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Review Research

A REVIEW ON SOIL CONTAMINATION SOURCES: IMPACT ON ENGINEERING PROPERTIES AND REMEDIATION TECHNIQUES

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Abstract: Soil contamination produced by improper management of various petroleum and industrial products causes potential risks to the environment and soil engineering properties. Such contamination causes environmental deterioration and adversely affects soil engineering performance, altering almost all geotechnical properties. Several remediation techniques have been proposed to decontaminate the polluted soils. Choosing the best technique depends on both the energy consumption during operation and the treatment efficiency. The lack of a universally appropriate treatment method and the unavoidable expansion of contaminated land have justified the sake of reviewing the behavior of contaminated soils to develop both environmentally and geotechnically suitable soils for construction projects. The present paper reviewed some soil contamination sources' backgrounds, effects, and remediation methods. Soils influenced by petroleum hydrocarbons and industrial effluents were evaluated. According to the reviewed studies, contaminants are evidenced to have a negative impact on soils' geotechnical characteristics by increasing settlement and swelling, reducing shear strength, and decreasing permeability. The need to restore the engineering characteristics of soils suggest the necessity to use remediation or stabilization technique. The electrochemical method, bioremediation, and stabilizing by additives are revealed to be efficient in improving the engineering properties and performance of contaminated soils.

Keywords: *Hydrocarbon; industrial effluents; soil treatment; petroleum contamination.*

1. Introduction

Soil contamination is one of the most significant challenges in nature. It can occur in various ways, with various materials acting as pollutants [1]. These pollutants are natural or synthetic chemicals resulting from environmental changes or human intervention [2]. The pollutants infiltrate the soil and permeate the pores around the soil grains, or they are retained by chemical adsorption. Because soil and contaminants are primarily inert, they are typically retained in soil pores or as a liquid over soil particles by capillary forces [3]. Changes in subsurface soil pore fluid qualities and their interaction with the environment influence their characteristics and, therefore, their behavior. Changes in pore fluid chemistry have long been acknowledged to impact soil strength properties [4] considerably. The local environment, mineral structure, particle bonding qualities, particle size, ion exchange capacities, and other variables determine the sensitivity of soil to contaminants [4]. Pollution of sanitary landfill soil [5] and acidic pollutants in groundwater [6] are examples of soil contaminations. However, petroleum hydrocarbons and industrial discharges are the substances most often implicated.

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It has been shown that petroleum contamination and industrial effluents in soil negatively affect its physical, chemical, and mechanical characteristics [4, 7]. Petroleum and its refined products, such as crude oil, gasoline, diesel, kerosene, and engine oil, are essential energy sources for the global industrial and transportation sectors. Multiple hydrocarbons have quickly expanded around the globe, surpassing the soil's capacity for self-purification and increasing the number of contaminated areas. Similarly, the discharge of untreated industrial waste into the environment may pose many environmental and health risks. Typically, industrial discharges are disposed of instantly into open lands or bodies of water, leading to soil contamination. Rainfall-induced leachate production in publicly deposited solid wastes also contributes to soil contamination. Although environmental rules describe the essential treatment for industrial discharges, their implementation in many regions remained far from a real application.

The increasing prevalence of soil contamination has generated much research into the impact of chemicals on the geotechnical characteristics of fine-grained soils [8]. Although researchers are making significant efforts to discover practical ways for degrading the contaminations, soil contamination remains an inevitable concern. An alternative solution could be using contaminated soil after proper stabilization in engineering practices, such as embankments, road bases, backfills, etc. Thus, a review of the geotechnical features of contaminated soils is desirable. The aim of this review, therefore, is to summarize the current state of knowledge to be utilized as a guideline in assessing the geotechnical properties of contaminated soils and choosing the most effective treatment strategy.

2. Petroleum Hydrocarbon

The primary sources of petroleum hydrocarbon contamination in the soil include large-scale leaks from pipelines, fuel storage systems, and improper petroleum waste disposal. The chemical composition, soil filtration, and retention capabilities control the level of soil contamination[9]. Crude oil, diesel, engine oil, and gasoline are the most common hydrocarbon-based compounds found in soils[10], and their effects are reviewed in the current study.

