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A review Research on Wind Erodibility of Some States and Their Interrelationships in Sudan

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Abstract

Wind erodibility of soils (WE) is a prime indicator of soil susceptibility to wind erosion. It is used for the prediction of wind erosion. The pooled data of the six states of non –erodible soil particles (NEP), WE and soil physicochemical properties were treated statistically. The main objectives of this paper are to present a review of research on wind erodibility; generation of statistical empirical relationships between NEP and WE with soil physiochemical properties and derived the relationship for the pooled data of the six states. The overall mean NEP of the six states ranged from 27.2 to 62.4 with a mean of 41.9% and CV of 27.7%, and the overall mean of WE ranged from 46.8 to 236.9 with a mean of 140.4 ton/ha and CV of 43.2%. The overall mean NEP of the six states gave a highly significant positive correlation with clay content with coefficients ranging between 0.8945 and 0.6731 with a mean of 0.8044 and a CV of 10.2%. The overall mean NEP was in the following order: Gezira> the Red Sea> Northern> River Nile> Kassala> North Darfur. The overall mean WE of the six states gave a highly significant negative correlation with clay content with coefficients ranging between - 0.8794 and - 0.6567 with a mean of - 0.8004 and a CV of 9.6%. The overall mean WE was in the following order: North Darfur> Kassala> River Nile> Northern> the Red Sea> Gezira. The pooled data of the six states gave a highly significant negative correlation between NEP and (sand/clay) ratio, which accounted for 70% of the variation of NEP. The pooled results of the six states gave a highly significant positive correlation between WE and (sand/clay) ratio, which accounted for 70% of the variation of WE. Sand particles that limit soil aggregation and their presence increases WE and decreases NEP, so the ratio is useful for the prediction of wind erosion. The five states were dominated by course to medium textured wind erodibility groups (WEGs). The five states are described as highly susceptible to wind erosion because of their texture.

Keywords: Wind erodibility, Non–erodible soil particles, Soil physiochemical properties, Wind erodibility groups, States Sudan.

1. Introduction

Wind erosion occurs in a two-step process, namely detachment of primary soil particles from the soil mass and their transport by erosive winds $V \geq 5.4$ m/sec (Skidmore and Woodruff, 1968). When the wind velocity or energy is below the threshold value to transport soil particles, deposition occurs. Soil particles are transported 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 conducive conditions 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 (Mustafa, 2007).

Wind erosion is governed by two main factors namely 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 (Mustafa, 2007).

Soil wind erodibility (WE) is the susceptibility of dry soil or its ease of detachment and transport by wind. WE are a prime indicator of the susceptibility of the soil to wind erosion and hence it is used for the prediction of wind erosion by the soil loss equation proposed by Woodruff and Siddoway (1965). Chepil (1953) found that soil particles > 0.84 mm, were resistant to entrainment by common erosive winds. Thus, these particles were considered non-erodible particles (NEP) and wind erodibility is estimated from knowledge of the percentage of NEP (Woodruff and Siddoway, 1965). Wind erodibility of cultivated soils is affected mainly by soil texture and various other soil physical, chemical characteristics and processes that influence soil aggregation (Harris et al., 1966; Wishmeier and Mannering, 1969; Romken et al., 1977; Young and Muchler, 1977; Lyles and Tatarko, 1986; Black and Chanasyk, 1989; Kheir El Seid, 1998).

National research project on the assessment and mapping of wind erodibility in various states was undertaken in the Desertification and Desert Cultivation Studies Institute (Medani and Mustafa 2003; Mustafa and Medani 2003; Rehan and Mustafa, 2005; Abdelwahab et al., 2009; Mohammed and Mustafa, 2011; Hassan and Mustafa, 2011 and Abdelgadir et al., 2013). Soil indicators were recommended for the prediction of non-erodible soil particles (NEP) and wind

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erodibility (WE) of the soils. For example, Mustafa and Medani (2003) recommended the use of the (Silt and Sand) / (Clay + $CaCO_3$) ratio for the prediction of NEP and WE of the soils of Khartoum State. WE showed a quadratic increase with the increase of this ratio. It was concluded that this indicator is a better indicator than the clay ratio alone, which was previously recommended by other authors. The present study was undertaken to achieve the following objectives:

1. Estimation and comparison of overall mean WE and NEP of the six states.
2. Identification of the correlation between (WE and NEP) with soil indices at the six states.
3. Generation relationships between (sand/clay) ratio, examined with (NEP and WE).
4. Establishment of wind erodibility groups (WEGs) for the studied states.

