DESERT

Desert
Online at http://desert.ut.ac.ir

Desert 23-2 (2018) 199-209

The impact of drought periods and wind erosion on the physical development of desert cities (Case Study: Zabol- Iran)

A. Shahriar[a*], Gh.A. Mozaffari[a], S. Poudineh[a]

[a] *Faculty of Humanities, Yazd University, Yazd, Iran*

Received: 27 April 2017; Received in revised form: 21 April 2018; Accepted: 1 June 2018

Abstract

The physical development of cities is always faced with natural barriers. The physical development of the city of Zabol, located in the Sistan plain, is threatened specifically with the development of sand dunes. For this reason, the region's drought conditions were investigated and the standardized precipitation index was calculated. The results showed that with the drying of Hamoon Lake, the frequency of dust storms has increased. Zabol weather station's anemometer data was collected, then annual and seasonal sand speed as well as the region's prevailing weather pattern, which was drawn using Integrated Data Viewer (IDV), Wind Rose Plots (WRPLOT) and Sand Speed Graph software. The results showed that the dominant wind direction is from the North West, followed by the North winds. In addition, it was found that frequent strong winds are more important during the spring and summer. The results of drawing sand speed showed that the final direction for carrying sand is to the Southeast and the that wind's features have provided the conditions for the formation and development of active dunes. It should be noted that the development of Zabol is toward the North and Northwest. In addition, the prevailing wind direction of the region and the active sand dunes are to the North and the Northwest of Zabol. Thus, it is evident that one of the major barriers of the physical development of Zabol is the movement of sand dunes, as the development of Zabol is in the same direction of regional winds.

Keywords: Physical development of the city; Sand dunes; Sand-carrying winds, Standardized precipitation index, Zabol city

1. Introduction

Sand dunes are observed in desert systems and created by sand density in arid conditions. For example, Barchan dunes are one of the most manifest and common faces of sand density. These dunes are dependent on the dominant wind regime in the region and the value of available sediment weight (Bagnold: 1941), such that if the wind is permanently blown in the same direction throughout the year and an insufficient amount of sand is provided to cover the earth surface completely, barchan dunes are created (Sauermann *et al*.: 2001: 245). Enormous, stabilized sand dune fields are a widely recognized geological feature found throughout the world, with investigated examples including the Kalahari Desert in southern Africa and most parts of the Australian Deserts, in addition to other arid place in the world (Tsoar, 2013). Sand dune movements are considered to be a specific threat to roads, irrigation networks, water resources, urban areas and agriculture (Wahby, 2004). They can move into cities when droughts occur, as they move 15 m per year on average (Sparavigna, 2013). The small dunes (up to 5 m height) move even faster – up to 47 m per year (Woronko, *et al*., 2017). Droughts have been proposed as a disturbance which may result in the activation of dunes by reducing protective plant cover and humidity. However, the role of vegetation as a driver of dune activity or stability is disputed, because dune field activity or stability is dependent on wind strength (Yizhaq *et al*, 2013). The lowering of humidity in arid and semi-arid regions allows winds to transport mineral deposits and leads to the formation of

* Corresponding author. Tel.: +98 35 31233393
Fax: +98 35 31233393
E-mail address: a.shahriar@yazd.ac.ir

sand dunes, meaning that climate change and the drying of surface deposits have a significant role in the transfer of sand to urban and rural settlements (Woronko, 2016; Zielinski *et al*., 2016). It is clear that every stabilized dune field was once active and only became static because of climate change or anthropogenic artificial fixation (Roskin *et al*., 2011). Models of dune evolution which incorporate vegetation utilize growth functions partly dependent on wind-driven sand transport rates with growth vigor to arrive to the results of dry or wet periods (Bel and Ashkenazy, 2014).

Firstly, the reason for the physical establishment and development of cities is relevant to their history and geographical and environmental conditions. Adjacent urban spaces have a decisive role in the development of cities with a variety of environmental factors, including the shape of unevenness, its proximity to natural features such as mountains, plains, rivers, coasts, and climate conditions that govern them. Thus, cities are shaped to comply with these natural conditions and continue to grow and develop while communicating with each other. These conditions hugely contribute in the determination of the size of cities and villages.

The suitability of geographic environments also holds great influence on their formation and development (Hossein zadeh dalir, and Hoshyar Hoshyar, 2005). The topographic and geomorphological characteristics of any geographic location are one of the effective factors in the physical growth of a city, even in terms of distribution or accumulation, as some geomorphologic features act as obstacles to urban growth. In addition, the reflection of geomorphic processes appears as difficulties and problems that may lead to irreparable damages to the body of a city, in case of failure of the consideration of such processes. Therefore, the effects of topography and geomorphologic conditions in any place have an undeniable role in issues such as urban construction and development. Thus, these conditions seem to be necessary in urban planning in order to increase the safety of citizens against the dangers of geomorphic processes.

