ISSN: 2538-2152; ECOPERSIA 2023;11(4):369-380.

Wind Tunnel and Threshold Wind Velocity Simulation in Different Land-Units of Sand and Dust Storm Sources

ARTICLEINFO

Article Type
Original Research

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How to cite this article
Salehi F., Panahi P., Abbas H.R. Wind Tunnel and Threshold Wind Velocity Simulation in Different Land-units of Sand and Dust Storm Sources. ECOPERSIA 2023;11(4): 369-380

DOR:
20.1001.1.23222700.2023.11.3.1.5

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Article History
Received: October 22, 2023
Accepted: November 23, 2023
Published: December 20, 2023

ABSTRACT

Aims: Dust is a natural hazard that predominantly occurs worldwide in arid and semi-arid regions. As such, it poses a significant challenge in the Khuzestan Province. This investigation seeks to understand more about the spatial distribution of dust sources based on land-units. Additionally, the study aims to estimate the threshold velocity and soil erodibility in Mahshahr, Omidiyeh, and Hendijan sources using a wind tunnel.

Materials & Methods: Due to the location of the relevant areas in flat and plain regions, the selection of samples and generally the basis of this research is on land types. Thus, in the mentioned study area, 32 points were selected. Then, by taking the average of each land-unit, ten points were selected as the surface soil sample and transferred to the wind tunnel laboratory. Then, the velocity of the erosion threshold and the erodibility of the soil were measured at speeds of 15, 20, 25, and 30 ($m.s^{-1}$) for a period of two (min).

Findings: The results of wind erosion threshold estimation in the studied area showed that the velocity of wind erosion threshold varied from 17-6 ($m.s^{-1}$), and the erosion rate ranged from 30 to 2200 ($gr.m^{-2}.min^{-1}$) at a wind velocity of 20($m.s^{-1}$). The lowest threshold velocity is located in the sedimentary plains of Jarahi-Mahshahr, located in the northwest of the center, and the highest amount of erosion was in the alluviums and Alluvial Fans of Hendijan anticline, located in the southeast of the center.

Conclusion: This study considers the primary factor of dust emission potential based on land-units and reveals the substantial of alluvium, alluvial fans, and alluvial plains as significant contributors to the erodible sediment contributing to dust emissions in the study area. Alluviums and alluvial fans deposited by ephemeral rivers in the eastern foothills of Hendijan contain fine-grained sediments and marl that are highly erodible and must be stabilized early on. Furthermore, according to the results of granulation tests conducted by the Chepil theory, the erodibility of all samples collected from the dust sources of Khuzestan Province was high, and all samples were sensitive to wind erosion. By locating dust sources based on land-units, we can implement more accurate and effective land stabilization methods against wind erosion in alluvium, alluvial fans, and alluvial plains. Furthermore, using the Chipel theory and grain size, we can classify the soil erosion susceptibility of these areas.

Keywords: Land Type; Sedimentary Plain; Erodibility; Arid Land; Threshold Velocity.

CITATION LINKS

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[DOI: 10.22034/ecopersia.11.4.369]

