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# Designing and testing of a portable filter for groundwater defluoridation and desalination, equipped with non-woven geotextiles

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ABSTRACT

Using non-woven polypropylene geotextile, a filtration unit was designed for portable prototype filter capable of defluoridation and desalination. The filtration unit contains geotextile bag filled with mica and graphite sand. Emphasis was given to make the filter design as simple as possible that is suitable for rural areas. The designed filter was continuously tested for three months along with ceramic (Candle) filter and Pureit filter for comparative studies. The performance of the filters was evaluated on the basis of the percentage of residue removed by the individual filters and cleaning period of the filters. The results of the improvement in the water quality made by prototypes filter without cleaning show reduction in concentration of fluoride and electrical conductivity (EC) by 83.06 and 45.75%, respectively. While the other two filters despite weekly cleaning shows reduction in concentration of fluoride and EC by 74.20 and 30.04%, (ceramic filter) and 93.68 and 86.37% (Pureit filter), respectively. The prototype filter with very simple in design has performed better than other filters with complex designs. The test shows that uses of non-woven geotextiles (polypropylene) along with sand can provide an alternate solution to the expensive defluoridation and desalination processes.

*Keywords:* Prototype filter; Non-woven geotextile; Defluoridation; Desalination; Economic feasibility

## 1. Introduction

In several parts of the world groundwater is the only source of water available for domestic and irrigational purposes, and if it contains high concentration of fluoride and salinity then it is difficult to treat it up to the permissible limit. Generally the enrichment of fluoride in groundwater is controlled by geologic and hydrogeological conditions, especially fluorine-bearing minerals present in alluvial formations and their dissolution/precipitation under the alkaline environment along groundwater flow [1,2]. Sometime intrusion of saline water from shallow aquifers might result in elevation of fluoride content of the groundwater [3]. In majority of the rural areas especially in developing countries hardly facilities are available for defluoridation and desalination of groundwater and people use to drink water with high fluoride and salt concentration. The consequence is dental and skeletal fluorosis that affects teeth and bones and causes stiffness, pain in the joints, and

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impairment of muscles. While the intake of saline water above the permissible limits shows significant adverse effects on general health including diarrhea, anorexia, vomiting, abnormal urine excretion (the possible formation of urinary calculi), or general weakness [4]. Although the problems of dental and skeletal fluorosis are present worldwide but poor countries are severely affected where there is scarcity of water and water treatment facilities. Fluoride is an inorganic ion and found in the majority of the rock and soil types. Groundwaters with high concentration of fluoride are common in the foothills of the mountains and in the areas with marine geological deposits. In human nutrition, fluoride plays a dual role by preventing dental caries at a certain level of intake and can cause serious damages in bony and dental tissues if taken above the permissible limits [5,6]. Skeletal changes and mottled enamel may result when drinking water content of fluoride exceeds 2 ppm [7]. Fluoride is considered as one of the most abundant chemical after Cl among the halogens. Worldwide fluoride occurrence, distribution, and effects on human health have been extensively studied [8–10] and fluoride-related health problems have reached an alarming proportion in several regions of the world. In India, approximately 62 million people including 6 million children suffer from fluorosis because of consumption of water containing high concentrations of fluoride [11]. In all developing countries, especially the rural areas affected with groundwater fluoride and salinity problems needs defluoridation and desalination techniques which is easily and economically feasible for them.

One of the common methods for the defluoridation of drinking water is the use of aluminum sulfate. The hydrolysis of aluminum sulfate in an alkaline medium produces polyhydroxy alumino precipitate which complexes with fluoride ions. The most common and widely used precipitation method is the Nalgonda technique [12,13]. In this method, alum (aluminum sulfate) and lime are added to form a precipitate of fluoride–aluminum complex which is separated to produce fluoride of less than 1.5 mg/L in the treated water. Another commonly used and well-studied adsorption method is based on activated alumina [14,15]. Both these methods are effective but not easily and economically feasible. Absorption process for defluoridation of drinking water is also very effective, convenient, ease to operate, economical and simple to design, and adsorption capacity decreases with repeated use of the regenerated adsorbents [16]. Studies also demonstrate potential capacity of zirconium hydroxide-modified red mud porous materials in defluoridation of drinking water [17] and good capabilities of Hydroxyapatite (HAP), and limestone-based processes in defluoridation [18].

