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Suitability of clayey soils from Jalore and Jodhpur, Rajasthan, India for the production of 3-Litre ceramic water filters

S. Duhan[a,*], S.K. Adari[b], N. Kanwar[c], S. Gupta[a], A.K. Nighojkar[a], M. Ahmad[a], P.K. Dammala[b,d], M. Chhabra[b,d], A.K. Plappally[a,d]

[a]*Department of ME, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan, India, email: sunil.2@iitj.ac.in (S. Duhan)*
[b]*Department of C&IE, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan, India*
[c]*Department of BSBE, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan, India*
[d]*CETSD, Indian Institute of Technology Jodhpur, Jodhpur, Rajasthan*

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ABSTRACT

Clayey soils in Raithal, Jalore, Rajasthan, India, have been used for local manufacturing of clay ceramic water filters by potter communities. Potters are trying clayey soils from different locations across India to produce these filters. The suitability of clayey soils from Jheepasani, Jodhpur, and Gajsinghpura, Jodhpur, Rajasthan, India, to manufacture these water filters is compared with soils from Raithal, Jalore, Rajasthan, India. The shrinkage limit and maximum dry density were the lowest for Jheepasani soils. Jheepasani soils have quartz in large quantities, while Gajsinghpura soils are characterized by zeolite. Scanning electron microscopy revealed dense, flaky structure of Gajsinghpura soils and a loosely packed matrix in Jheepasani soils. The micrograph of soils depicts the presence of crystalline character in constituents of Raithal and Gajsinghpura soils. A 3L frustum-shaped composite is made by mixing an equal amount of each of the three soils listed above (taken on their own) with an equal amount of burnout material. The mixture is then pressed into the shape. These press-formed frustums were traditionally baked at 750°C in a potter's open-hearth kiln at Banad village, Jodhpur, Rajasthan, India, to get the new 3L ceramic water filters. A maximum percolation rate of 1.8 L/h was observed from filters manufactured using Jheepasani soils. The samples extracted from the walls of Gajsinghpura soil-based ceramic water filters were comparatively more substantial than those manufactured from the soils of Raithal and Jheepasani. The effectiveness of these 3L filters was tested using *Escherichia coli* as a surrogate for other waterborne pathogens. *E. coli* removal with a log reduction value of 2.62 was showcased by Raithal soil-based ceramic water filters. On the basis of this result, Raithal soil-based ceramic water filters were found to be functionally better among the three ceramic water filter variants manufactured from clayey soils found near the Thar Desert in India.

Keywords: Ceramics; Filter; Clay; *Escherichia coli*; Zeolite; Waterborne

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1. Introduction

Pitcher or matkas for household water storage in Jalore and Jodhpur region of Rajasthan in India are off-white in color [1]. Evaporative cooling of drinking water using baked clay pots has been practiced in this region for ages [2]. The off-white coloration of these storage vessels was due to high content of Mg oxide and low iron oxide in the clays of region [3]. Further salty nature of these clays was evident from high sodium oxide content present within the clay [4]. Apart from this type of clay Rajasthan has 10 different clays that get mined from its crust [4]. Rajasthan is a

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* Corresponding author.

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water scarce location with the thar desert nearby [5,6]. The cultural setting of hamlets or Dhanis for distinct communities are of dispersed spatial nature. This introduces culture specific water resources which are unavailable to people from other cultures. This introduces an inherent unspecified distance to fetch water from a source in Rajasthan [7]. To fetch water an individual needs to walk an average of half hours by foot in the rural location of this region under study [8,9]. The water source from where the water is fetched can be impure. In India only 3 rivers are fit for bath and there are 3 lakes which are having a biochemical oxygen demand less than 3 mg/L [9]. This situation indicates the possibility of impurity in the fetched water at point-of-use (POU). Further the above comment also indicates the high cost that may need to be incurred in future to provide piped treated water supply. Therefore, this arid south Asian region requires a POU solution for household water treatment.

There are two sustainable options for drinking water provision at low cost [10]. As per the thought process of reliability of ceramic water filter has lesser number of parts as compared to MIT biosand filter therefore, more reliable [11]. In 2015 G-filter an indigenous ceramic water filter (CWF) was introduced in India by IIT Jodhpur [9]. The design of machines for manufacturing frustum shaped porous ware was also put forward by Gupta et al. [8]. For first time potter from several region where require to be trained considering the distinct nature of clays at distinct location across India. The manufacturing process as enumerated in Gupta et al. [8] was modified and indigenized by Satankar [12]. The mixing of clay with saw dust for CWF manufacturing process was effectively formalized using a traditional approach by Satankar [12]. The baking process of this material in order to obtain the functionality of water filter is enumerated in Gupta et al. [8]. Removal of other impurities which are anionic in nature using the 9-L G-filter was enumerated by Kaurwar et al. [13]. While doing this experiment it was made sure that the filtrate from G-filter conformed to drinking water standards put forward by World Health Organization (WHO). Zero *Escherichia coli* count per 100 mL of drinking water is considered safe by WHO standard [14].

