# 2
# Review of Literature

## 2.1 WATER SCENARIO IN INDIA

According to Aquastat (2011), total internal renewable water resource (IRWR) in India is shown in **Figure 2-1**. This is calculated as a summation of internal sources of ground and surface water of 432km$^3$/yr and 1404 km$^3$/yr respectively and their mutual overlap of 390km$^3$/yr [FAO, 2017].

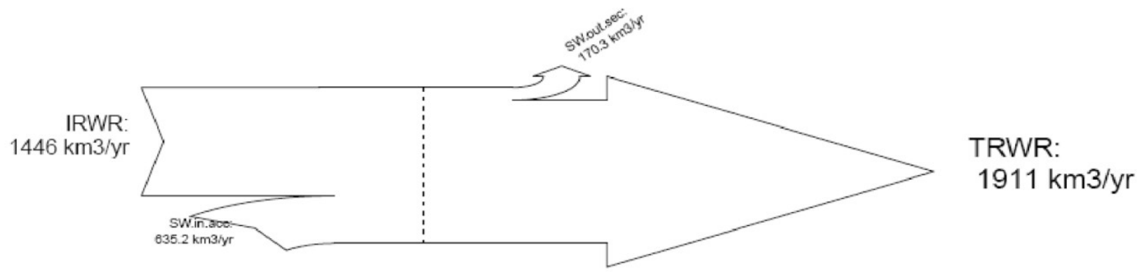


**Figure 2-1 :** Sankey Diagram of the water resource in India [*Source*: FAO, 2017]

From **Figure 2-1**, it can be observed that surface waters (example: river Brahmaputra) entering the country are around 635 km$^3$/yr. Approximately 210.2 km$^3$/yr water from Nepal, 347.02 km$^3$/yr water from China, 78 km$^3$/yr water from Bhutan enters India [FAO, 2017].

Surface water leaving India and not submitted to water treaties is 1142 km$^3$/yr. Surface water leaving India as calculated and sometimes provided to other circumjacent nations (example: Bangladesh) is 243 km$^3$/yr. Further, required water provisions made by India through water treaties to nations such as Bhutan, and Pakistan is 170.3 km$^3$/yr. By subtracting the surface water entering the country and lost due to required water provisions made by India under the specific treaties is the total external renewable surface water equivalent to 464.9 km$^3$/yr.

Total surface water in India is a summation of total external renewable surface water (464.9 km$^3$/yr) and internal surface water (1404 km$^3$/yr). Total groundwater in India is a summation of total internal groundwater and total external groundwater received (0 km$^3$/yr). While doing this calculation, it should be noted that precipitation in India provides with 3560 km$^3$/yr of water. While performing the calculation of the precipitation, the total area and mean precipitation in India is assumed to be 32872.6 x 10$^4$ hectares and 1083 mm/yr respectively [FAO, 2017].

It should not be forgotten that India is sallying into development as this dissertation is being written to closely follow a trend as promulgated by Amarasinghe *et al.*, 2007 and shown in **Figure 2-2**. If this is true, the boring of groundwater will also climb. This work assumed inputs from 2001 census, food consumption patterns from the National Sample Survey Office of the Ministry of Statistics and Programme Implementation, Government of India data of 2001, and land use and production patterns from the agriculture surveys by the Government of India [Amarasinghe *et al.*, 2007].

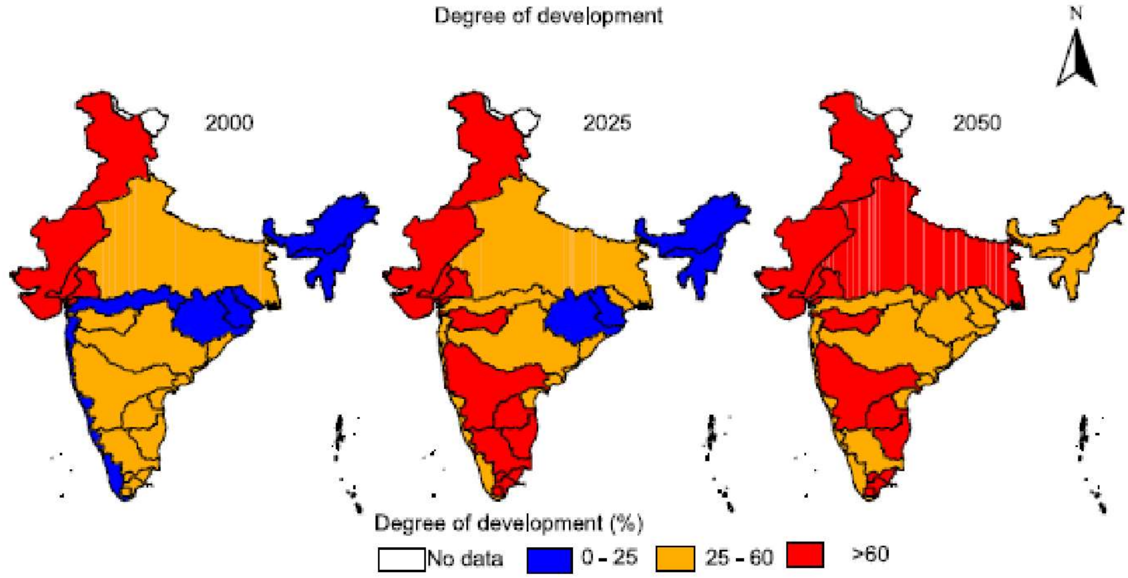


**Figure 2-2 :** India's development scenario projected till 2050 [*Source*: Amarasinghe *et al*., 2007]

The groundwater abstraction ratio is calculated using the PODIUMSIM by Amarasinghe et al. (2007) and is illustrated in **Figure 2-3** below [PODIUMSIM, 2007]. It is a policy based prediction tool for simulating the alternative scenarios of water future with respect to the variation of food and water demand drivers. The abstraction ratio is taken to be the total groundwater withdrawals to total recharge from the rainfall and the return flows for the calculation by Amarasinghe et al. 2007. It is clear that according to predictions groundwater abstraction will rise, increasing the possibility of the increase in geological contaminants as well. The water available would decline to 1,341 $m^3$/yr/capita and 1,140 $m^3$/yr/capita by 2025 and 2050, respectively. Therefore the objective of this thesis is to make the indigenous filters such as G filter such that they can remove these geological contaminants and still be cost-effective.

Further aspect being that with development the demography of the cities is going to rise while rural societies moving to cities on lookout for earning [Amarasinghe *et al.*, 2007]. This would mean a rampant increase in urban populations toward 2025-2050.

