Use of Spatial Technologies to Study the Winds’ Directions in Rub’ Al-Khali Desert, Saudi Arabia

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Abstract: Studying environmental phenomenon in Rub’ Al-Khali (Arabic name of “Empty Quarter”), as one of the largest deserts in the world, requires adopting some advanced spatial technologies in conjunction with the data recorded in the field in order to device better understanding. The paper utilizes the technologies of GIS (geographical information systems) and RS (remote sensing) in order to study large amount of weather data recorded in the field from different sources related to oil and gas industry in Rub’ Al-Khali desert. The main objective is to identify the wind directions and its movement in Kidan areas and the areas south and east of Shaybah in Rub’ Al-Khali desert. The study used different sources of data mainly recorded by the seismic campaigns’ base camps and the drilling rig camps or the civil works camps. Wind Roses were created for all metrological weather stations in the study area. Also, the study tried to analyze the dune types using satellite imageries and identify the relation of its shapes to the wind direction. The final aim of the result of this study is to help in planning best locations to build facilities for new major oil and gas project.

Key words: Wind, oil, directions, roses, GIS.

1. Introduction

1.1 Sand Dunes and Winds’ Regimes

Rub Al-Khali desert represents potential natural and large laboratory for studying dune fields and regional wind regimes. However, access to this desert is usually very difficult and requires large amount of logistical efforts and safety precautions. Moreover, some studies were even not able to access this desert due to political conflicts near to Yemen border [1]. Morphologies of the sand dunes in the deserts are significantly affected by the seasonal changes in winds directions. Consequently, formation of the dunes can be used as indication of winds regimes such as barchan dunes. However, it is very difficult to estimate winds in other types of the complex dunes such as star dunes that require at least tri-directional winds [2]. Understanding the winds regime in Rub al-Khali and knowing major wind directions in the study area is critical for any planned industrial development, especially for gas facilities as the gas leakage transfer easily with the winds direction. GIS-based literature plays an essential role in understanding potential wind energy in a map-based approach [3].

1.2 Background about the Study Area and Dunes’ Types

The study area is located in the south eastern edge of Saudi Arabia, south of the UAE (United Arab Emirates) and west of the Sultanate of Oman border. It covers dunes in areas of Rub’ Al-Khali desert such as Kidan, Shaybah, Zumal, Suhul and near Tumaysha. Topography of the Rub’ Al-Khali desert south of the Arabian peninsula can be classified mainly into 13 to 15 different types which include: Barchanoid ridges, Bedrock, Convergent dunes, Dome dunes, Draa or 'Uruq, Gravel plains, Hooked dunes, Megabarchans, Pyramidal dunes, Sand sheets, Seif dunes, Sigmoidal dunes and Small Linear dunes [4]. The study area (47,000 km²) contains only 6 types of these dunes: Megabarchans (63%), Small Linear dunes (18%), Draa or 'Uruq (8%), Sigmoidal dunes (7%), Seif dunes (3%), Gravel plains (0.95%), and Hooked dunes (0.05%) (Fig. 1).
1.3 Importance of the Wind Data for Oil & Gas Industry

Feasibility study of any giant oil and gas project needs to consider environmental aspects of the area of operations to support the critical decisions of the project. This would include for example the topographical information and weather data. GIS and RS technologies play major and efficient role in this aspect. Weather data are important for decisions related to dispersion models and plant/camps design. Having good understanding of winds’ movements and energy will play major role in deciding best locations of huge investments such as CPF (central processing facilities) or remote stations. However, availability of the data in its own is not enough to support these decisions without implementing some processing and analysis to extract useful information. The real value of this analysis will be obtained when applying the spatial dimension to the study using GIS and RS.

1.4 Effect of the Wind Direction on the Shape of Dunes

The winds were very powerful during the colder intervals of Late Quaternary where storms during that period played major role in carrying huge amount of sand and accumulating it into the Rub’ Al-Khali desert [4]. For example, the Megabarchans dunes which represent majority of the study area require continual wind supply from one direction to be formed. Similar case is with the “Small Linear Longitudinal dunes” where its long sand ridges are

![Fig. 1 Location map of the study area with regional dune types in Rub’ Al-Khali desert digitized and reviewed by the author based on Edgell (2006) classification and using Landsat images as reference.](image-url)
parallel to the wind direction but angle of this wind is varying slightly and carrying limited sand supply within one particular direction [5]. On the other hand, for the Star dunes to be formed, it would require the winds blowing from different directions during seasons of the year [6]. Fig. 2 illustrates possible wind directions for some types of the dunes.

2. Methods, Materials and Results

The data used in the study were mainly either satellite data or field data. Both types of data were combined and overlaid in GIS environment for mapping and spatial analysis.