The CWF have showcased effectiveness in preventing diarrhoea in village population in the hinterlands of Nigeria among children below 5 y of age [15]. Diarrheal diseases account for 21% of mortality amongst children less than 5 y of age across the world. Fewtrell and Colford Jr. [16] said that POU water treatment methods are more effective in reduction of diarrheal incidents. During this study it was found that apart from a good ceramic filter academic literacy and awareness to health and WASH practices are important to maintain operational effectiveness of household water treatment devices [17]. *E. coli* strain were used as indicator of fecal pollution. CWF removed them due to their porous and tortuous nature [18]. The G-filter manufactured in the area under the study adhere to WHO standard as mentioned by several authors like Gupta et al. [8], Nighojkar et al. [3] and Duhan et al. [20] while doing trials on the field and in the laboratories. Thus G-filter became a popular POU household water treatment solution for India's rural population [19]. With the advent of the requirement of energy free gravity-based G-filter as well as personalized used thought process evolution of small volume G-filter become important. Major problem in village of India is power cut which restrict working people from utilizing energy intensive water purifier as their offices, therefore the design and development of 3L G-filter gains prominence.

2. Experimental methods

2.1. Setting

In this article, design of 3L G-filter in a decentralized manner is purported. Therefore, clayey soils from three different location are considered which are supposed to be closer to their respective potter households. Gajsinghpura (26°49′21.6″N 73°26′33.8″E), Jheepasani (26.468268, 73.108064) from Jodhpur and Raithal (25°37′50.8″N 72°40′33.9″E) from Jalore district Rajasthan, India are the locations from where clays were mined [20].

2.2. Soil plasticity

The clayey soil of Gajsinghpura had a large range of water holding capacity compared to clay from Jheepasani [20]. According to Duhan et al. [20] Jheepasani clayey soils were cohesionless, compared to two other aridic soils. In this article, Atterberg limit tests as per ASTM D4318 2010 are used to investigate variations in plasticity as a function of liquid limit. Casagrande apparatus will be utilized for their measurement on the said inland salt [21].

2.3. Clayey soil physics and related properties

Following guidelines elaborated in ASTM D2216(2010), moisture content in clayey soils from Gajsinghpura, Jheepasani and Raithal villages were measured. The results are elaborated as water content in soil per unit of its mass [22]. A modified proctor test has been performed to obtain the maximum dry density (MDD) and optimum moisture content (OMC).

ASTM D854(2014) elaborated methodology that was used as a reference for conducting specific gravity measurement of these soils. Here a water pycnometer test was used for all the different soils sieved separately through a 4.75 mm sieve. Further a modified proctor test is performed to elaborate the relationship between MDD and OMC of the distinct soils. This will help to enumerate changes in the properties of the soils during different degrees of compaction [23]. Micrograph of the soils will be studied using the scanning electron micrograph Carl Zeiss SEM EVO 18 (Germany) at IIT Jodhpur and diffraction results from Bruker D8 ADVANCE diffractometer (Germany) at IIT Jodhpur will be analysed for elemental and chemical characteristics. X-ray diffraction (XRD) analysis of the produced 3L G-filter material was performed using the advanced X-ray diffraction test. This pattern analysis was done by using X′pert Highscore Plus Software. The total number of points is 4,251. XRD test was performed at the wavelength of 1.540590 A.

3. Manufacturing

3.1. G-filter

The equal volume of clay and sawdust should be mixed together to get the initial new mix for the G-filter manufacturing [9]. A similar process was followed for each of the clayey soil considered here [24]. The uniform clay sawdust mixture is added with 70% overall volume of water to get the green or wet clay composite mold mix for press forming [25].

3.2. Manufacturing 3L G-filter

Using the mold design illustrated by Duhan et al. [20], the press forming process can be accomplished for the prepared wet clay composite. Wet clay-sawdust composite balls of approximately 4 kg are manually press formed using die pattern shown in Fig. 1 to get frustum shaped molds or green ware.

As illustrated in Fig. 1 the strategy of baking the 3L greenware is elaborated in Duhan et al. [20] and is followed to produce the sintered 3L G-filter. The dimension of the final manufactured G-filter mold is illustrated in Table 1.

Thus 3 different G-filter materials were developed using the 3 distinct clay soil from Gajsinghpura, Jheepasani and Raithal village of Rajasthan India.

3.3. Wall strength

The compressive strength of the ceramic material along the slant wall of the 3L G-filter (manufactured here) is to be measured. Universal testing machine model (UTM) EZ-50 Loyd Instrument, Germany make is used to perform the compressive strength test. Geometry (1.5 cm^3 × 1.5 cm^3 × 1.5 cm^3) is extracted from the slant ceramic wall of each of the distinct 3L G-filters.

3.4. Gravity based flow experiments

Prior to the flow experiments, the ceramic water filters were soaked in water for 12 h [26]. This was done to avoid transient flow phenomena during early stages of the flow experiments. At the start of the experiments, each saturated ceramic water filter was mounted in the receptacles and filled with 9 L of water. After that, the flow through the filters was measured by recording the volume of water discharged from the ceramic water filter every hour. Six frustum-shaped ceramic water filters with the same clay: sawdust composition was tested. The flow rate and water level were measured at every 2nd hour in a day for a total of 12 d.

3.5. E-coli microbial removal study

A test for water-borne bacterial contamination using *E. coli* as an introductory of fecal contamination is performed here [27]. The bacterial removal capacity of the prepared filters was examined using non-pathogenic *E. coli* Top

Fig. 1. Steps of manufacturing with a 3L G-filter.

