

## **EVALUATION OF LOW-COST FILTER MATERIALS FOR MANGANESE REMOVAL FROM GROUNDWATER UNDER ANOXIC CONDITIONS**

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### **ABSTRACT**

Manganese contamination in groundwater constitutes a significant public health concern in Bangladesh, especially in Rajshahi, where concentrations frequently surpass national and WHO drinking water regulations. This study examines the efficacy of inexpensive, locally sourced filter media for manganese removal via a non-aeration (anoxic) treatment approach. The aim is to evaluate the effectiveness of removal, emphasizing sustainable materials and straightforward filtration methods. The impact of filter thickness and flow rate was analyzed utilizing sand, anthracite, plastic chips, and crushed concrete as filtration media. The efficacy of the anoxic system was compared to that of the aerobic technique. Experimental columns were fabricated using vertical uPVC pipes filled with various filter media, allowing manganese-contaminated groundwater to flow under regulated anoxic conditions. Weekly water samples obtained from various depths were evaluated utilizing a UV-VIS spectrophotometer. *Pseudomonas aeruginosa* microbial growth was detected in the filter beds. The findings indicated that plastic chips attained an entire (100%) manganese removal under anoxic conditions, in contrast to 95.78% observed in prior aerobic research. Crushed concrete demonstrated increased permeability but diminished manganese removal effectiveness. The comparison results illustrate the efficacy of the anoxic technique and underscore the viability of locally sourced materials for sustainable, small-scale groundwater remediation in manganese-impacted areas.

**Keywords:** *Manganese; groundwater; anoxic; filtration; plastic chips; sustainable.*

## 1. INTRODUCTION

Groundwater is an essential worldwide resource, comprising almost 97% of Earth's freshwater and facilitating drinking water, agriculture, and industrial activities. It is particularly vital in regions with unpredictable precipitation and scarce surface water (Abanyie et al., 2023). Approximately 90% of the population in Bangladesh depends on groundwater, while surface water contamination has been exacerbated by urbanization and industrialization (Tajwar et al., 2024). Groundwater quality is jeopardized by both natural and anthropogenic sources, including industrial and agricultural pollution, excessive extraction, and contamination from harmful substances such as arsenic, lead, and heavy metals (Shaji et al., 2021). Manganese (Mn), a vital element, frequently surpasses health thresholds in groundwater in South Asia (Ramachandran et al., 2021). In 2021, the WHO established a provisional guideline value (pGV) of 0.08 mg/L for manganese in drinking water to safeguard vulnerable populations, such as infants (WHO, 2021). Chronic manganese overexposure is associated with neurological, developmental, and cardiovascular complications (J. Bruins, 2017). In Rajshahi, Bangladesh, groundwater manganese often exceeds national and WHO thresholds, with levels of high to 3.43 mg/L (Chowdhury & Chowdhury, 2021).

The removal of Mn is challenging owing to its considerable solubility (Kulkarni, 2016). Chemical oxidation, adsorption, and membrane filtering are constrained by their cost and complexity (Rahman et al., 2023). Manganese-oxidizing bacteria, such as *Pseudomonas putida*, demonstrate potential as an environmentally sustainable and economical biological filtration technology (Cai et al., 2023). Biofilters oxidize Mn(II) to Mn(IV), facilitating effective removal without the use of chemicals (McKee et al., 2016). This research diverges from previous studies that mostly employed aerobic filtering by concentrating on anoxic conditions and utilizing low-cost, locally sourced filter media, such as plastic chips and crushed concrete, to assess their manganese removal efficacy and microbial interactions. This denotes the inaugural systematic anoxic manganese removal experiment utilizing local groundwater in Rajshahi.

## 2. METHODOLOGY

### 2.1 Location of Experiment

The experiment was carried out in Ward No. 02 of Rajshahi City Corporation, where the groundwater manganese concentration was 2.37 mg/L, indicative of standard levels throughout the city. The research area is depicted in Figure 1 of the location map. Table 1 delineates the physicochemical characteristics of the unprocessed groundwater.

