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Assessment of Horizontal and Vertical Wind Erosion and their Interrelationship in a Bare Land in Gozalhalag Area, River Nile State, Sudan

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Abstract

A field experiment in a bare land was conducted over two-successive seasons (August 2008- March 2009, August 2009-March 2010) to assess wind erosion. The intensity of wind erosion (IWE) was measured monthly in four directions, namely West (W), North West (NW), North (N), and North East (NE), using vertical (IWEv) and horizontal (IWEh) soil traps. In the two seasons, the IWE and IWEv/IWEh ratio varied according to month and direction. In the first season, IWEh ranged from 99.9 (W) to 109.8 (NE) with a mean of 104.4 tons/ha/day, a standard deviation (STD) of 4.1 tons/ha/day and a coefficient of variation (CV) of 4%. Furthermore, IWEh ranged from 2.1 (Nov.) to 260 (Sept.) with a mean of 104.4 tons/ha/day, a STD of 97.5 tons/ha/day and a CV of 93.4%. The IWEv values obtained for each month or direction were lower than the corresponding IWEh values. The overall mean IWEh value was 2.4 and 2.0 fold the overall mean IWEv value in the first and second seasons, respectively. The variation according to direction was much lower than the monthly variation. Regression between IWEv and IWEh gave a highly significant polynomial relationship, ($P< 0.001$, $r^2=0.98$) and ($P< 0.001$, $r^2=0.94$) for the first and second seasons, respectively.

Keywords: Wind erosion, Wind erosivity, Soil traps, River Nile.

1. Introduction

Wind erosion occurs, naturally, in all lands wherever the surface soil is loose and dry and blown by erosive winds. However, it is predominant and has serious adverse impacts on agricultural lands in the arid and semi-arid lands characterized by low, variable, erratic, and unpredictable rainfall, and high temperature, high wind velocity, and consequent high rates of evapotranspiration. In developing countries it is accelerated by environmentally non-sustainable land use and management systems. Wind erosion is governed by two main factors, namely soil or wind erodibility as an indicator of the vulnerability of the soil mass to detachment by wind, and wind erosivity as an indicator of the ability of the wind energy to transport the detached soil particles.

Abdelwahab et al. (2014) assessed the status and rate of wind erosion in part of the River Nile State. Remote sensing data during the period 1987-2005, showed that the total area of loose and shifting sand dunes in some areas in south east Atbara, north Atbara and south Atbara, increased by 1.3%, 110.1% and 34.4%, respectively. Moreover, the total area of irrigated tree crops decreased by about 11.6% and 8.2% in south east Atbara and north Atbara respectively. In south Atbara there is a meager increase in the area of irrigated tree crops. According to these indications, wind erosion may be described as very severe, moderate, and slight in north Atbara, south east Atbara, and south Atbara, respectively.

Abdelwahab and Mustafa (2015) assessed the monthly and diurnal variation of wind speed and direction and wind erosivity in the River Nile State. They found that winds and erosive winds (velocity>5.4 m/s) varied widely in direction and speed during each month and day even within the same climatic season. The high percentages of erosive wind contribution in the summer season blowing from SW and S directions were 75.6%, and 10.5 respectively, whereas the high percentages of erosive wind contribution in the winter season blowing from NNW and N directions were 59.4%, and 19.9. Erosive wind ranged from 0 (Nov., 2008) to 369.8 (Feb., 2009) with a mean of 255.1 $(m/s)^3$, and a CV of 43.6%. The wind pressure of the erosive winds ranged from 0 (Nov., 2008) to 27.1 (Jan., 2009) with a mean of 21.1 (Nm^{-2}) and a CV of 42.1%. The trend of the monthly variation of wind pressure was qualitatively similar to that of wind erosivity (Wr).

Dawelbait et al. (2013) identified changes in the ground cover of the endangered range plant species in north Kordofan state. They found changes in range attributes which were

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clearly noticed and that some important plants are being endangered. Their study recommended a strategy for range land rehabilitation to be adopted in relation to composition of important, palatable endangered plant species. These studies are very important as they contribute to the determination of the trends of range land for the sake of controlling degradation in plant and natural vegetation composition; furthermore, carrying capacity should be calculated to avoid the negative impact of overgrazing.

