



# Environmental impact of waste disposal sites on physicochemical properties of soil in Enugu State, Nigeria

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## Abstract

This current study evaluates the effect of waste disposal sites on soil physicochemical qualities in Enugu State, Southeast Nigeria. A total of 216 soil samples were taken in 2020, 2021 and 2022 from soil depth (0–20 cm, 20–40 cm and 40–60 cm) using standard analytical methods. In addition, seasonal (wet and dry) effects were also considered. Data sets were analysed using Fisher's Significance Least Difference (F-LSD) at 0.05 probability level. The study showed that at 0–20 cm soil depth profile, bulk density in the study period significantly ( $p < 0.05$ ) decreased by 48, 38, and 41%, and by 14, 9, and 12% in the wet and dry periods at the study sites relative to the controls. Similar results were obtained at 20–40 cm and 40–60 cm soil depth profiles. Consequently, there was a significant ( $p < 0.05$ ) increase in the values of other studied soil physical parameters in both periods relative to the controls. Across the three soil depth profiles, hydraulic conductivity values ranged from 12.25 to  $95.89 \pm 5.63$  cm/hr (a CV of 12%) and 8.73 to  $122.23 \pm 5.80$  (a CV of 10%); 10.15 to  $91.66 \pm 4.03$  (a CV of 22%) and 18.41 to  $64.48 \pm 4.21$  (a CV of 21%); and 1.55 to  $155.33 \pm 6.71$  (a CV of 14%) and 10.66 to  $134.10 \pm 6.23$  (a CV of 11%) in wet and dry periods at Enugu, respectively. Based on these new findings, it is concluded that waste disposal sites had a positive effect on the fertility of the soil.

**Keywords** Environmental degradation · Farm · Landfills · Physicochemical properties · Soil quality · Waste dumpsite

## Introduction

Improved agricultural output and human health depend on healthy soil. However, pollution from waste disposal sites and other human-induced process work together to deteriorate their qualities, causing significant environmental degradation. In cities or urban areas with high residential, domestic, and commercial activity levels, the situation is undoubtedly worse. Although municipal garbage is more effectively managed in developed economies, which results in a reasonably healthy environment, developing nations like

Nigeria confront serious environmental degradation issues as a result of inefficient waste management and/or disposal. In this regard, Adesuyi et al. (2015) observed that Nigeria is not immune from this issue and that improper management of vast volumes of garbage produced by human (domestic and industrial) operations is one of the most important issues confronting emerging countries. Aguwamba (2015) asserts that population expansion, urbanisation, and industry are the causes of this complicated problem. The average quantity of municipal and industrial garbage produced by a Nigerian citizen daily and annually is 0.85 kg and 119 million tonnes, respectively (Ayatomuno and Gobo 2019). This is a troubling problem.

Municipal trash dumpsites in Nigeria, particularly in the country's southeast, lead to environmental degradation. In numerous Nigerian cities, Lawan et al. (2019) observed an upsurge in open and dangerous waste disposal sites that contain significant home, municipal, and medical waste disposal. Elaigwu et al. (2021) further remarked that it is prevalent in Southeast Nigeria since big garbage dumpsites are present in residential neighbourhoods as well as on other highways and roads. Disposal sites are frequently supplied

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with waste from landfills. Nwocha and Emeribe (2021) counted 150 dumps in cities and outlying areas of Southeast Nigeria, both legal and illegal. According to Ngwulaka et al. (2022), these dumping sites are open, open-burning, situated in undeveloped or farmland, on riverbanks, in neighbourhoods, or in poorly maintained areas; they create breeding grounds for pathogens and bacteria, as well as leachates that seep into the ground. Sharma and Shah (2022) issue a dire warning, predicting a sharp rise in the production of solid municipal garbage as developing nations attempt to catch up to industrialised nations by the year 2050.

The majority of natural pollutants can breakdown in soil, which also serves as a waste sink, a device that reduces the passage of chemicals into groundwater, and a bioreactor. However, throughout the uniformity process, soil can purify some persistent contaminants or manmade compounds. These include hazardous mercury, DDT, refrigerators, CFCS, carbon dioxide, and other pollutants like CFCS. Various pollutants, including simple decaying organisms, multifaceted organic pollutants, non-perishable pollutants, and radioactive pollutants, are released from dumpsites. Organic materials, including potassium and nitrogen, as well as organic matter, have an impact on microorganisms because their microorganisms, which have not yet been depleted of contaminants in the soil, are unable to decrease the degree

to which their content exceeds the limitations (Narayanan 2022). The specific objectives of the study were to assess the environmental impact of waste dumps on the physical and chemical properties of soil in Enugu State, Southeast Nigeria.

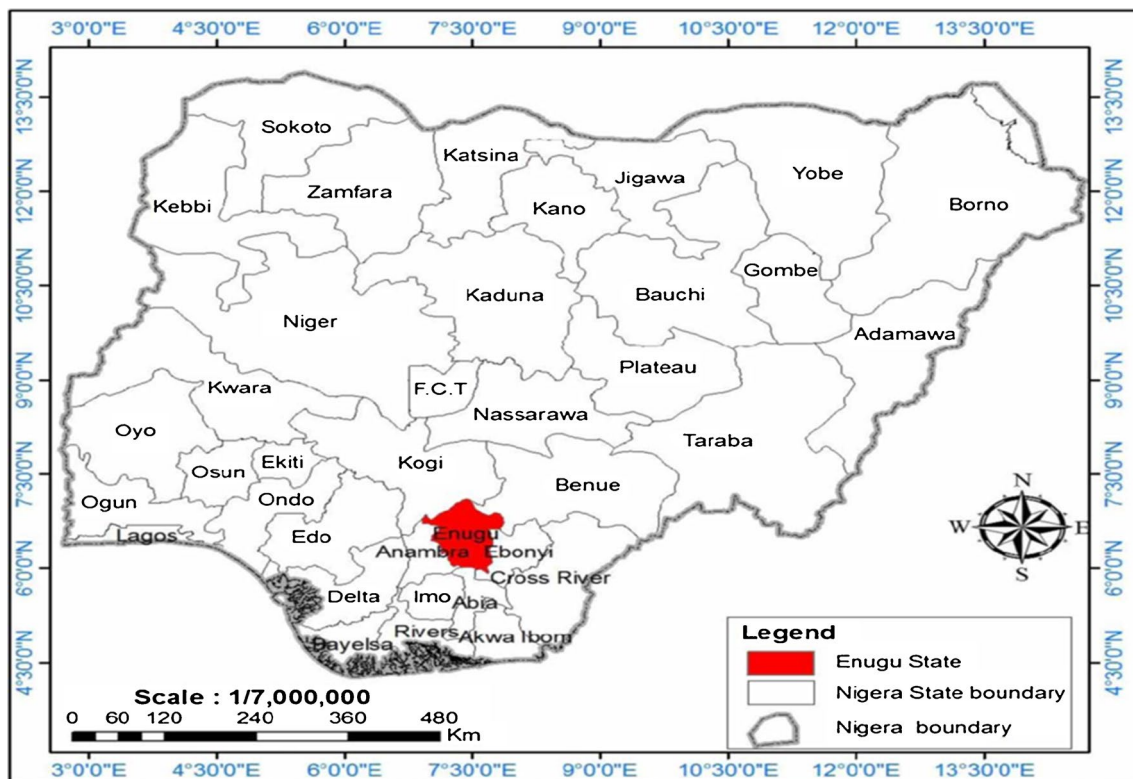
## Materials and methods

### Study sites and methods of investigation

A waste disposal site in Enugu State in the Southeast of Nigeria was randomly selected. The refuse disposal site was composed of the usual solid waste materials, such as paper wastes, food wastes, garden wastes, metal wastes, glass wastes, plastics, rubber wastes, leather wastes, batteries, rags, and other miscellaneous materials. This municipal refuse disposal site location is described in the subsequent paragraphs:

