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Monitoring Sand Drift Potential and Sand Dune Mobility over the Last Three Decades (Khartouran Erg, Sabzevar, NE Iran)

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Abstract: Aeolian sediments cover about 6% of the earth's surface, of which 97% occur in arid regions, and these sediments cover about 20% of the world's lands. Sand drifts can harm sensitive ecosystems; therefore, this research has aimed to study wind regimes and the monitoring of sand drift potential and dune mobility in the Khartouran Erg (NE Iran). The study investigated 30 years of wind speed and direction to better understand sand dune mobility processes using the Fryberger and Tsoar methods. The results of the wind regime study showed that the eastern (33.4%) and northeastern (14.3%) directions were more frequent, but the study of winds greater than the threshold (6 m/s) in winter, spring, and autumn indicated the dominance of eastern and northern wind directions. Findings of calm winds showed that winters (40.4%) had the highest frequency, and summers (15%) had the lowest frequency; the annual frequency was 30%. The average wind speed in summers was the highest (4.38 m/s), and, in the winters, it was the lowest (2.28 m/s); the annual average wind speed was 3.3 m/s. The annual drift potential (DP = 173 VU) showed that it was categorized as low class, and the winds carried sand to the southwest. The monitoring of drift potential showed that there was a sharp increase between 2003 and 2008, which could have been attributed to a change in wind speeds in the region. Unite directional index, the index of directional variability, has been alternating from 0.3 to 0.6 for 30 years. Furthermore, monitoring of sand mobility recorded a value from 0.1 to 0.4, and the lowest and highest values were registered from 0.08 to 0.9, with an average of 0.27. Finally, it can be concluded that sand dunes have been fixed for a long time, and the intensity of the mobility index is affected by climate changes.

Keywords: aeolian; arid environment; Fryberger and Tsoar method; land degradation; soil erosion; wind regime

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Citation: Rahdari, M.R.; Rodríguez-Seijo, A. Monitoring Sand Drift Potential and Sand Dune Mobility over the Last Three Decades (Khartouran Erg, Sabzevar, NE Iran). *Sustainability* **2021**, *13*, 9050. https://doi.org/10.3390/su13169050

Academic Editors: Ágota Horel and Zsófia Bakacsi

Received: 19 May 2021
Accepted: 9 August 2021
Published: 12 August 2021

1. Introduction

Arid conditions limit human activities [1,2], so they destroy the sustainability between ecosystem components in more degraded areas [3,4]. The concept of sustainability is related in an ecological principle, and, according to it, sustainability is maintained if the exploitations are commensurate with the capacity [5–7]. Furthermore, the persistence of sustainability in arid area regions require some assessments, such as human factors, natural factors, flora, fauna, and interactions between humans and the environment [8]. Therefore, evaluation and monitoring of climatic indicators, such as wind, play an effective role in maintaining sustainability as an influential factor in arid areas [9,10]. Since the second half of the nineteenth century, wind erosion has been recognized as one of the most widespread environmental problems [11,12], especially in areas with different seasonal climates [13,14] and high levels of human activity [15,16]. This process occurs in all regions of the world, even in humid and sub-humid regions, and has dangerous effects [17,18]. In fact, wind erosion is a major process in arid and semi-arid regions [19,20], and the landscapes created by it include sand sheets and different shapes of sand dunes [21–23]. On a global scale, the importance and risk of wind erosion is less than that of water erosion, but its size and magnitude are sometimes greater than water erosion [24,25].

Aeolian sediments are important to the development of desert landscapes, especially in arid and semi-arid lands [26]. Desert sand seas (also called "Erg") are areas that are created by sedimentation processes in desert areas, with different degrees of vegetation. Ergs have been specified to cover at least 125 km^2 [27], but it is an Arabic-African word that is used by the local population of the northwest of Sahara to describe aeolian deposits of any size. Generally, most sedimentologists and geomorphologists consider an area of about 125 km^2 to identify an Erg, and areas smaller than this are considered to be sand sheets [28]. Furthermore, Reference [19] considered an area of 40 km^2 as the minimum area of an Erg in Iran. According to other studies, Asia has the largest area of Ergs (45.5%), followed by Africa (34.2%), Australia (20%), and America (0.3%) [29]. Research conducted in the framework of the national project of sand dunes in Iran showed that Ergs in Iran were registered in 15 provinces, each province including one or more cities, and they totally covered 56 Ergs over about 4.4 million hectares [30].

Interpretation of wind data has a direct relationship with wind events, as well as wind sediments [31]. The wind regime also has an influential role in the formation and types of sand dunes [32,33]. Wind has been known as an erosivity factor [34], and wind speed and strength are key elements in the wind erosion process. Some studies have also shown that wind erosion has a positive correlation with wind speed [35,36]. Furthermore, the frequency, magnitude, and directional modality of competent winds have been shown to exert a major control on dune form and morphodynamics [37]. Because wind is the main cause of destruction and erosion in desert areas, it is necessary to know enough to prevent its destructive effects [38,39]. Some studies have shown that the interpretation of wind roses, windstorms, and sand drift potential have a great role in the analysis of wind regimes [40,41].

Sand drift potential is a diagram obtained by performing complex algebraic operations and calculating the amount of portable energy of sand by wind [42]. It also shows the wind erosion capacity and the relative amount of sand transported in different directions. There is a regular method [27] for the calculation of sand drift potential that is used in different regions in the World, and it registered significant findings by field study [43–47]. The mobility and stabilization of sand dunes is very important, and, in various studies, some climatic indicators have been expressed. Some researchers, e.g., References [48–50] believed that precipitation and evapotranspiration play an important role, but Reference [51] proved that sand dunes in desert areas are only affected by the wind regime. Furthermore, sediments carried by aeolian processes cause damage and detrimental effects on agricultural lands, residential areas, roads, filling drainage, and irrigation canals, reducing fertility and causing dangerous diseases [11,52,53]. In recent years, numerous numeric models have been developed associated with different aspects of wind erosion processes, such as: wind speed [54–56] and sand mobility [51,57]. Numerical models have been continuously pursued, based on their flexibility and low cost, when a large number of various conditions are of interest [58]. In addition, one of the basic needs of managers is to achieve easy, fast, and practical methods of analyzing wind data to know the wind regime [59].