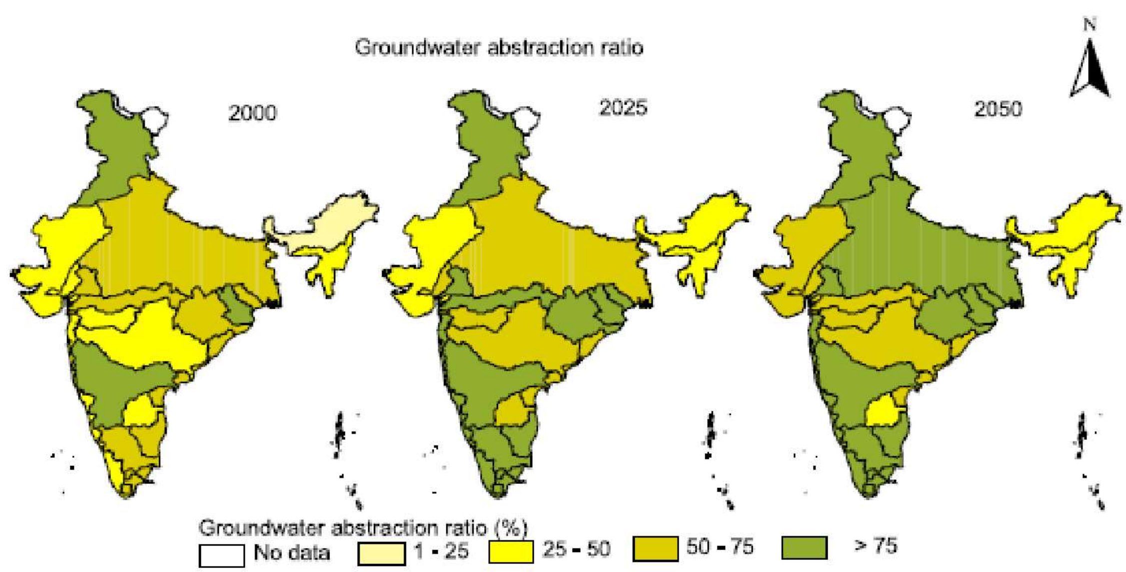


**Figure 2-3:** India's groundwater use predicted till 2050 [*Source*: Amarasinghe *et al*., 2007]

For an urban household in Delhi, 2.7% of the total water which enters is drinking water. This figure is illustrated through the study of the life cycle of water in a fully sourced Delhi household as shown in **Figure 2-4.**

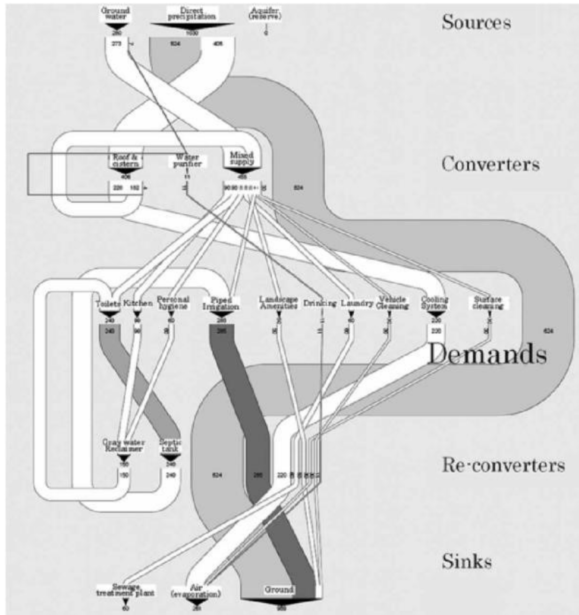


**Figure 2-4 :** Life cycle of water in a fully sourced Delhi household [*Source:* Water Aid, 2017]

Even though planning for the future is a necessity but solving the present rural and urban water problem with future in thought is optimal. The present scenario of a village Narai Ka Pura in Madhya Pradesh, India is very poignant with 90% people practising open defecation. The village water source is under threat of possible microbial contamination due to human excrement leaching during precipitation [Water Aid, 2017]. Present situation is that India is the country with the largest number of rural people without clean drinking water. National Rural Drinking Water Programme in India sets 40 litres per capita per day (LPCD) per habitation as a standard of water availability to calculate the habitations covered with or said to have a drinking water provision [LokSabha, 2017].

**Table 2-1 :** The five countries having rural population without the reach of clean water [*Source*: Water Aid, 2017]

| Country | Number of People (Millions) |
|---|---|
| India | 63.4 |
| China | 43.7 |
| Nigeria | 40.9 |
| Ethiopia | 40.9 |
| Democratic Republic of Congo | 28.1 |

With the present infrastructure, India has more than 45% of the population also residing in un-piped locations. Therefore from the illustration in **Figure 2-5**, the possibility of consuming water from an un-treated source is highly probable for every 1 in 3 people residing in India [Water Aid, 2017].

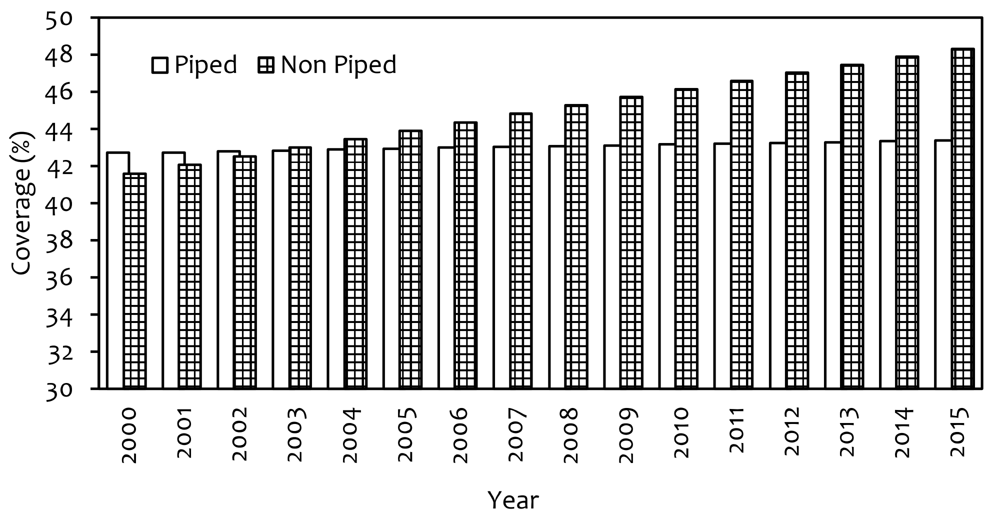


**Figure 2-5 :** Coverage of piped and non-piped water [*Source* : Water Aid, 2017]

Untreated source has geogenic and anthropogenic mineral contaminants [Loksabha, 2017]. From **Figure 2-6** the different contaminants across India and their specific location of presence have been illustrated [Kakoty, 2013]