Reverse osmosis (RO) is an important available membrane technique, which is widely used for water purification processes such as desalination [19]. Studies have shown that composite RO membranes made from sulfonated poly(arylene ether sulfone) containing amino groups (aPES) and hyper-branched aromatic polyamide-grafted silica (HBP-g-silica) can enhance chlorination resistance and improve membrane performance [20]. Fly ash agglomerates [21] and low-cost ceramic membranes [22] can also be used for the removal of hazardous toxic chemicals from water. Moreover, the studies shows that the use of subsurface intake systems for seawater reverse osmosis desalination plants significantly improves raw water quality, reduces chemical usage and environmental impacts, decreases the carbon footprint, and reduces cost of treated water to consumers [23]. The use of photosynthetic bacteria like cyanobacteria in desalination has been demonstrated. For example, cyanobacteria, or fractions that they secrete in response to salt stress, have been shown to remove $Na^+$ from aqueous solutions and soils, as well as enhancing seed germination rates [24,25].

In order to design a simple portable filter for desalination and defluoridation, in the present study a geotextile material was selected on the basis of its excellent performances indicated by several studies [26]. Geotextile materials like woven and non-woven fabric are one of the most suitable materials for the practices of filtration, drainage, reinforcement, protection, isolation, and packing. Several studies have been conducted on the filling behaviors of geotextile tubes, bags, and containers by large-scale field model tests [27–29], hanging bag tests [30–32], pressure filtration test [33], or pillow model test. These works shows the interaction between filling material and geotextile, and prove its suitability as one of the best filtration material.

Studies related with the development of a fluoride, salts, and metals removal filter was previously carried out by adsorption on slag [34,35] through slag filters. But the major difficulties related with slag filters are frequent clogging and decline of efficiency [36]. Therefore, further work is needed to assess the capacity of such systems to treat wastewaters containing fluoride, salts, and metals. The problem of dental and skeletal fluorosis has aggravated due to the lack of appropriate and user friendly defluoridation technology. However, a simple, efficient, and cost-effective technology is not available for widespread use in many affected regions especially in rural areas. In this paper, we present a novel cost-effective defluoridation and desalination method. The results showed excellent fluoride and salt removal efficiency and the adsorption capacity. In the present work, a prototype filtration unit has been developed, suitable for rural areas.

### 1.1. Objectives and scope

The main aim of the present work is to analyze the suitability of geotextile materials for defluoridation and desalination applications. The problems of high fluoride and salt concentration and other chemical constituents (pH, turbidity, total suspended solids, BOD, DO, conductivity, fluoride, chloride) in the aquifers are common. This study had three main objectives: (1) to develop a prototype filtration unit equipped with geotextile bag filled with mica and graphite sand, suitable for rural areas, (2) to evaluate the suitability of geotextile as good filtration material, and (3) to design a potable prototype filter suitable for defluoridation and desalination. This work would help in the designing of potable filters which can make defluoridation and desalination of groundwater easily and economically feasible.

## 2. Design of the prototype filter

The designed prototype water filter relies on the small pore sizes of non-woven geotextile materials made up of polypropylene and the absorption capacity of the graphite and mica sand to filter dirt, debris, fluoride, salt, and bacteria out of water. Filtration is a critical process that extends or reduces the life of expensive filters by removing unwanted particles. Large numbers of water treatment systems are available in the market despite that problems related with excessive intake of fluoride and salt continues and diseases like dental and skeletal fluorosis are common worldwide. These filters are designed for rural areas and are very effective in minimizing the fluoride and salt concentration along with other water quality parameters. These filters can efficiently provide clean, bacteria-free drinking water. Fig. 1 shows the basic design of the prototype filter while Figs. 2 and 3 shows the basic design of Candle and Pureit filters. The prototype filter is designed in a stainless steel unit with total capacity of 16 l. The filter consists of following units:

(a) Storage chamber
(b) Collection chamber
(c) Filtration unit

(a) Storage chamber: Storage chamber is cylindrical in shape like other available filters in the market, where the water is stored prior to its microfiltration. Within the storage chamber, the first stage filtration process occurs in which water passes through a

