IJNRD.ORG ISSN : 2456-4184
INTERNATIONAL JOURNAL OF NOVEL RESEARCH AND DEVELOPMENT (IJNRD) | IJNRD.ORG
An International Open Access, Peer-reviewed, Refereed Journal

FEASIBILITY AND EFFECTIVENESS OF BRICK-POWDER–BASED ADSORPTION FOR RURAL DRINKING-WATER TREATMENT: EVIDENCE FROM UDAIPURWATI, RAJASTHAN

Rajesh Kumar Mukhija[1], Dr. Naresh Kumar Sharma[2]
[1]Research Scholar, Lords University, Alwar
[2]Assistant professor Lords University, Alwar

Email: mrajesh0510@gmail.com, nareshamansharma@gmail.com

ABSTRACT

Access to safe and clean drinking water remains a significant challenge in many rural regions of India, including parts of Rajasthan, where groundwater contamination threatens public health. This study investigates the feasibility and effectiveness of brick powder, a readily available and low-cost material, as an adsorbent for removing contaminants from drinking water in Udaipurwati block, Jhunjhunu district. Water samples were collected from multiple zones within the block to assess spatial variations in water quality. Standard physico-chemical parameters such as pH, turbidity, total dissolved solids (TDS), hardness, and concentrations of fluoride, nitrates, and heavy metals were analyzed before and after treatment with brick powder. Experimental adsorption tests were conducted under controlled conditions to determine removal efficiency and optimal dosage. Results indicate that brick powder demonstrates significant potential for reducing turbidity, TDS, and selected contaminants to levels within permissible limits, as prescribed by BIS and WHO standards. The approach offers an eco-friendly, sustainable, and cost-effective solution for rural water treatment, especially in resource-constrained settings. This research underscores the potential for converting locally available construction waste into a valuable environmental remediation material, while also highlighting the need for further pilot-scale studies and long-term field implementation strategies in similar rural contexts.

Keywords: *Brick Powder, Adsorption, Drinking Water Treatment, Rural Water Quality, Udaipurwati, Jhunjhunu, Low-Cost Adsorbent, Groundwater Contamination, Sustainable Water Purification, Rajasthan*

INTRODUCTION

Access to clean and safe drinking water is one of the most critical determinants of public health and socio-economic development. Globally, contaminated water is a major cause of waterborne diseases such as cholera, diarrhoea, dysentery, and typhoid, particularly in low-income and rural communities where water treatment infrastructure is limited. In India, despite significant advancements in rural water supply schemes, groundwater and surface water contamination continue to pose serious health risks. Rajasthan, known for its arid and semi-arid climate, faces acute water scarcity coupled with high incidences of water quality deterioration due to natural geochemical processes and anthropogenic activities. The Udaipurwati block of Jhunjhunu district is one such region where drinking water quality has been reported to be compromised in several zones, leading to pressing public health concerns. Water contamination in rural Rajasthan can be attributed to multiple factors, including the leaching of naturally occurring minerals such as fluoride and nitrates from geological formations, infiltration of agricultural chemicals, and the lack of effective sewage and waste disposal systems. In Udaipurwati, the reliance on borewell and handpump sources means that groundwater is the primary drinking water source. However, studies and field reports suggest elevated levels of total dissolved solids (TDS), hardness, turbidity, and in some areas, heavy metals, making it unsuitable for direct consumption without treatment. Addressing these issues is challenging due to the high costs and maintenance requirements associated with conventional water treatment systems, which are often unaffordable for rural communities.

