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A Low-Cost Solution for Arsenic in Water: Integrating ZVI Technology into Ceramic Pot Filter: MatiKalp

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Abstract: ***Arsenic contamination in drinking water is a severe problem for human health. One feasible solution to this problem could be the integration of a low – cost ceramic pot filter called MatiKalp and zero-valent iron (ZVI) technology. MatiKalpis widely used in many developing countries to address microbial contamination and turbidity present in water. When water is poured into the filter, the integrated ZVI adsorbs the arsenic, which is further separated through filtration. This solution has potential, particularly for low-income households, because it is low-cost and does not require any additional infrastructure. To assess the feasibility of this integration, a study was conducted in Bihar, where arsenic contamination is present in groundwater in varied concentrations. The study found that integration is capable of reducing arsenic, which makes this solution practical and effective and can be easily implemented in many communities. Furthermore, the filters can be produced locally, creating employment opportunities for promoting economic development.***

Keywords: MatiKalp, ZVI, arsenic, economic development, low – cost

1. Introduction

Access to clean water continues to be an essential concern to human health in developing countries (Gardner and Guggenberger, 2018). Globally, microbiological contamination is the largest cause of water-related mortality and morbidity, but some chemical contamination in water remains a big challenge (Villanueva, et al., 2014). Safety and accessibility of drinking water are global concerns, especially where groundwater plays a vital role in rural and urban domestic, industrial, and irrigation needs in India (Bhattacharya, et al., 2019).

Contamination from geological formations (termed geogenic contamination) is the major source of chemical contamination in groundwater. Geogenic contaminants originate naturally through weathering of rocks/formations deposited in the aquifer and are soluble in water. Arsenic and fluoride are geogenic contaminants that pose a greater risk to human health (Ghosh, 2017). In India, many people suffer from fluorosis and arsenicosis due to the intake of fluoride and arsenic – contaminated drinking water. Per the National Health Program, high levels of fluoride were reported in 230 districts of twenty states of India (Sharma, et al., 2019). According to PIB, Govt. of India, press release dated 12 Dec 2022, groundwater in 221 districts spread over twenty-five states and UTs contain arsenic above the permissible limit.

Arsenic (As) is a potent environmental pollutant and a silent toxic element, havingits concentration dependent on local hydrology, geology, and geochemical characteristics of the aquifer. In 2001, WHO ranked arsenic as number one on the list of hazardous substances and named it “King of Poison” (Shaji, et al., 2021). In groundwater, arsenic is found to be in two valence states, one is trivalent arsenic (As [III], arsenite), and the other is pentavalent arsenic (As [V], arsenate). Arsenite is more toxic in nature than arsenate (Shaji et al., 2021). Continuous exposure to high-arsenic water causes pigmentation, hyperkeratosis, ulceration, and skin cancer, and also affects the liver, kidney, heart, and lungs (Sun, et al., 2019).

Arsenic is spread worldwide, particularly in the south and southeast Asian belt. Global data reveals that 107 countries are affected by this contamination beyond the permissible limit of 10 ppb defined by WHO, majorly regions with tropical climates, as this aggravates the release of arsenic (Ranjan, 2019). India is one of the largest countries struggling with the geogenic contamination of arsenic. West Bengal, Jharkhand, Bihar, Uttar Pradesh, Assam, Manipur, Chhattisgarh, Haryana, Punjab, and Karnataka are the reported arsenic-affected states in India (Bhattacharya, et al., 2019). In India, groundwater in shallow aquifers is reported to have a higher concentration of arsenic than in deeper aquifers (CGWB, 2018). The Bureau of Indian Standards (BIS) has set the desirable limit of arsenic in drinking water to 10 ppb.

Bihar, an eastern state of India, is located in the Ganga-Meghna-Brahmaputra basin. Bihar is highly dependent on groundwater sources. Therefore, the prevalence of arsenic in the area is high. Other water sources, such as dug well, ponds, lakes, and rivers, are present but are not commonly used for drinking purposes. Eighteen districts out of thirty-eight districts of Bihar experience high concentrations of arsenic in groundwater (Kumar, et al., 2016). The authors also report that there is a correlation between the prevalence of arsenic in the groundwater and the high incidence of cancer. The study further reiterates the fact that the people living in the Gangetic basin are continually exposed to arsenic toxicity and have developed several types of cancers. Kumar, et al., 2023, reported a strong linkage between high chronic exposure to arsenic and gallbladder carcinogenesis.