Introduction

Wind erosion is one of the destructive phenomena that causes environmental changes, changes in the quality of the weather, threatens public health, and other economic and social issues in regions with arid and semi-arid climates [1]. Wind erosion is an irreversible destructive phenomenon with irreparable effects [2]. Wind erosion occurs when the wind velocity exceeds the threshold for the erosion of the dry soil surface and when the ground surface is not protected by vegetation cover, low-height obstacles, or other protective measures [3]. In dry and desert areas, soil erosion and particle transport are mainly influenced by wind force [4]. Soil displacement and loss are significant in such areas because soil formation is slow due to the prevailing climatic conditions [5]. Wind erosion first lifts loose and unvegetated soil particles, causing intensified erosion and increased damage during transport. The transported material is ultimately deposited as dunes and hills [6]. Measuring the factors affecting wind erosion in natural conditions of dust hotspots has always been difficult and costly [7]. Additionally, due to the limitations of measuring erosion using sediment traps in desert conditions, the wind tunnel has become one of the alternative and executable methods that researchers have paid attention to [8]. The wind tunnel experiment allows for examining the mechanisms of wind erosion and measuring its intensity in desert and laboratory conditions [8]. Many studies have been conducted on wind erosion and dust storms inside and outside Iran. Ries and Fister estimated the amount of wind erosion in the *Ebro* basin using a portable wind tunnel in 2009. To evaluate the rate of soil loss, three sample locations were evaluated, and the results showed that the areas with unchanged ground surface had the lowest amount of wind erosion [9]. Webb et al. (2016) estimated the wind erosion threshold in five New Mexico locations. The results showed that the wind erosion threshold increased in seasons and locations with higher soil moisture [10]. Marzen et al. (2019) measured the highest rate of wind erosion using a wind tunnel device, which was 908.19 (g.m^{-2}.h^{-1}). They also reported mean erosion rates ranging from 1.55 to 618 (g.m^{-2}.h^{-1}) for the wind-eroded material across all tested sites[11]. Ayazi et al. (2016) investigated the potential of sedimentation in geomorphologic formations in *Aran* using a wind tunnel and the Erosion Function Apparatus.The results obtained from the wind tunnel showed that the highest erosion threshold under natural conditions belonged to the desert plain's hard and dry crust formations [12]. Noorzadehhaddad and Landi (2018) studied the sensitivity of dust production sources to gravel cover on the soil surface in Khuzestan Province. The results indicated that three different gravel covers lacked a statistically substantial difference in mean soil loss during the storm at the studied velocities. However, with an increase in the storm's speed, the average soil loss increased in all tested areas, and soil loss decreased due to the creation of gravel cover on the soil surface [13]. Zamani et al. (2011) studied the effect of particle size distribution on wind erosion intensity and found that increasing particle size reduces wind erosion intensity [14]. Mohammadnia et al. (2022) conducted a study in Gonabad County to measure and estimate the susceptibility of geomorphologic formations to erosion using a wind tunnel. They exposed the surface soil of different formations to wind erosion to estimate their erosion threshold and susceptibility. Their results showed that sandy formations with a threshold velocity of 9 (m.s^{-1}) were the most susceptible to erosion, followed by gentle slopes, elevated hills with a

[DOI: 10.22034/ecopersia.11.4.369]

threshold velocity of 10 ($m.s^{-1}$), which are sensitive areas to wind erosion in the region [15]. Mina et al. (2023) conducted a research study titled "Prediction of Wind Erosion Threshold Velocity Using Portable Wind Tunnel Combined with Machine Learning Algorithms". For this purpose, wind erosion threshold velocity was measured in Fars Province using a portable wind tunnel; wind erosion threshold velocity was predicted by a support vector regression algorithm using easily measurable soil properties; the results showed that the characteristics of soil moisture, the size distribution of soil particles including the mean weight diameter of aggregate and the wind erodible fraction of soils, and organic matter have a high and significant correlation with wind erosion threshold velocity and play a key role in determining the threshold velocity of wind erosion in the region [16]. Khuzestan Province is a major source of dust in the country, with seven active sources. The most critical sources are Mahshahr, Omidiyeh, and Hendijan, which have considerably sensitive soils and are experiencing severe wind erosion [17]. A report from the Forests and Rangelands Research Institute (2019) acknowledged this issue. However, there is a lack of information on the wind erosion threshold velocity and determining the erosion susceptibility of soils based on the land-unit's classification in this area. Land-units that have been created as a result of natural processes have a fixed appearance and definable characteristics [17]. So far, very few studies have been conducted on investigating the erosion threshold velocity and erodibility of soils in the land-units of relevant sources, as well as simultaneous particle size analysis for prioritizing them to achieve practical solutions for erosion management in these areas. Therefore, considering the importance of the subject and the necessity of its investigation, the present study was conducted to determine the erosion threshold velocity and erodibility of soils taken from the dust sources of Mahshahr, Hendijan, and Omidiyeh using a wind erosion measurement device.

