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A Study on Removal of Contamination in Ground Water by Bricks Powder of Udaipurwati Block in Jhunjhunu District

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Abstract: ***Water pollution in groundwater is an environmental and human health emergency in semi-arid areas of Rajasthan, India. The Jhunjhunu District, especially the Udaipurwati Block in the Shekhawati region, is particularly susceptible to high levels of fluoride, nitrate, arsenic, total dissolved solids (TDS), and heavy metals in groundwater resources. This research question examines the effectiveness of locally sourced brick powder, a low-cost, sustainable adsorbent made from fired clay, as a remediation agent for removing major groundwater contaminants under controlled laboratory conditions. There were 30 bore wells and hand pumps spread across six revenue villages of Udaipurwati Block, where groundwater was sampled. Physicochemical sample characterisation was performed in accordance with the Bureau of Indian Standards (BIS 10500:2012) and the WHO (2017) standards. To determine the efficiency of brick powder in removing fluoride, nitrate, arsenic, iron, lead, and turbidity, batch adsorption experiments were conducted at different adsorbent doses (0.5-5.0 g/L), contact times (15-120 minutes), and pH values (4-10). Findings showed that the efficiency of brick powder for fluoride removal reached 84.6 per cent at a dosage of 4.0 g/L and a contact time of 90 minutes at neutral pH. The removal of nitrate was 71.3, and that of arsenic was about 67.8. The adsorption isotherm was Langmuirian (R2 = 0.981), indicating monolayer adsorption on a homogeneous surface. Pseudo-second-order kinetics was found to be the predominant mechanism in kinetic studies. The research finds that the local brick powder from the Udaipurwati brick kilns is a viable, cost-effective, and environmentally friendly adsorbent that can be implemented as a decentralised water treatment solution for rural populations in the Jhunjhunu District.***

Keywords: ***Groundwater Contamination, Brick Powder Adsorbent, Fluoride Removal, Jhunjhunu District, Udaipurwati, Adsorption Isotherm, Rural Water Treatment, Rajasthan***

Nomenclature:
PHED: Public Health Engineering Department
RO: Reverse Osmosis
CGWB: Central Ground Water Board
RGD: Rajasthan Groundwater Department
EC: Electrical Conductivity
TDS: Total Dissolved Solids
HG-AAS: Hydride Generation Atomic Absorption Spectroscopy
FAAS: Flame Atomic Absorption Spectroscopy
EPR: Extended Producer Responsibility
FHTC: Functional Household Tap Connection
JJM-DIU: Jal Jeevan Mission District Implementation Unit
XRD: X-Ray Diffraction
BIS: Bureau of Indian Standards
NRDWP: National Rural Drinking Water Program

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I. INTRODUCTION

One of the most urgent problems that rural India faces is access to clean, potable drinking water [1]. The reports of the National Green Tribunal and the Central Ground Water Board (CGWB) [2] highlight that in India, more than 200 districts have severe groundwater quality problems, and the threats to human health are critical due to contamination from both geogenic and anthropogenic sources. Rajasthan, the largest state in terms of area and mostly arid and semi-arid, is one of the most stressed states in the country for groundwater. Groundwater quality is an economic and social necessity because the state relies heavily on aquifer systems, given the limited availability of surface water [3].

The district of Jhunjhunu, in the Shekhawati region of northeast Rajasthan, is a microcosm of these broader regional issues. The area is defined by low yearly rainfall (around 380450 mm), elevated evapotranspiration rates and shallow and medium-depth aquifers, which are vulnerable to contamination due to the natural dissolution of minerals, agricultural chemicals leaching into the environment, and industrial effluents released by the multitude of brick kilns and small-scale industries populating the area [4]. The Udaipurwati Block, one of the nine administrative blocks of Jhunjhunu District, has experienced a boom in agricultural growth over the last 20 years, characterised by an increasing reliance on nitrogenous fertilisers, pesticides, and irrigated agriculture. The trend has led to nitrate loading of shallow groundwater, which has worsened the already existing geogenic contamination from fluoride-bearing rock formations [5].

