Infiltrometric Determination of the Hydrogeological Characteristics of Some Benin Formation Topsoils, Southeastern Nigeria

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ABSTRACT

Using a double ring infiltrometer, the infiltration characteristics of the Michael Okpara University of Agriculture, Umudike soils were assessed at seven sites in both bare and vegetation conditions. The soil covering, initial moisture content, textural class, and degree of compactness were found to be the possible contributors to the variability of soil infiltration at the investigated sites, with no discernible relationship to the soil pH or porosity. Sandy loam and clay loam were identified as the two soil textural class present. The infiltration rate results reflect a similar pattern in all the soils with values ranging from 1.19 to 4.22 cm/hr at 150 minutes and an outlier value of 9.99 cm/hr reported at the New COLPAS. Similarly, the cumulative water intake value of the New COLPAS soil was observed to be 31.15 cm/hr while those of the six other locations ranged from 3.21 to 10.05 cm/hr.

The soil texture class was significant as its effect could be observed in the infiltration capacity of the soils with those of the sandy almost doubling the values of the clay loam soils. Findings of this study are useful for further understanding of the hydrogeological processes both locally and regionally and thereby ensure adequate land management of the area.

(Keywords: Infiltrometer, Benin Formation, Hydrogeological, Soil texture and Infitration capacity)

INTRODUCTION

Infiltration describes the capacity of water to travel vertically down the soil profile. This process may be quantified since it is a key factor in hydrologic, pedologic, hydrogeologic, and irrigation investigations (Kale and Sahoo, 2011, Mahapatra *et al*., 2020).

The total amount of water that soil strata can absorb from irrigation or rainfall is known as cumulative infiltration. The rate at which it occurs is known as the infiltration rate, and it is dynamic due to the effects of various factors like land use type, initial moisture content, biological matter and activities, degree of compactness, soil texture, porosity, etc. (Angelaki, *et al.,* 2013, Ma *et al.,* 2015).

The soil profile's water transmission properties set a restriction on the rate of infiltration. According to Hillel (1998), swelling in clay soils and an impervious soil layer slow down infiltration, but macropores, high organic matter, good porosity, and dense vegetative cover speed it up. Infiltration helps move substances through the soil, contributes to ground water recharge, reduces runoff and erosion, and affects the water budget of vegetation, among other things (Angelaki, *et al.,* 2004, Amos-Uhegbu, *et.al*., 2017, Mahapatra, *et al.,* 2020). Therefore, it is crucial to characterize infiltration since its rate is crucial to the performance of groundwater modeling, runoff forecast, irrigation design and efficiency (Khatri and Smith, 2006). This investigation was carried out at field scale with the aim of quantifying the spatial variability of infiltration of topsoils in Michael Okpara University of Agriculture, Umudike, Nigeria.

STUDY AREA

The research area (Michael Okpara University of Agriculture, Umudike) has typical annual average temperature ranges of about 29º -31º C and is located between latitudes 5º 28' and 5º 29' N and longitudes 7º 32' and 7º 33' E (Figure 1). With relative humidity levels of 70%, the region is in the subequatorial belt.

