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Comparative Evaluation of Geotechnical Properties of Soil in a Municipal Dumpsite and Undisturbed Land for Use in Foundations (A Case Study of Osogbo, Osun State Capital, Nigeria)

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Abstract

Large volumes of municipal solid waste are generated daily in Osogbo, Nigeria, a rapidly growing city. These wastes, comprising heterogeneous materials, are indiscriminately deposited on soil surfaces, leading to environmental degradation and potential alteration of soil stability and foundation performance. However, limited experimental data exist to support engineering decision-making in the metropolis. This study evaluates the geotechnical properties of soils from five municipal dumpsites and adjacent undisturbed locations in Osogbo. Ten samples were collected, comprising dumpsite soils (A) and nearby undisturbed soils (B), and subjected to laboratory tests including moisture content, specific gravity, particle size distribution, Atterberg limits, compaction, California Bearing Ratio (CBR), shear strength, and in-situ cone penetration tests (CPT). Statistical analysis was performed using ANOVA in R. Results show that waste decomposition generally reduces moisture content and specific gravity, while influencing soil gradation, consistency, and compaction characteristics. Dumpsite soils exhibited higher maximum dry density (MDD), CBR, and shear strength, but were predominantly gap-graded. CPT results indicate the need for deeper foundations to reach competent strata. ANOVA confirmed significant differences among key parameters. The findings highlight the altered geotechnical behavior of dumpsite soils and the potential risks associated with shallow foundations without proper ground improvement, providing valuable insights for waste management, environmental protection, urban planning, and sustainable development in Osogbo metropolis.

Keywords: Municipal Solid Waste, Index Properties, Geotechnical Properties, Dumpsite Soil, Foundation Design

Introduction

Solid municipal waste, which is generated in the thousands of tons in most African countries, contains some chemicals after undergoing several natural processes over long periods and hence tends to have effects on the land on which it is dumped (Besufekad *et al.,* 2020). Most virgin/natural land on the face of the earth possesses different engineering characteristics. These characteristics tend to experience some changes when such lands are exposed to use, say in this case, receiving solid waste permanently over time. The ongoing practices of landfill and uncontrolled waste dumping within or outside of towns/cities have created a series of environmental and public health challenges (Okeke *et al.*, 2019). This challenge is affecting the engineering characteristics of the soil.

In civil engineering, structures such as buildings, highway pavements, culverts, and dams are constructed on the ground so that no damage occurs to the structure due to the failure of the underlying foundation soil (Onyeka *et al.*, 2023). The conventional method of foundation design is based on the concept of soil bearing capacity or allowable bearing pressure. The bearing capacity of the soil is its ability to sustain an imposed load without excessive settlement or shear failure. It is the average contact stress between a foundation and the soil that will cause shear failure in the soil. The maximum contact stress that the foundation can bear is termed the ultimate bearing capacity of the foundation (Manjriker, 2013). A building is generally comprised of a superstructure above the ground and a substructure, which extends from the foundations below the soil. Foundations transfer and spread the loads from structural columns and walls in a building, and asphaltic/surfacing courses and stone base in highway pavement into the soil.

Onyeka *et al.* (2023) explained that foundation failure can affect a structure's overall stability; hence, it is liable to slide, lift vertically, or overturn. The earth beneath the foundation is the most variable of the materials considered in the design and construction of an engineering structure. The allowable bearing capacity of soil should not be exceeded; otherwise, excessive settlement may occur, resulting in serious damage to buildings, pavements, and other of its service facilities, such as the water or gas mains. Adeyemo and Bello (2024) also studied the nature and properties of the soil in landfills and dumpsites and concluded that soil experiences change with season and weather, which act on the waste and produce substances that influence the properties of the soil in the area. It is important to have a geotechnical investigation of the soil under a proposed civil engineering structure, so that variations in the state and the soil properties can be determined (Singh and Uchimura, 2023).

This research aims to assess the effect of solid waste decomposition on the geotechnical properties of the receiving soil. This study aligned with Sustainable Development Goals (SDGs) 3, 11, and 12 (United Nation 2015), as it investigates the effects of solid waste disposal on soil properties, public health, and sustainable urban development. By conducting a comparative analysis of soils from a waste dumping site and a nearby undisturbed land, the research generates scientific evidence that is relevant to environmental protection, informed land-use planning, and the promotion of responsible waste management practices within urban communities such as Osogbo, Osun State, Nigeria. (United Nations, 2015).