Table 1
Dimensions for 3L G-filter male and female dies

Male die				Female die			
Volume of G-filter	Base radius (mm)	Taper angle	Thickness	Inner base radius (mm)	Outer base radius (mm)	Thickness (mm)	Taper angle
3L	38.51	9.97	20	61.5	70.25	20	9.97

10 cells. The *E. coli* cells were grown in Luria Bertani (LB) broth at 37°C for 24 h by stirring at 150 rpm in an incubator shaker (Rivotek, India). The 400 mL bacterial samples were passed through the filters, and filtrates were collected to examine the bacterial removal efficiency. Five replicates of the sample, along with the control, were investigated for microbial removal study. Samples were investigated for bacterial removal by using Most Probable Number (MPN) technique [28,29].

4. Results and discussion

4.1. Physical properties results of clay

The water or moisture content of the three distinct soils found using Casagrande's experiment are plotted against the number of blows as shown in Fig. 2. The moisture content corresponding to 25 blows (shear stress equivalent to 1.7 kPa or 25 g/cm^2) provides the liquid limit for each of soils tested here. From Fig. 2, Jheepasani soil, Gajsinghpura soil and Raithal soil has liquid limit values of 28.5%, 47.1% and 52%, respectively.

The soil samples collected from Jheepasani, Gajsinghpura and Raithal are of clayey nature. This is confirmed from the location of the respective data sets above the A-line in the plasticity chart depicted in Fig. 3. Further it has been confirmed that Raithal soil has highest clay plasticity and lowest clay content is of soil from Jheepasani as illustrated in Fig. 3.

Raithal clay is also found to have high organic content. From the value of liquid limit of Raithal and Gajsinghpura as well as their plastic limit ranges between 35%–100%, respectively confirming presence of kaolinite. It also confirms that Jheepasani and Gajsinghpura soils have low liquid limit because they have corresponding plasticity data lying on the left of the 50% liquid limit line.

The number of finer particles is the least in Gajsinghpura as shown in Fig. 4. Clayey soils from Raithal are having the maximum finer particle percentage till the size of 0.1 mm and below. It is important to see that highest fineness of the particles is attained beyond a size of 1 mm in Raithal soils.

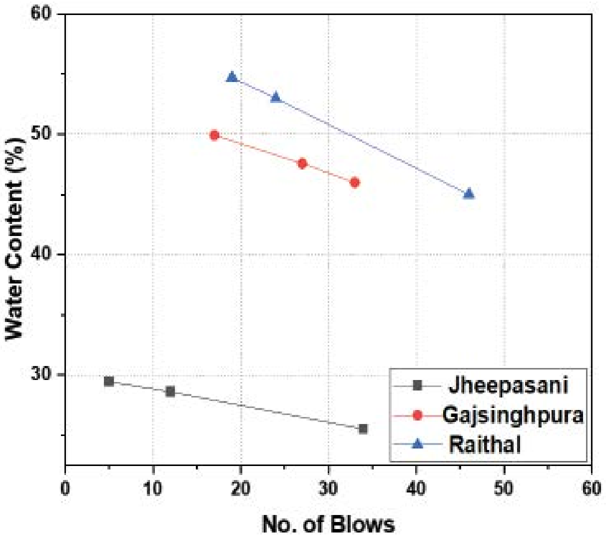


Fig. 2. Liquid limit chart.

Fig. 5 illustrates compaction curves for each of the distinct soils analysed here. It was observed that highest plasticity soils from Gajsinghpura had the least dry density and largest optimum content conforming to observations similar to those of Tartt Harris [30].

Shrinkage limit helps in understanding volumetric changes in soils when they pass through a moist and dry cycle. From the test calculated adhering to IS 2720 part 6, Gajsinghpura soil is found to showcase maximum reduction in volume (highest shrinkage) as it loses water during a drying event as depicted in Fig. 6. Too much shrinkage in clays cannot be good character for G-filter manufacture.

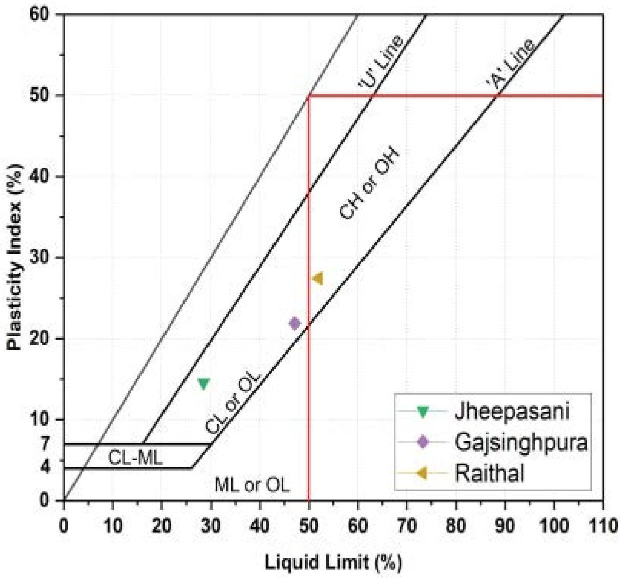


Fig. 3. Plasticity chart for the Jheepasani soil, Gajsinghpura soil, and Raithal soils.

