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POLLUTION ASSESSMENT AND REMEDIATION OF A CONTAMINATED SITE: A CASE STUDY

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Abstract: Industrial activity is necessary for the socio-economic progress of a country, but at the same time, it generates large amounts of solid and liquid waste. Industrial waste is usually much smaller in volume, but is more likely to contain hazardous materials, such as toxic chemicals, flammable liquids and asbestos. Although the total amount is less, the disposal of hazardous industrial waste is a matter of greater concern than that of domestic waste because of health hazards and the risk of environmental contamination. A case study was conducted to assess the effects of pollution on soil and water quality in Cherthala, Alappuzha District, Kerala State, India. Currently, many industries are located in and around Cherthala. A majority of these are small-scale industries, ice plants and fish units. As a primary step, reconnaissance of the site was carried out. Experimental investigations were conducted on water and soil samples collected from different areas. Water quality and soil quality parameters were analysed. Chemical analyses of soil samples primarily revealed the presence of iron, sulphur, zinc and copper above permissible limits. Considering the greater abundance of sulphur in the soil than the other constituents, the remediation of sulphur-contaminated soil was undertaken. It was found that chitosan, a by-product of the fish industry, could be effectively used for this purpose.

Keywords: Soil Pollution, Water Quality, Soil Quality, Chemical Analysis, Remediation, Chitosan.

1. INTRODUCTION

Human health and well-being are intimately linked to environmental quality. Over the last three decades, global concern about the public health impact attributed to environmental pollution has been increasing, in particular, the global burden of disease. The World Health Organization (WHO) estimates that about a quarter of the diseases affecting mankind today occurs because of prolonged exposure to environmental pollution, which includes soil, water and air pollution. Improper management of solid waste is one of the main causes of environmental pollution, public health issues and degradation of land, especially in developing countries. Waste is disposed of on available land area or in water bodies near industries, leading to soil and water pollution, respectively. The vegetation of these regions is affected by the pesticides and chemicals discharged from industries, and their consumption causes human health problems. Soil is nature's wonderful gift, but now, soil degradation or pollution due to various pollutants, agrochemicals, trace elements, etc. from industries is an important global issue. The contaminants become attached physically or chemically to soil particles or remain trapped in the small spaces between soil particles. In the presence of excess moisture or precipitation, a leachate is formed, which reaches the groundwater table and finally the water resources.

Gangadhar [1] described that soil contamination may be responsible for health effects, and human activities, such as mining, smelting, agriculture, industries and burning of fossil fuels, result in the deposition of heavy metals, for example, Cd and Hg, in the soil. Raman and Sathiya [2] studied a landfill site at Pallavaram District in Tamil Nadu and analysed the soil and water quality parameters in the surrounding area, which indicated the presence of contamination due to solid waste materials dumped in the area. Alsolame and Alhogbi [3] conducted a case study to determine toxic elements in soil in Jeddah, Saudi Arabia. A total of 23 samples were collected from three different areas of Sewage Lake: area A (highly polluted area), area B (southeast) and area C (northwest). The results indicated that the indiscriminate disposal of hazardous waste in the study area was a significant source of soil contamination. Alhassan [4] studied the effect of municipal solid waste on the geotechnical properties of soil and showed that municipal solid waste lowers the maximum dry density, cohesion and angle of internal friction. Moreover, it increases the permeability and compressibility of soil and these effects reduce with depth. E The study on the impact of municipal solid waste on the geotechnical properties of soil and water quality in Trichy conducted by Evangelin et al. [5] indicated severe pollution in groundwater and revealed that the compressibility and liquid limit were increased.