2. Materials and methods

2.1 Study area

The study was conducted in Sudan (1,882,000 Km^2), that locates in northeast Africa at latitudes 14° and 22° north and longitudes 22° and 38° east. Sudan is dominated by two types of winds, the dry north-easterly wind in winter (October, November, December, January and February) and the humid southerly wind in the rainy season during (May, June, July, August and September). There is a high variation in the spatial and temporal distribution of rainfall in Sudan. Lines of equal rainfall depth (isohyets) were used by (Harison and Jakson, 1958) to classify the vegetation zone of Sudan. Aridity index (AI) is defined as a measurement of precipitation divided by evapotranspiration. Five degrees of aridity were defined (0.03 - 0.65) by Dregne et al., (1991) and become a global measure.

2.2 Soil sampling and methods

Wind erodibility of selected farms was estimated using bulked surface (0-3cm) soil samples carefully collected at random, after completion of land preparation, from transects delineated across the field of each of (28-50) agricultural farms in each studied state accounted 268 samples. The soil samples were carefully saved in bags to avoid aggregate fragmentation.

Wind erodibility of soils was determined by the dry sieving method proposed by Chepil or Woodruff (1959). The soil samples were air-dried, and straw and stones, if any, were removed. One kilogram of an air-dry soil sample was sieved with a 0.84 mm diameter sieve. The mass of soil aggregates greater than 0.84 mm, considered to be non-erodible particles (NEP). Non-erodible particles were calculated for each sample, and its equivalent WE (ton/ha) was obtained from a standard table established by Woodruff and Siddoway (1965). Furthermore, the main soil physicochemical properties were determined by acceptable standard methods. Particle-size distribution was determined using the hydrometer method described by Black et al. (1965). By Chapman and Pratt (1961), organic carbon (OC) was determined by the dry-aching method of Fredrick, described by Ibrahim (1991), and organic matter (OM) was then calculated.

Statistical empirical relationships between NEP and WE and soil properties for six individual states were derived. The relationships for the pooled data of the six states were also derived by “Microsoft Excel 2003”

3. Results and discussion

3.1 Relationships in individual states

Table 1 shows the range of the mean soil particle-size distribution, organic matter (OM), NEP, WE, of the farm soils in each of the six studied states. The relatively high CV of the particle-size distribution in each state may be partially attributed to wind erosion. The data collected from farms in the Northern State will be presented as an example of the six studied states. Regression analysis of the data collected from farms in the Northern State showed that NEP significantly increased linearly with increase of clay (r^2 = 0.402) , silt (r^2 = 0.317), OM (r^2 = 0.139), and $CaCO_3$ (r^2 =0.279),(Fig.1, 2, 3 and 4)and decreased with increase of sand (r^2 = 0.410), and increase of (silt sand)/clay ratio (r^2 = 0.440) (Fig.5 and 6). The reverse correlation trends were obtained with WE (Abdelwahab, 2005, Abdelwahab and et al., 2009). Multiple regression analysis yielded a highly significant (P < 0.001, r = 0.718) correlation between NEP and multiple soil variables as follows:

$$NEP\% = 365.6 - 2.3\ Clay\% - 3.7\ Sand\% - 4.0\ Silt - 3.0\ CaCO_3$$

According to this relationship, the four soil properties account for 52% of the variation of NEP. The negative sign of the coefficients of clay and $CaCO_3$ is contrary to logical expectation but such anomalies are known in empirical statistical models.