In the physical development of the city, geomorphologic, weather, hydrological, geological conditions, etc., must be studied, and the cross-interactions of these phenomena must be checked (Rajaei, 1994). However, population growth, developments in construction, and increases in industrial activities, in addition to environmental degradation, cause major disruption in the land's dynamic equilibrium, the consequences of which can be dangerous in terms of the intensification of geomorphic phenomena. Paving sloping land to build housing, embankments and highway construction, etc. have presented new challenges for humans besides natural factors (Bourke *et al*: 2009). On this basis, studying the role of geomorphological characteristics in the location and physical development of the city of Zabol has been selected as the research subject. This city is located in the Southeast of the Central Plateau of Iran in the Sistan plain, and the triple plains are located to the West and North of the town, between Iran and Afghanistan. The drought in Sistan and consequently, the reduction in vegetation, the drying of Hamoon Lake, and 120 days' winds have provided favorable conditions for the occurrence of dust storms. This has caused many losses in infrastructure, urban and rural roads and houses, and has provided unfavorable conditions for the physical development of Zabol.

However, studying the role of geomorphological and climatic characteristics in the positioning and physical growth of Zabol is a topic that will help remind urban planners of the dangers of geomorphic processes for urban settlements, and will help reveal topographic and geomorphologic obstacles preventing the physical growth of this city. Those involved in urban development projects will be able to select the right locations for urban expansions and settlement, taking into consideration the environment's morpho-dynamic potential. Several studies have been made to estimate the rate of climate and physical development of cities in many areas of world, especially in Iran, as a number of them have been mentioned.

El Bana. (2009) used Enhanced Thematic Land satellite (ETM+) images from 2002 and aerial photographs from 1955 along with field observations and diagrams of geomorphic changes in the coastal area between the Kitchener drain and Damietta harbor in the Northeast area of the Nile Delta to infer the induced changes caused by humans in that area. This location was recognized as a vulnerable area to any rise in sea levels caused by global warming.

However, increasing urbanization, the conversion of marshes to agricultural fields and conversion of wetlands to fish farms, the construction of apartments on coastal areas, and the reduction of the extent of wetlands by less than 0.50, an annual coastline retreats of 14 meters, coast enlargement by up to 15 meters per year and the development of dunes 12km away in the Southeastern cape of Damietta, are caused by a natural process in a seamless pattern of erosion and sediment transportation. In general, the main reason is the human impact on the structure and manipulation of coasts. Arenas also used the rate of sand transport potential (RTP) and sand resultant transport direction (αRTP) in order to calculate sand transport potential (TP); these metric factors much resembled sand drift potential (DP), sand resultant drift potential (RDP) and sand resultant drift direction (RDD), and as such was able to review the morphological changes of sand dunes (Arenas, 1996).

Another important index that is very important in sand dune morphologic changes is the uni directional index (UDI), which high UDI ratios characterize near unimodal wind regimes, which as a result, would produce in crescent dunes, Barchans, simple linear dunes and transverse dunes whereas low ratios indicate complex wind regimes and multi-directional winds in the region which result in the appearance of star sand dunes more than crescent and barchan dunes (Navarro and *et al*.: 2011).

Baz *et al*. (2010) identified unplanned development in the city of Istanbul to the North, East, and West based on empirical modeling techniques and GIS-based analysis. Ahmadi *et al*. (2013) used the TOPSIS model to evaluate and prioritize areas for development and housing and to investigate the effect of geomorphic processes in the localization and development of Khorramabad. In this method, regional classification seems to be necessary. For this reason, the land analysis method has been used and the results showed that TOPSIS is highly efficient in prioritizing and ranking the region in terms of living conditions. The fluvial region was thus found to rank first in terms of living conditions. Few studies had been conducted on the dynamics of the processes of the land’s surface using the Co-registration of Optically Sensed Images and Correlation (COSI-Corr) technique such to determine movement rates and direction of sand dunes and their potential hazards on cities (Al-Ghamdi and Hermans, 2015, Hermans, 2015, Al-Mutiry and *et al.*, 2016). Li *et al*. (2016) monitored the aeolian desertification on the Tibet Plateau during the period stretching from 1977 to 2010 by interpreting a series of Landsat images. This study was carried out using a quantitative assessment of the relative role of climate change and human activities in desertification and the movement of winds on sediments in the Qinghai- Tibet Plateau. This research is conducted to identify the prevailing morphogenetic phenomenon in the studied area, especially the phenomena that create impediments in the physical development of Zabol.

2. Materials and Methods

2.1. Study Area

This case study concerns the encompassing area of the city of Zabol, located in the far east of Iran. This area is part of the vast province of Sistan and Baluchistan. It involves a large and important part of the north of the province (and indeed, a large part of Iran). In terms of geographical location, this city is located at the coordinates of 30° 7'' N to 31° 29'' N and 59° 58'' E to 61° 50'' E.