Materials and Methods

The study area is Osogbo, the capital city of Osun State, South-western Nigeria, with coordinates of $07^{0}30$’N, $4^{0}30$’E. The materials used in this work are limited to ten samples, five each, designated as sample A (dumpsites) and sample B (undisturbed soil), within/around the Osogbo metropolis. The undisturbed samples were taken 30-50 m away from the dumping sites. Samples were collected at an average depth of 500 mm during the wet season. The samples used for the index properties test are disturbed soil, while those used for the geotechnical test are undisturbed samples. The sample locations for dumpsites are named 1A-5A, while undisturbed samples are named 1B-5B.

Various laboratory investigations of index properties were carried out on the collected sample, including natural moisture content, specific gravity, particle-size distribution, and the Atterberg/consistency tests, according to BS 1377, Part 2 (1990), ASTM D2487 (2017), and AASHTO standards for soil classification. Geotechnical properties test for compaction, CBR, and shear strength test according to BS 1377, parts 4 and 7 (1990), and in-situ cone penetration test according to BS EN ISO 22476-1(2012) were also carried out. The laboratory investigations were performed at the Materials, Structures, and Geotechnical Laboratory, Osun State Ministry of Works and Infrastructure, Aiyegbaju Market, Osogbo, Osun State, Nigeria. Statistical analysis, ANOVA, was conducted on the dataset for comparison of the variance and mean of the results using the programming language, R. Tables 1 and 2 show the dumpsite positions and methods of testing, respectively.

Table 1: Position of dumpsites and the average year of existence of sample locations.

Location	Position	Year of Existence
1	7.80442° N, 4.49598° E	About 15 Years
2	7.80271° N, 4.57355° E	About 10 Years
3	7.77881° N, 4.56202° E	About 30 Years
4	7.76545° N, 4.55553°E	About 20 Years
5	7.77195° N, 4.53605°E	About 30 Years

Figure 1: Map of the study area. (Source: Google Earth Map)

Table 2: Experimental Test and Method of Testing

Test	Method/Standard
Natural Moisture Content	BS 1377 (Part 2)
Specific Gravity	BS 1377 (Part 2)
Particle Size Distribution	BS 1377 (Part 2)
Atterberg Limit	BS 1377 (Part 2)
Compaction	BS 1377 (Part 4)
CBR	BS 1377 (Part 4)
Shear Strength	BS 1377 (Part 7)
Cone Penetrometer(in situ)	BS EN ISO 22476-1

Results and Discussion

The results of the laboratory investigations of the samples are presented below. The results of the natural/field moisture content in Tables 3 show that the soil samples at the solid waste dumping sites have less moisture content compared with the soil in undisturbed land in the surrounding environment.

Sample at location 1A has 3.2 % as compared with 5.3 % for sample location 1B. The same for sample locations 4A and 5A, 4.4 % and 5.0% respectively, and sample locations 4B and 5B, having 4.6 % and 5.4 % in that order. This may be a result of organic materials in the dumping area preventing infiltration/percolation of water into the soil. The amount of water and the water table level are critical factors in decision-making in the design of a foundation for both roads and buildings (Onyeka *et al*., 2023).

Moisture Content

Table 3: Result of Natural Moisture Content for all Sample Locations

Natural Moisture Content (%)	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
Mass of Container(g)	9.1	9.7	9.2	9.3	9.4	9.5	9.9	9.9	9.8	9.6
Mass of Container + Wet soil(g)	28.5	33.5	44.0	36.8	46.2	44.6	41.0	37.5	34.9	33.0
Mass of Container + Dry Soil(g)	27.9	32.3	42.3	35.3	45.5	43.6	39.7	36.3	33.7	31.8
Mass of Water(g)	0.6	1.2	1.7	1.5	0.7	1.0	1.3	1.2	1.2	1.2
Mass of Dry Soil (g)	18.8	22.6	33.1	26.0	36.1	34.1	29.8	26.4	23.9	22.2
% Moisture Content $\frac{\text{Mass of water}}{\text{Mass of dry soil}} * 100\%$	3.2	5.3	5.1	5.8	1.9	2.9	4.4	4.6	5.0	5.4