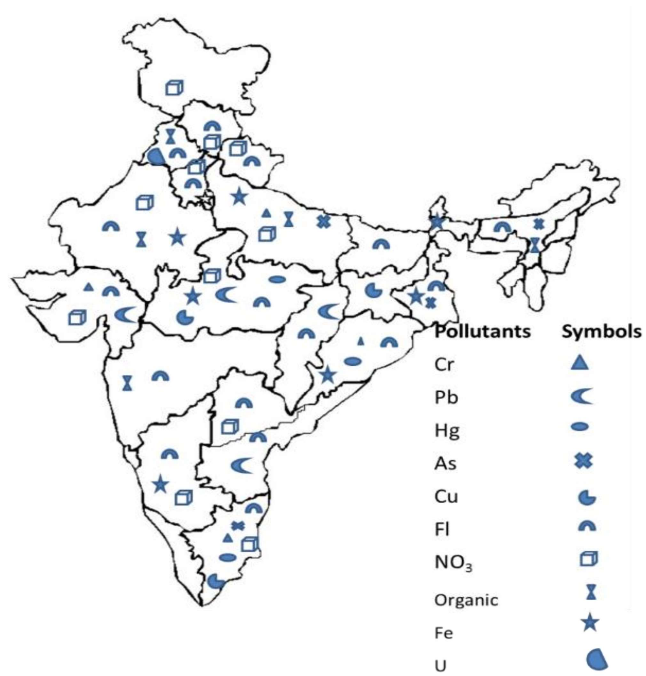


**Figure 2-6 :** Chemical contaminants present in water, India [*Source*: Kakoty, 2013]

For example, from **Figure 2-7**, Fe was found in piped water supplied to 30% or 19,720 rural habitations (or villages) in India as of March 2017 while another element, Arsenic, was found in the un-piped sources of 21% rural habitations in India [LokSabha, 2017]. Arsenic problems can be more pervasive than that caused by Fe. Thus apart from other minerals to be taken as under from water As becomes an important one for this thesis. **Figure 2-7**, also illustrates the presence of arsenic in parts of Rajasthan which make this study much more pertinent.

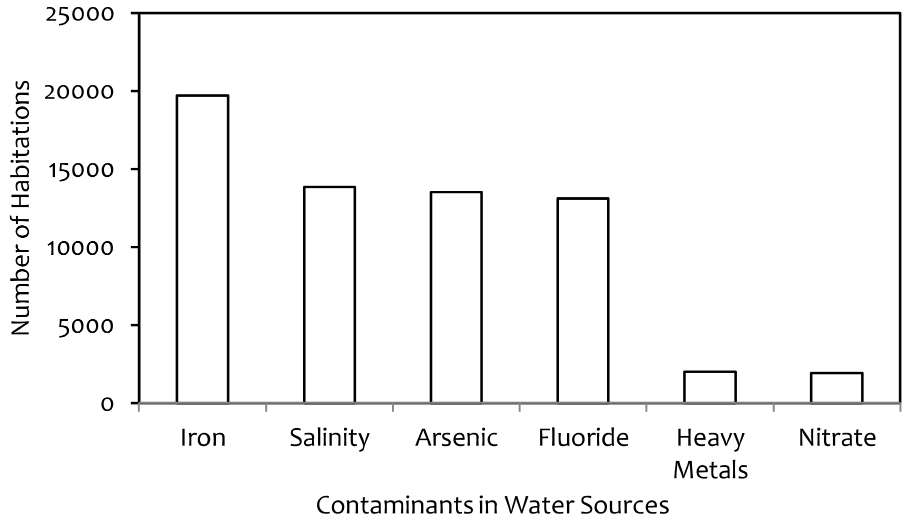


**Figure 2-7 :** Plot showing rural populations in India affected by different inorganic contaminants [*Source*: LokSabha, 2017]

As per Safe Drinking Water Act, the term contaminant indicates the presence of physical, chemical, biological or radiological matter in water. The chemical and biological contamination of water poses higher health risks when compared to the presence of the physical and radiological substance in water (except at extreme conditions) [Burrows and Renner, 1999; Malmqvist and Rundle,2002].Chemical contamination indicates the presence of higher concentration of contaminants beyond their permissible dose. Due to increased industrial activities, mining, excessive usage of fertilizers and agriculture waste are considered the main sources for heavy metal pollution in rivers and groundwater. Consumption of heavy metal polluted drinking water for a long duration can be dangerous to life.**Table 2-2** tabulates number of villages across different states of India without sterile drinking water facility.

**Table 2-2 :** Number of villages without sterile drinking water facility [*Source* : Kakoty, 2013]

| State | No. of Districts | No. of Villages | State | No. of Districts | No. of Villages |
|---|---|---|---|---|---|
| Madhya Pradesh | 48 | 52117 | West Bengal | 19 | 37955 |
| Kerala | 14 | 1364 | Uttar Pradesh | 38 | 97962 |
| Karnataka | 27 | 27481 | Uttarakhand | 71 | 15761 |
| Jharkhand | 4 | 29354 | Tripura | 4 | |
| Jammu and Kashmir | 12 | 6417 | Tamilnadu | 30 | 15400 |
| Himachal Pradesh | 9 | 17495 | Sikkim | 16 | 450 |
| Haryana | 19 | 6764 | Rajasthan | 32 | 40699 |
| Delhi | 12 | 158 | Pondicherry | 4 | 90 |
| Chandigarh | 16 | 19744 | Punjab | 17 | 12278 |
| Chandigarh | 14 | 23 | Nagaland | 8 | 1278 |
| Bihar | 22 | 39032 | Mizoram | 8 | 707 |
| Assam | 8 | 25124 | Meghalaya | 7 | 5782 |
| Arunachal Pradesh | 16 | 3863 | Manipur | 9 | 2199 |
| Andhra Pradesh | 23 | 26613 | Maharashtra | 35 | 41095 |
| Andaman Nicobar | 2 | 501 | | | |

## 2.2 LOW-COST HOUSEHOLD CONTAMINANT FILTRATION TECHNIQUES

The removal of contaminants from water at the point of use (POU) can be achieved by household water treatment techniques (HWT). Such low-cost household water treatment technologies have been adopted across different parts of the world [Sobsey *et al.*, 2008].The HWTs can be commonly classified into disinfection and filtration technologies [Sobsey *et al.*, 2008].

### 2.2.1 Filtration: Fundamentals

Filtration is separating solid from the liquid through a filter medium. The liquid passes through the porous medium (filter medium) whereas solid particles get suspended in the filter media. The fluid that is collected after percolation through a filter is called the filtrate. The most basic form of filtration is using gravity to filter water. The water is poured from above onto a filter medium and liquid percolates down due to gravity. The contaminants more than the size of the pores in the filter are left on its surface, while the rest of the fluid flows through it.

