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Assessment of Temporal Variation of Wind Speed as an Indicator of Intensity Wind Erosion in Northern State, Sudan

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ABSTRACT: *The study was conducted in the Northern State, which is severely affected by wind erosion. It is located between longitudes 30˚ 15′ - 32˚ 00′ east and latitudes 17˚ 45′ - 19˚ 15′ north, there are three meteorological stations in the State, Wadi Halfa, Dongolla and Karima. The area of the State is approximately 348697km^2. Daily observations of wind speeds data during the two periods 2001-2003 and 2011-2013 were collected for meteorological station of Karima in the Northern State. Erosive Winds (EW_S) are speed of winds causing erosion ($V \geq 5.0$ m/sec) estimated from the total wind speed. The study aimed to estimate and determine the ability of EW_S from the total winds, comparison of wind speeds in different seasons (months +years), and generating correlation between total winds and EW_S for the two studied periods. The SPSS program was used for statistical analysis. The results showed that the wind speed varies greatly in frequency and speed during each month and year, even within the same climatic season. In two periods the variation (CV%) due to annual was much lower than the monthly due to the higher monthly variability of wind speed, accounted about 1.6 and 1.9 folds for the first and second periods respectively. Furthermore, the total mean of EW_S for the second period is 1.2 times greater than the first period. In the second period (2011-2013), the mean EW_S ranged between 19.5 (November) and 45.6, 45.1 (February and March respectively), with a mean of 30.8 m/sec, a standard deviation (STD) of 9.7, and a (CV) of 31.7%. The results of the regression analysis between the total winds and the EW_S for the two periods showed strong correlation with a high, direct and significant relationship ($p < 0.001, R = 0.971$) and ($p < 0.001, R = 0.978$) for the first and second periods respectively. The total winds contributed by 94.2% and 95.6% of the wind variability of WE_S for the first and second periods respectively. In the study area, the climatic conditions are suitable for generating energy from solar radiation and wind.*

KEY WORDS: Wind erosion; Erosive wind, wind speed and frequency; regression; correlation; seasonal and annual variations.

INTRODUCTION

The phenomenon of desertification is considered one of the most prominent environmental concerns during the past two decades. Desertification is defined as the degradation of lands in arid, semi-arid and semi-humid areas resulting from various factors, including climate changes and human activities. Desertification is the main environmental problem and the main constraint to biological production (plant and animal activity) in Sudan (Mustafa, 2008). The lands of the arid and semi-arid regions are characterized by fragile soils that are easy to disintegrate and transport by wind, and the vegetation cover in those regions is weak and does not provide protection for the lands exposed to the winds. Wind erosion is the most important process in the desertification processes in the Northern State. Mustafa, 2007 defined wind erosion as "the soil physical process by which dry, loose and fine surface soil particles are picked up or moved on the ground surface and transported by wind and the soil surface material is abraded by wind-particles." Wind erosion occurs in a two-step process, namely detachment of primary soil particles from the soil mass and their transport by erosive winds $V \geq 5.0$ m/sec (Skidmore and Woodruff, 1968). Certain conditions can be conducive to wind erosion include: lack or sparse vegetative cover, large and extensive field, loose, dry, and dispersed soil particles, smooth surface soil, and erosive winds. The northern state is located in the desert plain, where sandy nature prevails. We find alluvial lands on both banks of the Nile River and are characterized by fertility and are exploited in the production of vegetables, fruits and food and cash field crops such as wheat and Egyptian beans. These lands have sand movement throughout the year from north to south, which exposes them to wind erosion (sand encroachment) from one bank of the river and water erosion (demolition) from the other bank. Wind erosion research has received a lot of attention globally, for example (Aleksandar *et al*. *2019*; Javadi *et al*. *2020*; Qi Luo *et al*. *2020*; XinLyu *et al*. *2021 and* Guocheng Yang *et al*. *2021*). On a national scale, a limited number of studies have been conducted to estimate and map wind erosion (Abdelwahab and Mustafa, 2013; Abdelwahab *et al., 2014;*Abuzeid *et al.,* 2017; Rizgalla *et al.* 1999;Farah,2003; and Haikal, 2005). Abuzied, 2009, evaluating and drawing wind erosion maps for the northern state, it was found that the winds caused the largest movement of sand blowing from the north and northeast direction in the period from October to May and the period from February to May. The amount of sand creep on the Nile River was estimated at 45.5 m3 / km width / day.

