

Post-Biomining Assessment of Groundwater and Soil Quality near Kureepuzha Dumpsite, Kerala

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Abstract - Leachate generated from municipal solid waste dumpsites contains dissolved salts, organic matter, and hazardous heavy metals that contribute to environmental contamination. To reclaim land and minimize environmental hazards, biomining was implemented at the Kureepuzha dumpsite in Kollam, Kerala. The present study assesses the quality of groundwater and soil in the surrounding regions after the biomining activities. Groundwater and soil samples were collected from selected sites within a 2 km radius and examined for various physicochemical characteristics and heavy metal concentrations. The pH of groundwater samples varied between 5.74 and 6.98, while electrical conductivity and total dissolved solids ranged from 102-648 microsiemens per centimetre and 65-415 milligrams per litre, respectively, and were mostly within the permissible limits. Based on pH, electrical conductivity, and organic carbon content, the analysed soil samples indicated acceptable soil quality. Analysis of heavy metals in groundwater revealed higher concentrations of lead, nickel, and iron at certain sampling locations, whereas cadmium and mercury levels were found to be within the permissible limits. Heavy metal concentrations in soil were generally within permissible standards. A natural permeable reactive barrier model developed as a remedial measure showed improvement in water clarity and reduction in pollutant concentration. The study highlights the environmental advantages of biomining and stresses the importance of continuous monitoring for long-term environmental protection.

Keywords - biomining, groundwater, soil, heavy metals, dumpsite, leachate.

I. INTRODUCTION

Municipal solid waste (MSW) dumpsites contribute significantly to environmental pollution through the generation of leachate containing dissolved salts, organic matter, and toxic heavy metals. Improperly managed waste disposal results in the infiltration of leachate into the surrounding soil and groundwater, causing environmental degradation. Groundwater contamination near dumpsites has become a serious concern because groundwater is widely used for drinking and domestic purposes in many regions.



Fig. 1. Kureepuzha Dumpsite after Biomining

For many years, the Kureepuzha MSW dumpsite in Kollam, was subjected to unscientific waste disposal practices. To reduce pollution and reclaim the land, biomining was carried out and completed at the site in 2022. The Kureepuzha dumpsite after biomining is shown in Fig. 1.

Groundwater and soil near dumpsites may contain high concentrations of physicochemical parameters and heavy metals such as lead, cadmium, nickel, mercury, and iron. These contaminants can persist in the environment for long periods and may affect human health, soil fertility, and ecological balance.

The present study focuses on assessing groundwater and soil quality around the Kureepuzha dumpsite after biomining. Groundwater samples were analysed for pH, electrical conductivity, total dissolved solids and heavy metals, while soil samples were analysed for pH, conductivity, organic carbon, and heavy metals to evaluate the environmental condition of the study area.

II. LITERATURE REVIEW

A literature review provides an overview of previous studies and research related to a particular topic. In the present study, the literature review focuses on groundwater and soil contamination caused by municipal solid waste dumpsites, the impact of heavy metals on the environment, biomining as a remediation technique, and the application of permeable reactive barriers for groundwater treatment.

Drall et al. (2025) investigated groundwater contamination around the Bhandewadi dumpsite and reported elevated concentrations of chromium (Cr), nickel (Ni), and lead (Pb), along with high Total Dissolved Solids (TDS) values within a 2 km radius. Similarly, Verma et al. (2025) identified a leachate plume extending 7–30 m below ground level and observed that many groundwater samples exceeded nitrate limits and were unsuitable for domestic use based on the Groundwater Quality Index (GQI). These studies indicate that leachate migration from dumpsites severely affects groundwater quality and creates significant environmental concerns.