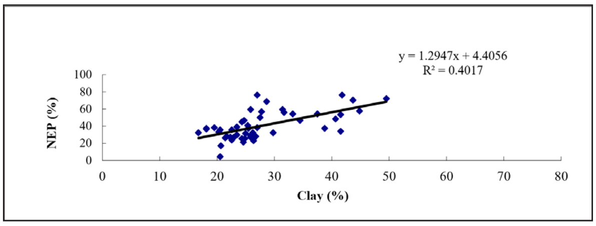

Figure 1. Mean non-erodible soil particles (NEP) versus clay content

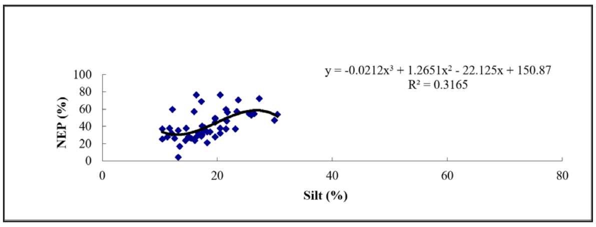

Figure 2. Mean non-erodible soil particles (NEP) versus silt content

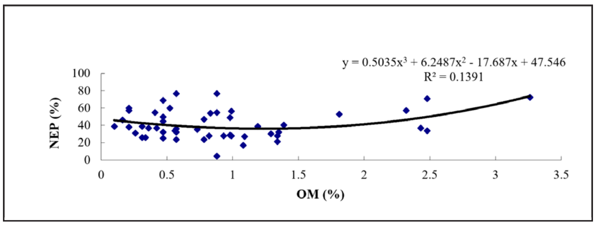

Figure 3. Mean non-erodible soil particles (NEP) versus silt content

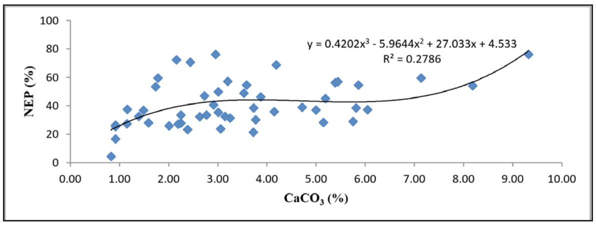

Figure 4. Mean non-erodible soil particles (NEP) versus CaCO3 content

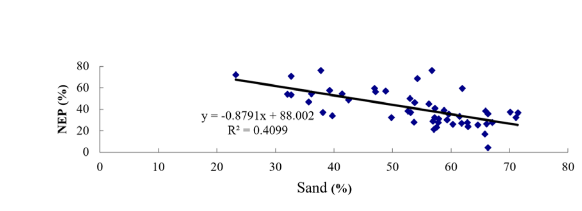

Figure 5. Mean non-erodible soil particles (NEP) versus sand content

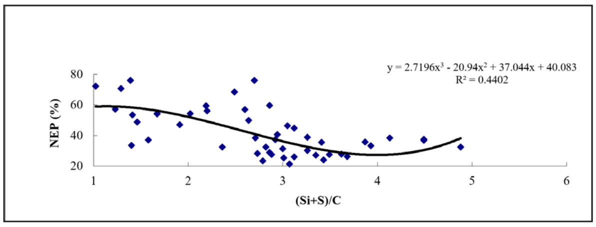

Figure 6. Mean non-erodible soil particles (NEP) versus (Si+S)/(C) ratio

Table 1. Range of mean soil physical properties, non-erodible soil particles (NEP) and wind erodibility (WE) of a number (n) of soil samples randomly collected from various agricultural farms in the six studied states

Soil characteristics	Range	Mean	CV
	Northern State(n = 50)		
Organic matter, %	0.10 – 3.26	0.91	76.3
Clay, %	16.8 – 49.5	28.1	28.1
Silt, %	10.4 – 30.5	18.2	26.6
Sand, %	23.2 – 71.4	53.7	21.9
NEP, %	4.2 – 76.1	40.8	39.5
WE, ton/ha	9.6 – 474.1	142.7	56.7
	Kassala State (n = 50)		
Organic matter, %	0.0 – 1.54	0.70	63.8
Clay, %	2.0 – 33.0	17.5	39.0
Silt, %	1.0 – 50.0	21.3	52.2
Sand, %	37.0 - 97.0	62.0	20.5
NEP, %	15.0 - 66.9	41.6	34.1
WE, ton/ha	34.2 – 262.0	124.2	47.8
	North Darfur State (n = 40)		
Organic matter, %	0.7 – 9.3	3.3	79.0
Clay, %	5.9 – 61.8	15.6	89.3
Silt, %	0.0 – 46.1	7.8	125.9
Sand, %	26.3 – 93.9	76.6	27.9
NEP, %	0.4 – 71.0	27.2	82.5
WE, ton/ha	25.0 – 695.0	236.9	69.2
	River Nile State (n = 50)		
Organic matter, %	0.01 - 0.60	0.10	109.8
Clay, %	5.7 - 47.8	29.2	33.2
Silt, %	4.1 – 32.8	11.2	42.2
Sand, %	34.6 – 87.5	59.8	18.9
NEP, %	4.3 - 98.1	43.6	61.7
WE, ton/ha	0.0 – 470.4	148.1	73.0
	Red Sea State (n = 28)		
Organic matter, %	0.05 - 0.68	0.20	104.6
Clay, %	21.3 – 60.9	37.6	22.4
Silt, %	7.9 – 38.1	14.7	49.1
Sand, %	11.0 – 68.0	47.7	27.0
NEP, %	17.0 – 57.2	36.0	30.3
WE, ton/ha	49.6 – 244.0	143.5	35.6
	Central Gezira (n = 50)		
Organic matter, %	0.15 – 0.57	0.31	30.8
Clay, %	24.0 – 60.0	38.9	26.6
Silt, %	14.0 – 46.0	29.6	28.0
Sand, %	17.0 – 48.0	31.9	24.1
NEP, %	36.0 – 85.5	62.4	16.3
WE, ton/ha	0.0 – 141.0	46.8	61.6