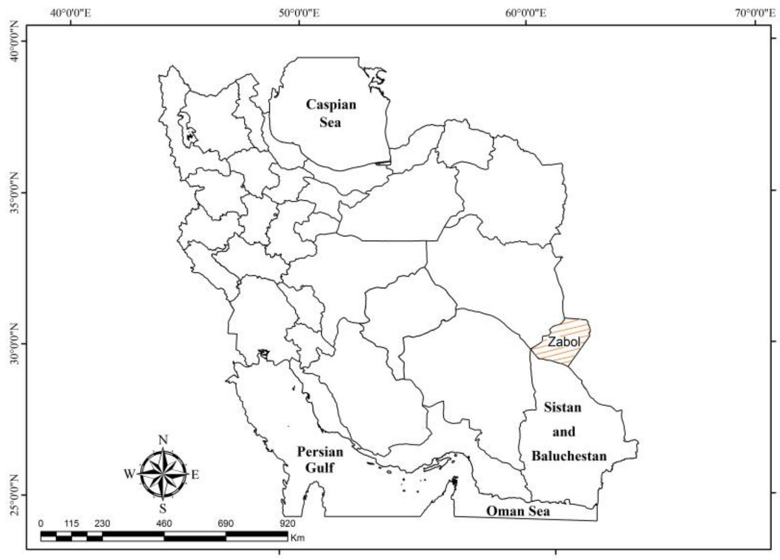

Fig. 1. Geographical location map of Zabol in Sistan and Balouchestan Province

2.2. Methodology

In this research, the daily wind data of Zabol over a period of 10 years was collected (2005-2015) from the Meteorological Organization in order to evaluate and analyze the direction of prevailing winds in this region. Then, the data that includes monitoring date and time, direction and speed were collected. Considering the role and effects of droughts on water resources, the region's drought was calculated over a period of 26 years (1986-2011) using the Standardized Precipitation Index (S.P.I). In order to analyze the data from the anemometer, annual and seasonal wind speeds and sand speeds were drawn in the eight directions and six classes using WRPLOT, and Sand Speed Graph. In addition, the status of sand dunes around Zabol was identified, and the map of the dunes' expansion direction and the prevailing wind direction were drawn toward Zabol using Google Earth. Finally, hypotheses testing was performed according to research findings.

3. Results and Discussion

3.1. Drought

Drought is a situation of rainfall shortage and temperature increase that may occur in any climatic condition. In the present research, due to the importance of water resources in the Sistan plain, the vulnerability of Zabol's weather stations located in the study area was evaluated in term of drought (in a statistical 26-year period) based on the S.P.I index, and using D.I.P software.

Standard precipitation index (S.P.I)

Among the quantitative indicators for drought analysis, the S.P.I index has a global acceptance as an appropriate index to analyze droughts due to the simplicity of the calculations, which use available rainfall data, and S.P.I ability to calculate for varying lengths of time and different spatial scales. The S.P.I index is calculated based on the difference between the amount of rainfall per month and the average rainfall during the specified timeline by the standard deviation of rainfall in the time scale. Time scales can be 3, 6, 12, or 24 months (Shakiba *et al*., 2010, p. 111). The S.P.I index in Zabol was calculated for a period of 26 years (1986-2011). As Table 1 shows, a drought has occurred in the years in which the S.P.I index is -1 or less. Here, a mild drought is observed for 7 years (1999, 2001, 2002, 2008, 2009, 2010, 2011), a moderate drought for 4 years (1986, 2003, 2005, 2012), and a severe drought is observed for 3 years (1988, 2000, 2007).

Table 1. Drought index for a period of 26 years in Zabol

Drought categories	Index	Year
Moderate drought	-1/25	1986-1987
Mild Humidity	0/65	1987-1988
Severe drought	-1/55	1988-1989
Mild Humidity	0/71	1989-1990
Relatively Humidity	1/45	1990-1991
Mild Humidity	0/73	1991-1992
Mild Humidity	0/86	1992-1993
Mild Humidity	0/9	1993-1994
Mild Humidity	0/09	1994-1995
Severe Humidity	1/65	1995-1996
Mild Humidity	0/28	1996-1997
Relative Humidity	1	1997-1998
Mild Humidity	0/78	1998-1999
Mild drought	-0/33	1999-2000
Severe drought	-1/53	2000-2001
Mild drought	-0/52	2001-2001
Mild drought	-0/15	2002-2003
Moderate drought	-1/14	2003-2004
Relatively Humidity	2/33	2004-2005
Moderate drought	-1/12	2005-2006
Mild Humidity	0/05	2006-2007
Severe drought	-1/55	2007-2008
Mild drought	-0/13	2008-2009
Mild drought	-0/88	2009-2010
Mild drought	-0/53	2010-2011
Mild drought	-0/34	2011-2012

In this research, we have attempted to combine the drought coefficient of Zabol with the frequency of dusty days to achieve the desired results. According to Figure 2, it can be shown that dust is partially the function of the drought coefficient. Dust is the result of various parameters such as humidity, vegetation, wind, etc. As can be seen in Table 1, dusty days in Zabol have increased since the year 2001 with the intensification of the drought.

