International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-9, Issue-9; Sep, 2023
Journal Home Page: https://ijaems.com/
Article DOI: https://dx.doi.org/10.22161/ijaems.99.5

Influence of industrial wastewater on the geotechnical and physicochemical properties of fine-grained soil

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Received: 03 Aug 2023; Received in revised form: 02 Sep 2023; Accepted: 12 Sep 2023; Available online: 23 Sep 2023

Abstract— *Fine-grained soil contamination is a daily occurrence due to industrial development and pipeline or reservoir leaks. The modification of the geotechnical properties of the polluted soil is a worry in addition to environmental issues like groundwater pollution. Recent studies have carefully examined the characteristics of contaminated fine-grained soils because it has been demonstrated that contamination modifies the geotechnical properties of soil. However, a thorough evaluation of the impact of industrial wastewater from paper (PW) and leather (LW) wastewater on the geotechnical characteristics of fine-grained soils is still lacking. As a result, thorough experimental studies have been carried out on both uncontaminated and contaminated fine-grained soils that include various concentrations of PW and LW. The soil samples were extracted from the lands in Benha City, Cairo, Egypt, which were exposed to PW and LW at 2, 4, 6, 8, 12, and 16 months. The findings showed that as soil ages, there is a decrease in the maximum dry density and Atterberg limits of the soil containing PW, as well as a increase in the optimum moisture content (OMC) and cohesive. On the other hand, the findings also showed that there is a decline in maximum dry density and Atterberg limits as well as a rise in OMC and cohesive. Additionally, ageing caused a further decrease in cohesion and increased the free swelling values in the case of the soil coated with PW, while decreasing the leather wastewater exposure. Finally, the microscopic investigations and mineralogical analysis confirmed the trend of the experimental results on the mechanical properties of the contaminated soils.*

Keywords— Fine-grained soil; Geotechnical; Mechanical properties; Wastewater; Microstructure.

I. INTRODUCTION

Massive amounts of both solid and liquid waste have been produced because of rapid industrialization. Such trash should not be disposed of carelessly, especially on land, which has led to severe environmental issues. There have been reports of foundation and structure failures brought on by contaminated soil, chemical spills, etc. [1–2]. It has been demonstrated that many geotechnical properties of fine-grained soils are impacted by the inorganic and organic contaminants found in industrial effluents [3–5]. Soil-pollutant interactions and the impact of pollutants and industrial effluents on different geotechnical qualities must be studied and understood for a variety of engineering applications. A critical analysis of the available literature has indicated that, up until now, the focus has been on understanding the impact of pure chemicals on commercial soils (kaolinite and bentonite), with relatively little research reported on the impact of industrial effluents, particularly on natural soils [6,7].

Some of the hazardous and relatively water-soluble hazardous substances found in industrial wastewater include paper, leather, and textile waste. Industrial wastewater contamination puts wildlife at risk of a number of threats, such as poisoning of animals at the top of the food chain who consume a lot of other organisms that have absorbed wastewater into their tissues, disruption of breeding patterns by rendering animals sick and unable to reproduce, irritation or ulceration of the skin, mouth, or nasal cavities, damage to red blood cells, and damage to the adrenal tissue of birds, which impairs their ability to fight off predators [8-10]. The hormonal balance of birds can also be impacted by exposure to industrial effluent, affecting things like the luteinizing protein.

Although scientists have extensively studied the geotechnical characteristics of contaminated fine-grained soils, few researchers have looked at the effects of paper and leather wastewater pollution on the geotechnical properties of fine-grained soils [11,13]. Khan et al. [3], Stalin et. al. [6], and Easa et. al. [8] conducted laboratory testing programs to evaluate the effects of industrial wastewater contamination and ageing effects on the geotechnical characteristics and behavior of fine-grained soil [3,6,8]. For the investigation by Easa et al. [14], samples of naturally contaminated groundwater from household wastewater were collected at the groundwater pumping level. X-ray and chemical conventional testing were done to figure out the amount of toxins in the groundwater [14]. It was concluded that the primary cause of groundwater pollution is thought to be residential wastewater. Its chemical composition is highly poisonous and dangerous. where it seriously affects issues with public health. Another study reported that the capacity of clay to expand due to changes in water content—which may be caused by ground water—puts pressure upward on the foundation. Expansion of clays and the resulting swelling pressure inflict significant damage, and uplift causes walls, beams, and columns to crack if the soil swelling pressure exceeds the foundation load [15-19].

Several studies investigated the Effect of wastewater on chemical, physical and mechanical properties of soil testing [20-21]. They found that full the industrial wastewater caused a markedly reduced the optimum moisture content and change the Atterberg limits as well as significant role in the free sell and compaction test. On the other hand, Anthor study [22] investigated the geotechnical performances of fine-grained soil treated with industrial wastewater sludge. They found that the soil mixtures treated with the sludge enhanced the geotechnical characteristics. Additionally, they recommended that industrial wastewater sludge be potentially employed for the improvement of fine-grained soil in the stabilization [22]. Karkush et al. [23] and Puri [24] evaluated the geotechnical characteristics of wastewater-contaminated soils using laboratory testing on samples. The results of the test demonstrated that wastewater-contaminated soils affects the compaction and swelling characteristics. Anthor study [24] evaluated the long-term effects of wastewater application on soil physical properties, two treatment sites between Taupo and Levin, New Zealand, and non-irrigated control sites were compared. The silty soil in Taupo has been treated with wastewater over the past 12 years. On Levin's land, sand-type soil has been watered with wastewater for 22 years. In terms of pH, organic matter (OM) content, bulk density, and total porosity, the disposal blocks at both sites were different from the control sites, but not in terms of microporosity. The disposal block at the Levin site showed a higher hydrophobicity than the control block, which was consistent with the elevated soil carbon. The Taupo soil, in comparison, showed a higher hydrophobicity at the control site, which had a lower quantity of OM [25].

Additionally, in the laboratory experiments [18-21], no effort has been made to recreate contamination close to field settings. Therefore, an experimental study has been conducted to determine the effects of paper and leather effluent (of the industrial variety) on the physio-mechanical behavior and geotechnical characteristics (physico-mechanical properties, compaction test, and free swell test) of 13 fine-grained soils (natural soil and contaminated soils) at 2-month, 4-month, 6 month, 8month, 12 month, and 16 months for each wastewater. Furthermore, the microstructure of natural and contaminated soils were studied.

