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Study the effect of Industrial Dairy, Textile, Leather and Paper Waste Water on the Engineering and Geotechnical Properties of Fine-Grained Soil

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***Abstract*— *Comprehend and forecasting the engineering characteristics of fine-grained soils is crucial for the practice of geotechnical engineering. Fine-grained soil contamination occurs on a daily basis as a result of industrial development and pipeline or reservoir leaks. Due to the influence of the surrounding condition, substantial damage occurs in the foundations of buildings. The presence of industrial wastewater in the soil contributes to a change in its physical, chemical and mechanical properties, and then negatively affects the foundations of various facilities. In addition to environmental issues such as groundwater contamination, the changing of the geotechnical qualities of polluted soil is a concern. As a result of the concentrations of pollutants resulting from the industrial businesses such as dairy products industry, spinning and weaving factories, paper factories and leather wastewater are extremely high in developing countries. Disposal of untreated industrial waste water is a common problem in these countries. This paper describes an experimental investigation that was conducted to explore the effect of four types of industrial wastewater; dairy (DW), textile (TW), leather (LW) and paper (PW) on the deformational behavior of fine-grained soil. Fine-grained soil was exposed to DW, TW, LW and PW for 2, 4, 6, 8, 12, and 16 months. Four remolded soil groups of samples are generated for this investigation and combined with the four types of industrial wastewater of constant moisture content (70%). The Atterberg limits, plasticity index, specific gravity, free swelling, optimal moisture content (OMC), and maximum dry density ($\gamma dmax$) of each mixture were calculated after 0, 2, 4, 6, 8, 12, and 16 months of mixing soil with industrial waste water. Comparisons were made between the results of four groups of samples.*

***Keywords*— Fine-grained soil. Contaminated soil. Industrial waste water. Geotechnical properties.**

I. INTRODUCTION

Soil pollution stemming from a variety of industrial wastewater byproducts stands as a significant geo-environmental concern, adversely affecting soil quality, groundwater, and the atmosphere. The acceleration of industrialization and urbanization has generated substantial quantities of both solid and liquid waste, consequently leading to extensive alterations in the geotechnical characteristics of soil due to the disposal of wastewater into the ground, as noted in reference [1-2-3]. Incidents of foundation and structural failures attributed to soil contamination and chemical spills have been documented in several reports [1, 2, 3, 4]. Extensive research has shown that various geotechnical properties of fine-grained soils can be influenced by both inorganic and organic contaminants typically present in industrial effluents [5, 6, 7]. To address the needs of diverse engineering applications, it is essential to thoroughly investigate and comprehend the interactions between soil and pollutants, as well as the repercussions of pollutants and industrial effluents on various geotechnical characteristics.

A comprehensive examination of the existing body of literature reveals that, to date, the primary emphasis has been on comprehending how pure chemicals affect commercial soils such as kaolinite and bentonite. There is comparatively limited research available regarding the effects of industrial effluents, especially on natural soils [8,9].

Industrial wastewater can contain hazardous substances that are relatively water-soluble, with examples including those originating from textile, dairy, and leather waste. The contamination of industrial wastewater poses significant risks to wildlife, including the poisoning of apex predators that consume organisms with accumulated wastewater in their tissues. This contamination can disrupt breeding patterns by making animals ill and unable to reproduce.

Despite comprehensive research on the geotechnical attributes of polluted fine-grained soils, there has been limited investigation into the impact of wastewater pollution on the geotechnical properties of such soils [11, 13].

Khan et al. (2017), Stalin et al. (2010), and Easa et al. (2002) have all conducted laboratory testing programs aimed at assessing the influence of wastewater contamination and its time effect on the geotechnical properties and behavior of fine-grained soil [1,6,8]. In Easa et al.'s (2010) study, samples of naturally contaminated groundwater sourced from household wastewater were obtained at the groundwater pumping level. The assessment involved the use of X-ray and conventional chemical testing to determine the concentration of toxins present in the groundwater [14]. The research findings suggest that residential wastewater is considered the predominant source of groundwater pollution due to its extremely hazardous and toxic chemical composition [15,16]. This contamination poses a substantial threat to public health. Additionally, a separate study highlighted the capacity of clay to expand as a result of fluctuations in water content, which can be induced by groundwater, leading to upward pressure on foundations. The expansion of clay and the resulting swelling pressure can result in substantial damage, including the cracking of walls, beams, and columns, particularly when the soil's swelling pressure exceeds the foundation load [17,18,19].

The thorough prediction of soil geotechnical parameters is a critical practice in geotechnical engineering, particularly in the presence of contamination [20]. Soil characteristics are altered as a result of ground pollution, Soil property changes cause a variety of geotechnical issues such as structural cracks, ground settlement, heaving of structures, slope instability, depletion of strength and deformation characteristics, changes in compaction characteristics, and so on.

Previously, the adequate attention of construction damages was attributed to many factors such as inadequate construction material, differential settlement, the destructive role of expansive and collapsing soil, etc. While, the effect of waste water on soils was taken as second or third reason of building and construction problems [8].

Recently, progressive increasing of constructions damage caused due to effect of waste water on soil was reported by engineers and investigations [21-24] So, engineers are concerned about the amount of damage caused by waste water to buildings, foundations, and soils.

On the other hand, if the chemical composition of the water in the pores of the clay is changed, the physical and mechanical properties of the clay are expected to change. Thus, the pore fluid type and composition strongly affect the engineering behaviour of most soils especially clayey soils [25-27].

Furthermore, several investigations have shown that, the pollution of soil has important influence on the physical and mechanical properties of clay [28, 29].

Hence, modern building necessitates not only a prior examination of the foundation material, but also a complete understanding of the processes that cause the changing of soil qualities over the life of the structures supported by it.

Kirov (1989) observed the influence of wastewater on deformation behavior of clayey soil, He found that soils interacting with a solution of detergents undergo a large amount of deformation. Srivastava et al. (1992) observed increase in consistency limit, permeability and coefficient of compression and decrease in shear strength and bearing capacity of a soil specimen permeated with fertilizer plant effluent[29,30].This is due to decrease in cation content and increase in hardness of leaching water after interaction Decrease of liquid limit and plasticity index of montmorillonite soil due to addition of pharmaceutical effluent to the soil has been found due to decrease of dielectric constant by contamination. Yaji et al. (1996) have investigated the influence of sugar mill liquid wastes on the behavior of shedi soil. At large percentages of sugar mill liquid wastes, shear strength decreases [31].

Generally, industrial wastes contain acids, alkalis, sulphates, salts, urea (amides), and oil pollutants, which cause changes in the physicochemical, mechanical and geotechnical properties of the soil. Several case studies of soil contamination with industrial pollutants and their impact on soil geotechnical behavior are presented below. El-Kasaby, A., Easa, A.F (2023) and El-Kasaby, A., Easa, E.M (2023).

The Problem Scope

The danger arises from industrial wastewater, which poses a real threat to the soil, groundwater, and the mechanical behavior of fine-grained soil. The effect of industrial spread throughout Egypt on fine-grained soil has not been studied, engh, the researchers try to identify the properties of contaminated soil to avoid potential risks and also to use contaminated soil beneficially in civil engineering projects.