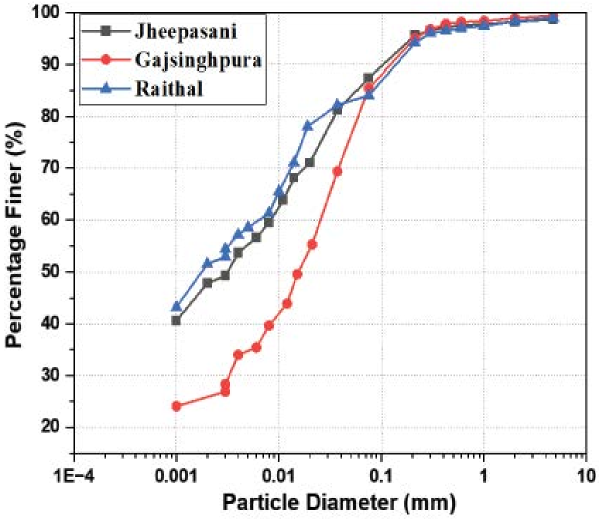


Fig. 4. Particle-size distribution of soils mined from Jheepasani, Gajsinghpura and Raithal in Rajasthan, India.

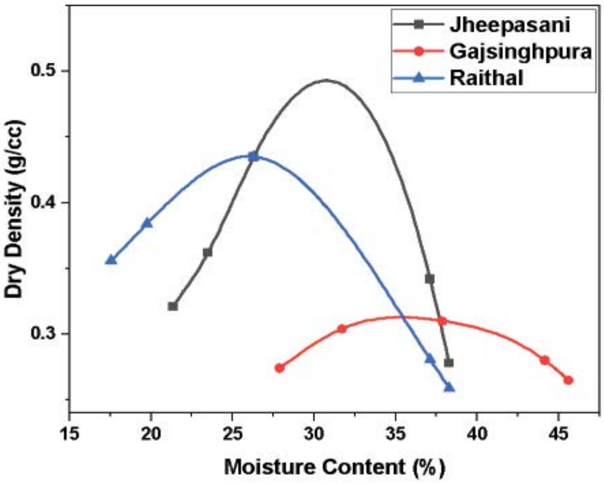


Fig. 5. Determination of maximum dry density (kg/m^3) and optimum moisture content (%) for all three clays.

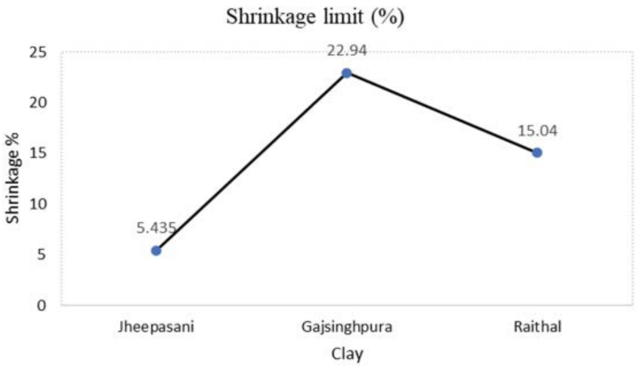


Fig. 6. Comparison of shrinkage characteristics in Jheepasani, Gajsinghpura and Raithal clayey soils.

Table 2
Physical properties of clays

Properties	Jheepasani	Gajsinghpura	Raithal
Specific gravity	2.498	2.539	2.614
Plastic limit (%)	13.95	25.23	24.56
OMC (%)	27	36	25.25
MDD (g/cc)	0.435	0.31	0.437

The specific gravity values for each of three distinct soils measured using water pycnometer test is illustrated in Table 2.

4.2. Scanning electron microscopy

Carl Zeiss SEM EVO 18 (Germany) special edition has been used to analyse ceramics' surface and cross-sectional morphologies.

4.2.1. Raithal

There is continuity in formation of flowy microstructures one over the other that tells about the characteristics of clay which is crystalline in nature. More magnesium has precipitated out after baking. All the elements, such as iron, calcium, potassium, and sodium, are in salt form, crystalline. For wavelength 10 µm, the elemental composition is shown in Fig. 7. The elements present in the sample are O, Na, Si, Al, Mg, Ca, Cl, K, and Fe.

When the resolution was changed to the wavelength of 30 µm, the weight and atomic were obtained from element 'O' was 53.4% and 68.53. Fig. 7 micrograph conforming to the nature of kaolinite microstructure [31].

4.2.2. Gajsinghpura

Waxy flow formation can be seen from scanning electron microscopy micrograph in the material suggesting layering is possible. Layering allows controlled deposition and stacking of individual layers, enabling the fabrication of complex structures with precise layer-by-layer control. This confirms the presence of kaolinite [31]. There is the precipitation of sodium after baking. This confirms saltiness in clay of Gajsinghpura. Potassium, sodium, and magnesium help in better sintering or baking. For wavelength 10 µm, the elemental composition is shown in Fig. 8. The elements present in the sample are O, C, Si, Al, Mg, Ca, K, and Fe.