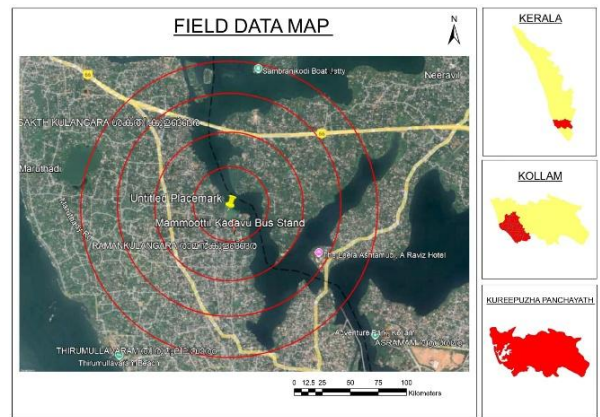
Heavy metal contamination caused by dumpsite leachate has been widely associated with serious health risks. Nlemolisa et al. (2025) reported acidic groundwater with heavy metal concentrations exceeding WHO permissible limits. Chowdhury et al. (2025) observed that lead (Pb), cadmium (Cd), and chromium (Cr) exceeded permissible limits in many samples, resulting in high Metal Pollution Index (MPI) and Water Quality Index (WQI) values, with children being more vulnerable than adults. Similarly, Afolabi et al. (2022) identified hazard index values above safe limits, confirming significant non-carcinogenic health risks near dumpsites.

Several researchers have focused on contaminant migration mechanisms and hydrogeological conditions influencing groundwater pollution. Verma et al. (2025) demonstrated the use of Vertical Electrical Sounding (VES) to identify subsurface contamination plumes caused by leachate infiltration. Alao et al. (2023) reported that low subsoil resistivity indicated high contamination potential, while Gyabaah et al. (2024) observed that soil plasticity and increasing distance from dumpsites reduced contaminant migration. Olasunkanmi et al. (2023) further reported that silty-clay layers acted as natural barriers limiting vertical leachate movement.

Different analytical methods and environmental factors also influence groundwater quality assessment near dumpsites. Nlemolisa et al. (2025) classified all groundwater samples as unsuitable for drinking using the Water Quality Index (WQI). Asomaku (2023) reported that the Heavy Metal Pollution Index (HPI) indicated unsuitability for drinking despite acceptable WQI values. Liu et al. (2025) used integrated analysis of soil, groundwater, and leachate to identify contamination pathways and environmental risks.

The reviewed studies show that municipal solid waste dumpsites cause significant groundwater contamination through leachate migration and heavy metal accumulation, leading to serious environmental and health risks. Various assessment methods have been used to evaluate contamination levels and identify pollution sources. Although several studies have investigated groundwater contamination near dumpsites, limited research is available on post-biomining environmental conditions at the Kureepuzha dumpsite. Therefore, the present study is important for evaluating groundwater and soil quality after biomining and assessing the effectiveness of remediation measure such as natural Permeable Reactive Barrier. The study will help in understanding the current environmental

condition of the area and support future waste management and groundwater protection strategies.



III. METHODOLOGY

The methodology adopted for this study involves groundwater and soil quality assessment in areas surrounding the Kureepuzha MSW dumpsite after biomining. The study area was selected within a 2 km radius of the dumpsite and divided into four buffer zones at 500 m intervals to understand the variation of contamination with distance. Sampling locations were selected systematically to ensure proper spatial representation of the study area.

Groundwater samples were collected from sixteen locations using clean and pre-washed bottles. The collected samples were analysed for physicochemical parameters such as pH, electrical conductivity, and total dissolved solids (TDS). Heavy metal concentrations including lead, cadmium, mercury, nickel, and iron were analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS).

Soil samples were collected from eight selected locations at a depth of 0–15 cm. Before analysis, the soil samples were shade-dried, crushed, sieved, and preserved in airtight containers. The samples were then analysed for pH, electrical conductivity, and organic carbon content. Heavy metal analysis of soil samples was carried out using Atomic Absorption Spectroscopy (AAS).

In addition, a Natural Permeable Reactive Barrier (PRB) model was developed as a control measure to reduce contaminant movement through groundwater. The PRB consists of layers of gravel, sand, charcoal, laterite soil, and eggshell arranged to promote filtration, adsorption, and ion exchange processes. Observations were made to evaluate the effectiveness of the PRB in improving water quality and reducing pollutant concentration.