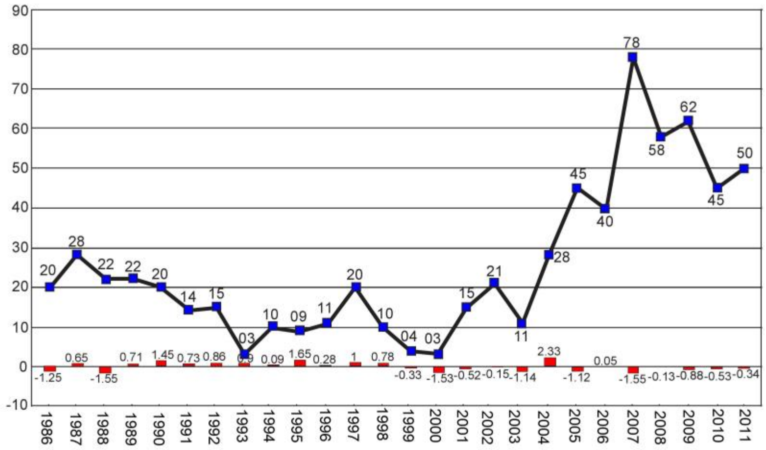

Fig. 2. Drought coefficient (line chart) and the number of dusty days (column chart) during a period of 26 years in the city of Zabol

Considering the successive droughts in the region, especially in recent years due to severe climate change and rainfall reduction, various droughts have affected the Sistan plain. Therefore, diverting attention to water resources through drought study, identifying features, monitoring and forecasting them may lead to better management.

The geographical position of Zabol is important in the Sistan region due its proximity to Afghanistan and the three wetlands of Puzak, Saboori, and Hirmand that give a specific function to the natural environment and human activities in terms of natural and human ecology. The rule of particular environmental conditions such as low relative humidity, low rainfall and its poor distribution, extreme temperature fluctuations and high evaporation rates, the lack of vegetation and active airflow, especially 120 days of wind in this region have led to the occurrence of droughts caused by the Kajaki dam (in Afghanistan) on the Helmand River and irreparable damage to the environment, not to mention water and soil resources. This has always been a problem in the development of the city's socio-economic foundations, and has led to the migration of a large part of the inhabitants of the region. Therefore, it can be concluded that the drying of Hamoon Lake (Puzak, Saboori, and Hirmand Hamoon) has a close relationship with increasing dust storms in Zabol.

3.2. Effective characteristics of wind

Speed is an important characteristic of wind. Wind speed in arid regions is an important factor of erosion because the soil is relatively bare. Prevailing wind direction is another important factor that can help determine the type and origin of the wind, identify the origin of the sands being transported and the formation of sand dunes. High-level atmospheric systems, as well as wind and sand speeds were studied to determine the prevailing direction of wind in various parts of the region so that the impact of effective winds is specified in the region.

3.2.1. Prevailing weather patterns

Wind can be called the most variable atmospheric element in pressure centers that always changes in terms of speed and direction over time. Winds are created in every region because of the difference in pressure between the two regions. On the other hand, the wind's intensity depends on the pressure gradient between the two points, as the more severe the gradient is between the two points, the quicker the pressure flow or the wind speed is between the two points. Therefore, studying this I.D.V seems to be necessary, considering the effect of I.D.V on wind speed and direction, to detect pressure and wind patterns in the region during the different months of the year.

