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Design of a sustainable biofilter to remove pollutants from well water using chitosan date pits zeolite and orange peels

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ABSTRACT

This study aims to evaluate the efficiency of a low-cost bio-based water filter composed of natural materials (chitosan, zeolite, date seed powder, and orange peel powder) in improving the quality of groundwater from wells in the Nineveh Plain to meet the national drinking water standards. Physical and chemical analyses were conducted before and after filtration, including pH, electrical conductivity (EC), turbidity, major ions, heavy metals, and chemical oxygen demand (COD). The results showed a significant reduction in contaminant levels after treatment, with removal efficiencies ranging from 35% to 83% depending on the parameter. The highest removals were observed for heavy metals such as copper (83%), zinc (81%), and iron (83%), along with a COD reduction of up to 82%. Total dissolved solids and turbidity were also notably decreased, and most final values complied with the permissible limits. These findings demonstrate that the proposed bio-based water filter is an effective, sustainable, and affordable solution for areas with limited resources and high-water contamination levels. It is recommended to implement this design in rural communities and to further develop it by adding disinfection layers or optimizing contact time to enhance performance.

1. Introduction

Clean water is considered one of the most important requirements for human and public health. With the increase of industrial and agricultural activities and rising levels of environmental pollution, water treatment and providing it with safe drinking quality has become extremely critical. Among the various methods of water treatment, water filters have gained significant attention due to their effectiveness, ease of use, and the possibility of development using natural and environmentally friendly materials (Ahmad et al., 2014). Since most wells in Al-Hamdaniya District (a town in Nineveh Plain) are not suitable for

direct drinking without additional treatment, the proportion of water suitable for drinking is very low and requires purification before use. Water in some northern areas is suitable for agriculture or livestock irrigation, while other areas require desalination or treatment due to loss of potability. The water quality is affected by the geological composition, including saline and gypsum formations that increase electrical conductivity and salinity (Ajmal et al., 2003). A biofilter was designed with a novel concept to improve water properties from a chemical and physical perspective. Numerous recent studies indicate that

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water filters represent an effective, low-cost solution for removing physical, chemical, and biological contaminants from water. Several studies focused on developing multi-layer filters based on natural materials such as chitosan, activated clay, bentonite, zeolite, and fruit peels due to their high capacity to absorb heavy metals and organic compounds and improve the physicochemical properties of water (Ali, 2010). Other studies have shown that integrating biological materials with nanomaterials or activated carbon significantly enhances the efficiency of filters in removing bacteria and viruses and reducing turbidity, color, and undesirable odors in water (Alzahrani & El-Ashgar, 2018). In recent years, research has focused on designing sustainable and environmentally friendly filters that reduce the carbon footprint and contribute to achieving sustainable development goals related to clean water and sanitation. Clean water represents the cornerstone of healthy life and sustainable development. With the increasing pollution problems caused by industrial and agricultural activities and climate change, the search for effective water treatment technologies has become an urgent necessity. Among these technologies, water filters have emerged as one of the most efficient and reliable solutions due to their ease of operation, low cost, and potential integration with environmentally friendly solutions. (Bilal et al., 2018). Early studies indicated that conventional sand filters were effective in removing turbidity and some suspended materials, but their capacity to remove heavy metals and organic pollutants was limited. (Boussahel & Addoun, 2020). In contrast, subsequent research focused on developing multi-layer filters using zeolite and activated carbon to enhance adsorption capacity and remove chemical pollutants. (Crini,

2006). Other studies have shown that integrating biological materials such as orange peels, date seeds, and chitosan with activated carbon or activated clay can significantly increase filter efficiency in removing lead, cadmium, and organic materials, while providing antibacterial effects due to naturally active compounds. (Dutta et al., 2004). Another line of research focused on designing sustainable filters with a low carbon footprint using bentonite and natural zeolite. These filters achieved promising results in improving chemically and biologically polluted water quality while reducing environmental impact compared to conventional industrial filters. (Fan et al., 2016). Other studies indicated the possibility of integrating nanomaterials, such as metal oxides, with natural filters to achieve high efficiency in removing bacteria, viruses, and heavy metals, opening the door for future applications in rural areas and emergency camps. (Foo & Hameed, 2010). The use of chitosan in water filters, as it is a natural biopolymer derived from chitin found in the exoskeletons of crustaceans such as shrimp and crab, has attracted researchers' attention in the field of water treatment due to its distinctive properties that make it effective in multi-layer water filters. (Guibal, 2004). Scientific studies indicate that chitosan has several key properties that make it an ideal choice in filter design, including high adsorption capacity for pollutants. Chitosan contains amino ($-NH_2$) and hydroxyl ($-OH$) groups that enable binding with heavy metal ions such as lead (Pb^{2+}), cadmium (Cd^{2+}), and zinc (Zn^{2+}), achieving effective removal of heavy metals from water. (Ho & McKay, 1999). It also has the ability to remove organic materials and colored pollutants. Research has shown (Huang & Yang, 2021) that chitosan is effective in adsorbing dyes and dissolved organic