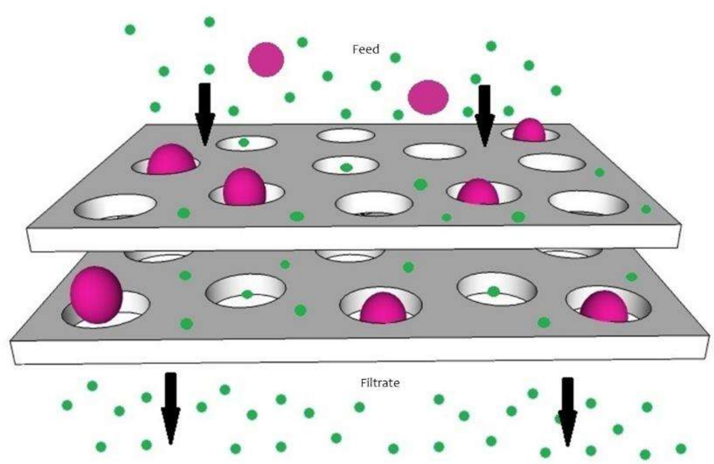


**Figure 2-8 :** Filtration through the pores [*Source:* Yakub, 2012]

There are four filtration mechanisms. They are :

1. **Sedimentation:** It is enhanced the weight of the sediment with respect to fluid and decrease in velocity of the sediment or particle in the fluid or water, which causes its settling.

2. **Interception:** If a particle is large enough in size it will not pass through the comparatively smaller pores of a filter media.

3. **Brownian diffusion:** Particles move randomly in zigzag or back and forth motion within the fluid, due to thermal gradients. This phenomenon is important for particles with diameters < 1 micron.

4. **Inertia:** This occurs when large particles travel fast enough into the streamlines and bump into filter media grains.

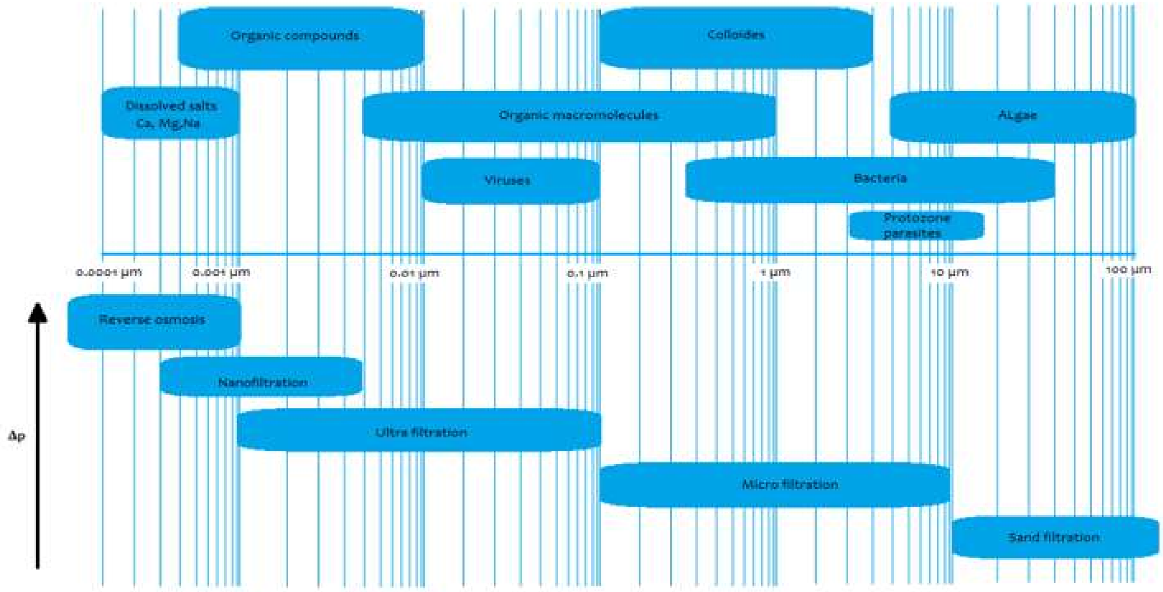


**Figure 2-9 :** Reverse Osmosis and Various filtration mechanisms [*Source:* Yakub, 2012]

The objective of filtration is to provide high quality drinking water (surface water) or high quality effluent (wastewater). From **Figure 2-9** reverse osmosis (RO) in not a filtration mechanism [Plappally and Lienhard, 2013]. There is an improvement in pressure of the treatment process with the decrease in the size of the containment that the process can help separate from water. Reverse osmosis is used for treating sea and brackish water. In India, RO systems have entered households negatively impacting health, immunity, and water conservation as well as contributing to high energy costs for drinking water [Plappally *et al*., 2013]. With the increase in process pressures there is an increase in cost for the said treatment.

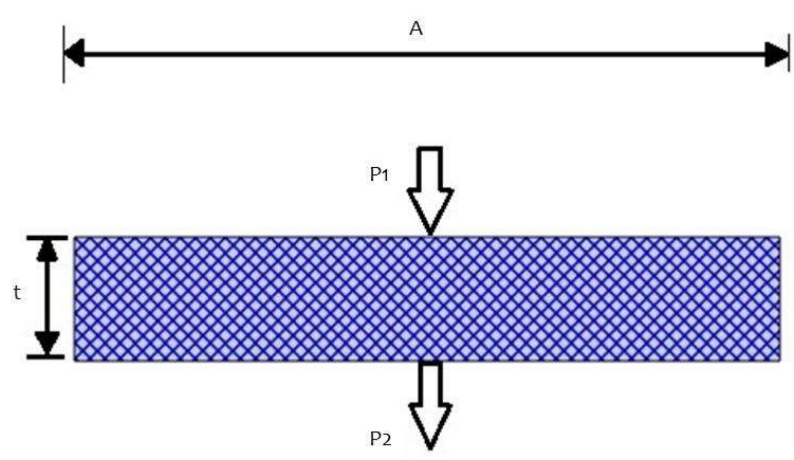


**Figure 2-10 :** Flow through a porous media with thickness t [*Source:* Yakub, 2012]

Flow through a porous body can be described by Darcy's law. **Figure 2-10** is an example of a porous media with a pressure difference on both sides of faces as shown. As per Darcy's law, the flow rate, Q, of fluid through the media can be given as [Plappally *et al*., 2009]

$$Q = \frac{\kappa A \Delta P}{\mu t} \tag{2.1}$$

where κ denotes permeability of the porous media material, A indicates the cross-sectional area, t represents the thickness of the material, μ designates the dynamic viscosity of the fluid (water) and ΔP is the pressure difference between the initial and final pressure. Darcy's law has been used to describe the flow of fluid through different geometries and shapes (Fahlin, 2003). Van Halem,2006 have used different variations of the Darcy's equation to model flow through gravity based frustum shaped ceramic water filters similar to the case studied here (Van Halem, 2006).

