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Determining the Risk of Sand Transportation to Residential Areas around Kashan Erg using Anemometry Data Analysis

A. Tavakkolifard[a], H. Ghasemieh[b]*, A.A. Nazari Samani[c], N. Mashhadi[d]

[a] M.Sc. Graduated, Faculty of Natural Resources and Geoscience, University of Kashan, Kashan, Iran
[b] Faculty of Natural Resources and Geoscience, University of Kashan, Kashan, Iran
[c] Faculty of Natural Resources, University of Tehran, Karaj, Iran
[d] International Desert Research Center (IDRC), University of Tehran, Tehran, Iran

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Abstract

The Kashan erg is one of the most important sand dune complexes in Iran. Being affected by wind erosion, the erg's borderlands face numerous problems as a result of sand movement. To evaluate the risk of sands moving into residential areas near the Kashan erg, anemometry data from synoptic stations located in Kashan, Ardestan, Meimeh, Naeen, and Qom were collected and analyzed to calculate the sand rose and to determine the amount and direction of sand transfer. Annual and seasonal data from the past 40 years were studied. Based on the position of different stations and the prevailing direction of erosive winds at the stations under study, Kashan is more vulnerable to sand transfer than other areas, because the prevailing direction of erosive winds in Kashan is from the northeast and west, and the Kashan erg is located exactly northeast of Kashan. In this area, wind forces result in sand movement towards Kashan. Thus, Kashan is much more exposed to moving sand than the cities of Ardestan and Naeen. The cities of Qom and Meimeh are not at risk from moving sands. According to the morphology of the erg and sand rose calculations, most sand transfer occurs first in the erg's vast sand dunes and then in the compound dunes in the center; it occurs less in the transverse dunes located north of the erg and in the linear ones south of it.

***Keywords**:* Moving sands; Wind rose; Storm rose; Sand rose; Kashan Erg

1. Introduction

Wind is the result of the horizontal displacement of air and is not synonymous with vertical movement in the atmosphere (Bafkar & Mojarradi, 2009). Wind is a fluid that influences 28% of land in the world (Saqaa & Saqaa, 2005). The most important characteristics of wind are its speed and direction (Refahi, 1999). Identifying prevailing winds is an important factor in controlling wind erosion. Methods used to evaluate wind direction and sediment sources in different places include wind rose surveying (Ghanei Bafghi & Yarahmadi, 2010), determining wind direction by the shapes of sand dunes (Ahmadi et al, 2001; Ahmadi et al, 2002), surveying the genetic relationship between sand dune sediments and the sediments surrounding them (Motamed, 1988; Motamed, 1996), and collecting questionnaires from area residents (Ghanei Bafghi & Yarahmadi, 2010). Different factors affect wind speed and direction, most importantly seasons, day and night, distribution of land and sea, mountains, and the presence of trees and buildings.

Among the different kinds of wind, only powerful winds have erosive activity. So, a wind’s speed is more important than its frequency. In addition to identifying prevailing winds, determining erosive winds is very important in controlling wind erosion. Wind is the main cause of wind erosion in the world, especially in dry lands. In order to prevent it from causing damage, this factor and its specifications must be investigated (Refahi, 1999).

* Corresponding author. Tel.: +98 361 5913227,
Fax: +98 361 5913222.
E-mail address: h.ghasemieh@kashanu.ac.ir

Sand is the sediment most commonly carried by wind (Motamed, 2000). In general, sand accumulates in places where wind energy is sufficiently reduced along the sand movement (Fryberger et al, 1979). Sand deposits form around 6% of the Earth's land surface, and 97% of these deposits are in dry areas and large fields of sand. About 20% of the Earth's dry areas are covered by sand (Lancaster & Hallward, 1984). Sand dune mobility causes destructive effects on infrastructures and in populated areas. In order to solve this problem, it is necessary to know the regional wind processes (Webb et al, 2006). Sand rose plotting, first proposed and used by Fryberger and Dean (Bagnold, 1941), is one statistical method used in wind analysis. The effect of wind erosion on sand dunes is determined by three conditions: a) a wind speed higher than the threshold wind velocity; b) wind frequency with speed higher than the threshold wind velocity; and c) the variability of the wind. Low variability of wind direction leads to an unidirectional wind, and total wind energy is distributed over the surface of the sand dunes. Uni Directional Index (UDI) is the Resultant Drift Potential (RDP) to Drift Potential (DP) (UDI=RDP/DP). When this number is close to one, there is more unidirectional wind; when it is close to zero, winds are powerful and multidirectional (Al-Awadhi et al, 2005).

