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Geo-Environmental Assessment for Naturally and Artificially Contaminated Cohesive Soil Remediated with Granular Carbon

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Abstract: The present study is focused on the ability of granular activated carbon (GC) for reduction of contaminants in polluted soils and its effect on physical and chemical properties of these soils. The effect of thermal power plant effluent on soil characteristics was also evaluated by conducting physical and chemical laboratory experiments. The contaminant was industrial effluent obtained from Al-Musayyib thermal power plant located in Iraq which is disposed as side product. With percolation of effluent from drainage into the soil, many processes like physico-chemical decomposition process, ion exchange reactions, chemical alterations, oxidation, hydrolysis etc. lead to the changes in natural soil properties. For these reasons, two types of soils have been proposed, first is naturally contaminated soil obtained from the site nearby of drainage channel which is located in Al -Musayyib power plant discharging industrial effluent for nearly 20 years. The second soil is artificially contaminated soil obtained from Aligarh (India), at depth "3 m"; the soil was contaminated by mixing with the 15% of the effluent collected from Al-Musayyib thermal power plant and contaminated for seven days.

Granular carbon was added to the naturally and artificially contaminated soil in proportions of 5 and 10%, by dry weight of the soil and thoroughly mixed to ensure homogeneity. For physical properties of each percentage performed by specific gravity, compaction, natural water content, filled and dry density and chemical properties for two percentages performed by pH, EC, TDS, ORG, Cl, SO_4, NO_3 and heavy metals. The soil samples were air dried and crushed and then sieved by 4 mm sieve, then the contaminated soil was mixed with GC which passed through sieve (1.17 mm). The results in this research showed slight changes in soil properties when mixed with effluent whereas in naturally contaminated soil, the results showed more changes in geo-environmental properties.

Key words: Granular carbon, contaminant soil, geo-environmental properties, naturally contaminated, artificially contaminated, thermal power plant.

Introduction

Contaminated place carries a number of compounds into the environment that could be a hazard to human health or the surroundings. These compounds might be chemicals, which can include heavy metals or solvents, or other pollutants like medical waste materials. Land contamination will probably be an outcome of: (1) manufacturing techniques after being transferred to the site, (2) materials preserved or disposed on the site, (3) several farming normal practices on the site, like sheep dip or where agriculture chemicals have been prepared for usage, (4) pollutants in selected fill, (5) destruction (Worksafe et al., 2005), (6) rainfall, like

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acidity rains coming onto a sanitary landfill, oil or chemical effluent dropped into the soil and (7) physico chemical conversions, that typically permit polluting compounds to shift inside or within soil layers.

The susceptibility of soil to environment is based not only on the regional environment but additionally affected by mineral composition, like particle size, bonding characteristics within particles, ion exchange capacity, etc. The tinier the soil particle higher is its capacity to bind to the environment. The weaker the bonding potential inside particles or larger the cation exchange capacity, the more the susceptibility of the particles to the environment. For, example, montmorillonite is potentially greater sensitive to the environment than illite and kaolinite. Sivapullaiah et al. (2009) studied the effects of oil contamination on the geotechnical properties of basaltic rock of grads (V and VI) and artificially contaminated with 4, 8, 12 and 16% oil of the dry weight of based soils. The results clearly showed a drop in the Atterberg limits, maximum dry density and optimum moisture content due to an increase in oil content. Similar behaviour was observed on permeability and shear strength of weathered basaltic soils. Hassan et al. (2013) researched the consequence of pH variance in geotechnical properties of contaminated soil samples with household and industrial waste. The undisturbed and disturbed soil samples were obtained at a depth of eight feet from natural ground level. The results pointed out that with increase in pH recompression index, moisture content, shrinkage limit, liquid limit and plastic limit increases in case of highly alkaline soil while undrained shear strength and pre consolidation stress increases with pH.