A. Study Area

The study was conducted around the Kureepuzha municipal solid waste dumpsite located in Kollam district, Kerala, near Ashtamudi Lake at coordinates 8°54'46"N and 76°34'08"E. The present study evaluated groundwater and soil quality within a 2 km radius of the dumpsite using sampling locations selected in different directions across the study area. For systematic analysis, the study area was divided into four concentric buffer zones at 500 m intervals from the dumpsite. Fig. 2 presents the study area map

showing the location of the dumpsite and the surrounding buffer zones selected for the investigation.

Fig. 2. Location of Study Area

B. Sample Collection

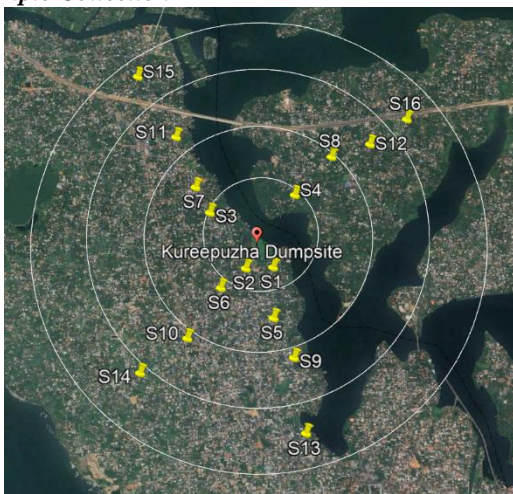


Fig. 3. Sampling Points

Groundwater and soil samples were collected from selected locations within the four buffer zones surrounding the Kureepuzha MSW dumpsite to assess environmental quality after biomining. A total of 16 groundwater samples and 8 soil samples were collected from different directions and distances around the dumpsite to ensure proper spatial representation of the study area. The sampling locations surrounding the dumpsite are presented in Fig. 3.

Groundwater samples were collected from open wells using clean pre-washed 1 L plastic bottles. Before sample collection, the bottles were rinsed with the respective sample water to minimize contamination. The collected groundwater samples were tightly sealed, properly labelled with sample ID and location details, and transported to the laboratory for physicochemical and heavy metal analysis.

Soil samples were collected from the topsoil layer at selected locations using suitable sampling tools and stored in clean labelled polythene bags. The collected soil samples were then transported to the laboratory for further analysis of physicochemical parameters and heavy metal concentrations.

C. Groundwater Quality Analysis

The collected groundwater samples were analysed for important physicochemical parameters such as pH, electrical conductivity, and total dissolved solids, along with heavy metals including lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), and iron (Fe).

The pH and electrical conductivity of groundwater samples were measured using a water analyser, while TDS was determined using the gravimetric method. For heavy metal analysis, the collected samples were acidified, diluted, and analysed using Inductively Coupled Plasma Mass Spectrometry.

The obtained results were evaluated based on the permissible limits prescribed in IS 10500:2012 drinking water standards. According to the standards, pH should be within the range of 6.5 to 8.5, while the permissible limit for

total dissolved solids is 2000 mg/L. Electrical conductivity was compared with the commonly adopted guideline value of 1000 $\mu\text{S}/\text{cm}$ used in groundwater quality studies. The permissible concentrations for heavy metals are 0.01 mg/L for lead, 0.003 mg/L for cadmium, 0.001 mg/L for mercury, 0.02 mg/L for nickel, and 0.3 mg/L for iron.

D. Soil Quality Analysis

The collected soil samples were shade-dried, crushed and sieved through a 2 mm sieve to obtain fine and uniform particles. The processed samples were stored in clean labelled airtight containers before analysis.

Physicochemical analysis of soil was carried out for parameters such as pH, electrical conductivity, and organic carbon. Soil pH was determined using a pH meter, electrical conductivity using a conductivity meter, and organic carbon by the Walkley-Black method. The obtained results were assessed according to the agricultural soil quality standards prescribed by the Indian Council of Agricultural Research (ICAR). Soil pH values ranging from 6.5 to 7.5 and EC values below 1 dS/m were considered optimum for normal crop production. Based on fertility status, soil organic carbon content was classified as low (< 0.50%), medium (0.50–0.75%), and high (> 0.75%).