Materials & Methods

Study Area

The dust sources of Mahshahr-Omidiyeh-Hendijan are located between 30°12'28" to 30°50'57" north latitude and 48°47'45" to 49°41'41" east longitude and have expanded between Mahshahr and Omidiyeh and Hendijan. This critical area is limited to the west by the Mahshahr-Shadegan road, to the east by the Omidiyeh-Hendijan city limits, to the north by the southern boundary of the agricultural lands of the Zohreh River, and the south by the wetlands of the Persian Gulf coast. It should also be noted that Omidiyeh County is located in the northeast of the area, and Bandar Mahshahr County is located in the west of the region. Finally, Hendijan County is located southeast of the area (Figure 1). In the area of the studied area, it should also be noted that the surface area of this region is equal to 254,825 (ha), and most of the existing waterways are located in the eastern and southeastern parts of the area. In terms of climate, the study area is classified as arid to hyper-arid climates near the coasts. This area has hot summers and moderate winters. Generally, this area has little organic matter in the soil due to the lack of vegetation cover. Except for a part of the North Hendijan wetland, reed-like plants such as *Aeluropus littaralis*, resistant to flooding, drought, and salinity, have formed a relatively dense vegetation cover [17].

Experiments and Computational Methods Collection

Using the land-unit map, maps from the Geological Survey Organization, and field studies, 32 points were identified in the dust sources of Mahshahr, Omidiyeh, and

[DOI: 10.22034/ecopersia.11.4.369]

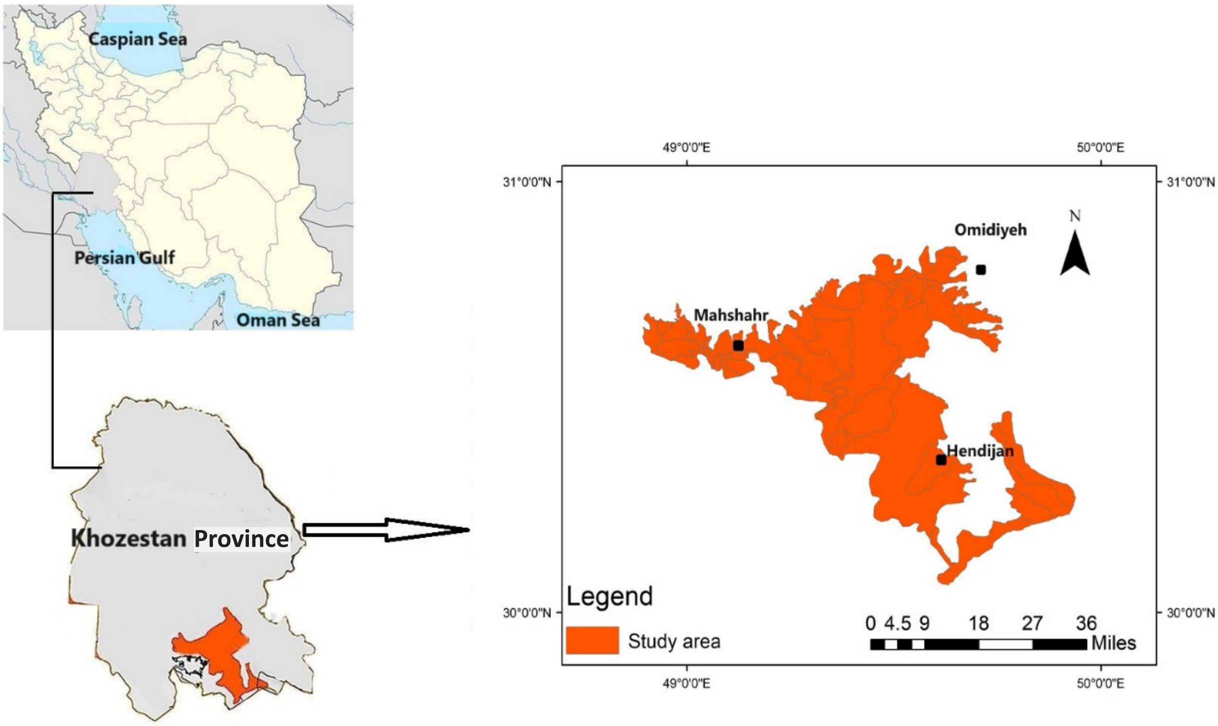

Figure 1) Location of Mahshahr - Omidiyeh - Hendijan dust sources in Khozestan Province

Hendijan, representing various land-units differentiated in the soil map. Finally, ten points were selected as the average of the selected points (Figure 2). The aim of selecting these sampling points was to choose those with the highest diversity in land-units. Using the erosion measurement device, you can measure erosion regardless of the season of erosive winds. Sampling was done in late autumn and before the rainfall of the new water year to have the least amount of moisture and physical and chemical changes in the area's soil. Then, using the Global Positioning System (GPS). Points were identified in the designated study area, and soil sampling was conducted at a depth of 0-3 (cm) from the topsoil (which is affected by wind erosion)[18]. Additionally, using the land-unit map, the land types of the sample points were identified in the study areas (Table 1).

