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Harmattan Dust: Composition, Characteristics and Effects on Soil Fertility in Enugu, Nigeria

Ifeanyi C. Enete[1*], E. A .Obienusi[1], I. N. Igu[1] and R. Ayadiulo[2]

[1]*Geography & Meteorology Department, Nnamdi Azikiwe University, Awka, Nigeria.*
[2]*Geography Department University of Nigeria, Nsukka, Nigeria.*

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ABSTRACT

Aim: This study examines the characteristics of harmattan dust and its composition in Enugu, Nigeria.
Study Design: Survey Study.
Place and Duration of Study: Enugu urban between October – April of 2009/10 and October – April, 2010/11.
Methodology: Five different sites were selected as experimental sites where dusts were collected (Achara layout, Abakpa, New layout, Independence layout and Trans-Ekwulu). Atomic absorption spectrophotometer (AAS) bulk scientific 205 model was used to determine the concentration of elements in the dust sample. Also, a modified version of Angstrom -Prescott method of estimating global radiation was employed.
Results: The result showed a significant difference in the composition of dust particles brought into Enugu via harmattan and that of soil existing in Enugu urban. The conclusion was reached based on the analysis conducted on the elemental analysis, mineralogy composition and physical properties of the dust. It also showed that solar radiation was depleted during harmattan season by dust particles.
Conclusion: Chemical properties of harmattan dust increases the fertility of Enugu soil while the depletion ability of harmattan dust is seen in the drastic reduction of visibility in the city during harmattan period with other multiplier effects.

Keywords: Harmattan; radiation; depletion; atomic absorption spectrophotometer; composition.

** Corresponding author: E-mail: ugwuenete@yahoo.co.uk;*

1. INTRODUCTION

The impact of harmattan on climate has been observed primarily on their effects on the radiation budget of the Earth's atmospheric system (EAS). This singular impact on the EAS has sparked off a multiplier effect, especially on the agricultural and health sectors. Harmattan dust haze is a phenomenon that occurs when fine opalescence dust particles are lifted and laid in suspension in the air for weeks or even months by winds of low velocity (Umoh, 1992). These tropospheric aerosols are of central importance to climate, and public health. The airborne solid and liquid particles in the nanometer to micrometer size range influence the energy balance of the Earth, the hydrological cycle, atmospheric circulation and the abundance of greenhouse and reactive trace gases (Poschel, 2005). The effects of aerosols on the atmosphere, climate and public health are among the central topics in current environmental research. Aerosol particles scatter and absorb solar and terrestrial radiation, they are involved in the formation of clouds and precipitation as cloud condensation and ice nuclei, and they affect the abundance and distribution of atmospheric trace gases by heterogeneous chemical reactions and other multiphase processes (Levin et al., 1996; Wurzler et al., 2000).Negative forcing such as the scattering and reflection of solar radiation by aerosols and clouds tend to cool the Earth surface, whereas positive forcing such as the absorption of terrestrial radiation by greenhouse gases and clouds tend to warm it (greenhouse effect).

There has recently been an increasing interest in harmattan dust processes including a number of dust deposition studies in West Africa. Harmattan particulate concentration and health impacts in sub-Saharan Africa have been described by Chineke and Chiemeka (2009), while the microphysics of sahara dust has been described by Kalu (1987). In most of these studies not much has been said about the constituent composition of the harmattan dust and its effects especially in the eastern parts of Nigeria. Hence, this study is designed to describe the characteristics of harmattan dust with regard to its constituent composition and its effects on the environment with particular reference to Enugu urban through the following objectives:

a) determination of the frequency and density of dust deposit.
b) determination of the composition of dust particles deposited.
c) determination of its depletion effects on soar radiation.