2.1. Crude Oil Contamination

The extensive usage of crude oil, the dumping process, and unintentional accidents have resulted in an abundance of soils contaminated with crude oil. Oil contamination has been found to have a significant impact on the engineering properties and behavior of soils, such as shear strength, compressibility, and hydraulic conductivity [11-16].

Khamehchiyan et al.[7] examined the influence of crude oil contamination on the geotechnical properties of silty sand, lean clay, and poorly graded sand samples contaminated with 4%, 8%, 12%, and 16% crude oil. The Atterberg limits values were found to fluctuate under the hydrocarbon contamination. As the content of oil in lean clay samples increases, the Atterberg Limits rate decreases. In addition, the strength, permeability, maximum dry density, and optimal water content of soil samples all decreased as crude oil content increased.

Harsh et al.[17] conducted various experiments on contaminated fine sand and kaolinite clay to determine the influence of crude oil contamination on soil geotechnical characteristics. The investigations found that when contamination increased in both kinds of soil, the liquid limit and grain density decreased, while the shrinkage limits, plastic limits, and swelling coefficients of kaolinite clay increased.

Using a direct shear mechanism, Mohammedi et al.[18] examined the interface behavior of crude oils-contaminated sand-concretes. The experiment results indicated that concrete surface roughness, normal stress, and crude oil content affected interface shear strength. As the crude oil level in the soil grew, the friction angle reduced, and the interface roughness rose.

The cyclic pressure behavior of circular footings on oil-contaminated sand was investigated by Hosseini and Busherian [19]. Equations predicting overall settlement and the number of loading cycles needed to achieve the required settlement were presented in their experimental and numerical analytical results. The formulae were based on loading frequency, cyclic load frequency, contaminated-layer thickness, and contamination percentage. Contaminants accumulating in the subsurface, according to this study, cause changes in soil shearing strength and hence the bearing capacity of foundations resting on them [20-27].

Ahmadi et al. [22] investigated the effects of crude oil on the engineering features of sand-kaolinite mixtures with varying clay-to-sand weight ratios. Mixtures containing 10, 30, and 50% kaolinite to sand contaminated with varied quantities of crude oil (0%, 4%, 6%, and 8% soil dry weight) were investigated. At the same dry density, standard compaction, unconsolidated undrained triaxial, permeability, pH, and water holding capacity (WHC) experiments were conducted on the clean and contaminated specimens. The microscopical interaction of crude oil, kaolinite, and sand particles was also studied using a scanning electron microscope (SEM). In the presence of crude oils, optimal water content, maximum dry density, permeability, and pH values were reduced. High clay/sand contamination substantially impacted WHC and soil shear strength measurements. The presence of crude oil reduced the internal friction angles in sandy specimens with low clay concentration but increased it in specimens with high clay content. According to SEM, crude oil contamination causes aggregation, flocculated structure, and more significant macropores in clay particles.

According to Salimnezhad et al.[28], the plastic limit of crude oil-contaminated soil increased while the plasticity index decreased as the contaminant concentration increased. Natural soil has been found to have a higher swelling pressure than polluted soil. However, the polluted soil had a larger free swell percentage than the native soil at 12% oil content. As the contaminant lowered the specific surface area of the soil, limiting the water absorption of the sand oil particles, and enabling water drainage, the settlement of the contaminated soil increased with increasing crude oil concentration.

Oil-contaminated soils may be treated in various ways, including replacing oily soils with uncontaminated soils, absorption, incineration, and biodegradation. These methods have been observed to be time-consuming and expensive procedures [29, 30]. On the other hand, adding cement to contaminated soils has been described as a desirable remediation technique because of its established technology and low cost [29, 31, 32]. The cement interacts with water and rapidly bonds loose particle components, providing strength and durability to the soil [33].