Patel (2014) studied the effects of toxins like Ba, Cr, Zn, Cu, Ni, Co, V and Sr obtained from Durga Enterprise, Vadodara on the geotechnical characteristics of black cotton soil. The results found that the addition of toxins decreases the specific gravity and optimum moisture content while the liquid limit, plastic limit and maximum dry density were increased with addition of toxins. Shehzad et al. (2015) introduced the effects of liquid effluents from three industries namely Paper, Textile, and Tyre and Tube industries on some geotechnical properties (strength, deformation characteristics and physiochemical) of low plastic clay. The soil samples have been mixed with the liquid effluent in a percentage of 5, 10 and 20% later the soil samples were remolded for additional shear strength and consolidation tests. Final results pointed out that the liquid limit, angle of internal and cohesion values decreased with increase of three influents percentage. Consolidation parameters of soil (void ratio and compressibility) increased with increase in effluent percentages. Karkush et al. (2015) studied the geotechnical properties of clayey soil artificially contaminated with different percentages of liquid effluent obtained from Al-Musayyib thermal power plant by soaking process. The results showed a decrease in the percentage of finer, Atterberg's limits, the coefficient of consolidation, and shear strength parameters while increasing the concentration of contaminant in the soil samples. Tadza et al. (2017) stabilized the soil with the addition of two percentages (5 and 10%) of powdered activated carbon (PAC) which is used as riverbank filtration (RBF) structure. Consolidation test reported that there have been a number of variations into the pressure-void ratio relationship, considering that the variation on soil characteristics when using the activated carbon filters could possibly influence equilibrium of the riverbank.

The objective of the present study was to investigate the changes in geo-environmental properties of soil contaminated with the effluent of thermal power plant. The remediation by adding granular carbon for both naturally and artificially contaminated soil is also presented.

Materials and Methods

Artificially Contamination Soil Sample (Indian Soil)

Disturbed unpolluted clayey silt soil sample was obtained from Aligarh Muslim University located in Aligarh city, India at depth 3 m named (S1). The particle size distribution curve for teased soil (S1) is shown in Figure 1. The sample was air dried and crushed by wooden hammer and then passed through sieve (4 mm) before conducting the physicochemical laboratory tests. The physicochemical properties of intact soil are given in Table 1. The liquid industrial effluent was mixed with intact soil in percentage of 15% by dry weight of soil and then kept for seven days in tight cover plastic container

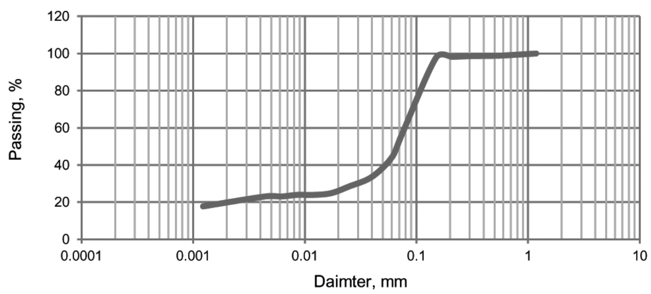

Figure 1: Particle size distribution curve for standard soil.

Table 1: Physico-chemical properties for artificially contamination soil samples

Type	*Test*	*Original soil sample (S1)*	*15% effluent (S2)*	*5% carbon (S3)*	*10% carbon (S4)*	*Standard specification*
Physical properties	*Gs	2.700	2.683	2.650	2.532	ASTM D 854-00 (ASTM)
	γd_{max} kN/m^3	18.42	18.10	17.60	17.21	ASTM D 698(ASTM)
	ωopt %	13.50	14.50	16.00	17.50	
	k m/sec	$3*10^{-9}$	$2*10^{-9}$	$2*10^{-9}$	$2*10^{-9}$	ASTM D 2434(ASTM)
Chemical properties	pH	8.50	8.39	8.75	8.88	BS1377:1990(BS 1377)
	EC µs/cm	709	770	698	696	EC meter
	Temp. °C	18.7	18.4	18.0	18.2	
	Org. %	1.13	2.18	3.4	4.9	BS1377:1990(BS 1377)
	TDS mg/l	396	435	395	391	
	Cl^- mg/l	169.95	219.93	197.94	193.94	
	SO_4 mg/l	145	175	155	145	
	NO_3 mg/l	2.2	7.5	5.5	3.9	Spectrophotometer (DR 2800)
	Cu mg/l	0.267	0.306	0.189	0.123	Atomic Absorption Spectroscopy (AAS). (Lenore et al., 2015)
	Zn mg/l	0.211	0.261	0.166	0.164	
	Cr mg/l	0.177	0.177	0.171	0.132	
	Pb mg/l	0.000	0.000	0.000	0.000	
	Fe mg/l	5.628	7.016	0.168	0.000	

