Omdurman Islamic University Journal(OIUJ)
مجلة جامعة أم درمان الاسلامية
https://journal.oiu.edu.sd/index.php/oiuj
https://doi.org/10.52981/oiuj.v18i1.2270
2022; 18(1):257-272
ISSN: 5361-1858

Textural Analysis of Windblown Sand as an Indicator of Susceptibility of Wind Erosion in Atbara Area, River Nile State, Sudan

Motasim Hyder Abd Elwahab[1*] and Hussain Mohammed Ahmed Abuzeid[2*]

[1]*Associate Professor, Faculty of Agriculture, Omdurman Islamic University, Omdurman, Sudan*
[2]*Associate Professor, Faculty of Agriculture, Omdurman Islamic University, Omdurman, Sudan*

Corresponding Email address: e-mail: abdo.momti76sag@gmail.com - **Mobile:** +249912830889

To cite this article:

Hyder Abd Elwahab, M., & Mohammed Ahmed Abuzeid, H. (2022). Textural Analysis of Windblown Sand as an Indicator of Susceptibility of Wind Erosion in Atbara Area, River Nile State, Sudan. Omdurman Islamic University Journal, 18(1), 257-272. https://doi.org/10.52981/oiuj.v18i1.2270

Abstract

Textural Analysis of Windblown Sand (TAWS) is essential for understanding the characteristics of wind sediment and behaviors of grain movement particularly in the climatically frame of wind erosion. This paper aimed to generate preliminary quantitative data on TAWS by estimating grain size distribution and some textural parameters e.g. median diameter (M50), mean grain size (Mz), graphic standard deviation (σ1) inclusive graphic skewness (Ski) and transgraphic kutosis (KG) in three selected sites namely, north, south east and south Atbara in river Nile state. Coefficient variations of the (M50) and (Mz) results exhibited a colossal similarity with minor differences between them accounted about 1.12%. In spite of the high variability of (σ1**)** between three sites (30%) but the data can be characterized as very well sorted (< 35), so the study area can be described as highly susceptible to wind erosion, the susceptibility decreased in the following order: north Atbara > south east Atbara> south Atbara. Regarding to (Ski) results the three sites can be described as positively skewed (north and south east Atbara) and very positively skewed (south Atbara). The (KG) data showed leptokurtic (north and south Atbara) and mesokurtic (south east Atbara). The dominant mean grain sizes for sand samples for north Atbara were fine sand 34% and medium sand 50%. Whereas the samples of south east Atbara distributed fine sand 34%, medium sand 45% and courses and 5%. South Atbara gave 25%, 38% and 12% for fine, medium and courses sand respectively.

Keywords: Textural analysis, textural parameters, graphic standard deviation, behaviors of sand grain, River Nile state, Sudan.

1. Introduction

Wind erosion is defined by [1] as "soil physical process by which dry, loose and fine surface soil particles are picked up and transported and/or moved along the soil surface by wind and thereby abrade the soil surface material by wind-born particles." This process is a two-step process, namely detachment of primary soil particles from the soil mass and their transport by erosive winds ($V \geq 5.4$ m/sec). When the wind velocity or energy is below the threshold value to transport soil particles, deposition occurs. Soil particles move by three mechanisms according to their diameter: suspension ($d < 0.1$ mm) saltation ($d = 0.1$-0.5 mm) and surface creep ($d > 0.5$ mm). The conditions conducive to wind erosion include: loose, dry, and dispersed soil particles, smooth surface soil, lack or sparse vegetative cover, large and extensive field and erosive winds. Wind erosion researches are widely acknowledged [2,3,4,5 and6]. Two main factors affect wind erosion: wind erosivity and soil erodibility. Wind erosivity is a measure of the ability of wind to pick the soil particles from the soil surface and transport them by saltation or push them on the soil surface (surface creep) or blow them and transport them by suspension [1]. Soil erodibility is the susceptibility of a dry soil or its ease of detachment and transport by wind. It is a measure of the susceptibility of the soil to erosion [1].

There are two indices of erosivity, namely the pressure of prevailing erosive winds and the index introduced by [7]. Both indices are dependent on erosive wind velocity. The velocity of erosive winds depends upon the size of the particles eroded by it. Erosive winds were classified according to Beaufort scale of wind velocity and equivalent pressure at 40 m height. It was reported that even under gentle breeze (3.4-5.4 m/sec.) soil particles are carried away [1].

[8] Assessed wind erosivity of Atbara for two successive seasons (August 2008 – March 2009 and August 2009 – March 2010) using an equation introduced by [7]. Erosive wind speeds ($V > 5.4$ m/sec), wind direction and duration data for both seasons were used. The results showed that both hourly and monthly wind speed and erosive wind speed varied widely in magnitude and direction in both seasons. The diurnal variation was much lower than the monthly variation. In the first season, for example, erosivity ranged from 0 (Nov.) to 369.8 (Feb.) with a mean of 255.1 and CV of 43.6%. The results showed that the direction of the highest contribution of erosive winds in August (75.6%) in summer was from SW followed by that from S (10.5%); whereas during January in winter the highest contribution was from NNW (59.4%) and N direction (19.9%).