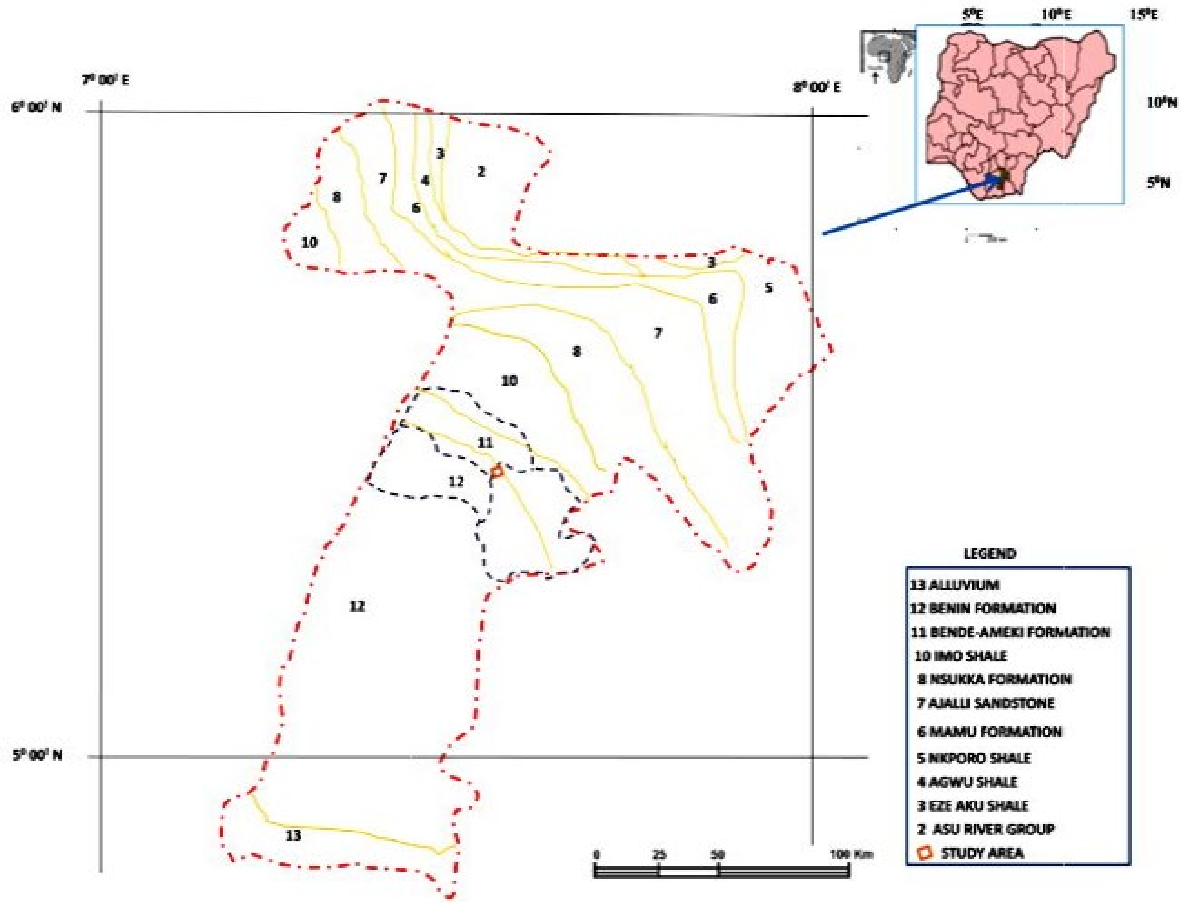

Figure 1: Geologic Map of Abia State, Nigeria showing the study area (Modified after Geological Survey of Nigeria (GSN), 1985).

The wet season lasts from mid-April to October, with rainfall peaks in July and September and a brief break in August. In Abia state, Nigeria, there are around 11 different geologic formations, although the Benin Formation of the Cenozoic Niger Delta makes up over half of the state.

Geologically, the Michael Okpara University of Agriculture, Umudike (MOUAU) study area is located in the Cenozoic Niger-Delta Basin of Nigeria in the Benin formation (Fig 1).The region is a portion of the earliest surface outcrop of the Cenozoic eastern Niger-Delta Basin due to its proximity the surface outcrop of the underlying the Bende-Ameki Formation of the Anambra Basin (Fig.1). . The study locations in MOUAU are presented in Table 1.

Table 1: The Study Locations

S/N	LOCATION	LATITUDE	LONGITUDE
1	D-Block	5° 28.879'	7° 32.640'
2	Old COLPAS	5° 28.899'	7° 32.422'
3	New COLPAS	5° 28.663'	7° 31.958'
4	PG Hostel	5° 28.652'	7° 31.917'
5	CEET	5° 28.284'	7° 32.416'
6	CAFST	5° 28.577'	7° 32.629'
7	COED	5° 28.913'	7° 32.485'

MATERIALS AND METHODS

The double ring infiltrometer method (Bouwer, 1986; ASTM, 2002) was used to investigate each site. Care was taken to carefully place the 60/30cm infiltrometer cylinders 10 cm into the soil, with the heights of the two rings (concentrically positioned to reduce unnecessary soil disturbance) roughly at the same level. Water was poured into both the inner and outer rings at the same time.

The soils' water intakes were calculated using the rule that was attached to the bridge. The inner ring's water level was periodically measured at intervals of 5, 10, 15, 20, and up to 150 minutes while the water levels in the outer rings were kept at a constant level of 5 cm. A pH meter was used to determine the soils' pH levels. To find the bulk density of the soil as well as other physical characteristics, core samples were collected using core samplers and the values were determined in laboratory.

RESULTS

The results of the study are presented as cumulative water intake (Table 2), average infiltration rates (Table 3), and the physical properties of soils (Table 4).