### Ugwuaji independence layout, Enugu refuse disposal site

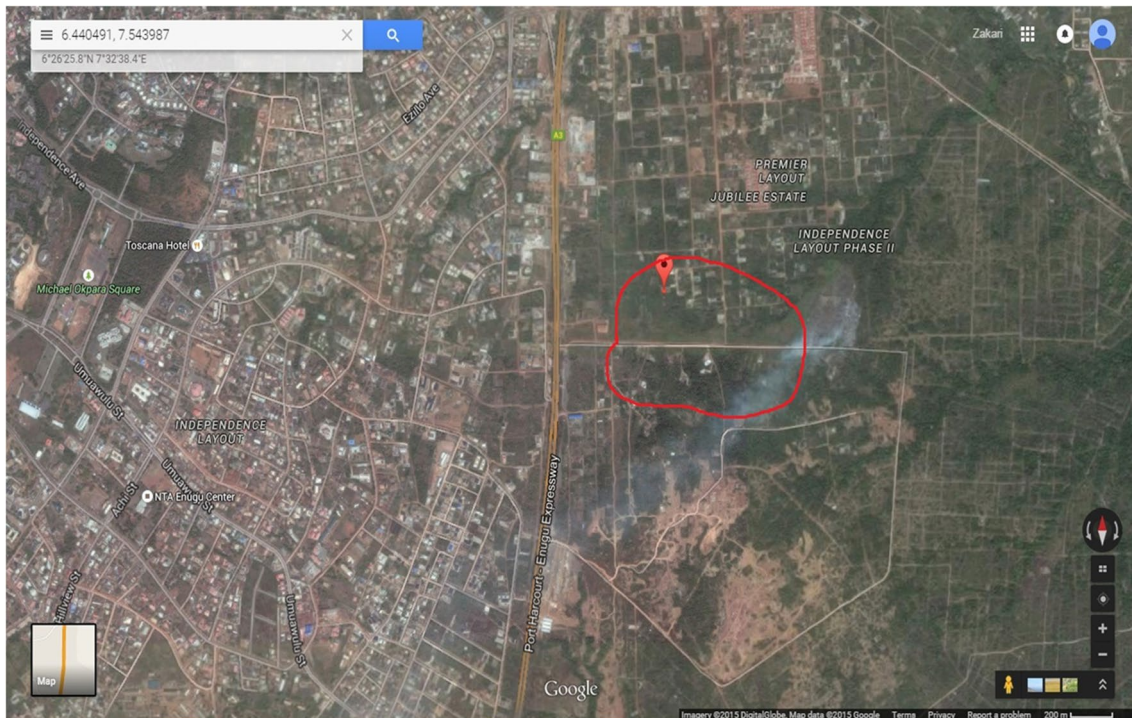
This study site is situated along the Enugu-Port Harcourt Motorway in the Ugwuaji community of Enugu Fig. 1. It



**Fig. 1** A map of Nigeria showing the study location, Enugu State. Source: Department of Geography, Alex Ekwueme Federal University Ndufu Alike, Ebonyi State Nigeria

is located between latitude  $6^{\circ}24' N$  and Longitude  $7^{\circ}37' E$ . The altitude of the site is 160 m above sea level. The solid waste disposal site is situated in a large expanse of farmland. According to residents of the area, the disposal site is over 20 years old. Figure 2 is a "GPS Google Earth map"

of Enugu State showing the solid waste disposal site and an enlarged section of the same map, while Fig. 3 depicts part of the disposal site itself. Figure 4 shows part of the refuse disposal site that had been decomposed through burning and was being planted with crops.



**Fig. 2** Map showing part of Enugu State and the position of Ugwuaji refuse disposal site. Source: Google GPS. Ugwuaji refuse disposal location

**Fig. 3** Part of Ugwuaji Enugu Waste Disposal Site





**Fig. 4** Cropped portion of Ugwuaji refuse disposals



**Table 1** Experimental sites and soil sampling points

Sites	Depth of Sampling and random sampling points		
	0-20 cm	20-40 cm	40-60 cm
Disposal Site EN	* * * * *	* * * * *	* * * * *
Control Site ENC	* * * * *	* * * * *	* * * * *

\* — randomized and replicated sampling points; EN — Ugwuaji waste disposal site in Enugu; ENC — Control

## Experimental design

The study site was subjected to sampling for the randomised complete block design in the location experiment. These included control sites without waste dump influence. The investigation was subjected to seasonal effects (in wet and dry seasons). In study location, soil profile effects, namely 0–20 cm, 20–40 cm and 40–60 cm depths, were considered. In each case, total of 216 soil samples were collected to increase accuracy and minimise experimental errors. This gave a total of 72 soil samples for wet and dry seasons for the study site and its control in the first year (2020) and 72 soil samples for each of the last two years (2021 and 2022), making it 144 soil samples. The details of the soil sampling site identifications and sampling points are given in Table 1. Samples of soil collected from the waste disposal site and control was properly identified. The Enugu refuse disposal site, at 0–20 cm, 20–40 cm, and 40–60 cm soil depths, had the 108 soil samples designated as ENw<sub>1</sub>, ENw<sub>2</sub>, and ENw<sub>3</sub>, while the controls were designated as ENCw<sub>1</sub>, ENCw<sub>2</sub>, and ENCw<sub>3</sub>, had also 108 soil samples. Details of the soil sample designations and location data (geographical) coordinates are shown in Table 2 and Fig. 5.

## Preparation for soil samples collection

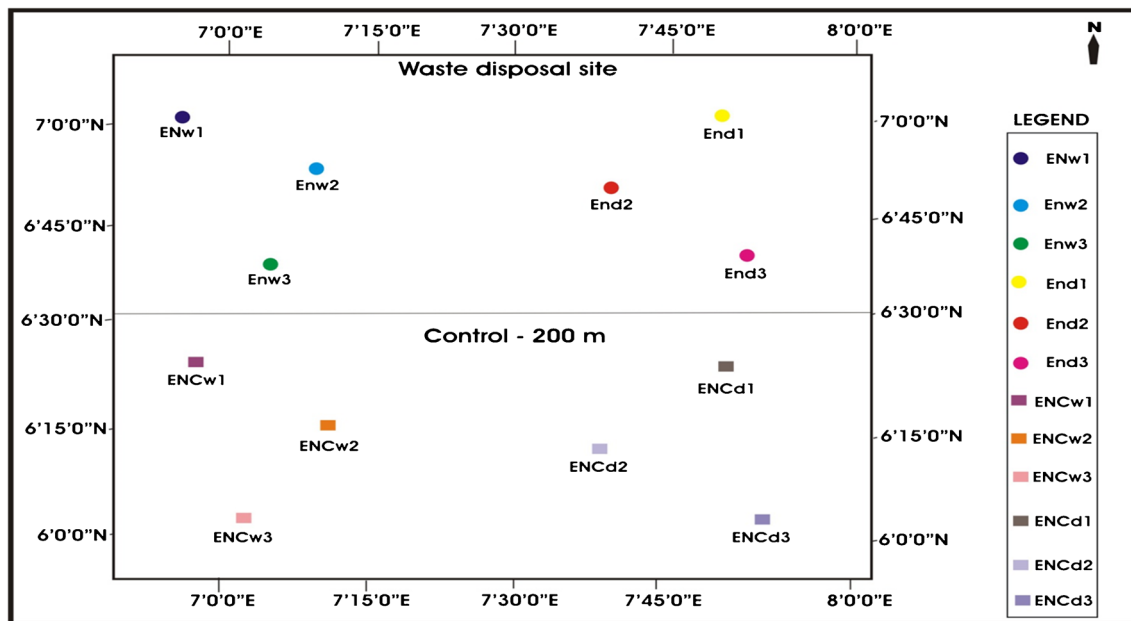
Prior to the first day of the first field trip for soil sample collection, empty core samplers (216 No.) used for the collection of core soil samples for bulk density determination at the study sites were selected and weighed in the laboratory. Empty can cups (216 No.) used for the determination of soil moisture content were also selected and weighed at the same time. The empty weights of these devices were all noted in a sampling notebook. The cores and can cups were all properly labelled with markers and measuring tape to receive soil samples from the field. Sampling bags (small black polythene) were equally arranged and labelled according to the numbers and the labelling of the cores and those of the can cups, using the masking tape and the marker. A number of baco bags to be used to carry the samples in the sampling bags were equally arranged. Other tools arranged for the field trip included the digger, the hoe, the shovel, the tape for measuring the depth of soil sampling, and the distances of the control sites from refuse disposal sites.

## Soil samples collection and preparation for analysis

Six soil samples were randomly collected each at 0–20 cm, 20–40 cm, and 40–60 cm depths in the soil profile at the refuse disposal site in Enugu (EN) and control in the months of September and February for wet and dry periods, respectively. These samples included core samples as well as those for other soil physical, chemical, or routine analyses. Soil samples collected from the disposal site was taken within the disposal site location. However, the collection points for soil samples for the control site at the Ugwuaji Enugu refuse disposal site (ENC) were 200 m away from the disposal site. This distance

**Table 2** Details of site samples identification

SYMBOL	DESCRIPTION
ENw <sub>1</sub>	Soil samples collected at 0-20 cm soil depth profile in the wet season from Enugu waste dump sites respectively
ENd <sub>1</sub>	Same as above but in the dry season
ENw <sub>2</sub>	Soil samples collected at 20-40 cm soil depth profile in the wet season
ENd <sub>2</sub>	Same as above but in dry season
ENw <sub>3</sub>	Soil samples collected in the wet period at 40-60 cm soil depth profile
ENd <sub>3</sub>	Same as above but in dry season
ENCw <sub>1</sub>	Control soil samples in the wet period collected at 0-20 cm soil depth from Enugu control sites respectively
ENCd <sub>1</sub>	Same as above but in the dry period
ENCw <sub>2</sub>	Wet samples collected at 20-40 cm soil depth
ENCd <sub>2</sub>	Same as above but in the dry season
ENCw <sub>3</sub>	Wet period soil samples collected at 40-60 cm soil depth
ENCd <sub>3</sub>	Same as above, but in the dry period



**Fig. 5** Map showing the location data (geographical) coordinates of the study site. Source: Researcher’s Intern, 2022

was necessitated by the fact that the refuse disposal sites are almost on tableland.