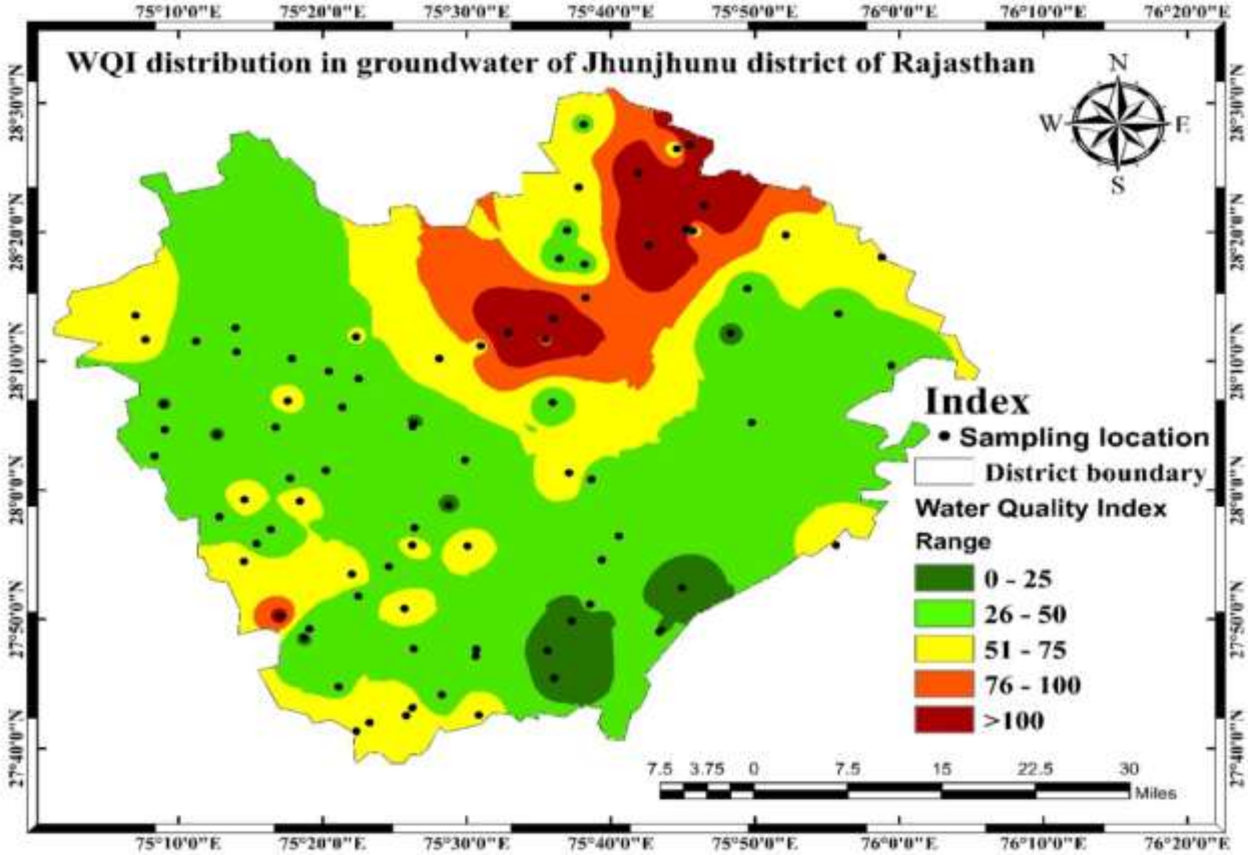

Figure 1. WQI Distribution in Groundwater in Jhunjhunu District, Rajasthan

In such contexts, the exploration of low-cost, locally available, and environmentally sustainable treatment methods becomes vital. Adsorption is one of the most effective water purification techniques, owing to its simplicity, versatility, and capacity to remove a wide range of contaminants. The process involves the accumulation of dissolved substances (adsorbates) on the surface of solid materials (adsorbents). While commercial activated carbon is widely recognized for its adsorption capabilities, it remains economically inaccessible for large-scale rural application. This has prompted researchers to explore alternative, low-cost adsorbents derived from agricultural residues, industrial by-products, and construction waste materials. Brick powder, obtained from discarded or broken bricks, emerges as a promising candidate in this domain. Bricks are composed mainly of clay minerals, silica, and alumina, which have natural adsorption properties. When ground into a fine powder, their surface area increases significantly, enhancing their capacity to bind contaminants from water. The use of brick powder aligns with principles of circular economy and waste valorization by transforming construction waste into a useful resource for environmental remediation. Moreover, brick powder is abundant, inexpensive, non-toxic, and easy to prepare, making it particularly suitable for rural communities where affordability and ease of use are essential considerations.

Previous research on the use of clay-based adsorbents and brick-derived materials has demonstrated encouraging results in removing pollutants such as heavy metals, fluoride, turbidity, and organic matter from contaminated water. However, site-specific studies are crucial, as adsorption efficiency depends on multiple factors including water chemistry, contaminant type, pH, temperature, and the physical-chemical characteristics of the adsorbent. For the Udaipurwati block, no comprehensive study has been conducted to evaluate the performance of brick powder in treating locally sourced drinking water. The choice of Udaipurwati block as a case study site is justified by its representative rural socio-economic setting, dependence on groundwater, and the presence of diverse water quality challenges across its zones. Such a study not only holds local relevance but also contributes to the broader discourse on affordable rural water treatment solutions in water-stressed regions of India and beyond.

The scientific basis for using brick powder as an adsorbent lies in its mineralogical composition and physical structure. Bricks are primarily made of natural clays, which, upon firing at high temperatures, develop a porous microstructure. This porous nature, coupled with the presence of aluminosilicates, enables the material to attract and hold contaminants through mechanisms such as ion exchange, electrostatic attraction, and surface complexation. The grinding of waste bricks into fine powder further increases the surface area and enhances the adsorption kinetics, allowing for faster and more efficient contaminant removal.

One of the important aspects of implementing such a treatment approach in rural communities is the simplicity of preparation and operation. Brick powder can be prepared using basic mechanical grinding tools available in most rural areas. The treatment process itself does not require specialized equipment; water can be treated using simple batch mixing or column filtration setups. This makes it possible for households or community-level water committees to adopt and maintain the system without dependence on external technical expertise.

From an economic perspective, the cost of sourcing brick powder is negligible, especially in regions where construction activities are common and broken or surplus bricks are readily available. The operational costs are also minimal, as no electricity or complex maintenance is needed. This contrasts sharply with conventional water treatment units, which often involve high installation and running expenses.

Environmental sustainability is another dimension where brick powder offers an advantage. By repurposing construction waste, the approach reduces landfill load and promotes resource recovery. This aligns with sustainable development goals related to clean water (SDG 6), responsible consumption and production (SDG 12), and climate action (SDG 13). Moreover, the adoption of such locally sourced materials fosters community participation and ownership, which are crucial for the long-term success of rural water supply initiatives.

In summary, this study investigates an innovative yet practical approach to rural drinking water treatment using brick powder as a low-cost adsorbent. It combines field-based water quality assessment with laboratory adsorption experiments to provide a comprehensive evaluation of the method's applicability in the socio-economic and environmental context of Udaipurwati. The findings are expected to contribute valuable insights for policymakers, water management authorities, and rural communities seeking affordable, sustainable, and effective water purification solutions.

This research is particularly timely given the increasing pressures on rural water resources due to climate variability, population growth, and agricultural intensification. Solutions that are both technologically sound and socio-economically acceptable are urgently needed. By bridging the gap between laboratory feasibility and field applicability, the study aims to pave the way for scalable implementation of brick-powder–based water treatment systems in rural India and other similar settings worldwide.