II. EXPERIMENTAL STUDY

According to a comprehensive review of the literature, studies on the influence of industrial wastewater of dairy, textile, leather and paper effluent on natural soils are infrequent or scarce. The wastewater used in this case originated from four separate sources. The first originated from Dairy factory in Minya Governorate, the second from Textile factory in Obour City, Qalyubia Governorate. The third came from tanneries in Ain Al-Sirah, Cairo, and finally from a paper factory, Islamic company in Quesna, Menoufia Governorate These potentially hazardous wastewaters, whose environmental consequences necessitate continuing monitoring, were collected after solids deposition but before treatment. According to a critical review of the literature, considering the foregoing, the four types of industrial wastewaters; dairy, textile, leather and paper wastewater, which are referred to as DW, TW, LW, and PW respectively, were chosen for the current investigation. Natural fine-grained soil used in this research was obtained in a natural phase from a soil excavation site for the construction of a residential building in the village of El-Kom Al-Ahmar, Shibin El-Qanater, Qalyubia governorate, Egypt, **Fig. (1).**

The various effluents in "as collected form" as well as the outflow from the experimental setup, i.e., pH, alkalinity, total solids, total dissolved solids (TDS), total volatile solids (TVS), chloride, and biochemical oxygen demand (BOD) were estimated to be characterized by the effluent parameters. The metrics are complete and adequate for describing the effluent and understanding its impact on the specified soils. The parameter analysis method was carried out in accordance with Standard Methods. The properties of dairy (DW), textile (TW), leather tanneries (LW) and paper (PW) effluent are listed in **Tables (1), (2), (3) and (4)**. Representative soil samples from the chosen regions were collected in 150 kilograms airtight polythene bags, transported to the lab, and stored in airtight containers under normal conditions and keep at laboratory temperature until usage.

Fig.1: Site of soil sample

Table. 1: Physical properties of wastewater (DW, TW, LW and PW)

Properties	Value			
	DW	TW	LW	PW
Color	light yellow	greenish grey	translucent	grey
Temperature (C)	22	24	21	23
PH (Value)	10.3	11.80	9.9	11.4
Total Suspended Solids (TSS), (mg/liter)	2772	2684	1913	2314

Table. (2). Organic properties of wastewater (DW, TW, LW and PW)

Properties	Value (mg/liter)			
	DW	TW	LW	PW
Volatile Suspended Solids (VSS)	985	1217	1683	1122
Biological Oxygen Demand (BOD)	686	912	821	1308
Total organic carbon (TOD)	284	448	336	677
Chemical Oxygen Demand (COD)	4513	3876	2757	6881
Oil &Grease	174	266	378	125
Phenol	8.5	9.7	11.5	9.2
Detergents	17.5	22.4	11.7	25,7
Pesticides	2.4	7.5	9.2	6.4

Table. (3). Chemical properties of wastewater (DW, TW, LW and PW)

Properties	Value (mg/liter)			
	DW	TW	LW	PW
Chloride (Cl-)	2942	1968	3764	1997
Sulfate (SO42-)	757	3827	2843	1719
Alkalinity (CaCO3)	176	868	473	574
Ammonia (NH3-N)	65	162	267	157
Phosphate (SO43-)	4.5	17.7	10.2	19.5

Table. (4). Chemical minerals of the samples (DW, TW, LW and PW).

Properties	Value (mg/liter)			
	DW	TW	LW	PW
Aluminum	0.20	0.40	0.25	0.15
Chromium	1.05	1.80	1.55	2.15
Copper	0.05	1.70	2.4	1.8
Iron	2.45	0.55	1.65	1.4
Lead	0.11	1.25	3.65	0.75
Manganese	1.80	7.2	11.6	9.1
Nickel	0.02	2.73	6.80	4.55
Borne	0.06	4.82	2.80	2.76
Selenium	0.12	0.58	0.57	0.75
Fluoride	10.85	8.73	4.65	12.52
Zinc	0.00	3.70	5.60	7.25
Arsenic	0.07	0.11	0.17	0.08
Cyanide	0.01	1.87	2.10	2.23
Mercury	0.001	0.057	0.057	0.068
Cadmium	0.03	0.063	0.088	0.075

III. EXPERIMENTAL SET-UP AND SOIL SAMPLE PREPARATION

Experimental program includes four groups, each with six contaminated soils (TW or DW or LW or PW) in addition to natural soil for comparison. These groups were constructed after mixing and according to the timeline. Each set of soils under consideration was generated and used for the following purposes:

1. Samples were collected from the site and stored in the laboratory.
2. Since each effluent was utilized to investigate how industrial waste materials affected the mechanical and geometric qualities of natural soil at different ages. As a result, only four sets of polluted soils were used for research purposes. Soil tests were conducted 2, 4, 6, 8, 12, and 16 months after the date the contaminant was added to the soil.
3. Total of 25 samples were used to study the influence of four effluents (TW, DW, LW and PW) on natural soil (S1). A 10-kilogram soil sample is manually mixed with effluents at their water content (70%) before being transported.

Scanning electron microscopes (SEM) and X-ray diffraction (XRD) were also utilized to examine the mineral compositions of natural and polluted samples [DW6, TW6, LW6 and PW6] that was, 16 months after the date of adding the pollutant. These techniques are available at Egyptian Mineral Resources Authority's Central Laboratories Sector's. The experimental program was developed in order to determine the swelling behavior of the tested soils in addition to tests for liquid limit (L.L), plastic limit (P.L), shrinkage limit (S.L), specific gravity (GS), and finally the standard Proctor test.

IV. RESULTS AND DISCUSSION

4.1 Physical Properties

4.1.1 Atterberg's limits

Atterberg's limits contains of liquid limit (L.L), plastic limit (P.L) and shrinkage limit (S.L). The obtained results of L.L, P.L and S.L, **Fig. (5), (6) and (7),** plasticity index (PI=LL-PL) **Fig. (8),** in addition to that **Table (5)** contains results of Atterberg's limits and specific gravity (GS) **Fig. (9).** According to these findings and the unified soil classification system (USCS) as listed in Table 5.

Based on the liquid limit results:

- Values of the liquid limit (for all contaminated soils) decrease as the duration of the contamination effect increases. But soil exposed to industrial wastewater from paper is more affected than soils exposed to other pollutants.
- There was a disturbance in the liquid limit (L.L) values, with the increase of contamination effect period for soil that had been contaminated by textile wastewater.
- The natural soil's plastic limit (PL) value was 33%. While the relative levels of contamination (PL) of soil with textile wastewater (TW) are ranged from 34.5% to 33%. The PL of soil contaminated with dairy effluent (DW) ranged from 32% to 27%, the PL of soil contaminated with leather wastewater (LW) ranged from 33% to 29% but the PL of soil contaminated paper wastewater (PW) ranged from 35% to 41%.

According to the plastic limit results:

- For soil that had been contaminated by Dairy (DW) and leather wastewater (LW), the plastic limit values were decrease with the increase of contamination effect period.
- There was a disturbance in the Plastic limit (P.L) values, with the increase of contamination effect period for soil that had been contaminated by textile wastewater.
- The soil that had been contaminated by paper wastewater (PW), the plastic limit values were increase with the increase of contamination effect period.
- The shrinkage limit (SL) of natural soil was 18%. While the (SL) values of soil that has been contaminated with textile wastewater (TW) range from 19.2% to 20.5%. The (SL) results of soil contaminated with dairy effluent (DW) were 19% to 21%, respectively. the SL of soil contaminated with leather wastewater (LW) ranged from 19% to 25% but the SL of soil contaminated paper wastewater (PW) ranged from 21% to 26%.