II. SCOPE OF THE PROBLEM

In light of the trends of the modern state, industry development occupies an important space for self-sufficiency within Egypt. Therefore, the government has paid attention to the industrial sector in recent decades. Therefore, the feast arises from industrial wastewater, which poses a real threat to the soil, groundwater, and the mechanical behavior of fine-grained soil. Therefore, to the best of the author's knowledge, the effect of industrial wastewater because of the paper and leather factories scattered in Egypt on fine-grained soil has not been studied. Therefore, the authors try to identify the properties of contaminated soil to avoid potential risks and to use contaminated soil beneficially in civil engineering projects. Accordingly, the results of this research can be used in the first phase of the development program studies.

III. EXPERIMENTAL PROGRAM

3.1 Sample preparation

Early in 2000, there were sporadic reports of once-fertile lands in Egypt becoming barren within a year because of indiscriminate wastewater discharge on land in several areas of Cairo and in various governorates. Studies on the impact of paper and leather effluent on natural soils have been found to be infrequent or scarce, according to a critical evaluation of the literature. In this instance, the wastewater that was used came from two different places. The first came from tanneries in Ain Al-Sirah, Cairo, and the second from a paper factory run by an Islamic company in Quesna, Menoufia Governorate. These potentially hazardous wastewaters, whose effects on the environment require ongoing monitoring, were collected after the deposition of solids and before treatment. Studies on the impact of types of wastewaters, such as industrial wastewater paper and leather wastewaters, etc., on soils are likewise rare or scarce, according to a critical evaluation of the literature. Considering the foregoing, the two types of industrial wastewaters— paper leather wastewater—which are referred to as PW and LW, respectively, in this research—were chosen for the current investigation. 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, Qualiobiyah governorate (Fig. 1).

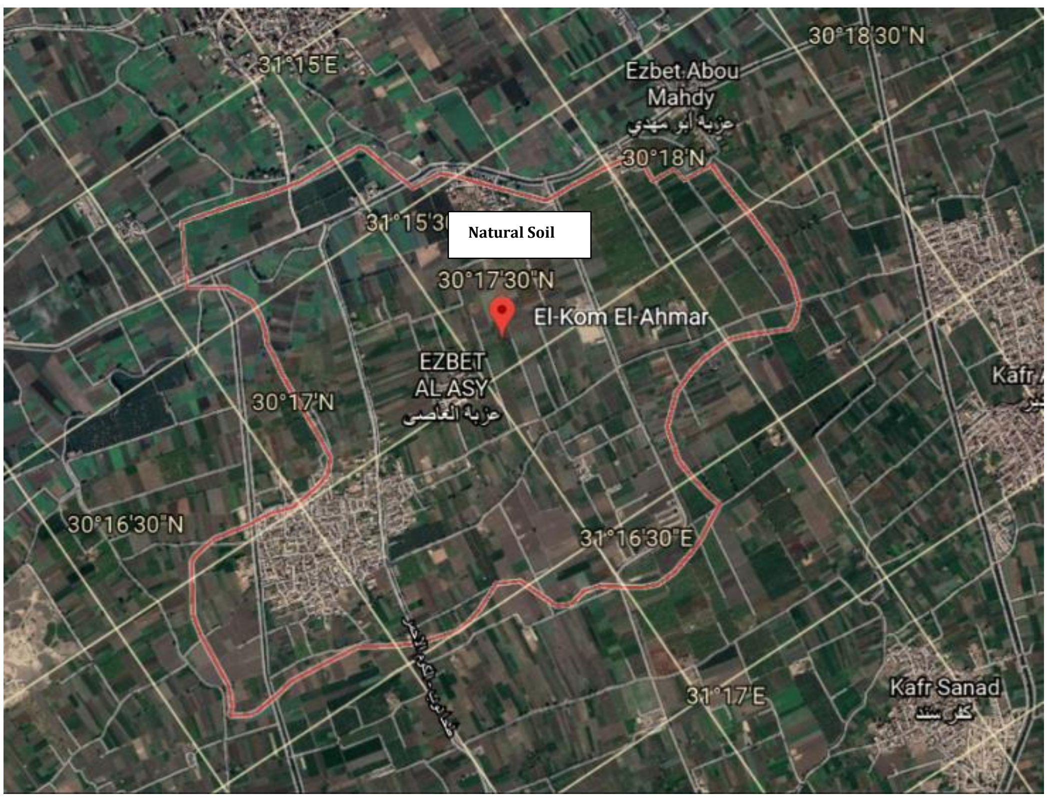


Fig. 1. Site of soil sample

The effluent parameters, including pH, alkalinity, total solids, total dissolved solids (TDS), total volatile solids (TVS), chloride, and biochemical oxygen demand (BOD), were calculated to characterize the different effluents in "as collected form" and for the outflow from the experimental set-up, i.e., The metrics are complete and sufficient to describe the effluent and comprehend its impact on the selected soils. The process for the analysis of the parameters was carried out in accordance with Standard Methods. Table 1-3 lists the characteristics of paper and leather effluent. In 50 kg airtight polythene bags, representative soil samples from the designated areas were gathered, transported to the lab, and stored in airtight containers under standard laboratory temperature until use.

Table 1. Physical properties of industrial wastewater (PW and LW)

Properties	Value	
	PW	LW
Color	grey	translucent
Temperature (°C.)	23	21
pH (Value)	11.4	9.9
Total Suspended Solids (TSS), (mg/liter)	2314	1913

Table 2 Organic properties of industrial wastewater (PW and LW)

Properties	Value	
	PW	LW
Volatile Suspended Solids (VSS)	1122	1683
Biological Oxygen Demand (BOD)	1308	821
Total organic carbon (TOD)	677	336
Chemical Oxygen Demand (COD)	6881	2757
Oil &Grease	125	378
Phenol	9.3	11.5
Detergents	25.7	11.7
Pesticides	6.4	9.2
Chloride (Cl^-)	1997	3764
Sulfate (SO_4^{2-})	1719	2843
Alkalinity ($CaCO_3$)	574	473
Ammonia (NH_3-N)	157	267
Phosphate (SO_4^{3-})	19.5	10.2

Table 3: Chemical minerals of paper and leather effluent.