One of the documented public health crises is the contamination of groundwater in Rajasthan by fluoride. The fluoride ion (F -) is washed away by the gneissic and granitic rocks that constitute the Aravalli belt into the groundwater as a result of the fluorapatite and biotite minerals. Persistently taking fluoride (exceeding 1.5 mg/L) in drinking water leads to dental fluorosis, skeletal fluorosis, and, in severe instances, crippling joint deformities [6]. The surveys in Udaipurwati Block have documented fluoride levels ranging from 1.8 to 4.7 mg/L in village hand pumps, significantly higher than the recommended limit of 1.0 mg/L for drinking

water in BIS 10500:2012. Nitrate levels were even detected to be more than 45 mg/L, which may lead to methemoglobinemia (blue baby syndrome) among the babies [7].

Traditional water treatment methods such as reverse osmosis (RO), ion exchange, electrodialysis, and chemical precipitation are technically viable but too costly for most rural households and village panchayats in Udaipurwati. The initial capital expenditure, maintenance and upkeep expenses, power demands, and the technical know-how required to install such systems are beyond the capabilities of communities with limited funds. There is therefore a dire need to find low-cost, locally sourced, and sustainable solutions for decentralised water treatment [8].

Adsorption has long been considered one of the most efficient, cost-effective, and operationally affordable methods for removing dissolved contaminants from water. Various types of natural and industrial waste materials have been studied as inexpensive adsorbents, including fly ash, rice husk ash, activated alumina, red mud, zeolite, bentonite, bone char, and agricultural residues. Of these, fired clay-based materials have received significant research attention due to their abundance, low cost, and proven affinity for ionic pollutants [9].

The fine particulate material formed during the cutting, shaping, and handling of fired clay bricks is called brick powder. It is generated in large volumes by the brick kiln industry of Udaipurwati Block, which has one of the highest densities of brick kilns in Rajasthan. This is now being used as waste and disposed of in open fields or on roadways. But its composition, which consists of amorphous silica (SiO 2) as the major component, alumina (Al 2 O 3) as the second component, and iron oxides (Fe 2 O 3) as the third component, implies that it may have a potentially high adsorption capacity of anionic and cationic contaminants [10].

The major aims of the present study were: (i) to characterize groundwater quality of selected villages in Udaipurwati Block; (ii) to characterize brick powder in the local kilns as an adsorbent material; (iii) to evaluate the removal efficiency of a brick powder on the major contaminants such as fluoride, nitrate, arsenic, iron, lead and turbidity; (iv) to determine adsor The research will help to add empirical data to the existing research on the topic of low-cost adsorbents and will provide a region-specific implementable solution to the water quality issues of the Jhunjhunu District.

II. STUDY AREA AND REGIONAL HYDROLOGY

A. Geographic and Administrative Context

Udaipurwati Block is situated between 2728N -2754N and 7520E -7548E, in the north-east of Jhunjhunu District. It covers an area of about 1,020 km² and has 72 revenue villages, with a total population of about 2.5 lakh people according to Census 2011 estimates. Its headquarters is situated in the Udaipurwati block, about 45 km northeast of the district headquarters, Jhunjhunu. The area is administratively adjacent to the Neem Ka Thana tehsil of Sikar District to the south, the Chirawa Block to the northeast, and the Khetri Block to the east [11].

It is a topography of mostly undulating semi-arid terrain, broken by sandy stretches in the west and the rocky tracts of the Aravalli ranges in the east and southeast. The major crop and the main source of livelihood is agriculture, where bajra (pearl millet), wheat, mustard, and groundnut are the main crops [12]. Irrigation is largely reliant on groundwater pumped from tube wells, boreholes, and conventional kunds (step wells). The brick kiln business is the largest non-agricultural employer in the block [13].

B. Hydrogeological Setting

Udaipurwati Block can be characterised by the Precambrian hard-rock topography of the Aravalli fold belt, which is in part covered by Quaternary alluvial sediments. Two major aquifer systems have been identified: (a) the weathered zone of some 15-40 m below ground level (mbgl) with shallow unconfined aquifers that are primarily exploited by hand pumps and dug wells; and (b) the deeper semi-confined aquifers of fractured quartzite and phyllites at depths of 60-150 mbgl, which are accessed using bore Shallow aquifers have a higher vulnerability to both natural and anthropogenic contamination, whereas the deeper aquifers tend to have a higher concentration of fluoride due to the long-term water-rock interactions with fluorapatite minerals [14].

Post-monsoon season mean water table depth in the block is between 5 and 18 mbgl, and during the peak of the pre-monsoon season, it is between 12 and 35 mbgl. The hydraulic conductivity values obtained from pumping tests range from 0.8 to 3.5 m/day in the weathered zone. The direction of groundwater flow is usually east-west, in accordance with the area's topography. It is mostly recharged by direct infiltration of rainfall and irrigation return flows, as well as by occasional flooding from the short-lived Kanto Nadi and Kantli river systems [15].

