Evaluation of Some Physical Properties of Soils as Factors Influencing Movement of Contaminants through Porous Soils Media of Gwari market Dumpsites, Yola, Nigeria

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Abstract - Pollution is a bad thing, no matter how you look at it. We can smell it when the air gets polluted and taste it when the water has gone bad, but soil is also another element that may be susceptible to different types of pollution. The present study evaluated some physical properties of soils such as bulk density, moisture content, particles size distribution, and textural classification as parameters that affect transport of pollutants through soils of the research area. Field in-situ and laboratory studies were conducted to characterize these properties using scientific calibrated equipment. Major results showed that bulk density was 3.1215kg/cm² at mean moisture content of 22.5% and temperature of 38.6ºC. There was correlation coefficient of 0.26 between bulk density and distance of points taken. Permeability rate was found to be 1.55cm/min and strength of relationship between points X and Y (0.9776) was positively strong while Bouyoucos hydrometer analysis produced sandy loam as textural classification of the site. This implies that the research area has low resistance to the flow of contaminants and therefore susceptible to pollution. It was recommended that before sitting any human activity/facility on an environment, there should be proper assessment of the physical properties of soils of that area.

Keywords: Permeability, transport, textural classification, bulk density, soil contamination.

1. INTRODUCTION

For a proper assessment of the hydrodynamic mechanism of contaminants in soils, a thorough understanding of the physical properties of soils is quite essential; especially that soil is a natural resource which is beneficial to humans, plants and animals. Soil is a mixture of sand, silt and clay in varying proportions and its basic characteristics is by its particle size distribution. The soils at the study site where waste vegetables were co-disposed on directly underneath the dumpsites on which decay metabolism takes place were collected and tested for textural classification, particle size distribution (soil texture), bulk density, porosity, moisture content, and permeability because these are parameters that affect the movement of contaminated leachate into soils which results into pollution [1]. Its pollution occurs when chemicals are released by spill, leachate from dumpsites, industries, sewage or underground leakage. Among the most significant soil contaminants are: hydrocarbons, heavy metals, herbicides, pesticides and chlorinated hydrocarbons, which reduce the productive capacity of soils [2]. The toxic substances from these dumpsites are leached out and percolate through the soil layer to contaminate the surface and groundwater [3] creating huge health issues. If soil is polluted with heavy metals such as chromium and lead, this can lead to higher incidence of cancer and leukemia in people. Permeability of a soil refers to its ability to transform hydraulic forces into fluid flow and it is a function of the total volume and structure of the pore space; it also depends on soil bulk density and moisture content [4]. If the pore space is saturated as in the bottom sediment, the permeability of the medium is at a maximum. Where the fluid only fills a portion of the pore space as in the upper layers of soil, the permeability of the fluid decreases and wettability becomes important because they consist not only of solid particles, but a network of interconnected pores. Furthermore [5] reported that the degree to which soils are permeable depends on a number of factors, such as soil type, grain size distribution, and water content, degree of compaction and stress history. The ability to transmit water is characterized by coefficient of permeability which is a product of Darcy's Law [6] that established the relationship for flow through saturated porous media. Previously, [7] indicated that nature takes thousands of years to form the soil to support food crops, but man can destroy it in a few years. This study is focused on stable soils, which are soils that are largely immobile. In such soils, contaminants can move only by releases into the pore fluid (either air or water) and by subsequent pore fluid transport processes [8]. This is the main reason why soil needs to be constantly tested for dangerous chemicals and their mobility or retention because their movement depends on some physical properties of soils, thus there is also a need to characterize these influencing parameters to help understand the hydrodynamic mechanisms of these pollutants for management strategies. Therefore, the aims of this work can be derived as to: (1) evaluate some physical properties of soils around the research area in terms of soil bulk density, soil permeability, electrical conductivity, and moisture content; (2) perform soil textural classification of the research area, and (3) compare the results statistically.

2. MATERIALS AND METHODS

2.1 Description of Study Site:

The case study dumpsite (Figure 1) is located at the north western part of Gwari International Vegetables Market, established in 1999 in the Greater city of Jimeta-Yola; the Headquarters of Adamawa State being one of the 36 states in the Federal Republic of Nigeria. The vegetables market lies between Latitudes 9º16` and 9º17`N; Longitudes 12º00` and 12º26`E [9]. The market occupies an area of 93,290.36m^2 and the vegetable waste dumpsite is 90m in length, width of 69m and depth of 2.2m with a capacity of 6,000tons spreading over an area of 3.2 hectares. Leafy and fruit vegetable wastes were co-disposed in the dumpsites with other items such as food wastes, plastic containers, motor parts, electronic parts, lubricating oil containers, and so on. The landscape is low with a slope of 0.033 and topography elevation of 500ft above the Mean Sea Level [10]. Non point source (NPS) runoff drains through the decayed vegetable waste dumpsites and contaminate soils with heavy metals leached from these dumpsites before emptying into an adjacent River Benue about 1½km away down the slope from these dumpsites. Some animals come to feed there and pass out their dungs which also help to pollute that environment.

