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Influence of Adding Plant Fly Ash on The Geotechnical Properties and Pollution of Sanitary Landfill Soil

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HIGHLIGHTS

- Using the addition of plant fly ash (dry tree leaves) on the geotechnical properties of the landfill soil.
- Two percentages of plant fly ash (10% and 15%) were used.
- The soil improved with plant fly ash gave results indicating a lower level of heavy metal pollution.
- The results indicated a decrease in the plastic and liquid limits with the addition of plant fly ash, and a decrease in the specific gravity and dry unit weight.

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ABSTRACT

This paper investigates the impact of the plant fly ash (dry tree leaves) addition on the geotechnical properties of the landfill soil, where an engineering laboratory landfill simulating a real landfill was manufactured. Two percentages of plant fly ash (10% and 15%) were used to reduce or prevent the penetration of heavy metals resulting from the decomposition of landfill waste into the soil and conducting laboratory tests such as the Atterberg test, specific gravity test, compaction test, permeability test, SEM test, and heavy metals analysis. The results of laboratory tests indicate a decrease in the plastic limit and the liquid limit with the addition of plant fly ash, as well as a decrease in the specific gravity and a decrease in dry unit weight with an increase in the need for water content when adding plant fly ash. In contrast, the permeability increased with the addition of plant fly ash. In the most important laboratory test, which is the chemical analysis of soil metals, the soil improved with plant fly ash gave results indicating a lower level of metals pollution at depths of (10 cm, 20 cm, and 30 cm) of soil layer compared to natural soil. The analysis was conducted on 7 basic pollutants (cadmium, copper, iron, Manganese, Zinc, Chromium, and lead), where the percentage of pollutants decreased in improved soil compared to natural soil under the same conditions by (50%, 74%, 62%, 68%, 60%, 68%, and 55%) respectively.

1. Introduction

Landfills are a major hazard to surface and groundwater resources, either because of waste products, coming into contact with soil and groundwater underflow, or precipitation penetration [1]. Organic matter (bio-degradable and non-biodegradable carbon), heavy metals, ammonia nitrogen, chlorinated organic and inorganic salts, and inorganic salts may be present in landfills leachate discharge [2,3]. Even though the microorganisms can digest some of those pollutants, the limitations of common biological procedures (degradation is just a part of COD and only limited bio refractory organic pollutants' removal) have made meeting the correlated discharge standard problematic [3]. The addition of solid trash creates several issues, including the possibility of pollutants leaking through the ground from the landfill site and polluting groundwater. Therefore, the proper treatment of leachate and solid waste management should be greatly considered [1-7].

The geotechnical qualities of waste soil were improved so that it can be used for landfill liners. To solve such issues, improvement with plant fly ash such as dried leaves is more successful in clay soils. It improves the bearing capacity of the soil by making it more stable [8, 9]. The engineering features of soil combined with stabilizers were studied in this research through a series of tests. The ideal percentage of additional plant fly ash was then found for each test by Al-Adhamii et al. [10]. The fly ash was mixed with the soil at different percentages by weight of the soil at 10%, 15%, and 20% of dry soil weight. Fly ash was also used as a component in the production of flowable fill and used as the filler mineral in asphalt road laying to fill the voids.

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Furthermore, fly ash is used as a component in geopolymers and Roller compacted concrete dams. When fly ash is treated with silicon hydroxide, it acts as a catalyst [5,6].

The lack of a sufficient bottom liner or collection system in many landfills exacerbates the leachate problem, increasing the risk of leachate dissipation through the waste layers and contaminating groundwater [4]. When it comes into touch with the surrounding soil, surface water, or groundwater, it may cause substantial pollution problems, resulting in negative effects on living organisms. As a result, the landfill liner and soil layers must be chosen to prevent groundwater pollution [1].

The main goal of the present study is to study some important engineering properties of the landfill soil and determine the effect of adding different percentages of plant fly ash to the soil to improve the engineering properties.

2. Experimental Part

2.1 Soil

The soil used in the study was selected from Al-Sada area in eastern Baghdad. It is yellow clay soil. The quality of the clay soil used in the research was chosen due to the need of some cities for sanitary landfill and because the sites where work can be carried out have clay soil, so that soil was chosen to work on it. The samples were taken from a depth ranging between (2-2.5 m) below the natural ground surface. The physical properties are shown in Table 1.

Table 1: The physical properties of the soil

Test		Natural soil	Standard
Atterberg limits	L.L%	43	ASTMD 4318
	P.L%	23	
	P.I%	20	
Specific gravity (G_s)		2.7	ASTMD 854
Maximum dry unit weight (KN/m^3)		17.3	ASTMD 1557
Optimum moisture content, (%)		20	ASTMD 1557
Particle size analysis:			
D_{10}, (mm)		-	ASTMD 422
D_{30}, (mm)		-	
D_{50}, (mm)		0.002	
D_{60}, (mm)		0.05	
	Gravel%	0	ASTMD 422
	Sand%	2	
	Silt%	26	
	Clay%	72	
Passing sieve No. 200 (0.075 mm), (%)		98	ASTMD 422
Classification		CL	USCS

2.2 Plant Fly Ash

Plant fly ash used in the study was collected from the gardens of Baghdad International Airport. The percentage was chosen as 10% and 15% based on [10]. The plant fly ash was burned in an electric furnace at 400°C and ground into fine powder particles as recommended by Al-Adhamii et al. [10], as shown in Figure 1.

Figure 1: Plant fly ash (PFA)

2.3 Scale Lysimeter Design

As a prototype of a traditional landfill system, a scale lysimeter was mounted and worked on researching and understanding the actions of landfill systems. A laboratory-built landfill system with dimensions of 1000 mm width, 1000 mm length, and 1000 mm height and a total volume of 1 m^3 was fabricated, standing on constructed moving wheels as a base field. The moving base was needed for working and handling. The collection was constructed of acrylic sheets with a 10 mm wall thickness and slightly slanted edges. There is a municipal sewage waste MSW sheet between the liner system and the cover system. The longitudinal slope of a drainage pipe with a diameter of 75 mm is 1% to minimize sedimentation and enable sufficient flow capacity. Leachate will be collected or drained through 3 rows. For the laboratory setup, the landfill liner and cover system specifications were reduced according to Ravindranath et al. [11]. The cover system is 1200 mm thick, and the linear system is 1050 mm thick. As a result, the cover and liner systems decreased to 8.3 % and 29 %, respectively, of the requirements stated above. For laboratory investigations, a waste thickness of 5 m was downscaled to 400 mm (8%) from a field thickness of 5 m following Ogwueleka [12]. A 1 mm thick geo-grid has been mounted as a separation layer at the top cover interface, MSW layer, and bottom liner system to prevent soil particles from clogging the drainage layer and mixing materials from different layers. To prevent leachate leakage, the device was also made airtight with silicone gel. The following parts describe the location and properties of the system's different components. The filling and components of the pilot-scale lysimeter are shown in Figure 2.

A 100 mm thick gravel layer with particle sizes that range from 12 mm to 10 mm has been mounted on the pilot system's liner to enable easy leachate to flow into the leachate collection tank. In addition, a 10 mm thick perforated plate was mounted just above the gravel layer to distinguish the liner layer from the leachate collection sheet.

A drainage layer and a compacted clay layer make up the 300 mm thick liner framework. In the liner scheme, locally accessible clay soil has been utilized as a barrier material. To achieve the necessary density at a particular water content, a clay thickness of 350 mm was compacted. The surrounding area, known for its high organic content, supported municipal solid waste (MSW) with a composition consistent with MSW at the point of generation (households).

After shredding the waste to a reasonable size, it was inserted into the pilot-scale lysimeter. In addition, the lysimeter had five side ports for MSW samples, thermocouples sensors, and moisture monitoring. At the top of the lysimeter, layers of compacted clay were given to cover for daily rainfall distribution and protect the outdoor atmosphere from lysimeter effects, such as odor or other pathogen effects.