* Gs = Specific gravity, γ_{max} = Maximum dry density, **ωopt =** Optimum moisture content, *k* = Permeability, EC = Electrical conductivity, Temp. = Temperature, Org = Organic matter, TDS = Total dissolved salts, Cl^- = Chloride content, SO_4 = Sulphate, NO_3 = Nitrate, Cu = Copper, Zn = Zinc, Cr = Chromium, Mn = Manganese, Pb = Lead, Fe = Iron

for analysis. This artificially polluted soil sample was named S2. For treatment purposes, two percentages (5 and 10%) of granular carbon passed through sieve (1.17 mm) were mixed with contaminated soil (S2) in solid face by dry weight. The treated soil sample mixed with 5% GC was named S3 and the sample mixed with 10% GC was named S4. The physicochemical properties of intact, contamination, and remediated soil samples are given in Table 1.

Naturally Contamination Soil Sample (Iraqi Soil)

The disturbed sandy clay soil samples used were provided by two sites for comparison purposes. The first one (site 1) consisted of naturally contaminated soil by the effluent of thermal power plant and second one (site 2) consisted of un-contaminated soil samples for examining the effect of effluent pollutants on soil physico-chemical properties. The particle size distribution curve for these soils is shown in Figure 2. The naturally contaminated soil samples were obtained from the site 1 nearby the drainage channel which is located at Al-Musayyib thermal power plant (Iraq) receiving the industrial effluent for nearly 20 years at depth (3 m) from two boreholes (No BHu1 and BHu2). The un-contaminated soil samples were obtained from site 2 which is located out of power plant site Al-Musayyib at depth (3 m) from one borehole (No BHs). The naturally contaminated soil in borehole No BHu2 was mixed with granular carbon in two percentages (5 and 10%) passed through sieve (1.17 mm) by dry weight in solid phase for treatment purposes. The treated soil sample mixed with (5%) GC named C5% and the sample mixed with 10% GC named C10%. The physicochemical properties of polluted, unpolluted, and remediated soil are given in Table. 2.

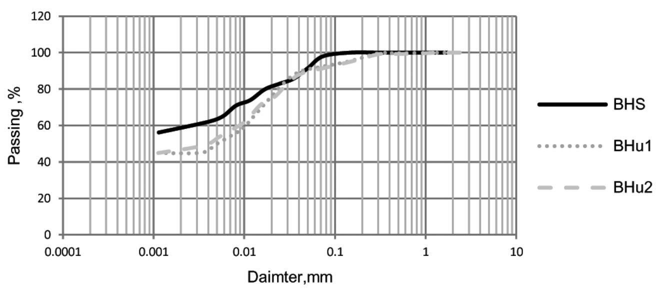

Figure 2: Particle size distribution curve for polluted and unpolluted soil samples.

Table 2: Physico-chemical properties for naturally contamination soil samples

Type	*Test*	*BHs*	*BHu1*	*BHu2*	*BHu2 C5%*	*BHu2 C10%*	*Standard specification*
Physical properties	Gs	2.84	2.71	2.65	2.62	2.61	ASTM D 854-00 (ASTM)
	γd_{max} kN/m^3	18.54	18.3	18.1	17.2	16.82	ASTM D 698(ASTM)
	ωopt %	17.1	17.5	17.46	18.50	21.00	
	k m/sec	9.0×10^{-11}	5.2×10^{-11}	4.9×10^{-11}	4.1×10^{-11}	4.1×10^{-11}	ASTM D2435(ASTM)
Chemical properties	pH	7.85	7.74	7.72	7.80	7.85	BS1377:1990(BS 1377)
	EC µs/cm	193	970	950	472	189	EC meter
	Temp. °C	28.7	29.5	29.4	28.9	29.5	
	Org. %	1.0	3.5	2.99	5.19	6.05	BS1377:1990(BS 1377)
	TDS mg/l	65.7	612	427	378	111	
	Cl^- mg/l	41	145	105	85	79	
	SO_4 mg/l	78.66	540	797	511	468	
	NO_3 mg/l	1.31	22.4	23.8	10.4	9.8	Spectrophotometer (DR 2800)
	Cu mg/l	0.27	21.4	24.6	21	17.85	Atomic Absorption Spectroscopy (AAS). (Lenore et al. 2015)
	Zn mg/l	0.06	25.2	65.0	59.3	47.1	
	Cr mg/l	0.023	57.9	56.5	51.6	45.6	
	Pb mg/l	ND	0.6	ND	ND	ND	
	Fe mg/l	2.02	32499	34508	32883	31938	