Pradeep et al. [6] analysed the water quality parameters of an organically polluted lake. Investigations were performed to assess the pollution status, and the large variations in parameters were due to the result of human activity and discharge of waste water to the Chandola lake. George et al. [7] examined the origin and spatial distribution of fluorides in the deep aquifers of Ambalapuzha river basin in Alappuzha District. The comparative study of past and present data on 15 tube wells revealed the drastic increase in fluoride, resulting in the increase in pH and withdrawal of groundwater from the clay bed, in turn leading to an increase in Na, which promoted the leaching of fluoride and focused to avoid deep aquifers in that basin. Bakkialakshmi et al. [8] conducted a spectrochemical study in a sugar factory in Cuddalore District in Tamil Nadu. A physico-chemical analysis of soil samples was conducted and the pH was found to be >7, indicating that the soils in these localities became alkaline because of waste from the sugar factory.

Remediation deals with the removal of pollutants or contaminants from soil or water to protect the environment and people from serious health issues. Researchers conducted studies on remediating chemical contamination by using different reagents, such as biomaterials, rock phosphate, and EDTA, in the soil to reduce pollution. Dadrasnia and Eminikamani [9] studied the remediation of contaminated sites and found that numerous organic pollutants, such as pesticides, polyaromatic hydrocarbons and inorganic pollutants, are resistant to degradation. Thus, bioremediation techniques became a promising alternative to traditional physico-chemical methods for the remediation of hydrocarbons at a contaminated site. Krishna [10] studied the effectiveness of in situ remediation technologies on soil and focused on the application of integrated electrokinetic remediation, which confers health, environmental and financial benefits. Electrokinetic remediation has a great potential for in situ low-permeability soils; it enhances remedial efficiency and overall remediation costs. Moret and Rubio [11] conducted sulphate adsorption studies with chitin flakes having a 25% deacetylation degree, produced from industrial shrimp shell waste at various adsorbent concentrations, medium pH and other operating conditions. The best sulphate removal efficiency of 92% was obtained at a pH of 4.5 with 15-min contact time. Yong et al. [12] showed that chitosan (poly-*N*-acetyl-polyamine), an efficient by-product of a waste biomaterial of the fish industry, has great potential for the remediation of organic and inorganic contaminants from waste water and soil. With certain limitations in acidic environments with high solubility and low structural capability, chitosan and its derivatives can be used to remediate contaminated soil and waste water. Schwarz et al. [13] conducted a study on the degradation of chitosan slurries. A parametric study was carried out with chitosan concentrations of 1% and 2% at different temperatures (25ºC, 37ºC and 50ºC). The samples were tested in dynamic sweep test mode, which relates viscosity variations with the degradation rate. Padill-Rodrígueza and Codling [14] found that extraction with chitosan successfully removed 0.96–17% of arsenic, 0.88–31% of phosphorous, and 0.66–11% of lead from lead arsenate–contaminated soils from seven sites in USA. Hou et al. [15] evaluated the life cycle impact of phytoremediation in cleaning up perchloroethylene-contaminated plumes at a site in the San Francisco Bay Area. As the sea level rises, the hydraulic gradient decreases, which resulted in slower plume migration and life cycle impact.

This study focused on the environmental issues of soil and water pollution in Cherthala region. The motivation of the study stemmed from newspaper reports on the environmental issues prevailing in Kodamthuruthu region of Cherthala and the health risks to people due to the existing improper waste management systems of small-scale industries in this area. The main aims of this study were to assess the pollution-causing elements and to remediate the soil using a waste biomaterial. The methods prescribed in the manual of soil testing in India were adopted in our experiments[16].

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted in Kodamthuruthu Panchayat in Cherthala, an area in Alappuzha District, Kerala State, India. The location of the study area is shown in Fig. 1. The area consists of many lakes, ponds and other water bodies. Several small-scale fishing units and ice plants are located in the area, mostly near the water bodies. These factories use various chemicals and after processing, dispose of the effluents into these water bodies. Newspaper reports have pointed out the spreading of diseases, such as cancer, allergy and itching of the skin, among the residents of areas near these factories. Thus, this study focused on the need to analyse this issue.