Figure 1: One of the Decayed Vegetable Waste Dumpsites at Gwari Market, Jimeta-Yola

2.2 Data Generation and Analysis:

i). Field method determination of soil bulk density (ρ)

In this research, field method of soil bulk density was adopted as in-situ testing. The test design was an E-W orientation where the entire study site was marked into 5 meter intervals indicating points of bulk density testing. Soil penetrometer probe was pushed through the soil profile of 30cm depth at those marked points and held in that position for 2 minutes until the reading indicator arrow was stable on a particular value. The depth of penetration into soil was measured and the same process was repeated at all marked points across the study site. The bulk density of the soil was then calculated by taking the mean of the readings obtained. A graph was used to describe how soil bulk density varied over the range of soil depths measured. Equipment used: Soil Penetrometer (Sq cm 60044 model), field thermometer, moisture meter, and a knife for cutting off roots and soil clod.

ii). Field Method Determination of Soil Permeability (Vadose Zone)

The permeability test is a measure of the rate of the flow of water through soil; therefore, it plays a role in the migration of contaminants. This study is focused on in-situ field method using double ring infiltrometers, stop watch, steel tape and a bucket of water (10 liters) for determining the permeability of the soil material by recording the drawdown (or change in water head) overtime. A 30m measuring tape was put at a distance of 5 meters (i.e., 5, 10, 15, 20, 25 and 30 meter marks). Permeability test was carried out at eight locations within the study area. The inner and outer ring infiltrometers were set at the first 5m mark and poured water on the surface of the soil; the steel ruler was inserted into water and noted the height or level of water in the inner ring; stop watch was used for timing after 5minutes, 10 minutes, 30 minutes or 60 minutes. Drawdown of water was recorded against the time in cm/min. The mean of the rate of infiltration was taken as the soil permeability of the field; and the infiltration rate at different points of the field was graphed and described.

iii). Laboratory Procedure for Soil Particles Size Analysis (Bouyoucos Hydrometer Method).

Textural soil classification of the
Samples A, B, C were collected from different parts of the research
study site was determined through Bouyoucos hydrometer.
area in clean plastic bags at depths of 0-10cm, 10-20cm and 20-30cm with the help of soil sampling spiral auger. They were carefully air-dried for one week; homogenized and grinded with mortar and pestle, then passed through 2.00mm, 1.18mm and 600µm sieves on mechanical shaker for 30 minutes then separated into coarse and fine fractions in the laboratory, weighed and percentages calculated. 50g of each sample was taken and 50ml of Calgon: Sodium hexametaphosphate [$Na\text{-}(P0_3)_6$] and 100ml of distilled water was added to each sample in rubber bottles. The samples were digested on digital orbital shaker for 30 minutes and after dispersion, each sample was poured into 1000ml glass filled with distilled water. The samples were allowed to stay for 40 seconds. While thermometer and hydrometer were dropped into the glass measuring tube of 1000ml for temperature and hydrometer (specific gravity) readings at room temperature of 32^{o}C. The readings were taken after 40seconds, 2 hours, 19 hours and percentages of sand, clay and silt were calculated. Thereafter, the textural classification was interpreted on the [11] triangular chart into percentage weights of sand, clay and silt.

2.3 Calculations:

The corrected hydrometer readings C (g/L) were obtained by subtracting the blank reading RL (g/L) from the hydrometer readings in the soil suspensions R (g/L) and adding 0.36 g/L for every degree above 20ºC. $C = R - RL + (0.36T)$ where; T = Room temperature minus 20.