Effluent

The liquid effluent was obtained from Al-Musayyib thermal power plant located in Iraq which is disposed as side product. The effluent was collected from the treatment unit in sampling bottles and immediately refrigerated at 4°C. To understand the effect of wastewater on physico-chemical properties for the soil, the effluent chemical analysis are given in Table 3. Wastewater chemical analysis were taken up in accordance with "Standard Method for the Examination of Water and Wastewater" (Lenore et al., 2015).

Table 3: Chemical properties of liquid effluent

pH	6.58	Mineral content mg/l	
Alkalinity	52	Cl^-	99.97
Total hardness mg/l	170	SO_4	200
Calcium hardness mg/l	112	NO_3	0.50
*BOD_5 mg/l	111	Cu	0.034
COD mg/l	50	Zn	0.005
EC µs/cm	880	Cr	0.000
TDS mg/l	800	Pb	0.000
TSS mg/l	40	Fe	1.962
Temp. °C	7.6		

*BOD_5 = Biochemical oxygen demand, COD = Chemical oxygen demand, TSS = Total suspended solids

Results and Discussion

Physical Properties

Specific Gravity (GS)

The specific gravity of soil solids is supported to recognize the quantity for soil grains in geotechnical characteristic. As shown in Figure 3 for artificially contaminated soil, the specific gravity was decreased with addition of wastewater. This may be due to the acidic nature of the effluent; some corrosion may happen for the weak surface layer of soil particle. Similar behaviour was noted in the naturally contaminated soil. Similar observations were reported by Patel (2014) and Pillai et al. (2014). The results also show that the specific gravity decreases with the addition of granular carbon for both naturally and artificially contaminated soil. This action is due to the low specific gravity of granular carbon and the results are in agreement with Tadza et al. (2017).

Proctor Compaction

The proctor compaction characteristics of both artificially and naturally contaminated soil were studied and the results are shown in Figure 4. The dry density was decreased in both types of soils. This may be due to the exchange of ions at the surface of polluted soil particles. The decrease in double layer thickness due to chlorides in the effluent leads to rise in attractive forces and reduction in repulsive forces leading to flocculated structure or, may be due to the low specific gravity for polluted soil. Similar attitude was discovered by Rao et al. (2012) for the soil treated with textile and battery effluents; Oluremi et al. (2012) for the effect of wastewater on soil properties; Prakash et al. (2013) for the soil treated with acid contaminates and Karkush et al. (2015) for the soil treated with thermal power plant effluent. From the results shown, it can be noticed that the maximum dry density value decreases with granular carbon addition to both type of soils (Figure 4). This action is attributed to the low specific gravity of granular carbon.

As shown in Figure 5, the optimum moisture content increased in both polluted and treated soils. This behaviour may be due to the contaminant entering the water within creative voids from flocculated structure, and this leads to water retaining capacity of soil increased; therefore optimum moisture content increased. These results are in convergence with those of Rao et al. (2012), Oluremi et al. (2012) and Karkush et al. (2015) during their study for the effect of industrial effluent on soil compaction characteristics.

Permeability

Falling head permeability test were conducted for artificially contaminated soils (standard and mixed). The contaminated soil permeability values were obtained from odometer test equation and the values are shown in Figure 6. The permeability decreases with the effluent addition, in mixed soil as shown in Figure 6a. A clear drop in permeability for naturally contaminated soil in comparison with reference soil is shown in Figure 6b. The reduction in permeability may be due to the total dissolved salts or acidic nature of the effluent leading to maximizing the fines in soil. These fines filled some of the void locations in the soil, thereby reducing the simplicity of water flows through the soil. The results also confirm that the addition of granular carbon has no affect on the permeability of either naturally or artificially contaminated soil.