For effective separation of solids from aqueous solution, filters must be porous. The main types of bio-contaminants in water are protozoans, bacteria and viruses. The range of the sizes of these organisms is provided in **Figure 2-9**.Viruses are considered the smallest waterborne microbes, ~20 – 100 nm [Sobsey, 2002]. The pores in the filters should be small enough to prevent the biological pathogens from pass through them.

### 2.2.2 Low-cost household filtration technologies

Filtration technologies depend on size exclusion for the removal of microbes from water. **Table 2-3** shows the lists of bacteria that are transmitted through drinking water.

**Table 2-3 :** List of bacteria and their effects on health [*Source:* Boulos *et al.*, 1999]

| Bacteria | Effects |
|---|---|
| Escherichia coli | Urinary tract infection (UTI), enterotoxin, diarrhoea, food born disease, vomiting |
| Pseudomonas aeruginosa | Give rise to inflammations of the middle ear, greenish pus |
| Enterobacter aerogenes | Food spoilage |
| Klebsiella sp | Pneumonia |
| Micrococcus luteum | A common skin flora |
| Streptococcus Incas. | Found on skin and non-pathogenic |
| Staphylococcus aureus | Food spoilage, chronic infections, abscesses, wound<br>infection, vomiting |
| Bacillus cereus | Diarrhoea, vomiting |

The mechanism of filtration relies on the performance through multiple or different pore-structured surfaces. The various household filtration systems are discussed below :

**3-Kolshi filter**

**Figure 2-11** illustrates a home-made and inexpensive three cruse or kalash filter unit. In this filter, the three kolshi's (clay pots/ kalash in sanskrit) are stacked over one another. The three kolshi's are of 18 litres volume each. Around one-third of the top kolshi portion is occupied with 3 Kgs of iron filings and 2 Kgs of coarse sand. The rest two-thirds of the volume is filled with raw water. The middle kolshi contains around 2 kgs of fine sand and 1kg of wood charcoal. A sari cloth is usually used as an additional filter between the top 2 kolshi. To allow free flow of water from the top and middle kolshi, a small hole is provided at their bottom (~0.5 cm dia). The inner side of holes are usually covered with a piece of synthetic polyester material. The top and middle kolshi contain small holes which are covered with a piece synthetic (polyester) material from inside. The bottom kolshi collects the filtered water.

The raw water poured in the top cruse when comes in contact with iron nails causes iron to rust thus creating ferric oxide. The heavy metal like arsenic present in the water gets adsorbed onto the ferric oxide particles. The layer of sand contained in the filter can trap these particles, along with the arsenic adsorbed onto them. Thus the arsenic gets separated from water in the top two kolshis [Hussam and Munir, 2007].

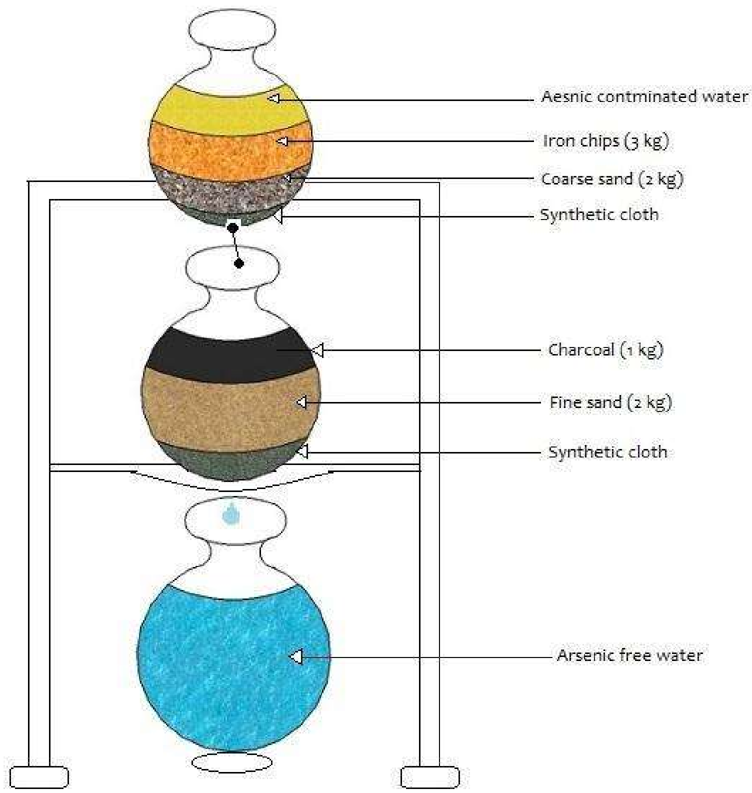


**Figure 2-11 :** 3 kolshi filter [*Source:* Ahmed, 2001].

**Biosand filter (BSF)**

The Biosand filter shown in **Figure 2-12** was first designed at the University of Calgary, Canada by Dr. David Manz. The filter is a standard concrete box standing 3 feet tall and 1-foot square. The mouth of the filter is usually covered with a wooden lid. This prevents the possibility of insects and other foreign bodies from entering inside the filter. A diffuser plate in the form of a steel sheet with several holes in it is placed inside the filter. Nearly ~ 16 inches of finely layered sand serves as the filtration media. The layer of small and large gravels is provided below the sand. Plastic tubing is incased in the concrete.

When a bucket of water is poured on the top of the filter, it passes through the diffuser plate holes. The holes in the plate slow down the force of water such that the surface of the sand layer is not disrupted. Then the water comes in contact with the top biological layer which lives in the top centimetre of sand. The microorganisms present in this layer consumes hazardous bacterias existing in the water. As the water continues to pass through rest of the sand bed other contaminants such as cysts, worms and viruses get trapped in the sand. The layer of gravel at the bottom of the filter prevents the traces of fine sand from exiting the filter. In the end, the filtered water is collected through the spout. [Stauber *et al*., 2006]

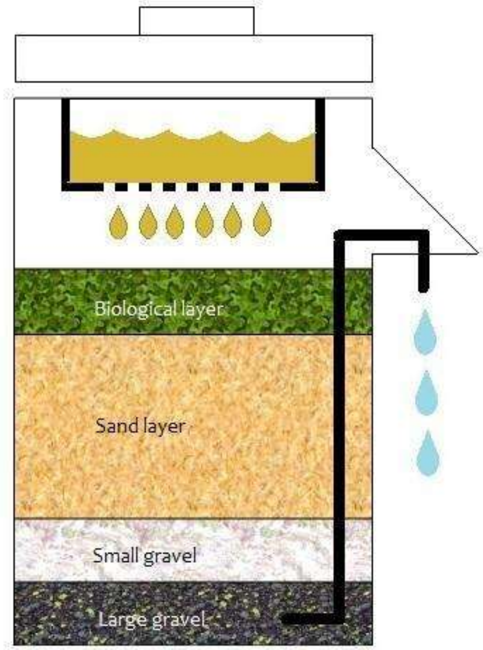


**Figure 2-12 :** Biosand Filter [*Source:* Baig *et al*., 2011]

**Kanchan MIT Filter**

The Kanchan sand filter is a modified version of the Biosand filter. All the parts in the Kanchan filter are similar to biosand filter, except an additional layer of iron nails and brick chips are incorporated.