The percentages by weight of the SILT + CLAY and SAND fractions are given by:

$$\%Clay = \frac{Corrected\ hydrometer\ reading\ at\ 2hours - blank}{Weight\ of\ soil\ taken} \times 100 \quad (1)$$

$$\%Silt = \frac{Corrected\ hydrometer\ reading\ at\ 40\ seconds - blank}{Weight\ of\ soil\ taken} \times 100 \quad (2)$$

$$\%Sand = 100 - (\%Silt - \%Clay) \quad (3)$$

3. FINDINGS AND DISCUSSIONS

3.1 Analysis of Soil Bulk Density and Moisture Content

The major results obtained from field determination of soil bulk density and moisture contents at specified temperatures and distances are in Table 1. The analysis of the results showed that bulk density values did not follow a specific pattern because the increase and decrease in values was attributed to the soil conditions. The density values are high which indicates that the soil is not compact but loose. It is generally desirable to have soil with a low bulk density (<1.5kg/cm^2) for optimum movement of air and water through the soil. Soil structural degradation increases if the bulk densities get higher. For moisture content, the harder the soil the less was the moisture content value of the area and vice versa. Temperature values followed the same pattern, where the moisture content was high the temperature reading was low and vice versa.

Table 1: Results of Field Soil Bulk Density and Moisture Contents

Soil Penetration (kg/cm)	Soil Moisture Contents (%)	Temperature (°C)	Distance (m)
2.90	25.3	33.0	20
1.98	28.6	31.0	30
3.40	17.4	37.0	40
3.50	15.2	40.0	50
3.20	5.4	42.0	60
3.00	7.3	41.0	70
4.20	9.3	41.5	80
3.30	8.4	41.7	90
1.10	34.6	29.0	100
2.20	22.7	32.0	110
3.10	49.4	28.0	120
4.40	24.5	30.0	130
4.30	44.4	29.0	140

3.2 Calculations:

The field method of calculating bulk density was adopted from [12]; where the mean penetration resistance of soil penetration readings gave the bulk density (bd) of the area under study. i.e.,

Bulk density (ρ_b) = $\frac{(40.58)}{13} = 3.1215 kg/cm^2$. The result suggests that the soil in the study area was more penetrable and can easily allow the movement of contaminants through it. This agrees with [12] findings that the bulk density of sandy or loam sandy soil is between 3 – 4 kg/cm^2. The mean moisture content of the soil was 22.5%. This implies that the porosity and moisture content of the soil were moderate and can allow the flow of contaminants. A graph of bulk density and distance points produced a weak positive correlation of 0.26 while there was negative correlation (- 0.15569) between bulk density and moisture content.

3.3 Analysis of Soil Permeability Test of the Research Area (Hydraulic Conductivity):

Results of the field soil permeability test are presented on Table 2. The experiment was performed at 5m mark on the upper part of the dumpsite at 19.2% moisture content; 15m mark in the centre of the field at 29.4% moisture content; and at 30m mark on the lower part of the dumpsites at 49.1% moisture content.

Table 2: Measurement Data of Field Soil Permeability Test (hydraulic conductivity)

X (cm)	Y (cm)	Z (cm)	K (min.)	$x-\bar{x}$	$y-\bar{y}$	$(x-\bar{x})^2$	$(y-y)^2$
14.8	6.4	11.5	0	1.5	3.9	2.25	15.21
14.5	4.5	10	5	1.2	2	1.44	4
14	4	9.5	10	0.7	1.5	0.49	2.25
13.8	3.5	9	15	0.5	1	0.25	1
13.6	3	8.5	20	0.3	0.5	0.09	0.25
13.4	2.5	8	25	0.1	0	0.01	0
13.2	2.3	7.8	30	-0.1	-0.2	0.01	0.04
13	2.1	7.2	35	-0.3	-0.4	0.09	0.16
12.8	1.9	6.8	40	-0.5	-0.6	0.25	0.36
12.7	1.6	6.5	45	-0.6	-0.9	0.36	0.81
12.5	1.3	6	50	-0.8	-1.2	0.64	1.44
12.4	1.1	5.5	55	-0.9	-1.4	0.81	1.96
12.3	0.9	4.5	60	-1	-1.6	1	2.56
173	32	100.8	60	0.1	2.6	7.69	30.04

$\bar{x} = 13.3 \quad \bar{y} = 2.5 \quad \bar{z} = 7.8 \quad \bar{k} = 5$

X, Y, Z, represent values of drawdown measurements at those points while K values were records of time taken after 5 minutes intervals. As can be observed, the measurements of drawdown values (X, Y, Z) decreased in the inner infiltrometers while the values of time (K) increased down the soil profile. At point X, the highest drawdown was 14.5 – 14.0 (0.5cm) in 5 minutes. At point Y, the highest drawdown being from 6.4 – 4.5 was 1.9cm within the first 5 minutes. Similarly, at point Z, there was a highest drawdown of (1.5cm) from 11.5 – 10.0 in the first record time of 5 minutes; then the values continued to decrease by 5 minutes intervals.