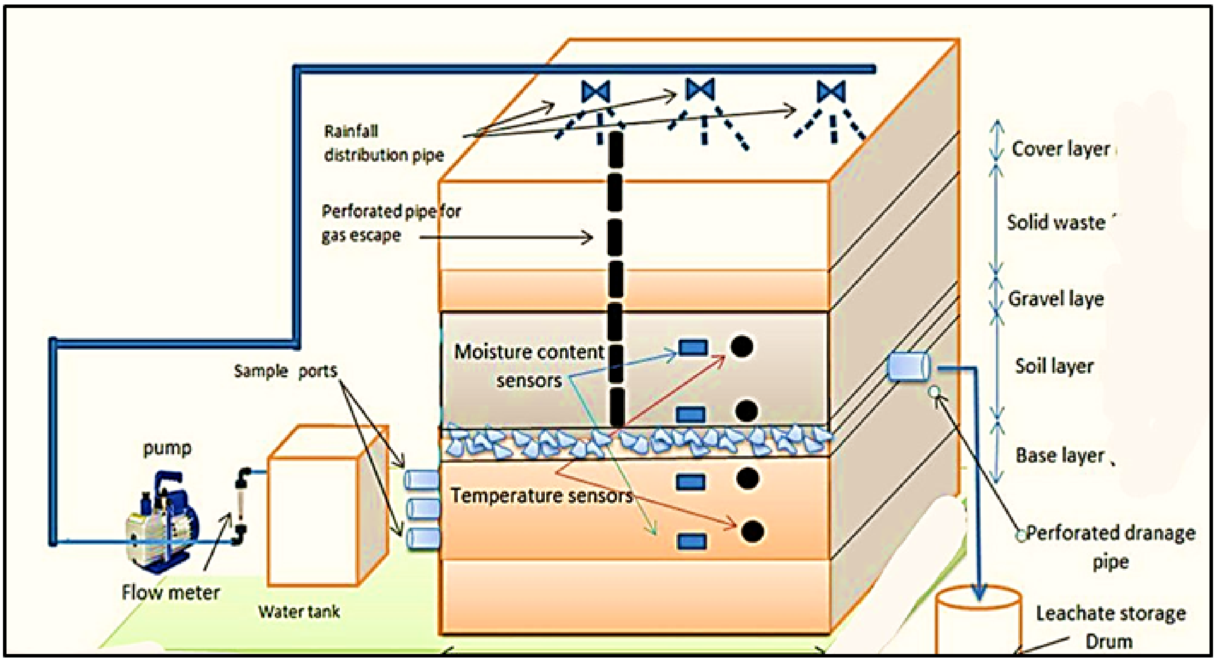


Figure 2: Pilot-scale lysimeter drawing

3. Results and Discussion

3.1 Grain Size Distribution

"ASTM D421-10 and D422-10" specifications were used to conduct the "grain size distribution." Figure 3 shows the grain size distributions before and after adding plant fly ash (PFA) at 10% and 15% by weight of soil. The graph shows the change in particle gradation as the plant fly ash (PFA) percent increases. The gradation curves are close together, indicating that the plant fly ash (PFA) gradation is like the original soil's. The soil becomes somewhat coarser as the plant fly ash (PFA) concentration increases, and the sedimentation time in a hydrometer test lowers somewhat as the plant fly ash (PFA) concentration increases

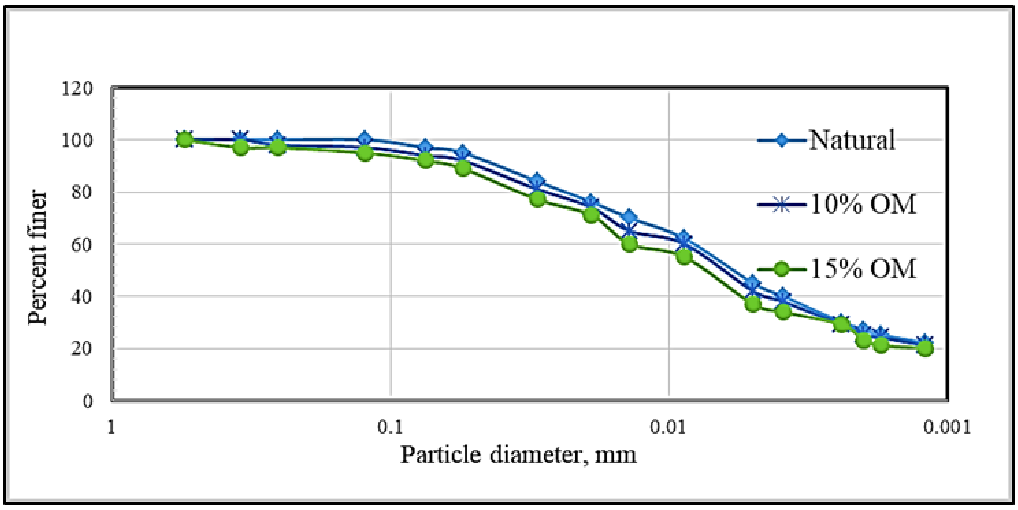


Figure 3: Grain size distribution of the treated and untreated soil

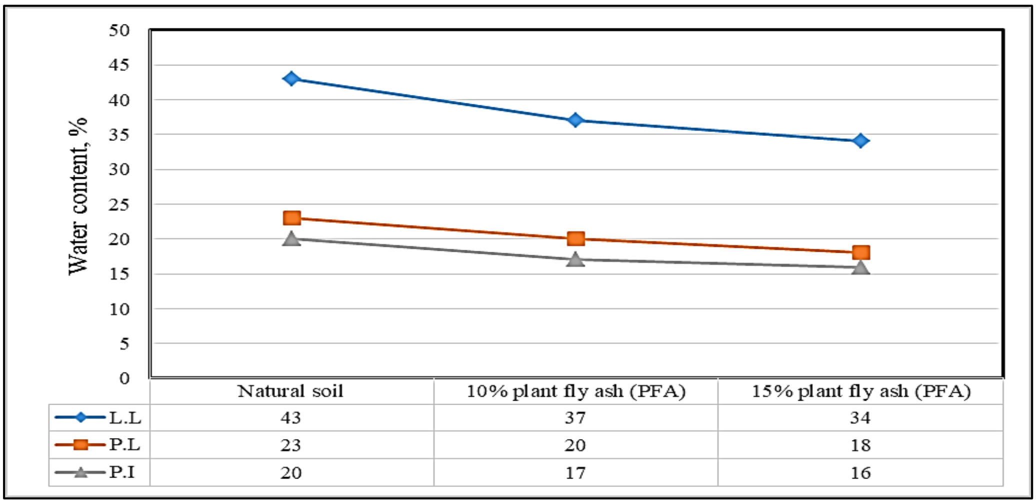


Figure 4: Effect of cement paste and plant fly ash (PFA) content on Atterberg limits

3.2 Atterberg Limits

Plastic and liquid limits, as well as the plasticity index, define Atterberg limits or consistency limits. As soaking conditions change, these limits govern the consistency of the soils [13, 14]. The change in the character of the soil is to blame for the decline in both the liquid and plastic limits, as shown in Figure 4. When the organic matter content increases, both the liquid and plastic limits drop, which can be attributed to the pozzolanic activity associated with the plant fly ash (PFA) (10% and 15%) reaction during the hydration process.

3.3 Specific Gravity (GS)

Figure 5 depicts the specific gravity of soils with various %ages of plant fly ash (PFA) due to the lower density of plant fly ash (PFA). The drop in specific gravity values of the soil with increased plant fly ash (PFA) content is the result of increasing lightweight elements of the same volume. The specific gravity of plant fly ash (PFA) is estimated to be around 2.2.

3.4 Compaction Test

Figures 6,7, and 8 show how the plant fly ash (PFA) presence affects the optimal moisture content (ω_{opt}) and maximal dry unit weight (γ_{dmax}). The (γ_{dmax}) lowers as the plant fly ash (PFA) content rises. However, when the amount of plant fly ash (PFA) content increases, the (ω_{opt}) grows. A drop in dry density could be related to the plant fly ash (PFA) lower specific gravity. In contrast, an increase in the optimal moisture content could be related to the need for water to hydrate, as indicated by [10].

Figure 7 demonstrates that the optimal water content increases at 10% and 15% plant fly ash (PFA). The rise in the optimum water content, despite the lower surface area caused by flocculation and agglomeration, is due to the samples' extra-fine contents, which require more water. In addition, the plant fly ash (PFA) requires even more water to begin pozzolanic processes. Likely, the increase in the optimal moisture level with the application of plant fly ash (PFA) is due to water adsorption by plant fly ash (PFA). According to Haricchane et al. [15], more water is required to compress the soil combinations.