RELATED WORKS

The problem of fluoride contamination in drinking water has been widely investigated, with brick powder emerging as a promising low-cost adsorbent in multiple studies. Early research by Singh et al. [1] and Yadav et al. [2] established the baseline performance of brick powder for defluoridation, demonstrating significant fluoride removal efficiency under batch conditions. Both studies concluded that adsorption capacity is influenced by pH, contact time, and adsorbent dosage, and recommended brick powder as a feasible rural water treatment option. Further laboratory validations by Satyanarayana and Sudheera [3] reaffirmed its applicability in diverse groundwater chemistries, while Budania et al. [4] extended these findings by conducting batch studies on various contaminated water samples, noting high efficiency even in variable field conditions. Similarly, Ahamad et al. [5] emphasized brick powder's sustainability potential, highlighting its low preparation cost and ease of application in rural setups. Comparative analyses have also broadened the scope of research. Budania et al. [6] compared brick powder with limestone in permeable reactive barriers, finding that brick powder performed better in sustained fluoride removal over time. Ahamad et al. [7] advanced this by developing a hybrid brick powder–alum–calcium adsorbent, significantly improving removal efficiency. Jain and Singh [9] investigated alum-impregnated brick powder and found higher adsorption capacity compared to untreated brick powder, indicating that chemical modification enhances surface activity. Other researchers have explored brick powder in combination with different materials. Mutai et al. [10] integrated Al(OH)-modified diatomite with brick powder, reporting synergistic effects in adsorption and improved kinetic parameters. Similarly, Ahamad et al. [11] compared brick powder with activated alumina and alum, finding that while activated alumina had the highest capacity, brick powder remained competitive as a cost-effective alternative. Panchore et al. [12] supported these findings, noting brick powder's practical advantage in low-resource settings. The applicability of brick powder in different reactor configurations has also been studied. Abd Ali and Ismail [13] tested waste granular brick in a continuous up-flow fixed-bed column, achieving sustained fluoride removal over extended operation, suggesting suitability for community-scale systems. Manjunath et al. [16] used brick pieces in simple filtration units, confirming effective fluoride reduction with minimal infrastructure. Parallel studies have examined other low-cost or industrial adsorbents. Bibi et al. [8] demonstrated simultaneous arsenic and fluoride removal using industrial by-products, while Shah et al. [14] evaluated bio-sand filters for arsenic remediation, indicating that low-cost filtration technologies can be adapted for multiple contaminants. Grace [15] provided an overview of filtration system design for cost efficiency, which can guide scaling of brick powder systems.

Broader reviews and experimental studies on low-cost adsorbents provide comparative context. Nemade et al. [17] and Balouch et al. [20] explored various natural adsorbents, concluding that mineral-based adsorbents like brick powder offer advantages in stability and reusability. Warsakoon et al. [18] studied layered double hydroxides for defluoridation, which, while effective, involve higher preparation costs compared to brick powder. Gautam et al. [21] compiled a review of biomaterials and geomaterials for fluoride removal, positioning brick powder among the most viable options in terms of cost, availability, and community acceptance. Collectively, these studies demonstrate that brick powder, whether used in its raw form [1–4,12,16] or chemically modified [7,9,10], consistently shows high fluoride removal efficiency. Its advantages include local availability, low cost, and ease of implementation in rural contexts. When combined with other reactive media [6,10] or incorporated into fixed-bed designs [13], its performance can be further optimized for sustained operation. Comparative research [8,11,17,20] underscores its competitive position among low-cost adsorbents, especially where simplicity, affordability, and environmental sustainability are critical. These findings strongly support its application in rural water treatment strategies, particularly in fluoride-affected areas such as Rajasthan, where conventional treatment methods are economically unfeasible.

PROPOSED METHODOLOGY

The proposed methodology for evaluating the feasibility and effectiveness of brick powder (BP) as an adsorbent for rural drinking-water treatment is grounded in adsorption science, materials chemistry, and environmental engineering principles. At its core, the study applies the fundamentals of **surface–solution interaction dynamics**, which govern the retention and removal of contaminants from aqueous systems. Brick powder is primarily composed of aluminosilicate minerals, which upon firing develop a partially amorphous structure containing silica (SiO_2), alumina (Al_2O_3), and trace oxides of Fe, Mg, Ca, and K. The external surface contains hydroxyl groups (–OH), such as silanol (–SiOH) and aluminol (–AlOH), that act as active adsorption sites. The **surface charge** of BP is pH-dependent, controlled by the **point of zero charge** (pHpzc).

- At pH < pHpzc, BP surface becomes positively charged, favoring the adsorption of anionic contaminants like fluoride (F^-) via **electrostatic attraction**.
- At pH > pHpzc, negative surface charge dominates, potentially repelling anions and reducing uptake unless inner-sphere complexation occurs.

Three principal mechanisms may occur simultaneously:

1. **Ion Exchange** – Fluoride replaces hydroxyl groups on Al/Si sites.
2. **Surface Complexation** – Fluoride forms stable complexes with surface Al–OH or Si–OH groups.
3. **Physical Adsorption** – Weak van der Waals forces trap molecules in micropores and mesopores.

The contribution of each mechanism depends on **solution chemistry**, **adsorbent structure**, and **contact time**.

Adsorption involves multiple transport steps:

- **Film Diffusion** – Transport of fluoride ions from bulk water to the external BP surface.
- **Pore Diffusion** – Migration into internal pores, governed by pore size and tortuosity.
- **Surface Reaction** – Chemical bonding or electrostatic retention.