Lancaster (1988) studied the sand transfer square in ergs and sand dunes and increases in their heights in the Namib desert. In his study, he divided the area dunes into two parts, A (first dunes) and B (new dunes), and concluded that in group A because of their increased height and reduced capacity to carry sand, the high dunes had consequently become more huge, while the smaller dunes had more power for sand transfer and showed less inclination for growth. In group B, the small dunes were more growth inclined, so their annual sediment transfer was less than that of the big dunes. Gradually, however, increased height and achieved proportional stability caused their ability to transfer sediment to increase (Saremi Naeeni et al, 2007).

Wang et al. (2001) investigated the relationships between morphology and air follow sand and particle size in sand dunes transmission in Taklimakan. They concluded that particle size and slope control the threshold shear velocity and sand flows on the stoss side of the dunes. The decreased threshold shear velocity and unsaturated sand flows are the main reasons why sands are not deposited at the toe of the dunes. Particle size controls sand flux through its influence on the aerodynamic roughness elements and threshold shear velocities. The sand flux is different for dune surfaces with different particle size distributions (Wang, 2001).

Negaresh et al. (1387) analyzed the process of sand dune advancement in the eastern Systan desert. They examined the morphology of area sand dunes and concluded that these dunes are among the new sand dunes in Iran and that their shaping is due to agriculture activities and excessive human interference in and manipulation of the natural environment (Negaresh & Lotfi, 2008).

2. Material and methods

2.1. The study area

The study area was the Kashan erg, one of the most important collections of sand in Iran. It is exactly next to Iran's Salt Lake and within the Masileh basin. It has a crescent-shaped arc, the convexity of which faces west. The length of external convexity is about 115 Km by considering the Buklieh sand dunes in northwest and the length of internal convexity is about 60 Km. Kashan city is located in its west and joints from the south arc to the Ardestan Erg sand collection located in the east of Ardestan and stretches to the north of Naeen in the form of a narrow collection with about 6 to 8 Km width and more than 240 Km length, in the way that it loses its adherence toward the east and southeast (Yamani, 2001).

2.2. Data and Analysis

2.2.1. Data collection

Anemometry data from synoptic stations located near the Kashan erg, including stations located in Kashan, Ardestan, Naeen, Meimeh, and Qom, were collected during the statistical period of 1992-2008. A map of the study area was prepared using aerial photography, Quickbird satellite images, and field observations (Figure 1).

2.2.2. Data analysis

Data was analyzed using WRplot and Sand Rose Graph software. Wind, storm, and sand roses of the studied stations were drawn, and the direction and frequency of erosive winds were determined. Drift potential (DP), total sand flux (TSF) and discharge sand flow(DSF) parameters were identified using Lettau's climatonomy equation. Finally, based on the obtained results and the positions of the stations other than those in the Kashan erg, the moving sand was prioritized in the areas around the Kashan erg.

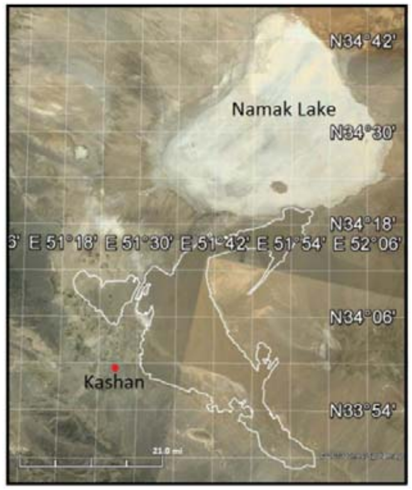

Fig. 1. Kashan Erg

3. Results

3.1. Annual and seasonal wind roses for the studied stations

To show the frequency and prevailing direction of wind velocities at the studied stations, annual and seasonal wind roses were drawn. Annual wind roses are shown in Figure2.