One of the sensitive areas to wind erosion is northeastern Iran, and there are many Ergs in this region. One of the most important Ergs is the Khartouran Erg, which is located near the city of Sabzevar (NE Iran). Numerous studies on wind regime [60,61], dust [62,63], and wind erosion [64,65] have been published in national journals related to the Khartouran Erg, but there has not been a comprehensive report on wind regimes published in international journals. Studying the wind regime, as well as the monitoring of sand drift potential and sand dune mobility, therefore, are the aims of this research.

2. Materials and Methods

2.1. Study Area

The Khartouran Erg, about 1650 km^2 [66], is located at a distance of 50 km to the southwest of Sabzevar city (NE Iran); due to its proximity to the Sabri village, it is also known as the Sabri Erg (Figure 1).

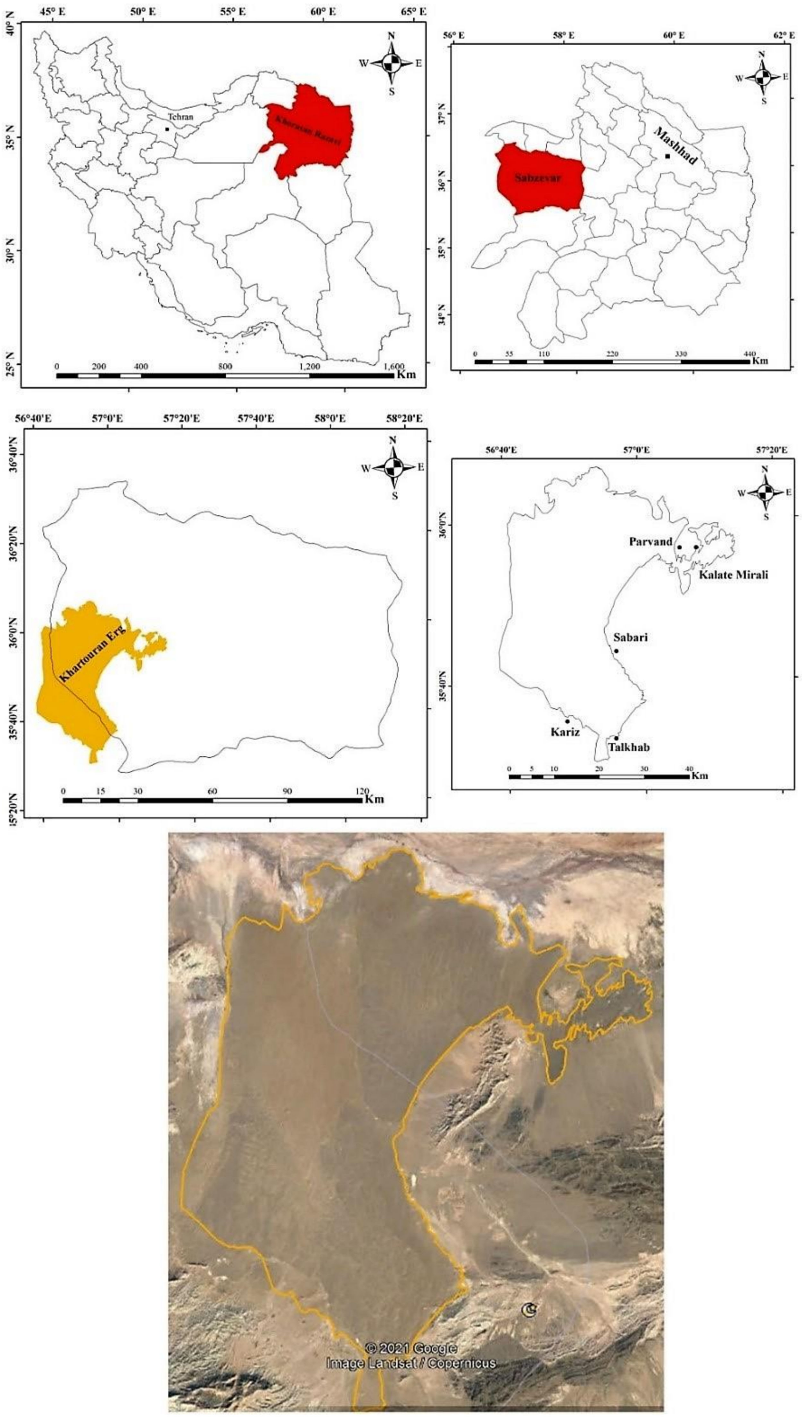

Figure 1. Location of study area in Iran.

The vegetation includes halophyte and psammite plants, such as *Haloxylon persicum* Bunge, *H. ammodendron* (C.A.Mey.) Bunge ex Fenzl, *Tamarix* sp., and *Salsola richteri* (Moq.) Kar. ex Litv. [67]. Analyses of climatic factors have shown that the average annual rainfall of the Sabzevar synoptic station is about 190 mm, and the annual evaporation and temperature are about 2500–3000 mm and 18 °C, respectively. The average wind speed and calm winds are about 3.3 m/s and 27.8%, respectively [68]. Geologically, the area consists of formations from the Cenozoic Era and the Quaternary period (Geologic map, 1:100,000 scale, GSI, Iran). Some of the villages, such as Sabari, Talkhab, Kariz, Parvand, and Kalate Mirali are located in the outskirts of the Khartouran Erg (Figure 1). Furthermore, physicochemical analyses of soil have shown that electrical conductivity (EC) and pH were registered 0.34–0.44 (dS m^{-1}) and 7.8–8.3 [69], respectively.