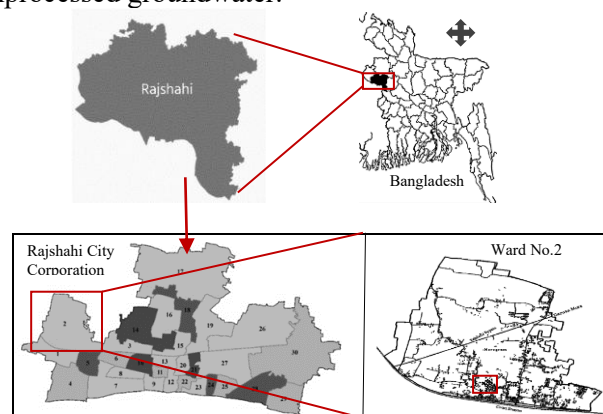


Figure 1. Location map of the experiment.

Table 1. Raw Groundwater Quality from Shallow Well (Influent for Pilot Experiments)

Water quality parameters	Unit	Raw groundwater
Temperature	°C	17±3
p <sup>H</sup>	[-]	7.2±0.01
Manganese (Mn)	mg/L	2.37
Iron (Fe)	mg/L	0.2
Electrical Conductivity	µs/cm	163±16

## 2.2 Filter Materials

Four economical, locally sourced filtration materials were utilized: quartz sand, anthracite, bio-chips, and broken concrete, as seen in Figure 2. Quartz sand was chosen for efficient physical filtering, with  $D_{10} = 0.27$  mm,  $D_{30} = 0.39$  mm,  $D_{60} = 0.61$  mm,  $C_u = 2.26$ , and  $C_c = 0.92$ . Anthracite provided depth filtration owing to its granular morphology, abrasive texture, and elevated carbon concentration. Bio-chips ( $25 \times 10$  mm, specific gravity  $0.94\text{--}0.97$  g/cm<sup>3</sup>) facilitated the proliferation of manganese-oxidizing bacteria and biofilm development. Crushed concrete (12–18 mm), obtained from deconstructed edifices, possessed a porous, alkaline surface that facilitated adsorption, entrapment, and microbiological activity.

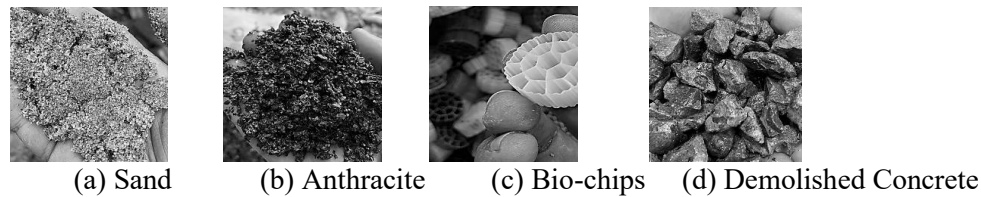


Figure 2. Filter Materials

## 2.3 Equipment and Experimental Setup

Two primary devices were employed for water quality assessment. The HACH DR 900 colorimeter, seen in Figure 3(a), quantified manganese levels utilizing Program HR 295, which combines Manganese Citrate Buffer and Sodium Periodate with water samples. The LaMotte 1766 Pocketester, depicted in Figure 3(b), assessed pH, TDS, conductivity, and temperature in situ, with calibration performed prior to each application.

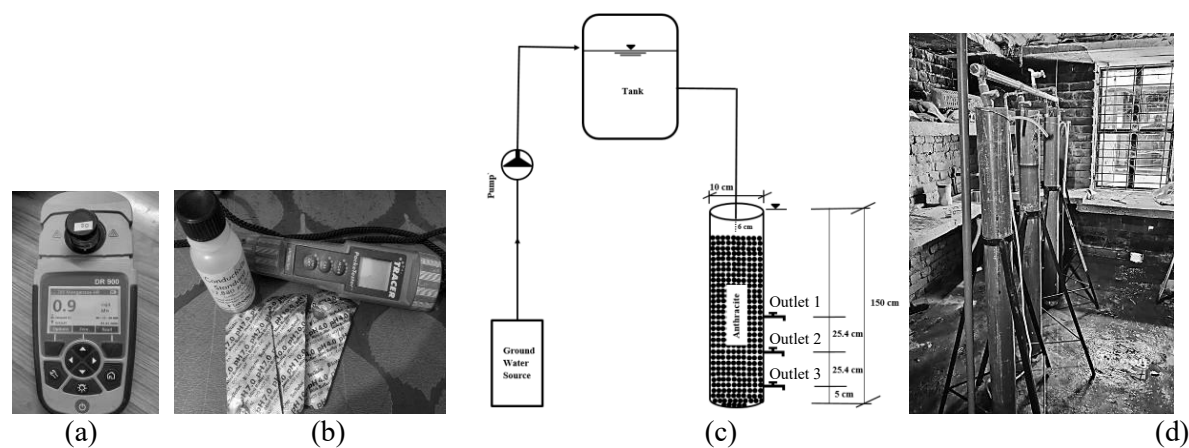


Figure 3. (a) Colorimeter, (b) LaMotte 1766 pH/TDS/Salt/Temp Tracer PockeTester with pH capsule and conductivity standard for calibration, (c) Schematic representation of filter set-up, and (d) On-site setup