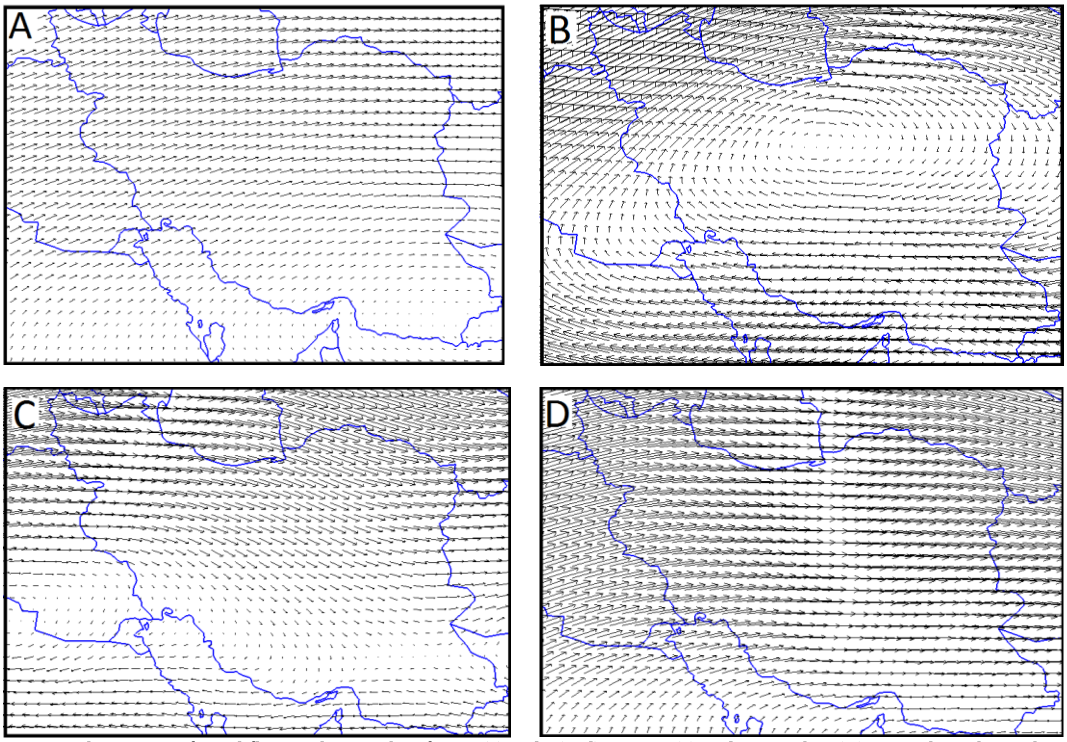

Fig. 3. The pattern of wind flow in the months of June (a), July (and) August (c) and September (D) at 925 hpa Shows the mechanism of wind of 120 days from the northwest, especially in September in Iran

As the wind flow pattern in the studied area shows, wind direction has changed in accordance with changing pressure centers at different times. The results showed that the 120-day winds occur with more intensity in the studied area during the summer, namely in August and September according to wind and storm speed results. As the results show, the wind direction in Figure C and D is headed from the North - Northwest to the Southeast. The density of arrows in Figure C represents the density of pressure at high atmospheric levels in August. In addition, the longer arrows shown in Figure D represent the high wind speeds in September.

3.2.2. Wind Speed

Wind speed is easily shown in anemometer data, in which the information related to many different classes of wind speeds, will be displayed in each direction. In order to prepare a graph of wind speed, all winds with a speed of more than 0.5 meters per second are checked. Although it should be states that research has shown that the speed of erosional winds that are capable of carrying particles is far more than the base amount (about 6 meters per second).
To evaluate the wind characteristics in the study area, the annual and seasonal wind speeds of Zabol station were drawn, as shown in Figures 4 and 5.

According to Figure 4, it was concluded that the prevailing direction of the region arise from the northwest, and that north winds are the second fastest.

According to the classification diagram of the different classes of wind speed, it is identified that 11 to 17-knot winds (17.7%) have allocated the most frequency to themselves and that some very strong winds (with a speed of over 28 knots) include 16.3% of the total wind in the region.

According to Figure 5, it was concluded that seasonal wind speeds are a function of annual wind speeds. The prevailing directions of winds in all seasons were from the Northwest, which were the fastest, followed by the North. It was also observed that the frequency of winds with a speed of over 28 knots increases during the spring and summer.

3.3. Sand Speed

Sand speed is shown in a diagram, which was obtained by complex operations of vector algebra and calculating the amount of energy needed to carry by wind. This diagram shows wind erosion and the relative amount of sand transport in different directions.

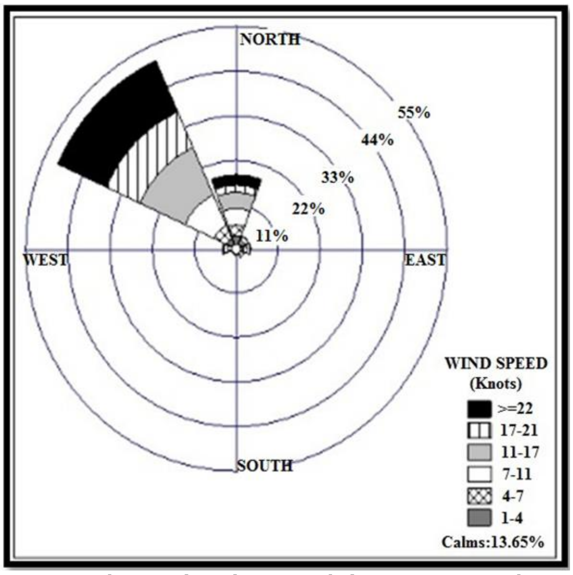

Fig. 4. The annual wind rose in Zabol Synoptic Station shows the prevailing wind from northwest yearly