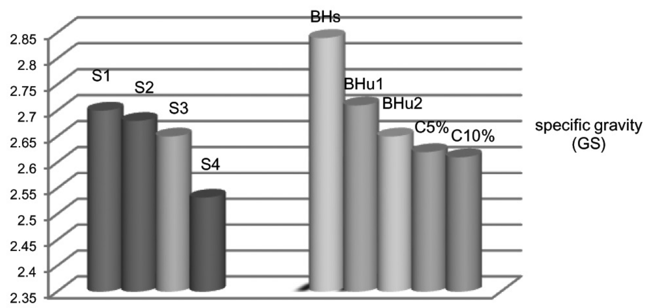

Figure 3: Variation of specific gravity.

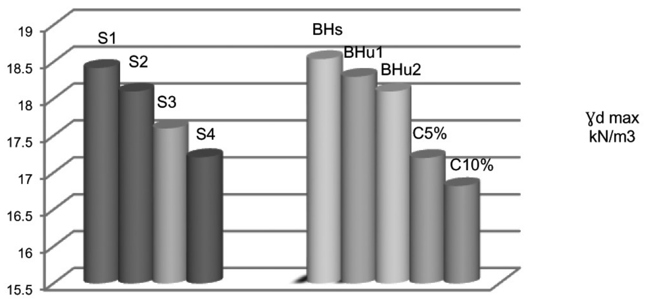

Figure 4: Variation of maximum dry unit weight.

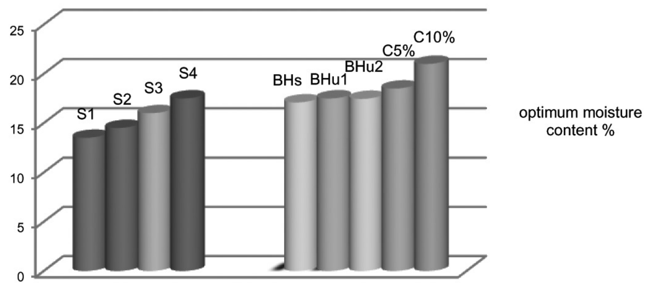

Figure 5: Variation of optimum moisture content.

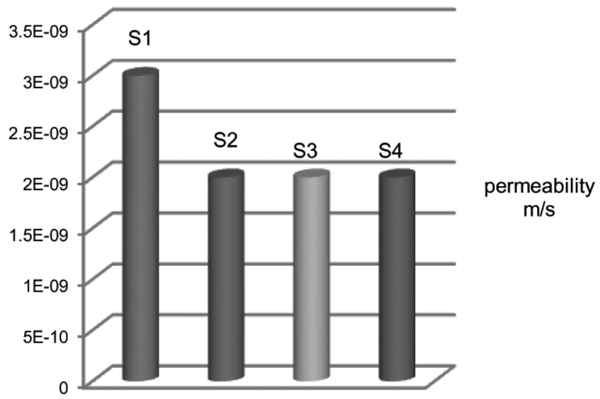

Figure 6a: Variation of permeability artificially contaminated.

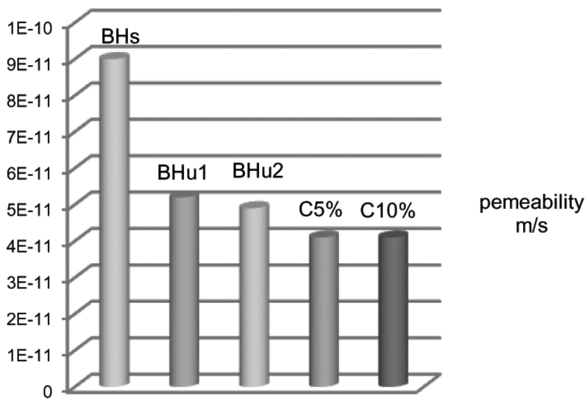

Figure 6b: Variation of permeability naturally contaminated.

Chemical Properties

pH Value

The pH is an important indicator of the leachate as a pure fluid of the soil. Due to the low pH for contaminant (pH = 6.58) as shown in Figure 7, the pH of soil is decreased in comparison to the reference soil for both artificially and naturally contaminated soil. The same was observed by Asadi et al. (2011), Wang et al. (2013), Pillai et al. (2014), Karkush et al. (2015) and Praveena et al. (2016). Generally, lowering the soil pH value leads to variations in the soil-water structure, the soil-water adsorption, and movement of the pore fluid. Reduced pH may assist the soil particles to aggregate and reduce the soil inter-particle repulsion. The pH value of soils after remediation with the granular carbon was found to increase which agrees with the findings of Tadza et al. (2017).