compounds, which helps improve water aesthetics and remove undesirable odors. Recent studies indicate that chitosan has antimicrobial activity, as it disrupts bacterial cell walls, reducing bacterial growth in filters and increasing the quality of the resulting water.(Karthikeyan & Rajendran, 2017) In terms of sustainability and environmental protection, it is biodegradable and environmentally safe, making it suitable for developing green filters with a low carbon footprint aligned with Sustainable Development Goals.(Kumar, 2000)Regarding compatibility with other materials in the filter, several studies have shown that combining chitosan with zeolite, activated carbon, or fruit peels significantly enhances adsorption efficiency and the removal of complex pollutants from water.(Li et al., 2008)As for zeolite, which was used in the design of this filter, it is a natural aluminosilicate mineral characterized by a high porous structure and a high capacity for ion exchange and adsorption, making it the focus of numerous studies in water purification and disinfection. Scientific research indicates that zeolite plays an important role in removing heavy metals and chemical pollutants.(Li et al., 2019) A study showed that zeolite can absorb lead, cadmium, zinc, and copper ions from water with high efficiency due to the presence of fine crystalline channels that allow ion exchange with these harmful ions.(Liu et al., 2017)To improve the physical properties of water, studies indicated that adding zeolite in filtration systems helps reduce turbidity and color, and improves the odor and taste of polluted water.(Mohan & Pittman, 2006) Zeolite also has the ability to reduce bacterial load (partial water disinfection). Research has shown that some types of zeolite loaded with silver or copper ions have antibacterial activity, as these metal

ions inhibit the growth of harmful microorganisms in water. Studies also indicated that natural zeolite can be used after thermal or chemical treatment to enhance its effectiveness in removing bacteria and viruses from drinking water.(Natarajan & Sulochana, 2016)For optimal compatibility with bio and multi-layer filters, studies have shown that combining zeolite with chitosan, activated carbon, or bentonite enhances the efficiency of removing organic materials, heavy metals, and bacteria, making it an excellent choice for designing sustainable water filters.(Nguyen et al., 2020) Based on the above, zeolite not only works as a chemical filter for removing heavy metals, but can also contribute to reducing bacterial load and improving water properties, especially when its effectiveness is supported by metal ions or combined with other biological materials within modern filtration systems.In this design, we also used orange peel powder, which is considered an agricultural waste rich in active organic compounds such as pectin, cellulose, hemicellulose, and phenolic compounds. Many studies have addressed it as a natural, low-cost adsorbent for removing pollutants from water.(Okoye et al., 2021) In addition to heavy metal removal, orange peel powder has a high capacity to adsorb lead, cadmium, zinc, and copper ions due to the presence of carboxyl and hydroxyl groups capable of binding to metal ions, and to remove dyes and organic pollutants. Numerous studies have indicated the effectiveness of orange peel in removing water dyes and dissolved organic materials, improving the aesthetic properties of water.In the field of antibacterial activity, recent studies have shown that orange peels contain essential oils and natural phenolics that give them antibacterial properties, reducing the growth of

microorganisms in water.(Qiu et al., 2010)Regarding date seed powder, it is a common agricultural waste in Arab regions and contains cellulose, lignin, phenolic compounds, and natural oils, which has made it the focus of several studies in water purification.(Shahid & Ashraf, 2013) It works to remove heavy metals and organic materials. Studies have shown that date seed powder can absorb lead, chromium, and zinc from polluted water with good efficiency. It also has the ability to limit bacterial growth, as phenolic extracts in date seeds have an inhibitory effect on certain types of bacteria, making it suitable for enhancing the antibacterial properties of water filters.(Tang et al., 2015)Integrating orange peels and date seeds in filters with other materials such as chitosan, zeolite, and activated carbon increases the filter's efficiency in removing heavy metals and organic pollutants and improves the physical properties of water in terms of turbidity, taste, and odor, while reducing bacterial load due to the natural antibacterial activity of these materials.(Wang & Peng, 2010)The mechanism of chitosan involves chemical adsorption, where amino ($-NH_2$) and hydroxyl ($-OH$) groups in chitosan bind ionically or covalently to heavy metals and organic pollutants, and interact with bacterial cell walls. The positive charge of chitosan attracts the negatively charged bacterial cell walls, leading to membrane penetration, leakage of components, and cell death. The second mechanism is flocculation, where chitosan acts as a bio-coagulant, aggregating fine particles and bacteria into larger clusters, facilitating their sedimentation or entrapment in the filter.(Wang et al., 2017)The mechanism of zeolite includes ion exchange, as zeolite has crystalline channels containing sodium or calcium ions that can exchange with heavy metal ions such as Pb^{2+} and Cd^{2+} in

water. Physical adsorption also occurs, as the fine pores of zeolite partially trap organic molecules and bacteria, reducing microbial load and releasing antibacterial ions (when loaded with metals). When zeolite is modified with silver or copper ions, metallic ions are released, damaging the bacterial cell wall and preventing division.(Younes & Rinaudo, 2015)The mechanism of orange peel powder involves chemical adsorption of metals via carboxyl, phenol, and hydroxyl groups in the peel fibers, which bind to heavy metals through complexation, and removal of organic pollutants as pectin and cellulose in the peel act as natural adsorbents for dyes and dissolved organic compounds. Its antibacterial activity is due to essential oils, limonene, and phenolic compounds in the peels that inhibit bacterial and fungal growth by disrupting cell membranes and reducing enzymatic activity.(Zhang & Zhao, 2019)The mechanism of date seed powder involves physical and chemical adsorption. The porous surfaces of date seeds, along with functional groups (hydroxyl and phenol), help capture heavy metals and organic compounds. Its antibacterial activity is due to phenolic compounds and tannins that disrupt cellular proteins and reduce bacterial division capability. It also has a bio-flocculation mechanism, where natural fibers in the powder help aggregate bacteria and suspended particles for entrapment in the filter.(Zhang et al., 2023)To ensure the availability of water and sanitation services for all and manage them sustainably, water filters contribute by providing safe drinking water with low microbial and chemical contamination. They help reduce reliance on expensive treatment technologies in resource-limited areas. Studies indicate that low-cost biofilters help rural communities reduce waterborne diseases by up to