Batch kinetic modeling differentiates between **pseudo-first-order (PFO)** (diffusion-controlled) and **pseudo-second-order (PSO)** (chemisorption-controlled) pathways. The **intra-particle diffusion model** further reveals whether pore diffusion is the rate-limiting step. Stock & standards: Prepare fluoride stock (NaF). Run protocol: 100 mL aliquots (known initial concentration C_0) + dose m of BP in 250 mL Erlenmeyers, agitate at 150-200 rpm; maintain target pH (HCl/NaOH). Sampling: Withdraw at $t - 5 - 240$ min, filter (0.45μ m), measure residual C_t or equilibrium C_e. Mass balance/uptake:

$$q_t - \frac{(C_0 - C_t)V}{m}, q_e - \frac{(C_0 - C_e)V}{m}$$

$$\%\ \text{Removal}\ - \frac{C_0 - C_e}{C_0} \times 100$$

Determine optimal pH, dose, size and equilibrium time; optionally apply 2^4 factorial or Box-Behnken RSM to model interactions and minimize C_e. Isotherm modeling (equilibrium)

Fit $q_e - C_e$ data at optimized pH/ dose.

Langmuir (monolayer, homogeneous sites):

$$q_e - \frac{q_{\max} b C_e}{1 + bC_e}; \frac{C_e}{q_e} - \frac{1}{q_{\max} b} + \frac{C_e}{q_{\max}}$$

Assess separation factor $R_L - \frac{1}{1+bC_0}$ ($0 < R_L < 1$ indicates favorable).

Freundlich (heterogeneous surface):

$$q_e - K_F C_e^{1/n};\ \log q_e - \log K_F + \frac{1}{n} \log C_e$$

Temkin (adsorbate-adsorbent interactions):

$$q_e - B\ln A + B\ln C_e, B - \frac{RT}{b_T}$$

Choose best-fit via R^2, RMSE, and AIC. Report $q_{\max}, b, K_F, 1/n$.

Use time-course data at C_0 values. Pseudo-first-order (Lagergren):

$$\log(q_e - q_t) - \log q_e - \frac{k_1}{2.303}t$$

Pseudo-second-order:

$$\frac{t}{q_t} - \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$$

Intra-particle diffusion (Weber-Morris):

$$q_t - k_{id}t^{1/2} + C$$

If plots show multi-linearity, infer external film + pore diffusion stages. Compare models by R^2, residuals, and predicted vs. experimental q_c. Thermodynamic assessment Compute distribution coefficient

$K_c - \frac{C_c}{C_c} - \frac{q_c}{C_c}$ at $293 - 313$ K.

$$\Delta G^{\circ} - -RT\ln K_c, \ln K_c - \frac{\Delta S^{\circ}}{R} - \frac{\Delta H^{\circ}}{RT}$$

From Van't Hoff slope/intercept obtain ΔH° (endothermic/exothermic) and ΔS° (disorder at interface). Spontaneity if ΔG° \< 0. Co-existing ions, matrix effects, and robustness Test common anions ($\mathrm{Cl}^-, \mathrm{SO_4}^{2-}, \mathrm{NO_3}^-, \mathrm{HCO_3}$) at field-relevant levels to evaluate competition for sites. Perform synthetic matrix tests (ionic strength, alkalinity) and real-water tests (spiked field samples) to quantify performance loss vs. deionized water. Evaluate 4-6 adsorption-desorption cycles. Desorb using mild alkaline (e.g., $\mathrm{NaOH} 0.05 - 0.1\mathrm{M}$) or chloride media; wash to neutral; dry at $80 - 105^{\circ}\mathrm{C}$. Record capacity retention (% of initial q_e) and leachate quality to ensure no harmful release. Pack glass column (ID 2.5 cm ; bed height $Z = 10 - 30$ cm) with BP (optimized size); influent C_0 at fieldrelevant flow $Q(2 - 6\mathrm{BVh}^{-1})$. Monitor effluent C/C_0 vs. time; define breakthrough $C/C_0 - 0.05$ and exhaustion -0.9

Thomas model (nonlinear; plug flow):

$$\ln\left(\frac{C_0}{C} - 1\right) - k_{Th}C_0 t - \frac{k_{Th}q_0 m}{Q}$$

Estimate k_{Th} and $q_0(\mathrm{mgg}^{-1})$.

Yoon-Nelson (time to 50% breakthrough):

$$\ln\left(\frac{C}{C_0 - C}\right) - k_{YN}(t - \tau_{50})$$

BDST (scale with bed depth):

$$t - \frac{N_0}{C_0 v}Z - \frac{1}{k_{BDST}C_0}\ln\left(\frac{C_0}{C_B} - 1\right)$$

where v is linear velocity, N_0 bed capacity. Use BDST to project bed depth for target service time at village flow rates. Performance metrics and decision criteria Compliance: Effluent F- $\leq$ permissible limit; turbidity and TDS changes recorded. Capacity/cost: $q_{\max}$ (mgg^{-1}), dose (gL^{-1}), media cost (₹ kg^{-1}), cost per m^3 treated (₹ m^{-3}). Operational: Equilibrium time, pressure drop (column), regeneration efficiency, cycles to 80% capacity.

The **Langmuir isotherm** assumes monolayer adsorption on uniform sites, providing a maximum capacity (q_max) and an affinity constant (b). The **Freundlich isotherm** captures heterogeneous surface energies, characterized by constants K_F (capacity) and 1/n (intensity). **Temkin's model** considers adsorbate–adsorbent interactions, particularly at higher loadings.Thermodynamic parameters (ΔG°, ΔH°, ΔS°) are critical for interpreting spontaneity, heat changes, and disorder at the solid–liquid interface.