The configuration comprised four vertical uPVC columns (150 cm in height, 10 cm in diameter), as illustrated in Figure 3(c), each containing one type of filter material: quartz sand, anthracite, bio-

chips, or broken concrete. Manganese-contaminated groundwater was extracted from a depth of 40 meters into a sealed tank situated 3 meters above the columns to sustain anoxic flow. Each column featured three sampling outlets, positioned 25.4 cm apart, with the uppermost outlet located 55.8 cm from the lowest. Throughout the operation, solely the lowest outlet remained accessible. Flow rates were quantified with a cylinder and a timer. All materials were sanitized prior to utilization. Filtration persisted for 49 days without the use of chemicals. The on-site configuration is illustrated in Figure 3(d).

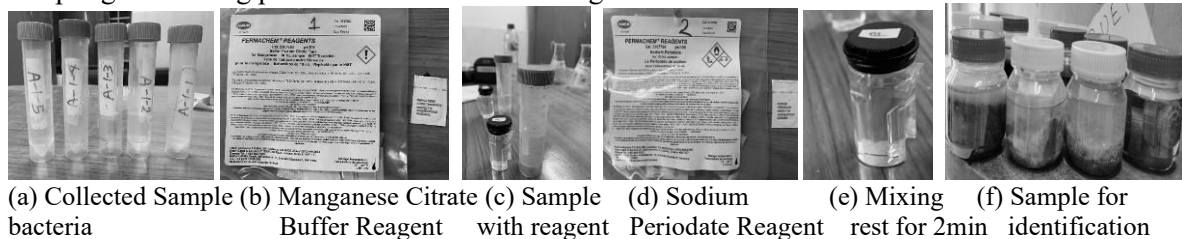
## 2.4 Sampling and Testing Procedure

Water samples were obtained from all three exits of each column and the overhead tank to evaluate manganese removal at various depths. Samples were preserved in 50 ml polypropylene vials and acidified to 1.5% using ultrapure HNO<sub>3</sub>. Samples, both filtered and unfiltered, were collected in each cycle. The LaMotte 1766 Pocketester was utilized to monitor on-site pH, temperature, and conductivity. Manganese concentrations were measured using a HACH DR 900 colorimeter with Program HR 295. Each 10 ml sample was combined with Manganese Citrate Buffer and Sodium Periodate, reacted for 2 minutes, and subsequently quantified. The colorimeter was calibrated using distilled water before to each test. All operations were conducted in duplicate to ensure precision. The proportion of manganese (Mn) elimination was determined using the subsequent equation:

$$\text{Mn Removal (\%)} = \{(C_i - C_f) / C_i\} * 100$$

C<sub>i</sub> represents the initial manganese concentration (mg/L), whereas C<sub>f</sub> denotes the final Mn concentration (mg/L).

To evaluate the microbial activity associated with manganese removal, water samples were taken from the columns at the conclusion of the experiment and dispatched to the National Institute of Biotechnology for medium culture testing to isolate and identify manganese-oxidizing bacteria. The sampling and testing procedure is illustrated in Figure 4.



(a) Collected Sample (b) Manganese Citrate Buffer Reagent (c) Sample with reagent (d) Sodium Periodate Reagent (e) Mixing rest for 2min (f) Sample for identification

Figure 4. Sampling and Testing

## 3. RESULTS AND DISCUSSIONS

This section assesses the efficacy of quartz sand, anthracite, bio-chips, and broken concrete in the extraction of manganese from groundwater in anoxic environments. The discourse encompasses removal efficiency, depth-dependent performance variance, flow rate dynamics, and microbiological activity noted during the experiment.