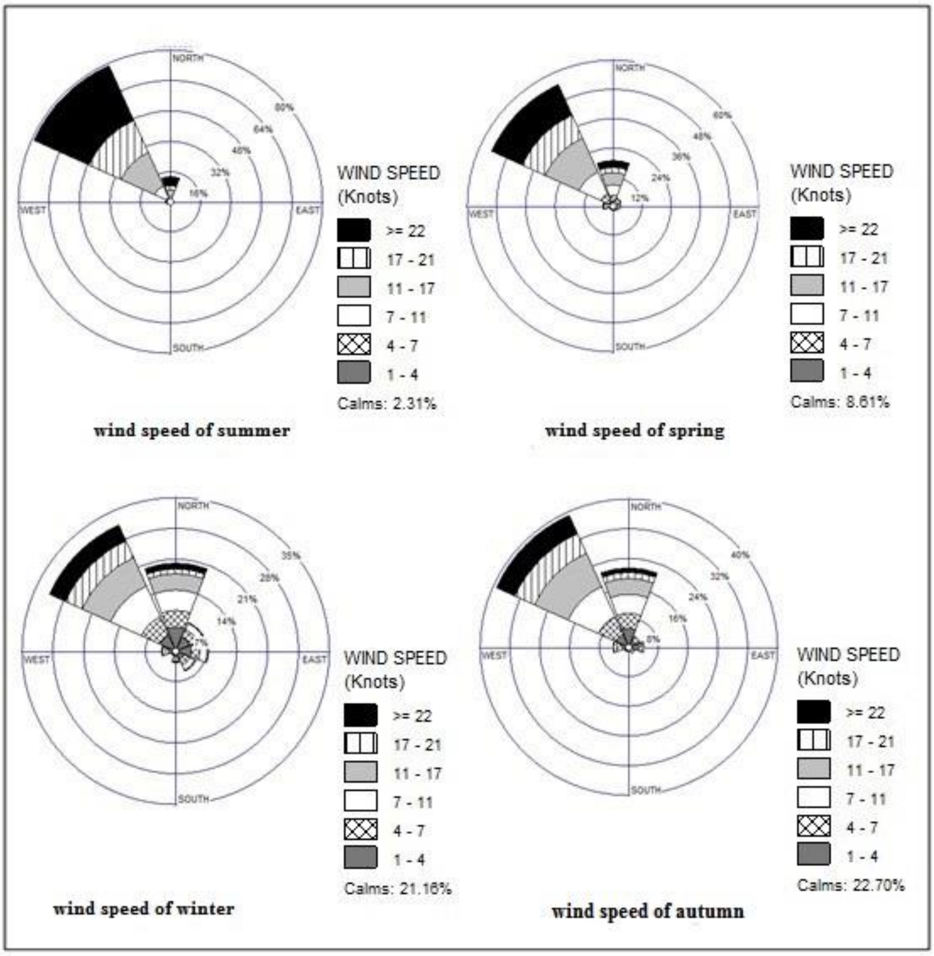

Fig. 5. Seasonal wind rose in Zabol station shows the prevailing wind from northwest

In order to evaluate the final direction for carrying sand and determining its parameters, the annual and seasonal wind speeds in Zabol station were drawn (Figures 6 and 7). According to Figure 6, it can be observed that the final direction for carrying the sand is to the southeast The sand-carrying power in this station is 2399.5 (VU) vector units per year, which reaches 1331 (VU) in the summer. Based on the classification of Fryberger and Dean (1979), the erosion power of wind is placed in the high class (DPt more than 400). In addition, the total amount of transported sand in a specified unit during a year (total sand flux) is equal to 431140Kg and the discharge sand flow is equal to 412882.2Kg per meter per year, respectively.

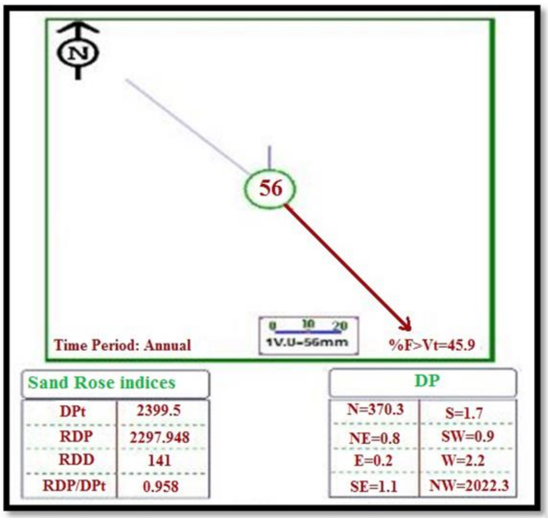

Fig. 6. Annual Sand Rose in Zabol Synoptic Station Shows the direction of the sand transportation to the southeast

According to seasonal sand speeds in Figure 7, it is concluded that the seasonal sand speeds are a function of the annual sand speeds and the final direction of carrying sand in all seasons is the Southeast. Given the DP (Drift potential) in different seasons, it can be show that the amount is more elevated during spring and summer than other seasons, and that confirms the results of the seasonal storm speeds.