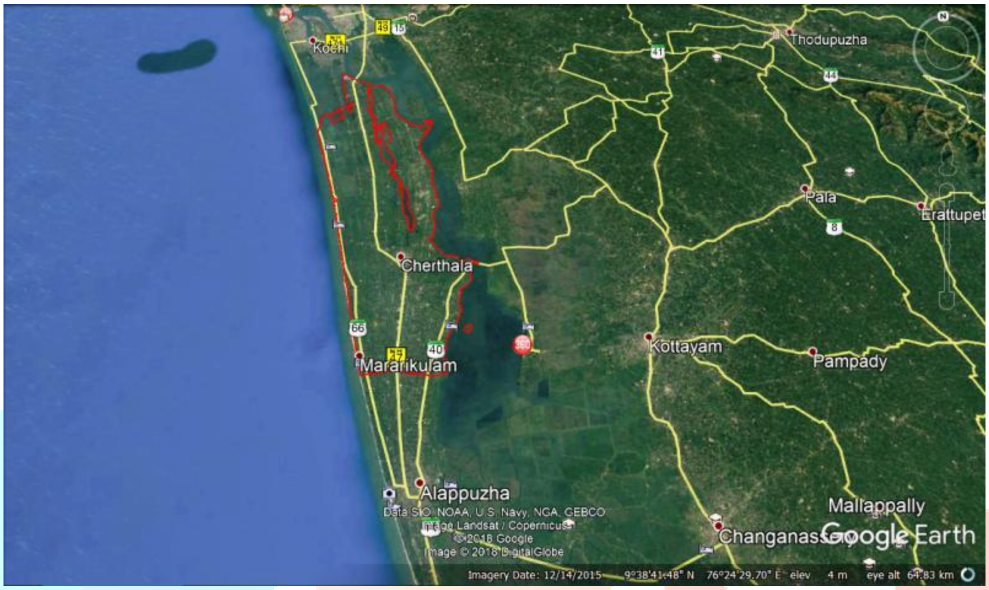

Figure 1. Location of the study area

A reconnaissance of the area was conducted to locate the most affected area in Kodamthuruthu Panchayat, using a questionnaire along with observations of water bodies and soil. From interactions with the public, the total population was found to be 21,295, of whom 44 were patients with cancer and 243 people with disabilities. Significant colour changes were visible in the wells, ponds and lakes. The well water was observed to be oily, with a musty odour and brownish-yellow colour. Kakkathuruthu, Chammanadu, Kuthiathode and Thykoodam were found to be the most affected areas. The people in these areas were severely affected by pollution. The location of the polluted area is shown in Fig. 2.

Figure 2 Location of the polluted area

2.2 Sampling and Sample Collection

Soil and water samples were collected from various sites of the study area according to the standards of sample collection.

2.3 Water Sample Collection

A total of eight water samples were collected from four distinct areas. The water samples were collected from two lakes (L1 and L2), three wells (W1, W2 and W3), two ponds (P1 and P2) and one canal (C) of the polluted area under consideration. Parametric studies of water samples were carried out according to Indian standards (IS).

2.4 Soil Sample Collection

Four soil samples were collected from four distinct areas as follows: sample S1 from a canal near Chammanadu, S2 near a pond from Chammanadu in Kodamthuruthu Ward 5, S3 near a pond from Kuthiathode and S4 from the locality of a house in Ward 7 of Chammanadu. Soil samples were dried by spreading them out on a clean plastic sheet placed over a bench in the laboratory, and pebbles and plant roots were removed manually. Samples were left to dry at room temperature for a week, after which they were stored at room temperature in self-sealing plastic bags. Sieve analyses were conducted using the air-dried samples. The geotechnical properties of the soil samples are presented in Table 1.