Related to the shrinkage limit (SL) results:

- the shrinkage limit (S.L) values increase with the increase in the duration of the pollution effect until 6 months have passed, then at effect period 8, 12 and 16 months, the samples were broken, for soil that had been contaminated by Dairy (DW) and textile wastewater (TW).
- For soil that had been contaminated by leather waste water (LW), the shrinkage limit (S.L) values increase with the increase in the duration of the pollution Up to 16 months.
- the shrinkage limit (S.L) values increase with the increase in the duration of the pollution effect until 8

months have passed, then at effect period 12 and 16 months, the samples were broken.

- The plasticity index (PI) of natural soil was 41%. While the (PI) values of soil that has been contaminated with textile wastewater (TW) range from 27.5% to 30%. The (PI) results of soil contaminated with dairy effluent (DW) were 36.5% to 35%. The PI of soil contaminated with leather wastewater (LW) ranged from 38% to 33% but the PI of soil contaminated paper wastewater (PW) ranged from 29% to 16%.
- According to the results of plasticity index (PI) for soil that had been contaminated by Dairy (DW) it was decrease with the increase of contamination effect period until 2months have passed, then at effect period 4, 6,8,12 and 16 months, there was stability in the values of the plasticity index.
- For soil that had been contaminated by (TW) and (LW) the plasticity index (PI) values were decrease with the increase of contamination effect period until 6months have passed, then at effect period 8,12 and 16 months, after that they increased slightly.
- The soil contaminated by paper waste water (PW) values were decrease with the increase of contamination effect period.

Table. (5). The results of Atterberg's limit for natural soil and contaminated soil with TW, DW, LW and PW at different time (Months).

Effect Period		LL %	PL %	PI %	SL %
O Si		74	33	41	18
2 Months	TW (%)	62	34.5	27.5	19.2
	DW (%)	66.5	32	36.5	19
	LW (%)	71	33	38	19
	PW (%)	64	35	29	21
4 Months	TW (%)	62	35	27	20.5
	DW (%)	65	30	35	20
	LW (%)	68	32	36	20
	PW (%)	62	36	26	23
6 Months	TW (%)	62.5	35.5	27	20.5
	DW (%)	64	29	35	21
	LW (%)	65	30	35	21
	PW (%)	60	37	23	25
8 Months	TW (%)	63	35	28	Broken
	DW (%)	63	28	35	Broken
	LW (%)	63	30	33	23
	PW (%)	59	38	21	26
12 Months	TW (%)	63	34	29	Broken
	DW (%)	62.5	27	35	Broken
	LW (%)	62.5	29	33.5	24
	PW (%)	58	39	19	Broken
16 Months	TW (%)	63	33	30	Broken
	DW (%)	62.5	27	35	Broken
	LW (%)	62.4	29	33	25
	PW (%)	57	41	16	Broken

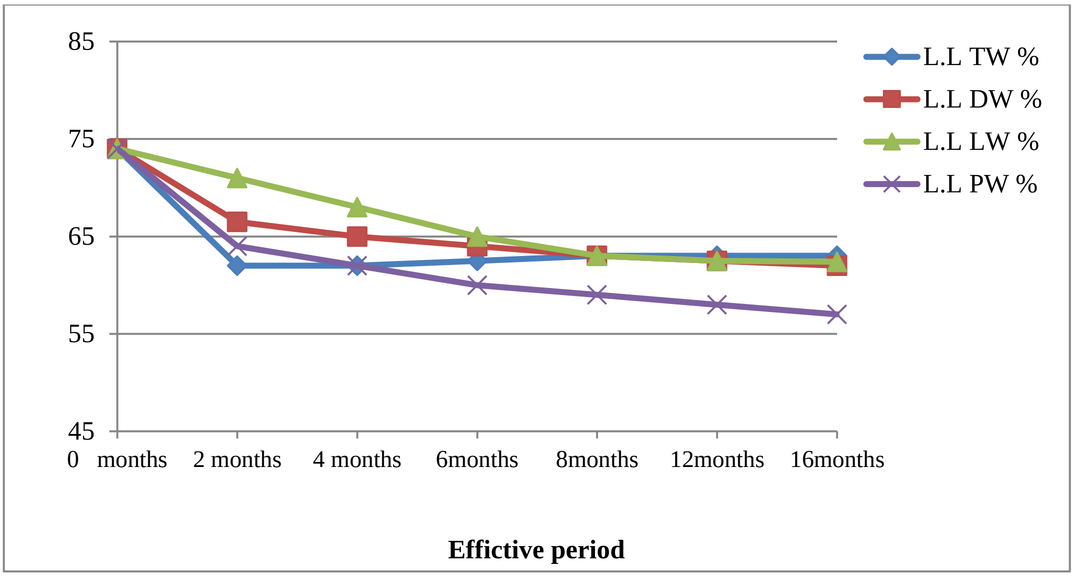

Fig. (5). Comparison between the liquid Limit results with ageing of exposure for TW, DW, LW and PW.

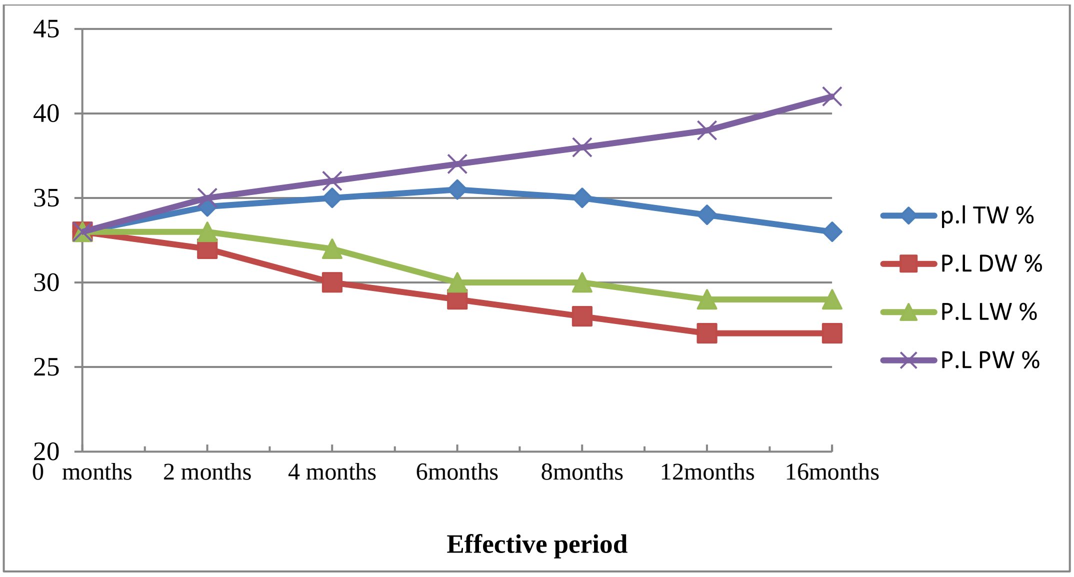

Fig. (6). Comparison between the plastic Limit results with ageing of exposure for TW, DW, LW and PW.