Soil erodibility by wind was referred to as wind erodibility to distinguish it from soil erodibility by water. A comprehensive research project on wind erodibility (WE) was implemented, in several States in Sudan, by postgraduate students as complimentary research in partial fulfillment of their M.Sc. degrees, in the Desertification and Desert cultivation studies Institute, University of Khartoum [9,10,11,12,13,14,15 and16].

In Sudan comprehensive reviews on intensity wind erosion (IWE) were presented by several research workers in different states [8,17,18,19,20,21,22,23,24,25,26 and27].

Textural Analysis of Windblown Sand (TAWS) deposit is essential for understanding the characteristics of wind sediment, behaviors of grain movement in any fluids and determine the areas that have highly susceptible to wind erosion[28]. In spite the importance of TAWBS till now there is no any research conducted in this area resulting on absence of literature reviews, so this paper can be considered as pioneer and guide work in the topic under concern. Actually the importance of this paper refers to the lacking of research pertaining to TAWS. The present study was undertaken to achieve the following objectives:

1. To generate comprehensive quantitative data on studies of TAWS in the study area.
2. To determine the percentage distribution of the grain size and estimate the textural parameters, i.e. Median diameter (M50), mean grain size (Mz), graphic standard deviation (σ_1) inclusive graphic skewness (Ski) and transgraphic kutosis (KG) in the study area.
3. To investigate and compare the wind erosion susceptibility of the three selected sides in the study area depends on the results of inclusive graphic standard deviation ($\sigma_{1)}$.
4. To calculate the dimensional empirical coefficient (c) values that used in the equation derived by [29] includes sand transported by saltation only in the study area.

2. Materials and Methods

2.1. Study area

The study was conducted in the River Nile State, which is severely affected by desertification processes. The state has an area of 121 km^2 that lies between latitudes 17^o and 19^o N and longitudes 32^o and 34^o E. There are two main soil orders along the banks of the River Nile. Entisols occur on the first terrace and Aridisols (salt – affected soils) on the second and third terraces of the Nile. Entisols form a narrow strip of recent alluvial fertile soils that are not salt – affected. However, they are adversely affected by gully erosion at the river side and desert encroachment from the other side. The State is dominated by arid and hyper – arid climatic conditions with mainly two seasons, a hot summer from April to September and cold winter from October to March. Mean annual rainfall is less than 100 mm. Diurnal range of temperature is large all the year round and temperatures as high as 49^{o}C are not uncommon in the period extending from April to June. In winter temperature as low as 1.5^{o}C have been recorded. The vapor pressure is only 10.8 mb and the relative humidity is less than 20%. Clouds are generally rare. Short-wave solar radiation is as high as 659 calorie cm^{-2} in May. Winds prevail from the north with a mean maximum speed of 17.6 km/hr. The River Nile and Atbara River are the main sources of irrigation water in the State. However, research proved that there are abundant amounts of ground water suitable for agricultural and domestic purposes. This is due to the fact that large areas of the State lie within the Nubian sand stone aquiver [30].

The following locations were selected for undertaking the study:

1. South east Atbara about 50 km from Atbara town. Location UTM zone 36 Q
   GPS (E 0636354 & N 1923591)
2. North Atbara about 36 Km from Atbara town on the western bank of River Nile. Location UTM zone 36 Q   GPS (E 0599293 & N 1992872)
3. South Atbara about 17 Km from Atbara town. Location UTM zone 36Q GPS (E 0603713 & N 1941843). In each location a samples were taken to laboratory for analysis of windblown sand (Fig.1).