Wind Tunnel Test

The wind erosion measurement device is a type of wind tunnel that has been designed and built in Iran. Using this device, many factors affecting soil erosion susceptibility, including the threshold wind erosion velocity, can be estimated. The wind tunnel device consists of three parts: the regulating motor, the test surface, and the sediment trap (Figure 3). This device can measure wind speeds up to 30 ($m.s^{-1}$). The dimensions of the wind tunnel test chamber are 40x40 (cm), made of Plexiglas. A Pitot tube is used to measure the average speed. Samples taken from the topsoil, almost undisturbed, were placed in galvanized sheet trays measuring 35 × 60 (cm) with a height of two (cm) inside a wind tunnel at Forests and Rangelands Research Institute.

Calculation of Wind Erosion Rate and Threshold Wind Velocity

To estimate the wind erosion threshold velocity, a tray was first placed inside the wind tunnel, and the wind tunnel was turned on at a base speed of four meters

[DOI: 10.22034/ecopersia.11.4.369]

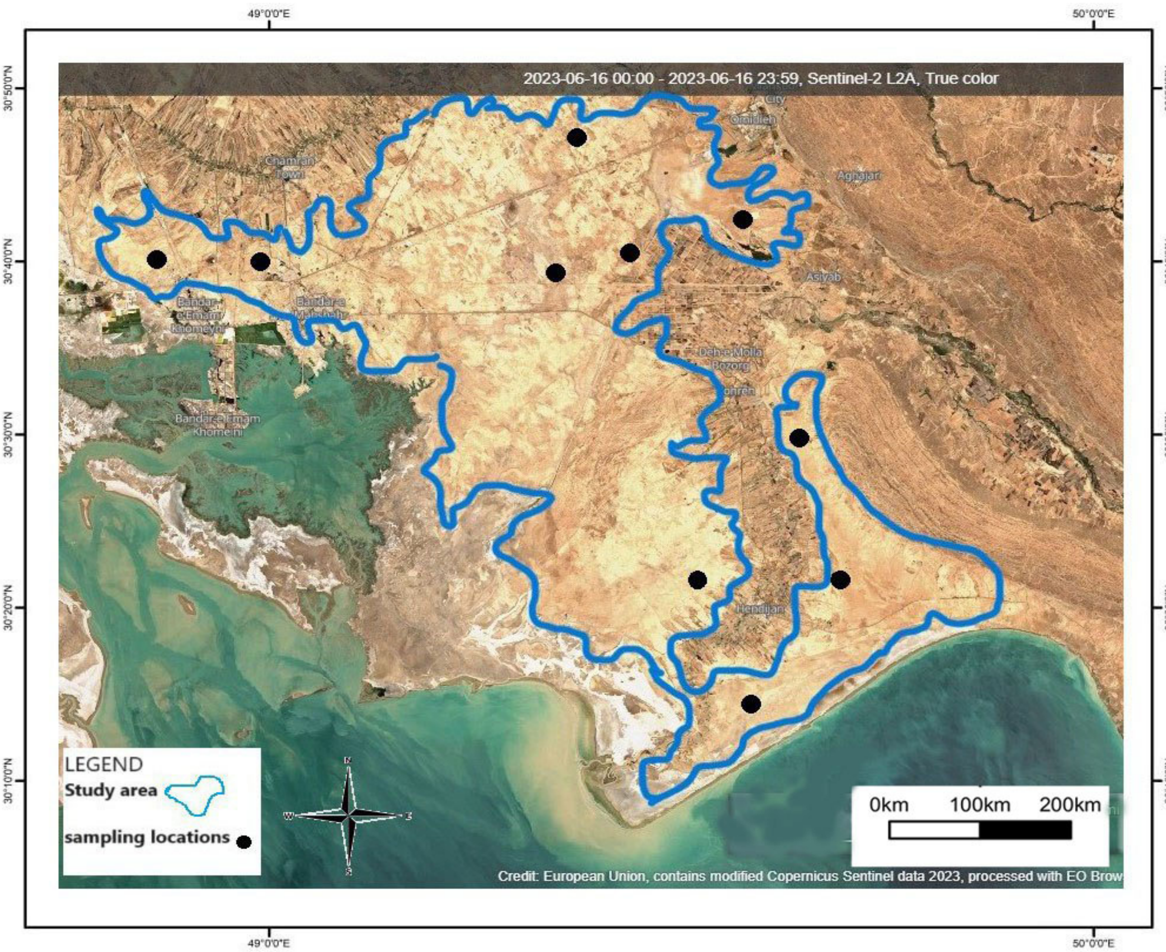

Figure 2) The location of the samples collected from Mahshahr- Omidiyeh -Hendijan dust sources, Khuzestan Province, shown on Sentinel image, 2023.

per second. Then, the speed was increased until it reached the wind velocity threshold. The threshold velocity was measured and recorded by an anemometer at the mouth of the wind tunnel at the first movement of soil particles [18]. Then, the wind erosion rate was measured at wind speeds of 15, 20, 25, and 30 ($m.s^{-1}$) for two (min) [19], and finally, the wind erosion rate of the sample points was obtained using the following equation [20].

$$Qwr = qw/st \qquad \text{Eq. (1)}$$

Where 'Qwr' is equivalent to the amount of wind erosion ($g.m^{-2}.min^{-1}$), and 'qw' is the weight difference of the soil before and after the wind event in (g). 's' is equal to the area of the soil tray in (m^2), and 't' is the duration of the test in (min). After that, the changes in wind erosion were plotted against changes in wind speed in Excel software.

Particle Size Distribution Calculations

Chepil divides soils into five main groups with different potentials against wind erosion in terms of texture, according to (Table 2) [21,22]. Therefore, to determine the potential erosion susceptibility of the samples, the median diameter, mean diameter, and dominant diameter of the particles were determined in (mm) using the Gradistat software (Table 4).

Findings

Investigation of the trend of changes in wind erosion rate VS. changes in wind velocity

The graph of the trend of changes in erosion rate VS. changes in wind velocity at the

[DOI: 10.22034/ecopersia.11.4.369]