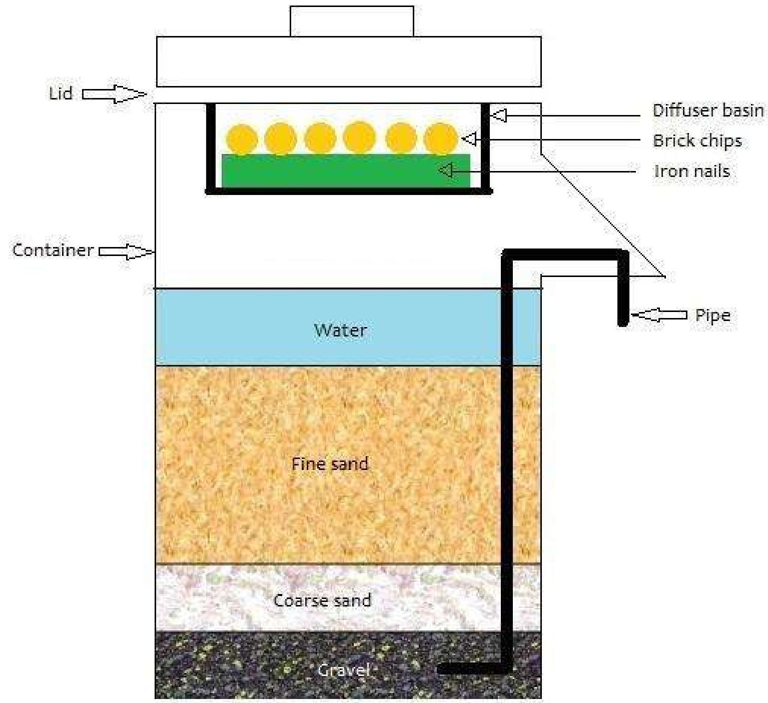


**Figure 2-13 :** Kanchan MIT Filter set up [Ngai *et al*., 2006]

From **Figure 2-13** , the presence of the layer of iron nails in the upper portion of Kanchan filter is similar to the layer provided in the setup of 3-kolshi filter [Ngai, 2002]. The layers of sand (fine and coarse) and gravel are formed below the iron nails arrangement. When the water is poured into the filter, it first comes in contact with iron nails. Iron nails have the tendency to rust quickly after being exposed to water, producing ferric hydroxide particles [Ngai, 2002]. Due to rusting, arsenic existing in water gets rapidly adsorbed onto the surface of the ferric hydroxide particles (**Figure 2-14**). Researchers from history have reported the formation of arsenic-iron surface complexes during adsorption of arsenic onto ferric hydroxide [Jang *et al*., 1996]. The arsenic-loaded ferrous particles get pushed into the layers of sand, as the water enters the sand layer. The arsenic-loaded iron particles get caught in the small void space present in the fine sand layer. The arsenic free water will percolate through the gravels and get collected through the pipe.

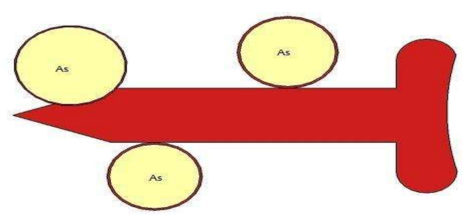


**Figure 2-14 :** Arsenic particles effectively adsorbed on the rusted iron nails surface [*Source:* Ngai, 2002]

**Ceramic water filter**

Clay-based pot filters were developed by Dr. Fernando Mazariegos of the Central American Industrial Research Institute (ICAITI) in 1981. Filtron, a frustum shaped filter was then implemented by Potters for Peace [Stauber *et al*., 2006]. For fabricating ceramic water filter, the clay is mixed with the combustible material in a certain proportion. The powdered mixture is processed into a green ceramic ware. The greenware is dried and sintered to form a ceramic water filter pot **Figure 2-15**. The sintered pots are coated with silver. The silver coating works as a disinfectant and prevents building up of biofilm on the surface of the filter [Silvestry-Rodriguez *et al.*, 2008]. Besides effectively removing bacteria it is also capable of reducing the turbidity of the water.

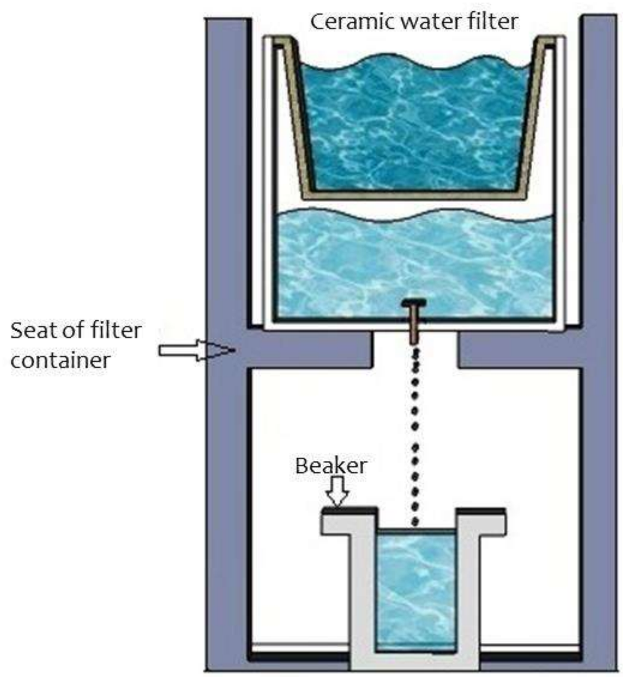


**Figure 2-15 :** Ceramic water filter system [*Source:* Gupta *et al.*, 2018]

### 2.2.3 Adsorption: Fundamentals

Adsorption is a surface phenomenon. The molecules or ions adhere to the surface of solids with which they are in contact. The process contains two elements - adsorbent and adsorbate. Adsorbent is that component on which liquid/gaseous or solid species gets accumulated. Adsorbate is the substance which gets adhered or accumulated on the surface. In other words, adsorbate gets adsorbed on adsorbent [Gregg and Sing, 1982; Fu and Wang, 2011].