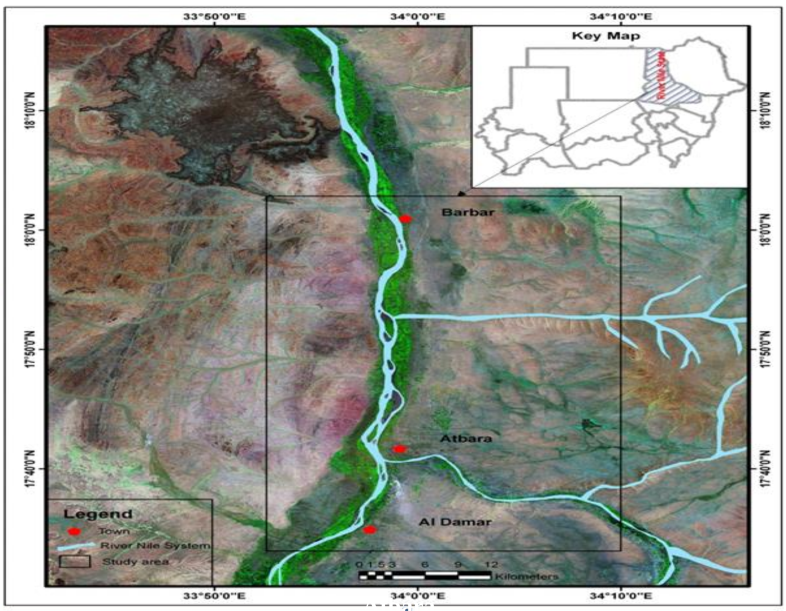

Fig.1. Locations of the study sites

2.2. Materials

2.2.1. Textural analysis of windblown sand

Three soil samples were collected from each studied location (3 kg) and taken to the laboratory (Building and Road Research Institute, University of Khartoum). Sample tested by gradual sieve ranged between 5.60 – 0.063 mm (table 1). The results of sieves analysis test illustrated in grain size distribution curves includes particles size distribution from clay to cubbies.

Table 1. Sieve analysis test in three locations of study areas

North Atbara		South east Atbara		South Atbara	
Sieve size (mm)	Retained by weight (g)	Sieve size (mm)	Retained by weight (g)	Sieve size (mm)	Retained by weight (g)
5.60	0.00	5.60	0.00	5.60	3.0
4.76	0.00	4.76	0.00	4.76	3.3
2.80	0.00	2.80	0.00	2.80	4.2
2.00	0.00	2.00	0.00	2.00	4.9
1.40	0.00	1.40	0.00	1.40	6.6
1.00	0.1	1.00	0.1	1.00	11.3
0.710	0.2	0.710	1.1	0.710	20.1
0.500	2.4	0.500	20.6	0.500	32.7
0.425	4.7	0.425	33.2	0.425	37.7
0.250	48.9	0.250	94.0	0.250	76.5
0.212	63.3	0.212	107.2	0.212	87.1
0.180	99.1	0.180	132.9	0.180	106.8
0.150	116.4	0.150	146.3	0.150	117.6
0.125	138.5	0.125	158.8	0.125	127.6
0.090	161.5	0.090	174.5	0.090	143.5
0.075	164.9	0.075	175.8	0.075	146.0
Pan (0.063)	169.6	Pan (0.063)	178.5	Pan (0.063)	149.3
Sample weight after washing (g)	169.8	Sample weight after washing (g)	178.7	Sample weight after washing (g)	149.5

Each data point is a mean of three data points

2.2.2. Sand transport equation

The equation [29] incorporate a cubic relationship between sediment transport (q_s) and the prevailing friction velocity (U*) includes sand transported by saltation only.

$$\mathbf{q_s = c\ (d/D)^{0.5}\ (p/g)\ U^*} \qquad \mathbf{(1)}$$

Where:

q_s = rate of sand transport in saltation (g/m/s)

U* = friction velocity or shear velocity or drag velocity

d = mean grain diameter of sand (mm)

D = standard grain diameter (0.25mm**)**

P = mass density of the air (1.2×10^{-4} g/cm^3)

g = gravitational acceleration (981cm/sec.^{2})

C = a dimensional empirical coefficient

The coefficient c depends, among other things, on the degree of sorting of sediment and varies between 0.8 and 3.5. The following numerical values may be used in practical calculation of **q_s**

C = 1.5 for very well sorted sand (highly susceptible to wind erosion)

= 1.8 well sorted sand such as typical dune sand (moderate susceptible to wind erosion)

= 2.8 badly sorted sand (very low susceptible to wind erosion)

= 3.5 for surface of non –erodible element such as pebbles bare rocky surfaces (None erodible elements) (table 2).

Table 2. Terminology to graphic statistical parameters values (modified after [31])

Inclusive graphic standard deviation or phi sorting (σ_1)		Inclusive graphic skewness orphi sorting (Ski)		Inclusive graphic kurtosis or phi sorting (KG)	
Very well sorted	≤ 0.35	Very positively skewed	+0.3 to +1.0	Very platykurtic	≤ 0.67
Well sorted	0.35-0.50	positively skewed	+0.1 to +0.3	platykurtic	0.67- 0.90
Moderately well sorted	0.50-0.70	Symmetrical	+0.1 to -1.0	Mesokurtic	0.90 – 1.11
Moderately sorted	0.70-1.00	Negatively skewed	-0.1 to -0.3	Leptokurtic	1.11 -1.50
Poorly sorted	1.00-2.00	Very negative skewed	-0.3 to -1.0	Very Leptokurtic	1.50 -3.00
Very Poorly sorted	2.00-4.00				