Biro et al. (2013) analyzed and monitored the land use land cover (LULC) changes using multi-temporal Landsat data for the years 1979, 1989 and 1999 and ASTER data for the year 2009. In addition, efforts were made to discuss the impact of LULC changes on the selected soil properties. Three main LULC types were selected to investigate the properties of soil, namely, cultivated land, fallow land and woodland. Moreover, soil samples were also collected at two depths of surface soil from ten sample plots for each of the LULC type. For these soil samples, various soil properties such as texture, bulk density, organic matter, soil pH, electrical conductivity, sodium adsorption ratio, phosphorous and potassium were analyzed. The results showed that a significant and extensive change of LULC patterns has occurred over the last three decades in the study area. Further, laboratory tests revealed that soil properties were significantly affected by these LULC changes. The change of the physical and chemical properties of the soil may have attributed to the changes in the LULC resulting in land degradation, which in turn has led to a decline in soil productivity. Adam et al. (2014) assessed land degradation in Rawashda, area Gedaref state by using remote sensing, GIS, and soil techniques.

Ali et al. (2012) assessed and mapped soil degradation at Gadambalyia schemes in Gedaref state, in relation to sorghum productivity. Satellite images and GIS were integrated with soil quality to detect and map the type and degree of severity of soil degradation. Soil quality indicators were determined and compared with the same indicators that were determined previously at the same locations in 1976. The System Integration Risk model was used to classify the area of schemes according to soil chemical and physical degradation. The results revealed that the soil qualities in 2005 were significantly affected ($P < 0.001$) both negatively and positively, compared with the 1976 data. Soil chemical degradation ranged from low to severe, while the soil physical properties were not significantly degraded.

A 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, 2004; Mustafa and Medani, 2003; Mohammed and Mustafa, 2005; Rehan and Mustafa, 2005; Abdelwahab et al., 2009; Mohammed and Mustafa, 2011; Hassan and Mustafa, 2011; Abdelgadir et al., 2013). Soil indicators were recommended for the prediction of non-erodible soil particles (NEP) and wind erodibbility of the soils (WE). For example, Mustafa and Medani (2003) recommended the use of (Silt + 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 is a better indicator than the clay ratio alone, which was previously recommended by other authors. Previous wind erosion studies included an assessment of the intensity of wind erosion (IWE) in El-Obeid (Kheirelseid, 1998), north east Al-Butana (Haikal, 2005) and the central part of the Northern State (Abuzied et al., 2015). Managing soils under intensive use and restoring eroded lands are top priorities to a sustained agronomic and forestry production besides conserving soil and water resources. 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. The present study was undertaken to achieve the following objectives:

I. To generate comprehensive comparative quantitative data on the intensity of wind erosion (IWE) in bare lands in the Gozalhalag area, River Nile State, using both horizontal and vertical traps.
II. To investigate the direction and monthly variation of the intensity of wind erosion.
III. To generate the interrelationship between the intensity of wind erosion measured by horizontal traps (IWEh) and the intensity of wind erosion measured by vertical traps (IWEv).

2. Materials and Methods

2.1. The Study Area

The River Nile State lies between latitudes 16° and 22° N and longitudes 31° 88¢ and 35° 70¢ E. It is dominated by hyper–arid and arid climatic zones with mainly two seasons, a hot summer from April to September and a cold winter from October to March. The mean annual rainfall is less than 100 mm, and temperatures as high as 49^o C are not uncommon during the period extending from April to June (Izzeldin and Ahmed, 2004). Winds prevail from the N and NNE with a mean maximum speed of 17.6 km/hr; these winds cause the greatest sand movement blowing from October to May, and become worse from February to May. The wind direction is stable throughout the year except for the months of July, August, and September when the wind blows from S, SW, and SSW directions (table 1). The wind speed is measured at 15.2 m height every three hours. In the River Nile State, the erosive winds (velocity>5.4 m/s) varied widely in direction and speed during each month and day even within the same climatic season. The high percentages of erosive wind contribution in the summer season blowing from SW and S directions were 75.6%, and 10.5 respectively, whereas the high percentages of erosive wind contribution in the winter season blowing from NNW and N directions were 59.4%, and 19.9. Erosive wind ranged from 0 (Nov., 2008) to 369.8 (Feb., 2009) with a mean of 255.1 $(m/s)^3$, and a CV of 43.6%.