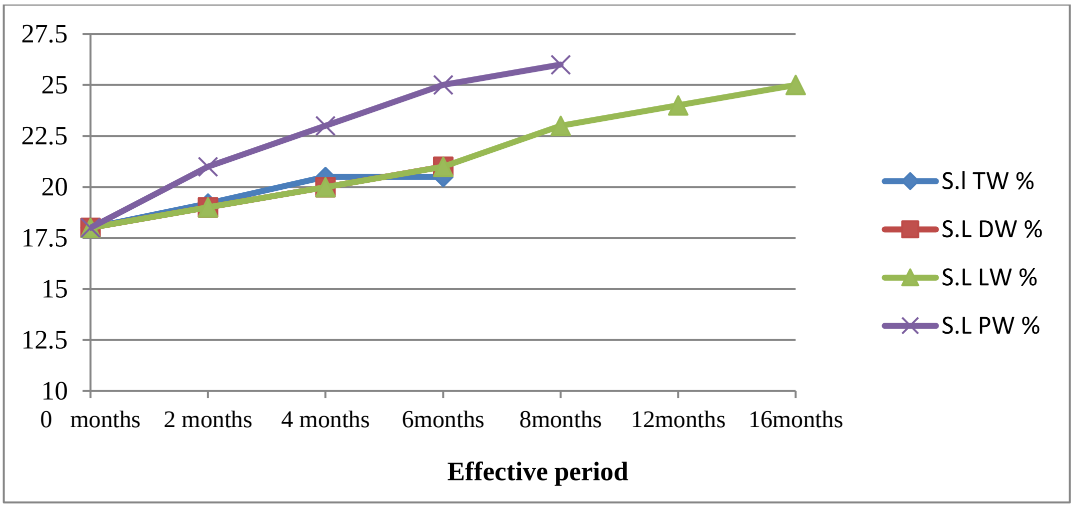

Fig. (7). Comparison between the (SL) values with ageing of exposure for TW, DW, LW and PW.

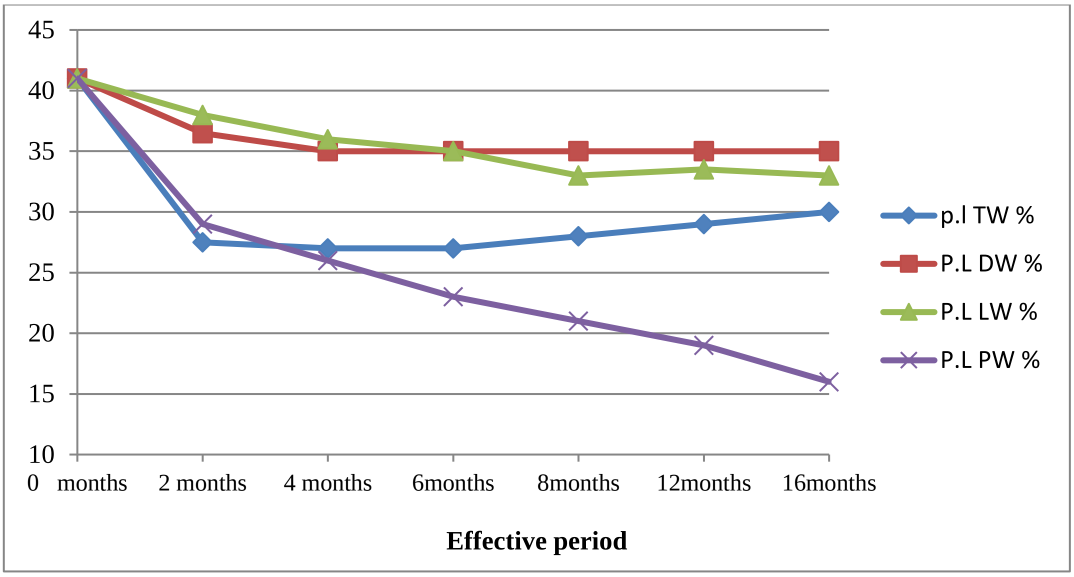

Fig. (8). Comparison between the plasticity index values with ageing of exposure for TW, DW, LW and PW.

According to these findings and the unified soil classification system (USCS) as listed in **Table (6):**

- The natural soil, which is categorized as silty clay with high plasticity (CH-MH).
- The contaminated soil samples for textile wastewater (TW) and industrial paper wastewater (PW) were classified as silt with high plasticity (MH) in the effect periods 2, 4, 6 and 8 months, but at 12 and 16 months, the (PW) classified as silt with low plasticity (ML) based on the impact of industrial wastewater as per the unified classification system (USCS).
- According to the effect of dairy wastewater (DW) was classified as clay with high plasticity (CH), while soil samples contaminated with leather wastewater (LW) was classified as (CH-MH) in 2 months and 4 months, and classified as clay with high plasticity (TH) in the effect periods 6, 8, 12 and 16 months.

Table (6). Classification of contaminated soils according to the unified soil classification system (USCS)

Effective Period	0 Months (S1)	2 months	4 months	6 months	8 months	12 months	16 months
TW	CH-MH	MH	MH	MH	MH	MH	MH
DW	CH-MH	CH	CH	CH	CH	CH	CH
LW	CH-MH	CH-MH	CH-MH	CH	CH	CH	CH
PW	CH-MH	MH	MH	MH	MH	ML	ML

- The specific gravity (GS) of natural soil was 2.67. While the specific gravity (GS) values of soil that has been contaminated with textile wastewater (TW) range from 2.65 to 2.6, (GS) values for soil contaminated with dairy effluent (DW) were 2.6 to 2.565, (GS) values for soil contaminated with leather wastewater (LW) range from 2.656 to 2.6 and finally (GS) values for soil contaminated with paper wastewater (PW) range from 2.65 to 2.58, **Table (7).**

According to the specific gravity (GS) results:

- For all contaminated soil with the different industrial waste water the (GS) values were decrease with the increase of contamination effect period. But soil exposed to industrial wastewater from dairy (DW) is more affected than soils exposed to other pollutants.

Table (7). The results of specific gravity for natural and contaminated soil with TW, DW, LW and PW at different times (months)

Effective Period	0 months	2 months	4 months	6 months	8 months	12 months	16 months
GS TW	2.67	2.65	2.635	2.63	2.61	2.61	2.6
GS DW	2.67	2.6	2.6	2.58	2.577	2.57	2.565
GS LW	2.67	2.656	2.65	2.644	2.634	2.6	2.6
GS PW	2.67	2.65	2.63	2.62	2.6	2.585	2.58

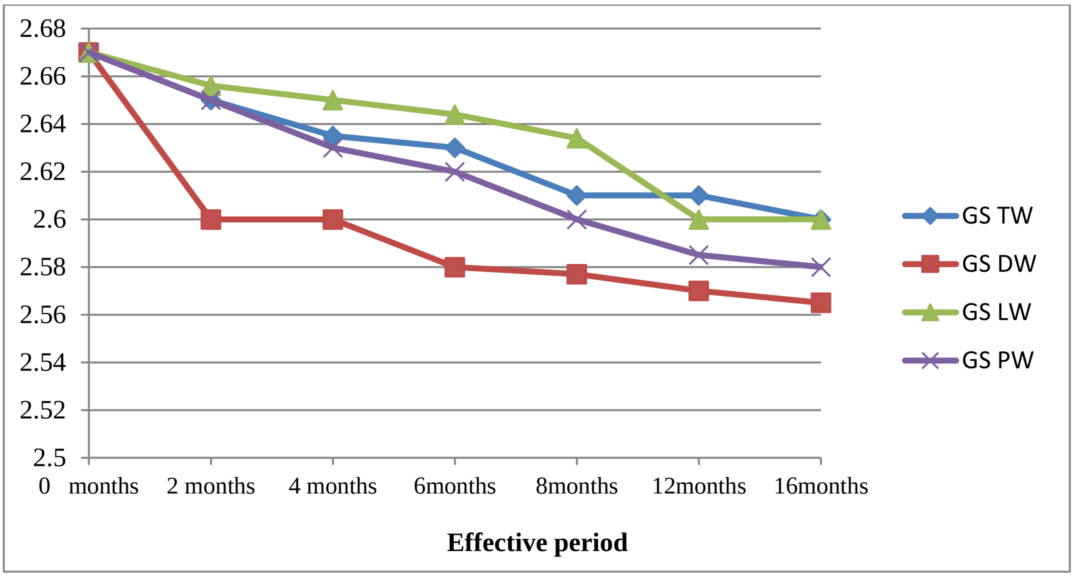

Fig. (9). Comparison between the specific gravity (GS) values with ageing of exposure for TW, DW, LW and PW