2.1 Satellite Data

It was important to acquire RS data for digitization, mapping and to recognize the different types of dunes. The study utilized two types of high-resolution commercial satellites imageries (Quick Birds and GeoEye-1) in some locations of the study area. However, it was not possible to buy the high-resolution imageries for other types of dunes. This was compensated by the acquisition of coarser satellite images from Landsat free mission. Fig. 3 clarifies the types and resolutions of satellite imageries acquired for each class of dunes in the study area.

2.2 Field Weather Data

The weather data were collected during the exploration operations of SRAK Company Limited (2005 to 2012). The metrological stations were
installed in the exploration well rig sites, seismic crew base camps, and civil works camps. The second source of weather data is Shaybah Airstrip (2006 to 2008). The third source is the NCDC (National Climatic Data Centre) during 1984 to 1986. This study is based on processing and analysis of data from 21 metrological stations using around 12,000 of the daily observations collected mainly in Kidan area during 2005 to 2012. The main data observed in each station include: wind direction, wind speed, and sometimes temperature, and humidity. Four zones were created to study the sub areas in more focused way as seen in Fig. 4.

Kidan north zone had the highest percentage (45%) of the daily wind observations with 5,667 records, while Shaybah South had the lowest portion (5%).

The map in Fig. 4 shows the geographic distribution of metrological stations within each of the zones. Table 1 shows more details about these stations including M (main) and S (secondary) wind directions in each station.

3. Discussion

3.1 Processing & Analysis of the Wind Data

The processing focused on preparing the wind directional data and creating a wind rose chart for each metrological station. These charts indicated main wind directions’ trend during a particular period of time. It also showed the average wind speed in each direction in addition to information about the geographic location and coordinates (see examples in Fig. 5). So, the next step was to study/analyze wind
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Fig. 4  Zones of the metrological stations in the study area (mainly Kidan and Shaybah areas).

Table 1  Details of the 21 meteorological stations used in the study.

| Station ID | S. Name          | Period               | Daily Observations | H. Direction | S. Direction | Season         | WGS84 L lat. | WGS84 L long. |
|------------|------------------|----------------------|--------------------|--------------|--------------|----------------|---------------|---------------|
| MS01       | Kidan North      | Oct. 2006 to Apr. 2011 | 792                | NW           | NE           | N22 19 12.0 | E53 09 00.0   |
| MS02       | Kidan South      | Jan. 2008 to Oct. 2008 | 2312               | NW           | NE           | N22 18 01.0 | E54 00 00.0   |
| MS03       | Shaybah Airfield | Jan. 2008 to Dec. 2008 | 1014               | NE           | NE           | N23 30 23.9 | E53 36 59.5   |
| MS04       | Worley Parsons   | Jan. 2008 to Dec. 2010 | 1824               | SE           | NE           | N22 15 36.0 | E53 10 48.0   |
| MS05       | Kidan 1          | Apr. 2008 to Sept. 2009 | 518                | NE           | N           | N22 16 53.7 | E53 17 23.5   |
| MS06       | Kidan 2          | Nov. 2005 to Mar. 2006 | 120                | NW           | SW           | N21 43 53.0 | E53 30 41.1   |
| MS07       | SRRAK South of Shaybah | 13-Mar-2011 to 11-Nov-2011 | 104              | SE           | NW           | N21 56 44.9 | E53 47 28.0   |
| MS08       | SRRAK South East ridge of B62 | 12-Nov-2011 to 1-Mar-2012 | 111           | NW           | SW           | N21 22 06.4 | E53 42 04.2   |
| MS09       | Kidan North SRRAK 1433 | 5-June-2005 to 30-Nov-2005 | 432            | SE           | NE           | N23 32 34.1 | E53 15 17.0   |
| MS10       | Kidan North SRRAK 1439 | 30-Jun-2005 to 26-Nov-2005 | 213             | NW           | SW           | N21 13 31.0 | E53 21 11.0   |
| MS11       | SRRAK 1413       | 5-Feb-2006 to 16-May-2006 | 308              | NW           | SW           | N21 34 35.0 | E53 05 17.0   |
| MS12       | Kidan North SRRAK 1439 | 19-May-2006 to 29-Jun-2006 | 128             | NW           | SW           | N23 32 39.0 | E53 18 02.0   |
| MS13       | Shabak SRRAK 431 | 30-Jun-2006 to 5-Jul-2006 | 128             | NW           | SW           | N23 42 32.0 | E53 37 10.0   |
| MS14       | Buceif South of Block 83 | 1-Nov-2005 to 20-May-2006 | 396             | NW           | SW           | N22 37 41.0 | E54 40 24.4   |
| MS15       | Middle of Block 83 | 7-May-2006 to 4-May-2006 | 397             | NW           | NE           | N22 37 45.0 | E54 34 06.9   |
| MS16       | South of Block 84 | 5-May-2006 to 2-Aug-2006 | 398             | NW           | SE           | N22 37 11.0 | E54 37 14.9   |
| MS17       | SRRAK 3058      | 8-Aug-2006 to 21-Nov-2006 | 310             | NE           | NE           | N21 34 36.0 | E53 36 16.1   |
| MS18       | North of Kidan South | Aug. to Nov. 2012 | 306              | NW           | NE           | N21 46 04.4 | E53 35 43.8   |
| MS19       | Mid de Kidan     | 1-Mar-2010 to 31-Mar-2012 | 124           | NW           | NW           | N23 58 95.2 | E53 19 35.1   |
| MS20       | North of Kifian 86 | 24-Oct-2009 to 30-Apr-2010 | 864             | NE           | NW           | N23 33 37.0 | E53 37 05.2   |
| MS21       | Kidan 6         | 20-Feb-2009 to 11-May-2009 | 440            | NE           | NW           | N22 28 33.0 | E53 17 40.8   |
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Fig. 5  Wind roses for the metrological stations: MS19 in Kidan South, and MS20 in Kidan North.