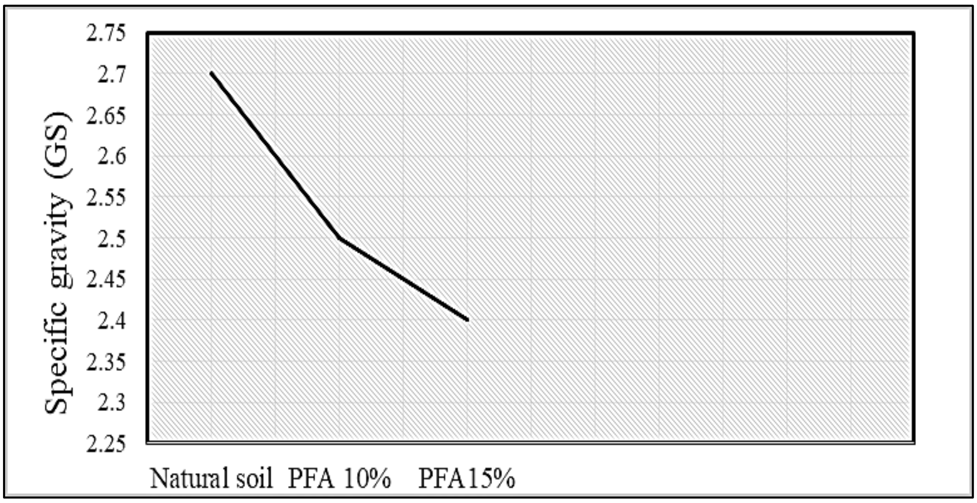


Figure 5: Values of specific gravity for treated and untreated soil

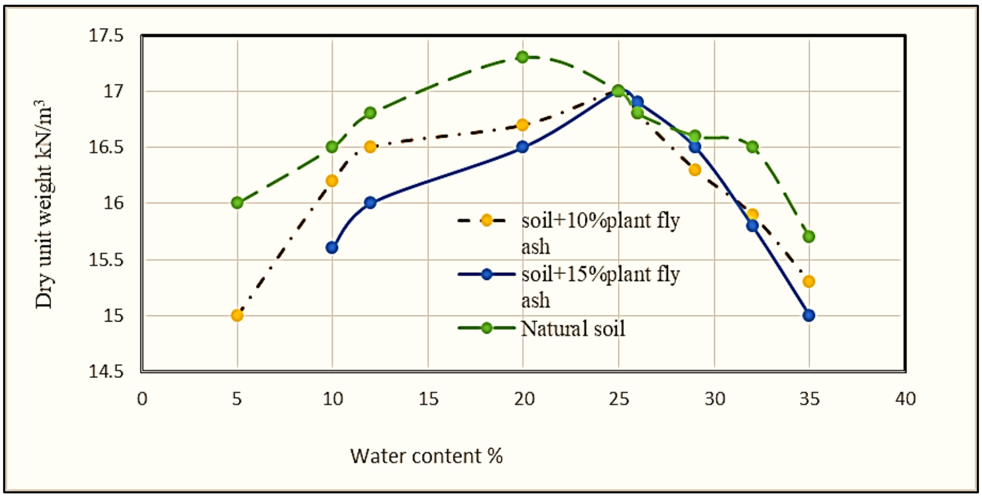


Figure 6: Variation of the dry density with moisture content for different (C/S) and plant fly ash (PFA) presents

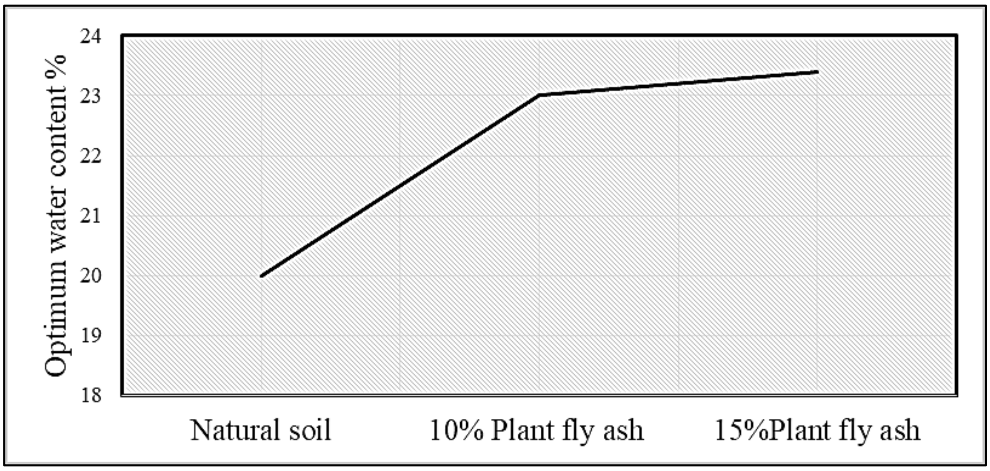


Figure 7: Variation of the optimum water content with different % of additive (C/S) and plant fly ash (PFA) presents

Figure 8 shows that increasing the plant fly ash (PFA) content lowers the maximum dry unit weight from 17.3 to 17 kN/m^3 due to the lower density of plant fly ash (PFA). The drop in the maximum dry unit weight can be attributed to the substitution of soil in the mixture by plant fly ash (PFA), which has a lower specific gravity (2.2) than soil (2.7).

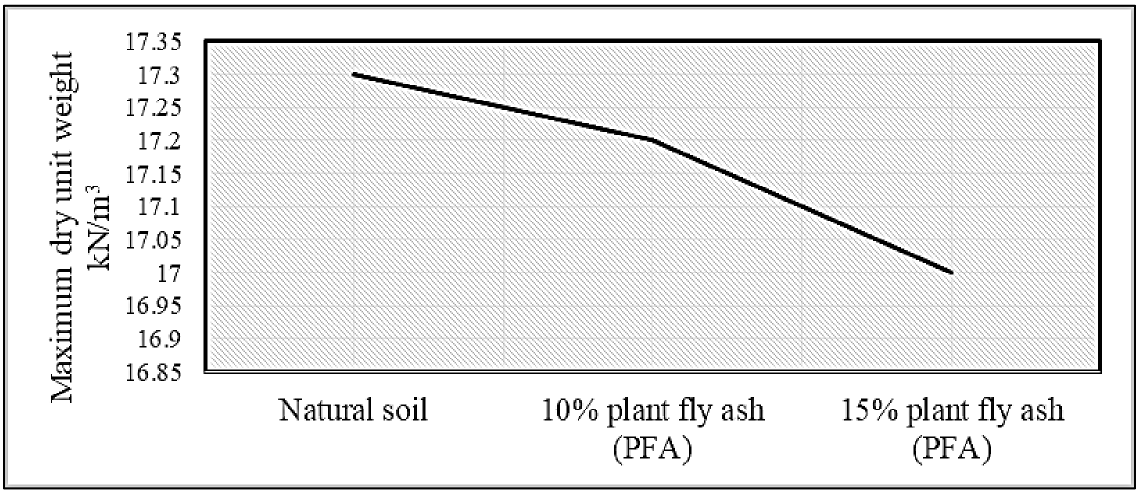


Figure 8: Variation of the maximum dry density for different (C/S) and plant fly ash (PFA) presents

3.5 Permeability

Table 2 shows that when adding 10% and 15% plant fly ash content (PFA) each by dry weight of soil, the permeability changes where the permeability of the dominant soil was 1.15×10-7. The results obtained show that the additional 10% from plant fly ash (PFA) increased the permeability to 5.36×10^{-6}, but when adding 15% plant fly ash (PFA), the permeability goes back to a small decrease to 3.15 × 106-, and this is due to the formation of chemical bonds and aggregation. The addition of a greater amount of plant fly ash (PFA) with soil particles that fill the voids of the composite sample, as well as the chemical reaction between the stabilizing agent (PFA) and the soil material, results in a reduction in the permeability values of the stabilized soil sample. The void ratio lowers as the stabilizing agent is applied in higher amounts to the soil.

3.6 Sem Test

The scanning electron microscope (SEM) showed the morphology of the samples prepared in a high-magnification scanning range ranging from (200-500 nm). As shown in Figure 9, the nanoparticles are in the form of granular aggregates of different sizes, with the appearance of other nanowire-like formations roughly consistent with ural [16].