**Determination of soil physical properties**

The bulk density was determined by determining the dry density of undisturbed core samples, taken from the sites. This was done according to the methods of Blake and Hartge (1986). The working formula was as follows:

$$Bd = ((A + C) - C) / \pi r^2 h$$

where:

$\pi r^2 h$  Bulk volume

$r^2$  square of radius of core

$h$  height of core

$A$  dry weight of soil

$C$  weight of core

Total porosity ( $T_p$ ) was calculated from bulk density using assumed particle density ( $P_d$ ) of  $2.65\text{gcm}^{-3}$ , in the equation:

$$T_p = 100 (1 - B_d/P_d).$$

Aeration porosity ( $A_p$ ) was computed from the relationship:

$$A_p = T_p - \emptyset(10\text{kPa})$$

where,

$\emptyset$  volumetric moisture content

$T_p$  Total porosity

Gravimetric moisture content was obtained by the use of pressure plate at 10 kPa, according to Stolter (1997). The calculation was done as follows:

$$\text{GMC} = (W_1 - W_2)/(W_2 - W_3) \times 100$$

where,

$W_1$  wet wt of soil + can

$W_2$  dry wt of soil + can

$W_3$  empty wt of can only

Aggregate stability or the distribution of aggregates was determined by the wet sieving technique described by Kemper and Rosenau (1986).

The percent water-stable aggregates or WSA was calculated using the equation:

$$\text{WSA} = \frac{M_a + s - M_s}{M_t - M_s} \times 100$$

Such that:

$M_a + s$  Mass of the resistant aggregates + Sand (g)

$M_s$  Mass of the sand fraction alone (in grams)

$M_t$  Total mass of the sieved soil (in grams)

All soil samples that fell within 4.25 and 0.25 mm were used to express WSA greater than or equal to 0.25 mm as the index of stability.

Hydraulic Conductivity was determined using conductivity meter according to the method outlined by Landon

(1991), and described by Godson et al (2002). The calculation was done as follows:

$$K = Q/At \times \Delta H/L$$

where,

$K$  Hydraulic conductivity.

$Q$  amount of water being collected constantly

$A$  Area of core containing soil sample

$T$  time interval of collection (5 min)

$L$  length of the core containing core sample

$H$  constant water level height being maintained

### Investigation of soil chemical properties

Organic carbon was determined by the Walkley and Black method (1934), as modified by Allison (1973) and with adaptations from Heanes (1984). This is a complete oxidation procedure, through which the amount of C was determined from a standard curve. % OC was calculated as follows:

$$\%OC = (\text{MgC}/\text{Mg of the sample}) \times 100$$

The conventional "Van Bemmeler Factor" of 1.724 was multiplied by the value of organic carbon (OC) to obtain the percentage of organic matter (OM) with the assumption that soil organic matter (SOM) contains 58% carbon.

The pH of the soil samples was determined both in 0.1 NKCl and in distilled water using a soil-liquid ratio of 1:2.5. This was stirred for 30 min, and the pH values were read using a Zeromatic pH meter Model 96A 9604, Beckman Coulter, according to Peech (1965).

Calcium (Ca), Magnesium (Mg), Sodium (Na) and Potassium (K) were determined from IM ammonium acetate ( $\text{NH}_4\text{OAC}$ ) using the flame photometer Model FP8400, Scitek Global by the complexometric titration method, described by Chapman (1962).

Total Nitrogen was determined by the macro Kjeldhal distillation method (Bremmer and Mulvaney 1982), using a  $\text{CuSO}_4/\text{Na}_2\text{SO}_4$  catalyst mixture. The ammonia from the digestion was distilled with 45% NaOH into 2.5% Boric acid and determined by titration with 0.05 N KCl.

Available phosphorus was determined by the Bray-11 method, referred to as Bray and Kurtz (1945). A procedure that led to plotting Absorbance vs. ppm P. The samples were read, and ppm P was obtained by interpolation on the graph R.

### Calculation

$$\text{Ppm P}(\text{ugP/kgsoil}) = R \times 30/5 = R \times 6$$

The available Phosphorus was read off from the standard curve after obtaining the optical density from a colorimeter.

### Data analysis

The soil data were subjected to an analysis of Variance (ANOVA) for a randomised complete block design (RCBD). Means that were significant were separated with the Fisher's Least Significant Difference (FLSD) (Steel and Torrie 1980; Okafor et al. 2023).

### Results

The mean results of the three-year study of the soil qualities of the waste disposal sites and the control sites with respect to their physical and chemical properties are presented.

### Effect of waste disposal sites on soil physical properties

Soil physical properties studied at three soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm at waste disposal site and control site in wet and dry seasons showed significant differences in values. Aside from soil texture, which was predominately loamy sand for Enugu waste disposal site, every other parameter showed changes in values relative to the control values. The mean values of these parameters observed in the wet period also changed relative to the dry season's results, as aggregated in Tables 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 and 22.

At the Enugu waste disposal site (EN) (Table 3), the wet season (ENw) bulk density value at a 0–20 cm soil depth profile, decreased by 38% relative to its wet season control. The Bd result for the dry period (ENd) decreased by 9% relative to its dry season control of  $1.31 \pm 0.24 \text{ g/cm}^3$ . At this soil profile level, the wet season Bd value increased by 34% relative to the dry period Bd value. At a 20–40 cm soil depth profile, Bd values in the wet and dry seasons increased by 5% and decreased by 3% relative to their respective control values.

At the EN study sites (Table 4), gravimetric moisture content results increased by 55, 100 and 5% in the dry

**Table 3** Results of Bulk density, Bd in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	23	23	23	15	15	15	23	23	23	20	40
ENw	87	77	69	40	25	99	34	24	43	11	50
FLSD <sub>(0.05)</sub>	0.04	0.03	0.03	0.02	0.01	0.02	0.03	0.02	0.03		
<i>Dry season</i>											
ENCd	1 0.31	10.31	10.31	10.47	1 0.47	10.47	10.37	10.37	0.37	10.38	24
ENd	1 0.09	10.23	10.25	10.38	0.35	10.27	10.61	10.35	10.33	10.31	30
FLSD <sub>(0.05)</sub>	0.05	0.04	0.02	0.02	0.01	0.03	0.06	0.02	0.03	0.04	

**Table 4** Gravimetric moisture content, GMC (%) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	25	25	25	23	23	23	26	26	26	264.6	1.00
ENw	16	18	17	18	20	21	24	23	22	19.89	1.41
FLSD <sub>(0.05)</sub>	0.12	0.08	0.05	0.09	0.08	0.05	0.06	0.09	0.12	0.10	
<i>Dry season</i>											
ENCd	9	9	9	8	8	8	12	12	12	9.67	1.40
ENd	14	14	13	17	17	15	20	18	16	16	1.41
FLSD <sub>(0.05)</sub>	0.10	0.11	0.07	0.06	0.07	0.09	0.05	0.08	0.10	0.07	

**Table 5** Results of Total porosity,  $T_p$  (%) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	54	54	54	46	46	46	46	46	46	48.67	2.00
ENw	68	70	74	47	52	63	50	53	46	58.11	3.20
FLSD <sub>(0.05)</sub>	0.45	0.81	0.49	0.07	0.45	0.41	0.01	0.01	NS	0.03	
<i>Dry season</i>											
ENCd	52	52	52	48	48	48	49	49	49	49.67	1.41
ENd	55	53	53	48	49	52	39	51	50	51.89	1.73
FLSD <sub>(0.05)</sub>	0.39	0.77	0.60	0.03	0.46	0.42	NS	NS	0.04	0.02	

