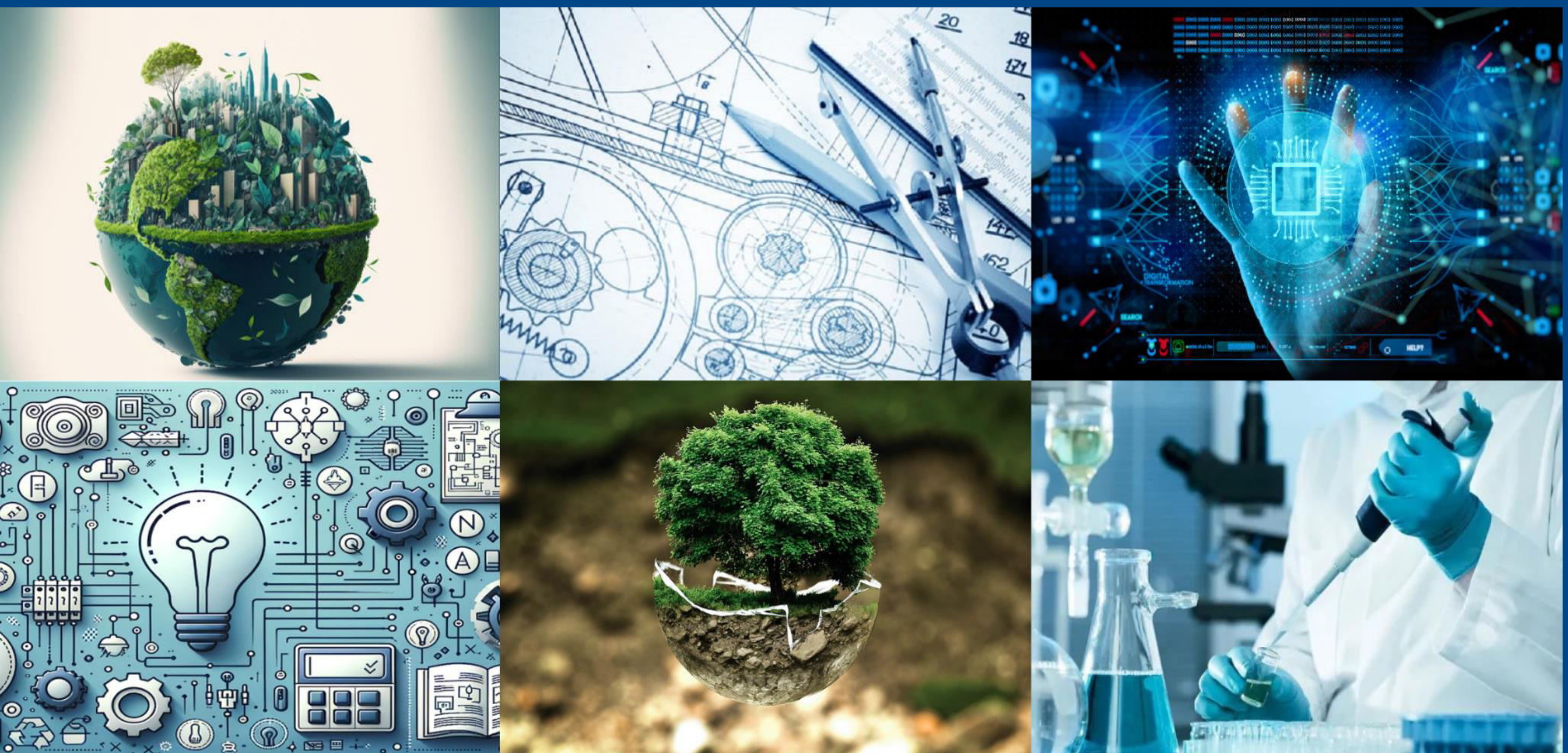
ISSN: 2582-7219

International Journal of Multidisciplinary Research in Science, Engineering and Technology

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 9.864

Volume 9, Issue 6, June 2026

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ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Synthesis of Sustainable Geo-Brickfromheavy Metal Extracted Clayeysoil