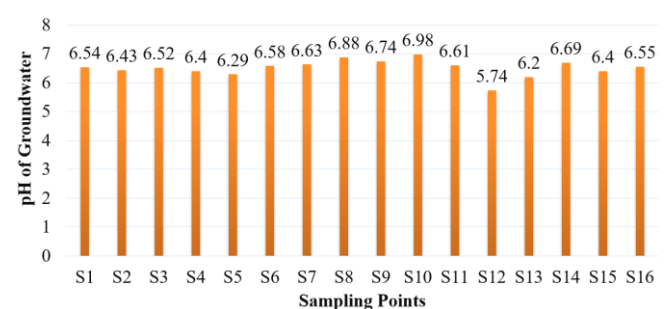
Heavy metal analysis was carried out to determine the concentrations of Pb, Cd, Hg, Ni, and Fe in the soil samples. The samples were treated with 0.1 M hydrochloric acid (HCl), filtered using Whatman No. 42 filter paper, and analysed using Atomic Absorption Spectroscopy.

E. Natural PRB Development and Evaluation

A natural permeable reactive barrier was developed as a simple and eco-friendly method for improving contaminated water quality. The natural PRB was constructed using layers of gravel, sand, charcoal, laterite, and eggshell materials to filter contaminants from water passing through the system. The efficiency of the natural PRB was evaluated by observing improvements in water quality and clarity after treatment.

IV. RESULTS AND DISCUSSION

A. Physicochemical Analysis of Groundwater



(a)

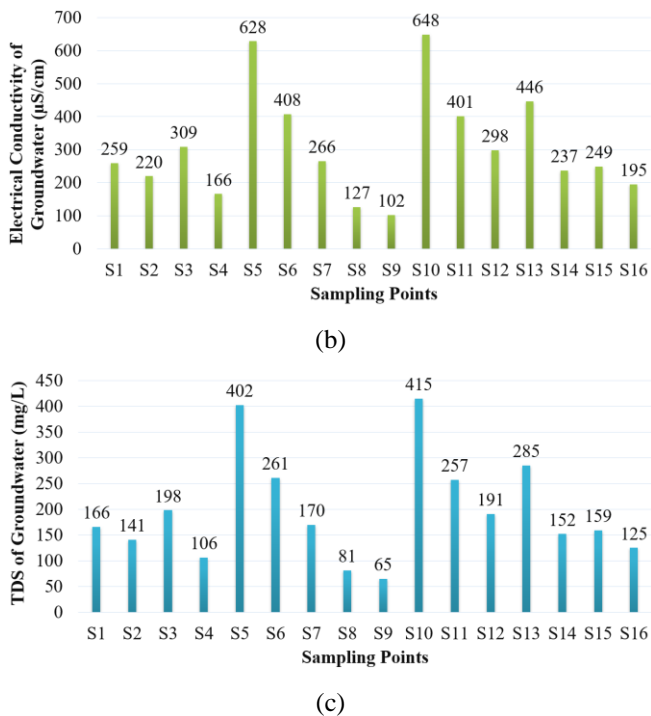


Fig. 4. Variation of Physicochemical Parameters in Groundwater: (a) pH, (b) Electrical Conductivity, and (c) TDS

pH values ranged from 5.74 to 6.98, indicating slightly acidic to nearly neutral groundwater. The lowest pH was observed at S12, while the highest was recorded at S10, as shown in Fig. 4(a). EC values ranged from 102 to 648 µS/cm, with the highest at S10 and lowest at S9, as presented in Fig. 4(b), and remained within the permissible limit. TDS concentrations varied between 65 and 415 mg/L, with maximum and minimum values observed at S10 and S9 respectively, as shown in Fig. 4(c), and were also within the permissible limit. Overall, the results show spatial variation in groundwater quality within the study area.