Mohammed and Mohammed, 2010 classified the climates of Sudan using indices of aridity into arid, hyper-arid, arid, semi-arid, semi-humid and humid regions. Abdelwahab and Mustafa (2015) conducted a study to assess the monthly and daily variation of wind speed and direction and wind erosion in River Nile State. Studies of wind speed and directions, and in particular the winds that cause erosion in the affected areas, did not receive enough attention, which resulted in a lack of previous studies, except (Abdelwahab and Mustafa, 2015 and Alzubair, and Abdelwahab, 2021). Analysis of meteorological data is essential for crop production at the local, regional and global levels. As matter of fact assessing and monitoring eroded lands in the affected areas in Sudan are essential for designing control measures for enhancing agricultural development particularly in arid lands. This point can be raised by analyzing meteorological data. Generation of analyzing meteorological data is a prime factor to determine the susceptibility of wind erosion, restoring eroded lands, sustained agro-forestry production, and designing wind erosion control methods particularly in arid lands. Furthermore, in Sudan, till now very little attention was paid to meteorological data analysis, so it is necessary to carry out studies in all climate elements particularly winds in arid lands to avoid its negative impacts on all live kinds. The present study was undertaken to achieve the following objectives:

1- To estimate and determine the ability of erosive winds (EW_S) from the total winds in the study area.
2- To assess the temporal variability of wind speeds (months +years) in the study area.
3- To generate regression relationship between the total winds and the EW_S for two studied periods.

MATERIALS AND METHODS

Materials

Study area

The study was conducted in the northern state, which lies between latitudes 17˚ 45' - 19˚ 15' north and longitude 30˚ 15 - 32˚ 00' east.(fig 1) It has three meteorological stations: Halfa, Dongola and Karima. The area of the state is about 348,697. Km^2. Irrigated agricultural land is about 1,337,451 acres (41,667 hectares). The prevailing climate in the state is very dry with hot summer from April to September and cold winters from October to March (Alzubair *et al.* 2021). The highest average maximum temperature was 43.1 °C recorded in Dongola, while the absolute maximum was 49 °C in Wadi Halfa, and the minimum temperature recorded was 8.3 °C in Wadi Halfa. The highest rate of evaporation was recorded in May and the lowest in January, the maximum duration of sunshine was 11.9 hours in June and the lowest duration was 9.8 hours in December. The pressure occurs in August and the lowest level occurs in February. The average annual total precipitation is 318 and 37.7 mm in Wadi Halfa Dongola and Karima respectively. The rain increases from north to south (Alzubair *et al.* 2021).

Meteorological data.

The daily observations (records) of erosive winds (EW_S) during the two periods 2001-2003 and 2011-2013 for Karima meteorological station in the Northern State were obtained from the Meteorological Authority of the Ministry of Environment, Forestry and Urban Development, Sudan.

Methods.

Daily data on erosive winds ($V \geq 5.0$ m/sec) and total winds (non-erosive+ erosive winds (EW_S)) were collected, where the wind speed and direction are monitored eight times during the 24 hours (8 observations per day). SPSS was used for means separation between monthly and annual wind speeds.