C. Historical Water Quality Issues

Government surveys of water quality in Udaipurwati Block date back to the 1980s. The Rajasthan Groundwater Department (RGD) has identified several villages in the block as having quality habitation, mainly due to high fluoride, TDS, and hardness [16]. A survey by the office of the District Collector under the Jal Jeevan Mission (JJM) in 2019 was able to identify that of the 72 villages surveyed, 34 were found to contain at least one public water source containing levels of fluoride above the legally permissible limit, and 22 were found to contain levels of TDS above 1000 mg/L [17].

III. MATERIALS AND METHODS

A. Water Sample Collection

The groundwater samples were collected at 30 sites in Udaipurwati Block in two sampling campaigns: the first in the pre-monsoon season and the second in the post-monsoon season. The area of Udaipurwati Block (adjoining six representative villages) was a sampling region comprising six hand pumps, eight open wells, and four boreholes, selected to represent a spatial cross-section of the block. The samples were collected in 1-litre HDPE bottles that were pre-cleaned and acid-washed. Samples to be analysed for

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heavy metals were stored in nitric acid to a pH below 2. All the samples were transported to the laboratory in ice-packed coolers and then analysed within 24-48 hours post-collection.

B. Physicochemical Analysis of Groundwater

Parameters studied were pH, electrical conductivity (EC), total dissolved solids (TDS), turbidity, total hardness, calcium, magnesium, sodium, potassium, bicarbonates, chlorides, sulfates, fluoride, nitrate, nitrite, iron, manganese, arsenic, and lead. Immediately after sampling, on-site measurements of pH (Hanna HI-98130), EC (Hanna HI-99300), turbidity (HACH 2100Q), and temperature were taken. All laboratory tests were conducted in accordance with the standard APHA [1BIS 3025 (Parts I–VI) and IS 10500:2012. It was analysed by use of SPADNS colourimetric method, cadmium reduction method, hydride generation atomic absorption spectroscopy (HG-AAS), and flame atomic absorption spectroscopy (FAAS) on a PerkinElmer AAnalyst 400 platform to determine the following: fluoride, nitrate, arsenic, and heavy metals [9] [18] [19][20].

C. Preparation and Characterisation of Brick Powder Adsorbent

Three representative brick kilns within the Udaipurwati town area were used to collect brick pieces. The bricks were made by firing local red clay at temperatures of about 900-1000 C, which is a characteristic of the traditional clamp kilns in Rajasthan. Brick samples were fractured into smaller pieces and ground in a ball mill. Sieving of ground material was performed to get particles between 75 and 600 2m (through 600 2m and retained on 75 2m). This fraction was chosen based on preliminary experiments aimed at achieving an optimal surface area-to-mass ratio. Washing with distilled water was performed several times to remove surface dust, followed by drying at 105 °C for 24 hours in airtight containers.

The brick powder was characterized by using: (i) X-ray diffraction (XRD) to identify the phases with a Rigaku Miniflex 600 diffractometer with Cu-Kα radiation; (ii) scanning electron microscopy with energy dispersive X-ray spect.

D. Batch Adsorption Experiments

Experiments were performed using batch adsorption in 250 mL conical flasks with an orbital mixer at 150 rpm. The influence of the following parameters was thoroughly researched:

i. *Adsorbent Dosage:* 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, and 5.0 g/L
ii. *Contact Time:* 15, 30, 45, 60, 90, and 120 minutes
iii. *Initial pH:* 4, 5, 6, 7, 8, 9, and 10 (adjusted with 0.1 N HCl / NaOH)
iv. *Initial Contaminant Concentration:* 5, 10, 15, 20, 30, 40 mg/L (for fluoride and nitrate)

The mixture was filtered using Whatman No. 42 filter paper after each experiment, and the filtrate was examined for the remaining contaminant concentration. The percentage removal efficiency (RE%) and adsorption capacity (qe, mg/g) were determined using standard equations. Each experiment was conducted thrice, and the analysis was performed using the mean values.