Specific Gravity

As shown in Table 4, the specific gravity of the soil samples at the dump sites has reduced compared with undisturbed land for sample locations 2, 4, and 5. Samples 2A, 4A, and 5A have a specific gravity of 2.67, 2.35, and 2.40, respectively, and sample locations 2B, 4B, and 5B have a specific gravity of 2.71, 2.69, and 2.72. Sample locations 1A and 3A at dump sites have a specific gravity of 2.85 and 2.44, higher than 2.68 and 2.43 at sample locations 1B and 3B, respectively, at undisturbed land. The changes in the specific gravity have changed the soil types in the locations, as a result of the presence of organic matter and the decomposition process, which reduces the soil weight and particles at the dumping site (Almadhoun, Y.S.M., 2017; Evangelin *et al.*, 2013; Ugwu *et al*., 2018). The changes in soil type are a risk for the choice of foundation in the area.

Table 4: Results of the Specific Gravity of all Sample Locations.

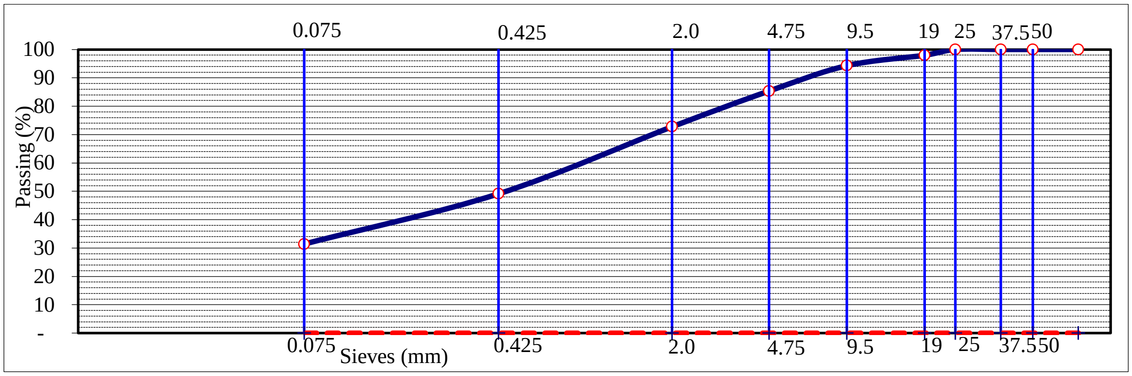
Sample Locations (USCS)	Specific Gravity Test	Soil Type
1A	2.85	Clay and Silty Clay
1B	2.68	Silty Sand
2A	2.67	Silty Sand
2B	2.71	Soil with Mica & Iron
3A	2.44	Organic Soil
3B	2.43	Organic Soil
4A	2.35	Organic Soil
4B	2.69	Silty Sand
5A	2.40	Organic Soil
5B	2.72	Inorganic Clay

Mechanical Sieve/Particle Size Analysis

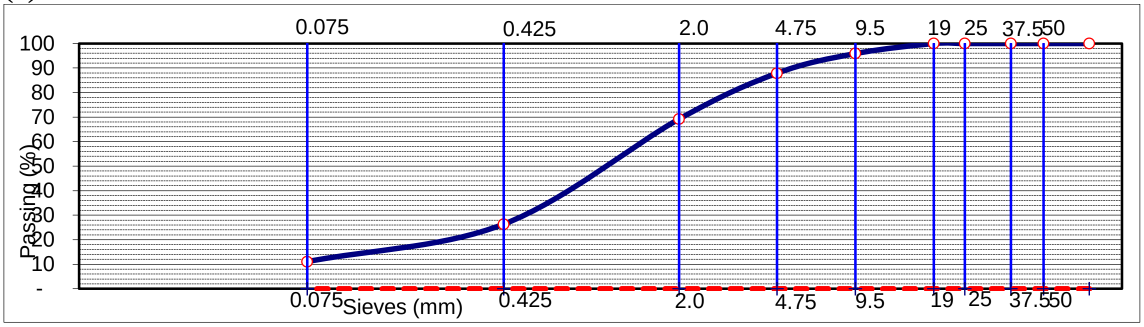
The result of the particle size analysis shows that sample location 1A contains materials that fall into the A-2-6 group according to AASHTO soil classification, i.e. Silt, Clay Gravel, and Sand, generally rated as a sub-base in pavement design, ranging from excellent too good, while soil sample 1B falls into the A-1-b group, containing stone fragment gravel and sand but falls into the same general rating as sub base, excellent to good. It means that the soil grains in the virgin land are better than those of the dumping site area. This result implies that soil from the undisturbed area will perform more effectively when used in road pavement than soil from the dumpsite. The results of samples taken from other locations also agreed with the results of sample location 1, except for location 3, which falls into the same classification A-1-b, as shown in Table 5. The graphs of the results in Figure 2 (a) and (b) show that samples in the undisturbed soil are well-graded, but the samples in the dumping site are gap-graded. This effect could be a result of leachate generated over time that breaks down the grains in the dumping site in a disordered manner.