2. METHODOLOGY

2.1 Methods of Data Collection

The study began in the dry seasons (October – April) of 2009/2010 and 2010/2011 with a routine half-hourly monitoring of the solar flux density in Enugu using KippSolatimeters. At the same period, the amount of dust settling in Enugu was measured with twelve 0.1m^2 collection plates each mounted at a height of 1m above ground. The dust was washed off the metallic plates, oven-dried and weighted weekly. The dry dusts swept off these plates were used in the physical and chemical characterization of the dust settling in Enugu. Comprehensive weather data measured at the Nigerian meteorological station located at Akanu Ibiam airport enabled some assessment of the dust effect on the climate of Enugu. Akanu Ibiam airport is one the international airports in Nigeria located in Enugu state and 10 km away from Enugu Urban.

2.2 Methods of Radiation Prediction

Various climatic parameters have been used in developing empirical relations for predicting the monthly average global radiation (Nguyen and Vo-Ngoc, 1993). Among the existing correlations, the data of sunshine duration are widely available in many countries; various formulas based on them have been proposed to determine solar radiation from sunshine duration (Dincer et al., 1995; Poltmeanu et al., 2002; Ulgen and Hepbasli, 2002; Udo, 2002; Akpabio and Etuk, 2003; Salaymeh, 2006). The most generally used method was developed by Angstrom (Angstrom, 1924) and later modified by Prescott (Prescott, 1940). The modified version of Angstrom-Prescott (Almorox et al., 2005) has been the most convenient and widely used correlation for estimating the global radiation. The formula is given by Duffie and Beckman, (1994) as:

$$H/Ho = a + b\, S/So \qquad (1)$$

Where H and Ho are respectively, the global radiation ($Mjm^{-2}\ day^{-1}$) and the extraterrestrial solar radiation on a horizontal surface ($Mjm^{-2}\ day^{-1}$); S and So are respectively, number of hours measured by the sunshine recorder and the maximum daily sunshine duration (or day length); and a, b are regression constants.

Regression equation (1) has been found to accurately predict solar radiation in several locations (Akpabio, 1992).

For monthly average, this formula holds (Duffie and Beckman, 1994).

$$\overline{H/Ho} = a + b\, \overline{S/So} \qquad (2)$$

Here, $\overline{H}$ is the monthly average daily global radiation on a horizontal surface ($Mjm^{-2}\ day^{-1}$), $\overline{Ho}$ is the monthly average daily extraterrestrial on horizontal surface (($Mjm^{-2}\ day^{-1}$), S is the monthly average daily number of hours of bright sunshine, So is the monthly average daily maximum number of hours of possible sunshine. Regression coefficient a and b have been obtained from the relationship given by Tiwari and Sangeeta (1977) and also confirmed by Frere et al., (1980).

$$a = -0.110 + 0.235 \cos \varnothing + 0.323\, (S/So) \qquad (3)$$
$$b = 1.449 - 0.553 \cos \varnothing - 0.694\, (S/So)$$

There are many methods to evaluate these constants. The extraterrestrial solar radiation on a horizontal surface can be calculated from the following equation (Duffie and Beckman, 1994).

$$Ho = \frac{24 \times 3600}{\pi} I_{sc} \left[1 + 0.033\cos\left(\frac{360\, dn}{365}\right)\right]\left[\frac{2\pi Ws}{3}\right.$$
$$\left.\sin \varnothing \sin \delta + \cos \varnothing \cos \delta \sin Ws\right) \qquad (4)$$

The value of $1367 Wm^{-2}$ has been recommended for solar constant I_{sc} (Frolich and Brusca, 1981).

The hour angle Ws for horizontal surface is given by Duffie and Beckman, (1994);

$Ws = Cos^{-1}$ (-tan ∅ tan δ) ------------------------------------ (5)

Declination is calculated as given by Cooper (1969);

$$\delta = 23.45\sin(360 \frac{284 + dn)}{365}$$ --------------------------------- (6)

Where dn is the number of days from January to December 31.

