is the duration of them.

"Note. Adapted from Zucca [6,21, 24,25]

3. EFFECTS OF DUST STORMS

Dust storms can cause various damages to human health, the environment, climate, and the economy. For example, they can increase the risk of respiratory diseases, affect cloud lifetime causing a significant change in the climate, and impair plant growth resulting in less productivity in farm products. Table. 2 illustrates the notable effects of the dust storm on various sectors. Since the impacts of dust storms depend on regional relations between urban areas and potential source locations, landscape, wind speed, and socio-economic activities, this section reviews various influences of the dust storms in several sectors from previous studies. Aghababaeian [22] reported that the cardiovascular and respiratory mortality rate for the

residents in Dezful city (the up triangle in Fig.1) from 2014 to 2019 has a positive relation with dust storm occurrences. Khaniabadi [23], studied the relation between the number of the hospital admission in southwest regions in Iran and the respiratory mortality rate.

they found that dust storms can increase diseases in Khuzestan province.

Another aspect is the effects on the commercial sectors. Miri & Middleton [26] studied the effects of dust storms on various factors in transportation sectors such as aviation, travel speed, the traffic volume of vehicles, traffic accidents, damages to roads and facilities, and impacts on railway transport, in southeast regions of Iran for seven years. The total damage cost by dust storms was estimated as approximately 46 million US dollars. The road transport sector was estimated to incur the most damage among other sectors, whereas over 103 flights were canceled during storms in Zabol and Zahedan cities, which were the main factors of the economic damage in the aviation sector. Accordingly, Kaftargi [27], also evaluated the physical damages of dust storms to traffic roads in the Sistan region and revealed that road paths critically effectuated by dust storms occurred as reported by Miri [28] as well, resulting in the total reconstruction costs over 300 million Rial (IR).

Additionally, dust storms with saline particles affect agricultural lands and turn them into barren lands. Therefore, the impacts of dust storms are more severe in rural than urban areas [29].

Dust storms can also affect indoor air quality due to the particle entrainment from gaps and openings of building walls. Since people spend over 80 percent of their time inside buildings, the effects of dust storms are indirect but considerably important for human health. In addition, the entry of dust particles into the indoor areas can cause damage to electronic equipment and shorten the lifetime of the furniture. Miri [28], evaluated that over 60 million US dollars had been spent for cleaning, and repairing electrical furniture for four years in the Sistan region because of the physical damages due to the entrained dust particles.

When dust particles begin to move, they cause damage in three situations based on three stages of wind erosion. In the entrainment and deposition state, most of the damages have occurred in the agriculture and infrastructure sectors. But dust in transporting and suspended states affects human health and communication sectors frequently. Table 2 provides a brief review of these effects.

4. NUMERICAL DUST STORM PREDICTIONS

4.1 Reginal Atmospheric Model

To quantify and predict the effects of dust storms and transported particles on the aforementioned various sectors, a common method is a numerical prediction using regional atmospheric models (RAM). RAM are the set of computer programs incorporating the governing equations of mass, momentum, and scalar conservations, particle transports, atmospheric chemical reactions, cloud physics, etc. based on ground boundary conditions determined by land use information, and the global reanalysis data provided by research institutes. [31,32].

WRF model is a RAM designed for mesoscale weather research and prediction by the Mesoscale & Microscale Meteorology Laboratory, National Center for Atmospheric Research [33]. In the WRF model, diagnostic equations of the momentum, moist potential temperature, dry hydrostatics pressure, and mixing ratios of moisture variables (water vapor, cloud water, rainwater, etc.) were employed based on the set of ensemble-averaged Euler equations and energy conservations. It employs the horizontal coordinates and terrain-following hydrostatic-pressure vertical coordinate. [34]

In addition to WRF, the national center for atmospheric research (NCAR) provides the advanced RAM incorporating various chemical reactions of atmospheric particles, WRF-Chem, which can consider the dry deposition of particles, biogenic emissions, and anthropogenic emissions, gas-phase chemical mechanisms, photolysis reactions and so on. The prediction and dispersion of constituents' transport in WRF-Chem also covers the simple transport of dust particles.

Table 2. Various effects of dust storms

Entrainment	Transport	Deposition
Soil loss	Sandblasting of crops	Salt deposition and groundwater salinization
Nutrient, seed and fertilizer loss	Radio communication problems	Reduction of reservoir storage capacity
Crop root exposure	Microwave attenuation	Drinking water contamination
Undermining structures	Transport disruption	Burial of structures
	Local climatic effects	Crop growth problems
	Air pollution	Machinery Problems
	Respiratory problems and eye infections	Reduction of solar power Potential
	Disease transmission (human)	Electrical insulator failure
	(Animals and plants)	
		Disruption of power supplies

"Note. Adapted from Middleton [30]"

4.2 Fundamental Mechanisms of Particle Transports

To select appropriate models of dust transport, an understanding of the fundamental processes of particle emissions and transport is required. Processes of land erosion and transport by wind can be divided into three stages: saltation, creep, and suspension as schematically displayed in Fig. 2.[35]

Some particles' diameters are between 0.5 and 3 mm. Thus, they are heavy to be lifted and wind just can roll them on the surface, and particles are just pushed on the ground. This is called surface creep. Generally, 5 to 25%

of soil texture is lost and carried by wind in a creeping way.

Another process is called saltation. The size of particles that lift by saltation is between 0.1 to 0.5 mm. They are light enough to be picked up by wind but too large to be suspended in the air by wind. Therefore, after lifting they hit the ground and then lift again. Repeating this process caused abrasion on the surface. 50 to 75% of lost soil is carried by wind in this way.

The last is suspension. Some particles are too small that they stay in suspension and are carried long distances. Their size is not bigger than 0.1 mm in diameter. They do not fall unless by precipitation. Additionally, the ratio of soil lost by suspension is 3 up to 4 % [36].

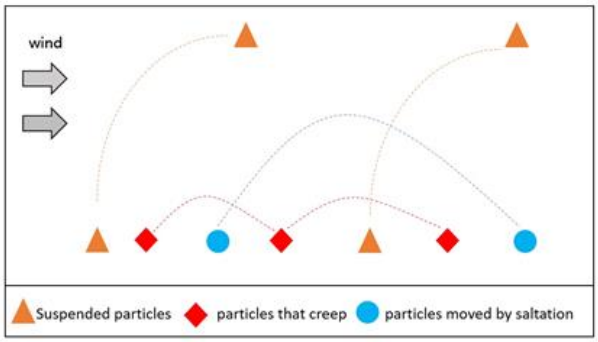

Fig. 2. Three processes of surface erosion by wind [36]

5. CONCLUSION

This paper represents a short review of the present situation in Iran, the social impact of dust storms, and their formation processes. A brief review has been provided of the numerical simulation method for dust-related emissions and environmental consequences associated with dust storms have been summarized and it concluded that it is not limited to one section, and it has various effects. Besides, it revealed that dust storms had influenced public health and many population ranges are vulnerable. Additionally, areas with a potential source of dust storms along with drivers of them within Iran borders has identified through reviewed papers.

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