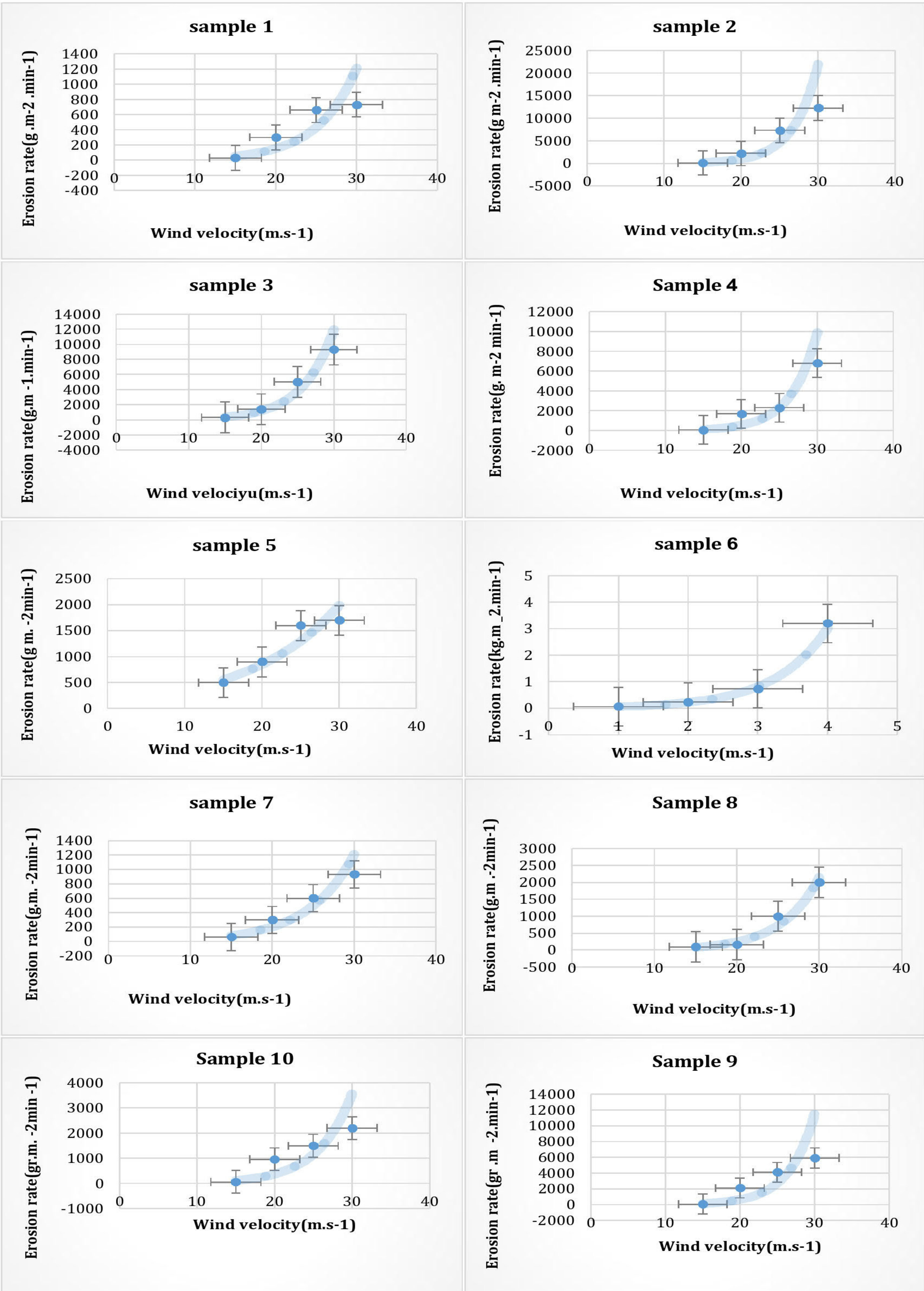

Figure 3) The trend of changes in the amount of erosion VS. the change in wind velocity.

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Table 1) Land types of Mahshahr-Omidiyeh-Hendijan dust sources in Khuzestan Province.

Number	Land Type	Land Area (ha)	Percentage
1	Alluvial plain	4857.84	1.91
2	Alluvial fan	6297.2	2.47
3	Low land	9630.2	3.78
4	Alluvial plain	28100.9	11.03
5	Alluvial fan	131.89	5.18
6	Alluvial plain	12405.2	4.87
7	Low land	1752.8	0.7
8	Low land	56953.3	22.3
9	Alluvial plain	3946.4	1.6
10	Low land	34906.9	13.7

Table 2) The relationship between the diameter of soil particles and the critical velocity of the start of the movement and its erodibility [22].

Classification of resistance	The dominant diameter of the particles (mm)	Wind velocity at a height of 30 ($m.s^{-1}$)	Soil erodibility
1	0. 15 – 0.1	3-4	Very high
2	0.15 - 0.5, 0.05- 0.1	4-4.5	High
3	0.01- 0.05 0.5-1,	5.5- 7	Average
4	0.005 – 0.01, 1-2	7-10	Low
5	2< , 0.005>	10<	Very low

Mahshahr-Omidiyeh-Hendijan dust source is shown in Fig (3). As can be seen, wind erosion increases at wind velocities of 15, 20, 25, and 30 ($m.s^{-1}$) throughout two (min). Under these conditions, higher wind velocities intensify soil loss and lead to an increase in the rate of wind erosion.