Table 5: Results of Grain Sizes/Soil Classification of all Sample locations.

Soil Classification (AASHTO)	
1A	A-2-6
1B	A-1-b
2A	A-2-6
2B	A-1-a
3A	A-1-b
3B	A-1-b
4A	A-7-5
4B	A-7-6
5A	A-2-4
5B	A-1-b



(a)



(b)

Figure 2: (a) Graph of percentage passing (%) against sieve sizes (mm) for sample location 1A
(b) Graph of percentage passing (%) against sieve sizes (mm) for sample location 1B

Consistency/Atterberg limit test results

From the results of Table 6, sample locations 1A and 1B, respectively, show that the soil at the dumping site has higher values of each limit than the soil in the surrounding undisturbed land, as liquid limit, L.L of sample 1A is 37.60 % as against 21.26 % of sample 1B. Plasticity limit, P.L for sample 1A is 20.23 % as against 16.12 % for 1B. This implies that samples at the dumping site are more plastic than the undisturbed land in the surrounding environment, as indicated by the plasticity index, P I of sample 1A 17.37 % as against 5.14 % for sample 1B. All other locations' results also agreed with this progression, except for the results of samples in location 4, which were reversed in this case. In this case, sample location 4A has a plasticity index of 13.93 %, which is lesser as compared with 14.86 % of sample location 4B. The increase in Atterberg limit is due to the organic materials present in the waste, which reduces the rate of infiltration/percolation of water into the underground stratum and increases the liquid limit, plastic limit, and plasticity index of the soil in the dumpsite locations (Zhao *et al*., 2023, and Ganiyu *et al.,* 2024).

Table 6: Results of Consistency Limit Test of all Sample locations.

Sample Locations	L.L %	P.L %	P.I %
1A	37.60	20.23	17.37
1B	21.26	16.12	5.14
2A	29.72	17.63	12.09
2B	21.60	15.91	5.69
3A	22.00	17.27	4.74
3B	15.82	12.36	3.45
4A	46.66	32.73	13.93
4B	28.00	13.14	14.86
5A	20.22	13.52	6.70
5B	29.38	24.49	4.89

Compaction Test Result

Table 7 represents the results obtained from the standard compaction test for sample locations 1A to 5B, and it shows that the Maximum Dry Density, MDD, for the dumping site, 2.121 g/cm^{3,} is higher than the value of the virgin land in it surrounding with MDD of 2.119 g/cm^3, for location 1.

Also, the Optimum Moisture Content, OMC, is 5.53 % as against 4.60 % in favor of the dumping site area. Results of other locations and the values of MDD and OMC of all other locations are seen to alternate with each other. For example, while the sample in location 2A has a higher value of MDD, 2.186 g/cm^3 as against 2.132 g/cm^3 for the sample in location 2B, the sample in location 2B has a higher value of OMC, 7.70 % as against 4.29 % for the sample in location 2A. Both the MDD and OMC for the sample in location 3A, 2.048 g/cm^{3,} and 5.24 % are less than the MDD and OMC for the sample in location 3B, 2.835 g/cm^3 and 5.77 %. While the sample in location 4A has a lesser value of MDD, 1.885 g/cm^{3,} as compared with that of the sample in location 4B, 1.988 g/cm^3, the OMC of the sample in location 4A, 8.83 %, is higher than that of the sample in location 4B, 7.36 %. The results of sample locations 5A and 5B aligned with the results of locations 2A and 2B. The reduction in MDD in some dumpsite locations was also observed by Geeta (2019), and this is due to the breakdown of soil particles and weakening of the interconnection forces between the soil, as a result of the decomposition of the waste and subsequent release of leachate (Gyabaah *et al.,* 2024).