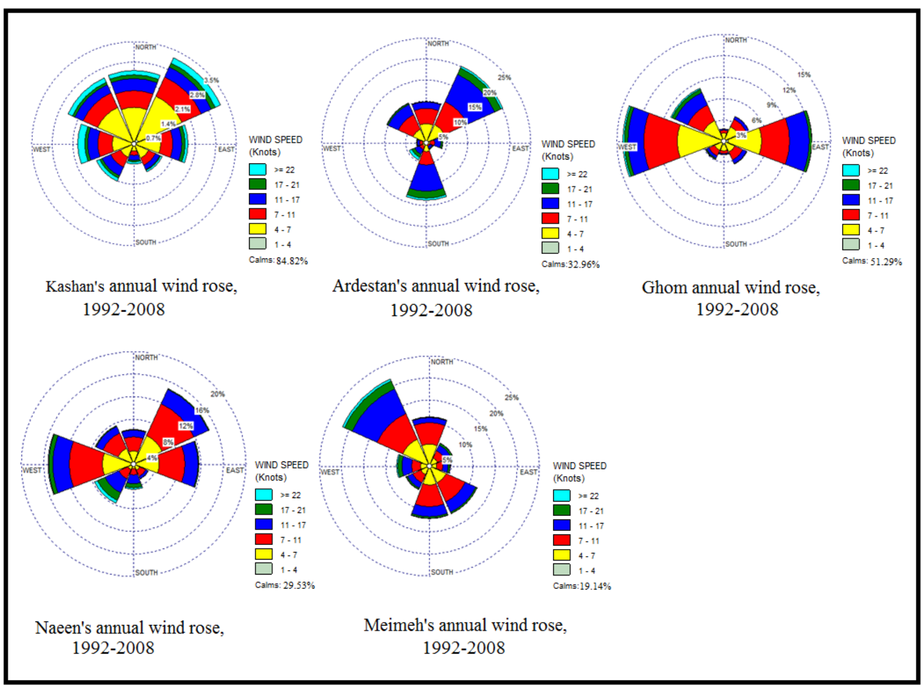

Fig. 2. Annual wind roses in the studied stations

According to Kashan's annual wind rose, the air was calm in 84.8% of total annual monitored hours. Moreover, northeast winds had the highest frequency, and winds from the north and northwest ranked second in frequency. Kashan's seasonal wind roses indicated that the prevailing wind direction was northeast in spring, summer, and autumn, and west in winter. According to the wind category frequency distribution chart in Kashan, winds of 4-7 knots and 7-11 knots had the highest frequency, and 10.3% of overall winds were found to be within these two ranges.

Ardestan's annual wind rose showed the air was calm for 32.96% of total annual monitored hours. Northeast winds had the highest frequency, and winds from the south had the second highest frequency. The prevailing wind direction was northeast in spring and summer, and south in autumn and winter. According to the wind category frequency distribution chart in Ardestan, winds of 7-11 knots and 11-17 knots had the highest frequency, and 41.5% of overall wind was found to be within these two ranges.

According to Qom's annual wind rose, the air was calm in 51.29% of total annual monitored hours. West winds had the highest frequency, and winds from east ranked second in frequency. The prevailing wind direction was east in spring, west in autumn and summer, and west and east with the same frequency in winter. According to the wind category frequency distribution chart in Qom, winds of 1-4 knots and 7-11 knots had the highest frequency, and 28.2% of overall winds were found to be within these two ranges.

Naeen's annual wind rose showed the air was calm in 29.53% of total annual monitored hours. West winds had the highest frequency, and winds from the northwest ranked second. Naeen's seasonal wind roses showed the prevailing wind direction was west in spring, autumn, and winter and northeast in summer. According to the wind category frequency distribution chart in Naeen, winds of 4-7 knots and 7-11 knots had the highest frequency, and 50.7% of overall winds were found to be within these two ranges.

Meimeh's annual wind rose showed that the air was calm in 19.14% of total annual monitored hours. Northwest winds had the highest frequency, and winds from the south, southeast, and north ranked second in frequency. The prevailing wind direction was northwest in spring, autumn, and winter, and southeast in summer. According to the wind category frequency distribution chart in Meimeh, winds of 4-7 knots and 7-11 knots had the highest frequency, and 56.6% of overall winds were found to be within these two ranges.

3.2. Annual and seasonal storm roses for the studied stations

In order to show the frequency and prevailing direction of erosive winds that generate dust at the studied stations, annual and seasonal storm roses were drawn. The annual storm roses are shown in Figure 3.