Under such climatic conditions, wind erosion is the predominant desertification process. The current study was conducted in a bare land in Gozalhalag village, about 50 km south east Atbara, River Nile State, to produce broad–base data on wind erosion in two-seasons (August 2008-March 2009, August 2009-March 2010).

Table 1. Monthly dominant wind direction and mean wind speed (1980-2000) in the study area.

Month	Atbara station	
	Direction	Wind speed (m/s)
January	N	2.7
February	N	3.2
March	N	2.7
April	N	3.6
May	N	1.8
June	N	2.3
July	SW	2.3
August	SSW	2.3
September	SSW	1.8
October	N	1.8
November	N	2.3
December	N	2.7

Source: Sudan Meteorological Department.

2.2. Methods

Oil cans [25 cm (l) × 23 cm (w) x 27 cm (h)] were used as horizontal sand traps for the measurement of wind erosion. They were buried in the soil leaving the open end level with the soil surface. A vertical sand trap was constructed locally as described by Leatherman (1978). It consisted of two PVC tubes. The first one was 60 cm long with an inside diameter (i.d.) equal to 5.1 cm, permanently closed at the bottom end, and inserted completely in the soil with its open end leveled with the soil surface. This tube is stationary. The second tube, was 90 cm long and 4 cm i.d. and was closed at the top and bottom with a moveable metallic cap in the bottom, and had two similar slits, which were 2 cm wide and 30 cm long, cut in the two opposite sides of the tube. One slit serviced as a collection orifice aligned toward the wind direction, while the other was covered with a fine metallic screen to restrict soil particle movement and allow for a free wind flow. In each field, IWE (ton/ ha/day) was assessed using three replicates for both vertical and horizontal traps in the following directions: West (W), North West (NW), North (N) and North east (NE), these directions were selected due to the predominance of northerly winds in the State. Vertical traps were installed at a spacing of 60 cm between the same direction and 1 m from another direction. The replicate traps were installed so that they do not obstruct free wind flow to the other traps. The horizontal traps were placed at a spacing of one meter from the vertical. Each month the horizontal traps were removed and soil particles were collected and weighed. Furthermore, the particles collected in the metallic moveable tube of the vertical traps were also weighed. To convert trapped soil particles into (ton/ ha/day) the following equations were used:

$$\text{IWEv} = \frac{\underline{\text{Mass (g) x 100}}}{\text{Area (2x30cm) x days (30)}}$$

$$\text{IWEh} = \frac{\underline{\text{Mass (g) x 100}}}{\text{Area (23x25cm) x days (30)}}$$

where:

IWEv= intensity of wind erosion measured by vertical traps.

IWEh= intensity of wind erosion measured by horizontal traps.

Mass (g) = the weight of soil particles collected in the traps in grams.

Area (2x30cm)= the dimension slit of the vertical trap 2 cm wide and 30 cm long.

Area (23x25cm)= the dimension of oil cans 23 cm wide and 25 cm long serving as horizontal traps; and 30 refers to the numbers of days in month.

2.3. Statistical Analysis

The statistical design for this factorial experiment was randomized complete block design. Analysis of variance and separation of means were undertaken according to Gomez and Gomez (1984).

3. Results and Discussion

3.1. First Season (August 2008-March 2009)

Table 2 shows the effects of wind direction and month on IWEh. For the main direction effect, the mean IWEh ranged from 99.9 (W) to 109.8 (NE) with a mean of 104.4 tons/ha/day, a standard deviation (STD) of 4.13 tons/ha/day and a coefficient of variation (CV) of 4%.The mean IWEh by the NE wind was significantly greater than that produced by the W direction. However, it was not significantly different from that given by N or NW winds, which were not significantly different from that produced by W winds. The mean IWEh values for the main month effect ranged from 260 (Sept.) to 2.1 (Nov.) with a mean of 104.4 tons/ha/day, a STD of 97.49 tons/ha/day and a CV of 93.4%. Statistically, IWEh was in the following significant order: Sept. > Aug. > Oct. > Mar. > Jan = Feb > Dec. = Nov.; the equal sign indicates that there was no significant effect.