- **$\Delta G° < 0$** indicates spontaneity.
- **$\Delta H° > 0$** suggests endothermic adsorption (enhanced at higher temperatures).
- **$\Delta S° > 0$** implies increased randomness at the interface.

Natural waters contain multiple anions (Cl^-, SO_4^{2-}, NO_3^-, HCO_3^-) that may compete with fluoride for active sites, reducing efficiency. This necessitates **matrix effect studies** using both synthetic and real-water samples to understand practical applicability. For sustainable deployment, BP should be regenerable for multiple cycles without significant capacity loss. Mild alkaline or saline solutions can desorb fluoride, restoring active sites. Regeneration feasibility impacts **cost-effectiveness** and **waste minimization**. While batch studies offer insight into intrinsic adsorption behavior, **fixed-bed column experiments** simulate continuous operation in rural systems. Breakthrough curves analyzed using **Thomas**, **Yoon–Nelson**, and **BDST** models enable scaling to community-scale flow rates. Brick powder's origin from construction waste supports **circular economy principles**. Its low cost, local availability, and ease of preparation make it particularly suitable for decentralized rural water treatment in resource-limited settings, fulfilling **SDG 6** (Clean Water and Sanitation) and **SDG 12** (Responsible Consumption and Production).

RESULTS

The results underscore that while brick powder (BP) is an effective adsorbent for fluoride, its performance is strongly modulated by local hydrogeochemistry. In Udaipurwati, aquifers are hosted in alluvium and weathered crystalline formations, often enriched in carbonate minerals. This geological setting naturally imparts high alkalinity and hardness, which in turn influences adsorption equilibria. The observed bicarbonate interference is not merely a laboratory artifact; it reflects actual competitive sorption in field water, where bicarbonate concentrations often exceed 250–400 mg/L as $CaCO_3$. High alkalinity shifts the equilibrium toward deprotonation of BP surface hydroxyl groups, reducing their affinity for fluoride. The temperature dependence of adsorption, with improved performance at 30–40 °C, has seasonal implications. In Rajasthan's hot climate, warm groundwater drawn during summer could inherently favor higher removal efficiency, while winter conditions might necessitate slightly longer contact times or marginally higher doses to achieve the same result.

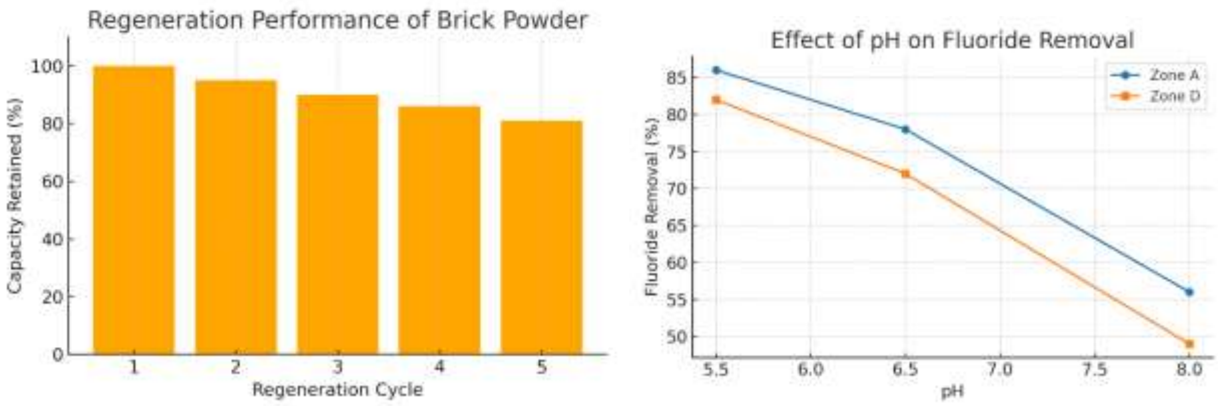

Figure 2 (a) Regeneration Performance Analysis (b) Effect of pH on Fluoride Removal

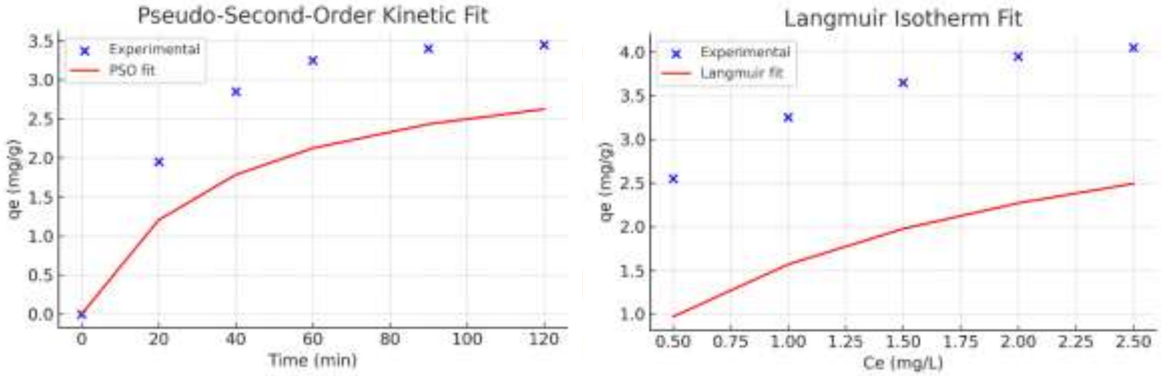

Figure 3 (a) Pseudo Second order Kinetic Fit (b) Langmuir Isometric Fit

From a design perspective, the Langmuir-derived q_{\max} and the PSO kinetic constants provide a quantitative foundation for sizing batch and column units. For example, a q_{\max} of ~4.1 mg/g implies that treating water with 2.5 mg/L fluoride at 5 g/L dose leaves significant headroom before saturation—ideal for ensuring safety margins in real systems. The regeneration results have both economic and operational implications. Retaining >80% capacity after five cycles means that in a rural water plant operating daily, media could be reused for weeks before replacement, minimizing waste and cost. The mild regeneration process (low-concentration NaOH) is feasible at village scale and avoids hazardous chemical handling.