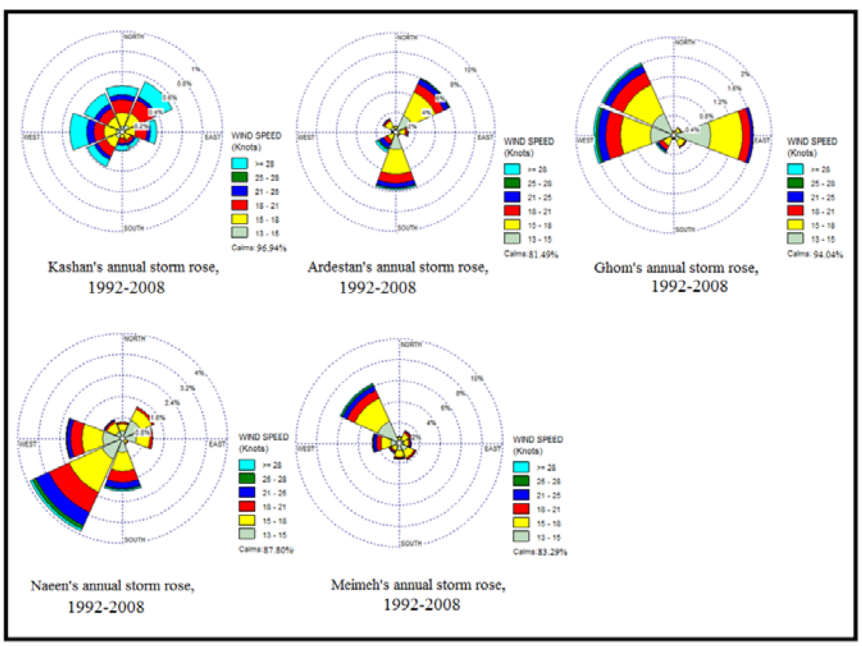

Fig. 3. Annual storm roses in the studied stations

The annual storm rose for Kashan showed that erosive winds from the northeast had the highest frequency; winds from the west and north ranked second and third, respectively.

The seasonal storm roses for Kashan showed that the prevailing erosive wind directions were northeast, southwest, and west in summer, autumn, and winter, respectively, and north and west with the same frequency in spring. According to the erosive wind category frequency distribution chart for Kashan, winds of 12-14 knots and 15-22 knots had the highest frequency, and 2.8% of the winds were found to be within these two ranges.

According to the annual storm rose for Ardestan, erosive winds from the northeast had the highest frequency, and winds from the south ranked second. The prevailing erosive wind directions were northeast in spring and summer, and south in autumn and winter. According to the erosive wind category frequency distribution chart for Ardestan, winds of 12-14 knots and 15-22 knots had the highest frequency, and 21.3% of the winds were found to be within these two ranges.

The annual storm rose for Qom showed erosive winds from the east and those from the west, with a lower frequency, had the highest frequencies. The seasonal storm roses for Qom showed that the prevailing erosive wind directions were east in spring and winter and west in autumn and summer. According to the erosive wind category frequency distribution chart for Qom, winds of 12-14 knots and 15-22 knots had the highest frequency, and 8% of the winds were found to be within these two ranges.

The annual storm rose in Naeen showed that erosive winds from the southwest had the highest frequency, and winds from the west were ranked second. The prevailing erosive wind directions were west, northeast, southwest and southwest in spring, summer, autumn, and winter respectively. According to the erosive wind category frequency distribution chart for Naeen, winds of 12-14 knots and 15-22 knots had the highest frequency, and 14.6% of the winds were found to be within these two ranges.

The annual storm rose for Meimeh showed that the erosive winds from the northwest had the highest frequency, and winds from the west ranked second. The seasonal storm roses for Meimeh indicated that the prevailing erosive wind directions were northwest in spring, autumn, and winter and southeast in summer. According to the erosive wind category frequency distribution chart for Meimeh, winds of 12-14 knots and 15-22 knots had the highest frequency, and 16.7% of the winds were found to be within these two ranges.

3.3. Annual and seasonal sand roses for the studied stations

In order to determine the drift potential (DP), total sand flux (TSF), and discharge sand flow (DSF), annual and seasonal sand roses were drawn for the studied stations using the Lettau method (1978). The annual sand roses are shown in Figure 4.

Kashan's annual sand rose showed that the direction of ultimate sand transport was southwest, and its DP was found to be 2153.1 vector units (VU), annually. Therefore, according to the classification of Frayberger and Dean (1979), the wind erosion power was found to be high. DPt calculations for different seasons showed that the strongest winds blew in spring; the power of the wind in this season was more than double that of other seasons. TSF equaled 75.29 ton/m.year and DSF equaled 27.23 ton/m.year.

Ardestan's annual sand rose showed that the direction of ultimate sand transport was north, and its DP was found to be 513.2 vector units (VU) annually. Therefore, based on the classification of Frayberger and Dean (1979), the wind erosion power was found to be high. DPt calculations in different seasons showed that the strongest winds blew in spring, summer, and winter, respectively. TSF equaled 45.56 ton/m.year and DSF equaled 13.22 t/m.year.