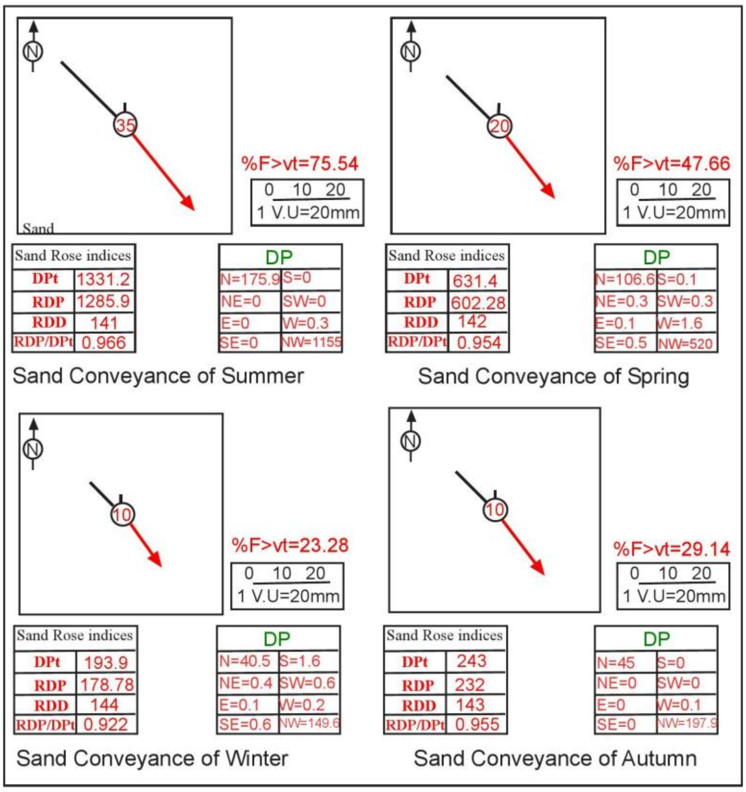

Fig. 7. seasonal sand rose in zabol synoptic station and the direction of sand movement

As stated earlier, U.D.I (Unit Directional Index) is a number between zero and one, which when tending to 0 expresses multi-directional winds, and when closer to 1 shows unidirectional winds. According to Figure 6. The U.D.I index in Zabol station is shown to be 0.985. As can be seen, the U.D.I index is closer to one and thus expresses unidirectional winds. Thus, according to the index, the sand dune type can be identified. In general, if the U.D.I index be smaller than 0.4, it is then revelatory of star-shaped dunes, if it should be between 0.4 and 0.7, then it shows linear dunes, and if it be more than 0.7, then it will show Barchan dunes and ridges. Given that this index is more than 0.7, then that means Barchan dunes and ridges (Shahriar, 2013).

In Figure 8, the status of sand sheets, their direction of expansion direction, as well as the prevailing wind direction in Zabol station has been shown.