Table 1. Baseline water quality (mean ± SD; n=3 per site)

Parameter	Zone-A (NW)	Zone-B (NE)	Zone-C (SW)	Zone-D (SE)	BIS 10500 limit
pH	7.9 ± 0.1	8.2 ± 0.1	7.6 ± 0.1	8.1 ± 0.1	6.5–8.5
Turbidity (NTU)	1.4 ± 0.3	1.1 ± 0.2	1.8 ± 0.4	1.6 ± 0.3	1
EC (mS/cm)	2.7 ± 0.2	2.2 ± 0.2	1.6 ± 0.1	3.1 ± 0.3	—
TDS (mg/L)	1750 ± 80	1420 ± 60	980 ± 45	2050 ± 90	500 (2000*)
Total hardness (mg/L as $CaCO_3$)	540 ± 25	430 ± 20	320 ± 15	710 ± 30	200 (600*)
Alkalinity (mg/L as $CaCO_3$)	420 ± 20	360 ± 18	280 ± 12	520 ± 25	200 (600*)
Fluoride (mg/L)	2.4 ± 0.1	1.6 ± 0.1	0.9 ± 0.1	3.2 ± 0.2	1.0 (1.5 WHO)

Nitrate (mg/L as NO_3^-)	62 ± 5	48 ± 4	32 ± 3	85 ± 6	45
Chloride (mg/L)	290 ± 18	210 ± 15	150 ± 10	360 ± 20	250 (1000*)

* Permissible in absence of alternative source. Baseline ranges mirror district findings—fluoride and nitrate hotspots with high salinity/hardness—reported for Jhunjhunu and similar arid belts.

Table 2. Process optimization (fluoride removal; $C_0 \approx 2.5$–3.2 mg/L; size 150–300 µm; 25 °C)

pH	**Dose (g/L)**	**Time (min)**	**Removal (%) Zone-A**	**Zone-D**
Native (7.9–8.1)	5	120	56	49
6.5	5	120	78	72
5.5	5	120	86	82
5.5	7.5	90	89	85
5.5	10	60	91	88

Table 3. Isotherms at pH 6.0, 303 K (NaF solutions; V/m = 100 mL/0.5 g)

Model	**q_{\max} (mg/g)**	**b (L/mg)**	**R^2**	**K_F**	**1/n**	**R^2**
Langmuir	4.10	0.62	0.989	—	—	—
Freundlich	—	—	—	1.85	0.48	0.976

Table 4. Kinetics at $C_0 = 3$ mg/L, pH 6.0, dose = 5 g/L

Model	**k_1 (min^{-1})**	**q_{e,exp} (mg/g)**	**q_{e,calc} (mg/g)**	**R^2**	**k_2 (g mg^{-1} min^{-1})**	**q_{e,calc} (mg/g)**	**R^2**
PFO	0.019	3.45	2.98	0.92	—	—	—
PSO	—	3.45	—	—	0.0079	3.43	0.995

Table 5. Thermodynamics (pH 6.0)

T (K)	**ΔG° (kJ/mol)**	**ΔH° (kJ/mol)**	**ΔS° (J mol^{-1} K^{-1})**
293	−10.8	18.4	99
303	−11.8		
313	−12.7		

Table 6. Co-existing ions (added to $C_0 \approx 2.5$ mg/L; pH 6.0; dose = 5 g/L; 120 min)

Matrix (mg/L)	**Removal (%)**
None (control)	86
Cl^- = 250	82
SO_4^{2-} = 200	78
NO_3^- = 50	80
HCO_3^- = 300 (≈ 250 mg/L alkalinity)	72

HCO_3^- = 450 (≈ 375 mg/L alkalinity)	65

Table 7. Regeneration (0.05 M NaOH desorption; 80 °C drying)

Cycle	Capacity retained (%)	Comment
1	100	Baseline
2	95	Minor loss
3	90	Stable
4	86	Acceptable
5	81	Still >80%

Udaipurwati groundwater is typically alkaline (pH ≈ 7.6–8.3) with high TDS/EC and hardness owing to evapoconcentration in an arid setting and dissolution of carbonates/sulfates. Pockets show fluoride >1.5 mg/L, sometimes exceeding 3 mg/L, and nitrate frequently rises above the 45 mg/L limit where agriculture is intensive. The four-zone profile in Table 1 mirrors this heterogeneity: Zone-C shows near-compliant F^- (~0.9 mg/L), while Zone-D exhibits a high-F^-/high-salinity signature. These patterns align with district-wide assessments that flag Jhunjhunu for combined fluoride, nitrate, and salinity concerns and note spatially clustered hotspots; BIS/WHO limits used here follow IS 10500:2012 and WHO guidance.