Table 1 Properties of soil samples collected from different sites

Soil properties	(S1)	(S2)	(S3)	(S4)
Specific gravity	2.66	2.66	2.65	2.66
Gravel (%)	0	0	0	0
Coarse sand (%)	16	1	10	15
Medium sand (%)	71	76	74	70
Fine sand (%)	13	17	16	15
Silt and clay (%)	0	0	0	0
Sand (%)	100	100	100	100
Cu	4.64	3	3.72	4.64
Cc	1.35	1.09	1.18	1.85
Angle of internal friction (°)	46	45	40	45
Permeability (cm/s)	1.56×10^{-2}	1.55×10^{-2}	1.64×10^{-2}	1.56×10^{-2}

Atomic absorption spectroscopy was used to determine environmentally toxic elements, according to methods of the Environmental Protection Agency (EPA).

2.5 Remediating Agent

The biomaterial chitosan was used for the remediation of soil samples. Chitosan has potential application to the remediation of contaminated soil. Its key property is the presence of amino groups ($-NH_2$) and hydroxyl groups ($-OH$), which provide binding sites for contaminants. Chitosan, a by-product of the fish industry, is produced from the shells of crab and shrimp. The powdered form of chitosan was obtained by the deacetylation of chitin, the structural element in the exoskeleton of crustaceans, such as crabs and shrimp (see Fig. 3). It was found that powdered chitosan can be used successfully to reduce different types of contaminants or chemicals in soil. Chitosan was procured from Pelican Biotech & Chemical Labs (Kodamthuruthu). One gram of chitosan powder was dissolved in 5 mL of acetic acid (0.01 N), which was then diluted with 10 mL of water. This solution was sprayed on to 100 g of collected soil samples, mixed well and air dried. The properties of chitosan are presented in Table 2.

Figure 3 Chitosan sample used in this study

Table 2 Properties of chitosan

Physical properties	Appearance	Off-white powder
	Particle size (nm)	15
	Specific gravity	2.8
	Specific surface area (m^2/g)	650–815
Chemical properties	Degree of deacetylation	>90%
	Solubility of 1% chitosan in 1% acetic acid	>99%

2.6 Experimental Study

The water characteristics of the collected water samples were evaluated and water quality parameters were analysed according to IS ([IS10500], [IS3025 (part 11)], [IS2296] and [IS456]). Parameters such as colour, pH, turbidity, hardness, acidity, alkalinity, biochemical oxygen demand, chemical oxygen demand, dissolved oxygen (DO), sulphate, nitrate, sulphide, chloride, etc. were analysed. The soil characteristics of the samples collected from the various sites were studied and soil parameters were analysed according to IS [IS2720]. Chemical analyses of the soil included iron, manganese, lead, sulphur, calcium and magnesium. The remediation of soil samples was carried out using chitosan.

3. RESULTS AND DISCUSSION

3.1 Water Quality Analyses

The comparative results of water quality parameters from the lakes, ponds, canal and wells, as well as their desired limits according to IS10500, are presented in Table 3. Turbidity values of all samples were within permissible limits. From the results, it was inferred that excess iron content (2–3 times more than the permissible limits) was present in samples collected from the lakes, canal and ponds. The iron content in well water samples was within the permissible limit. Increased iron content in the body is toxic to human health and can cause genetic diseases such as iron overload. A high iron content in water samples indicates the effect of industrial pollutants. An increase in the iron content in water is harmful as it promotes the undesirable growth of iron bacteria in water.