2.2. Methodology

2.2.1. Data Sources

Hourly wind data from 1986 to 2016 collected at the Sabzevar synoptic station in north-eastern Iran were collected from the Iranian Meteorological Organization (IRIMO) [68].

2.2.2. Wind Analysis, Sand Drift Potential, and Sand Mobility

A wind rose (WR) of the dataset was analyzed using MATLAB 2018 and WRPLOT (Version 8.2) software. The Fryberger method [27] was selected to analyze the whole wind dataset as the following:

$$DP = V^2 (V - V_t) \times T \quad (1)$$

where DP is the amount of sand drift based on the vector units (VU), V represents the average wind velocity at a 10 m height (m/s), V_t is the impact threshold of wind velocity (m/s), and T is the time the wind blew expressed as a percentage in a wind summary. A drift potential value higher than 400 VU indicates a high-energy wind environment, values less than 200 VU represent a low-energy wind environment, and values in between are classified as intermediate wind energy environments.

Other parameters of interest are the resultant drift potential (RDP), the resultant drift direction (RDD), and the unit directional index of wind estimated by vector analysis [27]:

$$RDP = \sqrt{(C^2 + D^2)} \quad (2)$$

$$RDD = \text{Arc tan } (c/n) \quad (3)$$

$$UDI = (RDP/DP_t) \quad (4)$$

$$C = \sum_{i=1} (DP_i) \sin \theta_i \quad (5)$$

$$D = \sum_{i=1} (DP_i) \cos \theta_i \quad (6)$$

where θ_i represents the midpoint of wind speed class i direction, and Vt is assumed as 6 m/s based on studies in Egypt [70], Iran [40,42], and Algeria [71]. The unit directional index (UDI), and index of directional variability [27], is the ratio of the resultant drift potential (RDP) to the drift potential (DP) of sand. Lower UDI values indicate greater directional variability of wind, whereas higher UDI values mean that the wind comes from the same direction. In addition, calm winds include winds with speed less than 0.51 m/s [27,40], and windstorm is winds with speed more than wind erosion threshold speed [40]. Finally, C and D are sand drift potential in vertical and horizontal components.

Several indices of dune mobility exist that include erodibility and erosivity parameters defined by climate data [72], some of which are based on precipitation and evaporation [48–50] and wind data [51,57]. So, Tsoar [51] presented a new indicator for evaluating sand mobility based on the research of References [48–50]. He believed that precipitation and evapotranspiration would not play an important role in the mobility of sand in desert areas. It was shown that sand was known as an inert soil that did not favor vegetation [73]. Furthermore, in previous studies, the magnitude and direction of the wind had not been considered. Then, Tsoar [51] presented the mobility of sand (M) as the following equation:

$$M = DP/(1000 - (750\ RDP/DP)) \quad (7)$$

Based on Equation (7), in areas with more than 50 mm annual rainfall on average, if the amount of M is greater than one, the sand dunes are non-vegetated and active, and, if the amount of M is less than one, the sand dunes are stabilized and inactive.

3. Results

3.1. Wind Analysis

The results of the wind rose analysis showed that the easterly and northeasterly directions, as well as the summer and autumn seasons, had the highest frequency (Figure 2a). It was also observed that the southeasterly direction and the winter season had the lowest wind frequency. Monthly results of the wind rose showed that the heights and lowest average winds frequency were in the east (33.45%) and south (1.44%), respectively (Table 1). Furthermore, the highest and lowest winds frequencies were recorded at 43.20% and 2.12%, respectively. The highest and lowest standard deviations were also related to the easterly (6.96) and northwesterly (0.84) directions (Table 1).