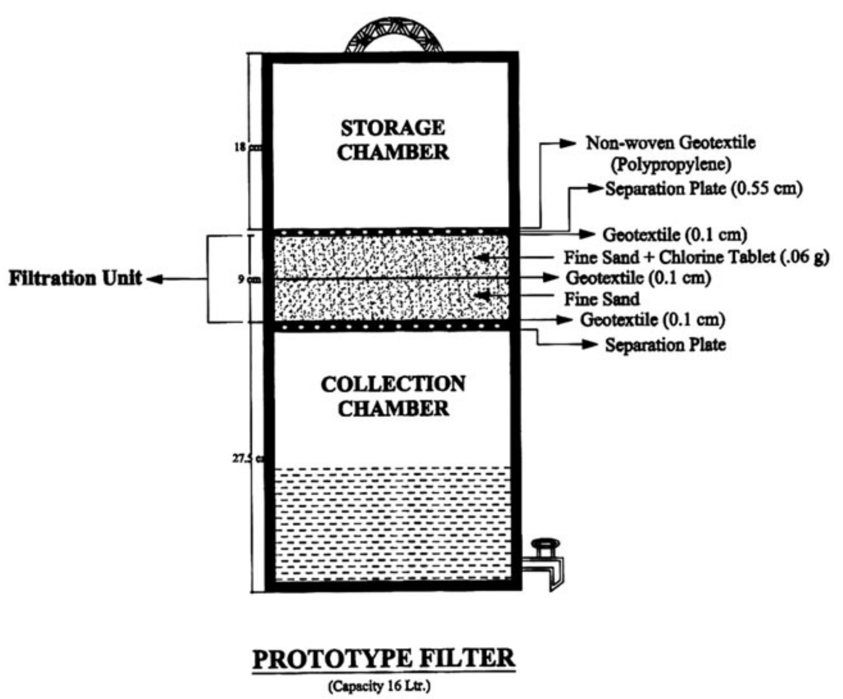


Fig. 1. The basic design of the portable prototype filter equipped with geotextiles.

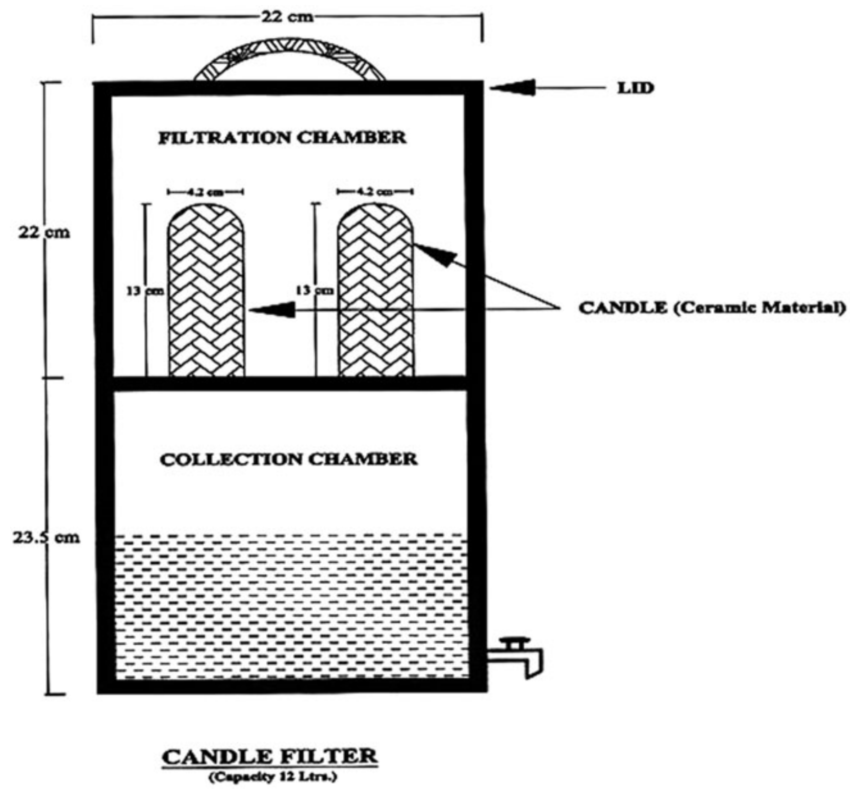


Fig. 2. The basic design of the Candle filter.

geotextile layer. That removes most of the suspended particles and contaminants.