Table 2. Effect of direction and month on the IWEh (tons ha^{-1} day^{-1}) measured in the bare field surface during the first season*

Direction	Months							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Mean
W	216.2	258	128.0	1.4	5.4	60	58	72.5	99.9 b
NW	224.1	260	130.0	2.3	9.0	66	58	75.4	103.1ab
N	229.0	260	129.3	2.2	2.1	67	64	84.1	104.7ab
NE	270.1	262	133.3	2.4	1.3	67	61	81.2	109.8 a
Mean	235 b	260 a	130.2c	2.1f	4.5f	65 e	60.3e	78.3d	

**Means followed by the same letter in the same row or column are not significantly different from each other at the 0.01 level by Duncan Multiple Range Test.*

Table 3 shows the effects of wind direction and month on IWEv. The mean IWEv values ranged from 30.7 (W) to 57.9 (NE) with a mean of 43.3 tons/ha/day, a STD of 11.52 tons/ha/day and a CV of 26.6%. The mean IWEv value produced by the NE wind was significantly greater than that produced by the wind blowing from the three other directions. The IWEv produced by N winds was significantly greater than that produced by W winds, but it was not significantly different from that produced by NW winds. The IWEv values produced by W and NW winds were not significantly different. The mean monthly data ranged from 80.7 (Sept.) to 0.65 (Dec.) with a mean of 43.3 tons/ ha/ day, a STD of 29.52 tons/ ha/ day and a CV of 68.1%. The monthly IWEv values were in the following statistically significant order: Sept. = Aug. > Oct. = Mar. = Feb = Jan. >. Nov. = Dec. This order is nearly similar to that for IWEh. The seasonal overall mean data obtained by the vertical traps was 41.5% compared to that obtained by the horizontal traps. The IWEv values obtained for each month or direction were lower than the corresponding IWEh values.

Table 3. Effect of direction and month on the IWEv (tons ha^{-1} day^{-1}) measured in the bare field surface during the first season*

Direction	Months							
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Mean
W	36.0	57.0	65.0	1.3	0.93	28.3	28.3	29.0	30.7 c
NW	42.0	90.0	24.0	2.0	0.37	51.0	51.0	50.0	38.8 bc
N	115.0	50.0	63.3	3.0	0.58	40.0	45.3	49.4	45.8 b
NE	101.7	125.6	83.3	1.1	0.71	51.0	50.0	50.0	57.9 a
Mean	73.7 ab	80.7 a	58.9 c	1.9 d	0.65d	42.6c	43.7c	44.6c	

**Letters as explained in Table1.*

Table 4 shows that the ratio of (IWEv/IWEh) according to month and direction. With respect to direction, the ratio ranged from 47.3 (NE) to 69.3 (W) with a mean of 58.5% and a CV of 15.9%. As for the monthly variation, the ratio ranged from 9.5 (Nov.) to 85.6% (Dec.) with a mean of 49.1% and a CV of 51.2%: 38.2 (W) to 67.2 (NW) with a mean of 56.2%. Figure 1 depicts a highly significant (P < 0.001) polynomial relationship between IWEv and IWEh.

Table 4. The ratio of IWE measured by vertical (IWEv) to that measured by horizontal (IWEh) traps as affected by month and direction of measurement in the bare field surface during the first season.

Month	IWEv	IWEh	Ratio, %	Direction	IWEv	IWEh	Ratio, %
January	42.6	65	65.5	W	30.7	99.9	30.7
February	43.7	60.3	72.5	NW	38.8	103.1	37.6
March	44.6	78.3	57	N	45.8	104.7	43.7
August	73.7	235	31.4	NE	57.9	109.8	52.7
September	80.7	260	31	Mean			41.2
October	58.9	130.2	45.2	STD			9.3
November	1.9	2.1	90.5	CV			22.7
December	0.65	4.5	14.4				
Mean			50.9				
STD			25.1				
CV			49.4				

Ratio=(IWEv/IWEh)x100

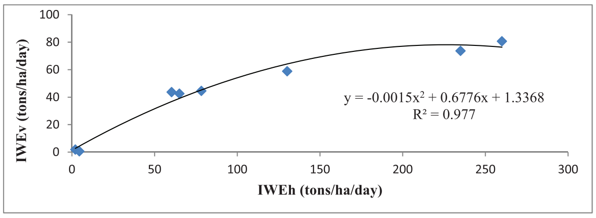

Figure 1. Regression relationship between intensity of wind erosion obtained by horizontal (IWEh) and vertical (IWEv) traps installed at the bare field surface in the first season.