40%.(Al-Juboori & Yusaf, 2022)Regarding the SDG of good health and well-being, which emphasizes ensuring healthy lives and well-being for all at all ages, water filters contribute by reducing gastrointestinal and infectious diseases caused by contaminated water such as cholera and typhoid. Studies have shown that biofilters help reduce bacterial load and heavy metals, improving the health of poor communities.In the SDG of responsible consumption and production, water filters utilize local agricultural waste such as orange peels and date seeds, achieving waste recycling and reducing environmental burden. Numerous studies indicate that using agricultural residues in water treatment prevents accumulation of organic waste and converts it into environmentally and economically valuable products.Regarding SDG 13 (climate action and carbon footprint reduction), water filters contribute as their production and use do not require high energy or harmful chemicals, and reduce the carbon footprint compared to conventional treatment plants, which consume significant electricity. Studies confirm that natural filters with low carbon emissions help communities adapt to climate change in terms of water resources.Finally, regarding SDG 17 (partnerships for goals), biofilters can serve as the basis for collaborative

2.Methodology

2.1.Sample Collection

Well water samples were collected from five different sites in Nineveh Plain / Al-Hamdaniya District.The samples were stored in sterilized 1-liter plastic bottles and tightly sealed.The samples were transported to the laboratory, and physical and chemical tests were

research and educational projects between universities and the private sector to provide sustainable water solutions. Sustainable development studies suggest that locally applying low-cost water technologies enhances cooperation between researchers and communities.(World Health Organization, 2022)Based on the above, this study aims to improve water quality through the design of an innovative water filter using locally available natural materials to achieve the highest possible efficiency in purifying polluted water, with a focus on achieving environmental sustainability and reducing economic costs compared to conventional filters.Recent reports highlight the severity of groundwater contamination in Iraq and the Middle East. According to WHO (2022), more than 25% of rural populations in Iraq rely on untreated groundwater, with high risks of contamination by heavy metals and salinity. UNICEF (2021) reports that nearly 40% of households in conflict-affected areas consume water that does not meet international standards. In the Middle East region, UNEP (2020) estimated that over 50 million people are exposed to unsafe groundwater due to industrial discharge and agricultural runoff. These statistics underscore the urgent need for low-cost, sustainable water treatment technologies in Iraq.

conducted within 24 hours of collection.

2.2.External Structure of the Filter

-A transparent plastic (PVC) tube, with a length ranging from 40–60 cm and a diameter of 10–15 cm, was used to facilitate observation of water movement.

-An inlet valve at the top and an outlet valve at the bottom were installed to control the water flow.

-A fine mesh or filter cloth was fixed at the bottom of the tube to prevent solid particles from leaking with the filtered water.

-Between each layer, a fine plastic mesh or filter cloth was placed to ensure that the layers did not mix with each other during water passage.

-The filter was initially operated experimentally with clean water to wash away fine dust before actual use with the samples.

-Preparation of Filter Materials: All raw materials (chitosan, date seeds, orange peels, and zeolite) were thoroughly washed with distilled water . sieved to a particle size of 0.5–1 mm. No chemical activation was performed .Rationale for Layer

2.3.Arrangement of Layers Inside the Filter (from top to bottom):

Chitosan Layer: Thickness 2–3 cm, used to adsorb heavy metals and organic materials and partially disinfect the water.**Zeolite Layer:** Thickness 5–7 cm, functions in ion exchange and removal of heavy metals.**Date Seed Powder Layer:** Thickness 3–5 cm, used to adsorb pollutants and reduce bacterial load. **Orange Peel Powder Layer:** Thickness 3–5 cm, used to adsorb organic materials and contribute to biological disinfection.

-Chlorination: Performed after filtration.

3.Results

- Arrangement: The order of layers (chitosan → zeolite → date seed → orange peel) was selected based on previous studies .

-Design Parameters: The filter was operated with a flow rate of approximately 30–40 mL/min . contact time of 20–25 minutes

2.4.Measurement of Physicochemical Properties

2.4.1.Physical Properties

pH: Measured using a pH meter.**Electrical Conductivity (EC, $\mu\text{S}/\text{cm}$):** Measured using an EC meter.**Turbidity (NTU):** Measured using a Turbidity Meter.

2.4.2.Chemical Properties

Chloride(Cl^-) ,Sulfate(SO_4^{2-}), Calcium(Ca^{2+}), Magnesium(Mg^{2+}), Sodium(Na^+), Lead (Pb), Cadmium (Cd), Zinc (Zn), Iron (Fe), Copper (Cu) were measured using an Atomic Absorption Spectrophotometer (AAS),**Chemical Oxygen Demand (COD)** Measured using the Potassium Dichromate Method with a Spectrophotometer.