Electrical Conductivity and Total Dissolved Solids

Electrical conductivity is the capacity of a material to conduct an electrical energy; its assessment correlates with soil characteristics such as soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, salinity, and porosity (Grisso et al., 2009). In this study, EC meter was used to measure the electrical conductivity of soil solution with 1:2 ratio of soil and water to give an indication of the total dissolved solids (TDS) (Glewa et al., 2013; Dutta et al., 2016). A significant increase in EC and TDS of the contaminated soil was noted as shown in Figures 8 and 9 respectively as observed by Asadi et al. (2011) and Praveena et al. (2016) when they studied the effect of municipal solid waste on soil properties. It shows that further dissolved solids in the soil may easily be discovered by electrical conductivity (Grisso et al., 2009). The effluent affecting as charge carrier due to the increased EC of pore fluid electrical potential of the soil may cause various changes in soil porosity (Rao et al., 2012). Due to granular carbon addition, a clear decrease in total dissolved solids leading to a decrease in electrical conductivity was observed.

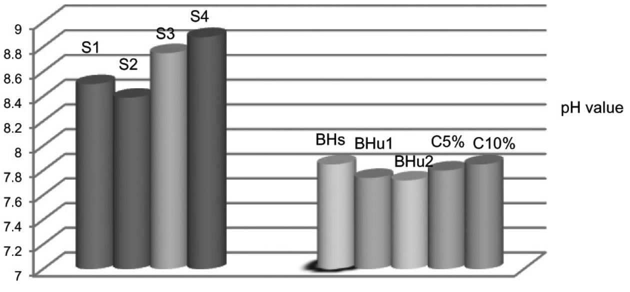

Figure 7: Variation of pH value.

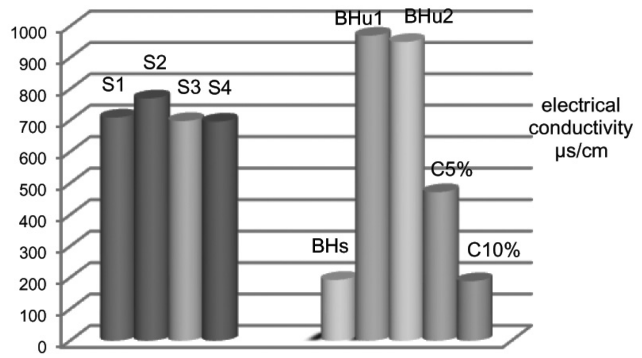

Figure 8: Variation of electrical conductivity.

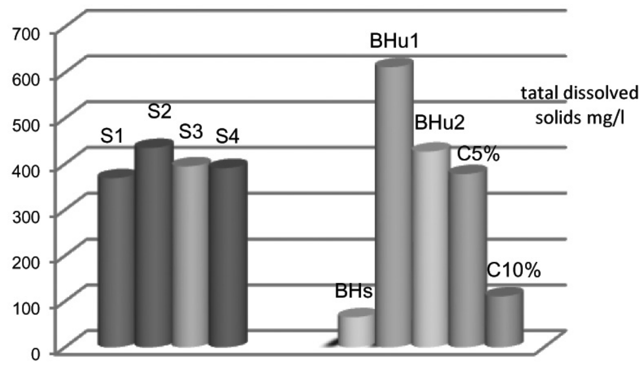

Figure 9: Variation of total dissolved solids.

Chemical Elements

The concentrations of Cl^-, SO_4, NO_3, Cu, Zn, Cr, and Fe in both artificially and naturally contaminated soil samples were significantly higher than the standard soil as shown in Figures 10 through 14. The increase in concentrations of metals in the polluted soil may be attributed to the effluent nature (Jayashree et al., 2012). The enhanced concentration of lead, manganese and iron seems to be associated with higher values of organic matter, pH and conductivity in soil (Deka et al., 2012). Raising the concentration of iron and manganese in soil is able to minimize the concentration of cadmium or lead dissolved in polluted soil (Mckenzie et al., 1980). The concentration of chloride, sulphate, nitrate, iron, copper, zinc, and chromium was found to decrease due to remediation with granular carbon due to the strong sorption characteristics of activated carbon. It does not move contamination problems from one place to the other, and it does not release new pollutants while dredging or digging (Hilber et al., 2010). The organic elements are normally incorporated inside the pores of the binding material, and their interring based on their solubility in water and their diffusivity within the waste matrix (Loretta et al., 2012).