3.2. Second Season (August 2009-Mrach 2010)

Table 5 shows the mean IWEh values for the main direction effect. The mean IWEh values ranged from 47.1 (W) to 49.2 (N) with a mean of 46.3 tons/ ha/ day, a STD of 3.51 tons/ ha/ day and a CV of 7.6%. The mean IWEh produced by wind blowing from the four directions were not significantly different. The mean IWEh values for the main month effect ranged from 2.3 (Sept.) to 97.3 (Aug.) with a mean of 46.3 tons/ ha/ day, a STD of 38.56 tons/ ha day and a CV of 83.2%. The monthly main effect was in the following significant order: Aug. = Mar. > Jan = Feb. > Oct. = Dec.> Nov. = Sept. The IWEh in the second season was much lower than that in the first season. The overall mean IWEh value in the second season was 44.3% of that in the first season. There was also variation in the order of magnitude of mean values in the corresponding months or directions.

Table 5. Effect of direction and month on the IWEh (tons ha^{-1} day^{-1}) measured in the bare field surface during the second season*

Direction	Months								
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Mean
W	116.9	1.7	18.4	4.3	30.0	55.8	59.7	91.2	47.1 a
NW	70.5	2.5	29.0	6.0	4.5	63.0	63.1	91.1	41.2 a
N	90.8	2.4	42.6	8.5	1.9	70.1	64.0	100.9	47.7 a
NE	111.1	2.4	18.4	1.2	33.4	64.2	64.6	97.9	49.2 a
Mean	97.3 a	2.3 d	27.1 c	5.0 d	17.5 cd	63.3 b	63.9 b	95.3 a	

**Letters as explained in Table1.*

Table 6 shows that the mean IWEv values for the main direction effect ranged from 16.8 (W) to 29.8 (NE) with a mean of 22.7 tons/ ha/ day, a STD of 5.39 tons/ ha/ day and a CV of 23.8%. The mean IWEV produced by NE winds was significantly different from that produced by W winds, but not different from that blown by N wind. North wind gave higher IWEv from W winds but not different from NW winds, which gave significantly higher IWEv than W winds. The monthly IWEv data ranged from 0.4 (Nov.) to 49.9 (Mar.) with a mean of 22.7 tons/ ha/day, a STD of 22.39 tons/ ha/ day and a CV of 98.4%. The main effect of the month showed that IWEv was in the following significant order: Mar. = Aug. = Jan = Feb. > Oct. = Sept. = Dec. = Nov. The seasonal overall mean data obtained by vertical traps was 49% compared to that obtained by the horizontal traps. The IWEv values obtained for each month or direction were lower than the corresponding IWEh values.

Table 7 shows that the ratio of (IWEv/IWEh) varied with month and direction. The ratio ranged from 35.7(W) to 60.6 (NE) with a mean of 50.8 and a CV of 21.1% and from 7.6 (Nov.) to 82.6% (Sept.) with a mean of 43% and a CV of 67 %. Figure 2 depicts a highly significant (P<0.001) polynomial relationship between IWEv and IWEh.

Table 6. Effect of direction and month on the IWEv (tons ha^{-1} day^{-1}) measured in the bare field surface during the second season*

Direction	Months								
	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Mean
W	35.2	1.4	1.7	0.17	1.9	27.1	27.4	39.2	16.8 c
NW	25.0	2.0	2.0	0.31	1.7	46.6	39.2	53.8	21.3bc
N	36.0	2.8	4.8	0.68	1.3	39.5	46.6	51.0	26.2ab
NE	74.1	1.3	8.5	0.37	1.1	50.2	47.6	55.6	29.8a
Mean	49.3a	1.9b	4.3b	0.38b	1.5b	40.9a	40.2a	49.9a	

**Letters as explained in Table1.*

Table 7. The ratio of the intensity of wind erosion measured by vertical (IWEv) compared to that measured by horizontal (IWEh) traps as affected by month and direction of measurement in the bare field surface during the second season.