B. Heavy Metal Analysis of Groundwater

TABLE I. Heavy Metal Characteristics of Groundwater

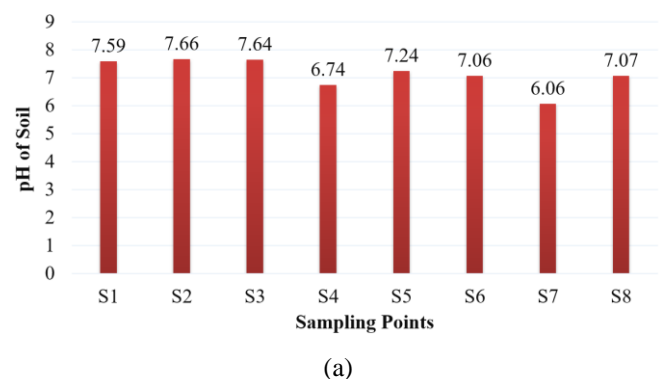
Sample	Pb (mg/L)	Cd (mg/L)	Hg (mg/L)	Ni (mg/L)	Fe (mg/L)
S1	0.0009	0.0001	BDL	0.0014	0.13
S2	0.0036	BDL	BDL	0.0268	0.45
S3	BDL	BDL	BDL	0.0011	0.37
S4	0.0009	BDL	BDL	0.001	0.35
S5	0.0019	BDL	BDL	0.0034	0.25
S6	0.01	BDL	BDL	0.0018	3.89
S7	0.005	BDL	BDL	0.0475	1.09
S8	BDL	BDL	BDL	0.0006	0.01
S9	0.0034	BDL	BDL	0.0047	0.44

S10	0.0013	BDL	BDL	0.0029	0.36
S11	0.0137	0.0001	BDL	0.003	0.09
S12	0.0004	BDL	BDL	0.0017	0.07
S13	0.0032	BDL	BDL	0.0049	0.17
S14	0.0027	BDL	BDL	0.0028	0.16
S15	0.0029	BDL	BDL	0.0205	0.26
S16	0.0092	BDL	BDL	0.0048	1.72

The heavy metal characteristics of groundwater samples collected from different sampling points are presented in Table I. The analysis showed that Pb, Ni, and Fe were detected in several samples, while Cd and Hg were mostly below detectable limits (BDL). Cadmium was detected only in samples S1 and S11 at a concentration of 0.0001 mg/L and remained within the permissible limit, whereas mercury was below detectable limits in all groundwater samples. The concentration of Pb ranged from BDL to 0.0137 mg/L, with the highest value observed at S11, slightly exceeding the permissible limit. Nickel concentrations varied between 0.0006 and 0.0475 mg/L, with the highest concentration observed at S7. Samples S2, S7, and S15 exceeded the permissible limit. Iron concentrations ranged from 0.01 to 3.89 mg/L, with samples S2, S3, S4, S6, S7, S9, S10, and S16 showing values higher than the permissible limit.

The presence of Pb, Ni, and Fe in groundwater indicates variation in the chemical composition of groundwater at different sampling locations. The elevated iron concentration observed in some samples may affect the taste, colour, and overall quality of groundwater. Similarly, the slightly higher concentration of lead at S11 and elevated nickel concentrations at S2, S7, and S15 indicate localized contamination in those areas. The very low concentration of cadmium and the absence of detectable mercury indicate minimal contamination from these metals in the study area. Overall, the variation in heavy metal concentrations among the sampling locations indicates differences in groundwater quality and possible influence of surrounding environmental conditions.