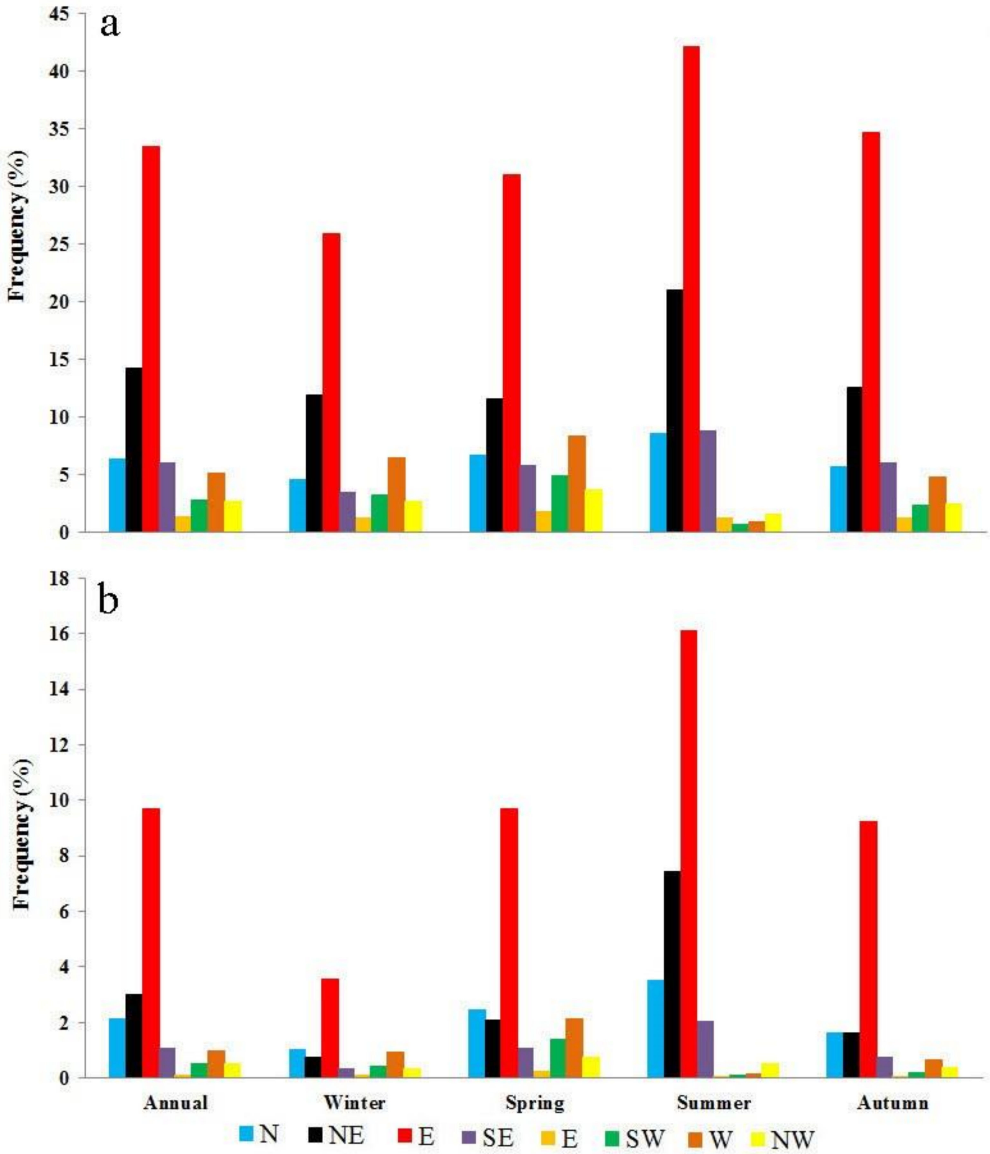

Figure 2. Annual and seasonal frequency of wind rose (**a**) and wind storm (**b**).

Table 1. Monthly distribution of wind regime at the Sabzevar synoptic station (%) (1986–2016).

Month	N	NE	E	SE	S	SW	W	NW	Calm Winds
January	3.56	12.54	26.22	3.33	1.35	2.9	5.90	2.59	41.61
February	6.14	11.92	26.54	4.05	1.59	3.9	7.84	3.36	34.66
March	5.96	12.02	27.50	4.66	1.65	5.32	9.47	3.8	29.62
April	5.76	10.77	30.48	5.13	2.12	5.75	9.25	3.91	26.83
May	8.17	11.89	35.16	7.71	1.77	3.61	6.29	3.38	22.02
June	9.15	18.63	42.36	7.73	1.50	1.36	1.95	2.30	15.02
July	7.88	24.26	42.59	8.83	1.15	0.44	0.28	1.29	13.28
August	8.57	19.93	41.55	9.87	1.23	0.37	0.37	1.23	16.88
September	6.01	12.93	43.20	9.08	1.25	1.59	2.62	2.01	21.31
October	6.07	12.43	33.50	5.60	1.26	2.21	5.87	2.86	30.20
November	5.06	12.48	27.37	3.45	1.29	3.36	5.91	2.66	38.42
December	4.08	11.29	24.89	3.19	1.06	2.95	5.68	2.31	44.55
Min	3.56	10.77	24.89	3.19	1.06	0.37	0.28	1.23	13.28
Max	9.15	24.26	43.20	9.87	2.12	5.75	9.47	3.91	44.55
Average	6.37	14.26	33.45	6.05	1.44	2.81	5.12	2.64	26.74
Standard deviation	1.68	4.08	6.96	2.35	0.29	1.65	3.02	0.84	10.04

The annual results of windstorms indicated that easterly and northeasterly winds dominated the region (Table 1). Northern winds were dominant over northeasterly in spring and autumn. All-season easterly winds also had the highest frequency in the region (Figure 2b). Results of calm winds showed that winters (40.4%) had the highest frequency, and summers (15%) had the lowest frequency; the annual frequency was 30%. The average wind speed in the summer was the highest (4.38 m/s), and, in the winter, it was the lowest (2.28 m/s); the annually average wind speed was 3.3 m/s (Figure 3).

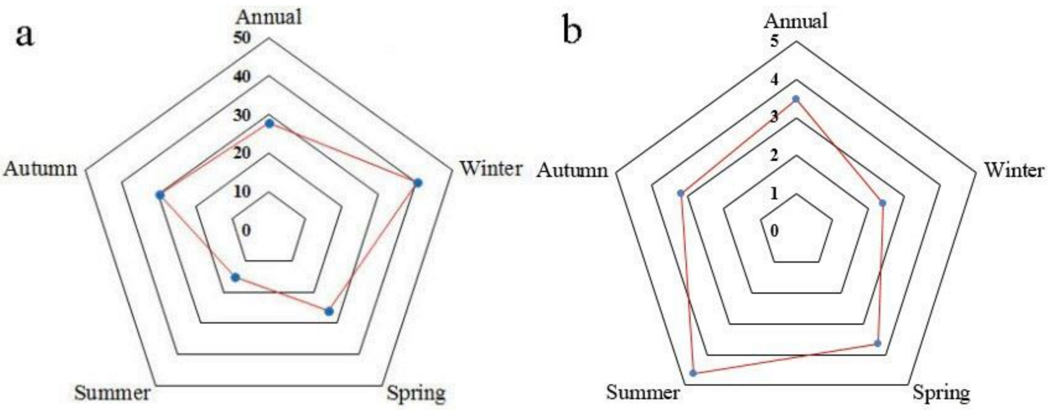

Figure 3. Annual and seasonal frequency of calm winds (%) (**a**) and average wind speeds (m/s) (**b**) at the Sabzevar synoptic station.

3.2. Sand Drift Potential and Mobility

A monthly assessment of sand drift potential showed that December (DP = 2.67) and June (DP = 29.80) had the lowest and highest values, respectively. During all months of the year, the direction of sand drift was also to the southwest, and it indicated the dominance of easterly, northerly, and northeasterly winds in the region (Figure 4). The highest and lowest value of the unite directional index were 0.78 and 0.05 in July and March, respectively (Figure 4), which indicated a difference in the wind regime over the year. Also monthly distributions of sand drift potential showed in Table 2.