Properties		Aluminum	Chromium	Copper	Fe	Lead	Mg	Nickel	Borne	Selenium	Fluoride	Zinc	Arsenic	Cyanide	Mercury	Cadmium
Value (mg/liter)	PW	0.15	2.15	1.8	1.4	0.75	9.1	4.55	1.76	0.72	12.52	7.2	0.08	2.23	0.068	0.075
	LW	0.25	1.55	2.4	1.6	3.65	11.6	6.8	2.8	0.57	4.65	5.6	0.17	2.1	0.057	0.088

3.2 Soil Sample Preparation and Experimental Set-up

The experimental setup planned for this work included two groups, each of which had six contaminated soils (PW or LW) and natural soil for comparison. These groups were constructed in accordance with the schematic designs. Each set of soils under study was created and used for the subsequent purposes:

(i) Samples were taken from the location and kept in the laboratory.

(ii) Since each effluent was used to examine how industrial waste elements affected the mechanical and geometric properties of the soil at specific ages. Due to this, the testing procedure was conducted at different times from mixing. The natural soils with wastewater, these times were 2, 4, 6, 8, 12, and 18 months.

(iii) A total of 13 samples were utilised to investigate the impact of two effluents on natural soils industrial wastewater (PW and LW). A 3-kilogram soil sample is manually combined with effluents at their optimum moisture content (OMC), then transferred.

Additionally, scanning electron microscopes (SEM) and X-ray diffraction (XRD) were used to analyze the mineral compositions of natural and contaminated samples [12]. These methods are accessible at the Egyptian Mineral Resources Authority's Central Laboratories Sector's Housing & Building National Research Centre in Giza, Egypt. The experimental program was created to ascertain the swelling behavior for the investigated soil with varying thickness.

IV. RESULTS AND DISCUSSION

4.1 Physical Properties

Tables 4 and 5 contains the natural and contaminated soil's index parameters, including specific gravity and Atterberg limits Liquid limit LL, plastic limit PL, shrinkage Limit SL, and plastic index PI. Based on these findings and the unified soil classification system USCS, it is noted that:

(i) Liquid limit LL, plastic limit PL, and plasticity index PI of natural soil are 74%, 34, and 40%, respectively. While LL, PL, and PI of PW-contaminated soil are range of 64%-57%, 35% to 41%, and 29% to 16%, respectively. The LL, PL, and PI of LW-contaminated soil are range of 71%-62%, 33% to 29%, and 38% to 33%, respectively.

(ii) Shrinkage Limit SL values of natural soil is 18%. The natural soil samples are categorised as silt of high plasticity MH. While SL of PW-contaminated soil is range of 21%-26%. The samples at 12 and 16 months were broken. The SL of LW-contaminated soil is range of 19%-25%.

(iii) Specific gravity Gs of natural soil is 2.67. While Gs of PW-contaminated soil is range of 2.65-2.58. The Gs of LW-contaminated soil is range of 2.65-2.60.

Table 4. The results of Atterberg limits for contaminated soil with industrial PW at different times months.

Sample No.	Liquid Limit L.L, %	Plastic Limit P.L, %	Shrinkage Limit S.L, %	Plasticity Index PI, %	G.s	USCS
Natural soil	74	34	18	40	2.67	MH
PW1 (2 month)	64	35	21	29	2.65	MH
PW2 (4 month)	62	36	23	26	2.65	MH
PW3 (6 month)	60	37	25	23	2.62	MH
PW4 (8 month)	59	38	26	21	2.60	MH
PW5 (12 month)	58	39	Cracked	19	2.59	ML
PW6 (16 month)	57	41	Cracked	16	2.58	ML

Table 5. The results of Atterberg limits for contaminated soil with LW at different times (months).

Sample No.	Liquid Limit L.L, %	Plastic Limit P.L, %	Shrinkage Limit S.L, %	Plasticity Index, %	G.s	USCS
Natural soil	74	34	18	40	2.67	MH
LW1 (2 month)	71	33	19	38	2.656	MH
LW2 (4 month)	68	32	20	36	2.65	CH
LW3 (6 month)	65	30	21	35	2.44	CH
LW4 (8 month)	63	30	23	33	2.44	CH
LW5 (12 month)	62.25	29	24	33.5	2.6	CH
LW6 (16 month)	62	29	25	33	2.6	CH

4.2 Compaction Results

Figs. 2 and 3 shows the compaction test results for the natural soil and contaminated soils at different times. In Table 6, which lists the compaction findings as maximum dry density (γmax) and optimum moisture content (OMC), it is evident that:

1- The optimum moisture content (OMC) of natural soil is 20%. while the OMC of PW-contaminated soil is in the range of 22%–26%. The OMC of LW-contaminated soil is in the range of 21%–25%. The OMC of both contaminated soils was higher than that of the natural soil.

2- The values of γdmax. of natural soil is 1.70 gm/cm3. while the γdmax of PW-contaminated soil is in the range of 1.63 gm/cm3 to 1.46 gm/cm3. The γdmax of LW-contaminated soil is in the range of 1.65 gm/cm3 to 1.52 gm/cm3.

3- The γdmax of both contaminated soils was lower than that of the natural soil. The γdmax of PW-contaminated soil is lower than LW-contaminated soil.

Table 6. Compaction parameters for the studied soils

Sample No.	Sample No.	OMC, %	γdmax., t/m^3
Natural soil	natural soil	20	1.7
Contaminated soil with PW	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
Contaminated soil with LW	LW2 (4 month)	22.25	1.63
	LW3 (6 month)	23	1.62
	LW4 (8 month)	24	1.60
	LW5 (12 month)	24.25	1.55
	LW6 (16 month)	25	1.52

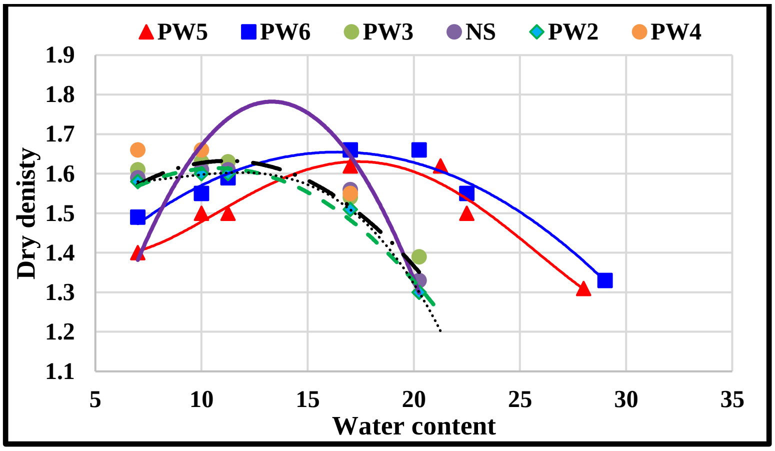


Fig.2 Standard proctor test of fine-grained soil contaminated with industrial wastewater (PW).