E. Adsorption Isotherms and Kinetic Models

The Langmuir and the Freundlich adsorption isotherm models were fitted to equilibrium data. In the Langmuir model, adsorption occurs on a homogeneous surface in a monolayer, with a uniform adsorption energy across the adsorption sites. The Freundlich isotherm is a model of adsorption on a heterogeneous surface that has an uneven distribution of adsorption heat. Both models were plotted in linear form, and the goodness of fit was assessed using the coefficient of determination (R^2). To analyse the experimental data, pseudo-first-order (Lagergren) and pseudo-second-order models were used, and intraparticle diffusion (Weber-Morris) was used to determine the rate-limiting steps.

IV. RESULTS AND DISCUSSION

A. Physicochemical Characterization of Groundwater

The summary statistics for the physicochemical parameters of the groundwater samples from Udaipurwati Block are presented in Table 1. The findings show extensive violations of the allowable drinking water parameters in BIS 10500:2012.

Table I: Summary Statistics of Groundwater Quality Parameters — Udaipurwati Block (n = 30)

Parameter	Min	Max	Mean	Std. Dev.	BIS Limit (2012)
pH	6.8	8.9	7.71	0.42	6.5–8.5
TDS (mg/L)	420	2840	1186	541	500
Turbidity (NTU)	1.2	28.6	9.4	6.1	1
Total Hardness (mg/L)	280	1420	622	287	300
Fluoride (mg/L)	0.6	4.7	2.31	0.98	1
Nitrate (mg/L)	8.4	98.6	47.8	22.1	45
Iron (mg/L)	0.08	3.4	0.74	0.52	0.3
Arsenic (µg/L)	BDL	48.2	12.6	9.8	10
Lead (µg/L)	BDL	42.7	8.3	7.6	10
Chloride (mg/L)	110	840	328	178	250
Sulfate (mg/L)	68	620	224	142	200

BDL = Below Detection Limit

The pH of the samples collected ranged from 6.8 to 8.9, with a mean of 7.71. Although the majority of samples are within the acceptable range of 6.5-8.5, five deep borewell samples in the southeastern part of the block had pH values exceeding 8.5, which may be due to the dissolution of carbonate minerals. The TDS exceeded 500 mg/L in 24/30

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samples (80%), with a maximum of 2840 mg/L in a borewell at Bissau village. High TDS can be explained by the dissolution of minerals in the geological substrate (gypsum, halite, and carbonatite), which is further enhanced by high evapotranspiration rates, which increase the concentration of dissolved solids in the vadose zone before recharge.

The most common and most serious quality issue within the study area appeared to be fluoride. The average fluoride level (2.31 mg/L) was more than twice the BIS allowable level of 1.0 mg/L, and 27/30 samples (90%) exceeded this level. A maximum of 4.7 mg/L was observed at a village school in Udaipurwati, underscoring the immediate public health importance of the result. Nitrate levels exceeded 45 mg/L in 16 samples (53%), with the highest reaching 100 mg/L in agricultural areas where high urea application rates are used. Iron contamination exceeding 0.3 mg/L was observed in 18 samples (60%), particularly in the eastern villages near lateritic formations.

B. Characterization of Brick Powder

The XRD analysis of the powdered brick revealed the major crystalline phases to be quartz (SiO2), mullite (3Al2O3 · 2SiO2), hematite (Fe2O3), and gehlenite (Ca2Al2SiO7). The preponderance of mullite and quartz agrees with the aluminosilicate firing of clays, which is of high temperature. Amorphous phases made up about 35-40 per cent of the total mass, as shown by a wide hump in the range of 15-35 °. The presence of an amorphous component is likely to play a major role in adsorptive capacity.

The SEM images showed a porous, irregular surface morphology with micro-cracks, fissures, and aggregated particles. EDX analysis confirmed the elemental composition: Si (28.4%), Al (14.7%), Fe (8.3%), Ca (5.1%), Mg (2.2%), K (1.8%), and O (balance). Of special interest is the iron content of the brick powder, since iron oxides and hydroxides are effective adsorbents of fluoride and arsenic as ligand-exchange and surface-complexation reagents.

BET analysis showed that the specific surface area was 18.7 m^2/g, the total pore volume was 0.041 cm^3/g, and the pore diameter was 8.8 nm, indicating mesoporosity according to IUPAC. FTIR spectra revealed typical absorption bands in 1087 cm -1 and 796 cm -1 (Si-O-Si asymmetric and symmetric stretching), 574 cm -1 (Al-O bending), 3447 cm -1 (O-H stretching of surface hydroxyl groups), and 1637 cm -1 (H-O-H bending). The high number of surface hydroxyl (-OH) groups indicates a high adsorption capacity for anionic contaminants. The pHpzc was determined to be 6.8, indicating that the surface of the brick powder has a net positive charge at pH values below 6.8 and a net negative charge at pH values above 6.8. This directly concerns the adsorption of anions (fluoride, nitrate) and cations (lead, iron) under various pH conditions.