Table 2: The Average Cumulative Water Intake (cm) at Investigated Sites.

Cumulative Time Intake (mins)	New COLPAS	Old COLPAS	D-Block	PG Hostel	COED	CAFST	CEET
5	2.14	0.55	0.15	1.01	0.72	0.39	0.24
10	3.61	1.05	0.25	1.53	1.09	0.67	0.44
15	4.59	1.33	0.29	2.05	1.23	1.05	0.65
20	5.59	1.54	0.31	2.52	1.73	1.21	0.78
30	7.38	2.22	0.52	3.33	2.02	1.61	1.08
45	9.38	3.44	0.88	4.22	2.71	2.33	1.33
60	11.52	4.33	1.11	5.95	3.04	3.07	1.61
75	13.56	5.22	1.44	6.36	3.22	3.54	2.03
90	15.58	6.02	1.75	7.65	4.04	4.02	2.31
120	24.66	7.74	2.52	9.48	5.11	5.11	3.12
150	31.15	9.64	3.21	10.05	6.23	6.02	3.72

Table 3: The Average Infiltration Rates (cm/min) at Investigated Sites.

Cumulative Time Intake (mins)	New COLPAS	Old COLPAS	D-Block	PG Hostel	COED	CAFST	CEET
5	23.23	7.01	1.23	12.35	5.31	8.46	2.74
10	19.65	6.55	0.61	9.47	5.22	6.06	2.65
15	16.69	5.22	0.44	7.91	4.63	4.14	2.56
20	14.81	4.54	0.95	7.47	3.94	4.27	2.47
30	12.44	4.41	1.09	6.68	3.25	4.17	1.38
45	12.35	4.26	1.11	5.59	3.11	3.62	1.28
60	11.86	4.21	1.22	5.21	3.09	3.33	1.19
75	11.66	4.14	1.21	5.04	3.07	2.52	1.17
90	10.57	4.01	1.2	5.01	3.07	2.48	1.52
120	10.42	3.82	1.19	4.24	3.01	2.32	1.49
150	9.99	3.79	1.19	4.22	3.01	2.32	1.47

Table 4: The Physical Properties of Soils of the Investigated Sites.

S/N	Location	Sand (%)	Silt (%)	Clay (%)	Texture	BD (g/cm3)	OM (%)	pH	MC (%)	Porosity (%)
1	CAFST	42	18	39	Clay loam	1.79	1.55	6.6	40.06	33
2	CEET	58	24	18	Clay loam	1.48	1.59	6.2	32.62	37
3	COED	43	19	38	Clay loam	1.49	1.14	6.5	45.34	32
4	PG Hostel	79.3	7	13.7	Sandy loam	1.61	1.95	5.6	39.11	38
5	Old COLPAS	78	18	4	Sandy loam	1.51	0.14	6.5	32.83	36
6	New COLPAS	82	10	8	Sandy loam	1.51	3.81	6.7	34.23	38
7	D-Block	76	18	6	Sandy loam	1.59	1.21	6.1	36.32	36

BD = Bulk density, OM = Organic matter, MC = Moisture content

INTERPRETATION AND DISCUSSION

With a value of 11,86 cm/hr, the site at New COLPAS is an outlier and fell beyond the typical infiltration rate (IR) range for other sites, which is 1.19 cm/hr to 4.21 cm/hr (Figures 2 and 3 and Table 3). The largest intake was also recorded at New COLPAS, with a value of 31.1 cm, continuing the trend, whereas the values for the other sites ranged from 3.2 cm to 10 cm (Table 2 and Figure 5).

Figure 2 shows that PG Hostel had the lowest infiltration rate during the course of the investigation, with D-Block being at the opposite end. Experiments have shown that whether the soil was initially dry or damp had no effect on the infiltration rate. Since more water can be absorbed by the soil both inside and outside of the soil, a constant infiltration rate is a good representation of the least capacity. According to the soils' compositional ratio, there are two textural classifications: clay loam and sandy loam (Table 4 and Figure 5).

For the sandy loam soils, the average cumulative intake at 150 minutes ranged from 9.64 cm to 31.15 cm, but for clay loams, it ranged from 3.21 cm to 6.23 cm.

The rate of infiltration seems to follow a consistent pattern (Figure 5). This grouping of the sites into coarser and finer textural groups, with the exception of the D-Block site, showed that the percolating rates of the coarser group were roughly twice as high as those of the finer group with sandy loam soils reaching their peak at 3.01 cm/hr and clay loam soils peaking at 9.99 cm/hr.