Table 2: Coefficient permeability of treated and untreated soil

Material + Stabilizer (%)	Hydraulic conductivity, k (m/sec)
Soil (S)	1.15×10^{-7}
S+ 10% plant fly ash (PFA)	5.36×10^{-6}
S+ 15% plant fly ash (PFA)	3.15×10^{-6}

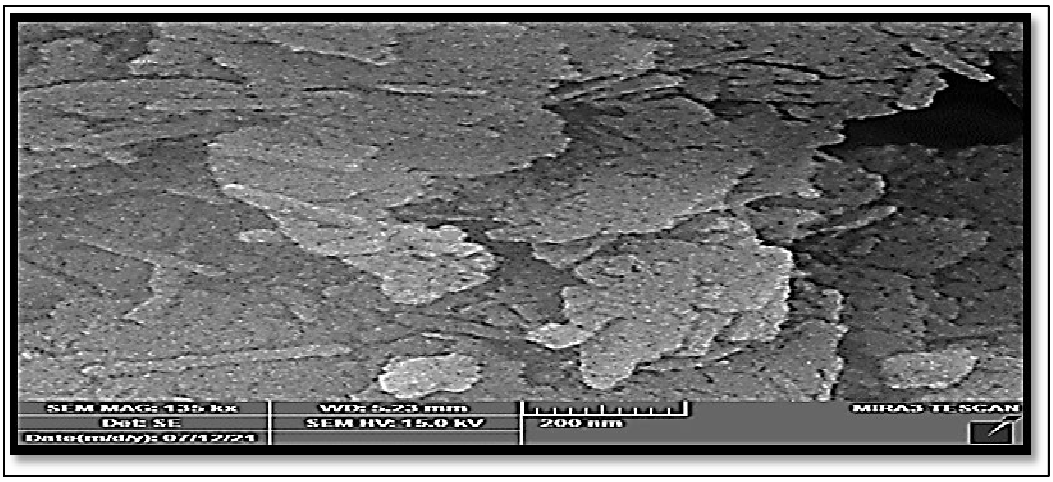
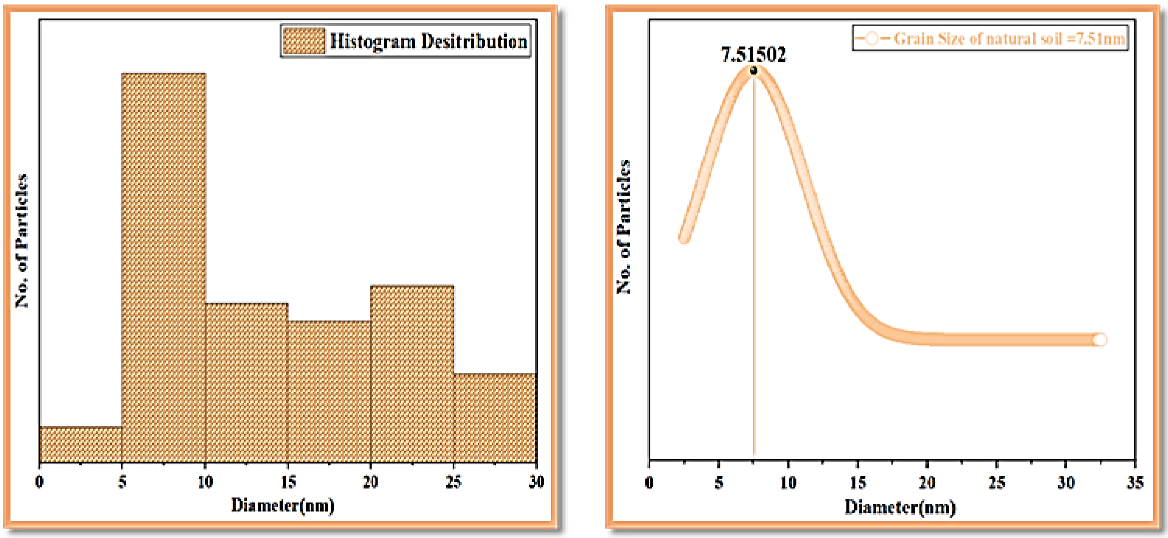


Figure 9: The morphology of the sample grains (natural soil in the scan range of 200 nm)

The grain diameters and the average grain diameter were found using the ImageJ program, and the grain diameters ranged between (2 nm-33 nm). As for the average diameter of the nanoparticles, it was found to be equal to (7.51 nm), as shown in Figure 10. It presents the particle sizes distribution and the granules' average diameter.



A) Distribution of granule sizes. B) The average grain diameter of the sample grains.

Figure 10: Distribution of granule sizes and the average grain diameter of the sample grains (natural soil) in the 200 nm survey range

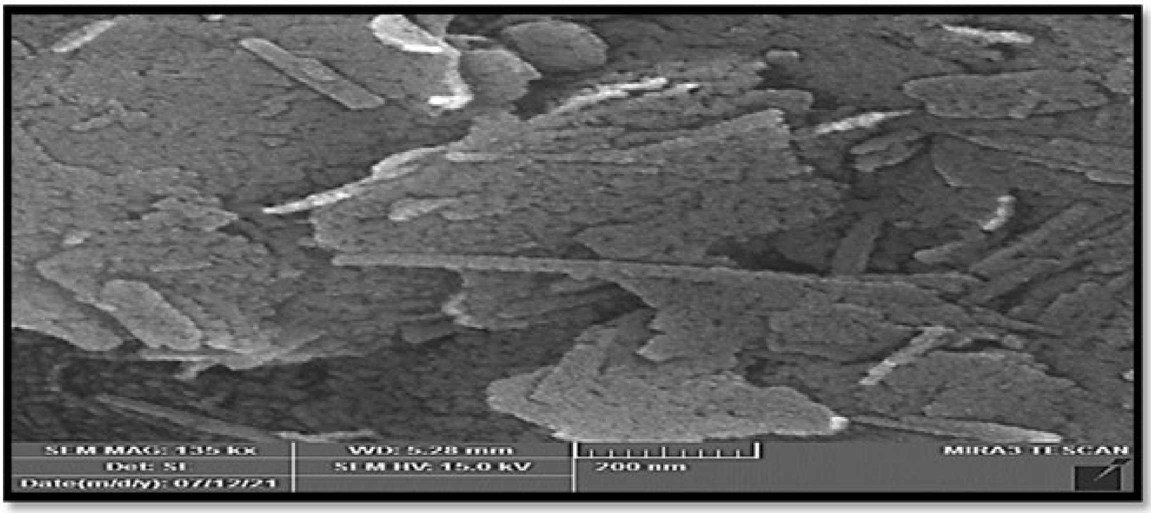


Figure 11: The morphology of the sample grains (10% plant fly ash to soil) in a survey range of 200 nm

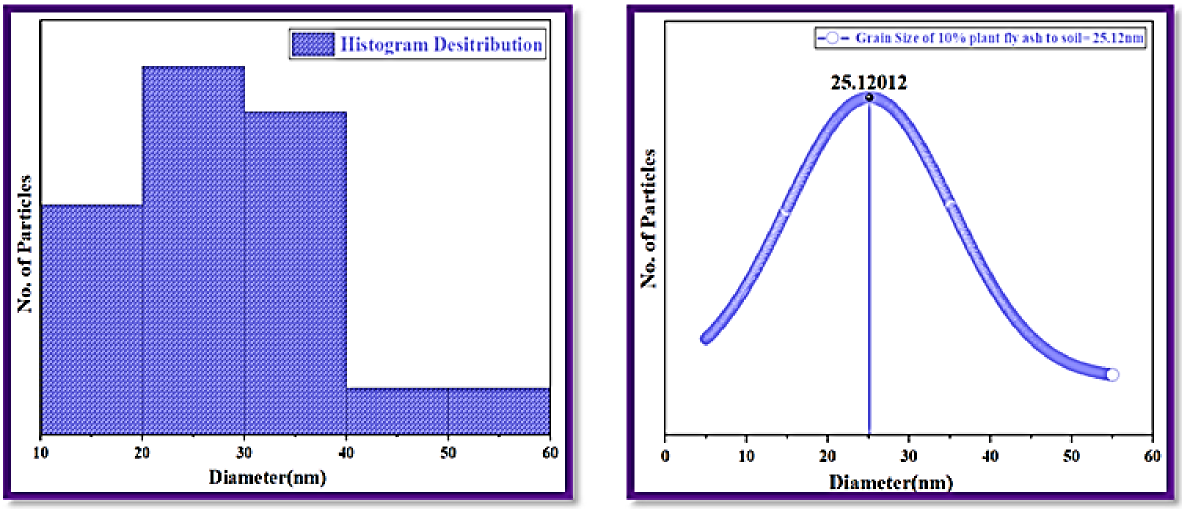
Scanning electron microscopy (SEM) showed the morphology of the sample of 10% plant fly ash to soil prepared in a high-magnification scanning range (200 nm). Figure 11 shows the random and compacted dense distribution of nanoparticles in the form of granular aggregations of different sizes with the appearance of other semi-spherical and rod-like formations nanoparticles, and the growth method of nanoparticles is roughly consistent with [17,18].