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ABSTRACT: Rapid urbanization and the continuous accumulation of municipal and industrial waste have resulted in severe heavy metal contamination in landfill soils, posing long-term environmental and health challenges. Traditional remediation and disposal methods are often energy-intensive and unsustainable, leaving behind vast quantities of underutilized treated soil. This project introduces an innovative two stage waste-to-resource framework that combines electrokinetic extraction with sustainable geo-brick fabrication to achieve both soil detoxification and material valorization. In the first phase, heavy metals such as lead, cadmium, and chromium are selectively extracted from landfill soil using an electrokinetic system that induces ionic migration through an applied electric potential, effectively separating and concentrating contaminants for potential reuse. The second phase re purposes the purified residual soil as the core ingredient for producing geo-bricks, a new generation of eco-friendly, high-strength, and thermally efficient construction materials. These geo-bricks not only mitigate the need for natural clay resources but also contribute to carbon footprint reduction and circular economy principles. The proposed approach transforms contaminated waste into a functional, value added product, providing a closed loop solution that integrates waste remediation, resource recovery, and sustainable infrastructure development. This study thus pioneers a pathway toward a cleaner environment and greener construction industry, redefining the boundaries between waste management and material innovation.

KEYWORDS: Electrokinetic extraction, soil detoxification, material valorization, sustainable geo-brick

I. INTRODUCTION

The rapid pace of industrialization and urbanization in recent decades has led to a significant increase in municipal and industrial solid waste generation. Large volumes of these wastes are commonly disposed of in landfills, which serve as a primary method of waste management. Over time, the percolation of rainwater through waste layers produces leachate a highly polluted liquid containing dissolved heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As). These toxic substances have the potential to migrate into surrounding soil and groundwater systems, posing serious environmental and public health risks. Heavy metal contamination can lead to the degradation of soil fertility, affecting agricultural productivity, and can accumulate in the food chain, causing long term health effects. Additionally, uncontrolled leachate release can adversely affect aquatic ecosystems and biodiversity. Conventional soil remediation techniques, such as excavation, chemical stabilization, and thermal treatment, are often expensive, energy-intensive, and may not completely remove the contaminants. Moreover, they generate secondary wastes and can disrupt soil structure, making the site less suitable for reuse. Therefore, there is an increasing need for sustainable and environmentally friendly approaches that can both detoxify contaminated soils and facilitate their reuse in civil engineering applications. Such approaches not only reduce environmental pollution but also contribute to resource recovery, aligning with the global goals of sustainable development and circular economy.

II. METHODOLOGY

The growing concern over soil contamination caused by industrial effluents, leachates, and improper waste disposal has intensified research into the extraction and stabilization of heavy metals from contaminated soils. Heavy metals such as lead, cadmium, chromium, and arsenic pose long- term ecological and health hazards due to their non-biodegradable and toxic nature. The accumulation of these metals in soil not only deteriorates its fertility and structure but also contaminates surface and groundwater resources. To address these issues, researchers have focused on

© 2026 IJMRSET | Volume 9, Issue 6, June 2026| DOI:10.15680/IJMRSET.2026.0906013

ISSN: 2582-7219 | www.ijmrset.com | Impact Factor: 9.864| ESTD Year: 2018|

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developing sustainable and cost-effective remediation techniques that can simultaneously detoxify soil and enable its reuse in construction and engineering applications. Among various remediation approaches, electro-kinetic extraction, chemical stabilization, and bioremediation have gained significant attention for their ability to remove or immobilize heavy metals efficiently. These methods aim to transform hazardous waste into safe, utilizable materials, promoting a circular economy while minimizing environmental hazards. several studies have been demonstrated the effectiveness of extraction of heavy metal and transform the RHMC to production of geo brick.