Table 3 Comparison of results of water samples collected from various sources

Parameter	Acceptable limit (mg/L)	Permissible limit (mg/L)	Values of samples taken from							
			Lake		Pond		Canal	Well water		
			L1	L2	P1	P2	C	W1	W2	W3
pH	6.5–8.5	No relaxation	7.1	7.1	7.1	7.5	7.3	7	7	7
Electrical conductivity (µ℧ s/cm)	-	-	494	375	97	100	404	480	350	90
Total dissolved solids (mg/L)	500	2000	296	225	58	70	266	205	215	250
Turbidity (NTU)	1	5	2	3	5	5	3	2	2.5	3
Total hardness (mg $CaCO_3$)/L	200	600	55	90	30	40	45	50	80	30
Calcium (mg/L)	75	200	8	26	8	56	8	18	18	16
Magnesium (mg/L)	30	100	8.5	6.1	2.4	20	6.1	3.6	3.6	1
Sodium (mg/L)	-	-	84	39	5.4	30	55	29	29	10
Potassium (mg/L)	-	-	0.6	0.5	0.3	2	0.5	1.43	1.4	0.3
Sulphate (mg/L)	200	400	19	16	3.8	100	16	44	3	20
Chloride (mg/L)	250	1000	155	108	13	153	115	44	44	-
Fluoride (mg/L)	1	1.5	0	0	0	0.1	0	-	-	0.11
Iron (mg/L)	0.3	No relaxation	0.8	0.7	1.3	0.25	0.7	0.18	0.18	0.1

Nitrate-N (mg/L)	10	No relaxation	1.2	0.25	0.6	0.5	0.24	0.1	0.1	-
Silica (mg/L)		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total coliform (MPN/100 mL)		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil

MPN, most probable number; NTU, nephelometric turbidity unit.

A high level of sulphur in the water samples indicates the presence of sewage or industrial waste, and can cause health problems such as diarrhoea. Such water should be used for domestic purposes only after proper treatment.

A fluoride concentration up to 1.0 mg/L in drinking water is beneficial for the human body. However, a fluoride concentration >1.0 mg/L is considered deleterious to health and is the cause for dental and skeletal fluorosis (Central Public Health Environmental Engineering Organisation [CPHEEO]). The water samples were tested for fluoride, and values <1 mg/L indicated that the concentration is reduced because of dilution. According to the CPHEEO manual, the permissible limit of fluoride in drinking water is 1.0–1.50 ppm. The test results showed that the presence of coliform bacteria was nil, which indicated no visible discharge of domestic and industrial waste into these water sources.

Table 4 shows the DO test results. DO is an important parameter for drinking water; hence, the water samples collected from wells and ponds were tested for DO. The DO from well samples ranged from 5.5 to 5.8 (5.5 (W1), 5.8 (W2) and 5.7 (W3)) and those from ponds (P1 and P2) ranged from 6 to 6.1. As per IS [IS2296], drinking water should contain a DO level >6 mg/L (6–8 mg/L). The well water sample results showed that they are polluted and can be used for outdoor bathing; however, they may be used for domestic purposes only after disinfection. The specification of the DO level for outdoor bathing sources for well water is 5 mg/L. For pond samples, the DO was >6.0 mg/L. Thus, they are recommended for drinking as no pollution was indicated. All the water samples tested from wells and ponds contained a DO level >4 mg/L, so they may be used for drinking after conventional treatment and disinfection. The DO level of water samples taken from the wells was not within the limit and they can be used for outdoor bathing or after disinfection.

Table 4 Dissolved oxygen (DO) test results of water samples

Sample designation	Source	DO (mg/L)
W1	Well	5.5
W2	Well	5.8
W3	Well	5.7
P2	Pond	6.1
P1	Pond	6.0

3.4 Soil Characteristic Studies

Soil characteristic studies were carried out on samples collected from four sites, Chammanadu, Kuthiathode and Kodamthuruthu wards of Cherthala area, in Alappuzha District (S1–S4). From the geotechnical properties of the collected samples, sand was found to be predominant. The samples contained about 70% of medium sand rather than fine and coarse fractions and all four samples were found to be well graded. The chemical analysis results of soil samples are presented in Table 5; they showed increased levels of certain elements, such as sulphur, calcium and magnesium, above the permissible values according to the EPA. Of these, the most dominant element was sulphur. The permissible value of sulphur in soil is 5 ppm, but the values obtained from the tests ranged from 31 to 789 ppm. The presence of sulphur in the soil has adverse effects on human health. It affects the human body when breathed in and shows symptoms such as coughing, asthma and brain damage. The sulphur content in the soil can decrease its pH, thereby making the soil acidic, which in turn has detrimental effects. The sulphur in the soil can also increase the sulphur content in the air.