The diameters of the particles and the average grain diameter were found using (ImageJ) program. The diameters of the particles ranged between ((5 nm – 55 nm). As for the average diameter of the nanoparticles, it was found that it is equal to (25.12 nm) as shown in Figure 12, which displays the distribution of the grain sizes and the average diameter of the granules.

As for the sample of 15% plant fly ash in the soil, the scanning electron microscope (SEM) showed the sample's morphology, which was prepared in a high-magnification scanning range (200 nm). Figure 13 shows the random and compact dense distribution of nanoparticles in the form of granular aggregations of different sizes with the appearance of other semi-spherical formations. Others are similar to nanorods, and the growth method of nanoparticles is roughly consistent with [18] to [19, 20].

The diameters of the particles and the average grain diameter were found using (ImageJ) program. The diameters of the particles ranged between ((12 nm – 100 nm). As for the average diameter of the nanoparticles, it was found that it is equal to (25.35 nm) as shown in Figure 14, which shows the distribution of the grain sizes and the average diameter of the granules.

Table 3 shows the particle diameters and particle size rates according to the SEM examination of the prepared samples.



(A) Distribution of granule sizes. (B) Average particle diameter of the sample grains.

Figure 12: Distribution of granule sizes and the average particle diameter of the sample grains (10% plant fly ash to soil) in a scan range of 200 nm.

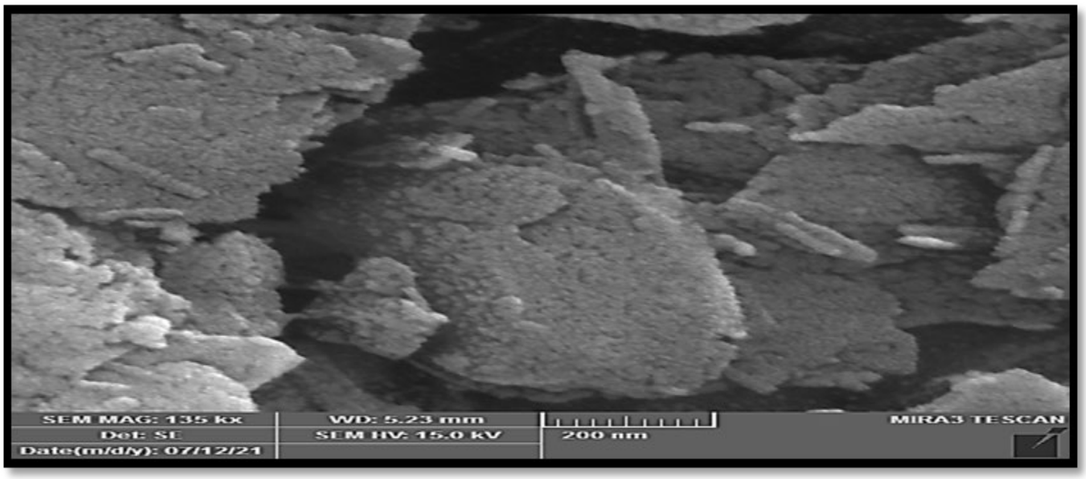
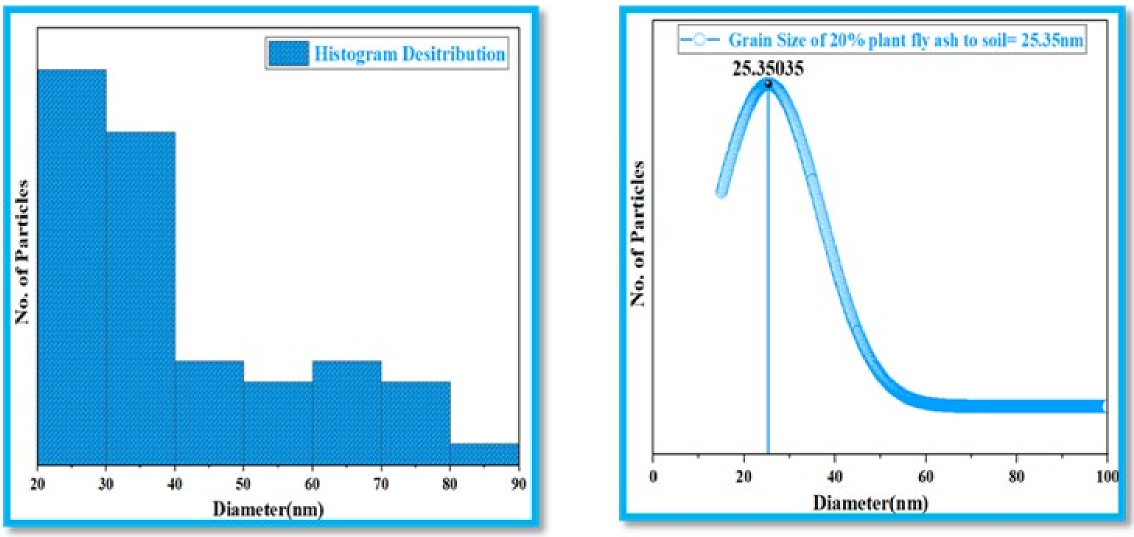


Figure 13: The morphology of the sample grains (15% plant fly ash to soil) in a survey range of 200 nm



(A) Distribution of particle sizes. (B) Average particle diameter of the sample grains.

Figure 14: Distribution of particle sizes and the average particle diameter of the sample grains (20% plant fly ash to soil) in the 200 nm survey range

Table 3: Grain diameters and particle size rates according to FESEM assay for MnO_2 films prepared on porous silicon, silicon and quartz substrates

Sample	Granular diameter range (nm)	granule diameter rate (nm)
Natural soil	2-33	7.51
Soil + 10% plant fly ash	5-55	25.12
Soil + 15% plant fly ash	12-100	25.35

Table 4: Results of EDS for natural soil

Element	Wt%	Wt% Sigma	Element	Wt%	Wt% Sigma
C	18.83	0.52	Cl	0.46	0.04
O	49.82	0.38	K	1.09	0.05
Na	0.48	0.04	Ca	10.92	0.12
Mg	2.22	0.05	Ti	0.36	0.05
Si	12.06	0.12	Fe	3.60	0.13
S	0.16	0.04	-	-	-