**Table 6** Results of Aeration Porosity,  $A_p$  (%) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	29	29	29	24	24	24	19	19	19	24	1.73
ENw	52	52	57	29	32	42	29	30	24	38.56	3.32
FLSD <sub>(0.05)</sub>	0.65	0.49	0.71	0.43	0.48	0.60	0.44	0.51	0.43	0.33	
<i>Dry season</i>											
ENCd	43	43	43	42	36	36	35	35	35	38	1.73
ENd	41	39	40	40	31	32	29	33	34	38.11	2.24
FLSD <sub>(0.05)</sub>	0.55	0.42	0.64	0.43	0.56	0.44	0.39	0.41	0.50	0.45	

**Table 7** Results of Hydraulic Conductivity (cm/hr) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	36.51	36.51	36.51	12.12	12.12	12.12	1.73	1.73	1.73	13.45	3.63
ENw	44.50	46.71	55.04	29.09	41.84	38.16	91.66	10.15	15.63	39.20	4.03
FLSD <sub>(0.05)</sub>	2.45	1.73	1.86	1.167	1.04	1.11	1.10	1.31	1.09	1.12	
<i>Dry season</i>											
ENCd	21.24	21.24	21.24	10.65	10.65	10.65	2.83	2.83	2.83	11.57	2.50
ENd	35.20	64.48	63.81	26.15	53.55	54.48	16.81	18.41	19.53	39.16	4.21
FLSD <sub>(0.05)</sub>	1.99	1.90	1.74	1.22	1.09	1.11	1.14	1.19	1.20	1.08	

season relative to the dry season control values at the 0–20 cm, 20–40 cm, and 40–60 cm depths, respectively. In the wet season, however, GMC values decreased by 32, 13 and 15% relative to their respective wet season control values in the three respective soil depth profile levels. The highest value of  $23 \pm 1.41\%$  was observed at the 20–40 cm soil depth profile at the control ENCw, while the least GMC result of  $8 \pm 1.40\%$  was observed in the dry season at soil depth profile 0–20 cm at ENCd. The second least GMC value was also observed at ENCd but at the profile depth of 0–20 cm.

At the 20–40 cm soil depth profile, the first year GMC results for the disposal sites, for both wet and dry season, showed significant ( $p < 0.05$ ) difference relative to GMC values at ENCw, and ENCd.

At the 40–60 cm soil depth profile, there were significant ( $p < 0.05$ ) differences in GMC results in the wet season at the waste disposal sites relative to the dry season results at the disposal site. At the EN study sites, GMC values across the soil depth profiles were significant ( $p < 0.05$ ) differences relative the control values, except for that of the third year result, and the first year result in the third soil depth profile.



**Table 8** Results of Aggregate Stability (%) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	27	27	27	24	24	24	25	25	25	25	2.65
ENw	50	53	56	40	50	48	25	42	47	46	2.24
FLSD <sub>(0.05)</sub>	1.44	1.38	1.00	0.88	1.07	0.76	1.10	0.63	0.79	0.58	
<i>Dry season</i>											
ENCd	25	25	25	18	18	18	18	18	18	20	2.00
ENd	51	49	51	40	42	47	45	36	43	45	1.00
FLSD <sub>(0.05)</sub>	1.39	1.60	1.11	1.00	1.05	0.76	1.21	0.88	0.57	0.65	

**Table 9** Results of Sand fraction (%) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	80	80	80	78	78	78	72	72	72	77	1.73
ENw	82	77	75	76	76	74	74	76	76	75	1.41
FLSD <sub>(0.05)</sub>	0.31	0.18	0.40	0.62	0.35	0.43	0.31	0.27	0.33	0.24	
<i>Dry season</i>											
ENCd	81	81	81	78	78	78	73	73	73	77	1.73
ENd	82	75	74	75	74	75	74	72	71	75	1.41
FLSD <sub>(0.05)</sub>	0.34	0.32	0.28	0.55	0.42	0.18	0.23	0.40	0.17	0.34	

**Table 10** Results of Silt fraction (%) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	4	4	4	4	4	4	16	16	16	8	1.00
ENw	8	10	11	8	9	10	8	9	8	9	1.00
FLSD <sub>(0.05)</sub>	0.08	0.07	0.04	0.05	0.06	0.08	0.03	0.05	0.07	0.08	
<i>Dry season</i>											
ENCd	4	4	4	5	5	5	14	14	14	8	2.00
ENd	8	13	13	9	12	10	8	12	11	11	1.41
FLSD <sub>(0.05)</sub>	0.06	0.10	0.05	0.04	0.05	0.08	0.07	0.05	0.06	0.05	

GMC results at the waste disposal site in the wet season showed some significant ( $p < 0.05$ ) differences relative to a number of dry seasons GMC values.

At the first soil depth profile of 0–20 cm, total porosity value at ENw in the wet season increased by 31%, while the total porosity in the dry season also increased by 3% relative to their respective controls, as shown in (Table 5). At ENw, Tp value increased by 14% relative to the control, while in the dry period, Tp value increased by only 4% relative to the dry season control value of  $48 \pm 1.41\%$ . At the soil depth profile of 40–60 cm, Tp value at ENw of  $50 \pm 3.2\%$  increased

by 11% relative to the wet season control value. In the dry season, however, the Tp value at EN decreased by 4% relative to the dry season control value.

Aeration porosity value observed at EN in the wet season at the 0–20 cm soil depth profile increased by 86% ( $54 \pm 3.32\%$ ) relative to the wet season control value of  $29 \pm 1.73\%$ , while the dry season (Table 6) mean Ap value decreased by 4% ( $40 \pm 2.24\%$ ) relative to the dry season mean Ap control result. While the Ap result in the wet period at the 20–40 cm soil depth profile at EN increased by 41%, the dry season result decreased by 8%, all relative

**Table 11** Results of Clay fraction (%) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	16	16	16	18	18	18	12	12	12	15	1.41
ENw	10	13	14	16	15	16	18	15	16	15	1.41
FLSD <sub>(0.05)</sub>	0.11	0.10	0.12	0.11	0.12	0.10	0.07	0.07	0.19	0.13	
<i>Dry season</i>											
ENCd	15	15	15	17	17	17	18	18	18	17	1.00
ENd	10	12	13	16	14	15	13	13	13	13	1.41
FLSD <sub>(0.05)</sub>	0.12	0.09	0.07	0.10	0.11	0.08	0.05	0.06	0.16	0.10	

**Table 12** Results of soil pH in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	5.55	5.55	5.55	4.66	4.66	4.66	4.56	4.56	4.56	4.95	0.50
ENw	7.45	8.58	7.88	7.00	8.41	7.54	6.87	7.39	7.46	7.59	0.70
FLSD <sub>(0.05)</sub>	0.10	0.12	0.14	0.12	0.10	0.12	0.13	0.18	0.14	0.16	
<i>Dry season</i>											
ENCd	5.00	5.00	5.00	4.42	4.42	4.42	4.15	4.15	4.15	4.5	0.60
ENd	5.29	8.10	7.44	4.66	8.00	7.35	4.56	7.16	7.17	6.64	1.13
FLSD <sub>(0.05)</sub>	0.06	0.09	0.13	0.13	0.08	0.11	0.10	0.15	0.11	0.09	

**Table 13** Results of Organic Carbon (%) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.61	0.61	0.61	0.58	0.58	0.58	0.56	0.56	0.56	0.58	0.20
ENw	2.60	1.88	2.08	1.44	1.87	1.79	1.06	1.22	1.34	1.70	0.81
FLSD <sub>(0.05)</sub>	0.07	0.10	0.11	0.05	0.05	0.09	0.06	0.07	0.02	0.04	
<i>Dry season</i>											
ENCd	0.55	0.55	0.55	0.52	0.52	0.52	0.47	0.47	0.47	0.47	0.28
ENd	1.50	1.62	1.45	1.35	1.60	1.37	1.06	1.34	1.08	1.11	0.25
FLSD <sub>(0.05)</sub>	0.05	0.08	0.12	0.07	0.06	0.06	0.07	0.08	0.04	0.06	

to the respective controls. Also at the soil depth profile of 40–60 cm, the wet season Ap result at EN increased by 47% relative to the control value of  $19 \pm 1.73\%$ , while that of the dry season, however, reduced by 8%.

At the EN waste disposal site (Table 7), at the 0–20 cm soil depth profile, the wet and dry seasons Hydraulic Conductivity values increased by 33% and 156%, respectively, relative to their control values of  $36.50 \pm 3.63$  cm/hr and  $21.24 \pm 2.50$  cm/hr. At a soil depth of 20–40 cm, the wet and dry Hydraulic Conductivity values of  $36.36 \pm 4.03$  cm/hr and  $44.46 \pm 4.2$  cm/hr at the EN sites increased by 200%

and 317%, respectively, relative to their control values of  $12.12 \pm 3.63$  cm/hr and  $10.65 \pm 2.50$  cm/hr, respectively. At the 40 cm–60 cm soil depth profile, the wet season Hydraulic Conductivity level recorded the highest increase of 2163% relative to its wet season control value. The dry season value also increased by 544% relative to the control value of  $1.83 \pm 2.58$  cm/hr.