The arsenic can be removed from water through some conventional technologies/processes such as oxidation, adsorption, membrane filtration, and ion exchange

(Kushawaha, et al., 2021). As [III] is considered to be more toxic, mobile, and much more difficult to remove than As [V]. However, once As [III] is oxidized into As [V], it is then ready for adsorption and can be further removed from water by a simple filtration technique.

The technology to remove arsenic is based on oxidizing the state of arsenic in water from As [III] into As [V], and then the total As [V] present in water is adsorbed by hydrous ferric oxide (HFO). HFO is an effective adsorbent for arsenic. It is formed via intermittent contact zero-valent iron (ZVI) in the form of iron shredding or nails on its surface with water and air. The adsorbed arsenic gets stripped off the surface of the ZVI which is further trapped on the inner surface of the CPF to remove from the water. This process of trapping the adsorbed arsenic is called mechanical trapping. According to the toxicity characteristic leaching procedure (TCLP), study conducted by IIT, Kanpur, the sludge thus formed by arsenic adsorption on ZVI is non-hazardous and can be disposed of safely in landfills along with regular municipal waste (Verma, et al., 2021).

Household water treatment technologies at the point of use hold an edge over community-level technologies, as they reduce the chances of secondary infection after the water treatment (Sharma, 2018). WHO, 2019 also identifies household water treatment, and safe storage (HWTS) as a potential solution. The most promising technologies for household water treatment are filtration (biosand filter, ceramic pot filter, membrane filter, and candle filter) accompanied by disinfection (boiling, chlorine, UV, SODIS, and more) (Agrawal, et al.2006). The integration of above discussed low-cost, yet effective, zero-valent iron (ZVI) technology with a locally produced ceramic pot filter being very low cost makes it appropriate for the removal of arsenic via the adsorption of As [V] on hydrous ferric oxide (HFO) produced by ZVI. The process is so designed that efficient oxidation of As [III] to As [V] is achieved by increasing the surface area of water poured by dividing it into the tiny streams or drops in the filter through a diffuser; and As [V], thus formed, is adsorbed on HFO.

The objective of the study: The purpose of the study is to investigate the feasibility of integrating zero-valent iron technology for the removal of arsenic with a locally produced low – cost ceramic pot filter, MatiKalp.

2. Materials and Methodology

Study area: The study took place in the Desari block of the Vaishali district and Tilak Rai ka Ahata in the Buxar district of Bihar state of India, situated in the eastern part of the Ganga river basin. As the districts are bounded by the Ganges and other rivers, flooding is one of the major concerns in these districts. The Ganga river system, originating in the Himalayas, carries nearly fifteen billion tons of sediments containing arsenic and other trace elements (Chakraborti, et al., 2018).

Considering the low affordability of the poorest of poor households in these districts, S M Sehgal Foundation is promoting a ceramic pot filter. The filter is capable of addressing microbial, iron contamination, and turbidity to improve water quality at the household level named MatiKalp (Sharma, et al., 2023). Figure1 shows the pictures of MatiKalp with steel and plastic receptacles along with schematic representation in between. Figure 2 shows the representation of the integration of zero-valent iron technology placed into the ceramic pot filter without a diffuser in a household setting. An integration of ZVI (single stage) into MatiKalp with the diffuser is shown in Figure 3. A two stage setting of ZVI is to remove the higher concentration of arsenic in water. The schematic representation of two stage ZVI is shown in Figure 4.