4.1.2 Free Swell Results

- Based on the free swelling (F.S) results obtained from the soil samples under study **Table (8),** the results showed that S1 (natural soil) was (60%), for soil contaminated with textile wastewater (TW) after (16months) from contamination was (79.5%) ,the results of the Free Swell (F.S) for soil contaminated with dairy effluent (DW) was (78%) and the results of the Free Swell (F.S) for soil with paper wastewater (PW) was (85%), on the other hand the Free Swell (F.S) value for soil contaminated with leather wastewater (LW) after 16 months was (40%) , **Fig. (10)**.
- For the soils (DW), (TW) and (PW) the (F.S) values were increase with the increase of contamination effect period, but for soil contaminated with Leather tanneries wastewater (LW), the free swell (F.S) values were decrease with the increase of contamination effect period.
- The soil exposed to industrial wastewater from paper is more affected than soils exposed to other pollutants.

Table (8). The results of (F.S) for natural and contaminated soil with TW, DW, LW and PW at the effective period

Effective Period	0 months(S1)	2 months	4 months	6 months	8 months	12 months	16 months
F.S TW%	60	70	72	75	76.5	77.5	79.5
F.SDW%	60	65	72.5	75	76	78	78
F.S LW%	60	55	50	43.5	43	40	40
F.S PW%	60	65	70	75	80	85	85

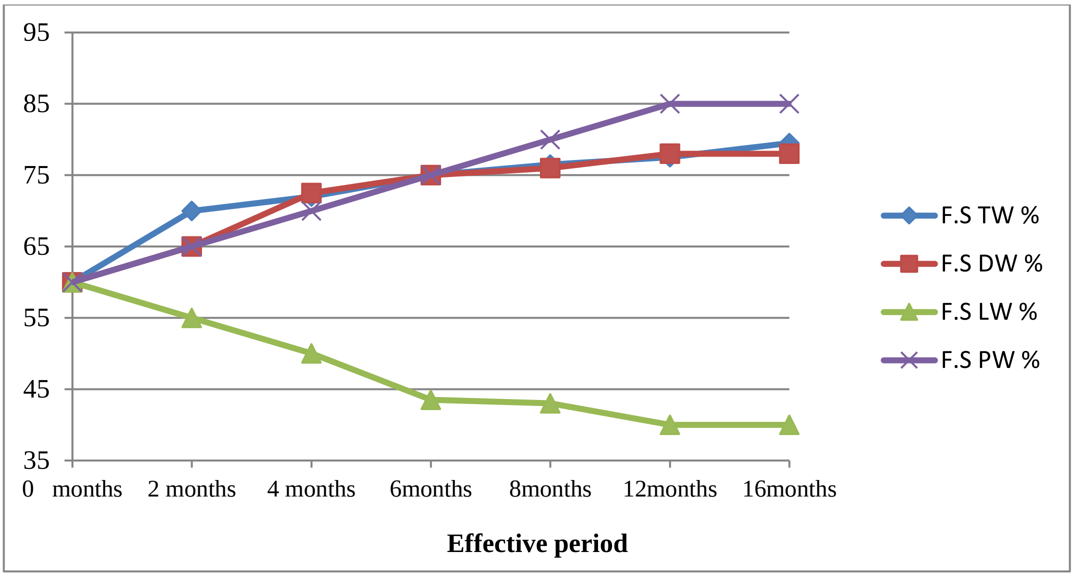

Fig. (10). Comparison between the FS values with ageing of exposure for TW, DW, LW and PW.

4.2 Compaction Outcomes

The compaction parameters (γdmax) and OMC are estimated for the natural soil and contaminated soils at different dates are shown in **Figs. (11) and (12).** Based on the results of the compaction test using the standard proctor apparatus. It is clear from **Table (9),** which includes the compaction findings as maximum dry density (γdmax) and optimum moisture content (OMC), that:

- The optimum moisture content (O.M.C.) and maximum dry density (γ_{dmax}) of natural soil (S1) were 20% and 1.70 gm/cm3, respectively, while these values ranged from 20.5% to 22.3% and 1.65 to 1.6 gm/cm3 for soil that had been contaminated TW. When soil was contaminated with DW effluent, the O.M.C. and dry density were, respectively, 22.5% to 24% and 1.61 to 1.53 gm/cm3.In another hand soil that had been contaminated LW waste water the (OMC) and (γdmax) values were, respectively, 21% to 25% and 1,65 to 1,52 gm/cm3 when soil was contaminated with (PW) the O.M.C. and dry density were, respectively, 22% to 26% and 1,63 to 1.46 gm/cm3
- The (γdmax) of all contaminated soils was lower than that of the natural soil. The (γdmax) of (PW) contaminated soil is the lowest, **Fig. (11)**.
- Optimum moisture content (OMC%) values increase of contamination effect period for all contaminated soils (TW), (DW), (LW) and (PW)
- For all contaminated soil with the different industrial waste water the maximum dry density (γ_{dmax}) values decrease with the increase of contamination effect period. But soil exposed to industrial wastewater from paper (PW) was the most affected

Table (9). Compaction out comes for the studied soils

Sample No	Sample No	O.M.C, %	γdmax., gm/cm3
Natural Soil	S1	20	1.7
Contaminated soil with TW	TW1 (2 month)	20.5	1.65
	TW2 (4 month)	21	1.64
	TW3 (6 month)	21.5	1.62
	TW4 (8 month)	21.75	1.61
	TW5(12 month)	22	1.6
	TW6(16 month)	22.3	1.6
	DW1 (2 month)	22.5	1.61
	DW2 (4 month)	22.75	1.6

Contaminated soil with DW	DW3 (6 month)	23	1.58
	DW4 (8 month)	23.5	1.57
	DW5 (12 month)	24	1.54
	DW6 (16 month)	24	1.53
Contaminated soil with LW	LW1 (2 month)	21	1.65
	LW2 (4 month)	22.25	1.63
	LW3 (6 month)	23	1.62
	LW4 (8 month)	24	1.6
	LW5 (12 month)	24.25	1.55
	LW6 (16 month)	25	1.52
Contaminated soil with PW	PW1 (2 month)	22	1.63
	PW2 (4 month)	22.5	1.6
	PW3 (6 month)	24	1.56
	PW4 (8 month)	24.75	1.55
	PW5 (12 month)	25	1.5
	PW6 (16 month)	26	1.46