At the EN waste disposal site, the state of aggregation values in the 0–20 cm soil profile depths, in the wet and dry seasons increased by 92% and 100%, respectively, relative to their respective controls, whose SA values were  $27 \pm 1.00\%$

**Table 14** Results of Organic Matter (OM) (%) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	1.05	1.05	1.05	1.00	1.00	1.00	0.97	0.97	0.97	1.01	0.14
ENw	4.48	3.23	3.58	2.48	3.22	3.08	1.83	2.10	2.30	2.92	0.63
FLSD <sub>(0.05)</sub>	0.10	0.07	0.08	0.15	0.11	0.07	0.08	0.12	0.09	0.11	
<i>Dry season</i>											
ENCd	1.05	1.05	1.05	0.90	0.90	0.90	0.82	0.82	0.82	0.92	0.09
ENd	2.59	2.84	2.49	2.33	2.56	2.36	1.72	2.15	1.86	2.32	0.11
FLSD <sub>(0.05)</sub>	0.09	0.06	0.07	0.13	0.11	0.06	0.10	0.14	0.11	0.12	

**Table 15** Results of Available Phosphorus (mg/Kg<sup>-1</sup>) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.39	0.39	0.39	0.34	0.34	0.34	0.35	0.35	0.35	0.36	0.42
ENw	1.05	1.72	1.84	0.87	1.37	1.52	0.68	1.31	1.50	1.32	0.60
FLSD <sub>(0.05)</sub>	0.09	0.08	0.11	0.10	0.07	0.06	0.08	0.07	0.10	0.07	
<i>Dry season</i>											
ENCd	0.37	0.37	0.37	0.33	0.33	0.33	0.33	0.32	0.32	0.34	0.42
ENd	0.54	1.01	1.61	0.65	0.84	1.40	0.93	10.77	1.36	02.09	0.60
FLSD <sub>(0.05)</sub>	0.06	0.07	0.07	0.12	0.08	0.07	0.10	0.08	0.11	0.06	

**Table 16** Total Nitrogen (TN) (%) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.28	0.28	0.28	0.42	0.42	0.42	0.67	0.67	0.67	0.46	0.57
ENw	0.05	0.24	0.36	0.18	0.27	0.31	0.22	0.18	0.25	0.23	0.80
FLSD <sub>(0.05)</sub>	0.05	0.03	0.02	0.04	0.03	0.02	0.04	0.01	0.02	0.04	
<i>Dry season</i>											
ENCd	0.19	0.19	0.19	0.30	0.30	0.30	0.10	0.10	0.10	0.20	0.20
ENd	0.17	0.30	0.32	0.18	0.22	0.27	0.14	0.16	0.21	0.22	0.22
FLSD <sub>(0.05)</sub>	0.03	0.02	0.02	0.02	0.03	0.04	0.04	NS	0.02	0.03	

and  $25 \pm 1.73\%$ , respectively. At the 20–40 cm soil depth profile, SA values in the two seasons also increased by 62% and 138% relative to the control values of  $25 \pm 1.00\%$  and  $18 \pm 1.73\%$ , respectively. SA values at the EN waste disposal site in the wet and dry seasons of  $35 \pm 2.65\%$  and  $41 \pm 2.00\%$  increased by 4% and 127%, respectively, relative to their respective control values. Comparing wet season results with those of dry season in the three soil profile depths, wet season values of  $52 \pm 2.65$ ,  $39 \pm 2.65$  and  $35 \pm 2.65\%$  increased by 4, 9 and 14% relative to their dry season values in the EN waste disposal site, respectively (Table 8).

At EN study sites, sand fractions in the wet and dry seasons, at the first soil depth profile of 0–20 cm, decreased by 2% and 4%, respectively, relative to the wet and dry seasons control values of sand (Table 9). At the soil depth profile of 20–40 cm, in the wet and dry seasons, sand values also decreased by 2% and 3% relative to their respective control mean values, respectively, in the wet and dry seasons. At the 40–60 cm soil profile, the EN value of sand increased by 4% relative to the control value, and the ENd value decreased by 1% relative to the control mean sand level of  $73 \pm 1.73\%$ . Mean sand levels in the wet season in the first and second

**Table 17** Carbon—Nitrogen ratio (C/N) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	2.18	2.18	2.18	1.38	1.38	1.38	0.84	0.84	0.84	1.47	0.70
ENw	17.93	7.83	5.78	8.23	6.93	5.77	4.86	6.78	5.36	7.72	1.56
FLSD <sub>(0.05)</sub>	0.79	0.12	0.94	0.52	0.74	0.59	0.83	0.76	0.71	0.55	
<i>Dry season</i>											
ENCd	1.89	1.89	1.89	3.01	3.01	3.01	4.61	4.61	4.61	3.17	0.10
ENd	8.86	5.30	4.53	7.45	6.77	5.07	7.04	7.81	5.14	6.44	1.12
FLSD <sub>(0.05)</sub>	0.76	0.35	0.88	0.44	0.68	0.57	0.75	0.58	0.83	0.71	

**Table 18** Sodium Adsorption Ratio (SAR) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.28	0.28	0.28	0.36	0.36	0.36	0.47	0.47	0.47	0.37	0.20
ENw	0.26	0.31	0.30	0.55	0.38	0.40	0.47	0.39	0.36	0.38	0.24
FLSD <sub>(0.05)</sub>	0.01	0.02	0.01	0.01	0.01	0.03	0.02	0.03	0.03	0.04	
<i>Dry season</i>											
ENCd	0.20	0.20	0.20	0.19	0.19	0.19	0.31	0.31	0.31	0.23	0.22
ENd	0.47	0.31	0.30	0.24	0.30	0.20	0.15	0.34	0.31	0.29	0.24
FLSD <sub>(0.05)</sub>	0.02	0.01	NS	0.01	0.02	0.02	0.01	0.02	0.04	0.03	

**Table 19** Results of Exchangeable Ca ( $\text{Cmol}_{(+)}\text{kg}^{-1}$ ) in wet and dry seasons

Study Sites	0—20 cm			20—40 cm			40—60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.18	0.18	0.18	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.17
ENw	5.77	6.75	6.89	4.28	4.80	4.87	4.11	4.42	4.96	5.21	5.21
FLSD <sub>(0.05)</sub>	0.10	0.12	0.06	0.09	0.07	0.11	0.18	0.09	0.11	0.10	
<i>Dry season</i>											
ENCd	0.14	0.14	0.14	0.12	0.12	0.12	0.10	0.10	0.10	0.12	0.14
ENd	5.09	5.44	6.15	3.17	4.12	4.54	4.01	3.00	3.66	4.35	0.92
FLSD <sub>(0.05)</sub>	0.08	0.15	0.09	0.10	0.08	0.14	0.21	0.11	0.09	0.12	

soil profiles decreased by 1% and 1%, respectively, relative to their corresponding dry season sand values.

At the 0–20 cm, 20–40 cm, and 40–60 cm soil depth profiles at the EN study sites, wet season silt fraction values increased by 150, 125 and 50%, respectively, relative to their respective controls. Similarly, dry season silt fraction levels in the respective soil depth profiles increased by 175% and 100% and decreased by 28% relative to their control in the dry season. At the three soil depths, wet season silt fraction levels decreased by 9, 10 and 20% relative to the dry season silt fraction values (Table 10).