Wind erodibility data collected from farms in North Darfur State showed that NEP significantly ($P < 0.001$), increased linearly with increase in OM ($r^2 = 0.825$), logarithmically with clay ($r^2 = 0.754$), cubically with silt ($r^2 = 0.737$).

Furthermore, NEP rendered quadratic decrease with increase in sand ($r^2 = 0.761$), and linear decrease with increase of (silt+sand)/ clay ratio ($r^2 = 0.766$) (Medani, 2001; Medani and Mustafa, 2003). In this and other states, lower coefficient of determination and regression trends in reverse to those derived for NEP versus soil properties were derived for WE versus soil properties. Multiple regression analysis yielded a highly significant ($P < 0.001$, $r = 0.910$) correlation between NEP and the four prime soil properties as follows:

NEP%=28.7-0.41Clay%-0.23Silt%-0.27Sand%+8.42OM%

The results of a similar wind erodibility study in the River Nile State showed a highly significant ($P < 0.001$) power increase of NEP with increase of clay ($r^2 = 0.7214$), $CaCO_3$ ($r^2 = 0.2904$) and OM ($r^2 = 0.3155$), and power decrease with increase of sand ($r^2 = 0.5515$), and increase of (silt+sand)/ clay ratio ($r^2 = 0.7200$). Multiple regression analysis yielded a highly significant ($P < 0.001$, $r = 0.8056$) correlation between NEP and multiple soil variables as follows:

NEP% = 21.78 +1.44 Clay% - 0.51 Sand% + 2.59 $CaCO_3$ + 14.10 OM%

According to this relationship, the four soil properties account for 65% of the variation of NEP. It was evident that clay alone or the compound indicators gave better accountability than these multiple variables (Hassan and Mustafa, 2011). Regression analysis of the data collected from farms in the Red Sea State showed a highly significant linear increase of NEP with an increase of clay percent ($r^2 = 0.8001$), and logarithmic increase with the increase of OM ($r^2 = 0.3824$), and quadratic decrease with the increase of sand ($r^2 = 0.8001$). The results also showed a highly significant quadratic decrease in NEP with an increase of (silt+sand)/clay ratio ($r^2 = 0.8094$). Reverse correlation trends were obtained with WE (Mohamed, 2008; Mohamed and Mustafa, 2011). Multiple regression analysis yielded a highly significant ($P < 0.001$, $r = 0.9001$) Correlation between NEP and multiple soil variables as follows:

NEP% = -6.06 +1.10 Clay% - 0.67 Sand% - 2.68 OM% +1.23 $CaCO_3$

According to this relationship, the four soil properties account for 81% of the variation of NEP. The negative sign of the coefficient of OM may be attributed to the empiricism of the equation. Clay, sand or the compound indicators gave nearly similar accountability as the multiple soil variables.

The wind erodibility study of the farms in Kassala State gave highly significant ($P < 0.001$) power increase of NEP with increase of clay content ($r^2 = 0.4245$), and quadratic increase with increase of OM ($r^2 = 0.9200$), and significant ($P < 0.05$, $r^2 = 0.0796$) exponential decrease with increase of sand. Furthermore, it gave highly significant ($P < 0.001$) power decrease of NEP with increase of (silt+sand)/clay ($r^2 = 0.3353$), (silt+sand)/ (clay+$CaCO_3$) (r^2= 0.3386), and (silt+sand)/ (clay+OM) ($r^2 = 0.4611$), and a significant ($P < 0.05$) exponential decrease with increase of sand (0.0796) (Abdelgadir, 2007; Abdelgadir et al., 2013)