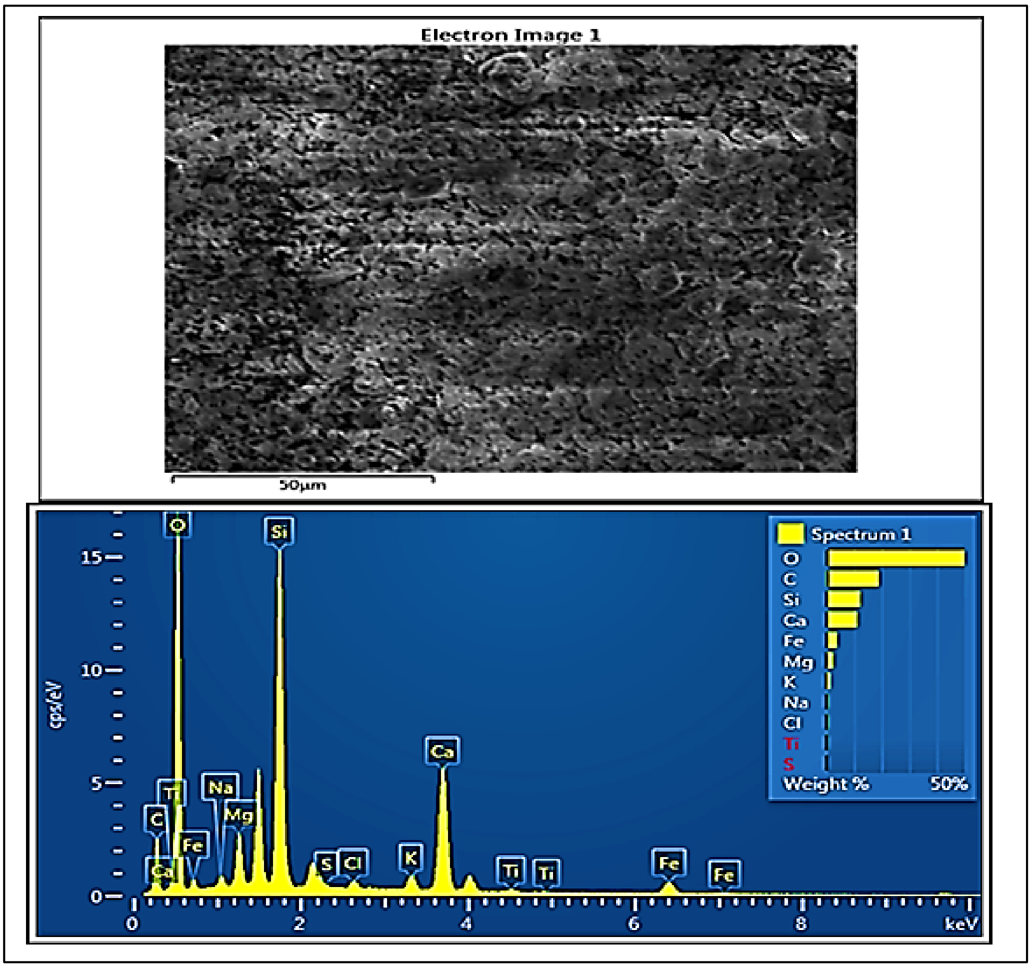


Figure 15: Results of EDS for natural soil

3.7 EDS Test

The test includes samples (Natural soil, Soil + 10% plant fly ash, and Soil + 15% plant fly ash). Test results obtained from the energy–dispersive X-ray Spectroscopy (EDS) are presented in Figures 15 to 17 and Tables 4 to 6. It is noted that the most available ions are calcium and silica.

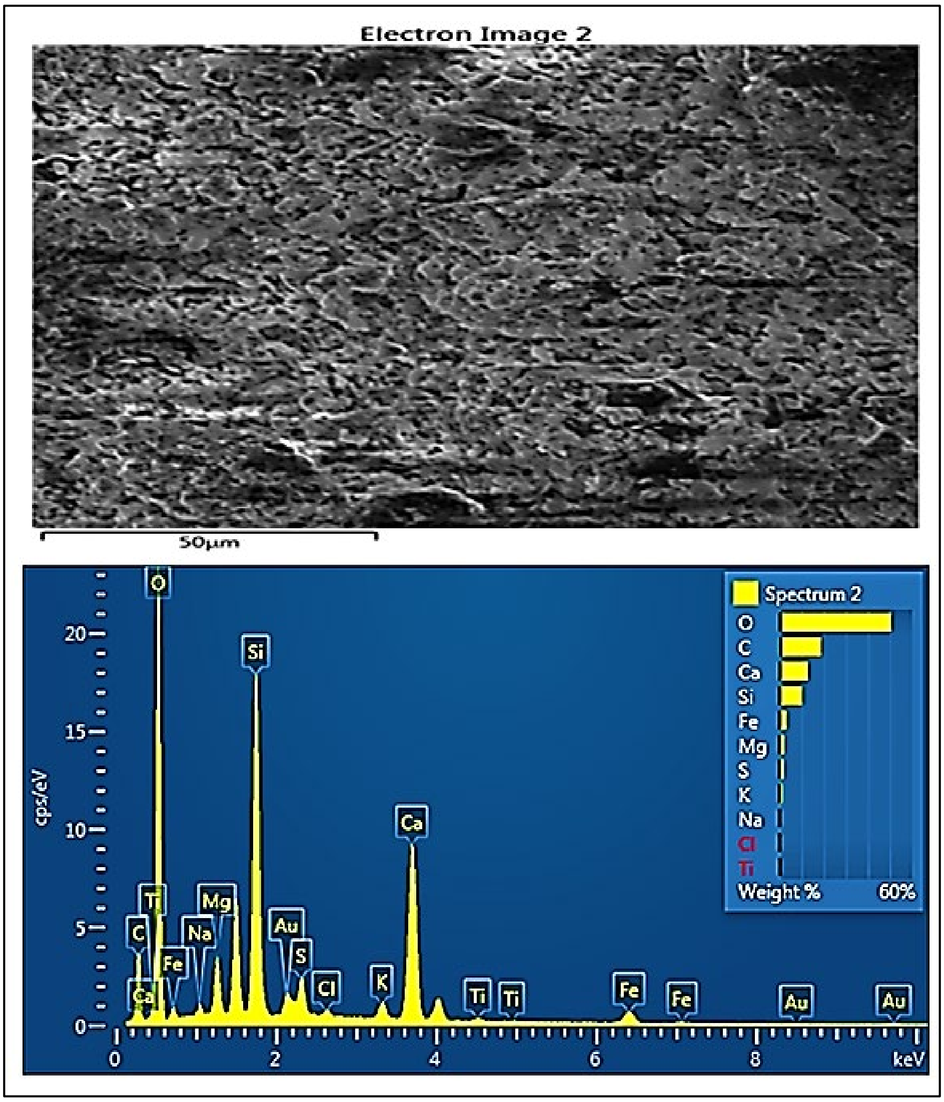


Figure 16: Results of EDS for soil+10% plant fly ash (PFA)

Table 5: Results of EDS for soil+10% plant fly ash (PFA)

Element	Wt%	Wt% Sigma	Element	Wt%	Wt% Sigma
C	18.57	0.50	Cl	0.33	0.03
O	50.36	0.38	K	0.97	0.04
Na	0.39	0.04	Ca	12.62	0.13
Mg	1.92	0.04	Ti	0.33	0.05
Si	10.00	0.10	Fe	2.88	0.12
S	1.62	0.05	Total:	100.00	-

Table 6: Results of EDS for soil+15% plant fly ash (PFA)

Element	Wt%	Wt% Sigma	Element	Wt%	Wt% Sigma
C	19.28	0.47	K	1.15	0.05
O	50.45	0.36	Ca	11.09	0.12
Na	0.38	0.04	Ti	0.31	0.05
Mg	2.23	0.05	Fe	3.87	0.13
Si	10.95	0.10	Total:	100.00	
Cl	0.30	0.03	-	-	-