III. TEST RESULTS AND DISCUSSIONS

(i) Extraction Efficiency of contaminants

Electro-kinetic extraction is a soil remediation technique that involves the application of a low direct electric current across contaminated soil through electrodes placed at opposite ends. The applied electric 2 field induces several transport mechanisms such as electromigration, electro-osmosis, and electrophoresis, which facilitate the movement of dissolved metal ions through the soil pores toward the electrodes. As a result, heavy metals such as lead can be mobilized and removed from the soil matrix effectively. At the beginning of the experiment, on day 0, the concentration of lead in the clay sample is recorded as 100 ppm. This value represents the initial condition of the contaminated soil before the application of the electro-kinetic treatment. At this stage, the lead ions are strongly bound within the soil particles and pore spaces. This initial concentration serves as a reference point for evaluating the effectiveness of the electrokinetic extraction process over the treatment period. After 4 days of treatment, the lead concentration decreases to 68.4 ppm. This reduction indicates the beginning of lead mobilization due to the applied electric potential. The electric field causes the migration of positively charged lead ions toward the cathode through the soil pore water. Although the decrease at this stage is moderate, it demonstrates that the electro-kinetic processes have started to influence the movement of heavy metal ions in the soil. By day 8, the concentration further reduces to 44.7 ppm. This gradual and consistent decline suggests that the electro-kinetic transport mechanisms continue to operate effectively. The sustained application of the electric field enhances the mobility of lead ions, enabling them to migrate steadily toward the electrode regions. This stage reflects the continuous progress of the extraction process. A significant reduction is observed by day 12, when the lead concentration drops to 21.6 ppm. This stage represents the intermediate phase of treatment, where the efficiency of metal removal becomes more evident. The electro-osmotic flow of pore water combined with ion migration helps to transport a larger portion of the lead ions out of the soil matrix. By day 16, the lead concentration decreases sharply to 8.9 ppm. This indicates that a major portion of the lead contamination has already been removed from the clay sample. The remaining lead ions continue to migrate toward the electrodes under the influence of the electric field. Finally, at the end of the 20-day treatment period, the lead concentration reaches a very low value of 0.76 ppm. This result indicates near- complete removal of lead from the contaminated soil. The substantial reduction from the initial concentration clearly demonstrates the effectiveness of electro-kinetic extraction in removing heavy metals from clay soils, making it a promising technique for soil remediation and environmental management. Final efficiency of lead removal(20^{th} day) = 99.16%

The same procedure was followed for the extraction of Cadmium from contaminated soil t obtain a final removal efficiency of 97.39 % at 20^{th} day.

The geo technical assessment was carried out to evaluate the suitability of clay for brick production. Basic index and consistency properties of the clay were determined through laboratory tests such as liquid limit, plastic limit, shrinkage limit, and plasticity index. The pH test was conducted to assess the chemical nature of the clay. These tests provided essential information on workability, molding behavior, and volume stability of the clay. The results obtained helped in assessing the feasibility of using the clay for effective and sustainable brick production.

(ii) Geo technical Assessment of Clay for Brick Production

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Soil: **Clay of Low Compressibility (CL)**

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Table 1:Test Results with IS Requirements for Brick Making

Parameter	Test result	IS Requirement
Liquid Limit	32%	20-35%
Plastic Limit	14%	10-25%
Plasticity Index	18%	10-20%
Shrinkage Limit	12%	>10%
PH	7.3	6.5-8.0
Electrical Conductivity	1.8 dS/m	< 2dS/m

(iii) Synthesis of Geobrick from contaminant free soil

The synthesis of geo-bricks involves the stabilization and compaction of soil-based materials using industrial by-products and suitable binders to produce durable and eco-friendly construction units without the need for kiln firing. In this study, geo-bricks were synthesized using restored heavy metal– contaminated soil in combination with supplementary cementitious materials to enhance strength and durability. The approach emphasizes sustainable utilization of waste materials, reduction in carbon emissions, and the development of cost-effective construction alternatives.