(b) Filtration mechanism of prototype filter: The removal of overall impurities from the water in filtration process depend upon the combination of several processes, like straining, sedimentation, adsorption, and bacterial and biochemical processes. The designed prototype filter provides dual media filtration (Non-woven geotextile + sand) and its filtration performance depends upon geotextile permeability (cross plane permeability when liquid flow is perpendicular to the plane of the fabric) and its sand retention property. The filtration rate of the prototype filter is high as compared to the Candle and Pureit filter.

In the prototype filter, the filtration unit consists of a double-layered non-woven geotextile bag with overall width of 9 cm. The polypropylene geotextile bag is filled with fine grained graphite and mica sand. In the second stage of microfiltration, the water passes through these layers and traps almost all the contaminants. The filtration unit can be easily replaced and replacement ensures the complete removal of all the harmful contaminants and debris from the filter. The filtration unit is very effective in reducing the fluoride and chloride concentrations. Fig. 4 shows the non-woven geotextile (polypropylene) bag fixed in the filtration unit of prototype filter. Both geotextile and sand play a very important role in the filtration of polluted water. Geotextile filtration property depends on textile pore size, the openings of pore size should be smaller than a specified maximum value of pollutant. Geotextile must be permeable enough to allow a relatively free flow of water through it. Majority of the suspended particles are retained by geotextile layer, and un-trapped particles and foreign matter are treated by sand.

Sand media, work as a good filtration material, as within the sand layers formation of a gelatinous layer, also called the hypogeal layer is formed in the top few millimeters after the water filtration process started [37] and that consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. When water passes through this gelatinous layer, particles of foreign matter are trapped in the mucilaginous matrix and dissolved organic material is adsorbed and metabolized by the bacteria, fungi, and protozoa [38].

The filtration resistance of prototype filter depends upon water concentration as well as applied pressure. Due to small thickness of the filter media, measurement of local pressure and porosity measurements are

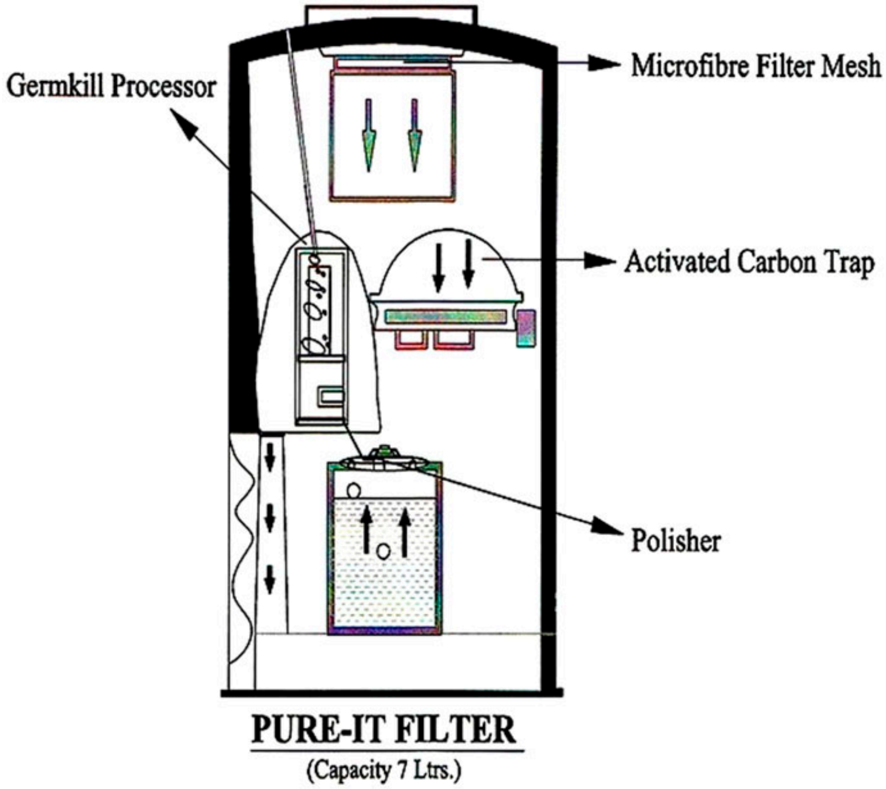


Fig. 3. The basic design of the Pureit filter.

difficult. Prototype filter shows excellent filtration resistance to water quality parameters like fluoride, chloride, TSS, and electrical conductivity (EC), its resistance against heavy metals has not been estimated. Non-woven geotextile provide nanofiltration and micro-filtration properties to the prototype filter and it rejects and holds all dust particles and contaminants larger than the textiles pore size. Sand media acts as an excellent absorbent and the combination of the two processes provides suitable filtration system.