C. Effect of Adsorbent Dosage

The efficiency of fluoride removal increased with increasing adsorbent dosage, reaching 84.6% at 4.0 g/L. Beyond this, no further improvement was observed, indicating saturation of available adsorption sites with respect to fluoride concentration. The removal of nitrates followed the same pattern, with 71.3% at 4.0 g/L and 67.8% at 4.0 g/L. The optimal dose of 4.0 g/L was therefore used in all subsequent experiments.

The increase in removal efficiency with dosage is mainly due to more adsorption sites becoming available as the mass of adsorbent increases. Nevertheless, at very high doses, the effective surface area may decrease due to particle agglomeration, resulting in a plateau. The specific adsorption capacity (qe) declined with dosage, a fact in the batch adsorption literature, and is explained by partial saturation of adsorption sites at lower initial adsorbate-to-adsorbent ratios.

Table II: Effect of Adsorbent Dosage on Removal Efficiency (Contact Time = 90 min, pH = 7.0)

Dosage (g/L)	F^- Removal (%)	NO_3^- Removal (%)	As Removal (%)	Fe Removal (%)
0.5	36.2	28.4	24.1	31.8
1	51.7	41.2	36.5	47.3
2	67.4	55.8	49.2	61.9
3	76.9	64.3	58.6	73.2
4	84.6	71.3	67.8	82.4
5	85.1	72	68.4	83.1

D. Effect of Contact Time and Kinetics

The adsorption process on the brick powder was rapid during the first 30 minutes (62 per cent of the total adsorption), then gradually approached equilibrium by 90 minutes. It is a two-stage behaviour, considered a faster phase and a slower phase, typical of surface adsorption and intraparticle diffusion. The rapid initial stage is explained by the large number of surface sites on the adsorbent's powder particles. In contrast, the slow second stage relates to the diffusion of adsorbate molecules into the micro- and mesopores of the adsorbent.

Pseudo-first-order kinetics (Lagergren model) had a poor fit (R 2 of 0.912- 0.938), whereas pseudo-second-order kinetics had an excellent fit (R 2 of 0.981- 0.994) to all the contaminants tested. The pseudo-second-order model assumes that the rate-controlling mechanism is chemisorption by valence forces, electron sharing or exchange, which is consistent with surface complexation and ligand exchange mechanisms suggested for adsorbing fluoride on iron oxide-containing materials. The rate constants (k_2) were between 0.0032 g/mg/min (fluoride) and 0.0087 g/mg/min (iron), suggesting that the removal of iron is faster compared to the removal of fluoride.

Analysis of the intraparticle diffusion (Weber-Morris ' plot) revealed multilinearity, indicating that intraparticle diffusion was not the sole rate-limiting mechanism. The first steep was due to diffusion of the film (boundary layer), and a plateau indicated equilibrium had been reached. The nonzero intercept of the linear segments also confirmed that the overall adsorption was a combination of film and intraparticle diffusion.

E. Effect of pH

The pH-activity of fluoride removal was most effective at pH 6-7 (84.6%) and sharply decreased at acidic (pH < 5) and alkaline (pH > 8) conditions. When the pH is acidic, surface hydroxyl groups (-OH 2 +) are protonated, which should positively affect the surface charge and, in theory,

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fluoride adsorption; however, when the pH is strongly acidic, the high H 3+ activity and dissolution of the adsorbent matrix compete and decrease net efficiency. The surface becomes more negative at alkaline pH values above the pHpzc (6.8), causing electrostatic repulsion with fluoride ions (F-) and increased competition with hydroxyl ions (OH-) for surface sites via anion exchange. The main reason for the weakening of fluoride removal above pH 7 is competition between F and OH.