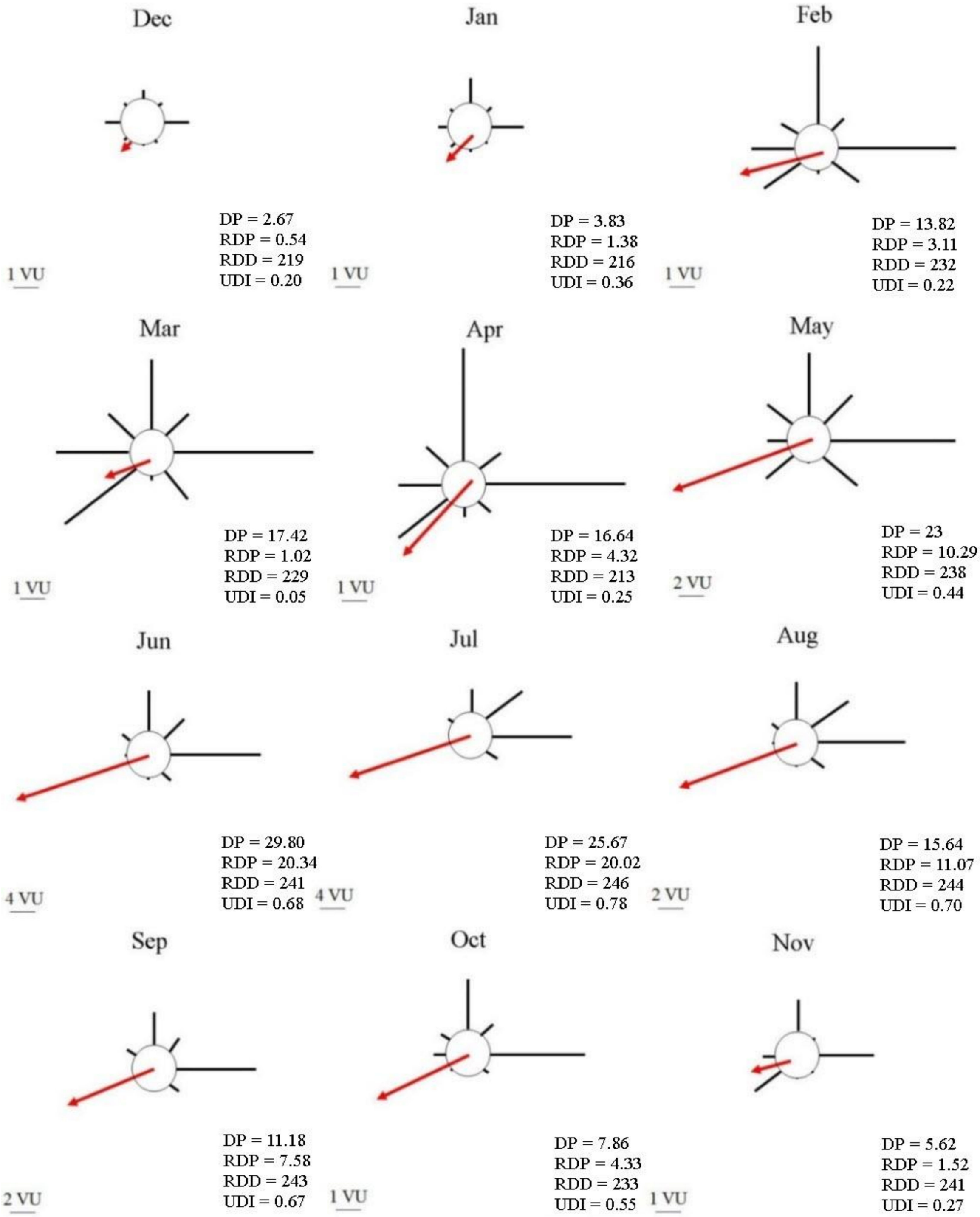

Figure 4. Monthly drift potential at the Sabzevar synoptic station.

The seasonal drift potentials were recorded from 20.3 VU (winter) to 71.1 VU (summer). The UDI was also registered from 0.20 (winter) to 0.72 (summer). Furthermore, changes in the sand drift potential are as follows: summer > autumn > spring > winter (Figure 5). The annual drift potential was 173 VU, which categorized it as low class, and the winds carried sand to the southwest (RDD = 239) (Figure 6).