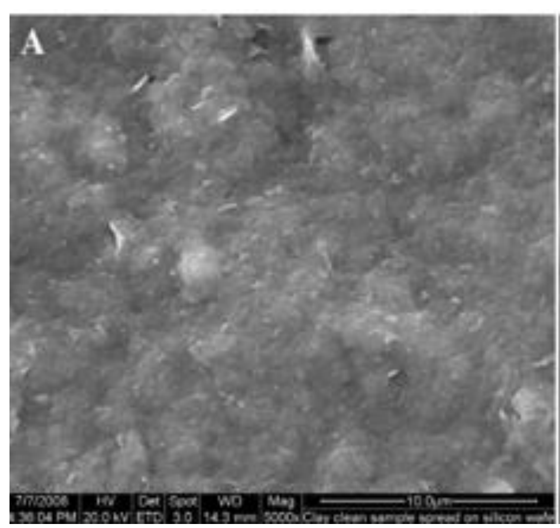
Other studies of contaminated soil stabilization and solidification stated that cement-stabilized soils have improved to the point where they could sustain a structural foundation or roadway paving [32, 34, 35]. Naser [36] researched the technical properties of oil-contaminated sand stabilized with cement kiln dusts (CKD) in rural road construction. The unconfined compressive strength (UCS) and California bearing ratio

(CBR) measurements increased when CKD was added to oil-contaminated sand. The stabilized contaminated sand strength decreased as the proportion of oil increased. The best UCS and CBR values were obtained by mixing 10% CKD with sand contaminated with 6% oil content. Yu et al. [37] performed an experimental study on Portland cement to stabilize polluted soils. Concrete-stabilized soil has been studied for its direct shear strength, Atterberg limits, microstructure, and unconfined compressive strength. The research demonstrates that utilizing cement to enhance engineering characteristics is viable. While the geotechnical properties of polluted soil are weak, the liquid limits and plasticity indices of contaminated soils samples are reduced when cement is applied along with developing strength. Scanning electron microscopy (SEM) findings demonstrate that cement-stabilized oil-contaminated soil has a stable supporting microstructure. It also demonstrates that cement might be utilized as an additive in treating oil-contaminated soils.

2.2. Diesel Contamination

Diesel fuel made from petroleum is a significant energy source worldwide and one of the most typical soil pollutants. Contamination substantially impacts soil properties due to the increased demand for fuel [38]. The impact of diesel contamination on the geotechnical properties of soils has been investigated, with contaminant concentrations ranging from 0% to 20wt.% [21, 39-41].

From a microstructure perspective, clay particles showed a change in microstructure after being contaminated with diesel. It results in a denser structure due to a shift in the pore size distribution [42]. Contaminated till has a more uniform distribution of porosity and less variability in the morphometric pore space characteristics. Due to pollution, the amount of intermicroaggregate pores and edge-to-face (EF) contacts among clay microaggregates increased, the packing of particles and clayey microaggregates decreased, and some of the microaggregates disintegrated [42]. Trzciski et al.[43] studied the microstructure of glacial till from NE Poland, both in uncontaminated and contaminated conditions. The soil samples were collected at a gasoline terminal where an inadvertent release of diesel oil from underground storage tanks transpired. The hydrocarbon content was 5395 mg/kg dry weight at a depth of 2 m. To corroborate previous microstructure research results, this examination may demonstrate the open porosity of diesel-contaminated clay soil. It results in more dispersed aggregates than the more cohesive uncontaminated clay sample in Mastersizer experiments. In contaminated sample data, the percentage of grains smaller than 0.1 mm was greater than in uncontaminated sample data across a broad range of diameters. SEM micrographs is shown Fig. 1. The contaminated sample produces porous, randomly dispersed EF-coagulated clay platelets and aggregates of clay nanoparticles, while the uncontaminated sample creates a homogeneous coating of submicron clay platelets onto the silicon wafer [43].



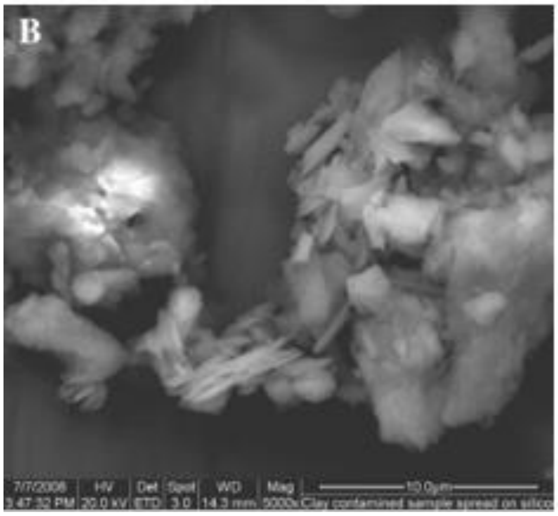


Figure 1. SEM micrographs of clay fraction dispersed in water and deposited onto the silicon wafer. (A) uncontaminated sample and (B) contaminated sample (After Trzciski et al.[43])