(c) Collection chamber: The collection chamber store filtered water that can be used for potable and other domestic purposes. Prototype filter leaves the beneficial minerals and electrolytes in the filtered water.

Fig. 4. Non-woven geotextile bag fixed in filtration unit.

### 2.1. Testing and data analysis of prototype filter

Groundwater samples from nearby areas that are affected with groundwater fluoride and salinity were collected in large quantities and kept in glass buckets after rinsing with the sample. The sample buckets were immediately sealed using rubber stoppers and aluminum protective caps crimped with a handheld crimping device. Within lab also water with high concentration of salinity and fluoride was formed using fluorine and salt, to maintain the regular supply of water. Daily approximately 150 l of water was filtered from each filter. The prototype filter was tested extensively continuously for 30 d for different water quality parameters (pH, turbidity, total suspended solids, BOD, DO, conductivity, fluoride, chloride) prior to and after the filtration along with two other filters (a)

Table 1
Overall performance of prototype filter

| S. No. | Parameters | Sample | Prototype | Percentage of residue removed (%) |
|---|---|---|---|---|
| 1 | pH | 8.29 | 7.3 | 11.94 |
| 2 | Turbidity (NTU) | 19.47 | 3.403 | 82.52 |
| 3 | TSS (mg/l) | 1.483 | 0.172 | 88.4 |
| 4 | Conductivity (Mhos/cm) | 4.11 | 0.696 | 83.06 |
| 5 | Fluoride (mg/l) | 7.19 | 3.90 | 45.75 |
| 6 | Chloride (mg/l) | 304.52 | 171.55 | 43.66 |

Table 2
Overall performance of Candle (ceramic) filter

| S. No. | Parameters | Sample | Candle filter | Percentage of residue removed (%) |
|---|---|---|---|---|
| 1 | pH | 8.29 | 7.95 | 4.1 |
| 2 | Turbidity (NTU) | 19.47 | 2.802 | 85.6 |
| 3 | TSS (mg/l) | 1.483 | 0.11 | 92.58 |
| 4 | Conductivity (Mhos/cm) | 4.11 | 1.06 | 74.20 |
| 5 | Fluoride (mg/l) | 7.19 | 5.03 | 30.04 |
| 6 | Chloride (mg/l) | 304.52 | 229.23 | 24.72 |

Table 3
Overall performance of Pureit filter

| S. No. | Parameters | Sample | Pureit filter | Percentage of residue removed (%) |
|---|---|---|---|---|
| 1 | pH | 8.29 | 7.99 | 3.61 |
| 2 | Turbidity (NTU) | 19.47 | 1.23 | 93.68 |
| 3 | TSS (mg/l) | 1.483 | .202 | 86.37 |
| 4 | Conductivity (Mhos/cm) | 4.11 | .288 | 92.9 |
| 5 | Fluoride (mg/l) | 7.19 | 3.43 | 52.29 |
| 6 | Chloride (mg/l) | 304.52 | 190.33 | 37.49 |

Candle (ceramic) filter and (b) Pureit filter. Tables 1–3 show the average performance of prototype filter along with Candle filter and Pureit filter. Both Candle and Pureit filters were cleaned along with their filtration unit every week, while the prototype filter was continuously used for three months without cleaning for the microfiltration of polluted water.

#### 2.1.1. Testing methods

SPADNS colorimetric method has been used for analyzing fluoride concentration in water samples. A calibration standard ranging from 0 to 6.0 mg F-/l was prepared by diluting an appropriate volume of standard F- solution. To 60 ml of standard solution, 10.0 ml of the SPADNS reagent was added and mixed well. The double beam UV–vIS spectrophotometer (UV5704 M) was set at a wavelength of 580 nm, and a calibration graph was prepared from different standard F- concentrations. When the graph gave a straight line, the instrument was considered to be ready for the measurement of F in the samples. Standard test method [39] was adopted for the measurement of the EC of water samples. This test method utilizes dip-type or pipet-type conductivity cells for testing static samples having conductivities greater than 10 μS/cm. Temperature control and correction methods are also provided.