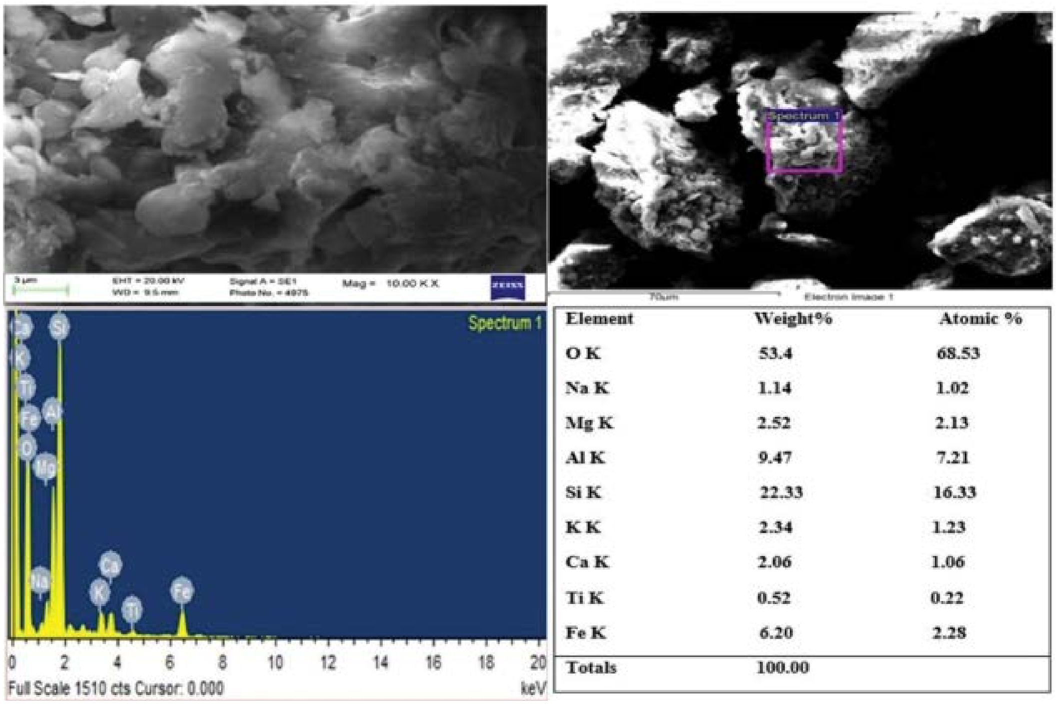
The weight and atomic of elements 'Al' and 'Si' are 6.68% and 5.24% and 19.34%, and 15.82%, respectively. After increasing the wavelength, the weight% and atomic% of all the elements are decreased. After increasing the wavelength, 'C' also shows the maximum peak.

4.2.3. Jheepasani

Non-flaky powdery texture shows that it is more amorphous in nature. It also confirms non clayey character. Here it looks like precipitation is observed at various sites, as shown in Fig. 9. As Jheepasani soils contains more silt and sand particles, it is difficult to find a clear picture of grain boundary formation in this soil. This clay had very low plasticity, making it difficult for the surface to show binding characteristics. From the EDS spectra, it has been observed that after baking Jheepasani clay the carbon popped out. This phenomenon is clearly supported by grain boundaries color which is comparatively dark than that for other clay at the same temperature. The highest peaks were obtained in the range between 0 to 2 Kev. If the energy is increased from 2 to 4 Kev, then the peak for the same element is reduced.