The wind erodibility study of the farms in Gezira State showed that NEP significantly increased linearly with increase of clay ($r^2 = 0.8236$), and OM ($r^2 = 0.6632$), and quadratic increase with increase of CaCO3 ($r^2 = 0.3254$), and c/ (si+s) ratio ($r^2 = 0.7813$). Furthermore, it gave quadratic decrease with increase of silt ($r^2 = 0.4162$), sand ($r^2 = 0.3486$) and (silt+sand)/clay ratio ($r^2 = 0.7125$). The reverse correlation trends were obtained with WE. Multiple regression analysis yielded a highly significant ($P < 0.001$, $r = 0.845$) Correlation between NEP and multiple soil variables as follows:

NEP% = 84.4+ 0.27 Clay% - 0.60 Sand% - 0.55 Silt + 0.66 $CaCO_3$

According to this relationship, the four soil properties account for 71.4% of the variation of NEP. The signs of the coefficient of the multiple variables are referred to as the type of impact (Rehan, 2004; Rehan and Mustafa, 2005). In all cases, lower correlation coefficients and regression trends in reverse to those derived with NEP and the studied soil properties were obtained with WE.

The mean NEP increased and WE decreased for the studied farms in the different states with an increase of the mean clay content. This is because clay particles form floccules and in the presence of cementing agents, e.g. polysaccharides, which is a microbial derivative of organic matter are responsible for the formation of stable soil aggregates that are not vulnerable to erosion (Emerson, 1959). This explains why the data in all states showed a highly significant ($P < 0.001$) increase in NEP and consequent decrease in WE with an increase of clay content in all states (Table 2). Because of its very low content and high variability in the drylands of Sudan, OM yielded a significant correlation with neither NEP nor WE. Furthermore, WE increased with the increase of the mean sand content, because sand is chemically neutral and it's nearly spherical shape is amenable to transport.

3.2 Wind erodibility groups of the individual states

Table 3 presents the mean non-erodible NEP and equivalent mean WE of the soil samples studied in each state having similar soil textures. Thes soil samples where thus placed into one class referred to as wind erodibility group (WEG) (Chepil, 1962; Hayes, 1965; Black and Chanasyk, 1989; Mustafa and Medani, 2003; Medani and Mustafa, 2003). Five states were dominated by coarse and medium-textured WEG.

Gezira is fine–textured WEG. In the six states, there were 280 WEG, 41% of them were coarse-textured (sand, loamy sand, and sandy loam), 42.8% have medium-textured (loam, sandy clay loam, clay loam) and 16.2% are fine-textured.

Table 2. The linear trend lines of non-erodible soil particles (NEP) and their equivalent wind erodibility (WE) as a function of clay content in the studied states [NEP or WE = a + b Clay %]

	a	b	r^2	r
	North Darfur (n = 40)			
NEP (%)	7.5512	1.2577	0.6105	0.7813
WE (ton/ha)*	2831.1	-1.1231	0.7243	- 0.8511
	Kassala(n = 50)			
NEP (%)	12.276	1.6737	0.6497	0.8060
WE (ton/ha)	246.29	-6.9727	0.6428	- 0.8017
	Northern State (n = 50)			
NEP (%)	5.7388	1.2407	0.4531	0.6731
WE (ton/ha)	287.7	-5.2674	0.4313	- 0.6567
	River Nile State (n = 50)			
NEP (%)	-19.854	2.1757	0.6122	0.7824
WE (ton/ha)	408.4300	-8.9278	0.6367	- 0.7979
	Red Sea State (n = 28)			
NEP (%)	-7.4978	1.157	0.8001	0.8945
WE (ton/ha)	343.85	-5.3239	0.7733	0.8794
	Central Gezira (n = 50)			
NEP (%)	28.278	0.8773	0.7906	0.8892
WE (ton/ha)	52.602	-0.2920	0.6652	- 0.8156

* *Power relationship:* $Y = aX^b$,

3.3 Relationships of the pooled data of the six states

Table 3 shows the mean non-erodible soil particles for the main textural groups found in the studied farms in the various states based on previous findings for the individual states, (sand/clay) ratio was used for predicting NEP and WE for all states. These results show that NEP decreased and WE increased significantly ($P < 0.01$) with an increase of (sand/clay) ratio content according to the following equation:

$$NEP\ (\%) = -\ 9.5427\left(\frac{Sand}{Clay}\right) + 61.689$$

($r^2 = 0.7429$)………. (1)

$$WE\ (ton/ha) = 51.965\left(\frac{Sand}{Clay}\right) + 9.6781$$

($r^2 = 0.7048$)………. (2)

Although these two empirical relationships are highly significant, the coefficients of determinations account for 74.3% and 70.5% of the variability NEP and WE. Other variables that may affect the aggregation process and consequently affect NEP are silt, $CaCO_3$ and OM (Mustafa and Medani, 2003; Medani and Mustafa, 2003). For example, Mustafa and Medani (2003) recommended the use of the (Si + S) / (C + $CaCO_3$) ratio for the prediction of NEP and WE of the soils of Khartoum State. WE showed a highly significant quadratic increase with an increase of this ratio. However, the present relationships depict linear relationships indicating a direct correlation with NEP or WE, which can be predicted from knowledge of routinely available sand and clay contents only. The weighted mean basic characteristics of the pooled wind erodibility groups of the six studied states are depicted in Table 4.