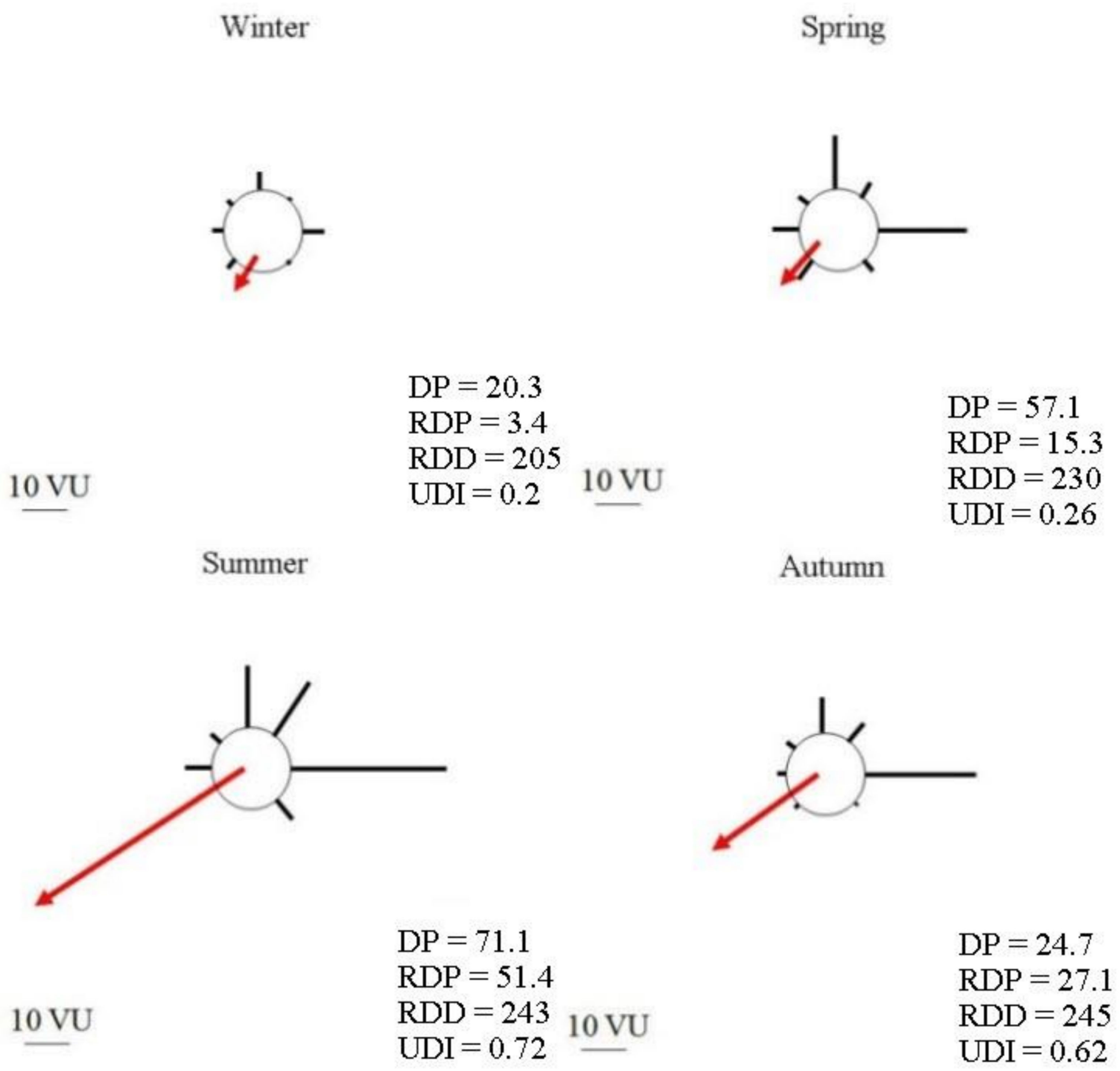

Figure 5. The seasonal drift potential at the Sabzevar synoptic station.

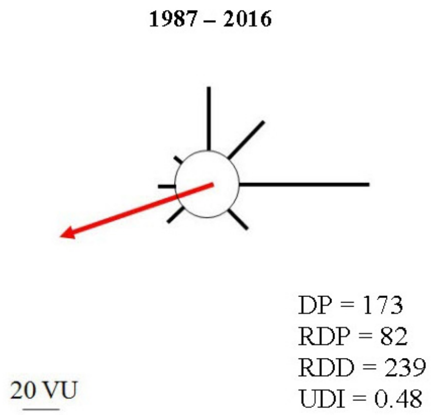

Figure 6. Annual drift potential at the Sabzevar synoptic station.

Table 2. Monthly distribution of drift potential in Sabzevar synoptic station (%).

Month	N	NE	E	SE	S	SW	W	NW
January	27.63	9.51	33.92	1.37	3.23	8.34	9.27	6.94
February	22.70	4.24	34.11	7.71	1.09	13.00	11.70	5.49
March	16.13	4.11	32.47	4.68	1.11	20.07	16.60	4.84
April	26.93	3.56	33.96	2.83	2.08	13.19	10.02	7.49
May	22.12	9.44	41.63	7.44	0.44	5.31	7.67	5.97
June	22.57	16.65	49.34	5.08	0.14	0.88	1.38	3.97
July	14.18	28.24	49.07	5.81	0.08	0.04	0.04	2.56
August	19.48	21.35	45.59	8.76	0.79	0.02	0.06	4.00
September	23.31	10.60	55.20	4.10	0.06	0.96	0.84	5.02
October	26.63	7.46	48.60	3.29	0.08	1.52	6.48	6.00
November	22.33	7.71	39.58	1.55	0.73	19.05	8.19	0.93
December	13.26	5.97	37.21	5.94	0.23	6.02	21.56	9.82
Min	13.26	3.56	32.47	1.37	0.06	0.02	0.04	0.93
Max	27.63	28.24	55.20	8.76	3.23	20.07	21.56	9.82
Average	21.44	10.74	41.72	4.88	0.84	7.37	7.82	5.25
Standard deviation	4.61	7.29	7.33	2.28	0.92	7.04	6.46	2.22

The monitoring of drift potential showed that there was a sharp increase between 2003 and 2008, and it could be attributed to a change in wind speeds in the region. In addition, the UDI alternated between 0.3 to 0.6 during 30 years at the Sabzevar synoptic station, and the highest and lowest values were registered between 0.63 and 0.29, respectively (Table 3). Monitoring of sand mobility showed a sharp increase between 2003 and 2008, and, in other years, it recorded values ranging from 0.1 to 0.4 (Figure 7). The lowest and highest values were registered from 0.08 to 0.9, with an average of 0.27 (Table 3).

Table 3. Monitoring of DP, RDP, UDI, and Mobility index from 1987 to 2016.