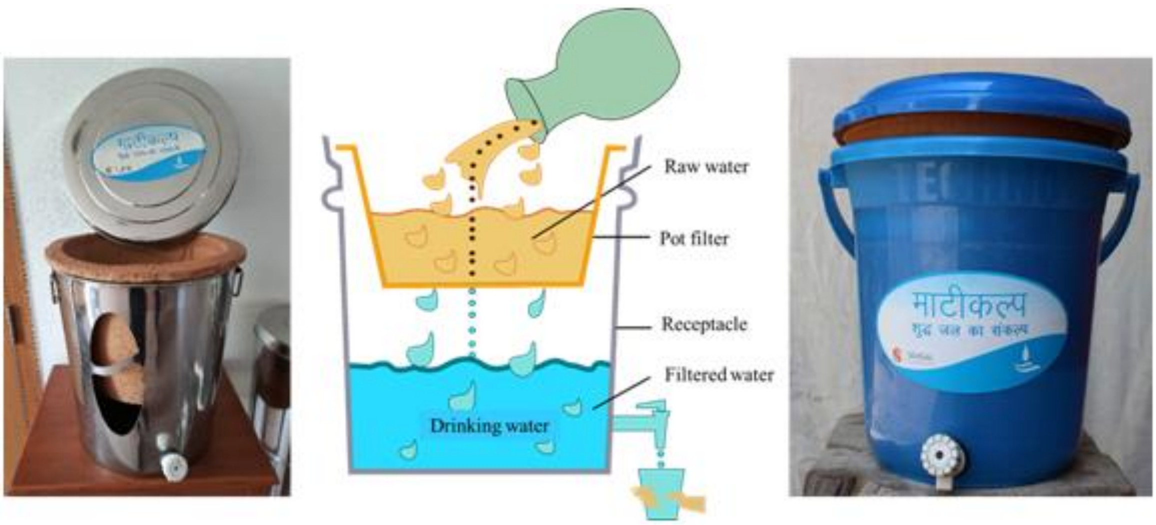

Figure 1: Schematic representation of MatiKalp in between steel and plastic receptacle

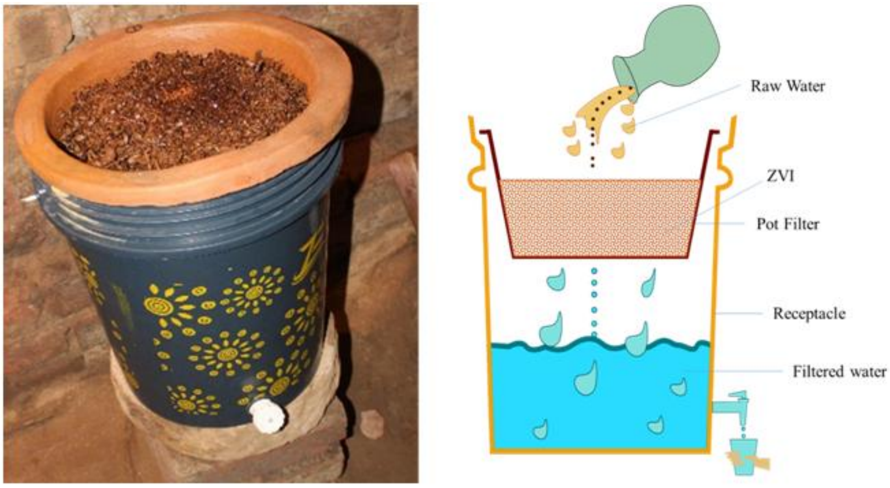

Figure 2: Integration of ZVI into MatiKalp with no diffuser

Figure 3: Integration of single stage ZVI into MatiKalp with diffuser

Figure 4: Integration of two-stage ZVI into MatiKalp with diffuser

2.1 ***Community interaction:*** Although there were visible symptoms of the impact of arsenic among the community members, it was observed that the community had limited knowledge and awareness regarding the widespread occurrence of arsenic contamination in their drinking water source. As a proactive measure, S M Sehgal Foundation initiated a sensitization campaign to educate the community members about the contamination issue and to introduce them to the concept of ceramic pot filters as a possible solution. The foundation also imparted training to the community on filter maintenance, enabling them to take responsibility for its upkeep.

2.2 *Ceramic Pot filter (CPF):* The raw materials such as clay, sand, and combustible material were processed locally and formed into the shape of the pot whereby the local artisans, who were losing their craft skills and livelihood, have turned challenges of clean drinking water into livelihood opportunities for them (Sharma, et al., 2023). During the firing process of the dried pot, the burn-out material got gasified, leaving behind a network of micropores connected with a microchannel to facilitate the filtration of water.

2.3 *Integration of zero-valent iron (ZVI) into MatiKalp:* The iron shredding (waste from the lathe machine) is placed in the filter body in a manner that, when raw water with arsenic having passed through the diffuser enters into the filter, it comes in contact with ZVI before getting filtered.

2.4 *Water sampling:* The selection of filter samples was based on households that had been using MatiKalp for at least three months. All the filters were manufactured in the same batch. All the households are using groundwater withdrawn by hand pump. Water samples were collected and tested at regular intervals.