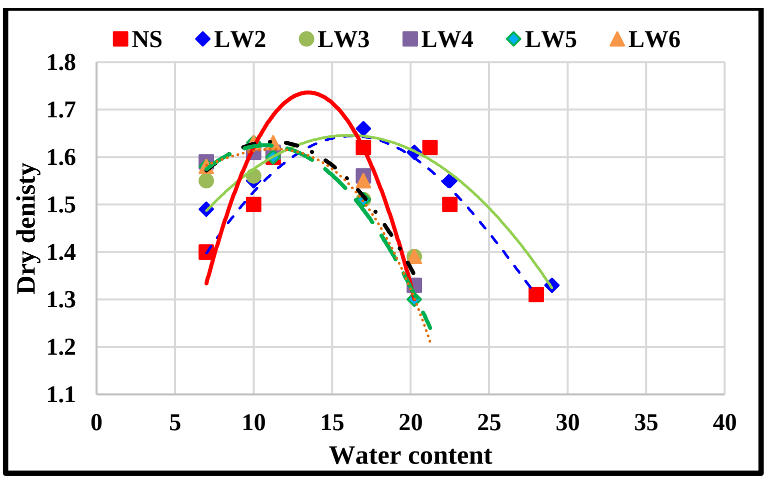


Fig.3 Standard proctor test of fine-grained soil contaminated with industrial wastewater (LW).

4.3 Free Swell

The results of free swell (FS) are listed in Table 7. Figs 4 and 5 represent the correlation between free swell FS percentage, dry density. Liquid limit LL, plasticity index (PL) and shrinkage limit (SL), respectively. Therefore, it is found that:

1- The free swell (FS) of natural soil is 60%. while the F.S of PW-contaminated soil is in the range of 65%–86%. The F.S of LW-contaminated soil is in the range of 55%–40%. The FS of PW-contaminated soil was higher than that of the natural soil and LW-contaminated soil.

2- The FS of LW-contaminated soil was lower than that of the natural soil.

3- The swelling PW-contaminated soil increases with the ageing increases, while the swelling LW-contaminated soil reduces with the ageing increases.

4- The swelling PW-contaminated soil increases with LL and PL at aging, while the swelling LW-contaminated soil reduces with LL and PL the ageing.

Table 7. Swell results for the studied soils

Sample No.	Sample No.	FS, %	Remarks
Natural soil	Natural soil	60	The swelling increases with the ageing increases
Contaminated soil with PW	PW1 (2 month)	65	
	PW2 (4 month)	70	
	PW3 (6 month)	75	
	PW4 (8 month)	81	
	PW5 (12 month)	86	
	PW6 (16 month)	86	
Contaminated soil with LW	LW1 (2 month)	55	The swelling reduces with the ageing increases
	LW2 (4 month)	50	
	LW3 (6 month)	43.5	
	LW4 (8 month)	43	
	LW5 (12 month)	40	
	LW6 (16 month)	40	

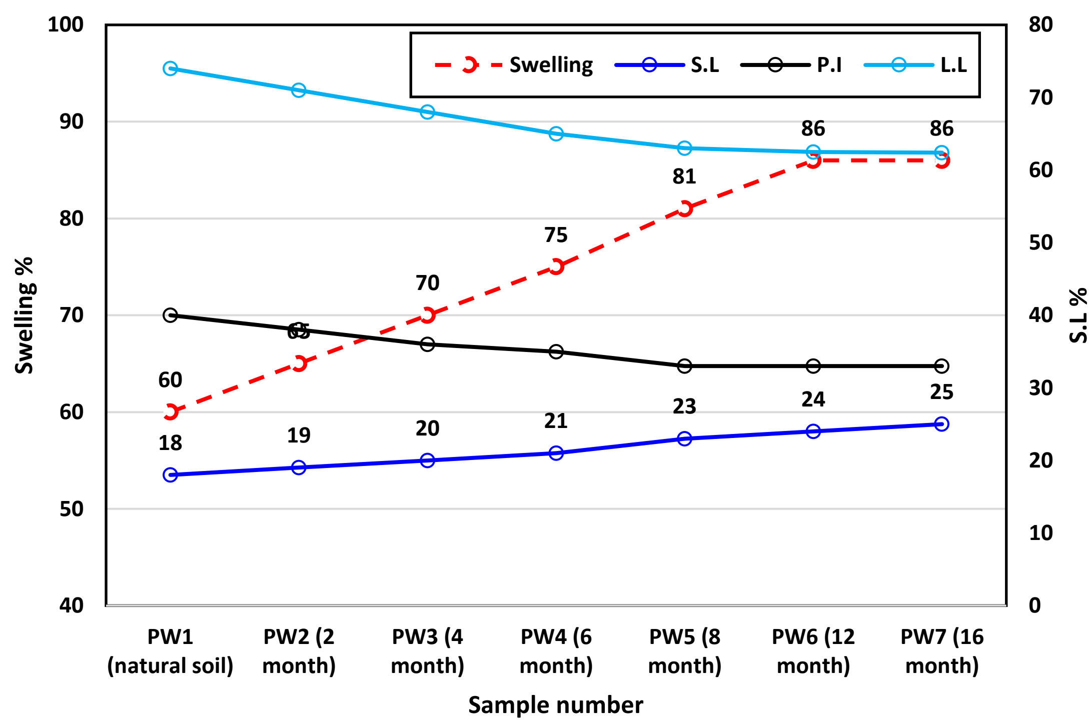


Fig. 4. Correlations of Free Swell with Plastic index, Shrinkage Limit, and liquid limit (PW).