Qom's annual sand rose showed that the direction of ultimate sand transport was east, and its DP was found to be 202 vector units (VU) annually. Therefore, based on the classification of Frayberger and Dean (1979), the wind erosion power was found to be medium. DPt calculations in different seasons showed that the strongest winds blew in spring and winter, respectively. TSF equaled 18.97 ton/m.year and DSF equaled 8.61 t/m.year.

Naeen's annual sand rose showed that the direction of ultimate sand transport was northeast, and its DP was found to be 269.5 vector units (VU) annually. Therefore, based on the classification of Frayberger and Dean (1979), the wind erosion power was found to be medium. DPt calculations in different seasons showed that the strongest winds blew in winter, spring, and summer, respectively. TSF equaled 25.24 ton/m.year and DSF equaled 15.91 t/m.year.

Meimeh's annual sand rose showed that the direction of ultimate sand transport was southeast, and its DP was found to be 285.7 vector units (VU) annually. Therefore, based on the classification of Frayberger and Dean (1979), the wind erosion power was found to be medium. DPt calculations in different seasons showed that the strongest winds blew in spring and winter, respectively. TSF equaled 33.17 ton/m.year and DSF equaled 13.72 t/m.year.

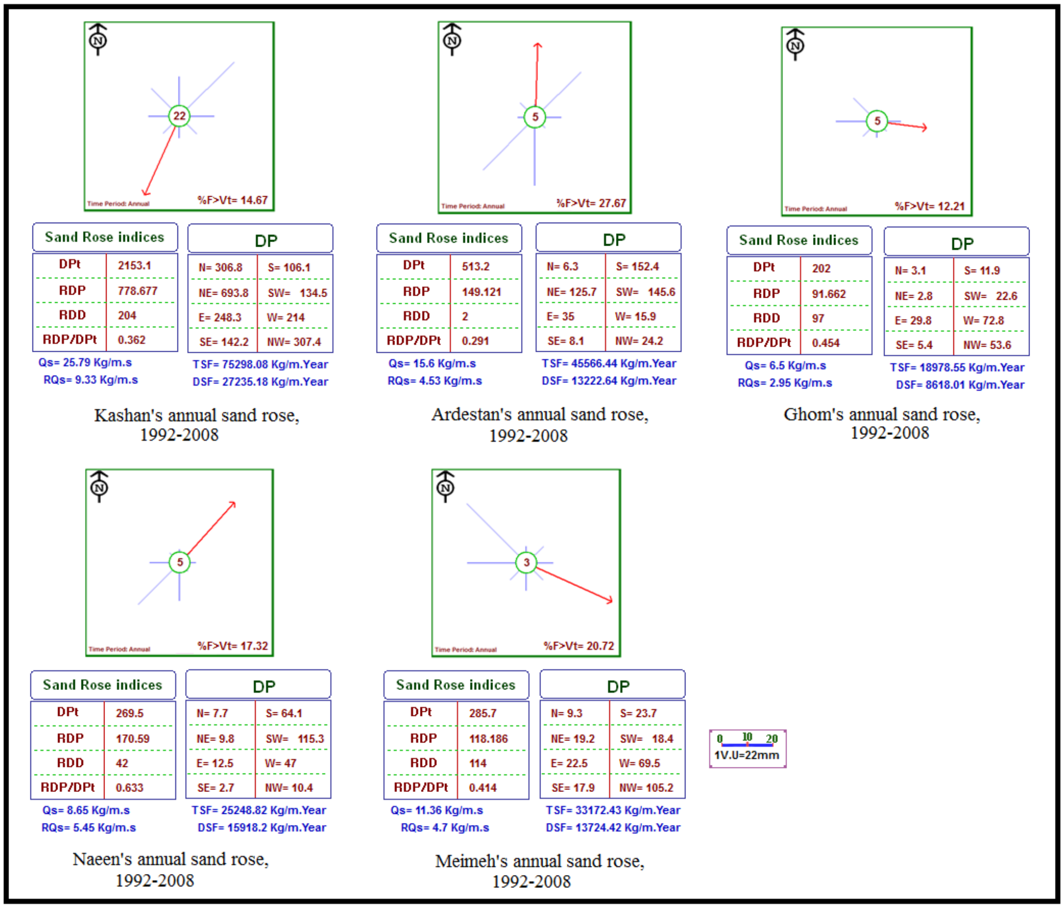

Fig. 4. Annual sand roses in the studied stations

4. Discussion and Conclusion

Investigating regional erosion threshold velocity and wind regimes plays an important role in evaluating wind erosion. Accordingly, the potential of sand transport and its ultimate direction can be estimated (Fraybergei et al, 1979). Analyzing the diagrams and identifying the direction of the prevailing erosive winds and the ultimate direction of sand transport at the intended stations and the position of these stations towards the Kashan erg showed that Kashan faces the greatest risk of moving sand (Figure 5).