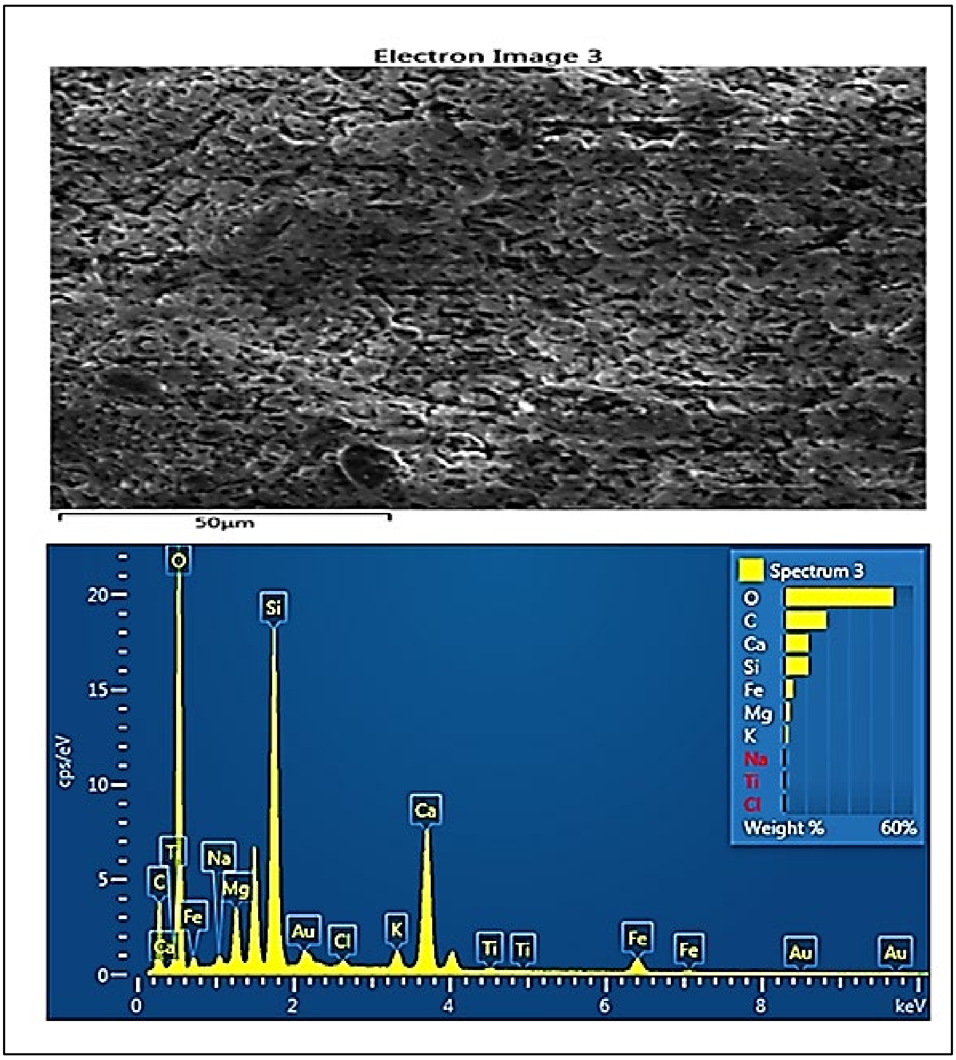


Figure 17: Results of EDS for soil+15% plant fly ash (PFA)

3.8 Chemical Concentration (Heavy Metals) In Soils

Plant fly ash (PFA) reduces leachability by incorporating the heavy metal species in a high pH matrix. Within this high pH matrix, a significant portion of the heavy metal ions is precipitated in their least soluble forms. Suitable plant fly ash control leachability to buffer the leachate that comes in contact with the treated waste. This ability to buffer the leachate is very important since most heavy metal species become increasingly soluble as the pH drops. Generally, the higher the buffering capacity of the waste, the greater the possibility of maintaining alkaline pH conditions, thus minimizing the amount of contaminant release due to dissolution.

The chemical analysis of the test soils passing within leachate at different depths (10 cm, 20 cm, and 30 cm) is discussed herein.

The concentrations of Cd, Cr, Cu, Fe, Mn, Pb, and Zn in the natural soil varied, with Fe having the highest concentration and Cd the lowest. Figure (18A) shows the variation of Cadmium concentration in the untreated (control) soil and treated soil. The low concentration of Cd at the lysimeter landfill, including the control site, may indicate naturally low concentrations of this heavy metal in the soil. In that concentration of Cadmium was found to vary from 0.5 mg/kg to 0.2 mg/kg.

Based on the chart review, approximately (50% on 30 cm depth) reduction in Cadmium concentration was observed with the addition of additives (Plant fly ash) to untreated soil. Maximum reduction in the Cadmium concentration was observed at a distance of 0.3 m depth from the point of application of leachate after 150 days.

The variation of the copper concentration in the leachate test soil is shown in Figure (18B). The concentration of copper was found to vary from 7 mg/kg to 5 mg/kg. Maximum and minimum Copper concentration was observed at depths of 0.2 and 0.3 m, respectively, 150 days after the beginning of the experiment. As well as, when the chemical concentration permeates into the treated (stabilized) soil, decreases in copper concentration have been observed with increasing the maturation period. It reached (74%) at a depth of 30 cm.

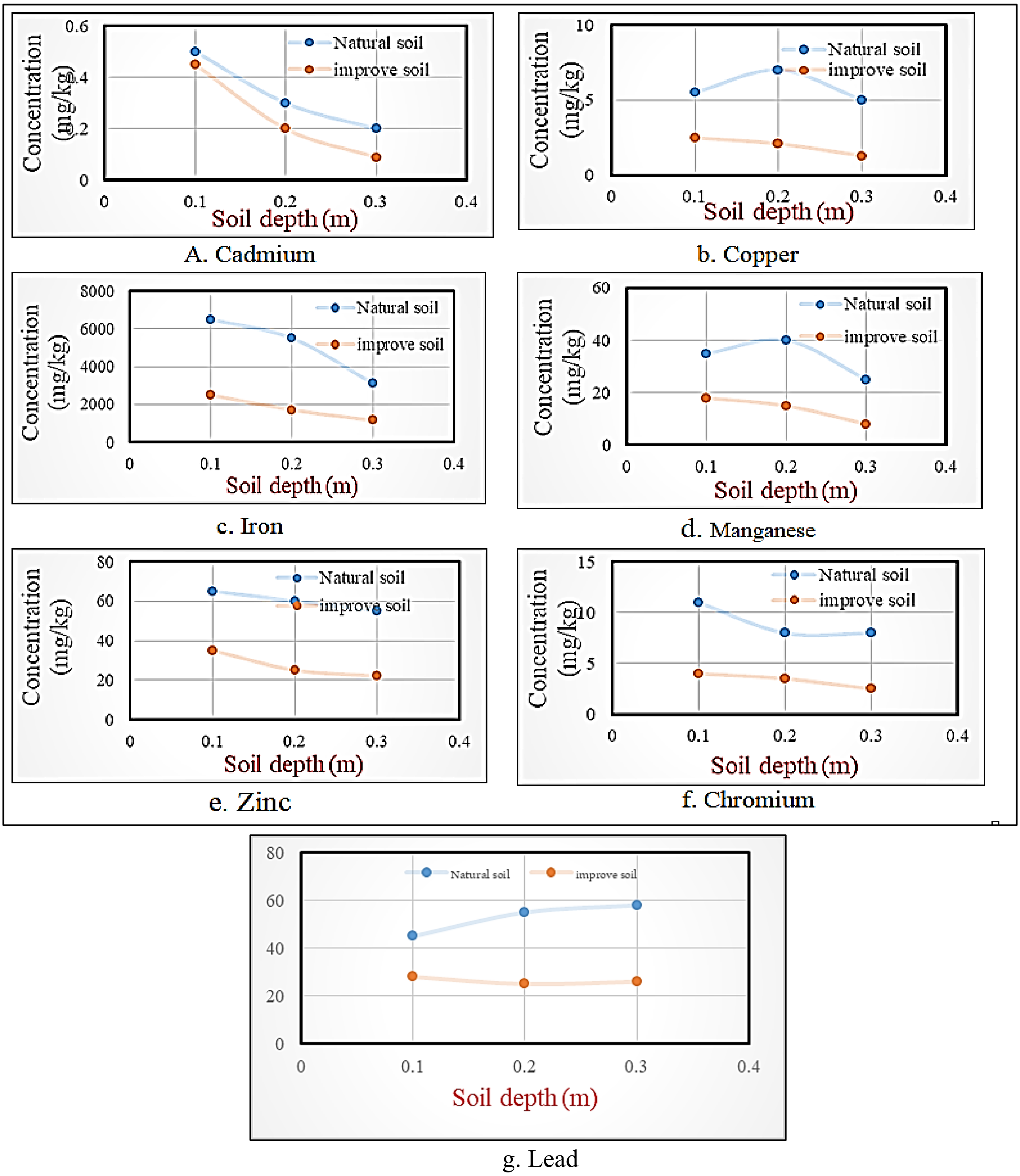


Figure 18: Heavy metal vs. mid-depth of soil samples

Differences were observed in Fe concentrations between treated soil of the landfill lysimeter and those from the control soil. Figure (18c) shows that in the leachate test in untreated soil, the Iron concentration at a depth of 10 cm (6500 mg/kg) was higher than those at a depth of 20 cm (5500 mg/kg). These, in turn, were higher than Fe concentration values for soils at a depth of 30 cm. Maximum quantity of Iron was observed at 0.1 m depth from the point of application of leachate after 150 days. Minimum was at 0.3 m depth after 150 days. As for the treated soil (plant fly ash), a decrease in the concentration of Iron was observed concerning the depth period. It reached (62%) at a depth of 30 cm.

The concentration of Manganese Figure 18d is found to vary from 40 mg/kg to 25 mg/kg, and that of Zinc Figure 18e varies from 65 mg/kg to 55 mg/kg. The maximum concentration of Manganese was observed at 0.2 m depth from the point of application of leachate after 150 days. The maximum concentration of Zinc was observed at 0.1 m depth from the point of application of leachate after 150 days. While in treated soil, there is a gradual decrease in Manganese and Zinc concentration. It reached (68% and 60%) at a depth of 30 cm.