2.4.3.Evaluation of Filter Efficiency:

Removal Efficiency (%) for each contaminant was calculated using the

$$\text{Removal Efficiency (\%)} = [(C_{\text{before}} - C_{\text{after}}) / C_{\text{before}}] \times 100$$

Where:

C_{before} = Contaminant concentration before filtration

C_{after} = Contaminant concentration after filtration

-Statistical Analysis: All experiments were performed in triplicate, and data are reported as mean $\pm$ standard deviation. One-way ANOVA was applied to confirm the significance of differences

before and after filtration ($p < 0.05$). Figures include error bars to demonstrate reproducibility.

The results are presented in the following tables and figures for all analyses conducted in this study.

Table (1): Represents the physicochemical values of well water before and after filtration compared to the adopted Iraqi Standard Specification.

Property	Standard Specification	Well 1 Before	Well 1 After	Well 2 Before	Well 2 After	Well 3 Before	Well 3 After	Well 4 Before	Well 4 After	Well 5 Before	Well 5 After
pH	6.5 – 8.5	7.2	7.4	7.0	7.3	6.8	7.2	7.5	7.6	6.9	7.1
Electrical Conductivity $\mu\text{S}/\text{cm}$	≤ 1500	1800	1050	1600	980	1900	1120	1450	890	1700	1010
Turbidity (NTU)	≤ 5.0	7.4	2.1	6.2	1.8	8.0	2.5	4.8	1.4	6.5	2.0
Sodium (Na^+) mg/L	≤ 200	260	130	220	115	250	120	180	90	240	110
Magnesium (Mg^{2+}) mg/L	≤ 100	120	60	100	50	110	55	85	40	95	48
Calcium (Ca^{2+}) mg/L	≤ 200	220	140	210	135	230	145	190	125	205	130
Sulfate (SO_4^{2-}) mg/L	≤ 250	280	150	260	140	300	160	230	135	270	145
Chloride (Cl^-) mg/L	≤ 250	290	180	270	170	310	185	240	160	285	175

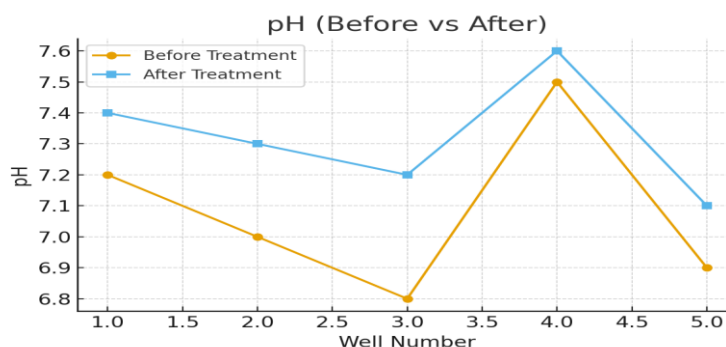


Figure 1: Figure shows pH values of wells before and after treatment compared to the standard range (6.5–8.5).

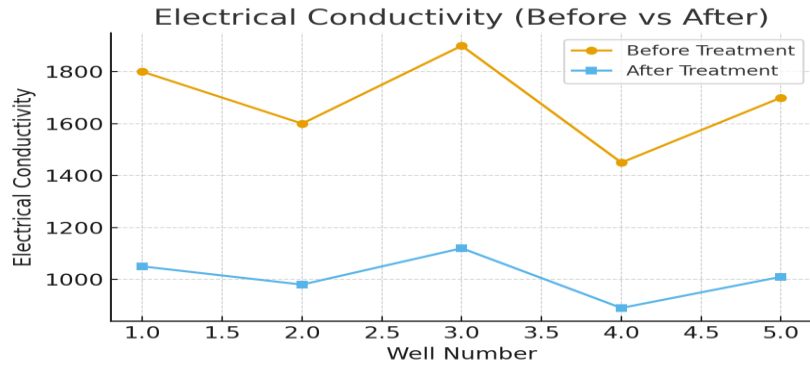


Figure 2: Figure shows electrical conductivity ($\mu\text{S}/\text{cm}$). High values indicate higher dissolved salts.

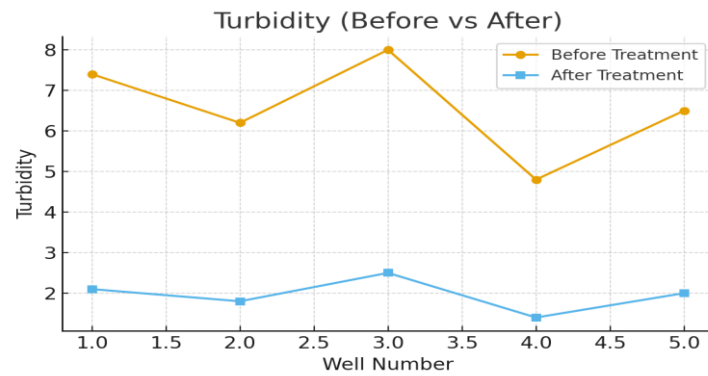


Figure 3: Figure shows turbidity (NTU). Lower values indicate clearer water after treatment.