2.3. Methods

2.3.1. Statistical parameters of granulometric analysis

Comparison between natural grain size distribution and the log-normal distribution can be made using a number of statistical parameters computed from the cumulative percentage frequency curve. The parameters proposed by [31] have been widely used. The textural parameters, i.e. Median diameter (M50), mean grain size (Mz), graphic standard deviation (σ_1) inclusive graphic skewness (Ski) and transgraphic kutosis (KG) will be used in this paper:

1- Median diameter (M50) = 50 percentile (mm)

2- The graphic mean (Mz) is given by: $Mz = (\Phi\ 16 + \Phi\ 50 + \Phi\ 84) \div 3$ mm (2)

Where Φ 16, Φ 50 and Φ 84 are phi size values corresponding to sixteenth, fiftieth and eighty-four percentiles, respectively red from frequency curve (Fig. 2)

3- Inclusive graphic standard deviation (σ_1). A measure of the spread about the mean, or sorting is given by inclusive graphic standard deviation (σ_1), defined as:

$$\sigma_1 = (\Phi\ 84 + \Phi\ 16)/4 + (\Phi\ 95 + \Phi\ 5)/6.6 \quad \text{mm} \qquad (3)$$

4- Inclusive graphic skewness (Ski). The asymmetry of skewness of the distribution is indicated by the inclusive graphic skewness, (Ski)

$$Ski = \Phi\ 16 + \Phi\ 84 - 2\ \Phi\ 50 / 2(\Phi\ 84 - \Phi\ 16) + \Phi\ 5 + \Phi\ 95 - 2\ \Phi\ 50 / 2(\Phi\ 95 - \Phi\ 5) \text{ mm} \qquad (4)$$

Positive value of (Ski) indicate that the distribution has a more pronounced tail of fine material compared with a long- normal distribution, conversely negative value of (Ski) indicate a tail of courser particle or a deficiently of fine particles compared with a long- normal distribution (Fig. 3A).

5- Inclusive graphic kurtosis (KG):

$$(KG) = \Phi 95 - \Phi\ 5 / 2.44\ (\Phi\ 75 - \Phi\ 25) \quad \text{mm} \qquad (5)$$

Frequency distributions which are flatter than a normal probability curve are referred to as platykurtic and strongly peaked curves are described as leptokurtic. Curves which approximately a Gaussian profile are referred to as mesokurtic (table 2& Fig. 3B).

The results of the particles size distribution and the statistical analysis of texture are derived from monologarithmic graph paper. Fig.2. shows example of the three monologarithmic graph paper.

2.3.2. Measurement and calculation of data

The calculations were based on phi unit (Φ) grade scale followed by equivalent in millimeters (mm) (wentworth grade scale) the progression as illustrated in the table 3. The cumulative mass percentage was plotted against size on a monologarithmic graph paper. The size distribution of samples and the median grain size (50%), the two quartiles 25 and 75 and the 5,16, 84 and 95 percentile were obtained from cumulative curves for each sample was presented in Fig. 2. The formulas applied for calculations of grain size statistical and textural parameters are listed above.

Table 3. Calculations of phi unit (Φ) grade scale and equivalent in millimeters (mm) in the study area

North Atbara		South east Atbara		South Atbara	
Φ 5%	0.0 mm	Φ 5%	0.0 mm	Φ 5%	0.0 mm
Φ 16%	0.06 mm	Φ 16%	0.1 mm	Φ 16%	0.0 mm
Φ 25%	0.12 mm	Φ 25%	0.15 mm	Φ 25%	0.06 mm
Φ 50%	0.18 mm	Φ 50%	0.23 mm	Φ 50%	0.18 mm
Φ 75%	0.25 mm	Φ 75%	0.37 mm	Φ 75%	0.35 mm
Φ 84%	0.3 mm	Φ 84%	0.42 mm	Φ 84%	0.5 mm
Φ 95%	0.4 mm	Φ 95%	0.59 mm	Φ 95%	1.00 mm