According to Figures 18f and 18g for the soil control test, a change in the concentration of Chromium and lead is observed to vary from 11 mg/kg to 8 mg/kg and 45 mg/kg to 58 mg/kg, respectively. The maximum concentration of Chromium was observed at 0.1 m depth from the point of application of leachate after 150 days, whereas, at 0.3 m depth at the beginning of leachate application, maximum lead concentration is observed. High levels of Cr at the control site compared to the natural soil have also been reported in other landfill site studies [21]. They have been attributed to leachate migration from landfill. It should be remarked here that, the concentration of Pb and Cr at the 10 and 20 cm, and 30 depths, the Pb accumulated more at the 30 cm depth than at the 10 cm depth, whereas Cr was deposited oppositely. These phenomena are due to the great variation in pattern and contamination rates in-depth as a result of pollutant discharge at the source. The fact that the lower strata seem to be more heavily polluted may indicate that pollution at the source is decreased over the years, and vice versa in the Cr.

While for treated soil (plant fly ash), all these chemicals show a gradual decrease in concentration on 150 days maturing period decrease in Chromium and lead concentration It reached (68% and 55%) respectively at a depth of 30 cm.

4. Conclusions

This paper investigates the impact of the plant fly Ash (dry tree leaves) on the geotechnical properties of landfill soil, where an engineering laboratory landfill simulating a real landfill was manufactured. Two percentages of plant fly ash (10% and 15%) were used to reduce or prevent the penetration of heavy metals resulting from the decomposition of landfill waste into the soil and conducting laboratory tests. The following conclusions could be obtained:

1) With increased plant fly ash content, the specific gravity of the soil samples decreased from 2.7 to 2.4.
2) Adding plant fly-ash increased the optimal moisture content while lowering the maximum dry density. For example, the ideal water content rises from 20 percent to 25 percent when plant fly ash is added at 10% and increases to 24.5 percent when plant fly ash is added at 15%.
3) The stabilizer (plant fly ash) reduces the maximum dry unit weight from 17.3 to 17.2, and 17 kN/m3 is validated by the maximum dry density. As a result, the permeability values increased, and adding plant fly ash increased its permeability. Still, it does not cause problems because the additive has a good adsorption capacity.
4) The analysis was conducted on 7 basic pollutants (cadmium, copper, iron, Manganese, Zinc, Chromium, and lead), where the percentage of pollutants decreased in improved soil compared to natural soil under the same conditions by (50%, 74%, 62%, 68%, 60%, 68%, and 55%) respectively.
5) At various depths, key soil chemicals such as iron, Chromium, Cadmium, Copper, Zinc, Lead, and Manganese were examined (10 cm, 20 cm, and 30 cm). The results demonstrated that adding plant fly ash increases the average removal efficiency of Cadmium, Iron, Manganese, Chromium, Copper, and Zinc and leads to concentrations as compared to the natural soil.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

References

[1] A. D. Taylor, J. Ladd, Q. Yu, S. Chen, J. Homola, S. Jiang, Quantitative and simultaneous detection of four foodborne bacterial pathogens with a multi-channel SPR sensor, Biosens. Bioelectron., 22 (2006) 752-758. https://doi.org/10.1016/j.bios.2006.03.012

[2] A. A. Tatsi, A. I. Zouboulis, K. A. Matis, and P. Samaras, Coagulation–flocculation pretreatment of sanitary landfill leachates, Chemosphere, 53 (2003) 737–744. https://doi.org/10.1016/S0045-6535(03)00513-7

[3] A. Uygur, F. Kargı, Salt inhibition on biological nutrient removal from saline wastewater in a sequencing batch reactor, Enzyme Microb. Technol., 34 (2004) 313-318. https://doi.org/10.1016/j.enzmictec.2003.11.010

[4] A. Mojiri, H. A. Aziz, M. A. Zahed, S. Q. Aziz, M. R. B. Selamat, Phytoremediation of heavy metals from urban waste leachate by southern cattail (Typha domingensis). Int. J. Sci. Res. Envir. Sci., 1 (2013) 63-70. http://dx.doi.org/10.12983/IJSRES-2013-P063-070

[5] Z. W. S. Abbawi, Geotechnical properties of expansive soil treated with silica fume, Eng. Technol. J., 31 (2013) 2458-2470.

[6] T. A. Abd, M. Y. Fattah, and M. F. Aswad, Improvement of Soft Clayey Soil by Bio-polymer, Eng. Technol., J.,39 (2021) 1301-1306. http://doi.org/10.30684/etj.v39i8.2053

[7] S. Renou, J. G. Givaudan, S. Poulain, F. Dirassouyan, P. Moulin, Landfill leachate treatment: Review and opportunity, J. Hazard. Mater., 150 (2008) 468-493. https://doi.org/10.1016/j.jhazmat.2007.09.077

[8] H. H. Karim, Z. W. S. Abbawi, and A. H. Jassem, Influence of Fly Ash Addition on Behavior of Soft Clayey Soil, Eng. Technol. J., 38(2020) 698-706. https://doi.org/10.30684/ETJ.V38I5A.426

[9] T. A. Kurniawan, W. Lo, and G. Y. S. Chan, Physico-chemical treatments for removal of recalcitrant contaminants from landfill leachate, J. Hazard. Mater., 129 (2006) 80-100. https://doi.org/10.1016/j.jhazmat.2005.08.010

[10] R. A. J. Al-Adhamii, M. Y. Fattah, Y. M. Kadhim, (2021). Geotechnical Properties of Clayey Soil Improved by Sewage Sludge Ash, J. Air Waste Manag. Associ., 72 (2022)34-47. https://doi.org/10.1080/10962247.2020.1862939

[11] N. H. Ravindranath, P. Sudha, and R. Sandhya, Forestry for sustainable biomass production and carbon sequestration in India, Mitig. Adapt. Strateg. Glob. Chang., 6 (2021) 233-256. https://doi.org/10.1023/A:1013331220083

[12] T. C. Ogwueleka, Survey of household waste composition and quantities in Abuja, Nigeria, Resour. Conserv. Recycl., 77 (2013) 52-60. https://doi.org/10.1016/j.resconrec.2013.05.011

[13] A. J. Alrubaye, M. Hasan, M. Y. Fattah, Improving Geotechnical Characteristics of Kaolin Soil Using Silica Fume and Lime, Spec. Top. Rev. Porous Media Intl. J., 7 (2016) 77-85. https://doi.org/10.1615/SpecialTopicsRevPorousMedia.v7.i1.70

[14] M. Y. Fattah, A. A. Al-Saidi, M. M. Jaber, Consolidation Properties of Compacted Soft Soil Stabilized with Lime-Silica Fume Mix, Int. J. Sci. Eng. Res., 5 (2014)1675-1682.

[15] K. Harichane, M. Chrici, S. Kenai, K. Grine, Use of natural pozzolana and lime for stabilization of cohesive soils, Geotech. Geol. Eng., 29 (2011) 759-769. https://doi.org/10.1007/s10706-011-9415-z

[16] N. Ural, The significance of scanning electron microscopy (SEM) analysis on the microstructure of improved clay: An overview, Open Geosci., 13 (2021) 197–218. https://doi.org/10.1515/geo-2020-0145

[17] A. Binal, The Effects of High Alkaline Fly Ash on Strength Behaviour of a Cohesive Soil, Adv. Mater. Sci. Eng.,(2016). https://doi.org/10.1155/2016/3048716

[18] P. Indiramma, and C. Sudharani, Scanning Electron Microscope Analysis of Fly Ash, Quarry Dust Stabilized Soil, Sustainable Civil Infrastructures, (2017) 284–296. https://doi.org/10.1007/978-3-319-61902-6_22

[19] A. A. Salem, Z. B. Mohammed, M. Y. Fattah, Leachate Properties of Municipal Solid Waste in Laboratory Landfill, Adv. Mech., 9 (2021) 143-150.

[20] D. H. Vu, H. B. Bui, B. Kalantar, X. N Bui, D. A. Nguyen, Q. T. Le, N. H. Do, H. Nguyen, Composition and morphology characteristics of magnetic fractions of coal fly ash wastes processed in high-temperature exposure in thermal power plants, Appl. Sci., 9 (2019) . https://doi.org/10.3390/app9091964

[21] S. Kanmani, and R. Gandhimathi, Assessment of Heavy Metal Contamination in Soil Due to Leachate Migration from an Open Dumping Site. Appl. Water Sci., 3 (2013) 193-205. https://doi.org/10.1007/s13201-012-0072-z