The day length So is the number of hours of sunshine or daylight within the 24hours in a given day. For a horizontal surface, it is given by Duffie and Beckman, (1994)

So = 2/15 Cos-1 (-tan ∅ tan δ) = 2/15Ws ---------------------- (7)

2.3 Sampling Technique

The study selected Enugu urban as the study area because of its position as the capital of former Eastern Region of Nigeria. Achara layout, Abakpa, New layout, Trans-Ekulu and Independence Layout were selected as the basic sampling units for the study because they formed the major layouts of Enugu Urban. Enugu Urban lies between 6°20´ and 6°30´N and 7°25´ and 7°30´E (Government of Anambra State, 1978).

2.4 Method of Data Analysis

Atomic absorption spectrophotometer (AAS) Bulk Scientific 205 model was used to determine the concentration of elements in the sample. In this technique, a volume of 0.2g of the sample was digested with concentrated trioxonitrate (v) and concentrated hydrofluoric acid. The choice of these reagents for digestion was mainly because of their performance as oxidants. Because of its ability to dissolve oxides, hydrofluoric acid is useful for dissolving soil samples (usually powdered) prior to analysis (Greenwood, 1984). The digested samples were diluted with distilled water at room temperature and the volume later made to 250ml with deionized water. Elements were analyzed using Atomic absorption spectrophotometer. Silicate was analyzed using platinum crucible and the percentage silicate calculated.

Atomic absorption spectrophotometry is based on the principle that metallic elements in their ground state will absorb light of the same wavelength which they emit when excited. When radiation from a given element is passed through a flame containing ground state atoms of that element, the intensity of the transmitted radiation ion will decrease in proportion to the amount of ground state elements in the flame.

3. DATA PRESENTATION AND ANALYSIS

3.1 Dust Settling Rate

The monthly quantity of dust settling in Enugu during the dry seasons of 2009/2010 and 2010/2011 and the total annual amounts for the years are shown in Table 1.

Table 1. Dust Settling Rate in Enugu

Month/year	2009/2010 (kg)	2010/2011 (kg)
Oct	38.2	22.2
Nov	41.3	24.3
Dec	54.2	37.9
Jan	55.1	41.7
Feb	39.8	24.8
Mar	30.1	42.8
Apr	20.8	19.8
Annual total	279.5	213.5
Mean	**39.9**	**30.5**

There appears to be a similar deposition pattern from year to year, and month to month except in the month of March. However, dust deposition appears more between the Months of December and January. Total annual deposition increased from 2009 through 2010 but dropped in 2010/2011 probably as a result of improved 2010 rainfall (Enete and Ebenebe, 2009; Enete and Ezenwaji, 2011). The total dust deposit for the two seasons was 493kg with 279.5kg and 213.5kg for 2009/2010 and 2010/2011 respectively. The monthly average dust deposits for two years were 39.9kg and 30.9kg.

3.2 Physical and Chemical Properties of Harmattan Dust

The range of elements and minerals present in the dust, including their relative proportions are given in Table 2. The physical and chemical properties of dust are shown in Table 3.

Table 2. Total elemental analysis and mineralogical composition of clay and silt fraction (%)

Clay elements	Elemental fraction (%)	mineral composition	Clay fraction (%)	Silt fraction
Si	33.60	Quartz	5-9	58
Al	21.9	Ca-Na feldspar	1-2	1-3
Fe	3.16	K-feldspar	1 - 2	12 – 30
Mn	0.01	Fe-illite	12-14	-
Fe	3.16	Vermicullite	6-8	-
Ca	0.43	Al-chloride	10-12	-
Mg	0.11	Sinectite	15 - 24	-
Na	0.19	Kaolinite	24-25	10-20
K	0.03	Fe-Al Oxyhydroxide	3-4	-
Zn	Nil	-	-	-
Pb	0.01	Mica	-	10 – 20