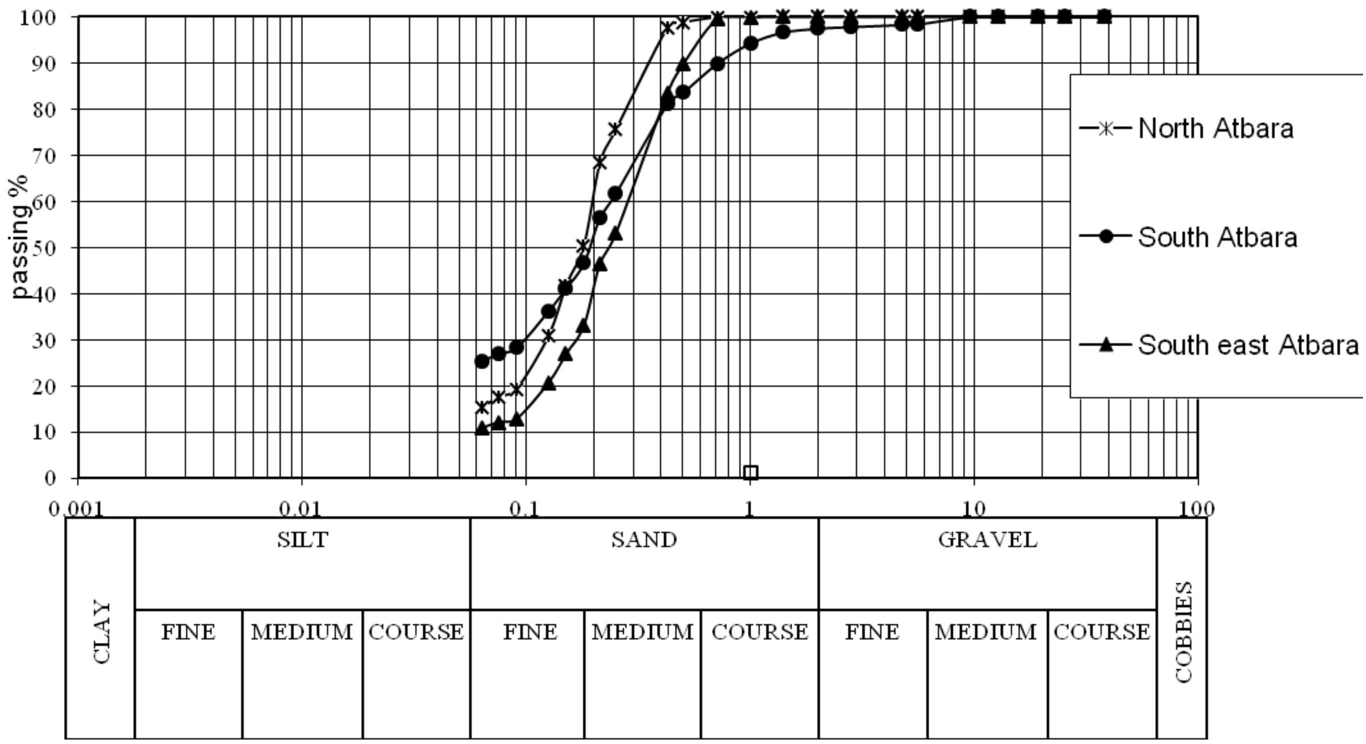

Fig.2. Grain size distribution curve in the three studied area

3. Results and Discussion

3.1. Results

3.1.1. Grain size distribution and textural parameters of windblown sand in the study area

3.1.2. Median diameter (M50)

Median diameter (M50) refers to the 50 percentile (mm). The data obtained for the median diameter for the three sites ranged from 0.18 to 0.23 mm with a mean of 0.21, a standard deviation (STD) of 0.03 mm and a coefficient of variation (CV) of 14.7%. The mean diameter samples gave 0.18, 0.23, and 0.18 for north Atbara, south east Atbara and south Atbara respectively (Fig.2). Furthermore the mean diameter sample (M50) of south east Atbara was 1.3 fold that of north and south Atbara.

3.1. 3. The graphic mean (Mz)

The data obtained for the graphic mean for the three sites ranged from 0.18 to 0.25 mm with a mean of 0.22, a standard deviation (STD) of 0.04 mm and a coefficient of variation (CV) of 16.4%. The mean diameter samples gave 0.18, 0.25, and 0.23 for north Atbara, south east Atbara and south

Atbara respectively. The M50 and Mz results exhibited a colossal similarity with very meager differences between coefficients of variations accounted about 1.12%.

3.1. 4. Inclusive graphic standard deviation (σ_1)

Standard deviation **(σ_1)** is a measure of the spread about the mean, or sorting, the results in the study area revealed that the values of **(σ_1)** ranged from 0.15 to 0.28 mm with a mean of 0.22, a standard deviation (STD) of 0.07mm and a coefficient of variation (CV) of 30%. The **(σ_1)** of samples gave 0.15, 0.22, and 0.28 for north Atbara, south east Atbara and south Atbara respectively. In spite of the high variability of inclusive graphic standard deviation between three sites (30%) but the data can be characterized as very well sorted (< 35) (table 2). These results a proved that the study areas are highly susceptible to wind erosion. The susceptibility decreased in the following order: north Atbara > south east Atbara> south Atbara, this finding reported by [17].

3.1.5. Inclusive graphic skewness (Ski)

Inclusive graphic skewness (Ski) means the asymmetry of the distribution values of inclusive graphic skewness for samples under investigations ranges from 0.05 to 0.5 mm with a mean of 0.25 mm a standard deviation (STD) of 0.23 mm and a coefficient of variation (CV) of 92%. Regarding to the (Ski) result the three sites can be described as positively skewed (north and south east Atbara) and very positively skewed (south Atbara) (Table 2& Fig.3A). The Ski of samples gave 0.05, 0.20 and 0.5 for north Atbara, south east Atbara and south Atbara respectively. The coefficient of variation (CV) between samples gave high value that can be explained as high variability in the study area for this parameter.