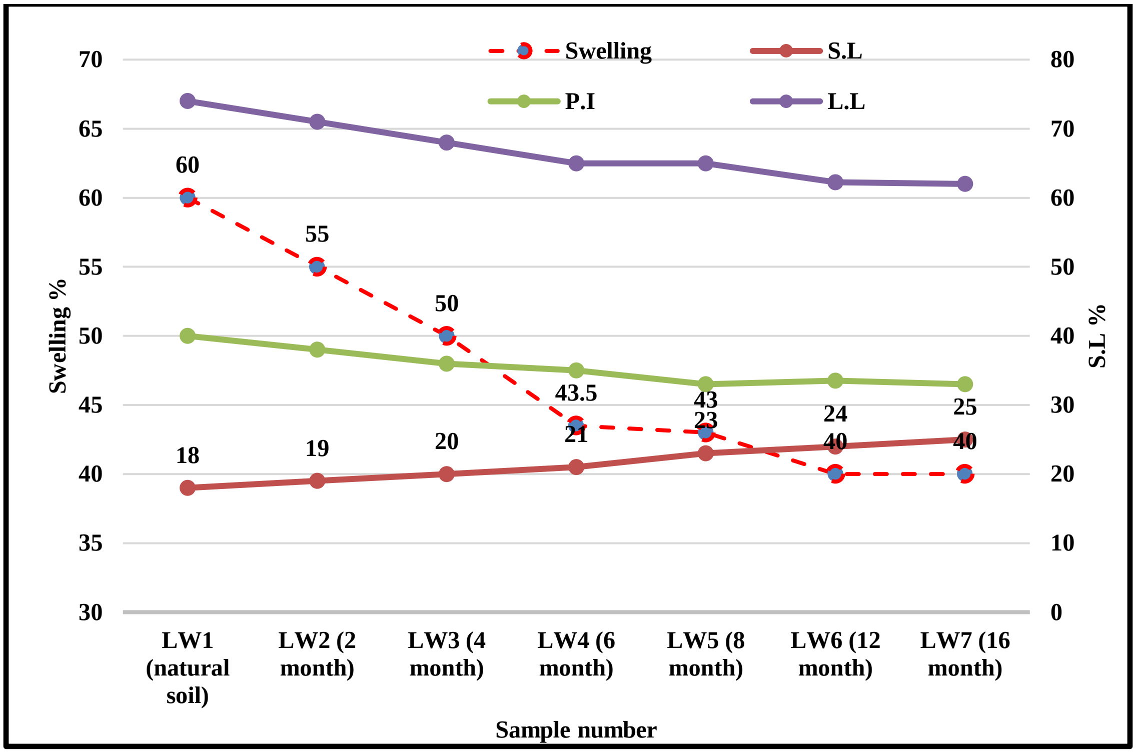
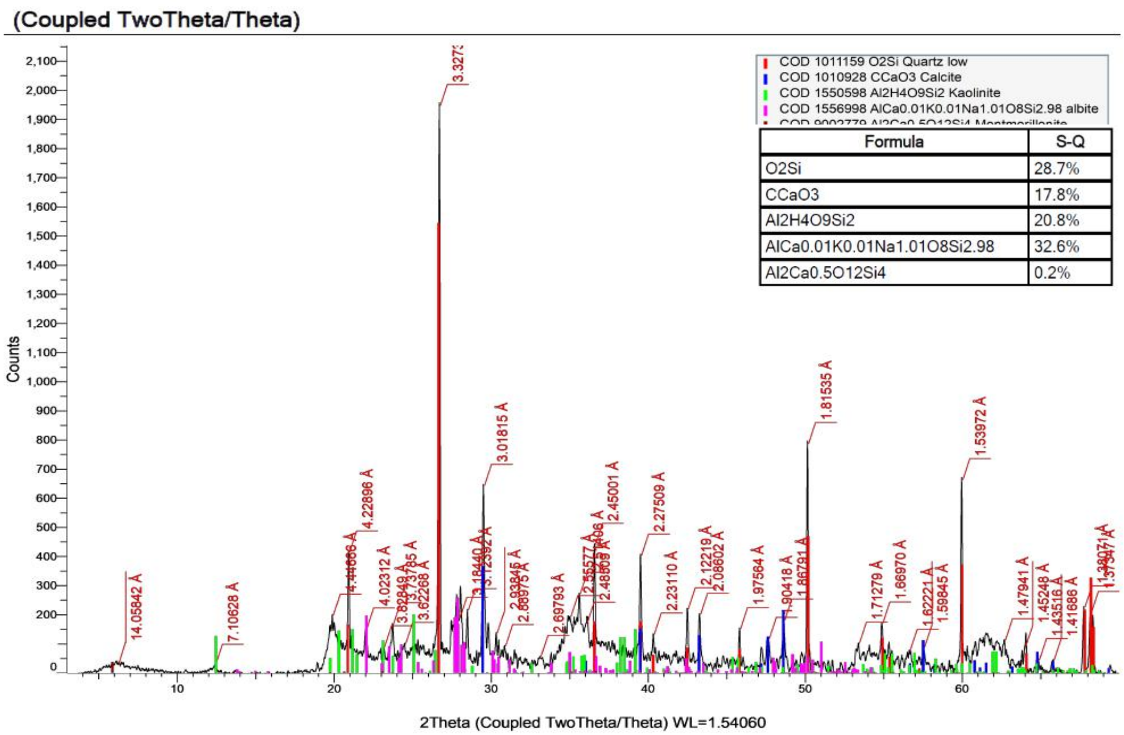


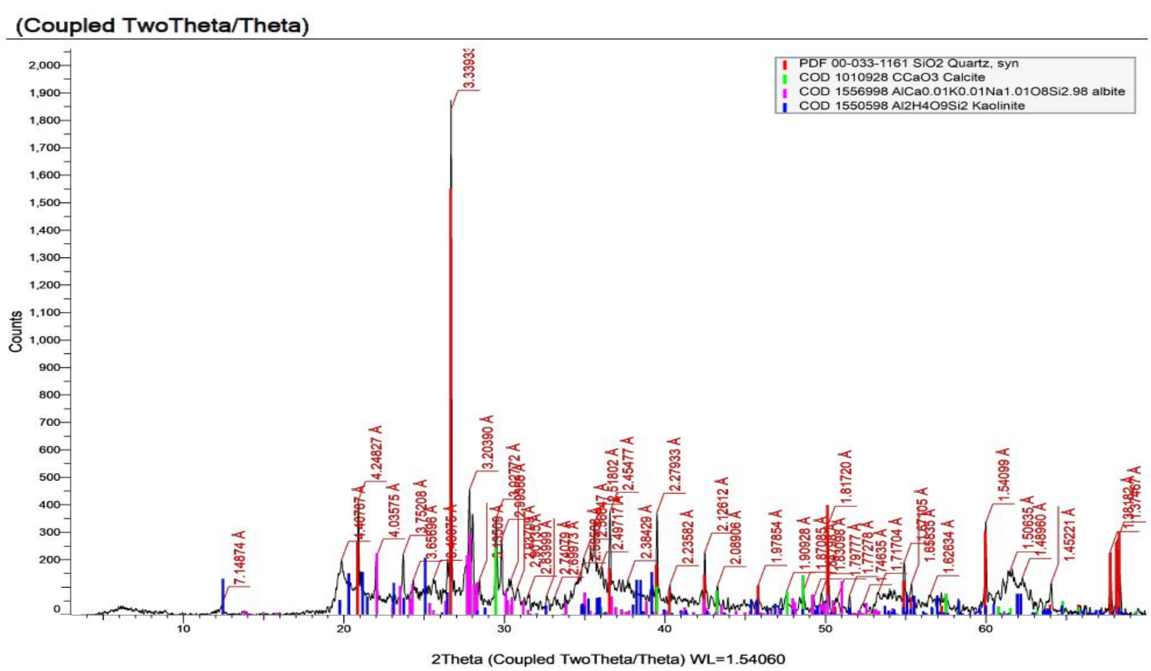
Fig. 5. Correlations of Free Swell with Plastic index, Shrinkage Limit, and liquid limit (LW).