The wind erosion threshold varies from 6 to 17 ($m.s^{-1}$). Since the highest threshold velocity was 17 ($m.s^{-1}$), we used the erosion rate at a wind velocity of 20 ($m.s^{-1}$) to compare erosion rates. The minimum wind threshold velocity is related to the Jarahi-Mahshahr sedimentary plain, located in the northwest region with an area of 4,3946 (ha), which is sensitive to wind erosion at a threshold velocity of 6 ($m.s^{-1}$) and the wind erosion rate of 2100 ($g.m^{-2}.min^{-1}$) for a wind velocity of 20($m.s^{-1}$s). The amount of erosion ranged from 30 to 2200 ($g.m^{-2}.min^{-1}$) for a wind velocity of 20($m.s^{-1}$), and the highest erosion rate was related to alluviums and alluvial fans of Hendijan anticline located in the southeast of the center with an area of 6297.2 (ha). The highest wind threshold velocity and the lowest erosion rate were related to the Jarahi-Omidieh sedimentary plain located in the north of the center with

[DOI: 10.22034/ecopersia.11.4.369]

a threshold velocity of 17 ($m.s^{-1}$) and a wind erosion rate of 30 ($g.m^{-2}.min^{-1}$) for a wind velocity of 20($m.s^{-1}$), which is more resistant than other parts (Table 3).