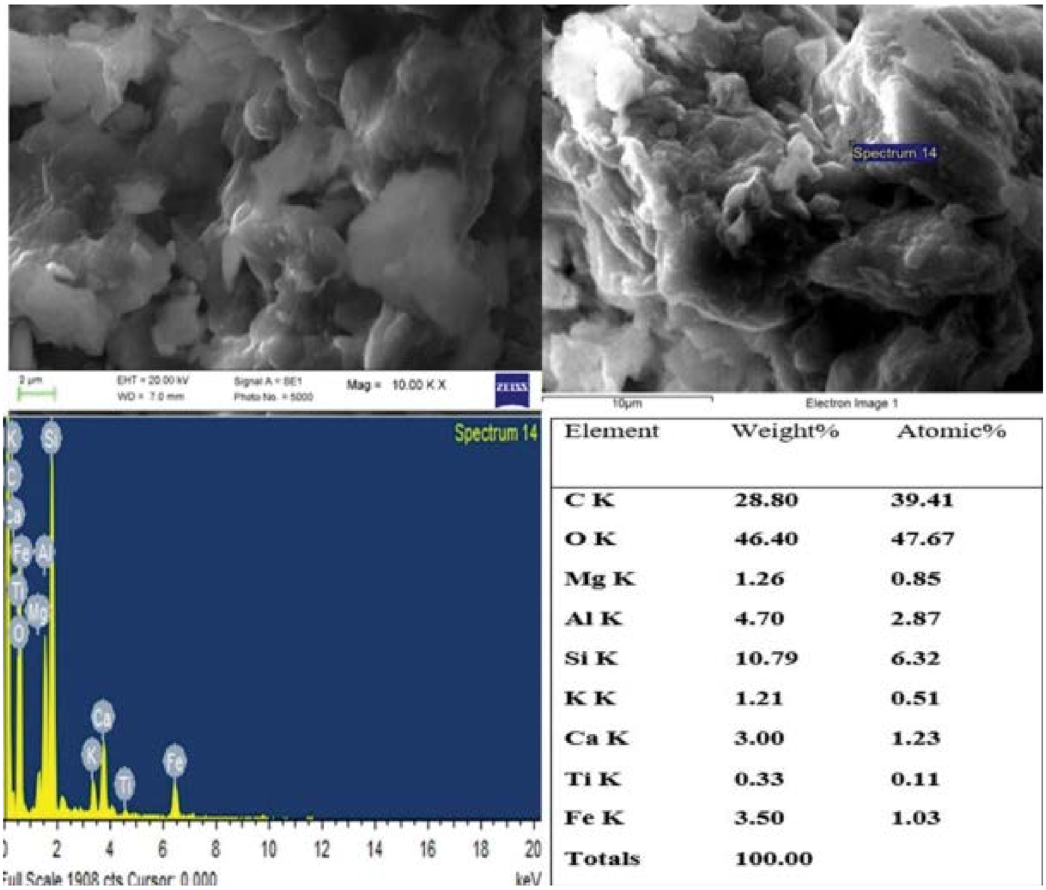
4.3. XRD results

Fig. 10 depicts the variation between the intensity on the y-axis and 2θ on the x-axis. The 2θ ranges from 5 to 90, and the spacing between each point is 0.02. In the above graph, the first graph belongs to Raithal, the second to Gajsinghpura, and the third to Jheepasani. Major elemental compositions for the Jheepasani sample are 'O' and 'Si'. Quartz is a silica-based mineral that is hard and crystalline in appearance (silicon dioxide). The total number of peaks in the graph is 71. In the Jheepasani graph, the highest peak is observed at 26.66, and the elemental composition at the highest peak is O (53.26%) and Si (46.74%). The next highest peak is at 28.02.



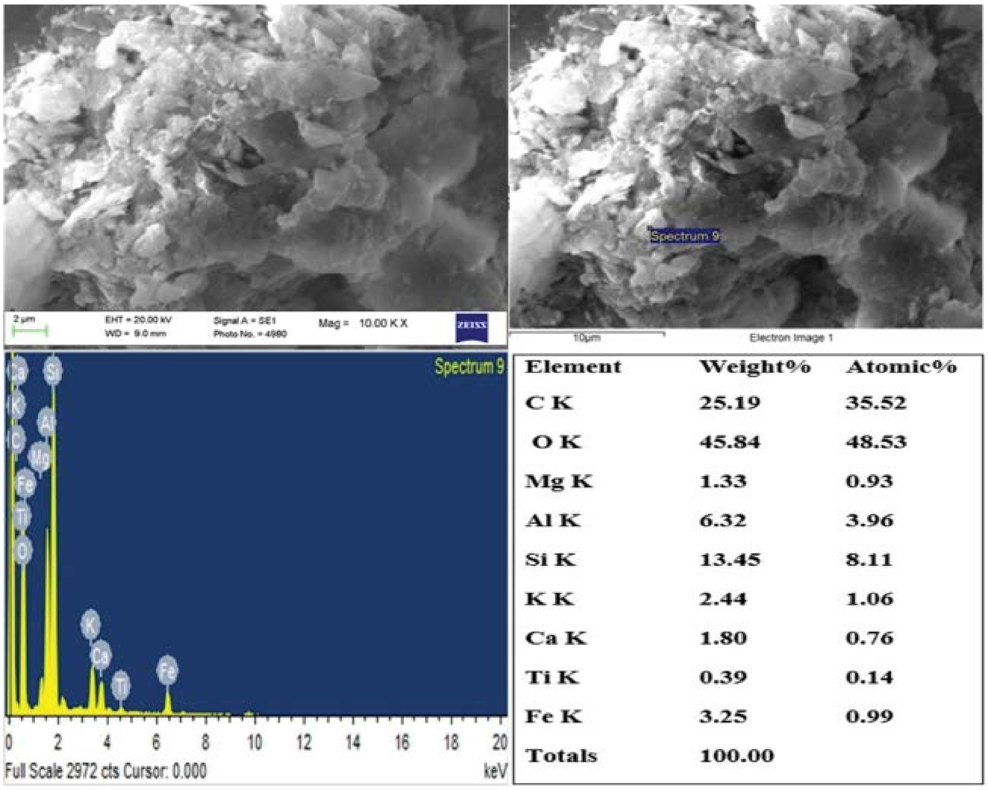
Element	Weight%	Atomic %
O K	53.4	68.53
Na K	1.14	1.02
Mg K	2.52	2.13
Al K	9.47	7.21
Si K	22.33	16.33
K K	2.34	1.23
Ca K	2.06	1.06
Ti K	0.52	0.22
Fe K	6.20	2.28
Totals	100.00	

Fig. 7. Sample surface visualization percentage variation of Raithal clay at 30 μm elemental weight in Raithal clay.



Element	Weight%	Atomic%
C K	28.80	39.41
O K	46.40	47.67
Mg K	1.26	0.85
Al K	4.70	2.87
Si K	10.79	6.32
K K	1.21	0.51
Ca K	3.00	1.23
Ti K	0.33	0.11
Fe K	3.50	1.03
Totals	100.00	

Fig. 8. Sample surface visualization percentage variation of Gajsinghpura clay at 30 μm elemental weight in Gajsinghpura clay.