2.5 *Water testing:* Tests were conducted to assess the quality of water through four parameters: pH, TDS, iron, and arsenic. The raw and filtered water was evaluated using field-testing kits at the actual location. The steps involved in the procedure are outlined below:

- Arsenic test*:* The arsenic was measured using an arsenic-monitoring field kit (Chem-in Corporation, Pune, India), which reduces arsenates to arsenites, and ultimately converts all As [III] to arsine gas. Upon reaction with a reagent present in the detector tube, the arsine gas produces pink-colored vapors, which were utilized to quantitatively estimate total arsenic.
- Iron test*:* The iron was measured using the Hanna Iron Checker Colorimeter. This field testing kit records the concentration of iron using the Phenanthroline method.
- pH test*:* pH was measured using a pH meter (HM digital meter) that was calibrated using buffer solutions of 4 and 7 pH.
- TDS test*:* TDS was measured using a TDS meter (HM digital meter). The carry case of the meter is filled with sample water, and the digital meter is dipped into the case. The reading is recorded digitally.

3. Results and Discussion

3.1. Arsenic Removal

A total of fifteen filters were evaluated under the same sampling condition with no diffuser where twelve filters were observed without ZVI and the remaining three were with ZVI. It can be seen in Figure 5below that in the same condition, the low concentration of arsenic is reduced to below the permissible limit. The possibility of this reduction could be by the natural adsorption within the terra-cotta filter body or/and by the oxidized iron present in water. However, the concentration of arsenic in raw water above 30 ppb was reduced to above the permissible limit. Therefore, for the concentration of arsenic in raw water above 30 ppb, 2.5–3 kg of ZVI was added in MatiKalp, which helped in lowering the concentration of arsenic up to and below the permissible limit.

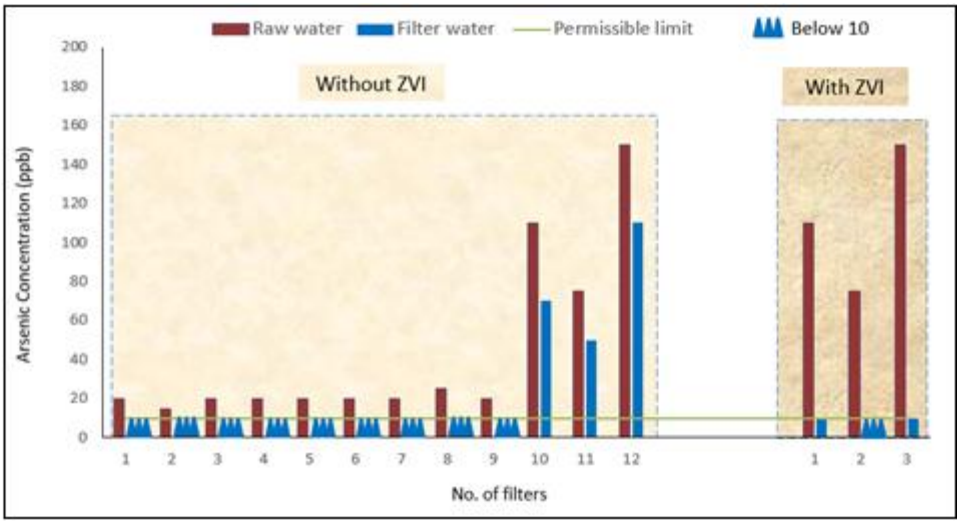

Figure 5: Removal of arsenic with and without ZVI (no diffuser)

The integration of zero-valent iron in the ceramic pot filter has reduced the arsenic concentration from 200 ppb to 15 ppb and 250 ppb to 25 ppb when the ZVI is placed in a single-stage setting along with the addition of a diffuser as shown in Figure 6, but still, it is above the permissible limit of 10 ppb. So one more stage of ZVI was added for water with a concentration of arsenic above 250 ppb. In Figure 7, it can be observed that the source having a concentration of 600 ppb reduced the arsenic level to 15 ppb.