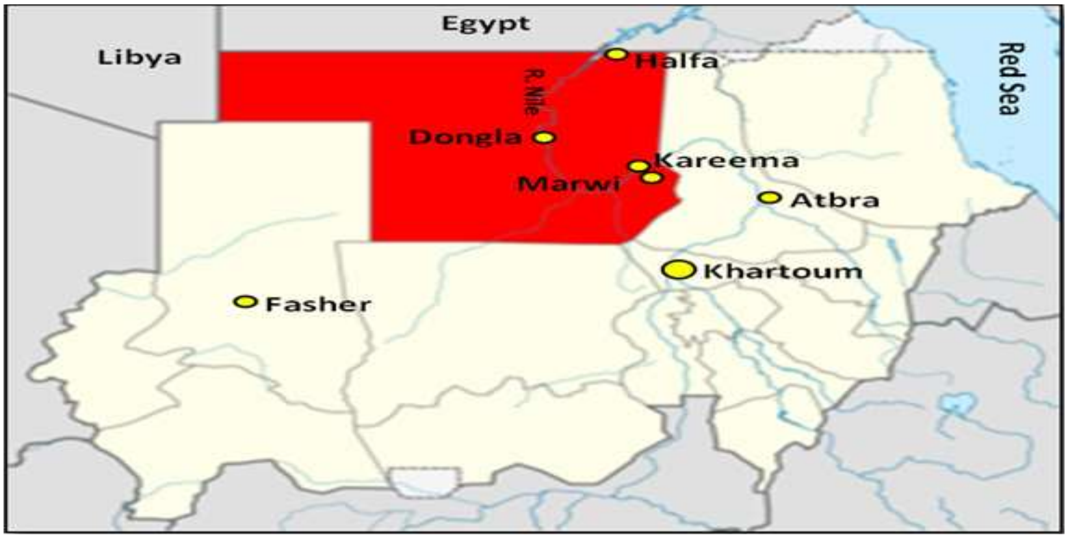

Fig.1. the location of study area

RESULTS AND DISCUSSION

The first period 2001-2003.

Table 1 shows the average monthly and annual of EW_S (m/sec) for the first period. The average monthly wind speed ranged between 12.4 (July) and 40.6 (March), with a mean of 24.8 m/sec, a standard deviation (STD) of 10, and a coefficient of variation (CV) equals 40%. The overall means of all months decreased in the following orders: Mar.>Feb.>Apr.>Nov.=Dec.>Jan.>Oct.>May>Aug.>Sept.>June>July (Fig.2). The mean annual wind speeds ranged between 18.5 (for the year 2001) and 30.8 (for the year 2003), with an average of 24.8 m/sec, with a STD of 6.2, and a CV of 24.8%. The monthly variation was much higher than the annual variation of wind speed, accounted about 1.6 times, this fact may be attributed to higher variability of monthly wind velocity than annual. Regarding to the annual means the difference between the highest and lowest means (12.3) is greater than 11.9, so the highest mean is significantly different from that of the lowest mean. For the two remaining means, the difference between the second highest and lowest means (6.8) is less than 9.9, so the second highest mean similar significantly from that of the lowest mean. The annual averages decreased as follows, 2003< 2002< 2001. (Fig.3).

Table1. Average monthly and annual of EW_S (m/sec) and their percentage of the total wind speed for the first period 2001-2003

	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Mean**
2001	12.3 (26.8)*	23.9 (45.8)	13.1 (32.9)	35.7 (62.6)	17.2 (38.8)	3.8 (13.4)	9.1 (27.9)	15.3 (39.7)	17.7 (40.1)	37.8 (57.6)	17.6 (33.5)	18.8 (38.7)	18.5 b (38.2)
2002	22.0 (44.5)	27.0 (58.9)	50.3 (71.0)	45.3 (69.2)	29.6 58.6 ()	15.7 (42.4)	11.4 (33.4)	27.4 (58.5)	15.3 (43.8)	14.0 (34.6)	12.0 (32.2)	32.7 (54.9)	25.3 b (50.2)
2003	42.4 (65.1)	70.1 80.) (9	58.3 (75.0)	30.0 (57.3)	11.4 (33.0)	21.4 (43.1)	16.7 (40.5)	14.1 (38.2)	17.9 (44.4)	9.5 (24.6)	39.2 (57.7)	38.2 (60.2)	30.8 a (51.7)
Min. value	12.3	23.9	13.1	30.0	11.4	3.8	9.1	14.1	15.3	9.5	12.0	18.8	-
Max.value	42.4	70.1	58.3	45.3	29.6	21.4	16.7	27.4	17.9	37.8	39.2	38.2	-
STD	15.4	25.8	24.1	7.7	9.3	9.0	3.9	7.4	1.4	15.2	14.4	10	
CV	0.60	0.64	59.5	0.21	0.48	0.66	0.31	0.39	0.85	0.74	0.63	0.33	
Mean	26.0	40.3 a	40.6 a	37.0 ab	19.4 ab	13.6 ab	12.4 bc	18.9 ab	17.1 ab	20.4 ab	22.9 ab	29.9 ab	24.8

* In parentheses indicates the percentage of erosive winds out of the total wind.
*Means followed by the same letters are not significantly different from each other at the 0.05 level by Duncan Multiple Range Test.