Ghasemzadeh and Tabaiyan [44] evaluated the effects of several additives on the geotechnical features of diesel fuels contaminated kaolinite, including cement, rice husk ash, lime, and Royal Road Product (RRP235 Special). Cement-stabilized soil was less impacted by an increase in diesel fuel contamination of up to 10% of the dry soil weight, whereas rice husks ashes and lime-stabilized soil was strengthened and cohesiveness enhanced. With rising contaminant concentrations, the friction angles of all the cement, lime, and rice husks ashes stabilized samples decreased. The shear strength parameters of the soil were unaffected by increasing RRP-235 Special.

Hernández-Mendoza et al.[45] investigated diesel contamination's effect on soil geotechnical characteristics and established the maximal diesel retention in unsaturated clayey soil. The results revealed that the soil could only hold 12.6% of the additional diesel, with the rest being expelled. The saturation rate of the soil was less than 80% at such a diesel concentration. The soil's flexibility and internal friction angle rose due to diesel contamination, whereas its cohesiveness was reduced significantly. The matric suction of polluted soil was lower than that of native soil, which should be highlighted. Its osmotic suction, on the other hand, was significantly higher. This finding suggests that when assessing the shear strength of polluted soils, osmotic suction should be addressed.

2.3. Gasoil Contamination

Gasoil is more commonly utilized in many sorts of machinery, and as a result, it contributes to the most land contamination. Khosravi et al.[46] performed various laboratory experiments on kaolinite samples under uncontaminated and contaminated gasoil conditions, including fundamental characteristics, consolidation, direct shear, Atterberg Limits, and unconfined compressive strength. The samples were mixed with 2, 4, 6, 12, 16, and 20% gasoil before keeping for 24 hours and then analyzed in the laboratory. Physicochemical changes were highly noticed in kaolinite samples contaminated with 16% gasoil.

To assess the geotechnical properties of remoulded clayey materials contaminated with gasoil, Hosseini et al.[19] conducted thorough laboratory tests. The data was analyzed, and behavioural equations were proposed using the Response Surface Methodology (RSM). Based on the RSM data, more contamination decreases Atterberg limits and increases maximum dry density. At 8% gasoil concentration, shear strength parameters (i.e., c and $\emptyset$) showed a turning point, despite their variation patterns being in different directions.

The liquid limit of gasoline-contaminated soil increased, reaching a maximum value at a contaminant content of 6%, according to Yazdi and Teshnizi [47]. Even while increasing the gasoline content reduced the soil's liquid limit, it was still higher than natural soil. The study found that as the contaminant concentration increased, the settling and ductility of gasoline-contaminated soil developed. The study also suggested that depending on the pollutant content in the soil, the soil failure mechanisms altered.

Based on a numerical model constructed in PLAXIS, Boushehrian [48] evaluated the influence of oil contamination on sand-carrying capacity. Various amounts of gasoil and kerosene contamination were blended into the contaminated sand layers. For numerical analysis, shear strength was measured directly from contaminated soil samples via direct shear testing. The effects of contamination type and depth were examined. According to the numerical model, the bearing capacity of circular foundations dropped as the percentage and depth of gasoil and kerosene contamination increased. This suggests that the soil's bearing capacity is negatively correlated with these two parameters. The bearing capacity for a circular foundation may be determined by its depth and pollution percentage, according to several different formulas.

2.4. Engine Oil Contamination

Used oils may be recycled and reprocessed, provided they are gathered safely and effectively. However, inappropriate disposal of engine oil contaminated subterranean soil and groundwater. One liter of oil may pollute up to one million gallons of water and accumulated in the subsoils, posing a threat to the ecosystem. On average, a single oil change will generate 4 to 5 litres of spent oil [4].