As seen in Figure 5, the cities of Qom and Meimeh were found not to be in danger of moving sands. The Kashan erg discontinuously stretches throughout a narrow range with an average width of about 6 to 8 Km. The cities of Ardestan and Naeen were found to be at much lower risk than Kashan. The analysis of Kashan's annual sand rose showed that prevailing erosive winds were from the northeast and west, and the Kashan erg is located exactly northeast of Kashan. Therefore, based on Lettau's climatonomy equation and the total amount of moving sand in one year (TSF), it was found that Kashan is exposed to an influx of approximately 28 tons of sand per year. Finally, the results showed that winds of 12-14 knots transport the maximum amount of sediment.

Kashan's seasonal sand rose showed that the strongest winds blew in spring. Therefore, the maximum displacement and sand transport towards Kashan occurs in spring. The coincidence of ultimate direction of sand transport in spring with the annual direction of sand transport confirmed this finding; it indicated that the spring winds have the greatest potential for sand transport.

An IDW-based interpolation map of sand transport along with the locations of the cities, villages, and roads around the Kashan erg are shown in Figure 6.

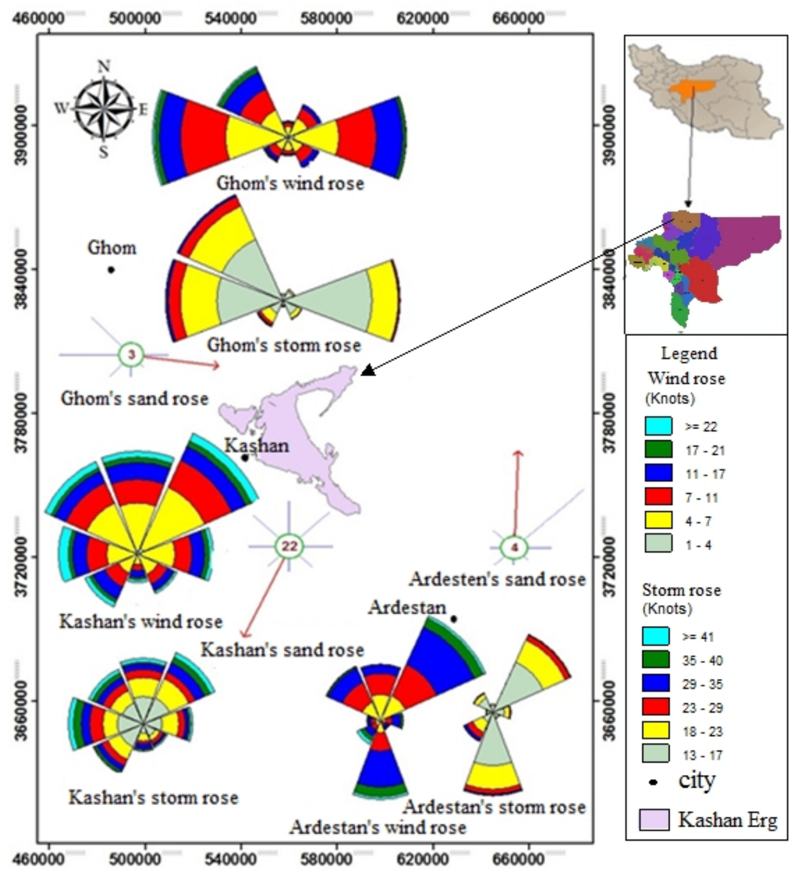

Fig. 5. Location of the stations to Kashan Erg

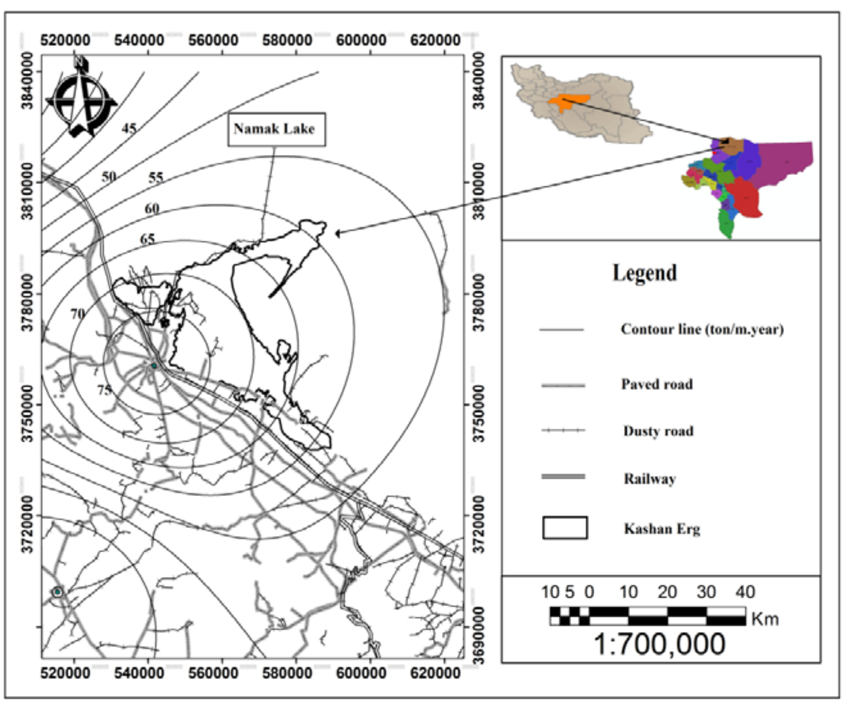

Fig. 6. nterpolation map of sand transport in Kashan Erg based on IDW

The results of the analysis of Figure 6 corroborated the results drawn from Figure 5. This issue confirmed the accuracy of the anemometer data and drawn diagrams. Figure 6 shows that the stations of Ardestan, Meimeh, and Naeen were ranked after Kashan in terms of being exposed to sand movement. It also shows urban and rural areas and paved roads that are more at risk from sand transport. Therefore, it is essential to prevent possible damage through management and the stabilization of sand dunes in hazardous areas.

The investigation of the direction of the expanding sand dunes using Quickbird satellite images showed that dunes located west of the erg (near Kashan) were consistent with Kashan's wind regime (dunes have expanded from northeast to southwest). This finding, however, is not true for the center dunes' erg (dunes that have expanded from north to south). Therefore, the obtained results showed that the wind regime in the center of the erg differs from Kashan's wind regime. Oshtori (2001) studied Kashan's wind regime and identified the winds from the west-southwest (wsw) as the strongest winds in this area (Saremi Naeeni et al, 2007). However, the results of the current study showed that the winds from the north and the east are the strongest winds; this is consistent with the sand dunes of the Kashan erg.

The findings of this study were compared with reality using long-term statistical data on number of dusty days at the studied stations collected from the Meteorological Organization. The investigations indicated no coincidence between the number of dusty days and the obtained results from Figures 5 and 6. The data demonstrated that the number of dusty days in Kashan is less than in Naeen and Ardestan. This result can be proven by the stabilization of sand dunes through the Haloxylon plantation and other plants, which play an important role in the trapping of sands (Figure 8) by significantly reducing the number of dusty days.

Figure 7 shows the morphology map of the Kashan erg.