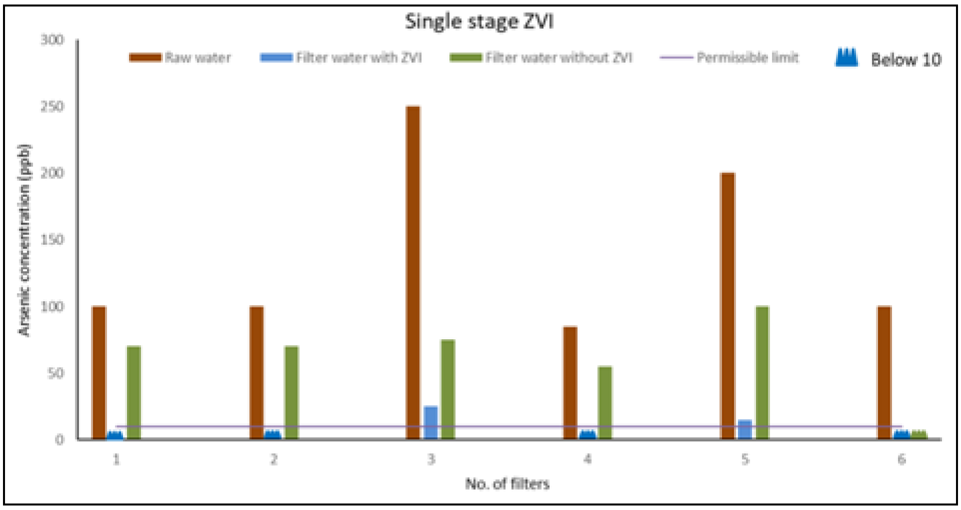

Figure 6: Removal of arsenic with and without ZVI (Single stage)

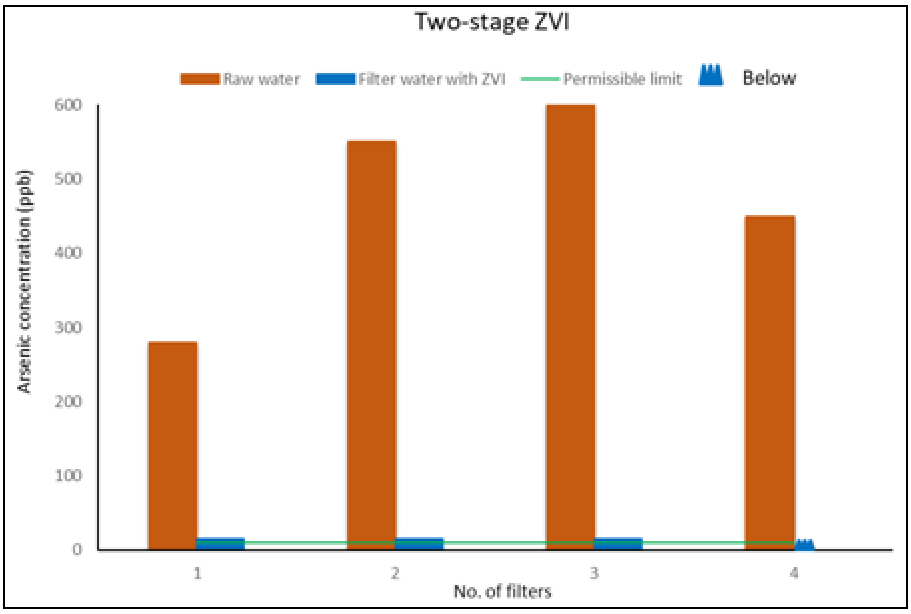

Figure 7: Removal of arsenic with two-stage ZVI

3.2. Iron Removal

To observe the removal of iron in ceramic pot filters, forty-eight filters were observed. The iron present in raw and filtered water was analyzed. In the below graph, it can be observed that all the filters were able to remove iron to the permissible limit of 0.3 ppm or even below, irrespective of ZVI integration in the filter. The highest concentration of iron in the groundwater source was recorded to be 5 ppm.

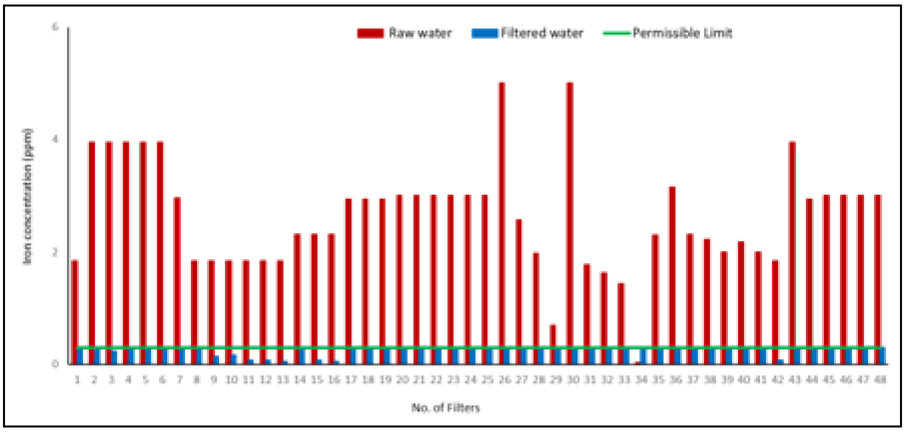

Figure 8: Shows the removal of iron from MatiKalp

3.3. pH

The pH of raw water and filtered water was monitored for thirty filters. The below graph of pH shows that almost all the source water and filtered water recorded a neutral pH of 7. The data confirms that the ceramic pot filter did not make any change in the pH of the water.