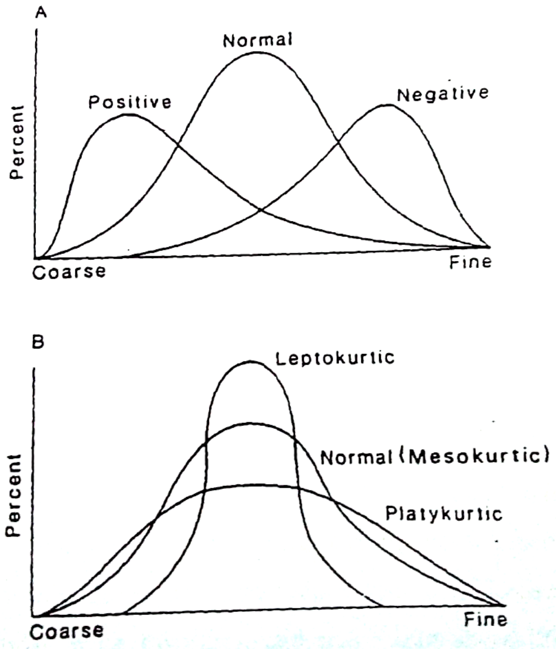

Fig.3. Diagram illustrating the nature of (A) skewness (asymmetry) and (B) kurtosis (peakedness) in grain size distributions

3.1.6. Inclusive graphic kurtosis (KG)

Graphic kurtosis ranges from 1.1 to 1.4 mm with a mean of 1.3 mm a standard deviation (STD) of 0.15 mm and a coefficient of variation (CV) of 12%. Inclusive graphic kurtosis (KG) data can be readied for the sites as follows leptokutic (north and south Atbara) and mesokurtic (south east Atbara)(Table 2& Fig.3B). South east Atbara shows mesokurtic distribution meaning that the sand samples are closely reassembly a normal frequency distribution. Five statistical parameters were depicted in table 4.

3.1.7. Grain size distribution in the study area

Table .4.Show the grain size distribution in the study area, the dominant mean grain sizes for sand samples for north Atbara were fine sand 34% and medium sand 50%. Whereas the samples of south east Atbara distributed fine sand 34%, medium sand 45% and courses and 5%. South Atbara gave 25%, 38% and 12% for fine, medium and courses sand respectively.

Table 4. Grain size statistical and textural parameters of windblown sand deposit in the study area.

Location	**Statistical parameters *1**					**Grain size *2**					**Fs+ Ms**
	(σ_1) mm	(Ski) mm	(KG) mm	(M50) mm	(Mz) mm	z	Fs	Ms	Cs	Fg	
North Atbara	0.15	0.05	1.3	0.18	0.18	0%	34%	50%		0	84
Southeast Atbara	0.22	0.20	1.1	0.23	0.25	0%	34%	45%	5%	0	79
South Atbara	0.28	0.5	1.4	0.18	0.23	0%	25%	38%	12%	0	63
Min.	0.15	0.05	1.1	0.18	0.18						
Max.	0.28	0.5	1.4	0.23	0.25						
Mean	0.22	0.25	1.3	0.21	0.22						
STD	0.07	0.23	0.15	0.03	0.04						
CV%	30	92	12	14.7	16.4						

***1**

- M50, median diameter egual 50 percentile (mm)
- Mz, the graphic mean
- σ_1, inclusive graphic standard deviation
- ski, inclusive graphic skewness
- k_G, inclusive graphic kurtosis

***2**

- Silt, (z) fine silt (0.002-0.006mm), medium silt (0.006-0.02mm), and course silt (0.02-0.06mm)
- Sand (Fs) fine sand (0.06-0.2mm), (Ms) medium sand (0.2-0.6mm), and (Cs) course sand (0.6-2mm)
- Gravel, (Fg) fine gravel (2-6mm), (Mg) medium gravel (6-10mm), (Cg), and course gravel (0.10-100 mm).

3.2. Discussion

Depend on dominant mean grain sizes and inclusive graphic standard deviation (σ_1) in the three study areas north Atbara, south east Atbara and south Atbara sand samples distributed as follows 84% (fine &medium sand); 79% (fine &medium sand) and 63% (fine &medium sand) and 0.15, 0.22, and 0.28 mm (very well sorted (< 35)) respectively. These results a proved that the study areas are highly susceptible to wind erosion. The susceptibility decreased in the following order: north Atbara > south east Atbara> south Atbara, this finding is typical to that reported to describe the Intensity of Wind Erosion (IWE) by [17]. So serious measures should be carried out to reduce the IWE in the state

Grain size analysis showed that values of median (M50) and mean diameter (Mz) were very similar for each sample. Sand collected from north and south of Atbara showed values of (Mz) less than that of south east Atbara with few variation. Mz being 0.18., 0.23 and 0.25 for north, south and south east Atbara respectively

Regarding to the inclusive graphic skewness (Ski) result the three sites can be described as positively skewed (north and south east Atbara) and very positively skewed (south Atbara). In general, the Ski result of study area fall in the positive skewed that meaning the distribution has a more pronounced that of fine material (drifting sand material) compared with a long normal distribution. The coefficient of variation (CV) between samples gave high value in high variability in the study area for this parameter.