Singh et al. [4] investigated soil behavior changes produced by interaction with used motor oil (UMO) and their treatment. The research comprised low plasticity clay (CL), highly plasticity clay (CH), and poorly graded sands (SP). In order to compare the geotechnical variables before and after contamination, laboratory investigations were performed on virgin (uncontaminated) soil samples and soil samples simulated to various contamination levels (i.e., 3, 6, and 9 percent by dry soil weight). It was discovered that the engineering characteristics deteriorated when exposed to pollution. Surfactant (sodium dodecyl sulfate (SDS)) assisted washing was utilized as a remediation approach. The optimal dose of SDS was discovered to recover the original geotechnical qualities of soils within 0 to 12 percent.

Son et al.[49] calculated the impact of diesel contamination on unsaturated soil electrical characteristics. Contaminated soils with a 5% water content had higher electrical resistivity and lower permittivity than uncontaminated soils. In contrast, contaminated soils with a water content of 15% had lower resistivity and increased permittivity.

Al-Hamaiedh and Maaitah [50] studied the impact of lubricating oil contamination on soil geotechnical parameters and assessed the feasibility of utilizing an electrochemical approach to treat contaminated soils. The findings revealed that oil contamination had a negative impact on the soil's basic geotechnical properties. The geotechnical properties of treated soil samples, on the other hand, have successfully improved. The electrochemical treatment method's viability has been demonstrated. Electrochemical treatment methods are distinguished by their great efficiency, environmental safety, and capacity to treat large amounts of soil.

Ijimdiya [51] researched the impacts of used motor oil on the characteristics of lateritic soil. The study revealed that when the pollutant concentration increased from 0% to 8%, the fine-grained size of the soil particles dropped.

Pandey and Bind [52] investigated the impact of pollution from engine oils on alluvial soil samples containing 0, 4, 8, and 12 percent hydrocarbon pollutants. The Atterberg limits of soils contaminated with hydrocarbons were decreased compared to uncontaminated samples in similar conditions.

Gidudu and Chirwa [53] investigated the influence of voltage variation, electrode distance, and biosurfactant application on the bio-electrokinetic remediation of motor oil-contaminated soil. The studies demonstrated that achieving appropriate decontamination with high voltage, low electrode spacing, and biosurfactants boosted efficiency and lowered energy costs. A summary of previous studies on the effect of petroleum hydrocarbon contaminants on the geotechnical properties of soils is provided in Table 1.

Table 1. Summary of the effect of petroleum hydrocarbon contaminant on geotechnical properties* of soils

Soil type	Contaminated soil properties	Ref.
	Crude oil Contamination	
Clayey and sandy soils	-Atterberg limits decreased. - Strength, permeability, γ_{dmax} and w_{opt} all decreased.	[7]
Fine sand and Kaolinite clay	- LL and Gs decreased. - SL, PL, and swelling coefficients of kaolinite clay increased.	[17]
Sand-concrete interface	-φ decreased and the interface roughness increased.	[18]
Sand-kaolinite mixtures	-γ_{dmax}, w_{opt}, permeability, and pH values all decreased. - φ decreased in sandy specimens with low clay concentration	[22]
Highly plastic clayey soil	- PL increased while PI decreased. - Swelling pressure decreased. -Settlement increased.	[28]
	Diesel Contamination	
Clayey Soil	- φ increased and c decreased. - lower matric suction, but higher osmotic suction.	[45]
	Gasoil Contamination	
Sandy soil	- Atterberg limits decreased. - γ_{dmax} increased. - φ and c fluctuated.	[19]
Silty soil	- LL increased. -Settlement increased.	[47]
	Engine Oil Contamination	
Clayey soils (CL and CH) and sandy soil (SP)	-Settlement and swelling characteristics increased for clayey soils. - φ decreased sharply for SP.	[4]
Clayey soils (CL)	-Atterberg limits increased. -UCS decreased - φ and c decreased.	[50]
Lateritic soil (CL)	-UCS decreased -Compressibility coefficients increased.	[51]

*γ_{dmax} = maximum dry density, w_{opt} = optimal water content, LL = liquid limit, PL = plastic limit, PI = plasticity index, SL = shrinkage limits, Gs = grain density, φ = friction angle, c = cohesiveness, UCS= unconfined compressive strength

3. Industrial Effluents

The industrial discharges are typically released untreated, contaminating water channels and eventually the soil via seepage. Index and engineering features of contaminated soils have been shown to vary as a result of chemical interactions between soil minerals and contaminants in previous studies [7, 8, 14, 54-61]. Foundation materials may be damaged by soil contamination [54, 61]. Waste dumps seep into the soil layer, weakening the structure's ability to withstand the effects of natural erosion.