Conclusions and Recommendations

1. The overall mean NEP of the six states ranged from 27.2 to 62.4 with a mean of 41.9% and CV of 27.7%, and the overall mean of WE ranged from 46.8 to 236.9 with a mean of 140.4 ton/ha and CV of 43.2%.
2. The overall mean NEP of the six states gave a highly significant positive correlation with clay content with coefficients ranging between 0.8945 and 0.6731 with a mean of 0.8044 and a CV of 10.2%.
3. The overall mean NEP was in the following order: Gezira> the Red Sea> Northern> River Nile> Kassala> North Darfur.
4. The overall mean WE of the six states gave a highly significant negative correlation with clay content with coefficients ranging between - 0.8794 and - 0.6567 with a mean of - 0.8004 and a CV of 9.6%.
5. The overall mean WE was in the following order: North Darfur> Kassala> River Nile> Northern> the Red Sea> Gezira.
6. The pooled data of the six states gave a highly significant negative correlation between NEP and (sand/clay) ratio, which accounted for 70% of the variation of NEP.
7. The pooled results of the six states gave a highly significant positive correlation between WE and (sand/clay) ratio, which accounted for 70% of the variation of NEP.
8. Organic matter content did not yield a significant correlation with either NEP or WE due to its very low content and high variability in the drylands of Sudan.
9. The six states were dominated by coarse to medium textured WEGs. The Gezira was dominated by fine-textured WEG.

Table 3. The mean non-erodible soil particles for the main textural groups found in the studied farms in the various states

Texture*	Number of samples	Mean NEP	Texture	Number of samples	Mean NEP
Northern State	Nile State				
SL	38	36.4	SL	7	17.3
SCL	9	54.0	SCL	30	38.5
L	2	50.7	CL	3	80.5
CL	1	72.2	SC	5	67.0
			C	5	80.5
Red Sea State	Central Gezira				
SCL	16	53.9	L	5	37.6
CL	2	38.9	SCL	4	45.5
SC	5	47.1	CL	21	32.8
C	5	31.6	C	21	27
North Darfur State	Kassala				
S	15	7.5	S	1	15
LS	10	20.6	LS	3	22.5
SL	6	41.7	SL	19	39.7
L	1	42.4	SCL	20	46.8
CL	2	57.4	L	3	43.1
SCL	4	60.5	CL	1	65.9
C	2	59.3	SiL	1	30.9
			SC	1	25.2

** S = sand, Si = Silt, C = clay, L = loam*

Table 4. The weighted mean measured non-erodible soil particles (NEP) and its equivalent wind erodibility, silt, clay, sand (%) and (sand/clay) ratio for the wind erodibility groups (WEG) of their number of samples in the six studied states

WEG	Number of samples	NEP (%)	WE (ton/ha)	Silt (%)	Clay (%)	Sand (%)	Sand/clay (%)
S	16	8.0	336.0	8.9	15.7	75.4	4.8
LS	13	21.0	213.0	10.4	16.0	73.6	4.6
SL	70	35.8	142.0	38.9	19.7	41.4	2.1
SiL	1	30.9	161.5	15	15	70	4.7
C	33	37.8	135.0	17.7	35.8	46.5	1.3
L	11	41.9	117.4	10.1	29.0	60.9	2.1
CL	30	42.0	117.0	15.1	39.7	50	1.3
SCL	83	46.5	103.0	8.9	27.7	63.7	2.3
SC	11	57.0	54.0	9.8	33.4	56.8	1.7

Acknowledgement

It is very important to mention that this work is a review of a comprehensive research project on wind erodibility (WE) was implemented, in several states in Sudan, by postgraduate students as complimentary research in partial fulfilment of their M.Sc. degrees, in the Desertification and Desert Institute, University of Khartoum. Furthermore, my deep thanks extended to postgraduate students and Desertification and Desert Institute (DADCSI), University of Khartoum.

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