Table 7: Results of Compaction Test of All Sample Locations.

Sample Locations	MDD (g/cm^3)	OMC (%)
1A	2.121	5.53
1B	2.119	4.60
2A	2.186	4.29
2B	2.132	7.70
3A	2.048	5.24
3B	2.835	5.77
4A	1.885	8.83
4B	1.988	7.36
5A	2.151	4.11
5B	1.950	6.77

California Bearing Ratio (CBR)

Considering the results in Table 8, sample location 1A for the dumping site has a higher CBR value of 82 as compared with that of sample location 1B for the virgin land in the nearby surroundings with a CBR value of 79. A similar result was obtained for sample location 3A with a CBR value of 60 and Sample location 3B with a CBR value of 29. Sample locations 4A and 4B have the CBR value of 72 and 69, respectively. The results of sample location 2A with a CBR value of 48 and sample location 2B with a CBR value of 75 show that the latter value is higher than the former. A similar result was obtained in sample location 5A with a CBR value of 62 as compared with a CBR value of 70 for sample location 5B. The alteration in the CBR values of the soil is influenced by decomposition and the release of organic and chemical substances into the soil (Ayininuola, 2014).

Table 8: Results of California Bearing Ratio (CBR) Test for all Sample Locations

	California Bearing Ratio Test (%)
1A	82
1B	79
2A	48
2B	75
3A	60
3B	29
4A	72
4B	69
5A	62
5B	70

Shear Strength Test Result

The results show that the samples in the dumping site's area have higher shear stresses and are more cohesive than those of the virgin land in their surrounding areas. The angle of internal friction of samples in locations 1 and 2 also possessed higher values in the dumping sites than in the virgin land, but samples in locations 3 to 5 had greater frictional angle forces at the virgin land than at the dumping sites in the surrounding area. In Table 9, for sample location 1A and 1B respectively, the shear stress, 274.20 kN/m^2 and the cohesion, C, 90 kN/m^2 of sample location 1A is higher than that of sample location 1B of shear stress 258.77 kN/m^2 and cohesion, c of 56 kN/m^2, but the angle of internal friction, Ø, 20^0 of 1A is lower as compared with that of sample location 1B of 25^0. Whereas, the shear stress, cohesion, and angle of internal friction of sample 5A are 294.38 kN/m^2, 80 kN/m^{2,} and 28^0 as compared with sample location 5B with 119.89 kN/m^2**,** 32 kN/m^{2,} and 22^{0,} respectively. This trend in shear strength aligned with the review by Zhao et al (2023). In general, the shear strength of the soil in the dump site area is higher than in the surrounding undisturbed areas, where there's no decomposition process. This is in agreement with Ayininuola (2014). In his work, he concluded that the experimental study showed that the soil properties, such as CBR and shear strength at the dumpsite, were higher than those of adjacent surrounding soils, which shows a positive effect of leachate from decomposed waste and an increase in overburdened pressure on the soil (Oluyomi *et al*,. 2013).

Table 9: Results of Shear Strength (Shear Box) test of all ample locations.

Locations	Shear Stress(kN/m^2)	Cohesion, C (kN/m^2)	Frictional Angle, Ø(^{0})
1A	274.20	90	20
1B	258.77	56	25
2A	826.16	80	24
2B	292.00	49	33
3A	212.47	54	22
3B	155.50	40	18
4A	192.30	38	28
4B	73.59	32	09
5A	294.38	80	28
5B	119.89	32	22

Cone Penetration Test/ Bearing Capacity Test

The results of the cone penetrometer test (CPT) show that the piling up of dumped materials on the site has greatly increased the depth at which a good bearing capacity value can be attained for all the samples. In the summary, Table 10, sample locations 1A and 1B have a depth of 1.50 m and 1.20 m, respectively, to attain the same allowable bearing pressure of 203.11 kN/m^2. Sample location 3A has a depth of 2.20 m to achieve an allowable bearing pressure of 209.08 kN/m^2, whereas sample location 3B in the surrounding environment only reaches 0.70m to attain the same value of allowable bearing pressure.