Table 2:Percentage Distribution of Materials in Geo-Brick

Component	Percentage by weight
RHMC	70%
Coal slag	10%
Quarry Dust	5-10%
Fly ash	5-10%
Lime	3-5%
Water	10-15%

(iv) Performance indicators of synthesized brick

To evaluate the performance and suitability of the developed geo-bricks, a comprehensive series of standard laboratory tests were conducted and the results were systematically compared with those of conventional clay bricks. These tests are essential to assess the physical, mechanical, and durability characteristics of the bricks, ensuring their reliability for practical construction applications. The primary tests carried out include water absorption, compressive strength, density, durability index, and overall durability.

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Table 3: Test Comparison of Conventional Brick With Geo-Brick

Tests	Geobrick	Conventional brick	Reference Standard
Compression Test	12 N/mm²	> 3.5-10 N/mm²	As per IS 3495
Water Absorption	14.29%	< 20%	As per IS 3495
Density	1800 kg/m³	1700 kg/m³	As per IS 3495
Durability Index	0.84	0.4 - 0.6	Literature

Geo-bricks exhibit superior compressive strength, lower water absorption, higher density, and enhanced durability compared to conventional bricks, making them a more efficient and sustainable construction material. These improved properties indicate better structural performance and an extended service life in construction applications. Therefore, geo-bricks can be considered a reliable and environmentally sustainable alternative to conventional bricks for modern construction practices.

IV. CONCLUSIONS

This study focuses on the remediation of heavy metal–contaminated clayey soil using the electro- kinetic extraction technique and investigates its subsequent reuse in the development of sustainable geo-bricks. With the rapid expansion of industrialization and urbanization, the generation of solid waste has increased substantially, leading to widespread reliance on landfilling as a disposal method. Over time, landfill leachate enriched with hazardous heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), and arsenic (As) infiltrates the surrounding soil and groundwater systems. This contamination not only degrades environmental quality but also poses significant risks to ecosystems and human health through bioaccumulation and toxicity. Hence, there is a critical need for efficient soil remediation technologies coupled with sustainable reuse approaches. Electro-kinetic extraction (EKE) was adopted in this study as an effective in-situ remediation method for fine-grained soils. The technique involves the application of a low-intensity direct current across electrodes inserted into the contaminated soil mass. The electric field induces several transport mechanisms, including electromigration (movement of ionic species), electroosmosis (flow of pore fluid), and electrophoresis (movement of charged particles), which collectively facilitate the mobilization and removal of heavy metal contaminants toward the electrode regions. Additionally, electrolysis reactions occurring at the electrodes influence pH gradients, which further enhance the desorption and mobility of heavy metals. Due to its ability to treat lowpermeability soils such as clay, electro-kinetic extraction is considered highly advantageous over conventional remediation methods like excavation or soil washing.

The experimental findings demonstrate a significant reduction in heavy metal concentrations in the treated clayey soil, indicating the effectiveness of the electrokinetic process. The remediation not only improves the environmental compatibility of the soil but also enhances its suitability for engineering applications. Following treatment, the soil was repurposed for the production of geo-bricks by blending it with appropriate stabilizing agents such as cementitious or geo-polymeric binders. The mixture was then subjected to moulding and controlled curing processes to achieve the desired mechanical strength and durability characteristics. The performance evaluation of the fabricated geo-bricks

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revealed that they possess adequate compressive strength, structural integrity, and durability required for construction purposes. In comparison to traditional fired clay bricks, geo-bricks offer substantial environmental benefits. These include a significant reduction in energy consumption due to the elimination of high temperature firing processes, decreased greenhouse gas emissions, and conservation of natural clay resources. Moreover, the reuse of treated contaminated soil contributes to waste minimization, reduces landfill dependency, and supports circular economy principles in the construction sector. In conclusion, the integration of electro-kinetic soil remediation with geo-brick manufacturing represents an innovative and sustainable approach to managing contaminated soils. This dual-benefit strategy not only mitigates the adverse environmental impacts of heavy metal pollution but also converts waste material into a value- added construction product. The outcomes of this study emphasize the potential of combining advanced remediation technologies with sustainable material development to promote eco-friendly, resource- efficient, and resilient engineering solutions for future infrastructure development

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