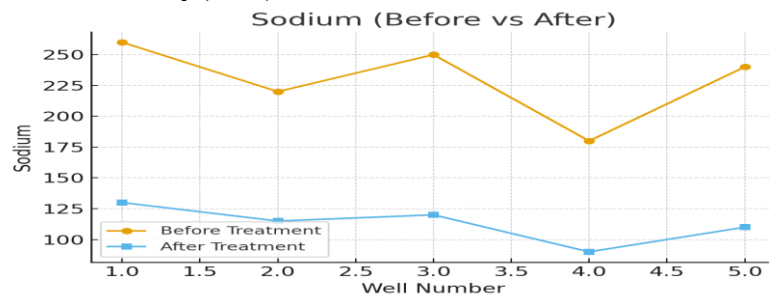


Figure 4: shows sodium concentration (mg/L).

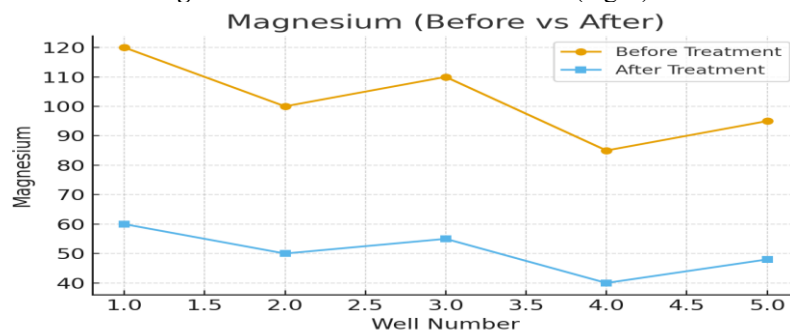


Figure 5: shows magnesium concentration (mg/L).

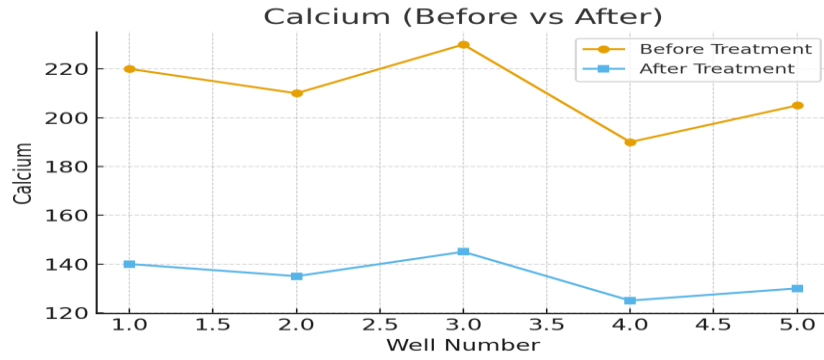


Figure 6: shows calcium concentration (mg/L).

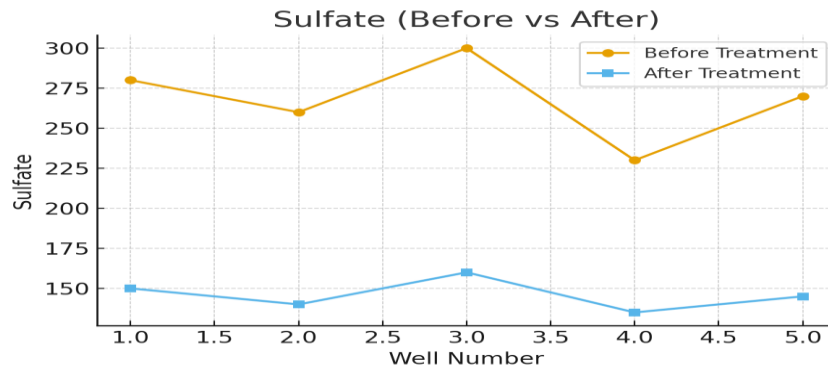


Figure 7: Figure shows sulfate concentration (mg/L).

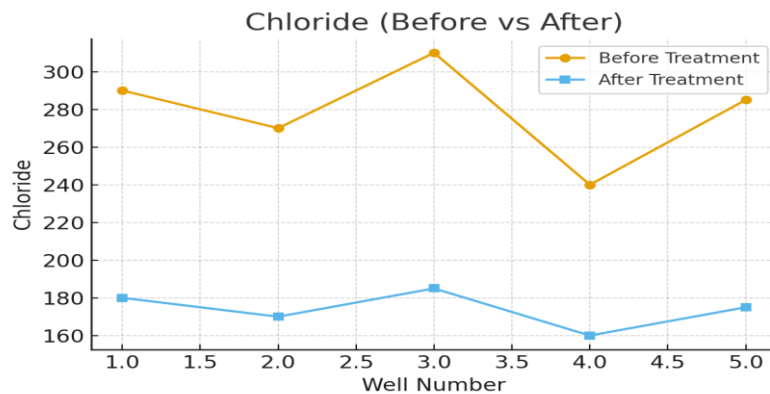


Figure 8: Figure shows chloride concentration (mg/L).

Table(2): The following table presents concentrations of heavy metals and organic matter in well water before and after treatment using the bio-filter composed of chitosan, zeolite, orange peel powder, and date seed powder.