Inclusive graphic kurtosis (KG) data can be readied for the sites as follows leptokutic (north and south Atbara) and mesokurtic (south east Atbara)(Table 2& Fig.3B), south east Atbara shows mesokurtic distribution meaning that the sand samples are closely reassembly a normal frequency distribution.

4. Conclusion and Recommendations

4.1. Conclusion

Eventually, Textural Analysis of Windblown Sand (TAWS) deposit is essential for understanding the characteristics of wind sediment, behaviors of grain movement in any fluids and determine the areas that have highly susceptible to wind erosion [28]. In spite the importance of TAWS; in Sudan till now there is no any research conducted in this area resulting on absence of literature reviews, so this paper can be considered as pioneer and guide work in the topic under concern. Furthermore the results generated from inclusive graphic standard deviation (σ_1) and inclusive graphic skewness (Ski) indicated that the study area are highly susceptible to erosion by wind.

Due to high values of fine and medium sand (drifting sand) accounts 84% and the selected site in north Atbara lies in bare land at the western bank of the River Nile and open in all directions with no barriers or shelterbelts. Therefore, windbreaks should be established to reduce northerly and southerly winds. The susceptibility decreased in the following order: north Atbara > south east

Atbara> south Atbara, this finding is typical to that reported to describe the Intensity of Wind Erosion (IWE) by [17]., So serious measures should be carried out to reduce the IWE in the state.

4.2. Recommendations

There is impressing and urgent need to conduct the TAWS research in large scale to cover the whole country. Moreover the climatic conditions in the River Nile are highly conducive to wind erosion resulting in high amounts of drifting sand (fine &medium sand) in the three selected sites. Accordingly serious measures should be carried out to reduce and reverse the suitable conditions of wind erosion in the state.

References

[1] Mustafa, M.A. 2007. Desertification Processes. University of Khartoum Press, 230 pp

[2] Aleksandar Baumgertel, Sara Luki´c, Snežana Belanovi´c Simi´c and Ratko Kadovi´, 2019. Identifying Areas Sensitive toWind Erosion—A Case Study of the AP Vojvodina (Serbia) Applied Sciences 2019, 9, 5106; doi:10.3390/app9235106 www.mdpi.com/journal/applsci

[3] Javadi S A, layeghi N, Jafari M, Arzani H. 2020. Measuring the Land Use Based Risk of Soil Erosion in a Mining-Dominated landscape in Northern Iran. Journal of Ecological Engineering 21(7):271-282. doi:10.12911/22998993/125546.

[4] Qi Luo, Lin Zhen, Yu Xiao and Haiyan Wang, 2020. The effects of different types of vegetation restoration on wind erosion prevention: a case study in Yanchi

[5] XinLyu; XiaobingLi; HongWang; JiruiGong; ShengkunLi; HuashunDou;and Dongliang Dang. 2021. Soil wind erosion evaluation and sustainable management of typical steppe in Inner Mongolia, China. Environmental Management journal, volume 277, 1 January 2021xd, 11148

[6] Guocheng Yang; Ranhao Sun; Yongcai Jing; Muqi Xiong and Liding Chen.2021. Global assessment of wind erosion based on a spatially distributed RWEQ model Journal of Progress in Physical Geography: Earth and Environment Volume 45Issue 3June 2021 https://doi.org/10.1177/03091333211030608

[7] Skidmore, E.L. and Woodruff, N.P.1968. Wind erosion force in the United States and their use in predicting soil loss.USDA Hand book No. 346, 42 pp. Washington DC.

[8] Abdelwahab, M. H., Mustafa, M. A. 2015. Monthly and diurnal variation of wind speed and direction and wind erosivity in River Nile State, Sudan. The International Journal of the Environment and Water Vol.4, issue 4: 1-10.