Adding textile effluent reduces soil pH by decreasing Atterberg's limit values by proportionately increasing the amount of effluent [62]. The disposal of effluents, whether solid or liquid, in the soil alters the index quality in the industrial zone [63]. For the design and construction of foundations on such soil, special concerns about the variations in the engineering behavior of such soils should be considered. The engineering behavior of soils contaminated by three effluents, paper industries (acidic), textiles industry (basic), and marble dust, is investigated in this study.

3.1. Paper and Textile Industries Effluents

Paper industry effluents are frequently acidic [62], whereas textile industry effluents are often basic [64].

Khan et al. [65] investigated the geotechnical parameters of local cohesive soils after exposure to industrial effluents from the paper and textile sectors. They produced contaminated soil specimens by mixing varying quantities of industrial discharge into virgin soil samples and studying their impact on contaminated soil engineering characteristics. The contaminated cohesive soil samples were generated by oven-drying and pulverizing the virgin samples before conducting various tests. The soil samples were then mixed with industrial effluents in 0, 5, 10, 15, and 20% by dry weight of soil. Researchers discovered that adding acidic (paper factory) and basic (textile factory) pollutants to the soil improved its plasticity. With varied ratios of acidic and basic contamination, the liquid limit of both CL and CH soils was enhanced.

Similarly, with the addition of pollutants, the plasticity index of both soils increased. The increased liquid limit suggests that polluted soils have more consolidation potential [66]. The high plasticity of polluted soils causes increased swell potential and significant collapsibility difficulties. As a result, industrial effluent pollution would degrade soil quality as an engineering material.

When contaminants were introduced to CH soils, Khan et al. [65] found that the specific gravity fell slightly. The specific gravity of CH soils was lowered by 1.4% and 2.3% as a result of the addition of basic and acidic contaminants. The CL soil's specific gravity was unaffected by the pollution. With the addition of 20 percent textile waste effluent, the pH value of CH and CL soil samples rose by 5.3 and 5.7 percent, respectively. Due to the acidic nature of the discharge from the paper industry, the pH of all soil samples dropped with its addition. With 20 percent contamination of paper discharge, the pH of CH and CL soil samples reduced by 5.3 percent and 7.1 percent, respectively. This conduct is in line with Sunil et al. results [54]. The influence of contamination on the compaction properties of both soils was shown in the optimal moisture content, which rose by roughly 10% for CL soils and around 7.5 percent for CH soils after contamination was added. However, when pollutants were added, the maximum dry weight of cohesive soils declined. The decrease in the highest dry unit weight of soil with the addition of 20 percent acidic/basic discharges was about 4 percent. In terms of engineering implementations, this signifies a high-water demand to achieve optimal moisture in the field, which generally elevates project costs and is undesirable. Alternatively, soil with significant levels of contaminants would be hard to compact. It might have a lower unit weight than uncontaminated soil over a similar compaction force and moisture conditions. The unconfined compressive strengths of CH and CL soils fell by roughly 5 and 6%, respectively, when pollution was added. Contamination causes a loss in strength owing to the possibility of internal bond breakage.

Khan et al. [65] measured the value of Cv (coefficient of consolidation) of CL soil. They found that it reduced by 40.2 percent and 50.0 percent, while CH soil decreases by 50.8 percent and 60.9 percent, respectively, owing to acidic and basic contaminants. As a result, the time necessary to consolidate contaminated soil would be longer than the time needed to consolidate parent soil to a similar degree. The Cc (compression index) of CL soil varied from 7.5 percent to 11.3 percent, indicating a significant rise in the amount of consolidation. For a 20% increase in acidic/basic contaminant, the equivalent increase in CH soil varied from 9.4 percent to 11.1 percent. This suggests that polluted soils have a more significant consolidation potential than uncontaminated soils.

3.2. Dyeing Industrial Effluents

The used colored dyes are dumped off in the soil, altering the soil profile's strength properties. Contaminated soil had lower Atterberg limitations and a poorer plasticity index than sterilized soil [67].