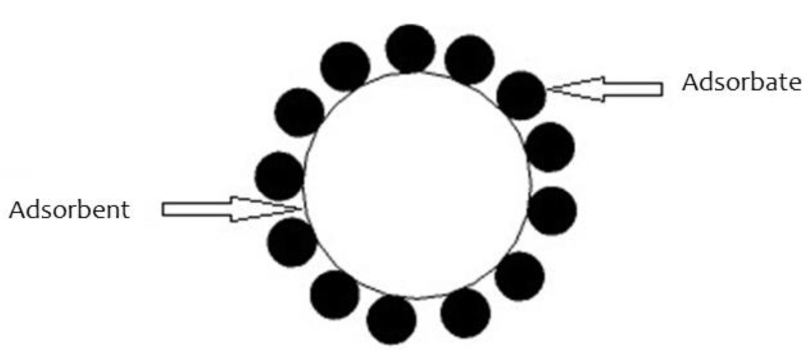


**Figure 2-16 :** Diagrammatic representation of adsorption phenomena [*Source:* Gaspard, 1982]

The attractive forces of attraction exist between adsorbate and adsorbent. When weak forces of attraction exist between the two components, adsorption occurs with formation of multi-layers of adsorbate on the adsorbent surface as shown in figure (**Figure 2-17**). This type of adsorption is called physisorption.

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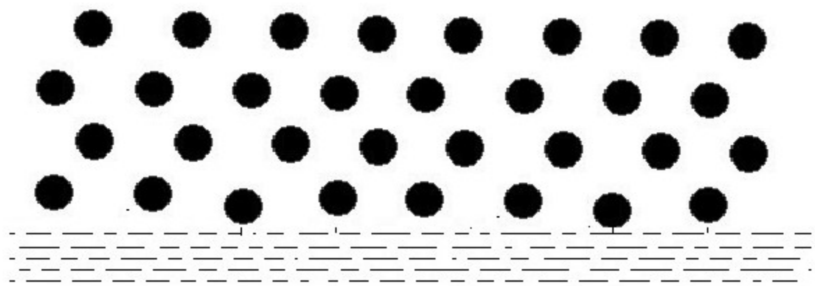

**Figure 2-17 :** Physisorption phenomena [*Source:* Gaspard, 1982]

The chemical forces of attraction between adsorbate and adsorbent system result in the formation of chemical bond between the two. This type of process takes places with the formation of monolayer of adsorbate ions on adsorbent (**Figure 2-18**).

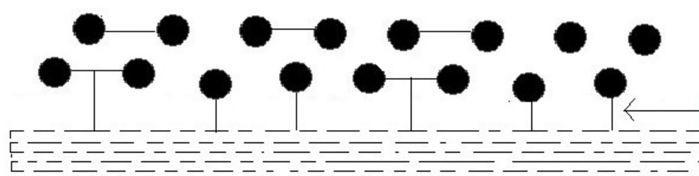


**Figure 2-18 :** Chemisorption phenomena [*Source:* Gaspard, 1982]

### 2.2.4 Diffusion of Adsorbate

There are generally four steps which occurs during an adsorption phenomena [McKay, 2001]. They are

a. Bulk diffusion : Adsorbate ions from the bulk solution moves to the exterior surface surrounding of the adsorbent.

b. Film diffusion : Adsorbate ions transfer across the external liquid film to the exterior surface sites on the adsorbent material.

c. Pore diffusion : Movement of ions with the voids of the porous adsorbent by intra-particle diffusion.

d. Equilibrium adsorption level : A stage when adsorption of ions occurs at the adsorption surface sites.

In a batch adsorption test, bulk diffusion (step a) and stage of equilibrium adsorption (step d) is usually very fast. Therefore, these are not considered to control the adsorption phenomena. Mostly, step b and c are considered to be the rate-limiting stages in the adsorption process. [Choy *et al*., 2004].The evaluation of adsorption process for the removal of chemical contaminants is done on the basis of two physicochemical aspects adsorption capacity and adsorption kinetics [Ho *et al*., 2000].

### 2.2.5 Adsorption in household Filters

In 1999, Bailey *et al*., reported on the qualities of a low-cost adsorbent. The author described low cost adsorbent as materials which are available in large quantities, require little processing time and are by products of wastes from processing industries [Bailey *et al*., 1999]. Ceramic filters discussed above make use of compositional and chemical modifications that cause microbes and chemicals to become adsorbed to filter media [WHO, 2011b]. Investigations on the suitable low-cost adsorbents for arsenic removal using ceramic water filter are not abundantly cited in the literature. However, some significant studies on removal of other chemical contaminants using ceramic water filter units are reviewed here.

In rural parts of India and in its neighbouring countries arsenic is a common contaminant that must be removed. Ngai *et al*., (2007) developed a design for removing arsenic with filters for households of Nepal. After investigating through many options, they selected a sand filter, using ferric hydroxide formed from the dissolution of iron nails as the main adsorption material. The arsenic was getting rapidly adsorbed onto the surface of the ferric hydroxide, this suggested an easy and economical method to remove arsenic, using ferrous material in the form of iron nails.

$$FeCl_3 + 3H2O \rightarrow Fe\ (OH)_3\ (s) + 3Cl- +3H+ \tag{2.2}$$

$$Fe(OH)_3 + H_2AsO^-_4 \rightarrow Fe\text{-}As\ Complex \tag{2.3}$$

The Eq. (2.3) and Eq.(2.4) describe the chemical reactions inside the filters. Following this concept, there were studies which reported the use of natural minerals and clays containing high iron content to remove arsenic [Hagan *et al*., 2009]. The reaction of Pentavalent As with iron oxides (FeOH) irrespective of their hydration powers) have been for Oxyhydroxide surfaces [Poole, 2002].

$$Fe(OH)_3\ (s) + H_3AsO_4 \rightarrow FeAsO_4.2H_2O + H_2O \tag{2.4}$$

In 2013, Yakub et al., modified the filter composition for the removal of fluoride from drinking water. The authors added hydroxyapatite to clay-sawdust mixture in five distinct proportions. These distinct sets of ceramics materials were fired at five different sintering temperatures ranging from 500 to 850°. The fluoride adsorption increased in proportion with the fraction of hydroxyapatite content in the filter composition. The fluoride adsorption followed the pore diffusion model. The free energy data revealed about the spontaneous nature of the adsorption process [Yakub and Soboyejo, 2013].

Erhuanga *et al*., 2014 manufacture ceramic filters using clay, laterite, bone char and charcoal for removing fluoride from water. The clay and laterite were used to form the matrix material. Bone char was introduced into the ceramic system due to its defluoridation properties . Addition of charcoal in the filter composition was done to impart porosity to the filter unit. The quantity of bone char added linearly influenced the fluoride removal ability of filters [Erhuanga *et al*., 2014].

Passman *et al*., 2014 used a bone char in the activated charcoal form as a separate unit attached beneath the clay pot filter.The combined filter - attachment system was developed for the removal of arsenic from water.The combined filter unit was tested to check the arsenic removal efficiency from water containing 500 ppb of arsenic concentration. It was found that attachment of a separate charcoal unit with ceramic filter showed 50 times reduction of arsenic concentration, whereas, only a 10 % reduction in arsenic concentration was achieved using ceramic filters alone [Passman *et al.*, 2014].