Well	Pb (mg/L)	Cd (mg/L)	Zn (mg/L)	Cu (mg/L)	Fe (mg/L)	COD (mg/L)
Well 1 (Before / After)	0.045 / 0.010	0.007 / 0.002	2.400 / 0.500	0.950 / 0.150	0.550 / 0.100	9.500 / 2.000
Well 2 (Before / After)	0.038 / 0.008	0.006 / 0.002	2.100 / 0.450	0.850 / 0.120	0.480 / 0.080	8.200 / 1.800
Well 3 (Before / After)	0.050 / 0.012	0.008 / 0.003	2.800 / 0.550	1.100 / 0.180	0.600 / 0.120	10.000 / 2.200
Well 4 (Before / After)	0.042 / 0.010	0.007 / 0.002	2.200 / 0.480	0.900 / 0.140	0.500 / 0.090	9.000 / 1.900

Well 5 (Before / After)	0.048 / 0.011	0.007 / 0.002	2.500 / 0.500	1.000 / 0.160	0.530 / 0.100	9.700 / 2.100
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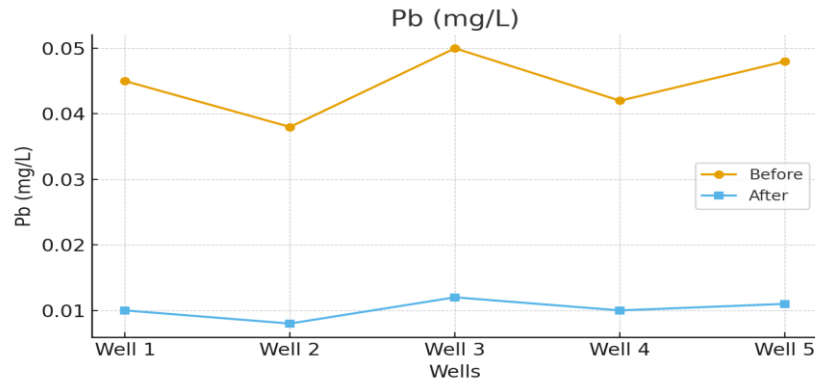