Table 3. The physical and chemical properties of the dust

Particle type	Particle size (Hm)	Fraction (%)
Coarse sand	2000 - 250	0.50
Medium sand	250 – 125	0.16
Fine sand	125 – 50	15.16
Coarse silty	50 – 20	14.53
Fine silt	20 – 2	44.28
Clay	2	25.82
Soil pH – 7.04	–	–
Organic carbon (%) – 5.87	–	–
Available P in Meg/kg – 88.0	–	–
Exchangeable Ca in Meg/100g of soil – 25.80	–	–
Exchangeable Mg in Meg/100g of soil – 5.00	–	–
Exchangeable K in meg/100g of soil – 3.65	–	–
Exchangeable Na in meg/100g of soil – 3.32	–	–
Cation exchange capacity in Meg/100g of soil		
ECEC – 30.25		
CEC (PH 7.0) – 15.23		
CEC(PH 8.2)		
CEC – clay (PH 7.0) – 42.10		

Analysis has shown that over 58 percent of the clay elements are made up of oxide of silicon and aluminum. The clay fraction is mainly composed of Kaolinite, Sinectite, Fe-Illite, Al-chloride and Quartz in that order of magnitude. The silt fraction is predominantly made up of quartz and constitutes 50 percent of the dust collected. Overall consideration of the chemical properties of the harmattan dust shows that its effects are more likely to improve the fertility of Enugu soils.

3.3 Solar Radiation and Sunshine Hours

The daily sunshine hour data were collected for a period of one year (from 1st November 2009 to 31st October 2010) from the meteorological section of Akanu Ibiam Airport, Enugu. The relevant meteorological and solar radiation data like H, Ho, $^{S}/_{S_o}$, W, S, a, and b calculated from equations (1) to equation (7) are presented in table 4.

Observation shows that regression co-efficient 'a and b' vary during the course of the year. Variation in a and b values are explained as a consequence of periodic climatological variations in the atmosphere. The (a) estimates varies from 0.34 to 0.25 which is maximum in March and minimum in August; while the (b) coefficient ranges from 0.44 to 0.63, being the highest in August and lowest in March. It is clearly observed that (a) is inversely proportional to (b).

This evidence from table 4 and table 5 showed that solar radiation is depleted in its passage through the atmosphere across the year but more drastically during the rainy season (July to early September, and December to January).

The decreasing solar radiation during the dry seasons is a reflection of solar radiation which in the absence of clouds, appear to have been caused by higher dust content in the North east wind prevalent at the time.

Table 4. Values of Monthly average daily global radiation

Month	S/So	A	B	$H_o(MJM^{-2}d\text{-}1)$	H	Wm^{-2}
Nov, 2009	0.63	0.33	0.47	32.31	19.91	230.96
Dec, 2009	0.62	0.32	0.47	30.94	18.92	219.47
Jan, 2010	0.62	0.32	0.47	31.78	19.43	225.39
Feb, 2010	0.65	0.33	0.45	34.24	21.31	247.20
Mar, 2010	0.67	0.34	0.44	36.69	23.29	270.16
Apr, 2010	0.48	0.28	0.57	37.87	20.96	243.19
May, 2010	0.47	0.27	0.58	37.60	20.40	236.66
June, 2010	0.57	0.29	0.55	37.06	21.14	245.22
Jul, 2010	0.48	0.28	0.57	37.14	20.56	238.50
Aug, 2010	0.39	0.25	0.63	37.51	18.59	215.64
Sept, 2010	0.41	0.25	0.62	36.95	18.63	216.11
Oct, 2010	0.47	0.27	0.58	34.89	18.93	219.59

Table 5. Sunshine hours for South East (2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Mean
Sunshine hour	4.0	5.6	5.8	7.3	5.5	5.3	3.0	3.1	3.5	6.5	6.1	4.2	59.9	5.00

Also, using mean visibility value for Akanu Ibiam airport, it was observed that visibility decreased mainly in the months of harmattan period (Nov – Mar), increased during transition months (April, May, October) and decreased again during rainfall months (June –Sept).This again confirms that harmattan dust affects meteorological parameters. Comparing Sunshine values (Table 5) and Visibility values (Table 6), it can be seen that both parameters displayed similar characteristics in their trends. Visibility and Sunshine values were lowest during harmattan and rainfall periods; while the highest values occurred during transition months. High accumulation of aerosols reduced both Sunshine and Visibility values during harmattan periods while cloud formation is the cause of reduction during rainy seasons.