At (Table 11) EN study sites, wet season clay fraction levels decreased by 25%, 25%, and increased by 33% relative to the wet season control value, with respect to the soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm, respectively. In the dry period, however, clay fraction values decreased by 20, 20 and increased by 30% relative to their control values in the respective soil depth profiles. Again, wet season clay fractions increased by 0, 0 and 5% relative to the dry season clay values at the respective soil depth profiles. Wet season clay fraction results also increased by 10, 10 and 88% relative to the dry season control clay fraction levels in the



**Table 20** Results of Exchangeable Cation, Na (Cmol<sub>(+)</sub>kg<sup>-1</sup>) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.11	0.11	0.11	0.11	0.11	0.11	0.14	0.14	0.14	0.12	0.10
ENw	0.46	0.58	0.57	0.86	0.60	0.66	0.69	0.61	0.59	0.63	0.26
FLSD <sub>(0.05)</sub>	0.04	0.03	0.02	0.06	0.04	0.02	0.04	0.03	0.05	0.02	
<i>Dry season</i>											
ENCd	0.10	0.10	0.10	0.09	0.09	0.09	0.07	0.07	0.07	0.09	0.10
ENd	0.79	0.53	0.55	0.33	0.45	0.52	0.22	0.44	0.42	0.47	0.33
FLSD <sub>(0.05)</sub>	0.05	0.03	0.02	0.02	0.01	0.02	0.06	0.05	0.05	0.06	

**Table 21** Results of Exchangeable Mg (Cmol<sub>(+)</sub>kg<sup>-1</sup>) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.14	0.14	0.14	0.03	0.03	0.03	0.02	0.02	0.02	0.06	0.26
ENw	0.36	0.45	0.53	0.32	0.37	0.47	0.25	0.36	0.41	0.39	0.24
FLSD <sub>(0.05)</sub>	0.06	0.05	0.06	0.03	0.10	0.05	0.04	0.04	0.03	0.02	
<i>Dry season</i>											
ENCd	0.12	0.12	0.12	0.08	0.08	0.08	0.04	0.04	0.04	0.08	0.30
ENd	0.58	0.47	0.46	0.56	0.44	0.4	0.24	0.35	0.25	0.41	0.32
FLSD <sub>(0.05)</sub>	0.07	0.04	0.06	0.03	0.09	0.03	0.02	0.02	0.01	0.03	

**Table 22** Results of Exchangeable K (Cmol<sub>(+)</sub>kg<sup>-1</sup>) in wet and dry seasons

Study Sites	0–20 cm			20–40 cm			40–60 cm			$\bar{X}$	SE
	2020	2021	2022	2020	2021	2022	2020	2021	2022		
<i>Wet season</i>											
EN Cw	0.33	0.33	0.33	0.42	0.42	0.42	0.29	0.29	0.29	0.35	0.22
ENw	1.65	1.68	1.74	0.92	1.45	1.55	0.91	1.18	1.23	1.37	0.52
FLSD <sub>(0.05)</sub>	0.16	0.25	0.23	0.18	0.15	0.22	0.15	0.17	0.16	0.19	
<i>Dry season</i>											
ENCd	0.40	0.40	0.40	0.38	0.38	0.38	0.19	0.19	0.19	0.32	0.30
ENd	1.00	1.37	1.60	0.82	1.36	1.38	0.64	0.84	1.11	1.12	0.51
FLSD <sub>(0.05)</sub>	0.17	0.21	0.22	0.15	0.19	0.23	0.11	0.17	0.13	0.16	

respective soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm, respectively.

**Effect of waste disposal sites on soil chemical properties**

The values of the parameters at each of the three soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm, according to the seasons and year of study for the three-year study period, are indicated.

At EN study sites, the wet season pH value of  $7.97 \pm 0.70$  and dry season pH level of  $6.94 \pm 1.13$  in the 0–20 cm soil depth profile increased by 43% and 38%, respectively, relative to their control values in the respective seasons. The wet season pH level increased by 14% relative to the dry season value of  $6.94 \pm 1.13$  in the first soil depth profile (0–20 cm). In the soil profile of 20–40 cm, pH levels in the wet and dry seasons increased by 55% and 50%, respectively, relative to their control values. The wet season pH value of  $7.65 \pm 0.70$  was an increase of 14% relative to the pH value in the dry season, in the same depth profile of

20–40 cm. The last soil depth profile of 40–60 cm recorded pH levels of  $7.24 \pm 0.70$  and  $6.63 \pm 1.13$ , which increased by 32 and 59%, respectively, relative to their control values. The wet season pH level in the same soil depth profile (40–60 cm) increased by 9% relative to the dry season pH value of  $6.63 \pm 1.13$  (Table 12).

At the EN study site, in the soil depth profile of 0–20 cm, organic carbon wet and dry season results increased by 259% and 178%, respectively, relative to the respective control values in ENCw and ENCd. In the soil depth profile of 20–40 cm of the same site, wet and dry season OC results increased by 193% and 169%, respectively, relative to their respective controls. In the 40–60 cm soil depth profile, wet and dry season results of OC were also higher by 128% and 136%, respectively, relative to their respective control values. In the three soil depth profiles, wet season OC values increased by 4%, decreased by 24%, and increased by 21%, respectively, relative to dry season OC values (Table 13).

At the EN study site, wet season organic matter results in the three soil depth profiles also increased by 258, 193 and 114%, respectively, relative to their control values of 3.76, 2.93, and  $2.08 \pm 0.81$ %. The dry season OM results also increased by 151, 168, and 132% in the 0–20 cm, 20–40 cm, and 40–60 cm, respectively, relative to the control results. Wet season OM values in the same soil depths increased by 42%, 21%, and 8%, respectively, relative to the dry season OM values of  $1.05 \pm 0.22$ ,  $0.9 \pm 0.22$ , and  $0.82 \pm 0.22$ % (Table 14).

At the EN waste dump site (Table 15), wet season available phosphorus values in the 0–20 cm, 20–40 cm, and 40–60 cm soil depth profiles increased by 294, 267 and 231%, respectively, relative to their control values. The dry season values also increased by 183, 181 and 76% in the respective soil depth profiles relative to their dry season control values. Also, in the three depth profiles at the site, wet season available phosphorus increased by 46, 34 and 110%, respectively, relative to the dry season available phosphorus results. The highest available phosphorus value of 1.84 (mg/Kg<sup>-1</sup>) was obtained in the third year on 0–20 cm soil.

In the soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm at the EN study sites (Table 16), wet season total nitrogen values decreased by 26, 40 and 67%, respectively, relative to their controls in the wet season. In the dry season, mean TN results in the three soil depth profiles increased by 36, 29 and 70%, respectively, relative to the dry season TN control values. The observed wet season TN results in the three soil depths increased by 15, 13 and 29%, respectively, relative to the dry season values of  $0.42 \pm 0.24$ ,  $0.36 \pm 0.24$ , and  $28 \pm 0.24$ %. The increasing order in the values of TN at the 0–20 cm soil depth profile was ENCw > ENd > ENw > ENCd. At the 20–40 cm soil depth profile, the order of increase of TN results was ENCw > ENw > ENCd. And in the last soil depth profile,

the increasing order of mean TN values at the study site was ENCw > ENw > ENd > ENCd. Across the three soil depth profiles, TN values increased in the order of ENCw = ENw > ENd > ENCd.

The Carbon–Nitrogen ratios of  $10.51 \pm 10.56$ ,  $6.98 \pm 1.56$ , and  $5.67 \pm 1.56$ % in the wet season at the EN waste dump site in soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm were increased by 382%, 405%, and 575%, respectively, relative to their control values. These wet season C–N ratios increased by 68, 8 and 14% in the three soil depth profiles, respectively, relative to their corresponding dry season C–N ratios (Table 17).

At the 0–20 cm, 20–40 cm, and 40–60 cm soil depth profiles at the EN waste dump site (Table 18), sodium adsorption ratio values in the wet season increased by 3, 22 and 12%, respectively, relative to the wet season SAR control values in the corresponding soil depth profiles. In the dry season, SAR results also increased by 8, 31 and 12% at the three soil depth profiles, respectively, relative to their controls. The wet season SAR values of  $0.29 \pm 0.24$ ,  $0.44 \pm 0.24$ , and  $0.41 \pm 0.24$ % in the soil profiles 0–20 cm, 20–40 cm, and 40–60 cm, respectively, decreased by 19% and increased by 76% and 51% relative to their dry season control results.

At the EN (Table 19) waste dump site in the wet and dry seasons, at a 0–20 cm soil depth profile, calcium values increasingly changed by 3494% and 3871%, respectively, relative to the control Ca values of  $0.18 \pm 0.24$  Cmol<sub>(+)</sub>kg<sup>-1</sup> and  $0.14 \pm 0.14$  Cmol<sub>(+)</sub>kg<sup>-1</sup>. At the 20–40 cm and 40–60 cm soil depth profiles, wet season Ca values changed increasingly by 2806 and 2712%, respectively, relative to the control values. Wet season Ca results at the site in the three soil depths also increasingly changed by 16, 18 and 26%, respectively, relative to the dry season Ca results. At EN waste dump site, the percentage increase was smaller in each case. For instance, at the soil depth profiles of 0–20 cm, 20–40 cm and 40–60 cm, in the wet season, changes in Ca values were by 84, 104 and 86% increase respectively relative to the control results in the wet period. The dry season Ca results in the same soil depth profile at the same site changed by 85%, 955 and 83% increase respectively relative to the Ca control values of 3.91, 3.11 and 2.81 at the 0.65 Cmol<sub>(+)</sub>kg<sup>-1</sup> in the dry season. The order of change in the values of Ca at the 0–20 cm soil depth profile was ENw > ENd > ENw > ENd > ENCw > ENCd. The increasing order of change at the 20–40 cm soil depth profile was ENw > ENd > ENCd > ENCw. The order of change at the 40–60 cm soil profile was ENw > ENd > ENCw > ENCd. Across the three soil depth profiles, Ca values obtained at the sites increased in the order of ENw > ENd > ENCw > ENCd.