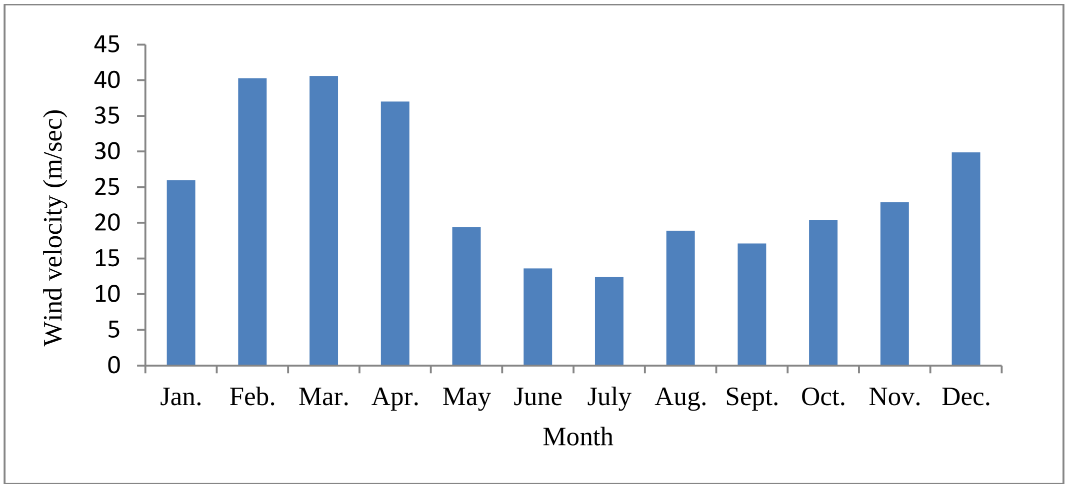

Fig.2. Monthly average of erosive winds (EW_S) for the first period (2001-2003)

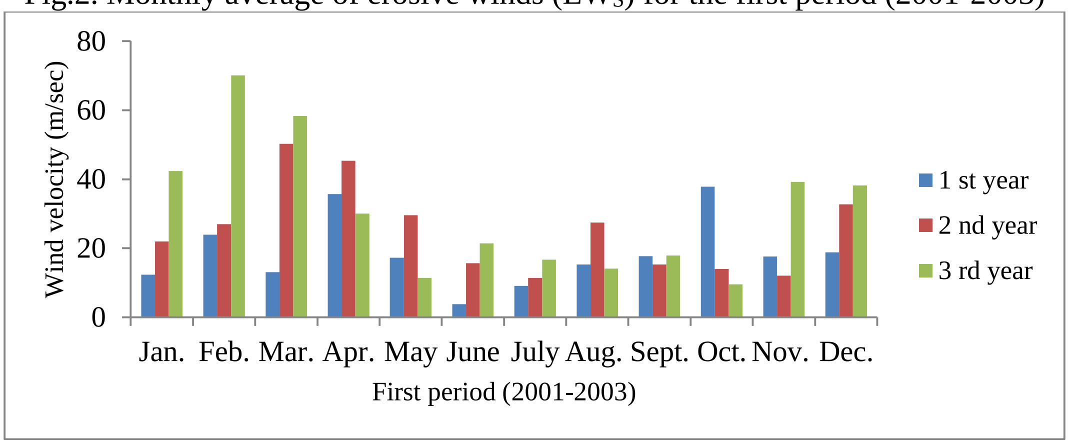

Fig.3. Annual average of erosive winds (EW_S) for 2001, 2002, and 2003, respectively

Regression and correlation between EW_S and total winds for the first period 2001-2003

Regression and correlation analysis (second-order equation) between the total winds and erosive winds EW_S gave highly positive significance ($p<0.001$, $R=0.971$), the EW_S increase with the increase of the total winds, and the total winds participate in 94.2% of the variability of the EW_S. The trend depicted by the following equation: $Y = 0.0083 x^2 + 0.1442 x - 3.9607$, where (Y) is EW_S, and (X) is the total winds speed (Fig. 4).