The same trend was observed in location 4, as the dumping site (4A) and virgin land (4B) have 3.30 m and 0.80 m depth, respectively, to give the same allowable bearing pressure of 227.00 kN/m^2. It implies that there may be a need to change the foundation type sometimes for a particular project, say from strip footing to raft or pile, as the case may be, and this may lead to an increase in the project's overall time of delivery and cost. This finding is in tandem with Otuaga (2015). He explained that the bearing capacity of soil at dumping sites is low at shallow depth.

Table 10: Results of Cone Penetration Test (CPT) of all Sample locations.

Location	Depth (m)	Allow. Bearing Pressure (kN/m^2)
1A	1.50	203.11
1B	1.20	203.11
2A	1.40	209.08
2B	1.30	209.08
3A	2.20	209.08
3B	0.70	209.08
4A	3.30	227.00
4B	0.80	227.00
5A	2.50	209.08
5B	1.80	209.08

Overall Results

Table 11 and Figure 3 show the overall results as discussed in each section above.

Table 11: Overall index/geotechnical parameters of the study area.

Locations	NMC	S.G	L.L	P.L	PI	MDD	OMC	CBR	Shear Stress	C	Ø	Depth	ABP
1A	3.2	2.85	37.60	20.23	17.37	2.121	5.53	82	274.20	90	20	1.50	203.11
1B	5.3	2.68	21.26	16.12	5.14	2.119	4.60	79	258.77	56	25	1.20	203.11
2A	5.1	2.67	29.72	17.63	12.09	2.186	4.29	48	826.16	80	24	1.40	209.08
2B	5.8	2.71	15.82	12.36	3.45	2.132	7.70	75	292.00	49	33	1.30	209.08
3A	1.9	2.44	22.00	17.27	4.74	2.048	5.24	60	212.47	54	22	2.20	209.08
3B	2.9	2.43	15.82	12.36	3.45	2.835	5.77	29	155.50	40	18	0.70	209.08
4A	4.4	2.35	46.66	32.73	13.93	1.885	8.83	72	192.30	38	28	3.30	227.00
4B	4.6	2.69	28.00	13.14	14.86	1.988	7.36	69	73.59	32	09	0.80	227.00
5A	5.0	2.40	20.22	13.52	6.70	2.151	4.11	62	294.38	80	28	2.50	209.08
5B	5.4	2.72	29.38	24.49	4.89	1.950	6.77	70	119.89	32	22	1.80	209.08

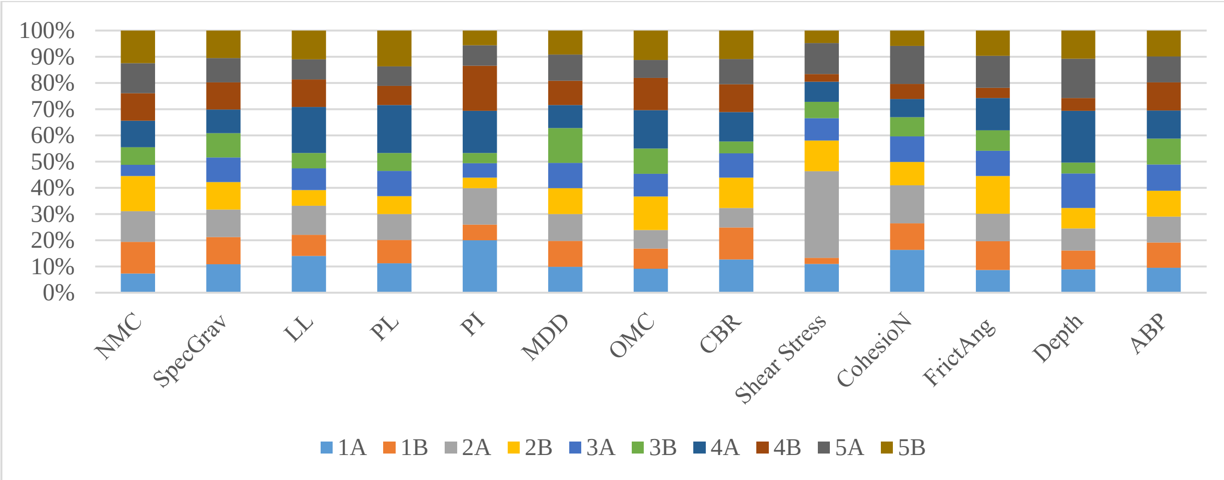


Figure 3: Index/geotechnical parameters of the study area.