The total suspended solid was calculated using the formula given by Todd [40]. The other water quality parameters such as pH turbidity and chloride were analyzed on the basis of the standard water quality procedures of APHA-AWWA [41], in the environmental engineering lab, Department of civil and environmental engineering, ITM University, Gurgaon, Haryana, India.

#### 2.1.2. Filter cleaning

Every weak both Candle and Pureit filters were cleaned to maintain their filtration efficiency and flow rate. Washing and cleaning have released all dirt, dead bacteria, and other organisms trapped in the pores of the surface within the filtration units. Usually the frequency of cleaning depends on the source of the water filtered. The more contaminated the water, the more frequently the cleaning is required. The prototype filter was cleaned after one month of continuous testing and its performance was recorded better than Candle filter and Pureit filters. Moreover, the total construction cost of this prototype filter was estimated approximately Rs. 1,000.00 and the cost of filtration unit is approximately Rs. 50.00, which is extremely low as compared to other available filters in the market. The total cost of the Candle filter and Pureit filter (5 l) is abound Rs. 1,500.00 and Rs. 2,000.00, while the filtration units cost around Rs. 200.00 and Rs. 400.00, respectively. Incase if the water has very high fluoride concentration (50–60 mg/l or more) or high salinity (EC => 10,000 microMhos), which is rare, then the filtration unit of prototype filter needs cleaning twice a month.

## 3. Results

The developed portable prototype filter is a good water purification system developed for rapid treatment of safe potable water supply. Designed filter shows effective desalination and defluoridation capabilities. The value of the adsorption parameters gives an indication that geotextiles along with sand are one of the best adsorbent materials for fluoride removal from water as it directly reacts and complexes with F-ions. This prototype filter unit works on the principles of oxidation, filtration, and disinfection. There are no changes in the dissolved mineral concentrations in raw and filtered water. The laboratory performance of prototype filter indicates that it can provide treatment to wide range of contamination in water sources with respect to organic matter, suspended solids, and bacterial load to produce the potable water within few hours without using electric power supply. It may reduce the expenditure on providing safe drinking water for which costly water treatment systems are utilized. The fluoride and salt adsorption of other two filters (Candle and Pureit) is equally good but both of them need frequent cleaning or replacement of filtration unit. In most of the prevailing water filters, filtration membranes required regular maintenance and cleaning. Cleaning of a conventional filter includes (a) emptying the entire filtration rack, (b) chemical cleaning, (c) disinfection and rinsing, and (d) replacement of entire filtration unit (usually after two to three months). Frequent cleaning of filtration membrane causes disintegration of membrane. Disintegration in membrane usually includes structural changes, embrittlement of membrane fibers, and compromised filtration performance. Designed prototype filter required low maintenance and its cleaning process is easy as compared to other filters.

The actual performances of all three filters, i.e. prototype filter, Candle filter, and Pureit filter, were evaluated on the basis of the percentage of residue removed by the individual filters and cleaning period of the filters. Tables 1–3 show the performances of prototype filter, Candle filter, and Pureit filter, respectively. Both Candle filter and Pureit filters were cleaned every week, while the prototype filter was cleaned after three months. The percentage of residue removed by prototype filter for turbidity, TSS, EC, fluoride, and chloride was 82.52, 88.40, 83.06, 45.75, and 43.66%, respectively. While the percentage of residue removed by Candle filter and Pureit filter for turbidity, TSS, EC, fluoride, and chloride was 85.60, 92.58, 74.20, 30.04, 24.72%, and 93.68, 86.37, 92.90, 52.29, 37.49%, respectively.

On the basis of the percentage of residue removed and the cleaning period of the filters, prototype filter has performed better than the Candle filter and Pureit filter. Figs. 5–7 show the performance of the Prototype filter, Candle filter and Pureit filter, while Fig. 8 shows the comparative performance of all the filters.