The maximum efficiency in nitrate removal was observed at pH 6-7, which was generally in line with the behaviour of fluoride but showed a steeper drop at high pH due to greater electrostatic repulsion. Removal of arsenic (as As 3 + and as 5 +) was counterintuitive to speciation, with as 5 + (arsenate) removal being greatest at pH 5-7, and as 3 + (arsenite) removal being less pH-dependent since its molecular form is neutral at this pH range. The removal of iron and lead was more efficient at neutral to slightly alkaline pH, consistent with the formation of surface complexes between the metals and hydroxides. Brick powder exhibited removal efficiencies within the optimal range for all target contaminants at pH 6.575, which was dominant in most Udaipurwati groundwater samples.

F. Adsorption Isotherms

Experiments on adsorption isotherms were conducted at pH 7.0 and a contact time of 90 minutes with different initial fluoride concentrations (5-40 mg/L). The equilibrium data were compared with the Langmuir and the Freundlich isotherm models.

The Langmuir isotherm provided a linear fit with R^2 = 0.981, indicating that monolayer adsorption on an unstructured surface is the dominant process. The highest monolayer adsorption capacity (qmax) of fluoride was determined to be 4.87 mg/g, and the Langmuir constant (KL) was 0.138 L/mg. The separation factor was dimensionless and ranged from 0.154 to 0.591, with all values between 0 and 1, indicating that the adsorption process is favourable under the experimental conditions.

The Freundlich isotherm also provided a good fit (R^2 = 0.952), with KF = 1.43 (mg/g) (L/mg) ^(1/n) and 1/n = 0.48, indicating favorable adsorption (1/n < 1). The fact that the Langmuir model fits slightly better than the Freundlich model implies that, although the surface is not perfectly homogeneous, the mechanism dominating is that of saturable surface sites, rather than a continuously increasing adsorption energy.

Table III: Langmuir and Freundlich Isotherm Parameters for Key Contaminants

Contaminant	qmax (mg/g)	KL (L/mg)	R^2 (L)	KF	1/n	R^2 (F)	RL
Fluoride	4.87	0.138	0.981	1.43	0.48	0.952	0.22
Nitrate	3.92	0.112	0.974	1.08	0.52	0.941	0.31
Arsenic	2.84	0.094	0.968	0.84	0.56	0.929	0.37
Iron	5.62	0.187	0.983	2.01	0.44	0.957	0.18

L = Langmuir, F = Freundlich

G. Comparison with Other Low-Cost Adsorbents

The maximum adsorption capacity of the brick powder towards fluoride (4.87mg/g) is comparable to that of several other reported low-cost adsorbents. One of the most widely used defluoridation media is activated alumina, with qmax values of 4-12mg/g, though this is dependent on the conditions and preparation of the material. Bone char, which has a long history of research in the African context, generally has a qmax of 2-8 mg/g. The qmax of fluoride in red mud (waste in industrial bauxite processing) is 2.5-5.1 mg/g. Reported values of qmax of 3.2-4.1mg/g have been observed in calcined clay minerals reported in similar geological settings in Rajasthan. Therefore, the adsorption performance of brick powder from Udaipurwati kilns is competitive and offers apparent benefits in terms of local availability, zero raw material cost, and low processing requirements.

In nitrate removal, the performance of the brick powder (qmax = 3.92 mg/g) is better than that of natural kaolinite and bentonite, but worse than that of modified clays treated with quaternary ammonium compounds. Nevertheless, the lack of modification to the brick powder makes it more suitable for the point-of-use market, where contamination of treatment chemicals is a secondary priority.

H. Turbidity and Microbial Considerations

Experiments of column filtration using a 30 cm deep powder bed (particle size 300 600 µm) of bricks showed that turbidity, which was 28.6 NTU initially, was reduced to 3.1 NTU at a flow rate of 0.5 L/min; a 89.2 per cent decrease. This is not quite within the BIS limit of 1 NTU for drinking water, but the remaining turbidity may be lowered to acceptable levels through a subsequent stage of sand filtration. The total coliform counts using the multiple-tube fermentation technique were reduced by 72-85 per cent with the brick powder filter bed, believed to be due to physical filtration and possible inactivation on the rough ceramic surface. But physical filtration alone cannot be deemed adequate for microbiological purification; disinfection (chlorination or UV treatment) must be used in conjunction with physical filtration in any practical water treatment system.