3.4 Calculation:

Two variables (X, Y) have been measured and a plot of the data above suggests that there is a linear relationship between them. A statistic that quantifies the strength of the relationship between the two variables is the correlation coefficient (r) as calculated below:

$$r = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} = 0.9776$$

r = 0.9776 indicates that there was a strong positive correlation between the variables which is attributed to the fact that values of X and Y were taken from the same type of soil. However, all correlations between points X, Y, Z, and time (k) in minutes were strongly negative because as permeability decreases towards soil profile, the time increases. They were moving in opposite directions.

The rate of permeability of the soil tested was obtained from the mean values of the measurements taken as follows:

For X location at 5m mark: rate of soil permeability = $\frac{\bar{x}}{\bar{k}} = \frac{13.3}{5} = 2.6 cm/\min.$

For Y location at 15m mark: rate of soil permeability = $\frac{\bar{y}}{\bar{k}} = \frac{2.5}{5} = 0.5 cm/\min.$

For Z location at 30m mark: rate of soil permeability = $\frac{\bar{z}}{\bar{k}} = \frac{7.8}{5} = 1.56 cm/\min.$

The mean of these values gave the soil permeability rate for the entire field as 1.55cm/min

This implies that it has low resistance to pollutants flow as also agreed by [13].

Particles Size Analysis and Soil Textural Classification (Bouyoucos Hydrology Method):

The result of the Bouyoucos hydrometer readings at specific temperatures is presented in Table 3 below.

Table 3: Results of the Soil Hydrometer Readings (specific gravity)

Sample	H_1	T_1	H_2	T_2	H_3	T_3
A(10cm)	5.00	31.0	1.00	31.0	3.00	28.0
B(20cm)	6.00	31.0	2.00	31.0	4.00	28.0
C(30cm)	13.00	31.0	8.00	31.0	13.00	28.0

H_1, H_2, H_3 represents hydrometer readings (specific gravity in g/cm^3) and T_1, T2, T_3 denotes temperature in (°C). A, B, C, represents soil samples taken from the field at 10cm, 20cm and 30cm depths below the soil surface from different locations of the research area. The Results showed that the highest hydrometer reading of 13.0 g/cm^3 was obtained from sample C taken at 30cm depth after 40 seconds at 31°C and after 19 hours at 28°C while the lowest hydrometer reading of 1.0 g/cm^3 was recorded from sample A at 10cm depth after an interval of 2 hours at 31°C. After 19 hours, there was improvement of the hydrometer reading from sample B of 4.0g/cm^3. Table 3 shows that the readings increased with depth throughout the experiment. Values obtained from the table above were substituted in the mathematical equations (1), (2), and (3) and obtained the percentages of sand, clay and silt in the soil samples as follows

Samples	% Sand	% Clay	% Silt
A	89.6	2.4	8
B	87.6	4.4	8
C	73.6	16.4	10

Plotted results from [14] triangular textural classification chart in Figure 2 showed that sample A was Sand sandy (i.e. Sand), sample B was Loamy sand (i.e. Sandy), and sample C was Sandy loam (i.e. Loam). This implies that the research area has a sandy loam type of soil