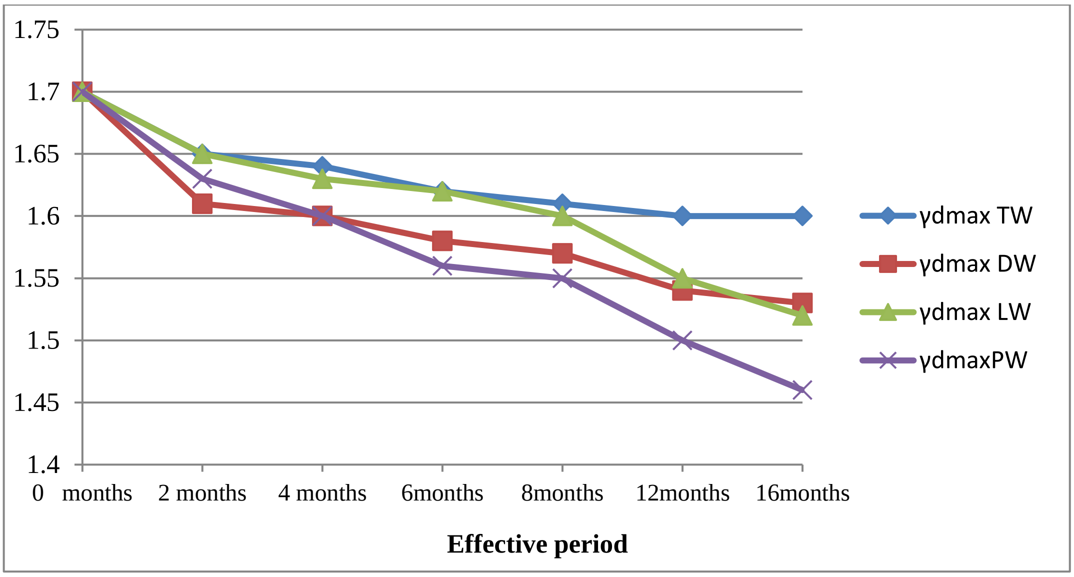

Fig. (11). Comparison between the (γdmax) results with ageing of exposure for TW, DW, LW and PW

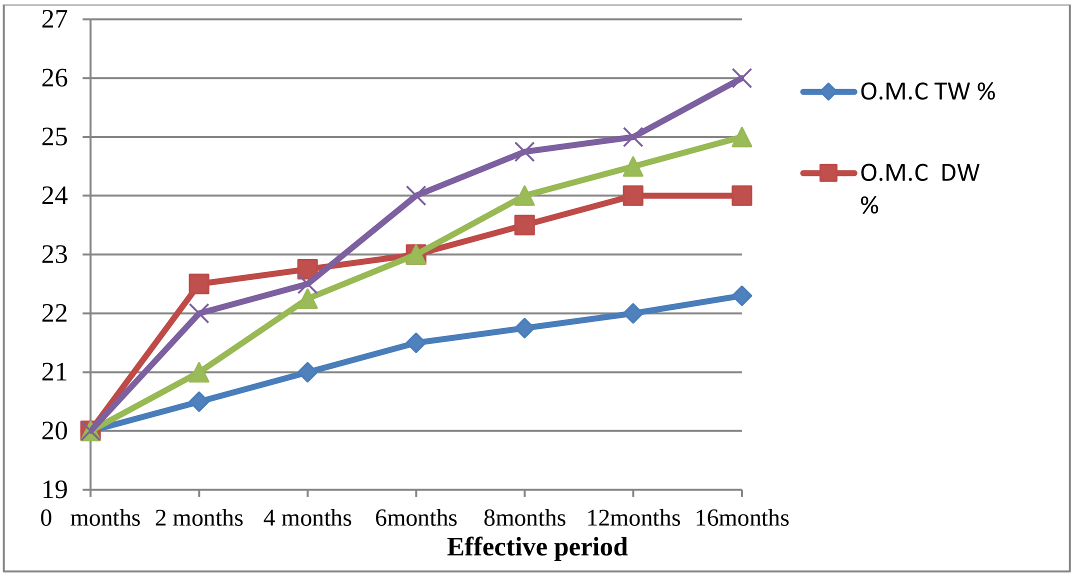

Fig. (12). Comparison between the (OMC) results with ageing of exposure for TW, DW, LW and PW

4.3 Chemical Analysis

4.3.1 Summary of Chemical Analysis of Soil

The chemical analysis of the natural soil sample S1 and the contaminated soils samples after 16 months from contamination for all contaminated soils (TW), (DW), (LW) and (PW) were carried out in National Research Center in Giza Governorate. **Table (10)** and **Fig. (13)** display the chemical analysis results, while **Fig. (13)** lists the major oxides for comparison between the values based on the chemical analysis.

- The presence of industrial wastewater can lead to an increase in certain chemical oxides. But soil exposed to industrial wastewater from paper (PW) was the most affected. It includes a high percentage of Alumina Oxide (Al2O3), Iron oxide (Fe2O3), and Titanium oxide (TiO2), in soil sample.
- Some chemical oxides in soil samples are decreased due to the contamination by paper industrial wastewater it contains the lowest percentage of Silicon oxide (SiO2), in soil sample.
- Some oxides are slightly decreased or increased.
- The above results of chemical oxides analysis agreed with the previous study by El-Kasaby, A., Easa, A.F (2023) and El-Kasaby, A., Easa, E.M (2023).

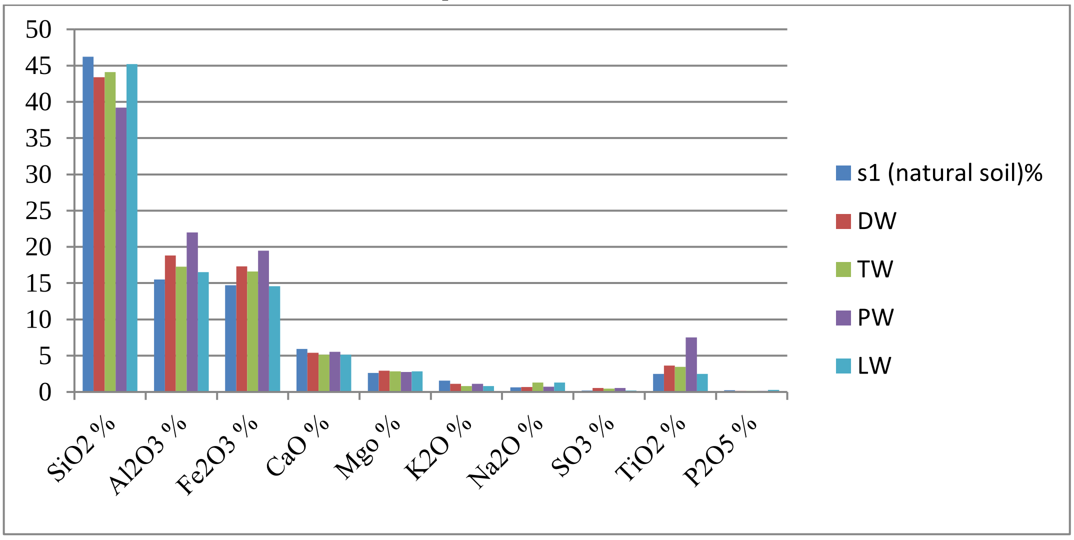

Fig. (13). Comparison between the Major Oxides in (S1) and the studied soils (DW), (TW), (LW) and (PW).