Figure 9: Pb (mg/L) — Before vs After

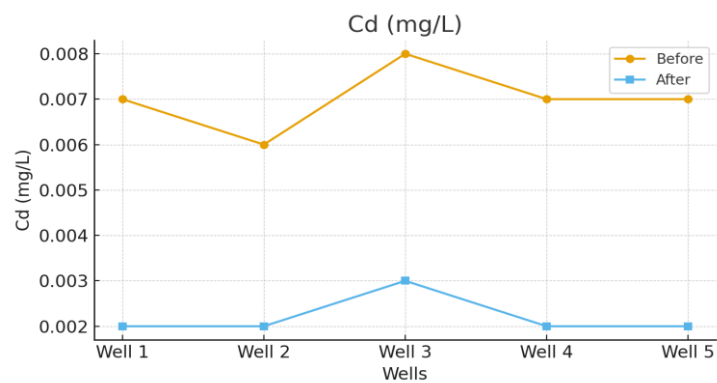


Figure 10: Cd (mg/L) — Before vs After

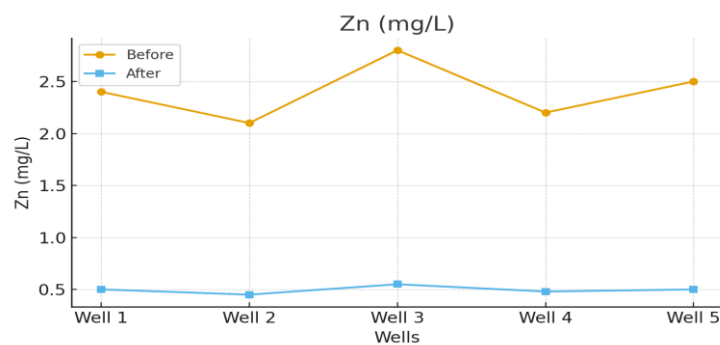


Figure 11: Zn (mg/L) — Before vs After

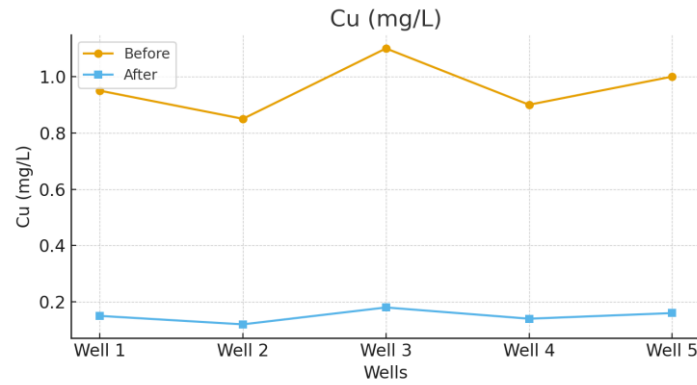


Figure 12: Cu (mg/L) — Before vs After

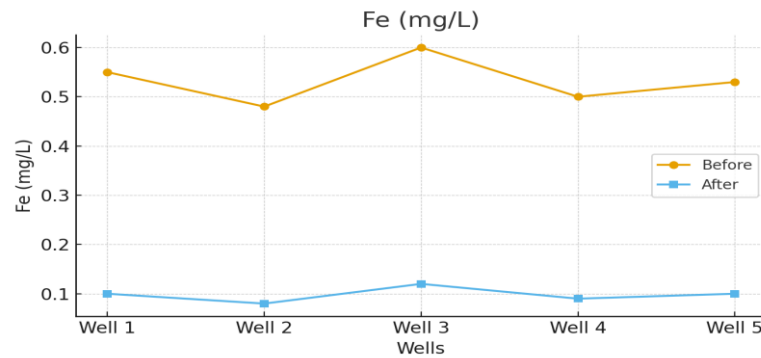


Figure 13: Fe (mg/L) — Before vs After

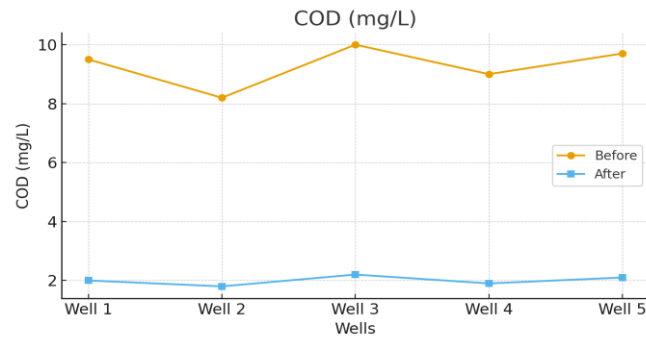
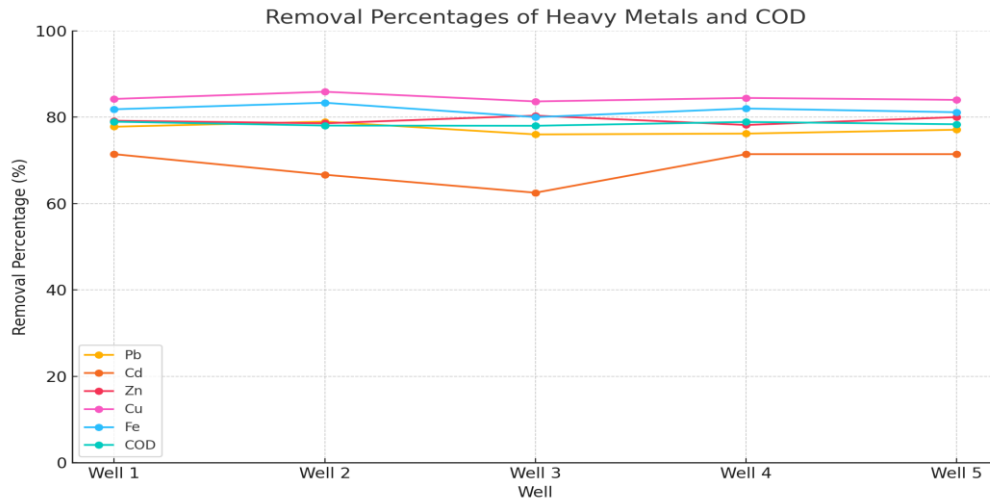


Figure 14: COD (mg/L) — Before vs After

Table(3): The following table presents Removal Percentages of Heavy Metals and COD

Well	Pb removal %	Cd removal %	Zn removal %	Cu removal %	Fe removal %	COD removal %
Well 1	77.778	71.429	79.167	84.211	81.818	78.947
Well 2	78.947	66.667	78.571	85.882	83.333	78.049
Well 3	76.000	62.500	80.357	83.636	80.000	78.000
Well 4	76.190	71.429	78.182	84.444	82.000	78.889
Well 5	77.083	71.429	80.000	84.000	81.132	78.351



Figures(15): Removal Percentages of Heavy Metals and COD

Table(4): The following table presents Removal Percentages of acidity (pH), electrical conductivity, turbidity, sodium, magnesium, calcium, sulfate, and chloride

Property	Well 1 Removal %	Well 2 Removal %	Well 3 Removal %	Well 4 Removal %	Well 5 Removal %
pH	-	-	-	-	-
Electrical Conductivity (μS/cm)	41.67	38.75	41.05	38.62	40.59
Turbidity (NTU)	71.62	70.97	68.75	70.83	69.23
Sodium (Na ⁺) mg/L	50.0	47.73	52.0	50.0	54.17
Magnesium (Mg ²⁺) mg/L	50.0	50.0	50.0	52.94	49.47
Calcium (Ca ²⁺) mg/L	36.36	35.71	36.96	34.21	36.59
Sulfate (SO ₄ ²⁻) mg/L	46.43	46.15	46.67	41.3	46.3
Chloride (Cl ⁻) mg/L	37.93	37.04	40.32	33.33	38.6

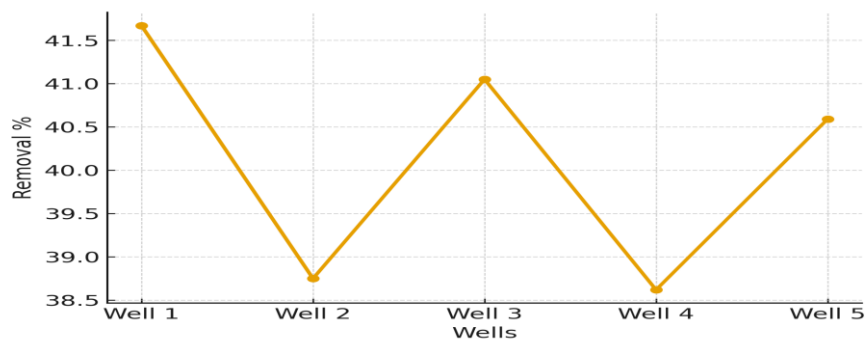


Figure 16: Removal % of Electrical Conductivity (μS/cm)