roses in each of the four metrological zones. Also, combining wind directions products with remote sensing products was very useful to get better understanding of the topography and its relation to the wind movements in any particular location.

Kidan North: the 9 metrological stations in this zone showed a visual trend of the winds that comes mainly from North and North East. This trend was based on 5,667 observations or 3,900 recording days during the period from June 2005 to April 2011. The map in Fig. 6 clarifies the main and secondary wind directions in each one of the 9 stations in Kidan North zone, where each arrow in the map represents one of the main directions in a particular station (with number of observation days annotated to the arrow). Fig. 6 also shows the wind rose compiled from the 9 stations for Kidan North zone. However, it is possible to go deeper and study data in any one of these meteorological stations. For example, the predominant wind direction in MS21 station was SE during March to May 2008. However, the predominant wind direction in this station was changed to NW during the three months (November 2008 to January 2009). But the highest wind direction frequency in this station is NE during the period February 2008 to May 2009.

Kidan South: the general trend in Kidan South is winds coming from North West apart from during the Autumn season where it is North winds. See wind rose of Kidan South in Fig. 7 to know more about other directions. This was based on 2,381 observations or 1,148 recording days from 5 different metrological stations in this zone.

Shaybah and Block 83: the main wind directions in Shaybah were North Eastern and North Western. Also, North Western trend can be seen in block 83 but based on limited amount of data, total of 171 recording days or 513 observations in two locations (MS14 and MS15).

Shaybah South: there was no real trend of the wind directions identified in this zone due to large area size and limited amount of data which was based on only 391 observations recording days. The three metrological stations in this zone were MS07, MS08 and MS16.

4. Conclusions

The final result after processing all available data in the study area showed that 59% of the wind in this area is coming from the Northern angle (NE, N, and NW), which were basically Shamal and Haboob winds. The Saus or Simoom winds, were secondly (26%), coming from East and South East directions. Figs. 8 and 9 clarify winds’ names and their distribution/directions in the study area.

Shamal wind is a dry wind which carries large amount of dust and sand and occurs in both summer and winter but Shamal wind is more powerful during the daytime of the summer [4].
Fig. 6  Map of the main and secondary wind directions in Kidan North zone with wind rose.
Fig. 7  Wind rose of Kidan South zone based on the number of observations (2,381) in 5 stations.

Fig. 8  Pie chart of the distribution of wind directions in the whole study area.
On the other hand, the Haboob is a storm that comes in a wall carrying dust and sand. Simoom is coming from North Africa as a violent hot dry and dusty wind while Saus wind blows as a low mild velocity wind.

Result of the study was plotted within the regional winds movement in order to get better understanding in larger scale on how these winds are moving? And from where they are coming? See Fig. 10 where study results are plotted in red color on top of the original maps from the Saudi Arabian Wind Energy Atlas (Al-Ansari et al., 1986, cited in Ref. [4]).

In conclusion, the study area has no main winds coming from the following directions: W, S, and E. The study also realized the importance of the winds coming from the northern angle (NW, N and NE). The season showed to have effect on the wind directions change. In Kidan North zone, the trend of the wind comes mainly from the northern angle and SE as Shamal, Haboob and sometimes Simoom winds. The general trend in Kidan South zone is Shamal wind (NW) apart from during autumn season where it is N. The remaining two zones (Shaybah and Block 83, and Shaybah South) were analyzed but no real wind trend can be guaranteed due to limited number of meteorological stations, large area size, and less amount of weather data. Finally, this study helped to understand the winds’ movement/directions in Kidan which is critical to support future decisions related to dispersion models and when choosing locations of development wells and facilities especially considering the availability of dangerous gas such as H2S in the sub-surface. In other words, the study recommends that positioning of the main camps and facilities of the project to be in the N or NE of potential H2S sources. These positions will protect lives of the operators/workers of the project in case of gas leakage considering the main winds directions from northern angle and SE.
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