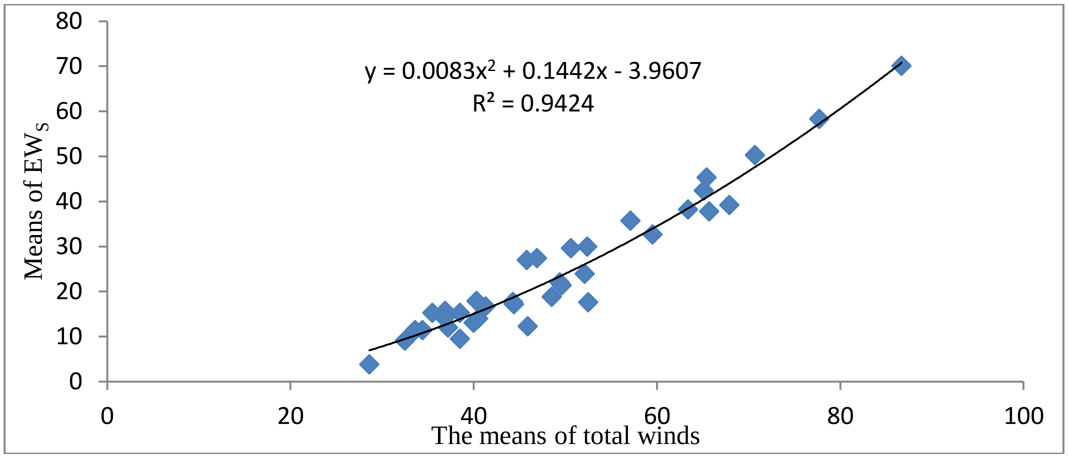

Fig. 4. Regression and correlation between average total wind velocity and average of EW_S (2001-2003).

The second period 2011-2013.

Table 2 shows the average monthly and annual of EW_S (m/sec) for the second period. The average monthly wind speed ranged between 19.5 (November) and 45.6, 45.1 (February and March respectively), with a mean of 30.8 m/sec, a STD of 9.7, and a CV equal to 31.7%. The overall means of all months decreased in the following orders: Feb.>Mar.=Apr.>Jan.>Dec>May>Oct.>Aug.>Sept.>July>June>Nov.(Fig.5).The average annual wind speed ranged between 25.3 (for the year 2012) and 35.8 (for the year 2011), with an average of 30.8 m/sec, a STD of 5.3, and a CV of 17.1%. The results showed that the monthly variation is much higher than the annual variation of wind speed, about 1.9 times, due to the high variability of monthly wind speed compared to the annual wind speed. The results revealed that the total mean for the second period is 1.2 times higher than the first period (30.8/24.8), and The annual averages decreased as follows, 2011> 2013>2012 (Fig.6). Regarding to the annual means the difference between the highest and lowest means (10.5) is less than 11.4, so the highest mean is not significantly different from that of the lowest mean. For the two remaining means, the difference between the second highest and lowest means (6.0) is less than 9.5, so the second highest mean similar significantly from that of the lowest mean.