## 4. Discussion

Worldwide several technologies like, ion exchange, precipitation, electro dialysis, and RO, adsorption are used for defluoridation and desalination of groundwater. Both defluoridation and desalination of water using the above-mentioned technique are expensive, usually the cost depends on the scale of application, efficiency, and efficacy of absorbent material, reuse potentials of adsorbent, etc. The use of sand for treating domestic wastewater is known for a long time and such techniques have been gaining popularity in recent decades with the development of small wastewater solutions and simple operation. The major objective of this work is the removal of excess fluoride and salts from drinking waters for domestic use in the rural areas where high concentration of fluoride and salts in drinking water leads to various ill health effects. The absorbent and technique required in defluoridation and desalination should be simple, easy to operate, and low cost with almost no or little maintenance apart from being eco

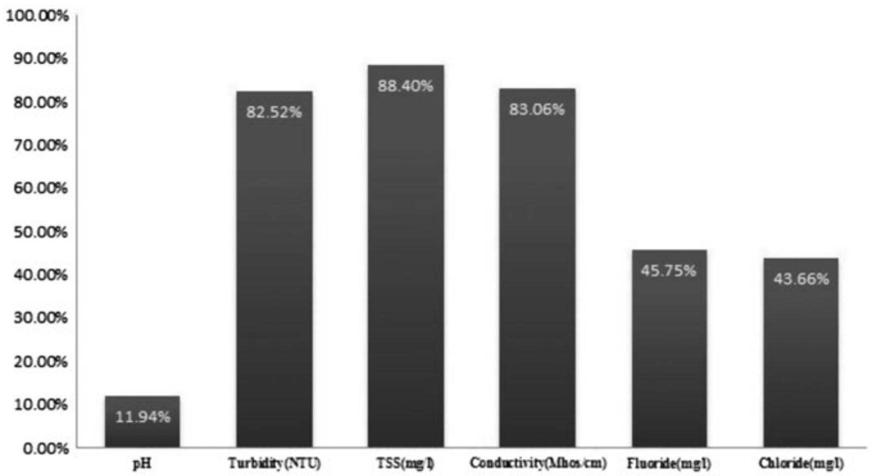


Fig. 5. Percentage of residue removed by prototype filter.

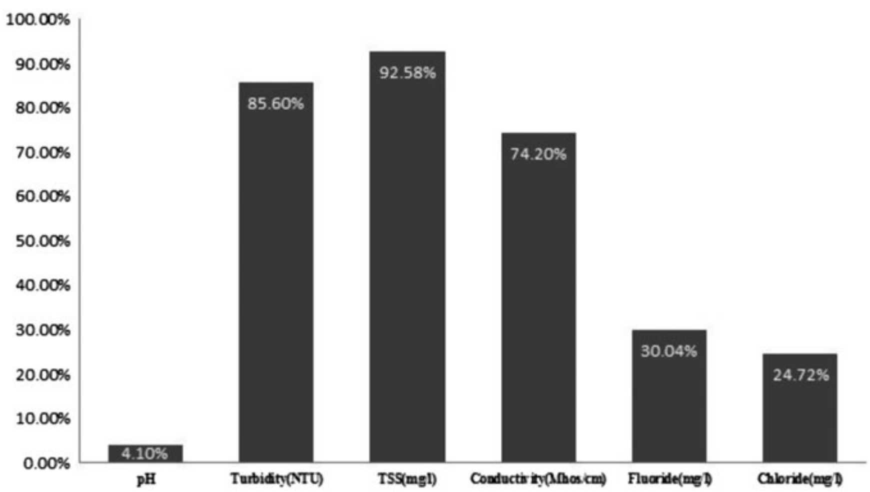


Fig. 6. Percentage of residue removed by Candle filter.

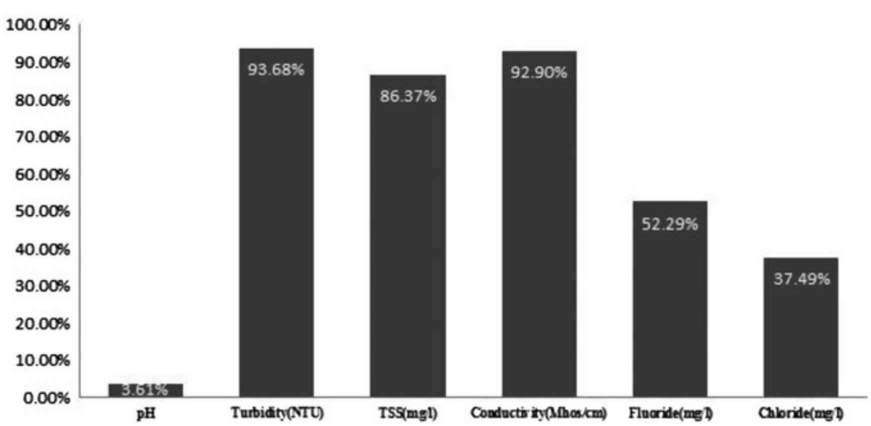


Fig. 7. Percentage of residue removed by Pureit filter.