### 3.1 Comparison of Manganese Removal Percentage from Outlets of the Four Columns

According to Figure 5-7, Bio-chips exhibited the highest and most consistent manganese removal, achieving 100% by week 4, which is attributable to their extensive surface area and adsorption capacity. This was followed by a slight decline due to surface saturation and clogging. Sand and anthracite demonstrated commendable performance but deteriorated over time due to particle accumulation, whereas demolished concrete proved least effective owing to restricted adsorption. Minimal removal was observed in the initial two weeks before the establishment of biofilm growth and adsorption equilibrium.

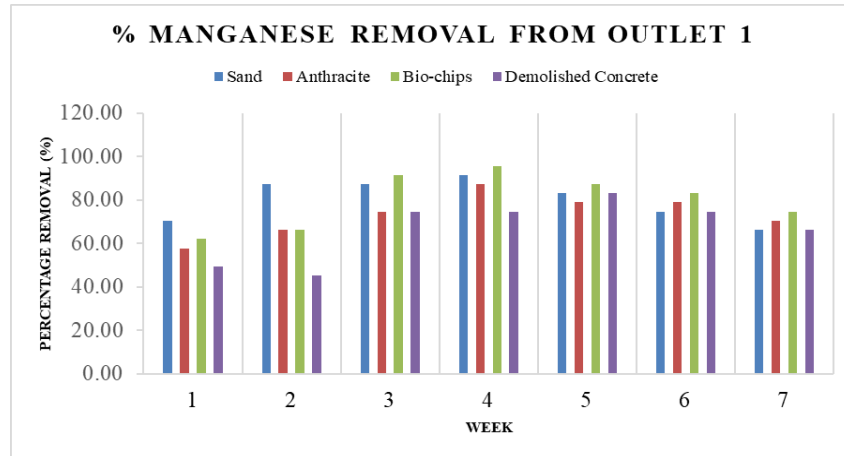


Figure 5. %Removal of Mn from Outlet 1 vs Weeks

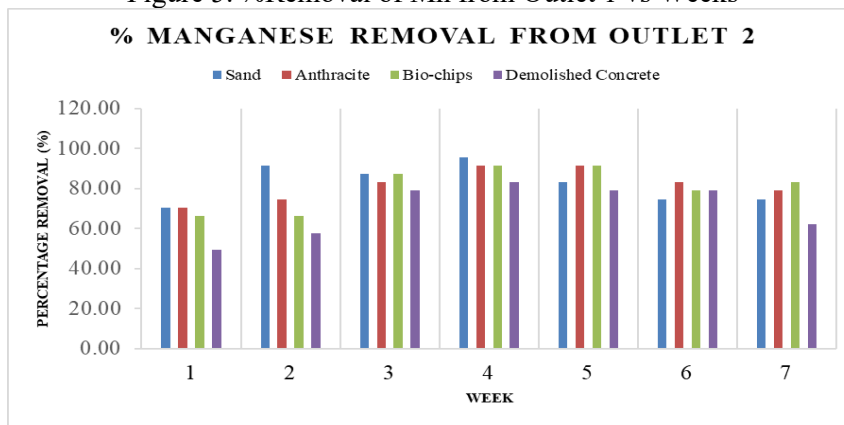


Figure 6. %Removal of Mn from Outlet 2 vs Weeks

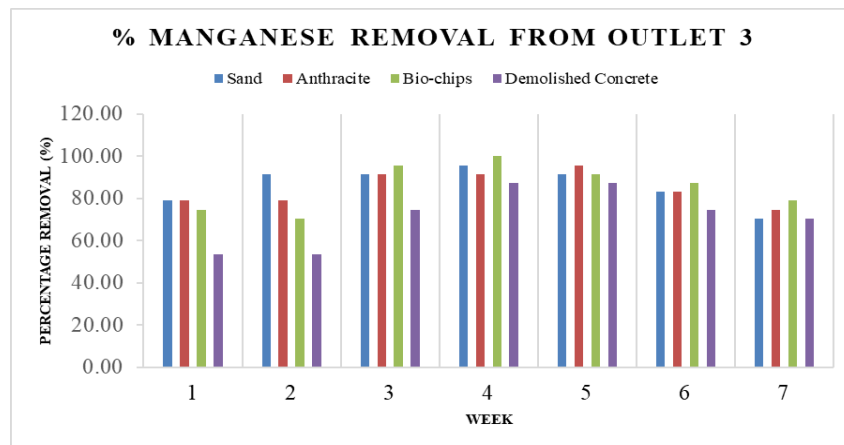


Figure 7. %Removal of Mn from Outlet 3 vs Weeks

### 3.2 Mn removal percentage for various depths of the filter bed of four columns

According to Figure 8-11, The removal of manganese escalated with depth, reaching its peak in week 4. Bio-chips attained 100% efficiency at 145 cm and maintained this performance until week 5, with a minor decline by week 7. Anthracite and sand reached around 96%, exhibiting initial fluctuations due to sludge. Crushed concrete attained 87%, which is below WHO criteria yet remains economically viable. The depth significantly influenced removal, but initial inconsistencies resulted from the behaviour of sludge and media.