Table (10). Chemical analysis results for natural soil S1and all contaminated soils DW, TW, LW, PW

Oxide Content %	**Soil Samples**				
	Natural soil (S1)	(TW)	(DW)	(PW)	(LW)
SiO2	46.2	44.1	43.4	39.2	45.2
Al2O3	15.5	17.25	18.4	22.0	16.5
Fe2O3	14.70	16.60	17.3	19.5	14.60
CaO	5.92	5.14	5.4	5.54	5.14
Mgo	2.64	2.84	2.94	2.74	2.84
K2O	1.54	0.80	1.1	1.1	0.80
Na2O	0.65	1.30	0.68	0.74	1.30
SO3	0.19	0.45	0.55	0.53	0.18
TiO2	2.47	3.48	3.64	7.5	2.48
P2O5	0.26	0.14	0.13	0.15	0.27
MnO	0.23	0.45	0.44	0.41	0.24
SrO	0.05	0.04	0.06	0.08	0.04
ZrO2	0.05	0.05	0.06	0.07	0.05
Cr2O3	0.05	0.04	_	_	0.04
BaO	0.06	0.02	0.025	0.02	0.07
CO3O4	-	-	0.04	0.04	-
Nb2O5	0.01	0.03	0.02	0.05	0.03
LOi	9.35	6.32	5.39	9.3	9.49
Cl-	0.04	0.70	0.80	0.85	0.13

Where,

SiO_2	Silicon Oxide	MnO	Manganese Oxide
Al_2O_3	Alumina Oxide	SrO	Strontium Oxide
Fe_2O_3	Iron Oxide	ZrO_2	Zirconium Oxide
CaO	Calcium Oxide	Cr_2O_3	Chromium Oxide
Mgo	Magnesium Oxide	BaO	Barium Oxide
K_2O	Potassium Oxide	CO_3O_4	Cobalt Oxide
Na_2O	Sodium Oxide	Nb_2O_5	Nickel Oxide
SO_3	Sulphur tri Oxide	LOi	Loss of ignition
TiO_2	Titanium Oxide	Cl^-	Chloride
P_2O_5	Phosphorus Oxide		

4.3.2 Mineralogical Analysis of the Tested Soil

At Giza Governorate's National Research Centre, an X-ray diffraction analysis of four soil samples natural soil sample s1 and contaminated soil samples TW, DW, LW and PW was carried out. By using X-ray diffraction (XRD) and X-ray fluorescence spectroscopy (XRF), The X-ray diffraction patterns of S1, TW, DW, LW and PW, **Table (11)** presents the calculated mineral percentages.

Table (11). XRD semi-quantitative percentages results.

Sample No.	Quartz	Calcite	Kaolinite	Ellite	Montmorillonite
Natural soil	8.8	6.8	20.8	32.6	31
TW	8.67	5.8	23.4	39.25	22.88
DW	9.38	5.5	22.85	38.77	23.5
LW	10.4	5.9	24.2	39.8	20
PW	9.7	5.2	23.3	38.8	23

4.3.3 Scanning Electron microscopy Investigations (SEM)

The particle structure of the soils and wastewater was compared using scanning electron microscope (SEM) research. **Fig. (14), (15), (16), (17) and (18)** show the morphology of the tested soils. The primary structure of the current study's main structure usually contains the chemical elements silicon and aluminum, which are shown to have prominent peaks in the analysis. Figure 14, which displays the micrographs of natural soil devoid of wastewater, displays scanning electron micrographs of uncontaminated natural soil. The unique characteristics of natural soil, such as its high clay content, are highlighted by the stark variations in soil micrographs of natural soil before contamination. When comparing the micrographs in **Fig. (15), (16) ,(17) and (18)** it is clear how Dairy, Textile, leather and paper wastewater affects natural soil. When compared to natural soil, the microstructure of the contaminated soil particles was looser, more porous, and had a different surface shape. Sulphate activity causes disaggregation and the removal/washing out of constituents, strengthening the voids in some areas while causing aggregation and changes in the surface texture of the soil mass in other areas. The presence of clay is to blame for this.

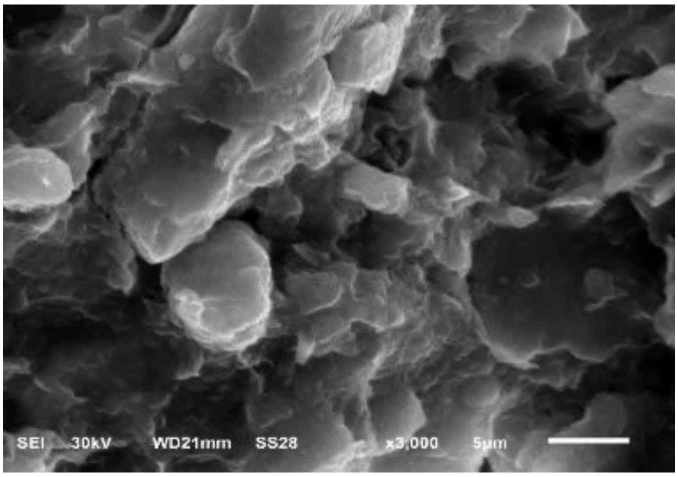

Fig. (14). SEM micrograph of natural soil before artificial contamination with wastewaters

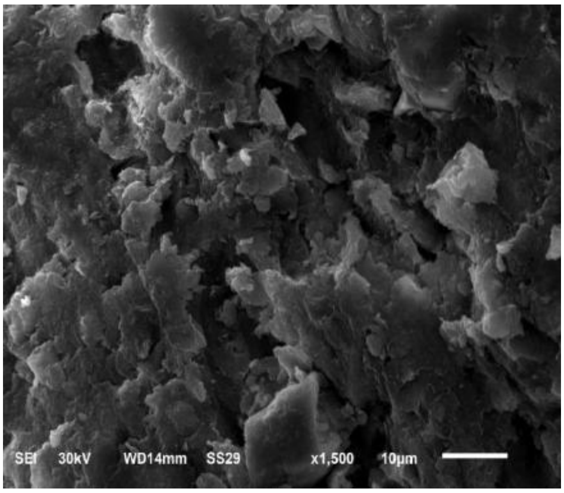

Fig.(15). SEM micrograph of natural soil after 16 months from contamination with wastewaters (DW)

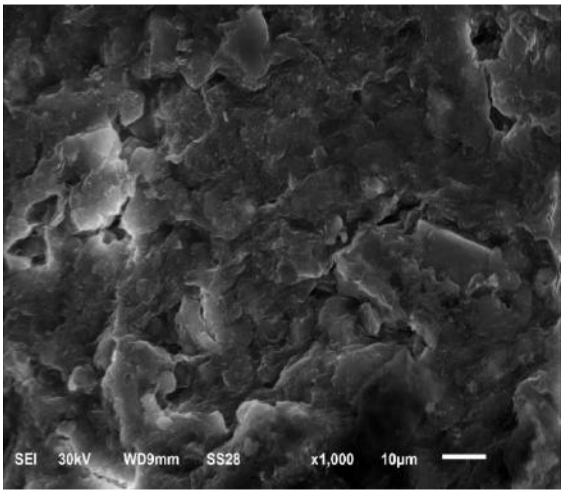

Fig. (16). SEM micrograph of natural soil after 16 months from contamination with wastewaters (TW)

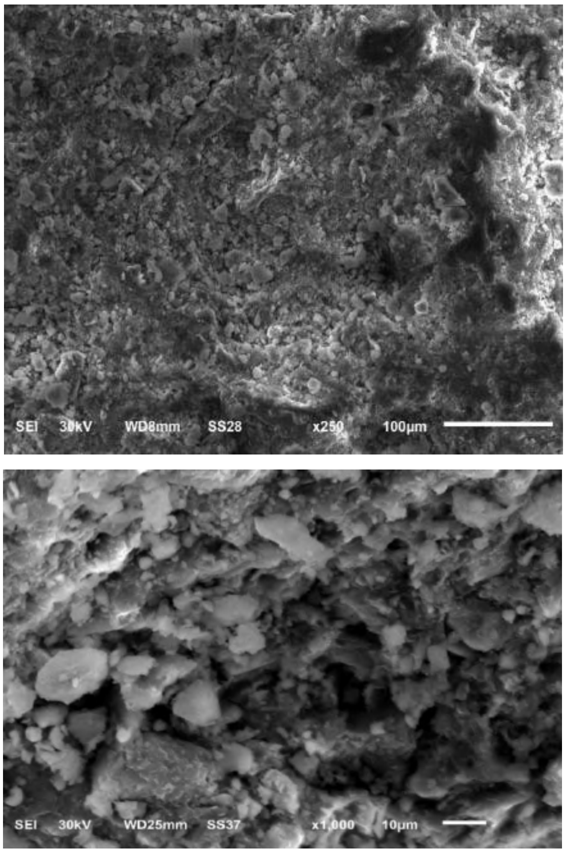

Fig. (17). SEM micrograph of natural soil after 16 months from contamination with wastewaters (LW)