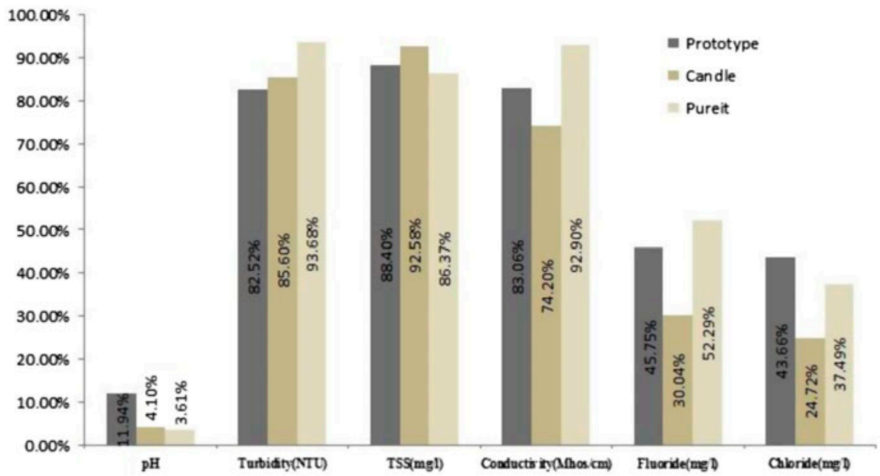


Fig. 8. Showing comparative performance of three filters.

friendly. The used technique is convenient and effective for the removal of excess fluoride and salts from drinking water, easy to be operated by a non-technical personal, and does not require extra addition of chemicals. Moreover, the capital cost is very low.

Geotextiles are high strength and durable materials, suitable for filtration applications. The geotextile-sand media exhibits excellent wastewater filtration capabilities. Application of a geotextile material along with sand, as a new absorbent has been reported in the present paper for fluoride and other salts removal. The study confirmed that geosynthetic materials are suitable for desalination and defluoridation of water. This new technology could be a hint to explore the new material in the desalination and defluoridation system, and could be expected to contribute to forming an easily and economically feasible filtration technology. Non-woven geotextiles if used in filters can enhance the performance and design life of sediment layers by providing the filtration and separation functions. In filtration units, the prevention of intermixing of different sizes of sand and other sediments can severely enhance the infiltration and microfiltration capacity of the filters. The preparative cost of the used absorbent material is less than other absorbents, which have been examined for similar objectives. The reported outcome of the study appears to have remarkable features making it eligible for further examination and finding appropriateness of its applicability in defluoridation and desalination of water for drinking purpose.

## 5. Conclusion

Groundwater fluoride and salinity are a common problem worldwide. Application of a new material, which can be used for defluoridation and desalination of groundwater, has been reported in the present paper. Some of the important conclusions from the observations and analyses made in present study are as follows:

(1) The use of non-woven geotextile along with sand can enhance both the infiltration and microfiltration capacity of the portable filters.
(2) The geotextile-sand media exhibits excellent filtration capabilities.
(3) The comparative studies of the prototype filter with existing filters demonstrate very good results. Prototype filter can be used for the defluoridation and desalination of groundwater and required low-cost and maintenance.
(4) Prototype filter is capable of purifying water with high to very high concentration of pollutants.
(5) The total construction cost of the prototype filter is approximately Rs. 1,000.00 and the cost of filtration unit is approximately Rs. 50.00.
(6) The production and marketing of this prototype filter can be easily carried out in industries.

Desalination and defluoridation techniques are needed at large scale and it involves science, engineering, and industrial business that include formation of effective filter media based on physical, biological, and chemical methods. The designed prototype filter is based on new filter media and the performance of its filtration unit is better than the other portable filters. The filtration unit equipped with geotextiles can be designed and produced at industrial level for drinking water filters for domestic and industrial level.

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