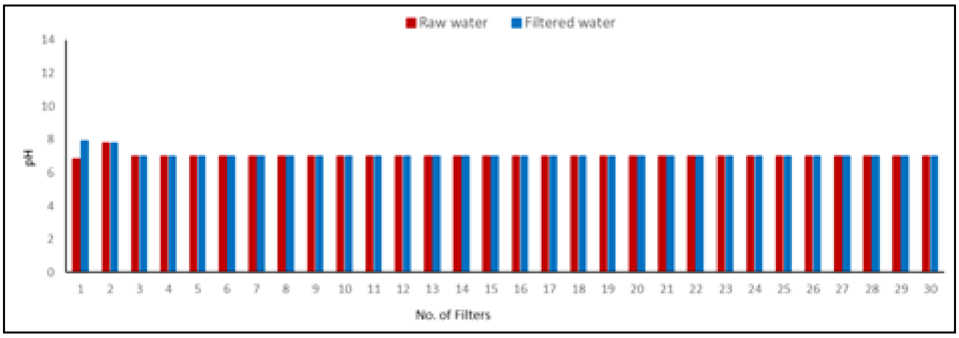

Figure 9: Shows the pH of raw and filtered water

3.4. TDS Removal

Fifty MatiKalp filters were evaluated to check the TDS level in raw and filtered water. It is observed that the filtered water from MatiKalp showed a small decrease in TDS level. The average TDS level reduction was found to be 26 ppm, whereas minimum and maximum reductions are 1 ppm and 61 ppm respectively. However, the reduction does not show any trend. It may be because different chemical constituents behave differently. To arrive at any conclusion, a detailed study of constituents may help.

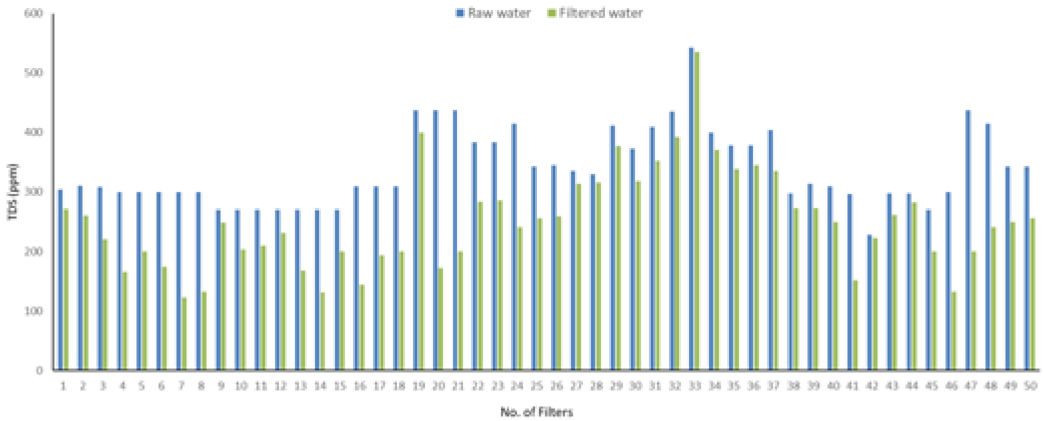

Figure 10: Shows the reduction of TDS from MatiKalp

4. Conclusion/Way Forward

The study shows that the integration of ZVI into the ceramic pot filter is feasible to remove arsenic from water. The use of ZVI integrated into MatiKalp, being low-cost, has high potential in arsenic-affected areas, particularly for people in low – income groups. The community at the base of the pyramid also showed a positive response toward the adoption of this combination of MatiKalp and ZVI. The community people who used this combination liked the taste and clearer appearance of filtered water. Some also believed that drinking untreated water would not cause any serious harm to their health. In response to this, Sehgal Foundation runs a campaign with younger schoolchildren and women's groups to sensitize and make them aware of the presence of contamination and its impact on health, aiming to pass on the knowledge to all family members. The results of the campaign are encouraging.

Looking at the results of this study and keeping the affordability of low-income groups in focus, it is evident that the integration of ZVI with MatiKalp can be developed and further optimized for arsenic removal. The study of interference of other ionic constituents in the treatment process would also have been a process of optimization.

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