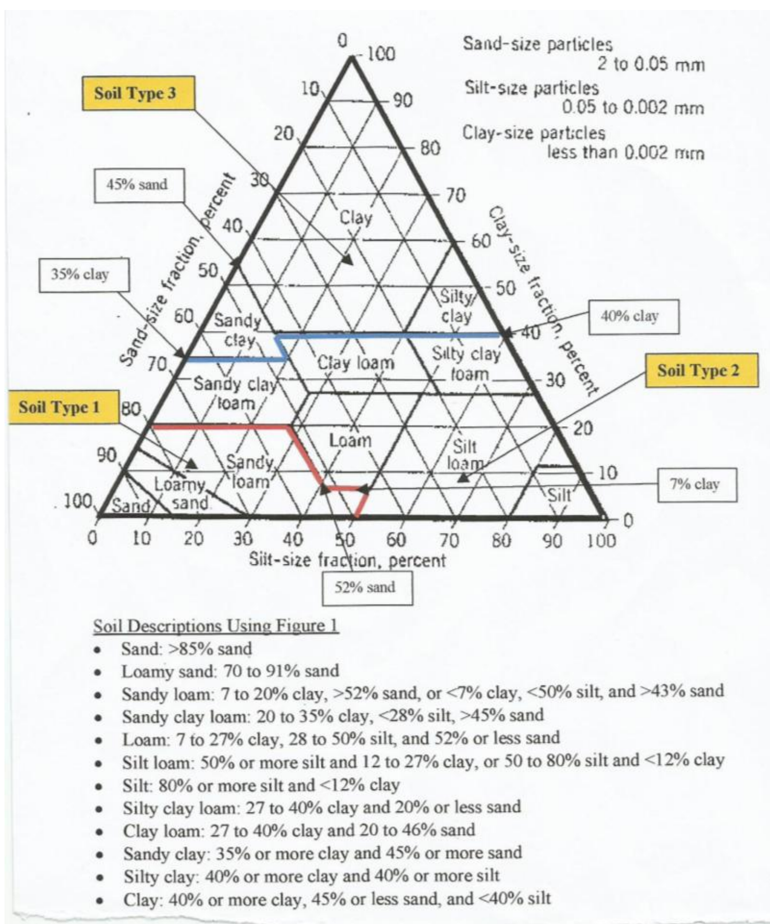

Figure 2: USDA (2005) Soil Textural Classification Chart

4. CONCLUSIONS

It can be concluded that soils are of interest as media for the transport of fluids because they are porous and permeable. Some of their physical properties such as bulk density, permeability, particles size distribution, and textural classification were studied as factors affecting the mobility of pollutants. Field work and empirical analysis were conducted on the soil samples collected using standard scientific calibrated equipment. Available results indicated that the soil bulk density of the research area was 3.1215kg/cm^2 at a mean moisture content of 22.5% and temperature of 38.6 ºC which agrees with previous findings that the bulk density of most soils range from 1 – 3kg/cm^2. This implies that the porosity of the soil was high and can allow the flow of contaminants. The soil permeability rate was found to be 1.55cm/min meaning that it has low resistance to the movement of contaminants while the textural classification of the area produced a sandy loam type of soil. It has been suggested that proper assessment of the physical properties of soils should be undertaken before siting any human activity/facility on an environment to ascertain the susceptibility of the soil to transport of pollutants.

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REFERENCES

[1] Elhag, Mohamed and Vasileios, Takavakoglou (2011). Upgrading groundwater quality using spatial assessment of pollution impacts on soil resources in Tagarades area, Greece. International Journal of Environmental Science and Engineering (IJESE), Vol. 1: 73-81,

[2] Rubin, H., Braxein, A., Daniels, H., and Rouve, G. (1994). Migration of Oil and Petroleum Pollutants in Soils and Groundwater in: Groundwater Contamination and Control, (Uri Zoller, ed.), Haifa, Israel, Pp 355 – 374

[3] Seyed, Reza Saghravani and Sa'ari, Mustapha (2011). Prediction of Contamination Migration in an unconfined Aquifer with Visual Modflow: A case Study, World Applied Science Journal, 14 (7), 1102 - 1106

[4] Onwuka, S. U., Okoye, C. O., and Onwuemesi, F. E. (2012). Mathematical Models for Predicting Pollutants Movement through Porous Rocks. Journal of Advances in Applied Science Research, 3(5): 3150 – 3159, Pelajia Research Library Research

[5] Sebastien, Fortin, E. T. T. (1998). Field and Laboratory Methods of Soil PermeabilityTests, Department of Transportation Engineering – Service Centre, Transportation, California Test 220, USA, Pp 11 – 20

[6] Henry Darcy (1856). Darcy's Law of Motion through Porous Soil Media

[7] Chalvatzaki, E., and Lazaridis, M. (2010). Estimation of greenhouse gas emissions from landfills: Application to the Akrotiri landfill site, Chania, Greece. Global NEST Journal, 12(1):108-116

[8] Keith, Loague and Richard E. Green (1991). Statistical and graphical methods for evaluating solute transport models: Overview and Application. Journal of Contaminant Hydrology, 3(5): 51 – 73, Elsevier Science Publishers B. V., Amsterdam

[9] Upper Benue River Basin Development Authority (UBRBDA, 2010). Climate and Irrigation Projects Data, Yola Office, Adamawa State, Nigeria

[10] ADSD: Adamawa State Diary (2010). Statistical Records and Documentation, Adamawa State Printing Press Ltd., Yola, Pp 10-15

[11] United States Department of Agriculture (USDA, 2005). Soil Textural Classification Triangle

[12] Martins James Lenial (1999). Hydrodynamics and Transport for water quality modelling, Boca Raton, Lewis Publishers, Pp 39 – 49

[13] Murthy, J. T. (2001). Soil and Water Pollution from Agricultural Activities in: Soil-Processes and Properties. Journal of Environment and Earth Science, Vol. 3, No. 8, Pp 1 – 9

[14] Egboka, B. C. (2015). Environmental impact assessment of gully erosion in Umuoji, Idemili North L.G.A. in A nambra State, Nigeria. African Journal of Engineering Research, Vol.9, Pp 1-15