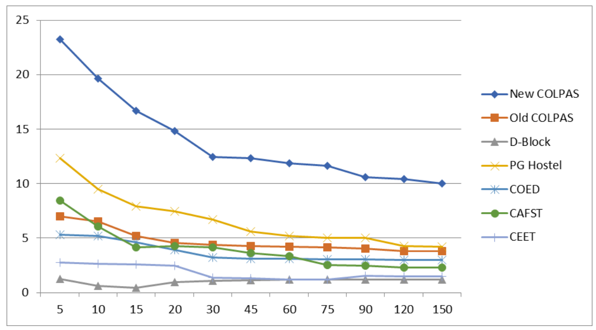

Figure 2: Average Infiltration Rates of the Investigated Soils.

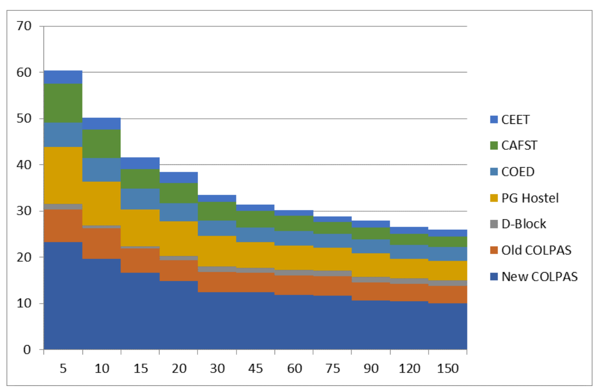

Figure 3: Average Infiltration Rates of the Investigated Soils.

With vegetation succession and the accumulation of organic matter, it is anticipated that the physical and chemical properties of soil will improve, resulting in a tighter soil texture and, ultimately, a higher water infiltration rate. This outcome illustrates how soil texture affects infiltration rate.

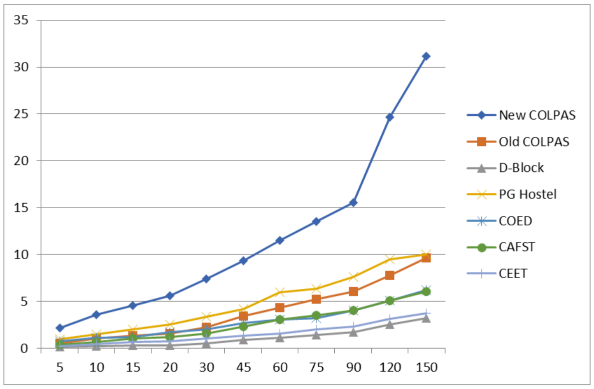

Figure 4: Cumulative Water Intake of the Investigated Soils.

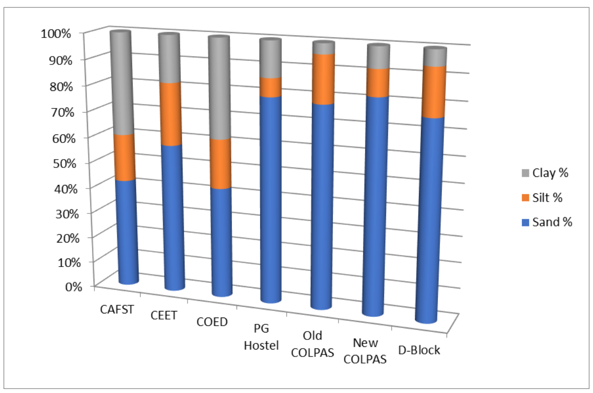

Figure 5: Composition Proportion of the Investigated Soils.

The higher clay content of the clay loams may be the cause of their lower infiltration rate. Clay particle swellings and dispersion are known to obstruct soil pores and cause slow percolation rates. At the Federal University of Technology Minna in Nigeria, Musa (2009) observed much lower values for clay loam soils, ranging from 0.17 cm/hr to 1.78 cm/hr.

Clay loam soils have a medium to fine texture compared to sandy loam soils, which may be another contributing factor. The infiltration rate of the group of coarse soil is significantly higher than that of the group of medium to fine soil, Gregory *et al.,* (2007) noted. For coarse soils, he obtained values of more than 100 mm/hr, but for medium-fine soils, he only got values of less than 50 mm/hr.