The pre-consolidation pressure, compression indices, consolidation coefficients, and swelling pressures of dyeing effluent-contaminated soil have changed [68]. Low moisture content and high consistency limits are found in contaminated and sterilized soil samples [69]. The soil is treated with dye effluent that has been intentionally produced for contamination at a depth equivalent to subgrade. The findings reveal that increasing dye effluent lowers the values of CBR and the proportion of water necessary for soil change, such as the plastic and liquid limits [70]. The dry density of clayey soils treated with reliable alkaline discharges was lowered [71]. The pH, plasticity, and unconfined compressive strength of soil are lower due to untreated wastewater.

Karthika et al. [72] improved the soil strength qualities by degrading soil samples and enhancing the engineering characteristics of the soil by introducing marble dust in proportions of 5%, 15%, and 25% by mass. Because marble dust is mixed with calcium carbonate, it is considered an admixture. The marble dusts utilized in this research was obtained from the Hosur marbles stones quarry. The soil samples came from a place in Pallipalayam near the Cauvery River 1.5 meters below the ground surface to prevent the effect of dumping the garbage. The soil samples were gathered in three rings surrounding the dyeing company containing ten samples. The soils sample were saved, and the discharge from the samples was assessed. Effluent contamination change in Atterberg limits in each ring, and it may be described as attributes that alter soil properties. The plasticity index increased from 18.33 percent to 21.35 percent in the first ring, 18.33 percent to 23.63 percent in the second ring, and 25.55 percent in the outer ring, all based upon discharge concentrations. Most of the variance in Atterberg's soil restrictions is due to available chemicals in the affluent among soil grains and dyeing discharge. The plasticity index of contaminated soils causes increased swell characteristics and settling issues. The behavior of clayey soils that lead to infectivity reveals a decline in strength and the contamination of around 30% of uncontaminated soils sample owing to industrial effluent. Whereas, the shear characteristics of soil treated with marble dust exhibited a larger range in unconfined compression strength.

The effect of industrial effluent contaminants on the geotechnical properties of soils is summarized in Table 2.

Table 2. Summary of the effect of industrial effluents contaminant on the geotechnical properties* of soils

Soil type	Contaminated soil properties	Ref.
Paper and Textile		
Clayey soils (CL and CH)	- LL and PI increased. - Gs of CH decreased. -γ_{dmax} decreased, w_{opt} increased. -UCS decreased. - Consolidation potential increased. -Swelling potential increased. -pH value increased in the textile industry and decreased in the paper industry	[65]
Dyeing		
Clayey soil	- Compression index decreased. - Consolidation coefficient increased. - Swelling pressure decreased.	[68]
Clayey soil	-PI increased. - Settlement increased. -Swelling potential increased. -Decline in strength	[72]

*γ_{dmax} = maximum dry density, w_{opt} = optimal water content, LL = liquid limit, PI = plasticity index, Gs = grain density, UCS= unconfined compressive strength

4. Conclusions

The issue of contaminated soils and choosing the best remediation strategy for polluted soils are currently a global concern. Petroleum hydrocarbons are major contaminants on a national and international scale. Soils impacted by petroleum hydrocarbon and industrial effluents are expanded, risking the use of such soils in engineering practices. As a result, contaminated soil remediation is a practical requirement. Changes in soil properties and behavior in response to contamination and the suggested remediation techniques are reviewed. According to the current review, it is possible to conclude that the geotechnical properties of contaminated soils were found to deteriorate upon contamination. For the same contamination, contradictory results are reported about the changes in Atterberg's limits. Some studies indicate decreasing while others showed increases. Similar behavior is also reported about the compaction characteristics. All the reviewed studies revealed a reduction in contaminated soil strength and increasing compressibility potential. Most of the reported studies in the literature are for artificially contaminated soils which questioned the reliability of their findings. With the availability of various remediation techniques, selecting the best and most efficient method is based on the contamination condition (i.e., contaminator concentration, contaminator types, contaminated-layer thickness) and the soil condition (i.e., soil type, soil type, soil type, soil properties, and saturation state).

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Author Contribution Statement

Author Sahar Al-Khyat proposed the research problem and reviewed two types of petroleum hydrocarbon contamination. Author Huda T. Hamad completed the review of the last two types of petroleum hydrocarbon contamination. Author Dalia Munaff Naji reviewed the industrial effluent contamination. Author Helen Onyeaka supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

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