Month	IWEv	IWEh	Ratio, %	Direction	IWEv	IWEh	Ratio, %
January	40.9	63.3	64.6	W	16.8	47.1	35.7
February	40.2	63.9	62.9	NW	21.3	41.2	51.7
March	49.9	95.3	52.4	N	26.2	47.7	45.9
August	49.3	97.3	50.7	NE	29.8	49.2	60.6
September	1.9	2.3	82.6	Mean			48.5
October	4.3	27.1	15.9	STD			10.4
November	0.38	5.0	7.6	CV			21.5
December	1.5	17.5	8.6				
Mean			43.2				
STD			28.7				
CV			66.4				

Ratio=(IWEv/IWEh)x100

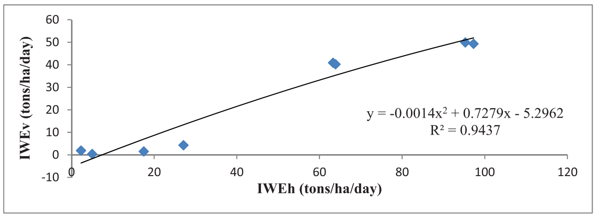

Figure 2. Regression relationship between intensity of wind erosion obtained by horizontal (IWEh) and vertical (IWEv) traps installed at the bare field surface in the second season.

3.3. Discussion

The intensity of wind erosion measured by horizontal traps (IWEh) in all directions and months was found significantly much higher than the intensity of wind erosion measured by vertical traps (IWEv). The overall mean IWEh value was 2.4 and 2.0 fold the overall mean IWEv value in the first and second seasons, respectively. This was attributed to the fact that horizontal traps collected soil particles transported by the three mechanisms of wind erosion, namely saltation, surface creep, and suspension; whereas vertical traps collected particles transported by saltation only (Abdelwahab and Mustafa, 2013). The seasonal overall mean data obtained by vertical traps were 41.5% and 49% compared to those obtained by the horizontal traps in the first and second season respectively. The IWE measured by both traps in the first season were much higher than those measured in the second season. The overall mean IWEh and IWEv in the first season were 2.3 and 1.9 fold compared to those in the second season, respectively. This effect was attributed to the higher wind erosivity in the first season. The wind erosivity was 2483 and 2309.3m^3/sec^3 for the first and second seasons, respectively (Abdelwahab and Mustafa, 2013). There is a variation in the order of magnitude of the monthly IWE. The variation according to direction was much lower than the monthly variation due to the higher monthly variability of wind erosivity. The IWE values obtained in Aug. and Sept. were caused mainly by S and SW winds, which were stronger but shorter in duration; these winds are slowdown the desert progress towards the south. However the prevailing N. winds caused high IWE values in Jan. (NNW), Feb. (NW), and Mar. (NW), and days of dust storms. Finally, the effects of high temperature on pressure and wind velocity in summer caused the transportation of heavier and denser particles compared to the opposite effect of low temperature in (Oct., Nov., and Dec.). This finding agrees with the previous findings of Abuzied (2009) and Farah (2003), which emphasized the minimum sand transport recorded in November and December.

In the two seasons, the ratio of (IWEv/IWEh) varied with month and direction; this may be attributed to the high impact of wind erosivity in the targeted area. Furthermore in the two seasons the regression between IWEv and IWEh gave a highly significant polynomial relationship ($P< 0.001$, $r^2=0.98$) and ($P< 0.001$, $r^2=0.94$), respectively. This result can be only attributed to the overlaps and interdependence in the movement of soil particles for each of the two types of traps.

4. Conclusions and Recommendations

The prevailing wind directions are north, north east, and North West in Jan., Feb., and Mar. The southerly winds were caused mainly by S and SW winds, which were stronger but shorter in duration. Regression between IWEv and IWEh gave a highly polynomial relationship; significant ($P< 0.001$, $r^2=0.98$) and ($P< 0.001$, $r^2=0.94$) for the first and second seasons respectively. The River Nile State occupies a large area with varying metrological conditions. Accordingly, there is a pressing need for establishing new meteorological stations in some appropriate locations. Comprehensive studies on wind velocity and direction should be undertaken in the early stages of establishing a scheme to help in making the design of the shelterbelt. Very little attention is given to studies on wind data analysis; unfortunately, most research on 1WE assessment is conducted in part of the affected states due to the limited financial resources given to research on anti-desertification in this area.

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