Determining the erosion potential

Table (4) presents the results of determining the erosion potential of soils collected from Mahshahr-Omidiyeh-Hendijan dust sources in Khuzestan Province, based on the Chepil theory. According to Table (4), the erosion potential of soils collected from dust sources is high, and the dominant particle diameter of the soil is 0.5-0.15 (mm) and 0.05-0.1 (mm), which are susceptible particle sizes to wind erosion. Therefore, all samples collected from dust sources in Khuzestan Province are sensitive to wind erosion.

Discussion

This study used the wind erosion measurement device as a relatively easy and accurate method for estimating the wind erosion potential and soil erosion of the lands. This device has been successfully used in other wind erosion studies [23,15,24,25]. The results of Mohammadnia et al. [15] study also support using wind tunnels as an accurate method for estimating soil sensitivity. The land type map should be used to classify land in mountainous regions, and the geomorphology map should be used in plains [20]. Also, due to their location near the Persian Gulf coast, these areas are completely flat. Therefore, this research recommends the classification of land based on land-units. Furthermore, our results showed that the main factor of dust emission potential is based on land-units. These results have been confirmed in other studies [26,27]. We identified three land types (Table 2) commonly found in arid and semi-arid regions, which differ in surface characteristics influencing their susceptibility to aeolian erosion [28]. Soil texture is an essential factor that affects wind erosion and dust emission [29], and wind velocity interacts with soil texture to define the dynamic conditions for wind erosion. During wind erosion, the content of erodible soil particles changes dynamically with increasing blowing time, which inevitably causes changes in wind erosion rates in soils with different textures. Zue et al. also confirmed this topic [30]. The results in the wind tunnel indicate an increase in the

Table 3) The erosion rate at a wind velocity of 20 ($m.s^{-1}$) and threshold velocity of sample points.

Sample number	(UTM)		Threshold velocity of erosion ($m.s^{-1}$)	values of erosion rate ($g.m^{-2}.min^{-1}$)
	X	Y		
1	384522	3349933	10	300
2	381909	3364318	9	2200
3	373403	3335451	10	1400
4	360887	3387676	9	300
5	378342	3389266	9	960
6	354442	3407412	17	30
7	308891	3385214	10	300
8	367477	3349518	10	160
9	319695	3387427	6	2100
10	353280	3385119	12	960

[DOI: 10.22034/ecopersia.11.4.369]

Table 4) Determining the erodibility potential of soils collected from Mahshar-Omidiyeh-Hendijan dust sources in Khuzestan Province.

Sample specification	Median diameter (D^{50}) (mm)	Mean diameter (mm)	Dominant particle diameter (mm)	Soil erodibility
1	0.527	0.383	0.1-0.05, 0.15-0.5	High
2	0.314	0.302	0.1-0.05, 0.15-0.5	High
3	0.417	0.305	0.1-0.05, 0.15-0.5	High
4	0.271	0.290	0.1-0.05, 0.15-0.5	High
5	0.316	0.318	0.1-0.05, 0.15-0.5	High
6	0.298	0.305	0.1-0.05, 0.15-0.5	High
7	0.264	0.265	0.1-0.05, 0.15-0.5	High
8	0.229	0.251	0.1-0.05, 0.15-0.5	High
9	0.290	0.287	0.1-0.05, 0.15-0.5	High
10	0.187	0.205	0.1-0.05, 0.15-0.5	High

Figure 3) Wind erosion laboratory, constant wind tunnel (left) and settings section (top), and sample under test (right).