C. Physicochemical Analysis of Soil



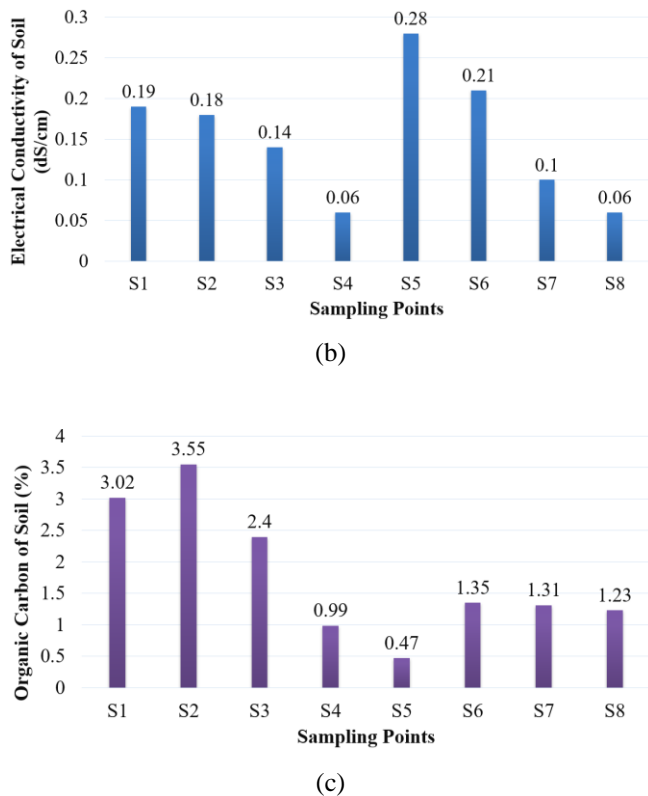


Fig. 5. Variation of Physicochemical Parameters in Soil: (a) pH, (b) Electrical Conductivity, and (c) Organic Carbon

Soil pH values ranged from 6.06 to 7.66, indicating slightly acidic to mildly alkaline soil conditions, with the highest pH observed at S2 and the lowest at S7, as shown in Fig. 5(a). Most sampling points were within the acceptable range, while S1, S2, and S3 showed slightly higher pH values, suggesting minor spatial variation in soil characteristics across the study area. Electrical conductivity values varied between 0.06 and 0.28 dS/m, with the maximum value recorded at S5 and the minimum at S4 and S8, as presented in Fig. 5(b), and remained within the permissible limit. Organic carbon content ranged from 0.47% to 3.55%, with the highest value observed at S2 and the lowest at S5, as shown in Fig. 5(c).

The observed pH values indicate that the soil conditions are generally suitable for plant growth and microbial activity, although slightly higher pH values were observed at S1, S2, and S3, indicating mildly alkaline conditions at these locations. The low EC values suggest that the soil is non-saline and contains a comparatively low concentration of soluble salts. Variations in organic carbon content among the sampling locations indicate differences in organic matter accumulation and soil fertility. Overall, the results suggest that the soil quality in the study area is generally stable, with slight spatial variations in physicochemical characteristics between sampling locations.

D. Heavy Metal Analysis of Soil

TABLE II. Heavy Metal Characteristics of Soil

Sample	Pb (mg/L)	Cd (mg/L)	Hg (mg/L)	Ni (mg/L)	Fe (mg/L)
S1	8.234	0.678	BDL	33.07	93.67
S2	6.968	0.346	BDL	29.09	92.8
S3	BDL	BDL	BDL	11.13	2.73
S4	BDL	BDL	BDL	10.87	10.64
S5	BDL	BDL	BDL	13.97	34.62
S6	BDL	BDL	BDL	12.1	1.74
S7	BDL	BDL	BDL	13.31	6.6
S8	BDL	BDL	BDL	14.11	8.81

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S2	6.968	0.346	BDL	29.09	92.8
S3	BDL	BDL	BDL	11.13	2.73
S4	BDL	BDL	BDL	10.87	10.64
S5	BDL	BDL	BDL	13.97	34.62
S6	BDL	BDL	BDL	12.1	1.74
S7	BDL	BDL	BDL	13.31	6.6
S8	BDL	BDL	BDL	14.11	8.81

The heavy metal characteristics of soil samples collected from different sampling points are presented in Table II. The obtained concentrations were evaluated against benchmark values of 50 mg/kg for Pb, 3 mg/kg for Cd, and 50 mg/kg for Ni, while Fe was compared with the standard natural background level of 50,000 mg/kg, according to the criteria adopted by Salem et al. (2020). The analysis showed that Pb and Cd were detected only in samples S1 and S2, while Hg was below detectable limits in all soil samples. Lead concentrations ranged from BDL to 8.234 mg/kg, cadmium from BDL to 0.678 mg/kg, nickel from 10.87 to 33.07 mg/kg, and iron from 1.74 to 93.67 mg/kg, with the highest concentrations observed at S1. All detected heavy metals remained within permissible limits.