Analysis of Variance (ANOVA) Result

Table 12 shows the result of a one-way ANOVA conducted to examine the effect of Location (A vs B) on various soil properties. Most variables, including LL, PL, PI, MDD, OMC, CBR, Shear Stress, Friction Angle, and ABP, showed no significant differences between groups ($p > 0.05$). The statistical analysis indicates that only a subset of the measured soil properties exhibited meaningful variation between the two locations. In particular, cohesion and sampling depth showed statistically significant differences, suggesting spatial variability in shear strength characteristics and subsurface conditions. The lower cohesion observed at Location B implies a reduced inter-particle bonding, which may be associated with differences in soil structure, mineral composition, or degree of saturation. Similarly, the slightly reduced sampling depth at Location B may reflect stratigraphic inconsistency or localized depositional variations.

In contrast, moisture content and specific gravity were notably higher at Location B, indicating a comparatively denser and more water-retentive soil matrix. Elevated moisture content is often linked to decreased effective stress and may partially explain the observed reduction in shear strength. The increased specific gravity at two dumpsite locations, 1 and 3, further suggests the presence of heavier mineral constituents or reduced organic content, which could influence the overall mechanical behavior of the soil. Collectively, these findings highlight that Location B is characterized by soils with higher moisture retention and density but lower shear resistance, which may have important implications for geotechnical performance, particularly in terms of bearing capacity and susceptibility to deformation. The absence of significant differences in other parameters suggests that the variability between the two locations is selective rather than systemic.

Table 12: Result of ANOVA for all locations and soil parameters

Variable	F(1, 8)	p-value	Tukey B–A Mean Diff	Tukey p-value	Significant
NMC	12.34	0.0045	0.95	0.003	Yes
S.G	15.2	0.002	0.10	0.37	No
LL	2.58	0.147	-9.18	0.147	No
PL	1.30	0.287	-4.58	0.287	No
PI	2.11	0.184	-4.61	0.184	No
MDD	0.55	0.478	0.13	0.478	No
OMC	0.68	0.435	0.84	0.435	No
CBR	0.001	0.971	-0.40	0.971	No
Shear Stress	3.09	0.117	-219.95	0.117	No

Variable	F(1, 8)	p-value	Tukey B–A Mean Diff	Tukey p-value	Significant
Cohesion	6.11	0.039	-26.60	0.039	Yes
Friction Angle	0.49	0.502	-3.00	0.502	No
Depth	6.50	0.034	-1.02	0.034	Yes
ABP	0.00	1.000	0.00	1.000	No

Conclusion

The index and geotechnical characteristics of ten soil samples from five locations within the Osogbo metropolis have been critically examined and compared in this research work. Five samples (tagged A's) of soil from the dumping site area that have been in existence for fifteen years or more, and five samples of soil from the nearby surroundings, undisturbed soil (tagged B's). In the end, the soil in the area under study was characterized, and the index/geotechnical characteristics of the soil in the dump site and nearby locations were also determined, and the impact of solid waste decomposition on the receiving soil was inferred. The results show that decomposition changes the soil's engineering behavior, indicated by lower natural moisture content and higher Atterberg limits, which reflect alterations in consistency and plasticity. A decrease in specific gravity at certain locations suggests a modification of soil composition caused by decomposed waste materials. Slight increases in maximum dry density (MDD) and optimum moisture content (OMC) were observed, indicating improved compaction characteristics. The California Bearing Ratio (CBR) values of most dumping site soils meet the Federal Ministry of Works (2016) requirements for sub-base materials, although isolated samples fall below the acceptable limit. Shear strength parameters also increased; however, poor gradation may affect pavement performance. From a foundation perspective, dumping site soils require deeper embedment to achieve an allowable bearing capacity of about 200 kN/m², unlike nearby undisturbed soils. Therefore, a detailed geotechnical investigation is recommended before construction, and the use of deep foundations or ground improvement techniques should be considered where necessary.

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