CHARACTERIZATION OF CLAY SAMPLES FROM MURANG'A, NYERI, EMBU AND THARAKA NITHI COUNTIES FOR ADSORPTION OF CADMIUM FOR WATER PURIFICATION

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for an award of diploma or conferment of degree in any institution.

Signature..... Date.....28/10/2025.....

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Recommendation

This thesis has been examined, passed, and submitted with our approval as University supervisors.

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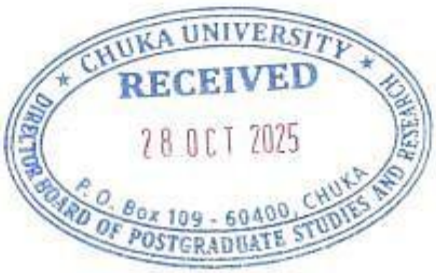

DEDICATION

This work is dedicated to my parents Mr. Amos Thuo and Mrs. Margaret Warimi on whose constant support, encouragement and prayers I really relied on for moral support during the study and even for their financial support.

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ABSTRACT

Heavy metal pollution, particularly cadmium (Cd^{2+}), remains a critical environmental challenge threatening water quality, aquatic ecosystems, and human health. Cadmium is widely introduced into aquatic systems through industrial effluents, agricultural runoff, and urban discharges. This study investigated the adsorption potential of locally available clay minerals as cost-effective and sustainable remediation materials. Clay samples were collected from Gakoigo (S), Mukurwe-ini (2A) Gakindu K1, Karurina (K2) and Mbogoni (M). The clay samples were characterized using Atomic Absorption Spectroscopy (AAS), X-ray Diffraction (XRD), and Fourier Transform Infrared Spectroscopy (FTIR). The results from elemental analysis and ANOVA revealed difference in concentrations of iron, magnesium, sodium, and aluminum across the counties, explaining the calculated F-statistics 2.83 ($p = 0.048$), 3.01 ($p = 0.035$), 4.51 ($p = 0.020$), and 5.22 ($p = 0.011$), respectively. These constituents are vital as they assist, particularly, the samples from Mbogoni (M) and Gakoigo (S), in boosting cadmium (Cd^{2+}) adsorption. On the contrary, calcium and potassium were seen to have less influence, evidenced by their F-statistics of 2.45 ($p = 0.068$) and 2.13 ($p = 0.080$), respectively. Physicochemical water quality analysis was done from 12 rivers sites within Nairobi County, Kenya. Turbidity ranged between 2.75–95.67 NTU, exceeding WHO's 5 NTU guideline in urban rivers due to runoff and effluent discharges. Electrical conductivity (556–1123 µS/cm) surpassed WHO limits across all sites, confirming high ionic loading, while dissolved oxygen (0.51–3.06 mg/L) was critically low, pointing to severe organic pollution. Total suspended solids (12–247 mg/L) and TDS (362–736 mg/L) were elevated in urbanized sites, further degrading aquatic health. Cadmium concentrations (0.0105–0.0498 mg/L) consistently exceeded WHO (0.003 mg/L) and KEBS (0.01 mg/L) standards, with highest levels in industrially impacted rivers, highlighting risks of bioaccumulation and human exposure. Batch adsorption studies demonstrated that pH was a key determinant, with maximum efficiency at neutrality (pH 7, 99.81% removal by K1), while acidic conditions reduced removal due to proton competition. Contact time experiments showed rapid uptake within 20 minutes, with equilibrium achieved at 40 minutes (69.16% removal by K1). Adsorbent dosage showed optimum performance at 0.1 g (99.72% removal at 8 ppm), though higher dosages reduced efficiency due to particle aggregation. Desorption confirmed strong Cd binding, indicating chemisorption via ion exchange and surface complexation. Agitation improved uptake by minimizing mass transfer resistance, with peak efficiency (92.29% by K1) at 400 rpm. Temperature exerted a negative effect, with maximum adsorption at 25 °C (97.52% by K1), confirming exothermic behavior. Isotherm modeling revealed Langmuir's model ($Q_{max} = 2.06$ mg/g, $K_L = 5.44$ L/mg, $R^2 = 0.77$) better fit the data compared to Freundlich ($R^2 = 0.67$), suggesting monolayer adsorption on homogeneous sites. Kinetic modeling indicated pseudo-second order ($R^2 = 0.8496$) best described the process, implying chemisorption. Thermodynamic evaluation showed that cadmium adsorption on the clay adsorbent was endothermic, with a positive enthalpy change ($\Delta H = 17{,}936.42$ J/mol) and a positive entropy change ($\Delta S = 64.18$ J/mol·K). Gibbs free energy (ΔG) remained negative across all temperatures ($\Delta G = 1.21$ to -1.27 kJ/mol), confirming spontaneous adsorption at higher temperatures.