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Table2. Average monthly and annual of EW_S (m/sec) and their percentage of the total wind speed for the second period 2011-2013

	Jan.	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Mean**
2011	57.7 (78)	43.6 (70)	48.7 (71.1)	55.6 (80.2)	34.5 (62.6)	28.3 (62)	21.0 56.6	30.4 (69.0)	23.7 50.2	23.6 (47.2)	39.4 (66.8)	23.2 (53.4)	35.8 a (63.9)
2012	25.4 (51.7)	37.9 (62.8)	58.0 (79.4)	26.0 (57.3)	29.9 (60)	12.3 (35.8)	16.4 (48.7)	17.8 (44.3)	15.5 (42.7)	19.8 (48.8)	16.7 (50)	27.5 (55.7)	25.3 a (53.1)
2013	34.9 (66)	55.4 (77)	28.6 (60)	41.7 (71.2)	19.0 (54.4)	19.0 (45.7)	27.5 (52)	28.7 (62.5)	29.9 (60.3)	39.8 (66.4)	2.3 (58.8)	48.9 (76.7)	31.3 a (62.6)
Min.value	25.4	37.9	28.6	26.0	19.0	12.3	16.4	17.8	15.5	19.8	2.3	23.2	
Max.value	57.7	55.4	58.0	55.6	34.5	28.3	27.5	30.4	29.9	39.8	39.4	48.9	
STD	16.6	8.9	15.0	14.8	8.0	8.0	5.6	6.8	7.2	10.6	18.7	13.8	
CV	0.42	0.20	0.33	0.36	0.29	0.40	0.26	0.27	0.31	0.38	0.96	0.42	
Mean	39.3 ab	45.6 a	45.1 a	41.1 ab	27.8 ab	19.9 bc	21.6 bc	25.6 ab	23.0 ab	27.7 ab	19.5 bc	33.2 ab	30.8

* In parentheses indicates the percentage of erosive winds out of the total wind.
*Means followed by the same letters are not significantly different from each other at the 0.05 level by Duncan Multiple Range Test.

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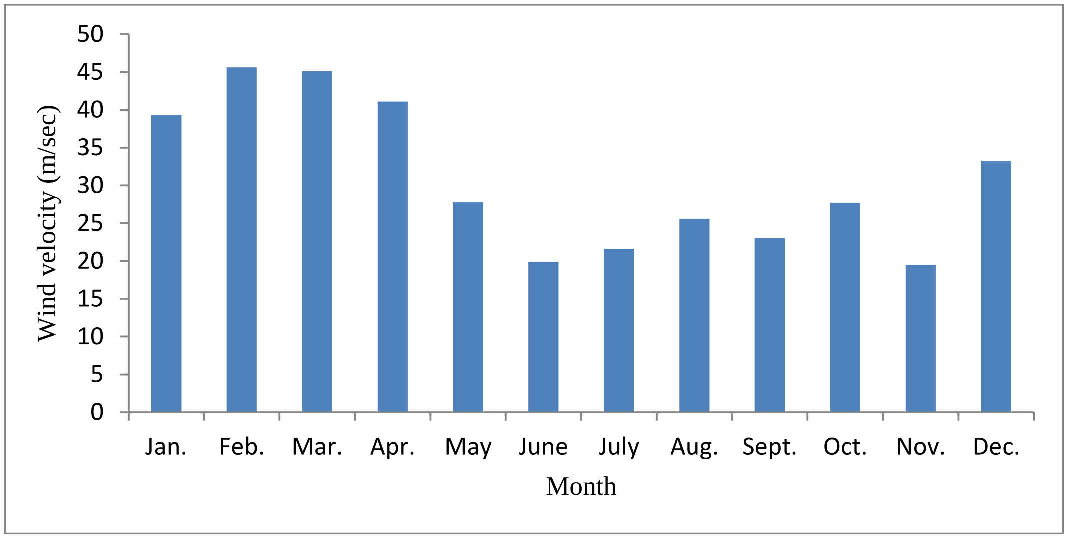

Fig.5. Monthly average of erosive winds (EW_S) for the second period (2011-2013)