At the EN study site, wet season sodium results at the 0–20 cm, 20–40 cm, and 40–60 cm soil depth profiles increased by 390, 545 and 350%, respectively, relative to their control values of  $0.11 \pm 0.10$ ,  $0.11 \pm 1.10$ , and

$0.14 \pm 0.10 \text{ Cmol}_{(+)}\text{kg}^{-1}$ . Na results in the wet season in the same three depth profiles of the soil increased by 520, 377 and 464%, respectively, relative to their dry season control results (Table 20). The wet season Na values in the same soil depth profiles decreased by 12% and increased by 65% and 75%, respectively, relative to their corresponding dry season Na values.

Magnesium results at the EN waste dump site at the soil depth profiles of 0–20 cm, 20–40 cm, and 40–60 cm increased by 367, 1000 and 600%, respectively, relative to their control results in the wet and dry seasons (Table 21). At the three depth profiles, wet season Mg results decreased by 10% and 17% and increased by 21% at the study site, respectively, relative to the dry season Mg results. At 0–20 cm, 20–40 cm, and 40–60 cm soil depth profiles, the changes in wet season Mg results were a decrease of 17% and an increase of 32% and 14%, respectively, relative to wet season controls. In the dry season, the changes were a decrease of 18% and increases of 9% and 6%, respectively, relative to their dry season values. Changes observed in the wet season Mg values relative to the Mg results in the dry period in the three soil depth profiles were a decrease of 9% and increases of 47% and 42%, respectively.

Potassium values of  $1.69 \pm 0.52$ ,  $1.31 \pm 0.52$ , and  $1.11 \pm 0.52 \text{ Cmol}_{(+)}\text{kg}^{-1}$  obtained in the wet season at the EN waste dump site in the soil depth profiles 0–20 cm, 20–40 cm, and 40–60 cm, respectively, increased by 412, 216 and 283%, respectively, relative to their corresponding control values. In the dry period, similar increases of 240, 202 and 336% were observed in the K results at the waste dump site in the respective soil depth profiles relative to the control K values of  $0.40 \pm 0.30$ ,  $0.38 \pm 0.30$ , and  $0.19 \pm 0.30 \text{ Cmol}_{(+)}\text{kg}^{-1}$ , respectively (Table 22). K results at the EN waste study site at the 0–20 cm, 20–40 cm, and 40–60 cm also increased by 24, 13 and 33%, respectively, relative to their dry season K values. Changes observed in K results at all the study sites at the 0–20 cm soil depth profile occurred in an increasing order of  $\text{ENw} > \text{ENd} > \text{ENCd} > \text{ENCw}$ . At the 20–40 cm depth profile, the changes in K results were in the order of  $\text{ENw} > \text{ENd} > \text{ENCw} > \text{ENCd}$ . At the last soil depth profile of 40–60 cm, the change in values of K was in the order of  $\text{ENw} > \text{ENd} > \text{ENCw} > \text{ENCd}$ . For the three soil depth profiles, K results increased in the order of  $\text{ENw} > \text{ENd} > \text{ENCw} > \text{ENCd}$ .

## Discussion

Bulk density levels at the study locations for waste disposal were considerably ( $p < 0.05$ ) decreased compared to the control data throughout both the wet and dry periods. According to Okolo et al. (2017), the Bd levels increased as the soil depth profile was revealed. The increase in soil volume

brought on by the loosening impact of waste materials may have contributed to the decrease in Bd levels at the waste dump locations. Bd data for the sites showed an inverse relationship with Tp, showing that an increase in soil volume favours Tp. Waste materials were employed by Anikwe et al. (2017), Nnabude and Mbagwu (2019), Mbah and Mbagwu (2019), and Asadu et al. (2020) to decrease Bd and raise Tp. Obasi et al. (2020) similarly showed decreased Bd in waste product-contaminated soils compared to the control. Mullins et al. (2021) also noted that Bd had a beneficial impact on OM and decreased the level of soil compaction.

Increased soil volume brought on by waste may be the reason for the significantly ( $p < 0.05$ ) higher total porosity levels at the waste-affected location of EN in the wet and dry periods compared to the control. Several researchers have shown a significant ( $p < 0.05$ ) increase in Tp in waste-affected soils compared to the control, including Anikwe et al. (2017) and Mbah and Mbagwu (2019). The fact that Tp and Ap values decreased with the depth of the soil profile suggested that the top soil had been disturbed more than the subsoil, which is why Bd had decreased. The wet season's significantly ( $p < 0.05$ ) had higher Tp and Ap values than the dry season may have resulted from the water's assistance in the breakdown of organic matter and opening up soil pore spaces. Organic waste increased Tp and enhanced aeration, resulting in a more favourable environment for plant root extension, growth, and nutrient uptake. Low Tp reduces soil production because it restricts aeration, water retention, and water transport (Mullins et al. 2021).

In comparison to the controls, values of the gravimetric moisture content at waste dumpsites considerably ( $p < 0.05$ ) increased during both the wet and dry seasons. This might be the result of increased soil volume at waste disposal sites, which also led to decreased Bd. GMC and Bd at the locations had an inverse relationship. Numerous researchers have noted increased GMC in waste-affected soils, including Mbagwu and Ekwealor (2020), Nnabude and Mbagwu (2019), who also noted an increase in GMC values with increasing soil depth. Nyamangara et al. (2022) also reported that waste-affected soils had increased moisture retention. Obasi et al. (2020) also noted a range of moisture content values in waste-affected soil from 38.5 to 88.56%. The ability to absorb and retain moisture has an antagonistic relationship with Bd and a direct association with Tp. According to Okolo et al. (2017), GMC values increased with increasing soil depth and decreased on top soil. This is consistent with the study's findings, which showed that wet season GMC results were greater than dry season GMC values. The increase in soil volume during the rainy season may be the cause of the latter.

In comparison to the controls, the waste-affected soils at the study sites had considerably improved pore spaces, which boosted water transfer both during the wet and dry

seasons ( $p < 0.05$ ). Many researchers, including Costa et al. (2017), Edemeades (2019), Wagner et al. (2021), Nwite et al. (2021), Njoku et al. (2021) and Adesodun and Ojeniyi (2022), have shown increased hydraulic conductivity in trash-damaged and/or treated soils. According to the authors, higher Tp and decreased Bd led to an increase in hydraulic conductivity. Water logging was decreased by improved water transfer. Bullock et al. (2022) and Fares et al. (2022) both observed enhanced hydraulic conductivity with decreased Bd and increased Tp in soil. At the disposal locations, hydraulic conductivity decreased as soil depth increased during both the wet and dry seasons. This may be because organic compounds in the soil loosen it, increasing its porosity and ability to absorb water from the surface into the subsurface. Numerous researchers, notably Okolo et al. (2017), have reported that hydraulic conductivity decreases as soil depth increases.

In comparison to the controls, aggregate stability levels at the waste dump locations were considerably ( $p < 0.05$ ) higher during the wet and dry seasons. According to Mbagwu and Ekwealor (2020), OM is known to bind smaller aggregates into larger ones. According to Njoku et al. (2021), an increase in the OM content of waste led to an increase in the total amount of organic chemicals, which in turn led to an increase in the size of soil aggregate. Increased AS was also observed in waste-affected soil, according to Mbah and Nneji (2022), who claimed that OM from waste linked smaller aggregates into bigger ones. In an ultisol at Abakaliki, southeast Nigeria, Nwite et al. (2021) assessed the productivity of soil modified with various animal wastes and noted higher soil aggregate stability in the treated soil. Both Edemeades (2019); Adesodun and Ojeniyi (2022) connected elevated AS to wastes that delivered OC to the soil.

Both seasons saw a predominance of the sand component at the waste disposal facilities. There were few instances of significant ( $p < 0.05$ ) differences in the levels of sand, silt, and clay between the waste dump study locations and the controls. According to Obot and Hanson (2022), the proportion of sand was about the same in the dumpsite compared to the control site, the proportion of silt was higher in the control than the dumpsite, and the proportion of clay was higher in the dumpsite compared to the control. As it is used for soil classification and soil quality evaluation, texture is a permanent attribute of the soil that cannot be changed by any cultural practise, according to Obot and Hanson (2022). Sand particles dominated the study sites. This is in line with FDALR's (1985) report that there is a dominance of sand particles in the southeast due to sand formation from unconsolidated coastal plains and sand stones from the ASU River. FDALR (1987) had linked high sand content to the climate of our region. Variations in particle distribution have been attributed to the alleviation of clay and silt such that a higher sand fraction is left on the soil surface. Ubochi

et al. (2021), in their study of the potentials of solid waste utilisation for agriculture in Imo State, Nigeria, observed that the top soil at the dumpsites was transformed by the solid waste as texture, productivity, and other physical and chemical parameters were improved. The waste disposal site at EN was either loamy sand or sandy loam in all the soil depth profiles. Sandy loam is recommended for its suitability for a disposal site, but fractions greater than 70% are not good since it is highly permeable. Clay and silt fractions greater than 31% are unsuitable for waste disposal as they encourage flooding and pollution. Sandy soils of the tropics, Brady (2021) observed, are susceptible to nitrate, anions, and cations leaching, which promote eutrophication, flooding, and pollution.