Table 6. Mean Visibility Values for South East (2010)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Mean
Visibility (km)	1.2	2.5	4	5	5.6	4.5	3	5	4.5	5.5	2.4	0.4	52.2	4.35

4. DISCUSSION

The finding in respect to the laboratory analysis revealed that the dust is more basic in reaction, has a higher CEC, a higher amount of extractable phosphate and organic matter, but less extractable Al and exchangeable acidity than Enugu soils. It also has a higher content of layer silicate minerals and a lower amount of oxy-hydroxides of Fe than Enugu soils. As such, dust particles are more likely to improve the fertility of Enugu soil.

The findings agree with the findings of Kowal (1968), Bromfield (1974) and Moberg et al., (1989) which sought to define the quality and composition of dust falling in Nigeria. They all agree that the mineral and chemical properties of dust falling into Nigeria are different from Nigerian soils. All the works are basic to the understanding of the characteristics of the soil in the environmentally fragile areas of the country. The quantity of dust deposit tends to progressively decrease every year. This could be linked with the wave of climate change across the globe, and this needs to be corroborated with a larger set of data (future work). The continuation of this trend need to be monitored religiously as it may affect soil fertility and thus food security in the country.

According to Adefolalu (1981), Umoh (1989) and Enete (2008), visibility is reduced during harmattan periods because of the high volume of aerosols introduced into the atmosphere. In comparing mean sunshine hours with solar flux density above the atmosphere, computed from tables 4 and 5), it is evident that the solar radiation is depleted in its passage through the atmosphere across the year, but more drastically during the rainy season. Tables 4 and 5 confirms that there has been reduced depletion during the rainy season and increased interference with incoming solar radiation during the dry season in the two years under study.

In table 4, solar radiation was reduced to 219.47Wm^{-2} in December, 2009 as against 230.96Wm^{-2} in November, 2009 when dust mobilization was just picking-u, as can be seen from table 4. In Table 5, the same evidence was seen in the reduced sunshine hours during dry season months although not so obvious as it was during rainy season months.

The decreasing sunshine hours during the dry season is a reflection of more atmospheric interception, which in the absence of clouds, were caused by high content of aerosols in the atmosphere during harmattan periods. During our study period (2009/10 and 2010/11) harmattan seasons, though Enugu had dust overpasses frequently, it did not occur at a scale that caused zero sunshine records in Enugu.

5. CONCLUSION

Harmattan is a regional environmental threat that is adversely affecting human by causing various health impacts in West African counties. This study has evaluated the composition and characteristics of harmattan dust in Enugu using Atomic Absorption Spectrophotometer (AAS) and a modified version of Angstrom-Prescott method. The analysis showed that while they may have enhanced the fertility of the Enugu soil with regard to chemical properties, the physical characteristics have in general, made the aesthetic environment of Enugu urban very poor.

The depletion ability of harmattan dust also reduced visibility in the City drastically during harmattan period. This depletion characteristic has a multiplier effect. It affects photosynthesis, thus affecting agricultural yield. Poor visibility during this period will also affect transportation sector, especially the aviation industry. More so, human diseases are triggered by the concentration of this harmattan dust in the atmosphere. The overall status of harmattan dust in Enugu is that it has high chemical values for agricultural production and high radiation depletion rate. Based on these findings, the following recommendations were made.

6. RECOMMENDATIONS

The study, based on the findings, proposed some design strategies for the mitigation of possible health impact of harmattan dust in Enugu. These strategies include substantial green cover increase in the city as well as compact designs of buildings that will allow minimal penetration of harmattan dust into living rooms. Planting street trees will reduce the aerodynamic potential of harmattan dust thus reducing the spread within the City.

We also produced drastic reduction on the number of trees with significant canopies around farm sites. The analyses showed that harmattan dust has increased nutrient value than Enugu soils as such, has great agricultural value. Increased harmattan dust in Enugu will encourage urban farming in the city, thus reducing food insecurity in the state and by extension the country.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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