Element	Weight%	Atomic%
C K	25.19	35.52
O K	45.84	48.53
Mg K	1.33	0.93
Al K	6.32	3.96
Si K	13.45	8.11
K K	2.44	1.06
Ca K	1.80	0.76
Ti K	0.39	0.14
Fe K	3.25	0.99
Totals	100.00	

Fig. 9. Sample surface visualization percentage variation of Jheepasani clay at 30 μm elemental weight in Jheepasani clay.

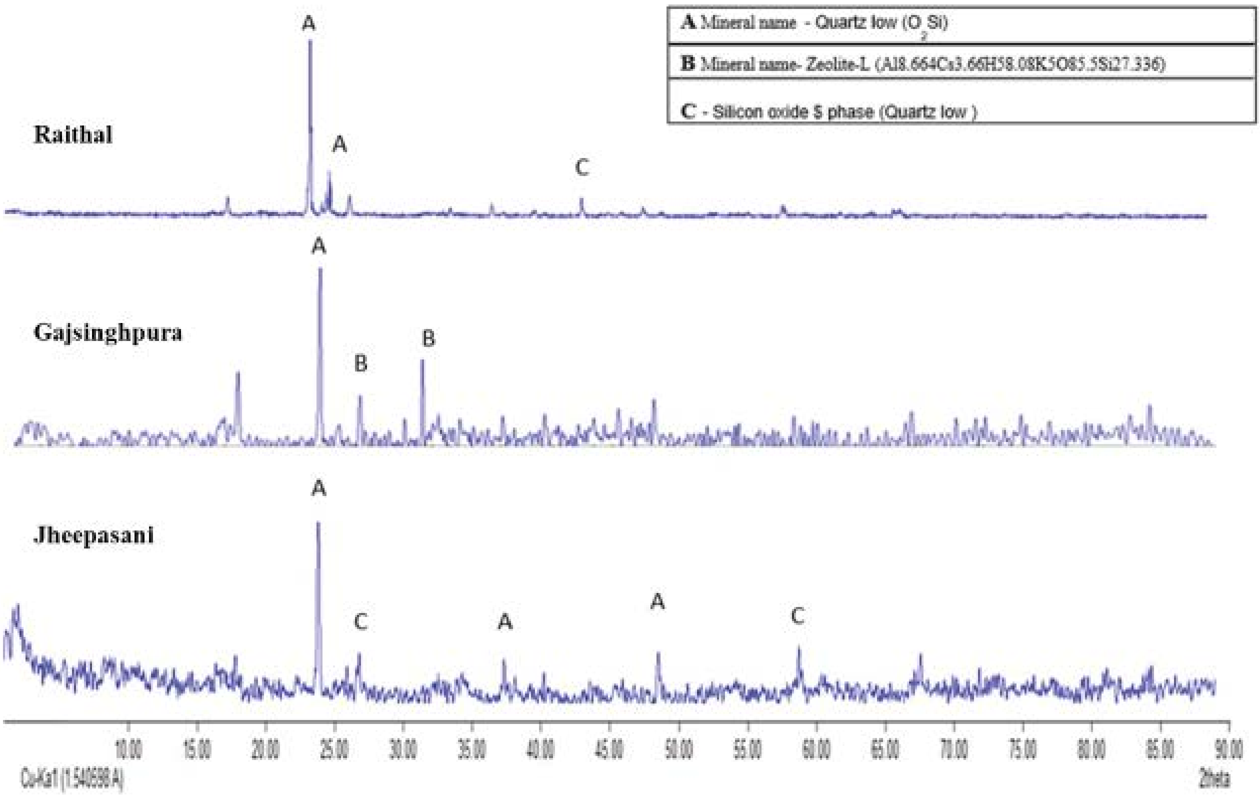


Fig. 10. X-ray diffraction graph of Raithal, Jheepasani, Gajsinghpura clay samples.

The second graph belongs to the Gajsinghpura, and the major elemental compositions of this sample are C, H, N and O, and all this elemental composition is denoted by 'A' in the graph. The remaining small amount of minerals belong to zeolite-L. Zeolite-L consists of minerals like Al, Cs, K, and Si, denoted by 'B' in the graph. The highest peak, 'A' in the graph, is observed at 27.02, and the elemental composition is C (34.65%), O (33.64%), and N (18.37%). The highest peak, 'B', is observed at 29.80, and the elemental composition is Cs (3.27%), Al (1.49%), and K (1.20%). Carbon has the highest elemental composition in Gajsinghpura and is very strong. The calculated density of the 'A' and 'B' samples is 1.541 and 2.328 g/cm^3.

4.4. Mechanical characterization

Universal testing machine (Model EZ-50, Lloyd Instruments, Germany) available at IIT Jodhpur was used to test the mechanical performance of sintered ceramic briquettes. For compression testing, 15 by 15 by 15 mm samples of slant wall of the ceramic filter frustum is taken from each of the 3 distinct G-filters tested here.

The samples are desiccated at room temperature for evaporation of moisture. These samples are utilized for compression testing in UTM at a loading rate of 0.1 N/s. The results plotted in Fig. 11 were those which were digitally recorded using Nexygen material testing software (Nexygen plus 01/3366, Lloyd instrument, Germany).

The compressive test results revealed that the maximum strength in wall compression was observed in Gajsinghpura soil. This notable strength can be attributed to zeolite-L, which acts as an enhancing agent and significantly improves the clay ceramic strength characteristics [32]. These results show that zeolite-L could be a helpful additive for stabilizing clay ceramics [32].