[9] Medani, G. H. and Mustafa, M.A. 2003. Wind erodibility of soils from North Darfur State. U. of K .Journal of Agriculture Science 11:369 – 384.
[10] Mustafa, M. A. and Medani, G. H. 2003. Wind erodibility of soils from Khartoum State. U.of K .Journal of Agriculture Science 11: 149– 164
[11] Mohammed, A.Y. and Mustafa, M.A. 2005. Wind Erodiblity of Soils from Wind Erodiblityof Soils from the White Nile State, Sudan. In the proceeding of the Regional Workshop "Scientific Research and National Research Plans of Action for Combating Desertification.", Tuesday 22-Thursday 24 November 2005, Al Sharga Hall, University of Khartoum
[12] Rehan, S. A. and Mustafa, M.A. 2005. Wind erodibility of soils from the Gezira State, Sudan. In the proceeding of the Regional Workshop "Scientific Research and National Research Plans of Action for Combating Desertification." Tuesday 22-Thursday 24 November 2005, Al Sharga Hall, University of Khartoum
[13] Abdelwahab, M. H., Mustafa, M. A. and Ganawa, E. S. 2009. Spatial variation of wind erodibility of soils from the Northern State, Sudan. Sudan Journal of Desertification Research 1: 56-70.
[14] Mohammed, M.A. E. and Mustafa, M.A. 2011. Assessment and mapping of wind erodiobility of Aridisols and Entisols in the Red Sea State, Sudan, University of Khartoum Journal of Agricultural Sciences 19(2): 128-144.
[15] Hassan, A.A., and Mustafa, M. A. 2011. Assesment and mapping of wind erodibility of Aridisols and Entisols in the Nile State, Sudan. Sudan Journal of Desertification Research 3 (1): 49-61.
[16] Abdelgadir, I. A., Mustafa, M. A., and Ganawa, E. S. 2013. Assessment and mapping of wind erodibility of soils of south western kassala state in Sudan. Sudan J. Des. Res. 5: (1): 19-33
[17] Abdelwahab, M.H Mohammed Ali, E.D, and Mustafa, M.A. 2014. Assessment of wind erosion using remote sensing techniques in Atbara Area, River Nile State, Sudan., Sudan Journal of Desertification Research 6:1-14
[18] Abdelwahab, M.H. and Mustafa, M.A. 2016a. Assessment of horizontal and vertical wind erosion and their interrelationship in Barber, River Nile State, Sudan., The International Journal of the Environment and Water 5(2):1-8.
[19] Abdelwahab, M.H. and Mustafa, M.A. 2016b. Assessment of wind erosion on bare and Lucerne cultivated lands in south Atbara, River Nile State, Sudan., The International Journal of the Environment and Water 5(2): 87-94.

[20] Abdelwahab, M.H. Ali Ahmed, E.E. and Mustafa, M.A. 2015. A note on impact of Vetiver hedges on intensity of wind erosion in north Atbara, River Nile State, Sudan. Sudan Journal of Desertification Research 5 (1): 134-139

[21] Abuzied, H.M. 2009. *Mapping and Assessment of Wind Erosion in Central Northern State, Sudan,* Ph.D. (Desertification and Desert Cultivation Studies Institute) thesis, University of Khartoum, Sudan

[22] Abuzeid, H.M.A. Mustafa, M.A. and Hamid, A.A. 2015a. Rate of sand movement by saltation and sand creep in the central part of the Northern State, Sudan. Sudan Journal of Desertification Research 7: 40-51.

[23] Abuzeid, H.M.A. Mustafa, M.A. and Hamid, A.A. 2015b. Relationships between rate, height of rise, direction and duration of measurement of sand saltation in three selected sites in the Northern State, Sudan Sudan Journal of Desertification Research 7: 52-66.

[24] Abuzeid, H.M.A. Mustafa, M.A. and Hamid, A.A. 2017. Assessment of wind erosion in central part of the northern state, Sudan, Sudan Journal of Desertification Research 9

[25] Rizgalla, A. M, Mustafa, M. A. and Mdibo, J. 1999. Wind erosion in North Kordufan State, Sudan. Desertification Control Bulletin 35: 39-44.

[26] Farah, A.M. 2003. *Wind Erosion in Khartoum State*. Ph.D. Thesis. Faculty of Agriculture, University of Khartoum, Sudan

[27] Haikal, S.M. S. 2005. *Assessment and Mapping of Wind Erosion in North East Butana Area*, Ph.D. (Desertification and Desert Cultivation) thesis, University of Khartoum, Sudan

[28] Wilson. I.G.1973. Ergs sedimentary, Geology 10, 77-106

[29] Bagnold, R. A. 1941. The physics of blown sand and desert dunes; London: Methuen and Co. Ltd. 265p.

[30] Izzeldin, S.I., and Ahmed, S.H. 2004. A proposed Plan of Action for Research on Desertification in the Sudan: Northern and Nile States. In: M.A. Mustafa, and A.A. Mahdi.(eds). Proceedings of the National Forum of Scientific Research on Desertification in the Sudan, 16-18 March, 2004, Al Sharga Hall, University of Khartoum, Sudan, Published by UNESCO Chair of Desertification Studies, Sudan, Khartoum University Press, 325pp.

[31] Folk and Ward 1975. Brazos river bar: a study in the significance of grain size parameters. Journal of Sedimentary Petrology 27, 3-26.