Rock fragments from the past and accumulated decaying vegetation are the sources of soil. The ratio of these two elements greatly influences how acidic a soil is, along with how much water is present in the pore spaces.

According to Johnson *et al.,* (1988), the main determinants of soil acidity are edaphic, climatic, and biological factors. Sandy soils get more acidic more quickly because they contain fewer clay particles and have a higher leaching potential. The acidity of the soil is also increased by the decomposition of organic matter. The physical characteristics of the examined soils were identified as a result of these findings.

The organic matter level of the soils is extremely high, ranging from 1.14 to 1.95% (Table 4 and Figure 6). The high porosity (33-38%) and moisture content (32.83-45.38%) values of the soils indicate its implications (Figure 7).

Furthermore, the geology of the region suggests that the parent material of the soils is likely sandstone (Figure 1), and because sandstone contains a lot of silica, the pH value range of 5.6–6.7 (Table 3) indicates that the soils are neutral to slightly acidic.

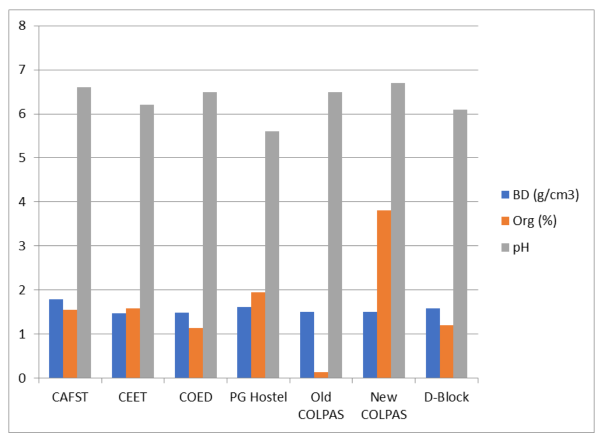

Figure 6: Organic Matter Proportion and pH of the Investigated Soils.

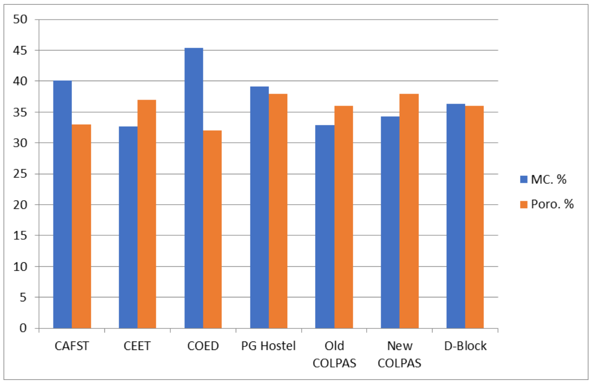

Figure 7: Moisture Content and Porosity Percentages of the Investigated Soils.

Other than that, the soil moisture content gradually rises from the initial soil moisture content to the saturated soil moisture content during the infiltration process, while the infiltration rate keeps falling and the cumulative infiltration keeps rising (which was generally high and found to range from 32.6% to 45.3%).

The experimental results, as shown in Tables 2 and 3, also corroborate this rule. The early stage is dominated by soil suction, which for a specific soil is determined by the moisture content. When this component is absent for extended periods of time, the infiltration rate is equal to the saturated field's hydraulic conductivity. As a result, the original soil moisture content's influence decreases as penetration progresses until it eventually disappears (Philip, 1957).

In their research, Marshall*, et al.,* (1999) found an inverse relationship between bulk density and infiltration rate, meaning that highly dense soils have low infiltration rates. Thrash (1997) also found that soils with low infiltration rates are more likely to experience runoff and ponding. It was found that the bulk density ranged from 1.48 to 1.79 g/cm3. Since the tested locations are still in use, human activity along with weather-related factors (such as evaporation-induced crusting and raindrop effects) may have improved the bulk density of the soils.

CONCLUSION

Characterizing the infiltration characteristics of the soils at the investigated sites has shown some effects of environmental and anthropogenic variables on the rate of water infiltration of the researched soils. According to the local geology, the soils must have come from the parent sandstone materials beneath. Although the dispersion of clay particles in the latter may have further lowered its infiltration rates, the coarseness of the sandy loams may have contributed to the higher infiltration rates seen in contrast to clay loams. The denseness of the exposed lands, which results in the reduced rate, is likely caused by treading and the raindrop effect. In general, the investigated sites are prone to ponding and flooding should there be very intense rainfall for a long duration.

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