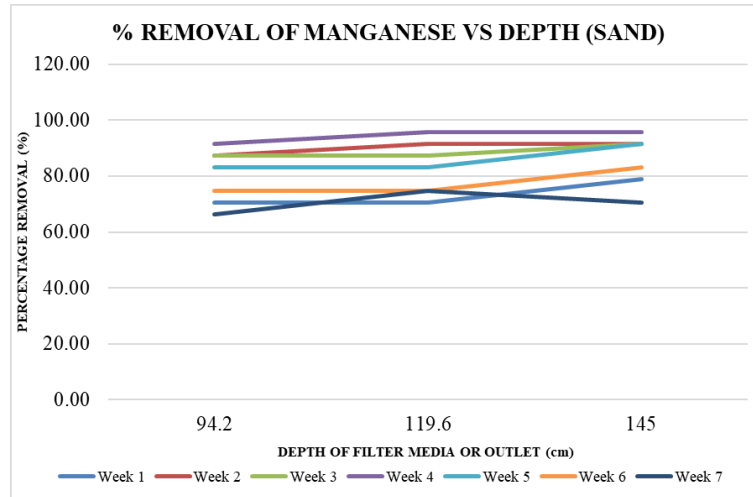


Figure 8. Mn Removal by Sand Column Depth

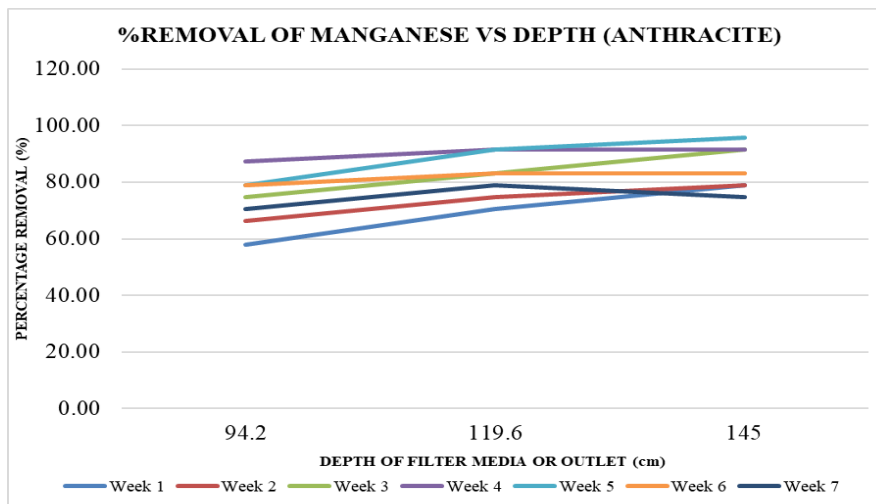


Figure 9. Mn Removal by Anthracite Column Depth

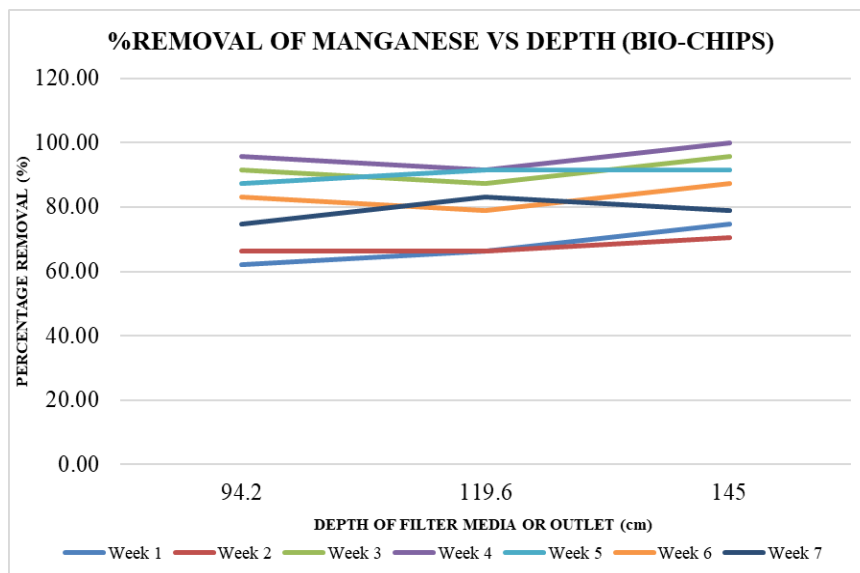


Figure 10. Mn Removal by Bio-Chips Column Depth

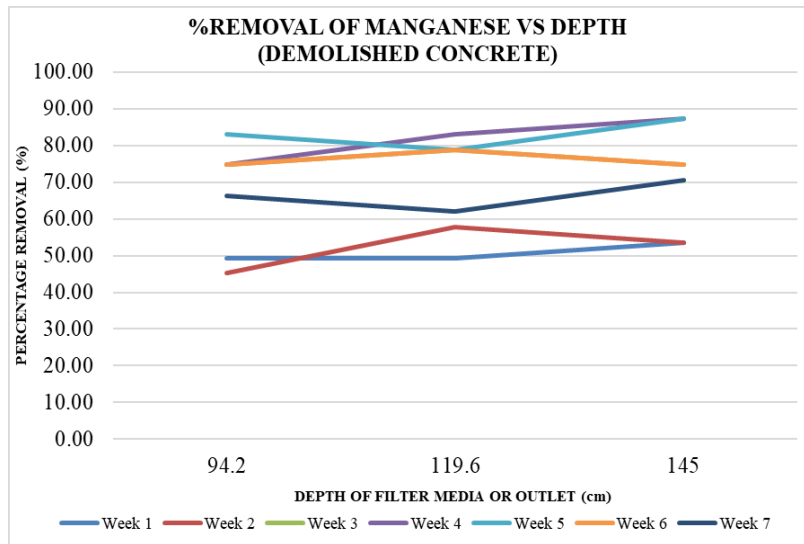


Figure 11. Mn Removal by Concrete Column Depth

### 3.3 Flow Rate Behaviour of the Filter Columns

According to Figure 12-15, Flow rates decreased across all mediums. Sand decreased from 48.54 to 14.69 L/day (Outlet 1) and from 56.3 to 21.46 L/day (Outlet 3). Anthracite experienced a decline in week 4 but subsequently recovered, registering a 10.8% decrease at Outlet 3 by week 7. Bio-chips maintained stability, ranging from 713.81 to 446.98 L/day. Demolished concrete decreased from 890.35 to 535.1 liters per day. Bio-chips exhibited optimal performance, while sand and anthracite required cleansing; demolished concrete performed the poorest.