Table 5 Results of chemical analyses of soil samples

Element	**Permissible value (ppm)**	**Observed values (ppm) of soil samples**			
		S1	**S2**	**S3**	**S4**
Fe	1	38.38	12.08	85.55	62.03
Mn	600	5.58	9.6	9.39	8,95
Zn	50	6.56	1.56	5.12	3.22
Cu	30	1.12	1.64	1.38	2.58
Pb	10	2.08	16.20	4.78	10.33
S	5	789.16	31.03	317.51	428.35
Ca	300	590	750	1064.25	295.03
Mg	120	201	275	325.48	987.52

This was evident from the pH obtained from the soil samples collected from various sites (5.2–5.4). Soil with a pH of 4 is ten times more acidic than soil with a pH of 5 and a hundred times more acidic than soil with a pH of 6. The odour of the area was unpleasant, which may be due to the harmful gases released into the air from the factories. The high sulphur content in the soil and the sulphur dioxide gas in the air are harmful to human health.

Calcium and magnesium are essential plant nutrients. All soils contain calcium and magnesium in the form of cations that attach to the soil, clay and organic matter. Calcium helps to maintain the chemical balance in the soil, reduces soil salinity and improves water penetration if found within the limit. From the results of collected soil samples (S1–S4), calcium and magnesium exceeded the limits, and it was inferred that the salinity of soil is affected.

3. 5 Remediation

The results of the chemical analyses of soil samples indicated that the presence of iron, sulphur, calcium and magnesium was greater than the permissible limits. On further analyses, the sulphur contents in the soil samples from the different locations were 99.4%, 83.9%, 98.4% and 98.8% higher than the prescribed permissible values. Compared to other elements that are also present in amounts higher than the prescribed limits, the sulphur content in the soil is extremely high. Hence, the remediation of sulphur-contaminated soils was considered for further investigation.

The samples remediated using chitosan were chemically analysed. After remediation of soil, the sulphur content was reduced greatly from 789.16 to 50.12 ppm (93.5%) for sample S1, 31.03 to 0 ppm (100%) for S2, 317.51 to 34.81 ppm (89%) for S3 and 428.35 to 40.85 ppm (90.46%) for S4. Chitosan is an excellent sorbent because of the abundant OH and NH_2 groups it possesses and its highly flexible structure. The mechanisms of action of chitosan include protonation of amine sites, which means that positive amines attract sulphate anions. The second method includes adsorption by ion exchange, where protonated amino groups interact with the hydroxyl group, which are displaced by the sulphate anions and are adsorbed on the negative sites, thus immobilizing the contaminants. Thus, it can be inferred that chitosan can drastically reduce the sulphur content in soil and it is suggested for use in field applications.

4. CONCLUSIONS

This case study focused mainly on the pollution assessment of water and soil samples from a contaminated site at Cherthala, Kerala, and provides a green solution to remediate this issue. The iron content was found to be above the permissible limit in the water samples collected from the lakes, ponds and canal, but it was within the limit for well water. From the analysis results, sulphur was the dominant contaminant in soil samples S1, S2, S3 and S4 (789.16, 31.03, 317.51 and 428.35 ppm, respectively), and corresponding percentage increase (99.36%, 98.42%, 83.88% and 98.83%) implied the reason for the pollution. Calcium, iron and magnesium were also found to be above the permissible limits. The soil characteristics were studied and the reduction in the sulphur content using chitosan was evaluated by using chemical analyses. The removal of 93.5%, 100%, 89% and 90.46% sulphur was achieved for soil samples S1, S2, S3 and S4, respectively. Thus, chitosan proved to be effective for the remediation of sulphur-contaminated soils.

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