4.5. Gravity-based flow experiment

Gajsinghpura soils high plasticity and pronounced compaction curve properties during drying may have resulted in a lengthier filtration through corresponding G-filter due

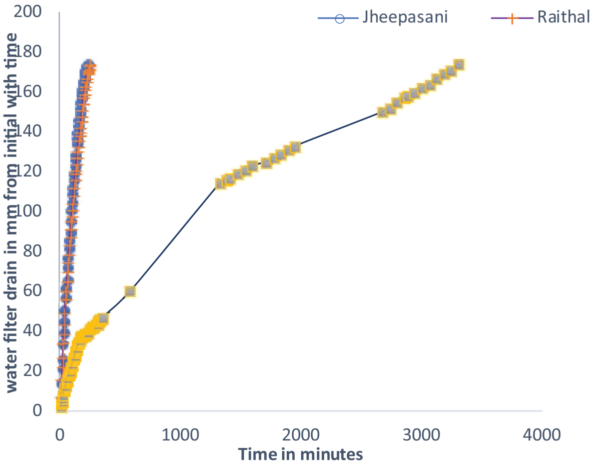


Fig. 12. Water filtration of different clay ceramic filter.

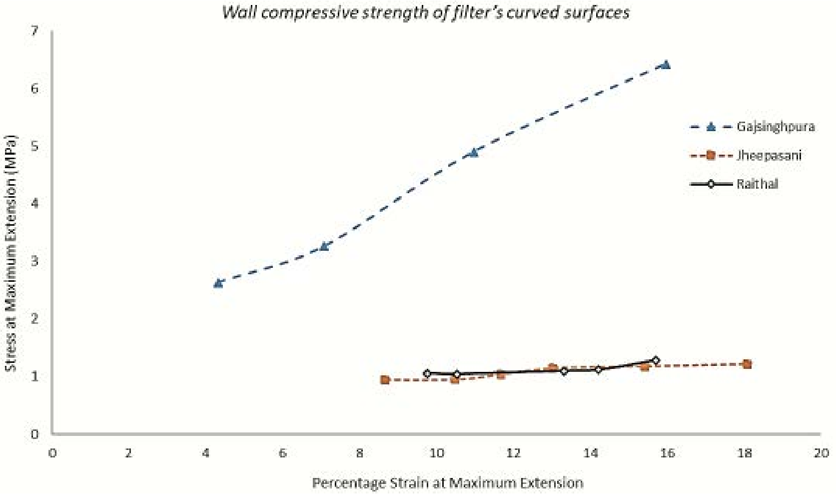


Fig. 11. Compressive strength of filter wall.

Table 3
E. coli removal data

Filter material	Pre-filter concentration (MPN/100 mL) (I)	Filtrate concentration (MPN/100 mL) (F)	I/F	Log reduction value (LRV) Log10 (I/F)	F/I	Filtration efficiency (1–F/I)
Raithal	2,400	5.7	421.05	2.62	0.0023	0.997
Jheepasani	2,400	25	96	1.98	0.0104	0.989
Gajsinghpura	2,400	33	72.72	1.86	0.0137	0.986

to constriction or complete blockage of pores compared to those produced from Jheepasani and Raithal soils. This phenomenon of slow filtration rate from Gajsinghpura make G-filters is clearly illustrated in Fig. 12. The 3 distinct G-filter were filled completely with water before conducting the filtration experiment. The filter was left undisturbed during this process. The porous flow phenomenon occurring through the G-filter vessel was purely dependent on gravity-based percolation.

4.6. Microbial removal

The *E. coli* filtration experiments were performed on the three distinct G-filters. The *E. coli* removal percentage for each of these G-filter vessel is shown in Table 3. It is very clear that the kaolinitic Raithal 3L G-filter has performed comparatively much better than the other G-filters manufactured from Jheepasani and Gajsinghpura soils.

5. Conclusion

The article elaborates an analysis of 3 different types of soils for its functionality to perform gravity-based water filtration in the regions near to the thar desert in India. The distinct location from where clayey soils can be mixed are surveyed and soil is collected. The soils are individually analysed for its physical as well as rheological properties. From the study, all the three-soil sample mined from Raithal village in Jalore, Gajsinghpura in Jodhpur and Jheepasani in Jodhpur districts respectively were sound to be clays.

Further to the analysis of plasticity chart for these three soils it was found that Raithal and the Gajsinghpura soils were kaolinitic in nature. further highest amount of carbon or organic content was found to be present in Raithal soils. Shrinkage was the highest in Gajsinghpura clayey soils. Raithal and Gajsinghpura soil also showcased a layered structure in their respective microgram confirming to kaolinitic microstructure. Once 3L clay sawdust frustum shape molds were baked to 750°C as per guidelines provided in Duhan et al. [20], 3L vessel ware ready for use. The 3L G-filter filter materials extracted from the slant wall of the frustum ware were tested for compressive strength. Gajsinghpura clay ceramic laced with a large quantity of zeolite were much stronger than other soil. similarly, they also showcased that least filtration rate. The microbial removal efficiency was found to be the best for 3L G-filter manufactured out of Raithal based clays. From the above results, the 3L G-filter made from the Raithal's kaolinitic clays were adjudged to have the best flow and filtration attributes.

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