4.4 Clay Minerals

Fig. 6 display the X-ray diffraction patterns of PW-contaminated soil and LW-contaminated soil, respectively. As a result, Table 8 shows the calculated mineral proportion. It is clear that: Minerals such as kaolinite (K), albite, calcite, and montmorillonite (M) were present in all samples. All soil samples included a sizable amount of the mineral montmorillonite (M), which is what gives the expansive nature. While these components not found in the PW-contaminated soil. The values of Kaolinite (K), calcite, albite, and Montmorillonite (M) percentage of PW-contaminated soil are 21.3%, 11.8%, 36.8% and 0% respectively. The values of Kaolinite (K), calcite, albite, and Montmorillonite (M) percentage of PW-contaminated soil are 20%, 4%, 43.60% and 0.2% respectively.



a) Natural sample



b) Soil contaminated with PW.

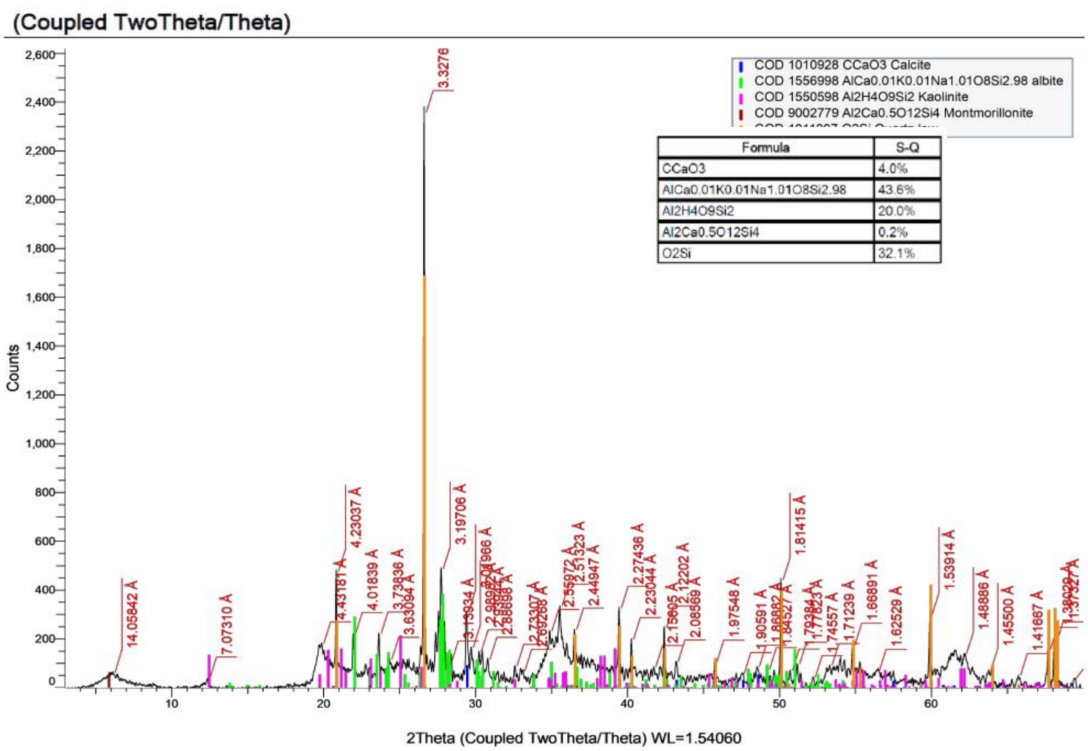


Fig. 6. X-ray diffraction patterns for the studied soils.

c) Soil contaminated with LW.

Table 8. XRD semi-quantitative percentages results.

Sample No.	Quartz	**Calcite**	**Kaolinite**	**albite**	**Montmorillonite**
Natural soil	8.8	6.8	20.8	32.6	31
PW	9.7	4.2	21.3	36.8	28
LW	11.4	3.0	20.0	43.6	22

4.5 SEM Analysis Results

Scanning electron microscopy (SEM) research was done to compare the particle structure of the soils with wastewater. The morphology of the examined soils is provided in Figs. 7, 8, and 9. Scanning electron micrographs of natural soil before contamination are shown in Fig. 7, which shows the micrographs of natural soil without wastewater. Micrographs of natural soil before contamination show vast differences, highlighting the unique nature of natural soil (i.e., classified MH). Comparing the micrographs shown in Figs 87 and 9, the effect of paper wastewater on natural soil is more detrimental than that of leather wastewater. The microstructure of contaminated soil particles became loose and porous, and the form of the surface changed compared to natural soil.