In comparison to the control data, the soil pH values at the waste disposal sites during the wet and dry seasons at the three different soil depth profiles were considerably ( $p < 0.05$ ) higher. According to Chinyere et al. (2019), several of the pH levels found at the waste disposal locations were above 7.00, which supported the buildup of heavy metals. The author also claimed that phosphorus was bound as calcium phosphorus at pH levels higher than 7.30, rendering it unavailable to plants. This study corresponds with Isirimah's (2019) observation that an accumulation of organic solid waste lowers acidity. According to Akubugwo et al. (2017), increased microbial activity has been linked to higher soil pH at the waste study locations. The pH values at the study sites for waste were consistent with those of Obasi et al. (2020), Uba et al. (2020), and Elaigwu et al. (2021) and are within the WHO's limit of 6.5–8.5. The pH readings at the control sites likewise matched the range of pH readings for tropical soils reported by Alloway and Ayres (2017). Bhattacharya and Michael (2022) noticed that the non-alkaline characteristics of tropical soils and control sites matched the acidic soil of the area, which is caused by high run-off saturation and the ensuing drop in clay content. According to Lawan et al. (2019), the pH values of the soil decreased as the soil depth profile increased. Their report and the findings of this study were in agreement. The pH levels at the 0–20 cm soil depth profile were higher, according to Oguntimehim et al. (2021), whereas Azeez and Hassan (2021) found the contrary. The amount of heavy metals in soil is more concentrated when the pH or acidity is low. Low pH reduces adsorption, according to Salt et al. (2018) and McBride (2022).

At the waste study locations in both the wet and dry periods, organic matter—the product of the breakdown of organic carbon—increased significantly ( $p < 0.05$ ) in comparison to the control. The findings of Uba et al. (2020) and Obot and Hanson (2022) were supported by higher OM values in the waste dump locations compared to the control. According to Badmus et al. (2022), increased OM values at waste disposal sites were caused by a variety of elements,



including soil microbial activity and the amount of organic waste present. According to Adesodun and Mbagwu (2019), OM increased soil porosity and improved its physical characteristics at waste dump sites. With an increase in the soil depth profile, OM at the study sites for waste decreased. These outcomes are consistent with Okolo et al. (2017) findings. Mullins et al. (2021) showed that OM decreases Bd and the degree of compaction. At the 0–15 cm soil horizon, Ubochi et al. (2021) reported some crucial characteristics that were increased by the presence of a waste dump, including OM, OC, TN, Ca, Mg, Na, and K. OM enhances the structure of the soil and boosts the soil's capacity to retain water. However, Elaigwu et al. (2021) and Azeez and Hassan (2021) found that OM in high quantities led to high concentrations of heavy metals such as Cu, Pb, Zn, and Fe in a waste dumpsite. Improved soil structure also enhances air-pore space and aids in preventing compaction, which decreases soil productivity and yields and limits root growth by preventing water infiltration and air movement in the soil. Alloway and Ayres (2017) claimed that the synthesis of chelates by OM makes metals primary adsorbents and immobile. Significant OM at the top of the soil is a sign of significant chelation activities in some waste materials, according to Okolo et al. (2017). According to Ibitoye et al. (2019), the critical levels of OM in the topical soil are between 15 and 20 g/kg. The amount of organic matter in waste dumpsites rises as a result of waste being decomposed by microorganisms. The greater acid stress at the waste dumpsite compared to the control could be the cause of the high variance in OC values. Due to fast mineralization brought on by high temperatures, OC in tropical soils is low (Asadu et al. 2020). Low mineralization and microbial immobilisation of the nutrients could both contribute to low levels of some metrics that were predicted to be high.

It can be seen that soil phosphorus is linked to organic matter by the significantly ( $p < 0.05$ ) higher values of Av.P at the waste disposal locations during the wet and dry seasons compared to the control. According to Njoku et al., (2021) findings, organic waste material increased the levels of Av.P in the soil; higher amounts of Av.P were found in waste-affected soils compared to the control. Increases in Av. P in waste dump soil compared to the control were confirmed by Njoku et al., (2021). According to Obasi et al. (2020), decomposed rice husk waste also enhanced Av.P in the soil. Wameke and Sinegar (2014), among others, observed improved Av.P values in a waste study site compared to the control.

The first and second soil depth profiles at EN showed significantly ( $p < 0.05$ ) greater values of TN during the wet and dry seasons. This may have been due to increased microorganism activity at waste dumpsites, which accelerated the mineralization of organic matter to release nitrogen. Obot and Hanson (2022) noted this finding and provided a TN value of 0.10.

This report's range of TN values concurred with those of Obasi et al. (2020). According to Biswas and Mukherjee (2021), a high C/N ratio denotes decreased nitrogen levels in organic waste. Biswas and Mukherjee (2021), who also noted that a higher C-N ratio increased the loss of carbon and immobilisation of nitrogen, the volume of nitrogen mineralized was found to have an inverse connection with the C-N ratio, according to Njoku et al. (2021). In keeping with these findings, Njoku et al. (2021) revealed a high C-N ratio at the waste study location in comparison to the control. According to Njoku et al. (2021), a C/N ratio between 11.00 and 20.45 implies that the soil can sustain a variety of plant species. Low C/N ratios were similarly associated with high N contents and a lower rate of organic waste breakdown, according to Njoku et al. (2021).

The three soil depth profiles and wet and dry exchangeable base and cation values across the waste disposal locations were significantly ( $p < 0.05$ ) higher than the controls, indicating that wastes enhance soil exchangeable bases. This finding is consistent with Njoku et al. (2021) studies. Na, K, Mg, and Ca were identified as the primary soil cations by Davies et al. (2018). Brady (2021) noted that these cations contain charges of varied strengths that operate as exchange sites, resulting in antagonistic relationships between the cations and constant competition for space on soil particles. Because of this, a surplus of one substance causes a deficit of another. With levels ranging from 3.00 to 8.30  $\text{Cmol}_{(+)}\text{kg}^{-1}$  across the waste disposal locations, Ca dominated the exchange complex in this study. This is consistent with Obot and Hanson's (2022) report, which found that the mean value of calcium was 4.57  $\text{Cmol}_{(+)}\text{kg}^{-1}$  higher than the average for the cations. Mg and Na critical limits were given as 1.2–2.0 and 0.2  $\text{Cmol}_{(+)}\text{kg}^{-1}$ , respectively, by FDALR (1990). Chinyere et al. (2019) also observed instances of an excess of one cation resulting in a deficit of another cation. According to their own research, Tan (2019) suggested that sufficient bicarbonate and carbonate ions in the soil may interact with soil Ca and Mg to cause a buildup of Na. SAR is the ratio or percentage of sodium in relation to the two other significant bases or cations, Ca and Mg. SAR values for the waste disposal locations in this study ranged from 0.01 to 0.97 throughout both the wet and dry seasons. This signalled a sodium threat because it was above the permitted range of 0.05 to 0.08. Chinyere et al. (2019), Obot and Hanson (2022) noted a low SAR range of 0.02 to 0.03, which is good for the stability of soil aggregates and implies minimal sodium concern. No salinity issues are indicated by SAR results that are within permissible limits.

## Conclusion

The results obtained in this study showed that waste disposal sites improved the quality of the soil. However, the improvement of waste disposal sites on the physical and chemical

properties of the soil altered its fertility by reducing the soil Bd, improving the Tp, Ap, GMC, State of Aggregation, and Hydraulic Conductivity; also, it increased the soil pH (acidity to alkaline), Organic Carbon and Organic Matter, Total Nitrogen, Available Phosphorus, Exchangeable Cations, and slightly increasing SAR. Therefore, the waste disposal sites had a positive effect on the fertility of the soil.

Consequently, no research work has covered Enugu State, southeast zone of Nigeria in the area of “Environmental impact of waste disposal sites on the physicochemical properties of soils.

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## Declarations

**Ethical approval** It does not require ethical approval. The article has not been previously submitted for publication in any publisher. I also has not been published anywhere.

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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