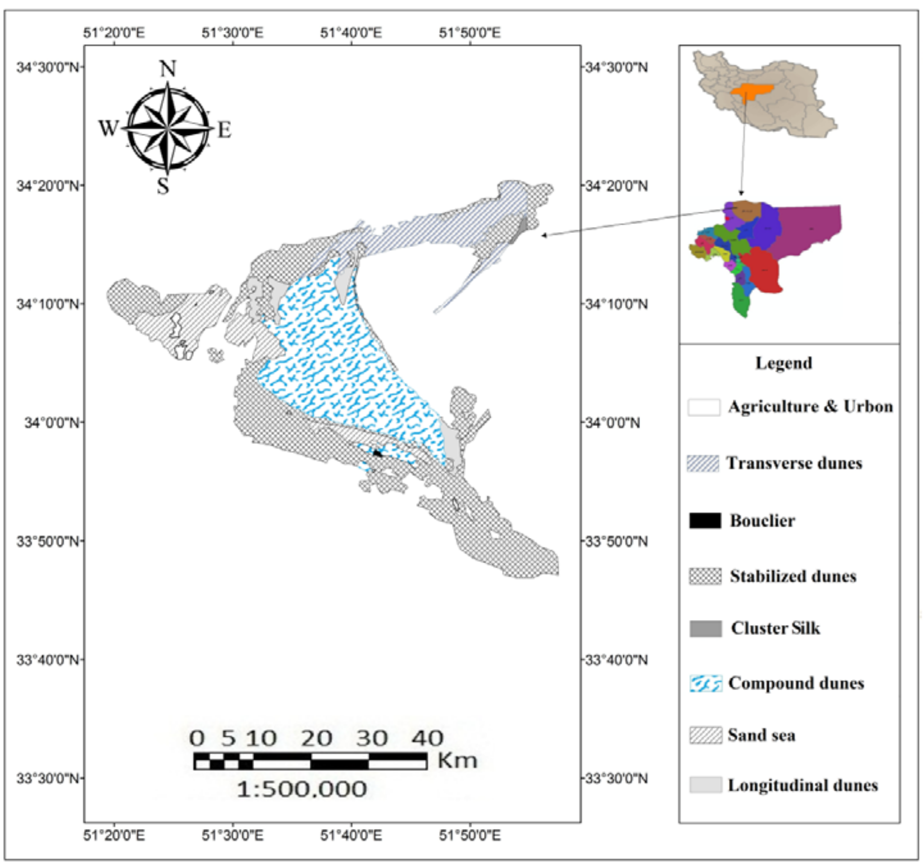

Fig. 7. Morphology map of Kashan Erg

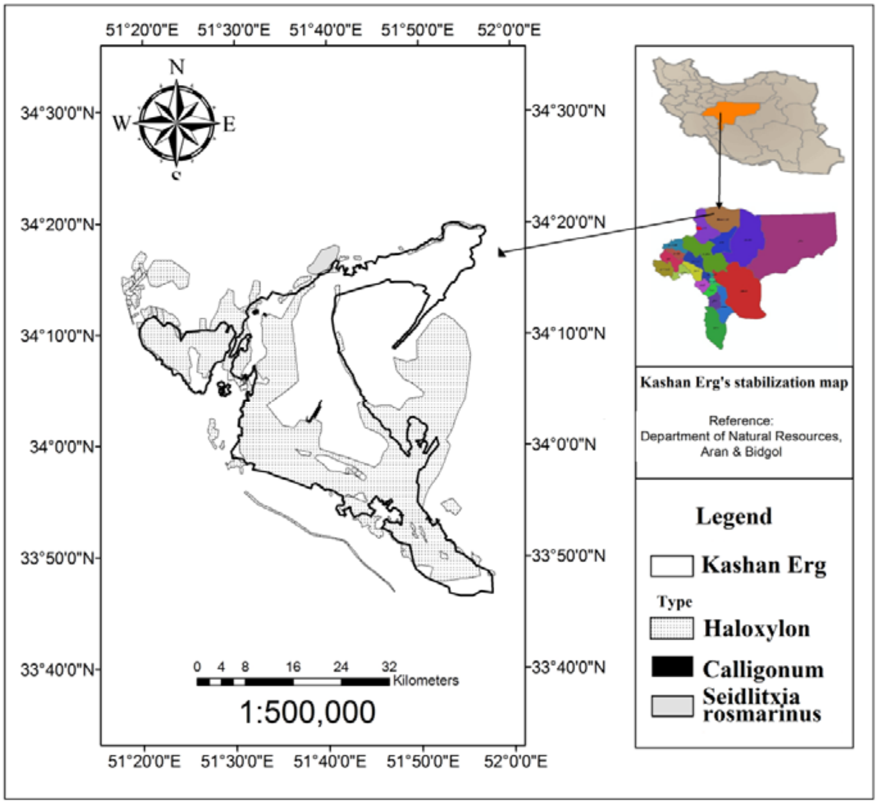

Fig. 8. Stabilization map in Kashan Erg

To investigate the relationship between the morphology of the erg and the coefficients of the sand rose, a morphology map and an interpolation map of sand transport were overlaid using GIS software. It was determined that the stabilized dunes in the west of the Kashan erg have been the main center for sand transport. Thus, the proper management practices and the stabilization of the sand dunes in these areas prevented the risk of sand transport. Moreover, compound dunes in the center of the erg were in the second priority. The transverse dunes in the northeast of the erg and the stabilized linear ones in the south are less involved in sand transport.

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