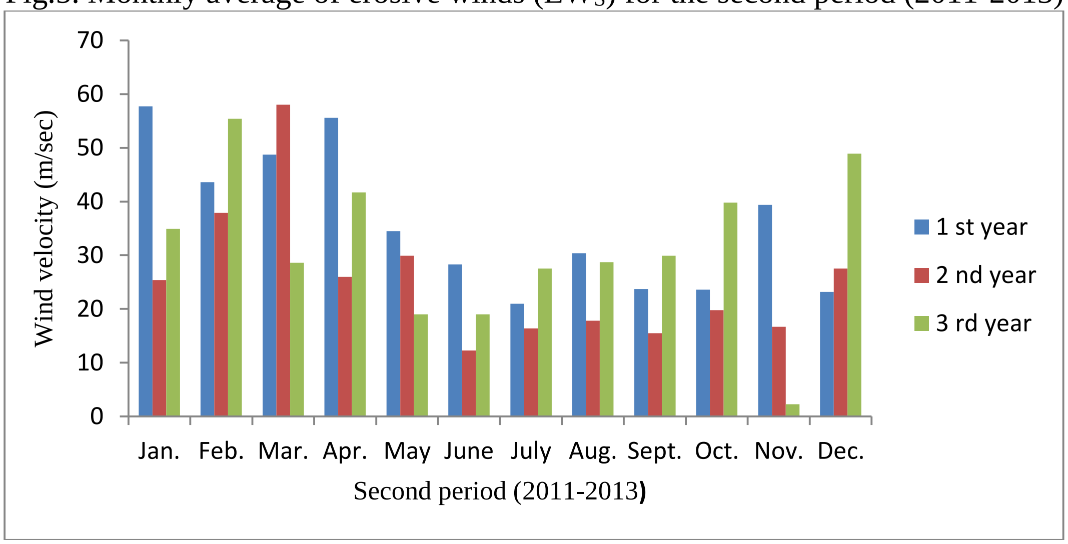

Fig.6. Annual average of erosive winds (EW_S) for 2011, 2012, and 2013, respectively

Regression and correlation between EW_S and total winds for the second period 2011-2013.
Regression and correlation analysis (equation of the third degree) between the total wind and the EW_S showed a high and positive significance ($p<0.001$, $R=0.978$), and the EW_S increases with the increase of the total wind, and the total wind participates in 95.6% of the variability of the EW_S. The trend depicted by the following equation: $Y = 0.0004x^3 - 0.053x^2 + 2.8912x - 0.2459$, where (Y) is EW_S, and (X) is the total wind speed (Fig.7).

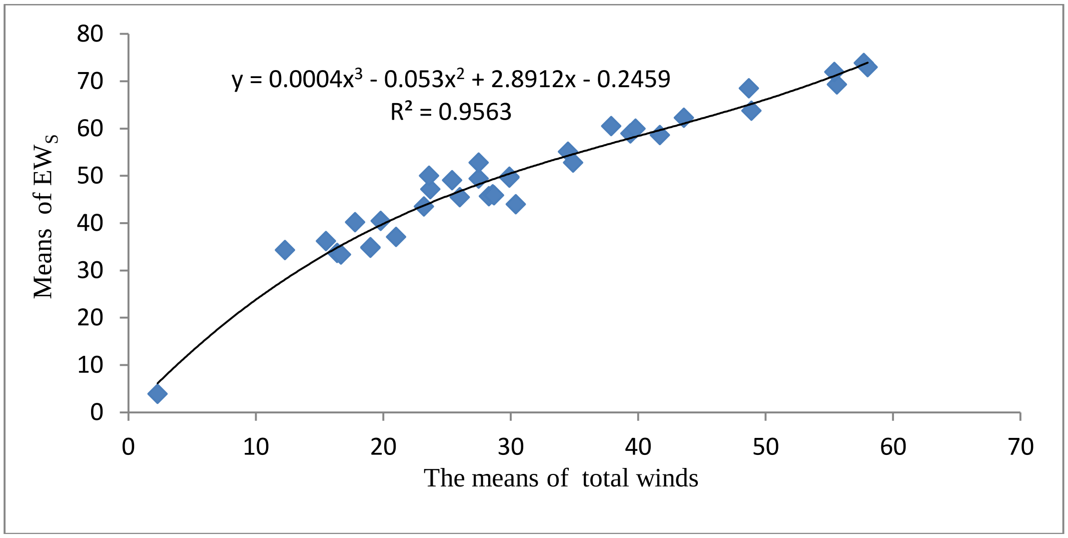

Fig.7. Regression and correlation between average total wind velocity and average of EW_S (2011-2013)

DISCUSSION

Wind is the horizontal movement of air in response to differences in atmospheric pressure, and is the means by which the atmosphere tries to balance the uneven distribution of pressure on the Earth's surface. Barriers and roughness of the earth's surface slow down wind speed. This paper intends to creation of an initial database on wind speed for the northern state (Karima area).