Year	DP (VU)	RDP (VU)	UDI	Mobility
1987	61	18	0.29	0.08
1988	135	63	0.46	0.21
1989	114	59	0.51	0.19
1990	145	85	0.59	0.26
1991	95	51	0.54	0.16
1992	97	34	0.34	0.13
1993	102	41	0.4	0.15
1994	192	108	0.55	0.33
1995	134	55	0.41	0.19
1996	93	59	0.63	0.18
1997	103	29	0.28	0.13
1998	139	57	0.41	0.20
1999	101	44	0.44	0.15
2000	89	39	0.49	0.13
2001	64	29	0.45	0.10
2002	134	50	0.37	0.19
2003	65	26	0.39	0.09
2004	125	48	0.38	0.18
2005	176	94	0.53	0.29
2006	400	209	0.52	0.66
2007	362	173	0.47	0.56
2008	539	289	0.53	0.90
2009	300	176	0.58	0.54
2010	225	133	0.59	0.40
2011	199	125	0.62	0.38

Table 3. *Cont.*

Year	DP (VU)	RDP (VU)	UDI	Mobility
2012	220	113	0.51	0.36
2013	151	85	0.56	0.26
2014	147	67	0.47	0.22
2015	165	103	0.62	0.31
2016	132	68	0.51	0.22
Min	61	18	0.28	0.08
Max	539	289	0.63	0.90
Average	166.8	84.33	0.48	0.27
Standard deviation	105.48	60.3	0.09	0.18

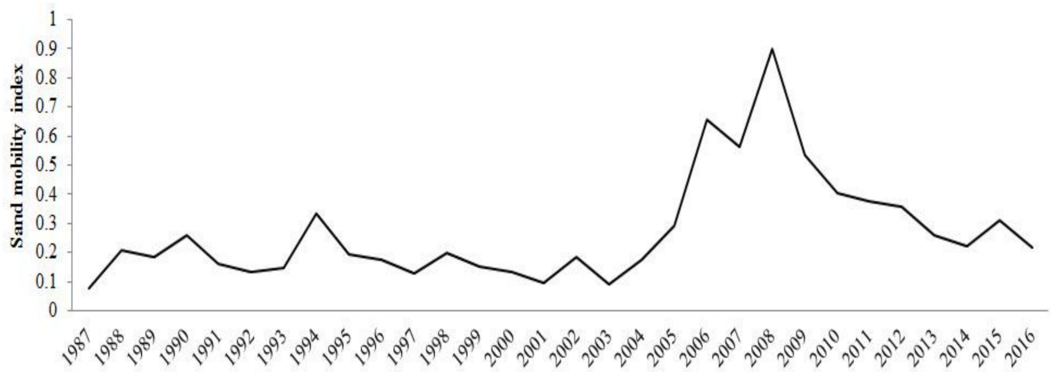

Figure 7. Monitoring of sand mobility index.

4. Discussion

4.1. Wind Analysis

The wind regime indicated that easterly winds were dominant in the region, but, in winter, spring, and autumn, northerly winds also had an effect. Indeed, this effect is important in the formation of sand dunes, and some researchers have reported on the influence of northernly winds on the formation of the Khartouran Erg [65–67]. Some studies in Iran had shown that the incidence of dust was higher in spring and summer [64], and the average number of dusty days was 15–17-days year^{-1} [63]. Furthermore, the results of this research showed that the predominance of the wind regime was in spring and summer.

In the analysis of wind regimes, the role of windstorms (higher than the threshold speed in the wind erosion process) was very important, and this has been evaluated in several studies in Iran [42,74], Nepal [75], and the United States [76]. In addition, soil erosion was affected by wind speed, and it was one of the most important aspects of land degradation that causes dust storms, as well as nutrient cycles, in terrestrial ecosystems [77,78]. Studies of the wind regime in Algeria had been shown that the western Hautes Plaines had become the victims of more and more frequent sandstorms [71]. Furthermore, wind regime and climate change had been evaluated for controlling of sand dunes development, and the findings showed that there was a complex relationship between wind regime and climate change [33].

A study mentioned that Sarakhs, Gonabad, and Sabzevar cities have the dustiest days in northeastern Iran [79,80] in spring, and it was closely consistent with the results of the wind regime analysis of this research. In addition, research has identified the sources of dust in Iran, and it has been reported that the northeasterly regions of Iran are in the middle class of the dust source in Iran [81,82], which is due to the geological structure of the wind regime. Calm wind percentage analyses have indicated that the highest percentage occurred in winter, autumn, spring, and summer, respectively; the long-term average of the region was about 27.8%, which was in accordance with a national study [83]. Seasonal analyses of the wind regime were the same as the results of a study on the wind regime in northeastern Iran [83]. Reports have also shown that one of the first wind farms in Iran was built in Binalood [84], and it is near the Sabzevar.

4.2. Sand Drift Potential and Mobility

Monthly monitoring of sand drift potential indicated that the study area had seasonal variations which increased in autumn, spring, and summer, respectively, as well as having the lowest amounts in winter. Therefore, the process of wind erosion and sediment detachment increased during the summer and spring due to a lack of vegetation [85] and rainfall [86] in the region. Furthermore, monthly and quarterly studies of sand drift potential showed that UDI was higher in the summers (0.72) and autumns (0.62) relative to winters (0.2) and autumns (0.26), and it can be said that the region had the climatic conditions for the formation of barchanoid dunes compared to other types; one research study also indicated that barchanoid and longitudinal dunes have been common in the Khartouran Erg [67]. The impact and importance of wind erosion varied in different parts of a desert because there was a lot of variability in wind energy [26], and the analysis of wind energy-based sand drift potential was significant evidence for evaluating these changes. Fryberger [27]-based conducted analyses of the wind regime in the desert regions of the world and interpretation of Landsat satellite images (Figure 8), showing that Khartouran Erg had a high capability to transverse dunes. It should be noted that the formation and type of sand dunes were particularly affected by the wind regime, so multi-directional winds were very suitable for forming star dunes, in which $0.4 < UDI < 0.8$ transverse dunes had more frequency.