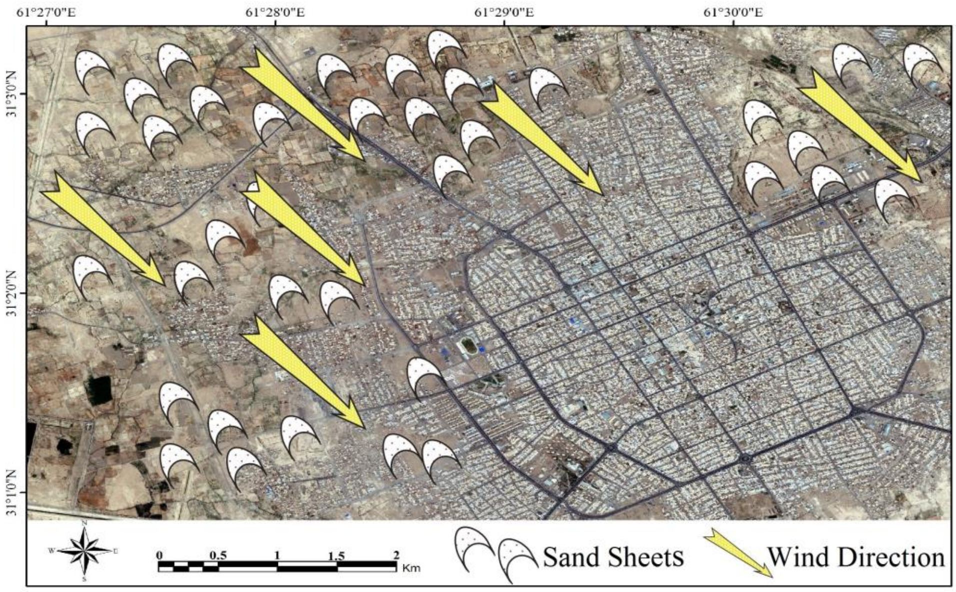

Fig. 8. The status of sand Sheets and their direction of expansion as well as the prevailing wind direction in Zabol Synoptic station

As can be concluded from Figure 8, the dispersion of sand dunes is in the Northern and Northwestern parts of Zabol. There are no sand dunes in the Eastern and Western parts of the region and they may be scattered or limited to a certain and small area. It can be shown that the frequency and volume of sand dunes in the Northwestern area of Zabol surpasses those in the North, and that is consistent with wind speed results. In fact, according to the prevailing wind direction in the region, sand dunes are formed and are developing.Since, the direction of development in Zabol is toward the North/ Northwest then it perfectly corresponds with the 120-day winds. These winds have created two types of climatic conditions for Zabol, as in wet and humid years, Hamoon Lake has abundant water resources in the direction of these winds. Favorable climate and cool air will accompany this wind. However, during dry years, Hamoon Lake will also dry up, and then its bed will become a source of suspended particles to be transported by the 120-day winds from Sistan to Zabol. Since, the sand dunes in the region are newly-formed, with high activity and movement (Barchan dunes and ridges), and given that these dunes are located in the way of the 120-day winds, the wind will move the sand toward Zabol, and this falls in accordance with the direction of the city's development. This case is one that concerns an important barrier that has made problems for the development of Zabol. All of the above cases confirm that the movement and the dynamics of the sand dunes are the barriers to physical development of the city of Zabol.

4. Conclusion

The results of the studies show that the Hamoon wetlands, with an area of over 293 hectares constituting the largest freshwater lake in Iran, which was known as the main factor of life in the Sistan region up to 1997 with a volume of over 8 billion cubic meters, after suffering from successive droughts from 1999 until the present, has witnessed the drying of this enormous wetland, and which in turn led to the breaking of the life chain in this region. Currently, all of the area of Hamoon Lake has been dried, and Sistan suffers from an environmental crisis. Studies show that in the years before the drought, when Hamoon Lake was full of water, the 120-day winds were the main contributing factor in the modulation of the air in hot seasons, due to the wind passing over the lake and absorbing its Humidity. Now that the lake is dry, however, these winds have changed their characteristics and have created suffocating conditions for the people of the region, not to mention with the already-existing high temperatures and large amounts of dust and soil.

The results of reviewing and analyzing the wind characteristics in Zabol showed that the prevailing wind direction of the region and the direction of the moving and developing sand dunes are completely consistent with one another, and are from the North to the Northwest. This issue is considered as one of the most obvious causes and barriers impeding the development of Zabol. Therefore, these winds are the main factor behind the creation of dust in Zabol. Wind erosion and its related processes are directly related to the activity of sand dunes. The higher the activity of these dunes is, the higher wind erosion and consequently, the transfer of sand dunes and quicksand by wind will be. The graph concerning the sand speed of Zabol (H.D.I index in Zabol station was 0.958) indicated that these winds resulted in the creation of Barchan dunes and ridges, which are young dunes with high activity. Some of the consequences of wind erosion in the region are respiratory and eye diseases, the transport of contaminants such as heavy metals along with wind, etc. which all aid in the increase of population migration. Therefore, the identification of active sand dunes and their stabilization by creating vegetation is essential to reduce the damage.

Creating vegetation on the sand dunes and their stabilization is changed by increasing the organic matter of the sediment texture, and the providing the conditions for forming silt and clay-sized particles. Studies have shown that the more the amount of silt and clay increases, resistance against sand movement will be higher due to higher adhesion. Tavakolifard *et al.* (2013) in their study about the aggregation of wind sediments around the Kashan concluded that the amount of silt and clay in the fixed dunes that have vegetation is about 4 times more than unfixed dunes.

Since, the direction of development in Zabol is toward the North and Northwest, and it is perfectly corresponded with the 120-day winds, it is recommended that urban development plans to the North and Northwest be revised to prevent the incidence of disease caused by dust and other environmental problems for the residents of the city of Zabol.

Indeed, continuing urban development to the north and northwest will increase socio-economic and healthcare difficulties. Therefore, it is necessary to take adequate and scientific measures to reduce the effects of this threat to public health, economy, and environment, and danger to the growth and development of the region.

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