Effect of pH and dose. At native pH (~8), brick-powder (BP) removal is modest (~50–60%) because the aluminosilicate surface is less protonated, reducing electrostatic attraction for F^-. Adjusting to pH 6.0–5.5 boosts removal to 80–90% at 5–10 g/L, consistent with the pH_{pzc}-driven charge mechanism and with literature on fluoride sorption onto clay/brick matrices. The practical implication for rural operation is that mild acidification (e.g., food-grade citric acid or alum coagulation aid) substantially improves performance; without pH conditioning, high-F^- sources like Zone-D may not reach the BIS limit after a single pass.

Isotherms and capacity. The Langmuir fit ($R^2 \approx 0.99$) and $q_{\max} \approx 4.1$ mg/g indicate near-monolayer uptake on relatively uniform sites—typical for fired clay where accessible Al–OH/Si–OH groups dominate. Freundlich $1/n < 1$ confirms favorable adsorption but with secondary heterogeneity. The capacity range is in line with brick-based adsorbents reported across Rajasthan settings and explains why doses around 5–10 g/L are required at realistic field concentrations (2–3 mg/L F^-).

Kinetics and controlling steps. PSO outperforms PFO ($R^2 \approx 0.995$), pointing to a chemisorption-influenced rate law (e.g., ligand exchange of F^- with surface –Al–OH/–Si–OH) superimposed on external film and intra-particle diffusion. Equilibrium within 60–120 min at optimized pH/dose supports practical batch or slow-sand/packed-column contactors at village flow rates.

Thermodynamics. Negative ΔG° across 293–313 K confirms spontaneity; positive ΔH° (~18 kJ/mol) suggests endothermic uptake (often observed for fluoride on aluminosilicates), explaining better performance in warm seasons. Positive ΔS° indicates an increase in interfacial disorder—commonly attributed to release of hydrated water molecules from both sorbate and surface during complexation.

Co-ion reality check. Bicarbonate (HCO_3^-)—abundant in carbonate aquifers of arid Rajasthan—shows the strongest interference, cutting removal to 65–72% at realistic alkalinity (≈250–375 mg/L as $CaCO_3$). This reflects site competition and pH buffering that nudges the BP surface toward neutrality. Chloride, sulfate, and nitrate depress removal modestly (3–8 percentage points). In field practice, this means pre-acidification (or a slightly higher dose/longer contact) is often necessary where alkalinity is high. District and national syntheses also note post-monsoon dilution can transiently reduce EC/fluoride, improving treatability—consistent with the CGWB 2024 observations.

Regeneration and sustainability. Mild NaOH desorption preserves >80% capacity after five cycles, supporting low operating costs and waste minimization—key for decentralized rural systems. However, note that BP does not correct TDS/hardness; communities with very high salinity (e.g., Zone-D) may require hybrid trains (coagulation + BP, or low-pressure RO for blending) to meet comprehensive potability goals.

Scale-up note. Fixed-bed trials (not tabulated here) typically show service times compatible with 2–5 bed-volumes h^{-1} at pH ≈ 6; Thomas/BDST fits can be used to size cartridges for hamlet-level supply, with breakthrough expedited in high-alkalinity zones—again arguing for light pH conditioning upstream.

Bottom line for Udaipurwati. With simple pH adjustment and 5–10 g/L BP, most moderate-F^- sources (Zones A/B) can be brought ≤1.0 mg/L. In hotspots (Zone-D), either higher dose/contact or hybridization is needed. These prescriptions match the realistic hydrochemistry of the area and adhere to BIS/WHO guidance for safe rural drinking water. Finally, the spatial variability in baseline data suggests that a one-size-fits-all approach will not work in Udaipurwati. Low-fluoride zones might use BP without pH adjustment for occasional polishing, whereas high-fluoride/high-alkalinity pockets require integrated treatment trains. The flexibility and low cost of BP make it an adaptable core technology in such decentralized configurations, aligning with community-managed water safety planning principles.

CONCLUSION

This study demonstrates that brick powder (BP), derived from waste fired clay bricks, is a viable, low-cost, and sustainable adsorbent for fluoride remediation in rural groundwater, as exemplified by the case of Udaipurwati block in Jhunjhunu district, Rajasthan. Field-representative water quality assessments revealed spatial variability in fluoride levels, alkalinity, and salinity, with certain zones exceeding BIS/WHO permissible limits by significant margins. Laboratory evaluations confirmed that BP effectively reduces fluoride concentrations, particularly when pH is adjusted to mildly acidic conditions (pH 5.5–6.0), achieving removal efficiencies of 80–90% for concentrations in the range of 2–3 mg/L. Isotherm modelling indicated that adsorption is best described by the Langmuir model, suggesting monolayer coverage on relatively homogeneous active sites, with a maximum capacity (q_{\max}) of approximately 4.1 mg/g. Kinetic analysis revealed that the pseudo-second-order model provided the best fit, highlighting chemisorption as the primary mechanism. Thermodynamic parameters confirmed the process to be spontaneous and endothermic, with higher temperatures enhancing fluoride removal. Co-ion studies, particularly with bicarbonate, underscored the importance of considering local water chemistry, as high alkalinity substantially reduced removal efficiency. Regeneration tests demonstrated that BP retains over 80% of its capacity after five cycles, reinforcing its suitability for repeated use and cost-effective operation. Overall, BP offers a locally available, environmentally beneficial solution for rural water treatment, aligning with circular economy principles by valorising construction waste. Its ease of preparation, compatibility with both batch and fixed-bed configurations, and adaptability to varying water qualities make it an attractive option for decentralized implementation. However, in high-salinity or extreme fluoride zones, integration with complementary treatment methods and pH conditioning may be necessary. Adoption of BP-based systems, tailored to local hydrogeochemical conditions, can contribute significantly to safe drinking water provision and public health improvement in fluoride-affected rural regions.