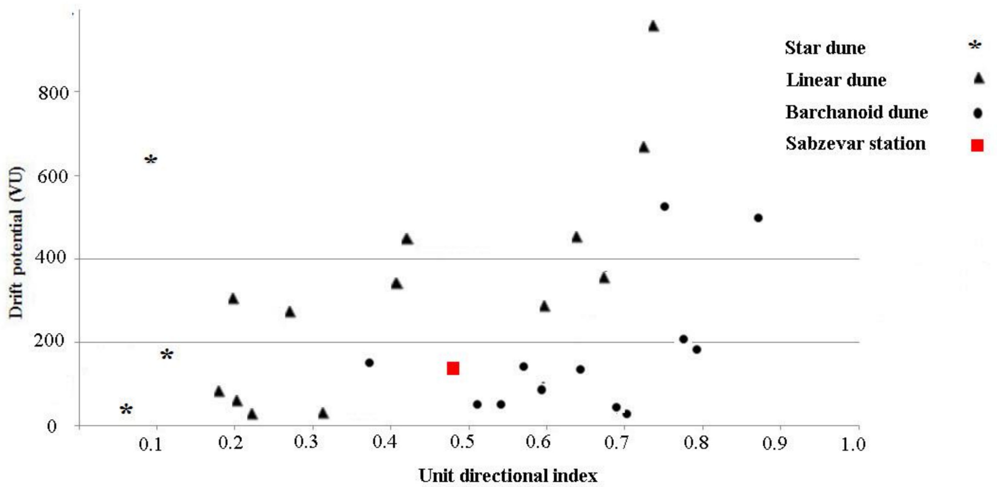

Figure 8. Comparison of Sabzevar wind regime with other sand dune regions [27] in the world.

Annual sand-drift assessment indicated that the Khartouran Erg was classified as belonging to the low class, as mentioned by Reference [50]. Low intensity of sand drift potential has also been caused by the formation of the highest dunes in the edge of the region, and one study noted that the highest sand dunes (≈100 m) are located in the southeastern edge of Khartouran Erg [67]. Monitoring the mobility of sand dunes indicated that $M < 1$ in the last three decades, and, because the rainfall exceeded 50 mm, the sand dunes of Khartouran Erg were not mobile. Tsoar [51] pointed out that, when $M < 1$, the loss of vegetation was due to human activities. Furthermore, one of the most influential factors for the development of the wind erosion processes in Khartouran Erg was the lack of management of stocking rates (camels and goats) in the rangelands and the migration of pastoral nomads from the southern regions of Iran [65]. Finally, it should be noted that the results of non-activity of Khartouran Erg in relation to the Tsoar index are consistent with a research [87].

4.3. Evolution of Sand Dunes in Khartouran Erg

In general, four factors, such as topographic, climate, sand sources, and wind energy, were very important in contributing to the formation of Ergs in the world [28], but national research has shown that topographic factors played an important role in Iran [30,66]. One research study showed that the origin of the sediments was from some oueds (a valley, gully, or stream-bed in northern Africa and southwest Asia that remained dry, except during the rainy season), such as Sabri, Dochahi, and Kal-e-Shor, as well as some lands sensitive to wind erosion at the margins of the Khartouran Erg [67]. Another study showed that some sand dunes expanded over time near of Khartouran Erg [88], but its activity during a year varied according to the regime in the region. In addition, a national research study based on remote sensing showed that, during the last 42 years, Ergs have not developed, and this has raised the theory of non-displacement of Ergs in Iran [89]. Furthermore, a study showed that sand dunes in the region are one of the main habitats of *H. ammodendron* in Iran, which is known as an important heritage reserve. Considering the importance of wind erosion in the development of sand dunes, it should be noted that about 72% of the erosion rate in the region is affected by wind erosion processes (10,200 $m^3/km^2/year$), and water erosion (4100 $m^3/km^2/year$) has a lower rate [90], so paying attention to wind erosion control with respect to native plants in the region will play an effective role in controlling wind erosion [91]. The difference in wind regime can be attributed to topographic conditions, as well as regional and local winds, which varied from region to region [26]. Regarding the similarity of the wind regime in Khartouran Erg with other Ergs in the World, we can refer to Figure 8, which showed a global trend on sand dunes formation. Evolution in sandy areas is directly related to changes in wind regime, and this can be further investigated in detail by setting continuous monitoring stations along the Ergs. Due to the wind regime and wind speed, wind farms in the region can be used for clean energy [92], but the high abundance of sand reduce the sustainability and continuity of clean energy production [93]. Furthermore, sand resources are used as a raw material for making silicon, and silicon wafers can be used in the manufacture of solar panels [94], which can make a great contribution to the sustainable and clean development of energy in northeastern Iran in, which it is a severe threat. In addition, in other studies in the World, changes in wind speed have been considered as a result of unstable management [95,96], so that decreased biological operations have reduced the surface roughness and increased wind speed [97].

5. Conclusions

In this study, the wind regime and sand drift potential and mobility of the Khartouran Erg in northeastern Iran were assessed. It should be noted that the sand dunes are not active because of DP < 200 and M < 1. Monitoring of indicators based on wind speed has shown that there has been an increasing trend, especially from 2003 to 2008, which could be related to a sudden increase of wind speed in the region. According to the studies of other sand dune regions in the world, the evaluation of the wind regime indicated the formation of barchanoid dunes, following a global trend. Instead of using wind data only, future studies should look into the installation of some sand traps in order to measure the sand flux in Khartouran Erg. In addition, it is strongly suggested that more studies be conducted on sand dune evolution by modeling future climate change. Finally, the adoption of biological programs it recommended, precisely perpendicular to the east direction, as well as control of the entry of livestock due to the identification of several oueds and migration of pastoral nomads in the region.

Author Contributions: Conceptualization, methodology, software, validation, formal analysis, and writing—original draft preparation (M.R.R.), writing—review and editing (M.R.R. and A.R.-S.). All authors have read and agreed to the published version of the manuscript.

Funding: This work has been financially supported by the University of Torbat Heydarieh and the grant number is 1400/01/21 96.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data that support the findings of this study are available from the corresponding author on reasonable request.

Acknowledgments: Authors are appreciative of I.R. of Iran Meteorological Organization (IRIMO) for providing climate data. ARS was supported by the Foundation for Science and Technology (FCT) and CIIMAR through their institutional funding (UIDB/04423/2020, UIDP/04423/2020) and research contract (CEEIND/03794/2017).

Conflicts of Interest: The authors declare no conflict of interest.

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