I. Regeneration and Disposal of Spent Adsorbent

Spent brick powder was regenerated using a 0.1 N NaOH solution. Once the adsorbent was loaded with fluoride to almost saturation, it was eluted using NaOH and then rinsed with distilled water. Five cycles of adsorption-regeneration revealed that the removal efficiency decreased to 71.2% in the fifth cycle, compared to 84.6% in the first cycle, indicating a 13.4% decrease, which is acceptable in practice. This decrease is caused by partial blockage of mesopores by precipitated reaction products and by the disappearance of surface hydroxyl groups during repeated exposure to alkalinity. The adsorption capacity of the material was regenerated at 500 C (thermochemical) to 94 per cent of its original value, indicating that thermal regeneration could be economically feasible in situations where kilns are already in place.

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The spent brick powder containing fluoride should be carefully disposed of, since concentrated fluoride can leach into the soil if disposed of in open areas. The recommended methods are stabilization-solidification in cement matrices or co-disposal with construction waste in lined landfills. The low heavy metal content of the powder from used bricks implies that the spent material will not be hazardous waste under the provisions of the Hazardous Waste (Management and Handling) Rules, 2016, provided that the arsenic and lead loadings do not exceed the threshold levels.

V. DESIGN CONSIDERATIONS FOR COMMUNITY-SCALE IMPLEMENTATION

A. Proposed Treatment Train

The findings of the experiment suggest that a three-stage point-of-use water treatment system be provided to households in the quality-affected villages of Udaipurwati Block. The treatment train will include: (Stage 1) coarse pre-filtration with a layer of gravel (2540 mm) to remove suspended material and organic matter; (Stage 2) filtration with a layer of brick powder (4.0 g/L equivalent loading, bed depth 4050 cm, 300600 m) to remove fluoride, nitrate, arsenic, iron and A 20-litre household batch can be estimated to take 4560 minutes total treatment time and produce treated water that falls within BIS limits of the three key parameters of fluoride (< 1.0 mg/L), arsenic (< 10 µg/L) and turbidity (< 1 NTU) when the raw water concentrations are less respectively.

B. Economic Analysis

An initial cost analysis of the proposed household-level brick powder filtration unit was conducted. The unit price of a 20-litre-capacity brick powder filter (made from a locally available earthenware pot) is estimated at INR 450-600, including the cost of brick powder (INR 80-100/kg from local kilns), gravel, fittings, and container. At a dosage of 4.0 g/L and a domestic consumption of 20 litres per day, the household price for replacing the brick powder (after 6 months of regeneration cycles) is INR 1,200-1,500. This is a very good comparison with commercial defluoridation units on the market, which cost INR 3,000-8,000 initially and INR 2,000-4,000 per year to replace the filter media.

A gravity-based central filtration unit supplying 200 households using brick powder beds would require about 120-150 kg of brick powder per filtration unit (tank volume: 300 litres; loading rate: 400-500 L/hour). Such a unit is estimated to cost INR 1.8-2.5 lakhs to construct and install, and INR 40,000-60,000 annually to operate and maintain. The cost of the brick powder system saves about 70 80% of the cost of the commercial RO plant (INR 812 lakhs to install a commercial RO plant + INR 12 lakhs of yearly maintenance.

C. Community Participation and Technology Adoption

Community participation, awareness and institutional support are essential to the successful implementation of low-cost water treatment technologies in rural India. The study, based on focus group discussions carried out in three villages of Udaipurwati Block, found that the community members are fully informed about the local problem of taste and quality of groundwater (they refer to it as 'khari paani' - salty water and nuksaan karne wala paani - harmful water) but are not aware of the specific health risks. Awareness campaigns that associated the prevalence of fluorosis (locally known as dant kharaabi - tooth damage) with fluoride in drinking water created high community motivation to adopt treatment solutions.

Women, who are the primary water managers in rural households, were most receptive to the concept of the brick powder filter when it was presented as an extension of the traditional use of matkas (earthen pots) for storing water. Two villages' Gram Panchayats were willing to provide some funds in the form of grants under the 15th Finance Commission to procure and maintain community-scale filters. The Jal Jeevan Mission District Implementation Unit (JJM-DIU) Jhunjhunu was informed of the study results, and initial consultations indicate that the defluoridation of brick powder may be incorporated into the JJM Functional Household Tap Connection (FHTC) quality improvement component.

VI. ENVIRONMENTAL AND REGULATORY IMPLICATIONS

The proposed use of brick powder as an adsorbent is consistent with India's water quality regulations and the use of industrial wastes. The updated IS 10500:2022 and the older IS 10500:2012 drinking water standards both require that drinking water sources in quality-influenced zones be treated to achieve the permissible levels. The National Water Quality Sub-Mission of the Ministry of Jal Shakti, under the National Rural Drinking Water Program (NRDWP), specifically focuses on fluoride, arsenic, and nitrate as priority pollutants requiring remediation. Brick powder technology can be marketed as a proven, indigenous, and low-energy treatment option within these national programs.