[DOI: 10.22034/ecopersia.11.4.369]

erosion rate with an increase in wind speed during a two (min) period. Under these conditions, higher wind velocity intensifies wind drift and leads to an increase in the rate of erosion. Moreover, studies on threshold velocity in land-units indicate that the threshold velocity in the studied land-units at the surface level ranges from 6 to 17(m.s^{-1}). In addition to the texture, it depends on the physical properties of the soil surface and the percentage of particles greater than 0.84 (mm). The results obtained from this research indicate that different soils have different sensitivities to wind erosion due to their inherent characteristics. Therefore, the threshold wind velocity for particle movement in different soils is significantly different [31]. These findings are also confirmed by direct measurements in this study. The minimum wind threshold velocity for sedimentary plains in the Jarahi-Mahshahr region, located in the northwest area, indicates the high sensitivity of the soil to wind erosion. A velocity of 6 (m.s^{-1}) is considered the minimum threshold for the sedimentary plain of Jarahi-Mahshahr located in the northwest center, indicating the high sensitivity of the soil in the region to wind erosion. However, the extent of these areas is also considerably large, which can pose a severe threat to the cities of Mahshahr, Omidiyeh, and Hendijan, as well as neighboring population centers. The highest wind erosion rate was related to the alluvial fans of the Hendijan anticline, located southeast of the relevant area. These results are consistent with those of Bullard and Livingston (2002) [32], who consider alluvium and alluvial fans the most important source of dust feeding. In their studies, Katheryn et al. (2022) confirmed this result [26]. The ephemeral rivers deposit fan-shaped alluviums at the foot of the anticline mountains east of Hendijan. The amount of gravel in these alluviums is low because the materials transported by the ephemeral rivers are primarily fine-grained and marl. For this reason, the erosion susceptibility of these soils is high and should be stabilized in the early stages. For example, in the eastern Mojave Desert, the silt deposited on alluvial fans via fluvial processes throughout the Holocene and Pleistocene represents a more significant dust source than the desiccating pluvial lakes [33]. Also, these results are consistent with Abbasi's, which led to preparing a map of land sensitivity to wind erosion in this center. Studies related to particle size distribution and measurement of median, mean, and dominant particle diameters also showed high sensitivity of the samples to wind erosion. Because the dominant diameters of all particles in the samples were 0.5-0.15 and 0.1-0.05 (mm), the potential for erosion susceptibility of all samples in the study area is high. However, in the Chepil theory, only the "particle size" factor is used to determine the soil erosion potential, and other parameters affecting erosion are not considered. Therefore, relying solely on this theory cannot be used to estimate erosion.

Conclusion

The extent of wind erosion-prone areas in the Khuzestan Province necessitates the identification of sensitive areas to wind erosion. The priority of stabilizing sensitive lands is the key to the success of implementing operations to control dust and sand storms. This research considers the main factor of dust emission potential based on land-units. It concludes that the land-unit and surface conditions determining dust emission flux result from interactions between fluvial (water-driven) and aeolian (wind-driven) processes. Reveals the importance of alluvium, alluvial fans, and alluvial plains as significant contributors to the study area's erodible sediment and

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dust emissions. Numerous small and large plains in this region of the country are mainly covered with alluvial deposits and fine-grained sediments of the Karkheh, Dez, Jarahi, Hendijan, and their branches, which are suitable beds for turning into centers of wind erosion and dust storms. In addition to the existence of aeolian sediments, sand hills, and sandbars in various areas of the country from the northwest of Karkheh to the outskirts of Ahvaz, they intensify the phenomenon of dust storms. Finally, it should be noted that the focus of the implementation section should be on stabilizing the peripheral parts of the southeast and northwest of the sources of Mahshahr, Omidieh, and Hendijan, and in the following steps, the eastern, northeastern, and central parts of the region, to be able to stabilize most of the erosion-prone areas and achieve reasonable results in combating wind erosion and dust storms in the shortest possible time. For a thorough understanding and more accurate prioritization regarding stabilizing wind erosion-sensitive areas in the central regions of Mahshahr, Omidieh, and Hendijan, they Recommended carrying out studies on soil and vegetation.

Acknowledgments
Thanks to the National Research Institute of Forests and Rangelands for providing the wind tunnel device, laboratory, and selfless assistance that supported this research.
Ethical permissions: None declared.
Author Contributions: The article extracted from a Ph.D. Dissertation.

Conflict of Interest
The author declares that there are no conflicts of interest regarding the publication of this manuscript.

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