Investigation on the removal efficiency of Co(II), Mn(II), and Cd(II) ions from polluted waters using ceramic water filter was reported in the literature [Jassim *et al.*, 2017]. Sanaa Abdul-Razak Jassim *et al.*, 2017 made ceramic water filter using paligorskiet as clay, porcelanite as a silica and wood ash as an additive. Wood ash was prepared from residual woods from a workshop. Fifty percent volumetric mixture of wood ash was added to the raw ceramic mixture to form cylindrical filter discs. The firing process of dried ceramic samples was carried out at 1100°C in an electric furnace. The polluted water was prepared at two different concentrations of 1 mg/l (Co(II), Mn(II) and Cd(II)) and 10 mg/l (Co(II), Mn(II) and Cd(II)). Both concentrations were passed through distinct sintered ceramic discs and the concentration of contaminants before and after passing was measured. The results displayed higher removal of heavy metals ions at initial low concentration 1 mg/l (99.50 and 99.9%). While at higher concentration 10 mg/l, the filter could remove 24 and 31% of the initial concentration of each ion. [Jassim *et al.*, 2017].

In 2017, Ali, A. and associates investigated the potential of ceramic water filtration in removing $Pb^{2+}$, $Cu^{2+}$and $Cd^{2+}$ from aqueous solution. The ability of ceramics to remove heavy metals was studied using ceramics with three distinct organic material content (0.5%, 2% and 5%). The effect of various parameters like pH, pressure head and heavy metal concentration was studied. The results displayed 99% removal efficiency. SEM images showed the presence of adsorbed ions on side walls of porous ceramic membranes. [Ali *et al.*, 2017].

Recently, Firmansyah (2018) made clay-based water filters using distinct mixture of clay and andisol to reduce cadmium ion concentration from the groundwater. The 60:40 clay saw dust filter composition showed effective cadmium ion adsorption for a 60 minute contact period. The adsorption followed freundlich model with a coefficient of determination of 0.99.

## 2.3 SUSTAINABILITY OF CERAMIC WATER FILTERS

The investigation of the production cost associated with different household filters used to treat water was done by Sobsey *et al.*, 2008. The author documented that ceramic filtration units were the least expensive (less than $0.001/L) followed by Biosand filters. The biosand filter units possessed high capital cost and low maintenance costs. The expected life cycle of the ceramic water filter unit was estimated at one year on the lower end, but some filters were found to be in use after four years [Sobsey *et al.*, 2008].

In 2009, Hunter (2009) conducted a meta-regression analysis which compared the overall performance of various other low-cost filtration systems with ceramic water filters. In this analysis, the author deduced that ceramic filters are most suitable for household water treatment. Further, in 2013, Ren et al. showcased that ceramic filters are cost effective and more environmentally sustainable in comparison with centralized water treatment systems (Ren *et al.*, 2013). The writers also investigated the social and economic sustainability of ceramic filters use over a 10 year period. The results revealed that ceramic filters are highly preferred in areas with low population densities

Ceramic water filter is reported to be most effective water treatment option in terms of diarrheal disease risk reduction [Sobsey *et al.*, 2008] and annual health cost offsets [Clasen *et al.*, 2007]. In 2009, Van Halem et al. examined the sustainability of ceramic water filters for low-income households. They found that the filter effectively removed diarrhoea-inducing microorganisms and provided excellent quality water. Ceramics filters are usually surface coated either inside or outside with a solution of colloidal silver. Coating of silver indicates approximately 10% of the cost of each filter made by Potters for Peace. Silver coating enhances antimicrobial properties which improve effluent quality [Jang *et al.*, 2008]. The effectiveness of silver coating decreases with time due to silver leaching into the effluent water. Silver is typically only effective for a few months of use [Van Halem *et al*., 2009]. This limitation drives the investigation of filter units without silver to reduce costs.

Brown *et al*., 2009 carried out a case study on the use of ceramic filters over a period of four years. They studied a group of 506 households, determining the rate of decline in usage of ceramic filters and the major causes associated with it. They found that filter use declined by 2% per month, primarily due to cracks and breakages in the filter. Parameters that influenced continued filter use involved the quality of water and hygiene practices adopted in the home, economic investment on the household technology and on the use of surface water for primary drinking purpose.

The advantage of the ceramic water filter is their very simple design, containing only one clay pot shaped filter and receptacle to collect filtered water. These ceramic filters, however, require periodic cleaning (because turbid water clogs the filter) and are expected to be replaced in every two years. The disadvantage of the filter is its brittle nature and ineffectiveness at removing chemical contaminants [Plappally, 2010].

Ceramic water filters can provide economic benefits as well as traditional skill-based entrepreneurship [Gupta *et al*., 2018]. The ceramic water filter (named G-filter) production in India was voluntarily initiated at two places, Tindivanum in Tamil Nadu and Jodhpur in Rajasthan [Gupta *et al*., 2018; ENACTUS IITM, 2017]. The Tamil Nadu project is being carried out by Enactus-IIT Madras but with other NGOs namely Shine NGO on the ground [ENACTUS, IITM Project, 2017]. In India, pottery is performed as a rural traditional family craft and business rather than factories. The traditional knowledge and experience of potters staying in Rajasthan is knitted skillfully to develop ceramic G-filter technology for rural parts of Western Rajasthan. This benefitted local potters to utilize their existing tradition skills for installing household (joint traditional extended family owned) filter production units. Since there are no factories so no jobs lost or no traditional skill loss is happening. Potter families get a new area of filtration based production to sustain their tradition and knowledge. Here the local clayey soil and sawdust is mixed to form the raw material for the frustum shaped ceramic water filter [Gupta *et al*., 2018]. Potter women in India play a major role is material selection for the ceramic water filters as well as clay artifacts and are knowledge bearers of soil properties [Gupta *et al*., 2018].

Extensive research showcasing field studies on effective microbial from water using ceramic water filter has been reported by several researchers across the globe. There is a dearth in literature where ceramic filters are known to treat arsenic contaminants as well as microbes in water. Therefore, the work in the thesis is aimed at developing a clay ceramic filter using local low-cost adsorbent that could treat bacterial and arsenic contamination in water at the household level.

The performance of the ceramic water filter is dependent on the type of clay been used, sintering temperature and heating profile being used. The structural stability of the ceramic filters requires improvement which can be improved by adding other additive materials. The efficiency of the G Filter to eliminate specific regional contaminants can be enhanced through the addition of other additive materials into the clay-organic material matrix system.

Can the local wastes be added to the clay to improve the mechanical sustainability of the clay ceramic based filters? Can the adsorption and filtration mechanism be twinned to remove arsenic and microbes from the water? These questions are tried to be resolved in this thesis