The higher concentrations of Pb, Cd, Ni, and Fe in samples S1 and S2 indicate variation in heavy metal accumulation among the sampling locations. The absence of detectable mercury in all samples suggests minimal Hg contamination in the study area. Overall, the heavy metal concentrations in the soil samples were generally within permissible limits, indicating comparatively stable soil quality within the study area.

E. Performance of Natural Permeable Reactive Barrier

The table-top model of a natural permeable reactive barrier, as shown in Fig. 6, is a small-scale experimental setup designed to demonstrate the natural treatment of groundwater through different reactive materials. In actual field-scale PRB systems, the reactive layers are generally arranged horizontally along the path of groundwater flow. However, in the table-top model, the layers are arranged vertically inside a plastic bottle to simplify the experimental setup and clearly demonstrate the treatment process.

The model consists of layers of gravel, sand, charcoal, laterite soil, and eggshell arranged in a specific sequence. The gravel layer supports smooth water flow and prevents clogging, while the sand layer removes suspended particles through physical filtration. The charcoal layer adsorbs organic pollutants, colour, and odour, whereas the laterite soil helps in the removal of heavy metals through adsorption and chemical interactions. The eggshell layer neutralizes acidic conditions and promotes precipitation of dissolved metals. A second sand layer provides final filtration of fine particles, and the gravel layer at the outlet ensures easy exit of groundwater and maintains permeability.

The control measures using the natural PRB showed noticeable improvement in groundwater quality after treatment. The pH of groundwater increased from 6.68 to 7.19, indicating a shift from slightly acidic conditions to near neutral. Turbidity values significantly decreased from 61 NTU to 6 NTU after treatment, showing effective removal of suspended impurities. Visual observations also confirmed that the water colour changed from yellowish and turbid to clear and colourless after passing through the PRB. These observations indicate that the Natural PRB effectively improved groundwater quality through filtration, adsorption, and neutralization processes. Overall, the results demonstrate that the Natural PRB is an efficient and low-cost method for groundwater remediation.



Fig. 6. Table-top Model of Natural Permeable Reactive Barrier

V. CONCLUSION

The present study focused on the assessment of physicochemical characteristics and heavy metal concentrations in groundwater and soil samples collected from different sampling locations within the study area. The analysis was carried out to evaluate the quality of groundwater and soil and to identify variations in important environmental parameters.

The physicochemical analysis of groundwater revealed variations in pH, EC, and TDS among the sampling points. The results indicated that the groundwater was slightly acidic to nearly neutral in nature, while EC and TDS values remained within permissible limits. These variations reflect differences in dissolved mineral content and groundwater characteristics within the study area.

The soil analysis showed variations in pH, electrical conductivity, and organic carbon content. The soil samples were generally slightly acidic to mildly alkaline and non-saline in nature. Variations in organic carbon content indicated differences in soil fertility and organic matter

accumulation among the sampling locations. Overall, the soil quality in the study area was found to be comparatively stable.

Heavy metal analysis of groundwater samples showed variations in Pb, Ni, and Fe concentrations among different sampling locations, while Cd was detected only at very low concentrations and Hg remained below detectable limits in all samples. Although a few samples showed comparatively higher heavy metal concentrations, heavy metals in most groundwater samples remained within the permissible limits, indicating moderate groundwater quality in the study area. Similarly, soil samples showed the presence of Ni and Fe in all samples, while Pb and Cd were detected only in two samples. Hg was below detectable limits in all soil samples, and all detected heavy metals remained within the permissible limits, indicating comparatively stable and acceptable soil quality in the study area.

A natural permeable reactive barrier using natural materials such as gravel, sand, charcoal, laterite soil, and eggshell was developed as a treatment measure for groundwater remediation. The table-top model demonstrated effective improvement in groundwater quality by reducing turbidity, improving water clarity, and shifting pH towards neutral conditions. The study concludes that Natural PRB is a simple, eco-friendly, and cost-effective method for groundwater treatment and can be used as a sustainable approach for environmental remediation.

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