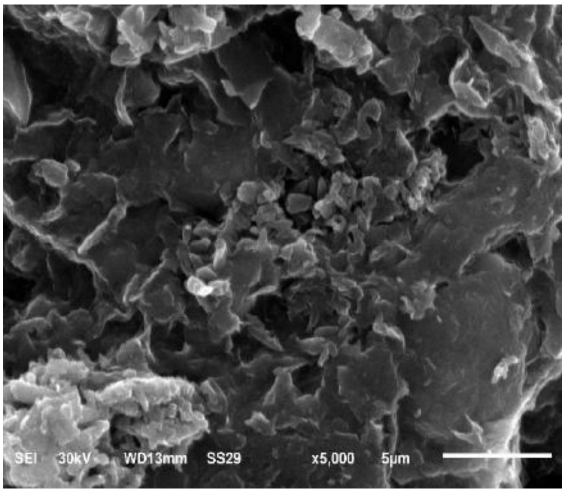

Fig. (18). SEM micrograph of natural soil after 16 months from contamination with wastewaters (PW)

V. CONCLUSION

According to Laboratory studies on these soil samples, the following can be drawn as:

1. It has been suggested that the geotechnical properties of fine-grained soil promote the degradation of dairy and textile products, perhaps posing threats to the site's current construction.
2. Values of the liquid limit (L.L.) decrease as the duration of the contamination effect increases. For all contaminated soils but soil exposed to industrial wastewater from paper is more affected than soils exposed to other pollutants.
3. There was a disturbance in the Plastic limit (P.L) values, with the increase of contamination effect period for soil that had been contaminated by textile wastewater.
4. For soil that had been contaminated by Dairy (DW) and leather wastewater (LW), the plastic limit values were decrease with the increase of contamination effect period.
5. There was a disturbance in the Plastic limit (P.L) values, with the increase of contamination effect period for soil that had been contaminated by textile wastewater.
6. The soil that had been contaminated by paper wastewater (PW), the plastic limit values were increase with the increase of contamination effect period.
7. the shrinkage limit (S.L) values increase with the increase in the duration of the pollution effect until 6 months have passed, then at effect period 8, 12 and 16 months, the samples were broken, for soil that had been contaminated by Dairy (DW) and textile wastewater (TW).
8. For soil that had been contaminated by leather waste water (LW), the shrinkage limit (S.L) values increase with the increase in the duration of the pollution Up to 16 months.
9. The shrinkage limit (S.L) values increase with the increase in the duration of the pollution effect until 8 months have passed, then at effect period 12 and 16 months, the samples were broken.
10. According to the results of plasticity index (PI) for soil that had been contaminated by Dairy (DW) it was decrease with the increase of contamination effect period until 2months have passed, then at effect period 4, 6,8,12 and 16 months, there was stability in the values of the plasticity index.
11. For soil that had been contaminated by (TW) and (LW) the plasticity index (PI) values were decrease with the increase of contamination effect period until 6months have passed, then at effect period 8,12 and 16 months, after that they increased slightly.
12. The soil contaminated by paper waste water (PW), the (PI) values were decrease with the increase of contamination effect period.

13. The natural soil, which is categorized as silty clay with high plasticity (CH-MH). The contaminated soil samples for (TW) and (PW) were classified as Silt with high plasticity (MH) after the effect periods 2, 4, 6 and 8 months, but (PW) classified as silt with low plasticity (ML) at effect periods 12 and 16 months, based on the impact of industrial waste water, as per the unified classification system (USCS).
14. According to the effect of industrial paper wastewater (PW), and industrial dairy waste water (DW) classified as clay with high plasticity. On the other hand, industrial leather wastewater (LW) classified as (CH-MH) at effect periods 2 and 4 months and classified as (CH) at effect periods 6, 8, 12 and 16 months
15. For the soils (DW), (TW) and (PW) the (F.S) values were increase with the increase of contamination effect period, but for soil contaminated with Leather tanneries wastewater (LW)The free swell (F.S) values were decrease with the increase of contamination effect period.
16. The (F.S) results for the soil exposed to industrial wastewater from paper is more affected than soils exposed to other pollutants.
17. For all contaminated soil with the different industrial waste water the (GS) values were decrease with the increase of contamination effect period. But soil exposed to industrial wastewater from dairy (DW) is more affected than soils exposed to other pollutants.
18. Optimum moisture content (OMC %) values increase of contamination effect period for all contaminated soils (DW), (TW), (LW) and (PW)
19. For all contaminated soil with the different industrial waste water the maximum dry density (γdmax) values decrease with the increase of contamination effect period. But soil exposed to industrial wastewater from paper (PW) was the most affected.
20. The presence of industrial wastewater can lead to an increase in certain chemical oxides. But soil exposed to industrial wastewater from paper (PW) was the most affected. It includes a high percentage of Aluminum oxide (Al_2O_3), Iron oxide (Fe_2O_3), and Titanium oxide (TiO_2), in soil sample.
21. Some chemical oxides in soil samples are decreased due to the contamination by paper industrial wastewater it contains the lowest percentage of Silicon oxide (SiO_2), in soil sample, and some oxides are slightly decreased or increased. The above results of chemical oxides analysis agreed with the previous study by El-Kasaby, A., Easa, A.F (2023) and El-Kasaby, A., Easa, E.M (2023).
22. For the natural sample, the percentages of quartz, calcite, kaolinite, albite, and montmorillonite are 8.8%, 6.8%, 20.8%, 32.6 and 31%, respectively. While these components changed with the addition of textile wastewater (TW). Therefore, the Quartz, Calcite, Kaolinite (K), Ellite (I) and montmorillonite percentage are changed to 8.67%, 5.8%, 23.4%, 39.25%, and 22.88%, respectively. On the other hand, the components of control soil changed with the addition of dairy wastewater (DW). Therefore, the Quartz, Calcite, Kaolinite (K), albite (I) and montmorillonite percentage are changed to 9.38%, 5.5%, 22.85%, 38.77 and 23.5, respectively.
23. For the soil contaminated with leather wastewater (LW), the percentages of quartz, calcite, kaolinite, albite, and montmorillonite are 10.4%, 5.9%, 24.2%, 39.8 and 20%, respectively. While these components changed with the addition of paper wastewater (PW). Therefore, the Quartz, Calcite, Kaolinite (K), Ellite (I) and montmorillonite percentage are changed to 9.7%, 5.2%, 23.3%, 38.8%, and 23%, respectively. These results matched with the chemical composition of samples analyzed with XRF test.
24. The microstructure of the examined soils shows that, in comparison to the natural samples, the industrial wastewater increased the morphology's porosity and looseness.
25. The engineering qualities of soil, particularly free swelling, are severely reduced by effluent from dairy, textile and paper industries. Additionally, it is possible that the mineral particles would disintegrate, resulting in a loss of soil density. This loss of soil density can be identified as a significant Factor in the differences in soil parameters that were tested using SEM techniques.

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