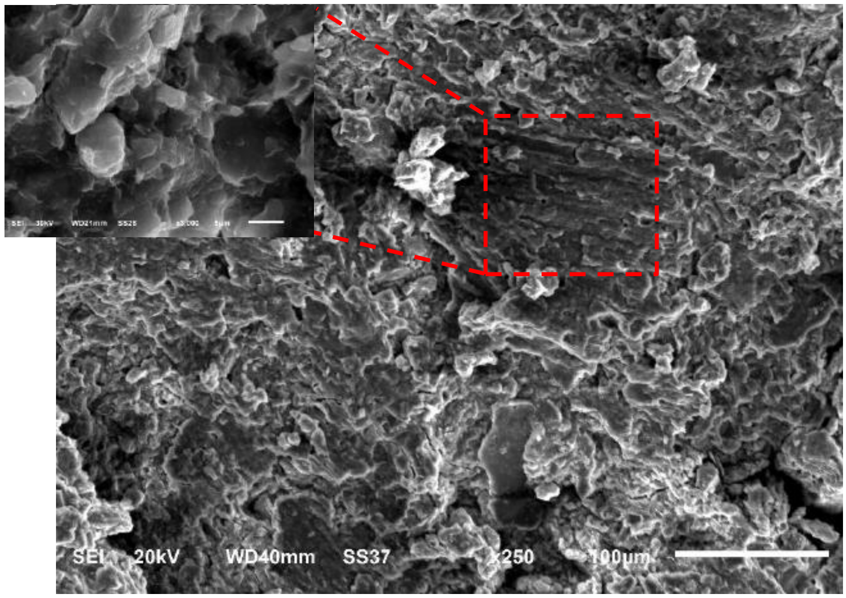


Fig 7. SEM micrograph of natural soil

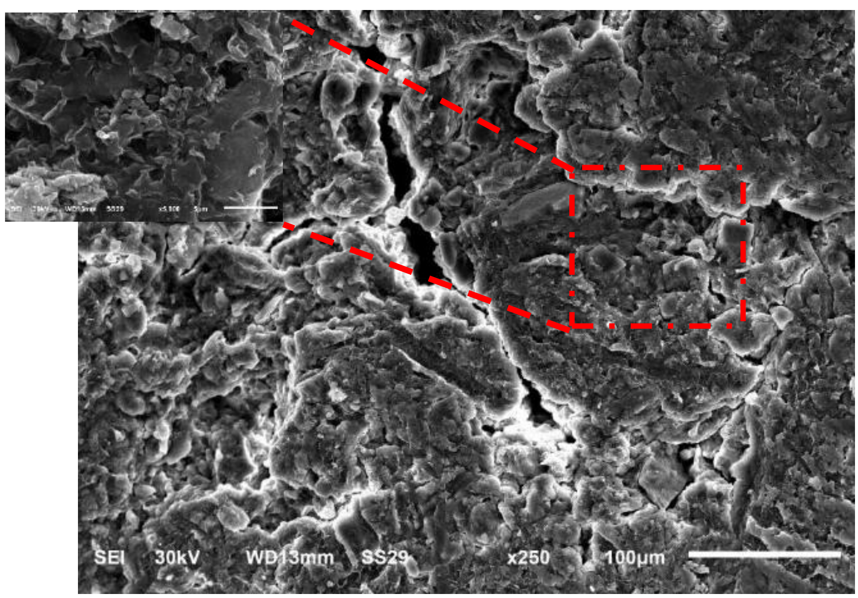


Fig. 8. SEM micrograph of contaminated soil with industrial paper wastewater PW

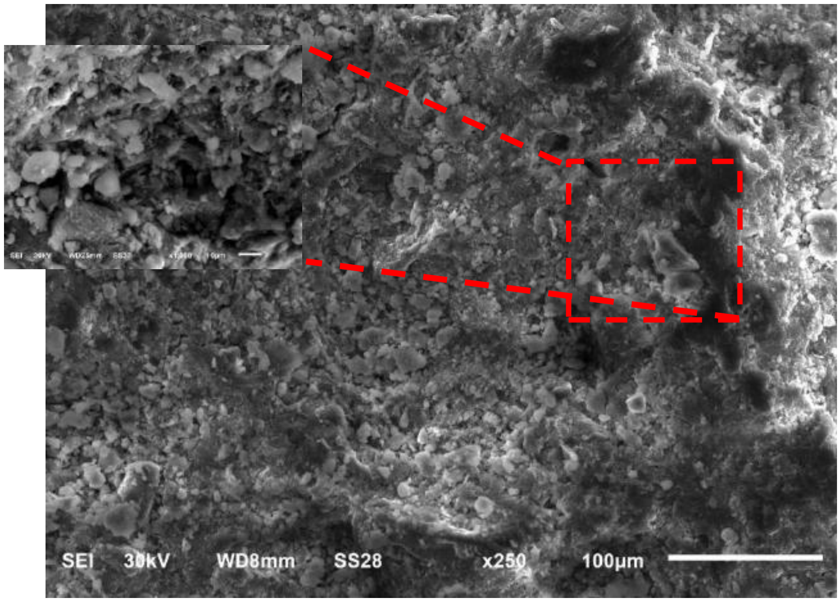
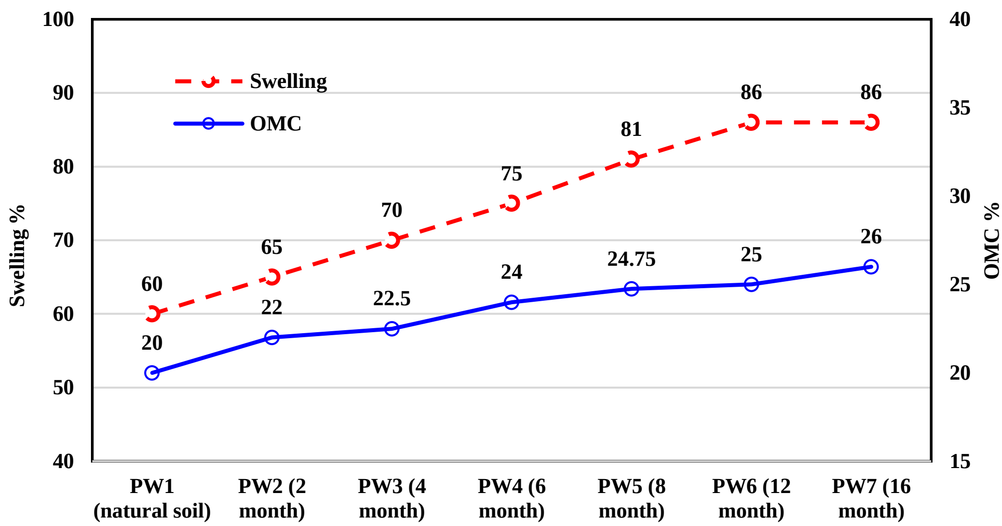


Fig. 9. SEM micrograph of contaminated soil with industrial leather wastewater LW