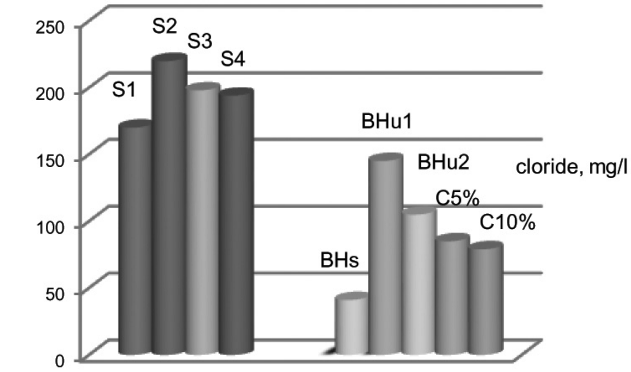

Figure 10: Variation of chloride concentrations.

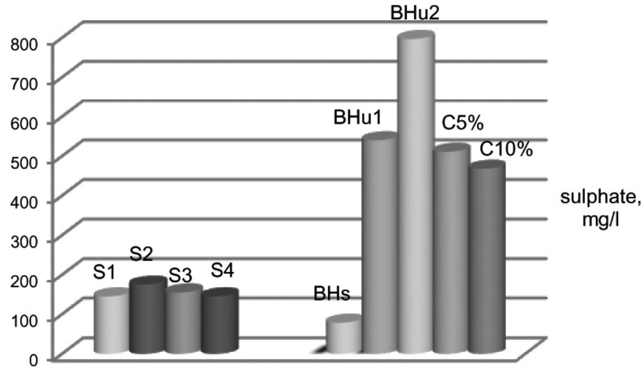

Figure 11: Variation of sulphate concentrations.

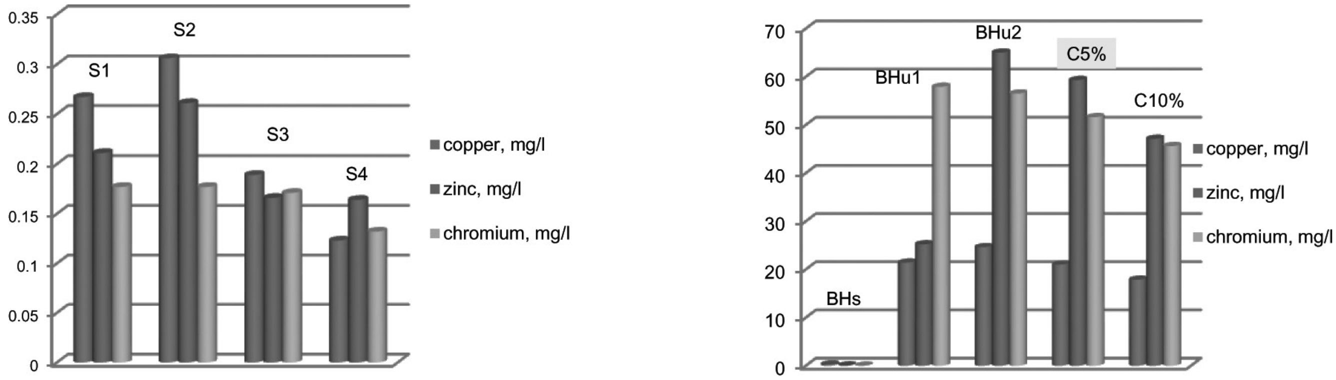

Figure 12: Variation of copper, zinc and chromium concentrations.