Two studies were conducted (Abdelwahab and Mustafa, 2015 and Abuzeid, 2009) dealing with wind speed and directions for the Nile River State and the Northern State respectively, and the results showed the prevailing wind direction in winter (October-March) are north and north-northwest, and in summer and autumn (April-September) south and southwest. So, this study did not address wind directions.

The results for the two periods showed that the wind speed varies greatly in frequency and speed during each month and year, even within the same climatic season. The results gave a high variability for months compared to years. This fact may be attributed to higher variability of monthly wind velocity than annual and the uneven distribution of pressure in the state. Moreover, the majority of the northern state lacked windbreaks and tree belts, in addition to the prevailing climatic conditions, including high temperature and a sharp decrease in precipitation. Rain and its irregularity lead to these high wind fluctuations. This result is consistent with the results of (Abdelwahab and Mustafa, 2015). The results showed that the total average of erosive winds (EW_S) for the second period was 1.2 folds that generated by the first period (30.8/24.8), which indicates a significant increase in the ability and intensity of winds to cause erosion in the second period, which necessitates taking the necessary measures.

In the second period (2011-2013), the mean of EW_S ranged between 19.5 (November) and 45.6, 45.1 (February and March respectively), with a mean of 30.8 m/sec, a standard deviation of 9.7, and a coefficient of variation of 31.7%. This result is similar to what was reached by (Abdelwahab and Mustafa, 2015). Therefore, measures must be taken in the winter period (February and March), when the winds blow from the northern direction (the Egyptian wind) in general, and it is known that these winds advance the desert southwards.

The results of the regression and correlation analysis between the total winds and the EW_S for the two periods showed a high significance and direct relationship ($p< 0.001$, $R = 0.971$) and ($p < 0.001$, $R = 0.978$) for the first and second periods respectively, and the total winds contributed 94.2% and 95.6% of the variability of EW_S for the first and second periods, respectively. This result indicates the strength of the correlation between winds and EW_S, where the total wind contributes to the formation of EW_S by (94.2% and 95.6%), and the remainder of this percentage is due to the influence of others interfering factors such as, duration of erosive winds, temperature, atmospheric pressure…..ect.

CONCLUSION AND RECOMMENDATIONS.

1. The results showed that the wind speed varies greatly in frequency and speed during each month and year, even within the same climatic season (summer and winter). In two periods the variation (CV%) due to annual was much lower than the monthly due to the higher monthly variability of wind speed, accounted about 1.6 and 1.9 folds for the first and second periods respectively
2. The results indicated that the total mean of erosive winds (EW_S) for the second period was 1.2 times greater than the first period.
3. The study area is described as hyper- arid, in addition to the prevailing harsh climate, including high temperatures and very low and irregular rainfall, which indicates that the climatic conditions are very favorable for wind erosion. Therefore, there is an urgent need to establish protective tree belts to reduce wind erosion in the state.
4. The results of the regression and correlation analysis between the total winds and EW_S for the two periods showed a high, direct and significant relationship amounting to ($p<0.001$, $R=0.971$) and ($p<0.001$, $R=0.978$) for the first and second periods respectively. The total winds contributed 94.2% and 95.6% of the variability of EW_S for the first and second periods, respectively.
5. There is little meteorological data available for quantitative analysis, and this is due to its unavailability on the internet and the lack of free access to this data for research agencies and universities.
6. The urgent need to establish new meteorological stations and rehabilitate the old ones to cover the entire state.
7. The results showed that the regression technique can be used effectively to show the relationship between wind variables and wind erosion, therefore it is recommended to re-conduct it periodically.
8. The climatic conditions in the state are suitable for generating energy from solar radiation and wind, safely and environmentally friendly

9. Applying and using the results of meteorological data analysis in designing strategic projects to reduce wind erosion and then promote sustainable land use.

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