Environmentally, using brick kiln waste (brick powder) as a medium for water treatment is a good conversion of waste into a resource. In Rajasthan, the amount of unusable broken pieces and powder produced in brick kilns is about 5-8 per cent of the total brick output, contributing about 0.5-0.8 million tonnes of waste each year. Redirecting even a portion of this waste for water treatment would reduce open dumping, reduce the brick kiln industry's waste footprint, and align with the goals of the circular economy. This complies with the principles of Extended Producer Responsibility (EPR) advanced in India's Environmental Policy Framework.

The power consumption for treating powdered bricks is considered insignificant compared to RO or electrodialysis, which require 0.5-3.0 kWh/m³ of treated water. A gravity-based brick powder filter has no external power requirements (except for initial pumping). It is therefore especially appropriate in off-grid rural settings where electrical power is intermittent, which is a widespread problem in some areas of Jhunjhunu District.

A secondary contamination issue arising from the adsorbent itself is another environmental issue that needs to be monitored. The raw material for the brick (clay) may contain heavy metals that could be washed into treated

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water, especially at low pH. Nevertheless, leaching tests under simulated groundwater conditions (pH 78, contact time 24 hours) revealed that the leachate concentrations of arsenic (3.2 µg/L), lead (5.1 µg/L), chromium (2.8 µg/L), and cadmium (0.8 µg/L) were all below the permissible limits set by BIS.

VII. CONCLUSIONS

This paper has thoroughly researched the physicochemical quality of groundwater in the Udaipurwati Block of Jhunjhunu District and assessed the feasibility of using locally available brick powder as an adsorbent to remove the major groundwater contaminants. The main findings are:

- The quality of groundwater in Udaipurwati Block is seriously impaired, with 90% of the sampled sources exceeding the BIS allowable levels of fluoride, 53% of nitrate, 60% of iron and 80% of TDS. The contamination is of both geogenic (fluoride, arsenic) and anthropogenic (nitrate, turbidity) origin.

The physicochemical properties of the brick powder, such as a mesoporous structure (BET surface area 18.7 m 2/g), a high density of surface hydroxyl groups, iron oxide content, and a pHpzc of 6.8, found in brick powder from Udaipurwati kilns, make the adsorption of anionic and cationic contaminants possible.

Within optimal conditions (4.0 g/L dosage, 90 minutes, pH 67), brick powder demonstrated the following removal efficiencies: fluoride 84.6, nitrate 71.3, arsenic 67.8 and iron 82.4 - enough to bring typical Udaipurwati groundwater within BIS allowable limits on these parameters in most situations.

Adsorption, Langmuir isotherm kinetics (R 2 = 0.981), and a maximum adsorption capacity of 4.87 mg/g, are consistent with adsorption on a monolayer surface via adsorption complexation and ligand exchange at iron oxide and aluminol surface sites. The adsorption rate can be best described by pseudo-second-order kinetics.

2. Brick powder can be used in the treatment of drinking water in the pH conditions of the groundwater of Udaipurwati (pH 7 -8.5), and there is no secondary contamination of heavy metals leached in the groundwater that is well beyond the permissible limits.

Economic analysis: It has been proven that the cost of filtration of the brick powder is about 70-80 per cent cheaper than conventional RO-based defluoridation; a household-based unit costs INR 450-600 and has annual running costs of INR 1200-1500.

- The technology is in line with the Jal Jeevan Mission goals and is a feasible, indigenous, decentralized water treatment technology to the quality-affected rural households in Jhunjhunu District. Community acceptance surveys show high potential for adoption, particularly when put in the context of current cultural practices of earthenware water storage.

The research provides a scientific basis for implementing brick powder-based filtration systems in Udaipurwati Block and other fluoride- and nitrate-affected areas in Rajasthan. To operationalise this technology through pilot demonstration projects, it is suggested that collaboration be pursued with the Rajasthan Ground Water Department, the Public Health Engineering Department (PHED), brick kiln associations, and Gram Panchayats. It is justified to recommend adding locally fired brick powder to the BIS-approved list of defluoridation media in IS 7389.

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As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

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