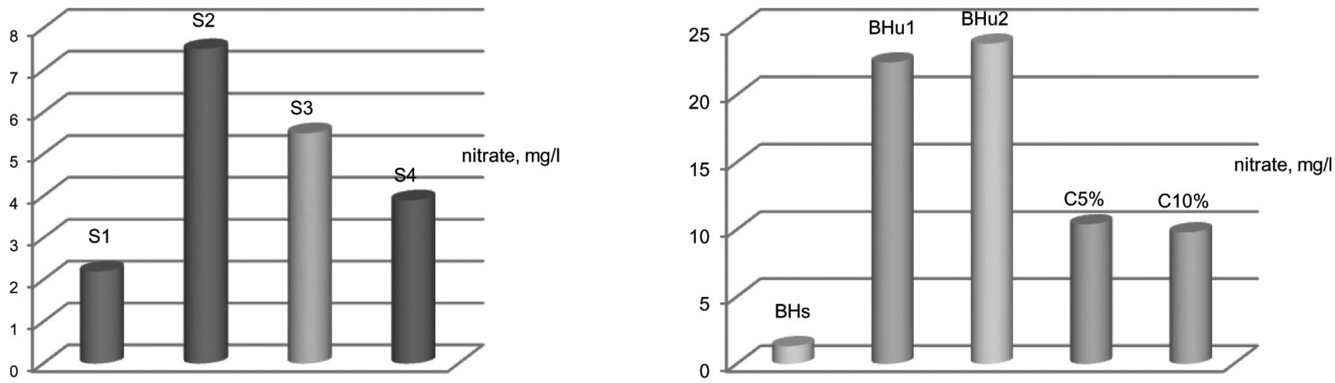

Figure 13: Variation of nitrate concentrations.

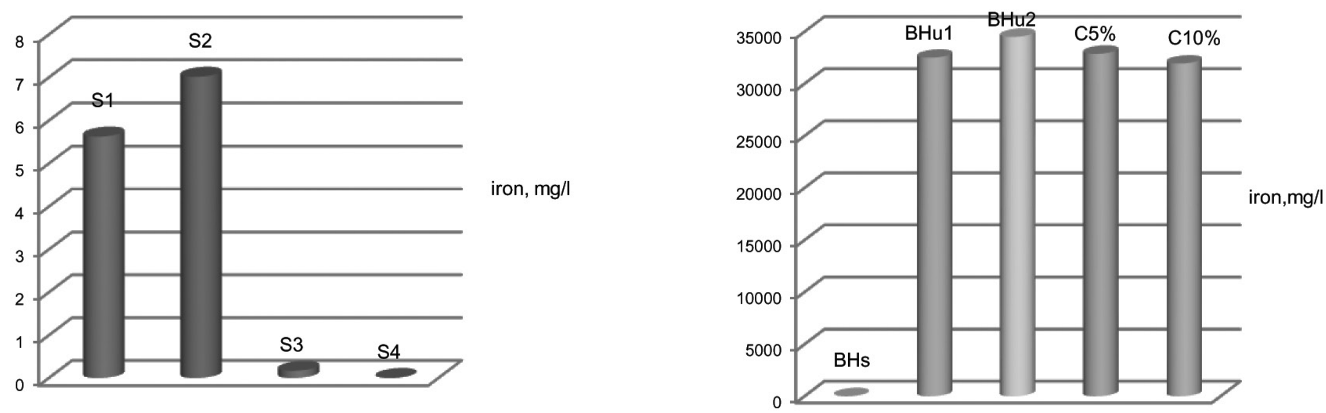

Figure 14: Variation of iron concentrations.

Conclusions

In this research, the geo-environmental properties of soil contaminated with the effluent of thermal power plant was studied. The remediation using granular carbon for both naturally and artificially contaminated soil is also presented. The following conclusions may be drawn from the test results:

- The naturally contaminated soil, exposed to pollution for twenty years, showed many changes in the geo-environmental properties as against the artificially contaminated soil.
- Specific gravity, maximum dry density, and permeability values were decreased in the contaminated soil while the optimum moisture content was increased due to the effluent physical properties. After remediation with granular carbon addition to contaminated soil, the specific gravity and maximum dry density were decreased. This may be due to the low specific gravity of granular carbon. The optimum moisture content was found to increase in the soils remediated with granular carbon.
- The pH value was decreased in the polluted soil due to the acidic nature of the effluent. The increase in the electrical conductivity of contaminated soil may be attributed to the dissolved solids in the effluent. Due to the addition of granular carbon, the pH of soil increased whereas EC and TDS values were decreased.
- The increase in chloride, sulphate, nitrate, iron, copper, zinc, and chromium concentrations is due to the effluent chemical properties. This change in chemical properties of soil may lead to problems in the foundation like the corrosion of concrete due to higher sulphate content. The use of granular carbon lead to minimize the concentration of these ions thereby proving the ability of this material to improve chemical properties of polluted soil and check the pollution.

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