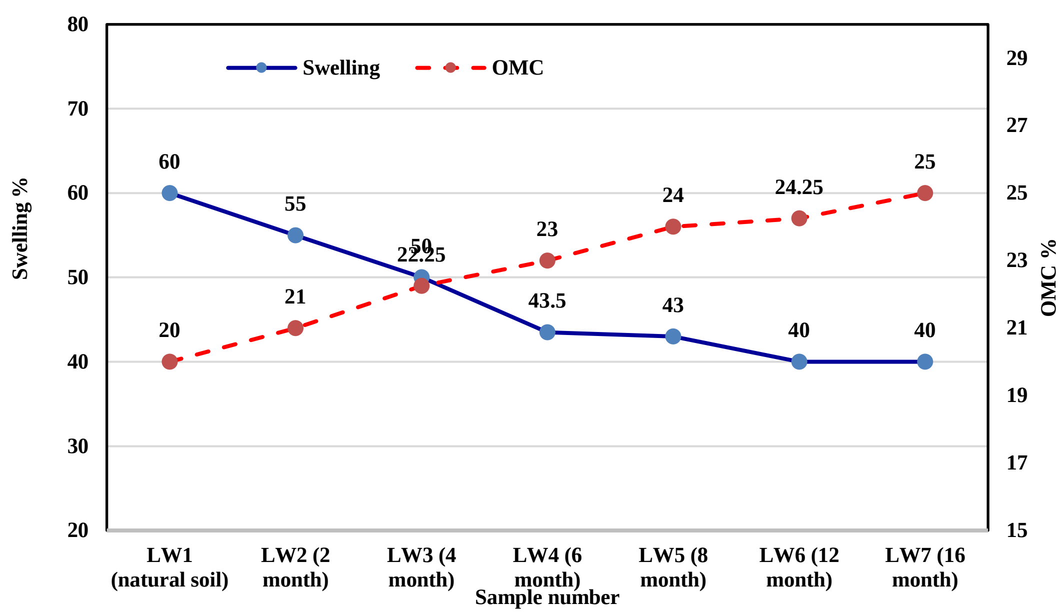
V. DISCUSSION

According to the results of free swell related to the correlations of F S with OMC of fine-grained soil with the different wastewater, it is noted that the free swell or differential free swell, also termed the free swell index, is one of the commonly used simple experiments performed by geotechnical engineers for getting estimates of soil expansion potential. Fig 10 represent the correlation between free swell FS percentage and optimum moisture content OMC for contaminated soils. It was also found that swelling values are in reverse proportion to optimum moisture content OMC and shrinkage limit SL. This result agrees with the results mentioned by. It was also found that Free swell values are in direct proportion to dry density, liquid limit LL, and plasticity index PL. Also, this result is in good agreement with the results mentioned by [14,16,18].

Finally, Table 9 compares the findings of the present study with those of Easa et al (2009), Cyrus et al., (2010), Karthika et al., (2021), Kermani (2012), Girisken (2013) [14]. Considering this comparison, it is concluded that: The effect of the industrial paper and industrial leather wastewaters on fine-grained soils is significant which change the properties of natural soil. The optimal moisture content OMC values for the current study are greater than the values for earlier investigations. However, compared to other investigations, the dry density values for the current study are lower. Additionally, the range of specific gravity Gs values is the same for the past and contemporary studies. The present study's compaction test results are lower than those of earlier research. The examined soils in the current study didn't contain as much sand as those in earlier investigations. Variable values for silt and clay content are seen in both the current investigation and earlier studies. The liquid limit LL values for the current investigation are higher than those for the earlier studies. In contrast, the analyzed soils in the current study exhibit higher plastic limit PL values than those in earlier research. Therefore, the plasticity index PI values for both the current and past investigations vary. The values of the shrinkage limit SL fluctuate between the results of the current investigation and earlier studies. The percentage values for clay minerals in the current study and earlier investigations were very similar.



a) PW



b) LW

Fig. 10. Correlations of Free Swell with O.M.C

Table 9. The experimental findings for the studied soils of the present study

Property	The current study (Paper wastewater)	The current study (Leather wastewater)	Alnos Easa et al (2009)	Cyrus et al., (2010)	Girisken (2013)	Kermani (2012)	Karthika et al., (2021)
OMC%	26	25	23	82	19.4	3.9	-
Maximum dry density	1.46	1.52	1.94	-	1.62	-	1.81

GS		2.58	2.60	2.72	2.7	2.67	-	-
Atterberg limits	LL%	57	62	48	95	29	23.9	35.25
	PL%	41	29	25	34	25	45.5	8.33
	SL%	Cracked	25	16	16	4		--
	PI%	16	33	23	61	-	21.6	18.33
Clay (%)		-	-	22	38	--	3	-
Silt (%)		-	-	70	29		89	-
Sand (%)		-	-	8	33	-	7	-
FS, %		86	40	60	-	40	-	-

VI. CONCLUSION

1. Properties of fine-grained soils contaminated with the industrial paper and industrial leather wastewater in Benha city, Egypt were experimentally studied. The following conclusions can be drawn:
2. Thirteen fine-grained soil samples were analyzed. The related liquid limit, plastic limit, and plastic index of natural soil values are 74%, 34, and 40%. The LL of industrial paper and industrial leather wastewater decreased by 22.9% and 16.2% respectively. While the PL of PW-contaminated soil increased by 20.60%, and the PL of LW-contaminated soil decreased by 14.70%. The plastic index of PW-contaminated soil and LW-contaminated soil decreased by 60% and 17.5, respectively.
3. The shrinkage limit of the natural soil is 18%. The samples of natural soil are classified as high plasticity silt (MH). While the SL of soil with PW contamination increased by 44.44%. At 12 and 16 months, the samples were damaged. The SL of LW-contaminated soil also increased by 38.88%
4. Natural soil has a specific gravity Gs of 2.67. Gs of PW-contaminated soil ranges decreased by 3.37%. Additionally, the Gs range for LW-contaminated soil decreased by 2.62%.
5. Natural soil has a 60% free swell. While the FS of soil contaminated with PW increased by 43.33%. While the FS of soil contaminated with LW decreased by 33.33%. In comparison to natural soil and LW-contaminated soil, PW-contaminated soil had a higher FS.
6. The FS of soil that had been exposed to LW was lower than that of uncontaminated soil.
7. The swelling PW-contaminated soil swells more as it ages, whereas the swelling LW-contaminated soil shrinks as it ages.

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