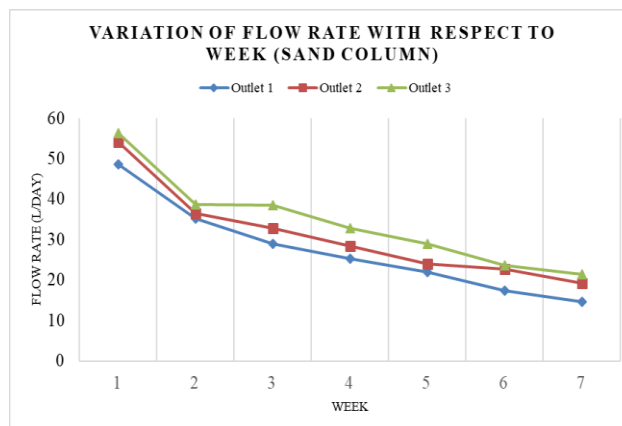


Figure 12. Flow rate of Sand Column vs Weeks

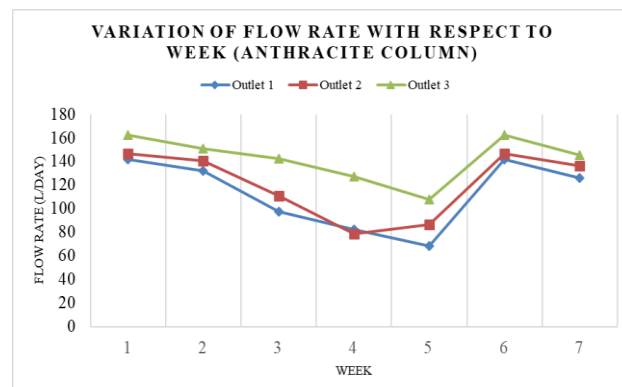


Figure 13. Flow rate of Anthracite Column vs Weeks

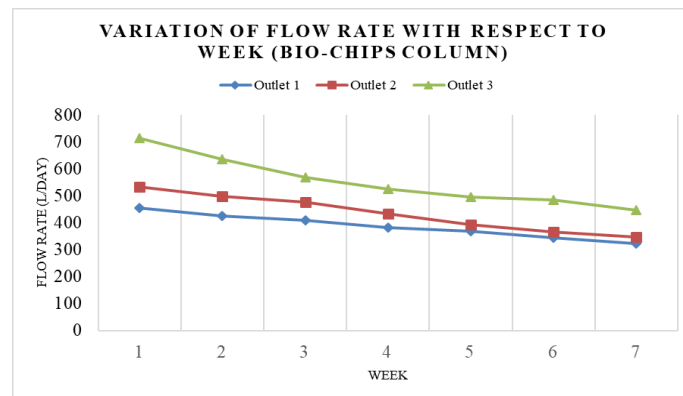


Figure 14. Flow rate of Bio-Chips Column vs Weeks

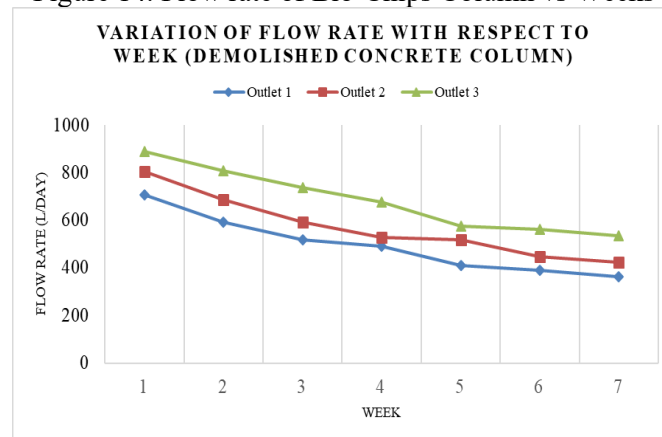


Figure 15. Flow rate of Concrete Column vs Weeks

### 3.4 Identification of Microbial Activity, Its Characteristics, and Role in Mn Removal

Microbial investigation revealed *Pseudomonas aeruginosa* as the predominant manganese-oxidizer in the bio-chip column, exhibiting robust growth (++++) in MN-C1 (scores 2.50 and 2.23) and characteristic morphology indicative of biofilm-mediated Mn oxidation (Xue et al., 2024; Ilamathi et al., 2019). The strain's mucoid phenotype and resilience to oxidative stress facilitated survival in metal-rich conditions (D. C. Nizer et al., 2021). Manganese oxide and redox metabolites such as pyocyanin facilitated the conversion of Mn(II) to Mn(IV), hence improving removal efficiency, particularly in bio-chips (Xue et al., 2024; C. Casalini et al., 2022). *P. aeruginosa* demonstrates significant promise for bioremediation and bioaugmented filtration, as shown in Figure 16.

Mn removal was the main focus; microplastics, pathogens, and other residuals were not analysed. Future studies should address these for safe domestic use. The anoxic system achieved 95.7%–100% Mn removal, outperforming earlier aerobic setups, showing that oxygen exclusion enhanced efficiency while reducing complexity and maintenance.



Figure 16. Identification of *Pseudomonas aeruginosa*

#### 4. CONCLUSIONS

The research indicated that manganese removal differed among filter media, with bio-chips achieving optimal performance (up to 100%), anthracite and sand approximately 96%, and crushed concrete below 90%. Increased filter depth enhanced removal efficiency across all media, with bio-chips attaining nearly total removal at the deepest outlet. Flow decreases impacted efficiency; sand and anthracite decreased after week four owing to clogging, whereas bio-chips sustained stable flow and high removal rates, and demolished concrete exhibited good permeability but inadequate treatment efficacy. *Pseudomonas aeruginosa* played a crucial role, as biofilm development and compounds such as pyocyanin facilitated manganese oxidation in anoxic.

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