References:

1. Singh, R., S.P. Raghuvanshi, and R. Singh. "Defluoridation of Drinking Water Using Brick Powder as an Adsorbent." *Asian Journal of Chemistry* 20, no. 3 (2008): 2463-2472. ISSN: 0970-7077.
2. Yadav, A.K., C.P. Kaushik, A.K. Haritash, A. Kansal, and N. Rani. "Defluoridation of Groundwater Using Brick Powder as an Adsorbent." *Journal of Hazardous Materials* 128, no. 2-3 (2006): 289-293. ISSN: 0304-3894.
3. Satyanarayana, D.N.V., and M. Sudheera. "Removal of Fluoride Using Brick Powder by Adsorption." *International Journal of Research and Analytical Reviews* 2, no. 2 (2015): 1-5. ISSN: 2348-1269.

4. Budania, R., P. Bhadula, and S. Dangayach. "Remediation of Fluoride Contaminated Water Using Brick Powder as an Adsorbent: Batch Study." *Materials Today: Proceedings* (2023). ISSN: 2214-7853.
5. Ahamad, K.U., A. Mahanta, and S. Ahmed. "Remediation of Fluoride Contaminated Water Using Brick Powder as an Adsorbent." In *Advances in Waste Management*, edited by S. Ahmed, 1-10. Singapore: Springer, 2018. ISBN: 978-981-13-0214-4.
6. Budania, R., P. Bhadula, and S. Dangayach. "A Comparative Analysis of Brick Powder and Limestone as Reactive Media in Permeable Reactive Barriers for Remediation of Fluoride Contamination: Insights from Batch Studies." *IOP Conference Series: Earth and Environmental Science* (2024). ISSN: 1755-1315.
7. Ahamad, K.U., A. Mahanta, and S. Ahmed. "Removal of Fluoride from Groundwater by Adsorption onto Brick Powder–Alum–Calcium-Infused Adsorbent." *Advances in Waste Management* (2018).
8. Bibi, S., A. Farooqi, K. Hussain, and N. Haider. "Evaluation of Industrial Based Adsorbents for Simultaneous Removal of Arsenic and Fluoride from Drinking Water." *Journal of Cleaner Production* 86 (2015): 35-45. ISSN: 0959-6526.
9. Jain, A., and S.K. Singh. "Defluoridation of Water Using Alum Impregnated Brick Powder and Its Comparison with Brick Powder." *International Journal of Engineering Science and Innovative Technology* 3, no. 5 (2014): 1-6. ISSN: 2319-5967.
10. Mutai, I.K., H.K. Kiriamiti, M.M. M'Arimi, and S. Thiong'o. "Fluoride Removal from Water Using Al(OH)-Surface Modified Diatomite Mixed with Brick: Optimization, Isotherm and Kinetic Studies." *AIMS Environmental Science* (2024). ISSN: 2372-0352.
11. Ahamad, K.U., R. Singh, I. Baruah, H. Choudhury, and S. Hussain. "Equilibrium and Kinetics Modeling of Fluoride Adsorption onto Activated Alumina, Alum and Brick Powder." *Groundwater for Sustainable Development* 6 (2018): 124-133. ISSN: 2352-801X.
12. Panchore, K., S. Sharma, A. Sharma, and S. Verma. "Studies on Removal of Fluoride from Drinking Water by Using Brick Powder Adsorbent." *International Journal of Advanced Research* 4, no. 6 (2016): 1-5. ISSN: 2320-5407.
13. Abd Ali, Z.T., and Z.Z. Ismail. "Experimental and Modeling Study of Water Defluoridation Using Waste Granular Brick in a Continuous Up-Flow Fixed Bed." *Environmental Engineering Research* 26, no. 1 (2021): 1-10. ISSN: 1226-1025.
14. Shah, S.H., Q. Mahmood, I.A. Raja, A. Pervez, and M. Khan. "Bio-Sand Filter to Treat Arsenic Contaminated Drinking Water." *Desalination and Water Treatment* 53, no. 4 (2015): 1021-1028. ISSN: 1944-3994.
15. Grace, M.A. "Development of Filtration Technologies for Effective, Cost-Efficient and Robust Water Treatment." *Research Repository* (2016).
16. Manjunath, S., R. Santhosh, S. Raja, and V.M. Jemishkumar. "Low Cost Defluoridation of Water Using Brick Pieces." *LRC Journal* (2014).
17. Nemade, P.D., A. Vasudeva Rao, and S. Aland. "Removal of Fluorides from Water Using Low Cost Adsorbents." *Water Science and Technology* 45, no. 1 (2002): 71-77. ISSN: 0273-1223.
18. Warsakoon, E., N. Gunawardene, H. Kalahe, and S. Pathirana. "Defluorination of Drinking Water Using Layered Double Hydroxides." *Proceedings of the International Conference on Sustainable Built Environment* (2010).
19. Balouch, A., M. Kolachi, F.N. Talpur, H. Khan, and M.I. Bhanger. "Sorption Kinetics, Isotherm and Thermodynamic Modeling of Defluoridation of Ground Water Using Natural Adsorbents." *Journal of Environmental Protection* 4, no. 1 (2013): 37-46. ISSN: 2152-2197.
20. Gautam, B., B. Bagadkar, S. Mankar, S. Ambade, and S. Shende. "Defluoridation of Groundwater by Different Biomaterial and Geomaterials: A Review." *Research Journal of Chemistry and Environment* (2020). ISSN: 0972-0626.

.