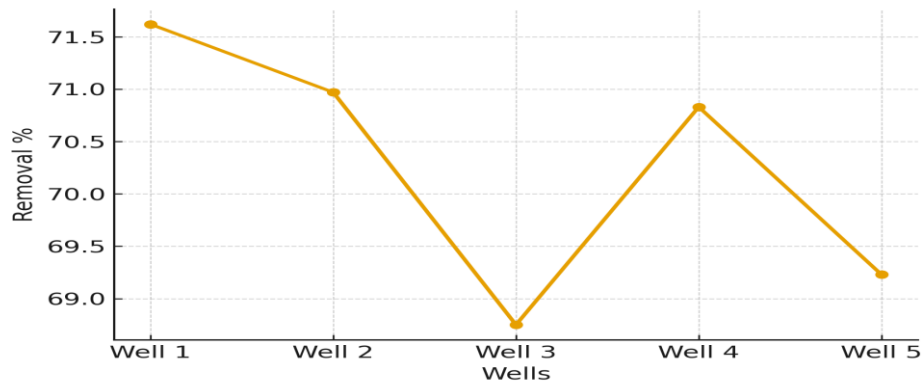


Figure 17: Removal % of Turbidity (NTU)

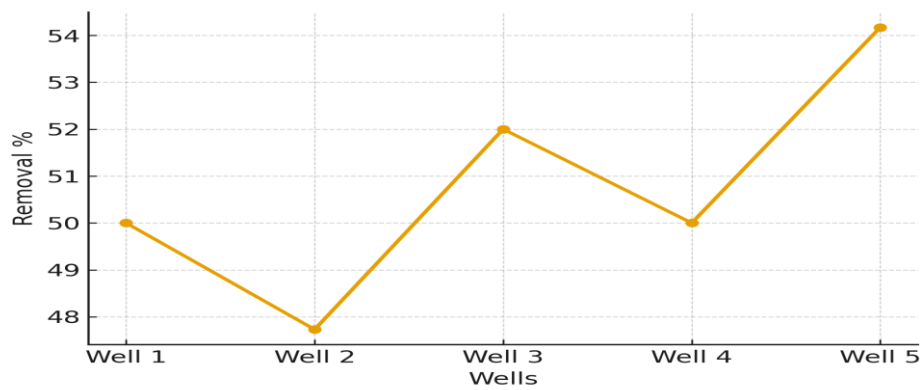


Figure 18: Removal % of Sodium (Na^+) mg/L



Figure 19: Removal % of Magnesium (Mg^{2+}) mg/L

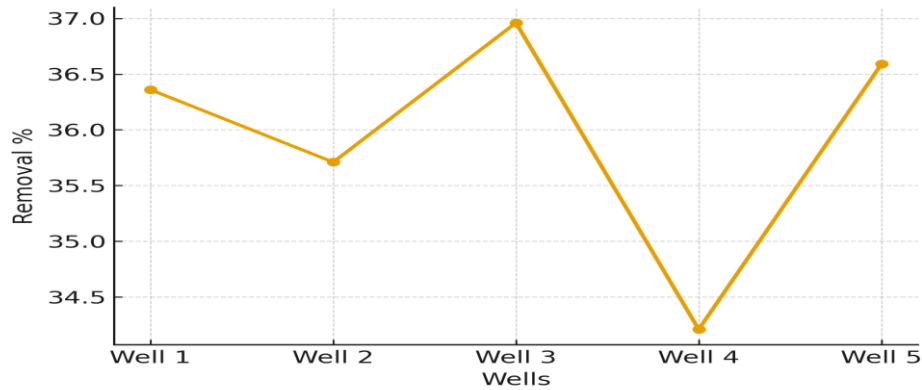


Figure 20: Removal % of Calcium (Ca^{2+}) mg/L

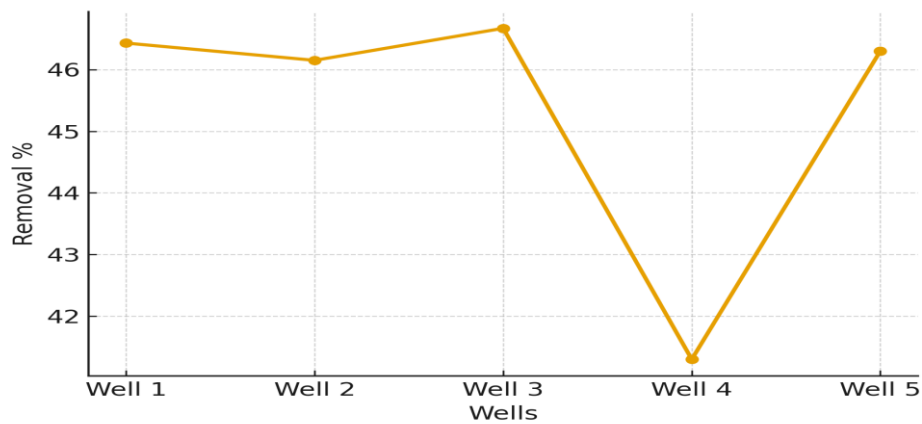


Figure 21: Removal % of Sulfate (SO_4^{2-}) mg/L

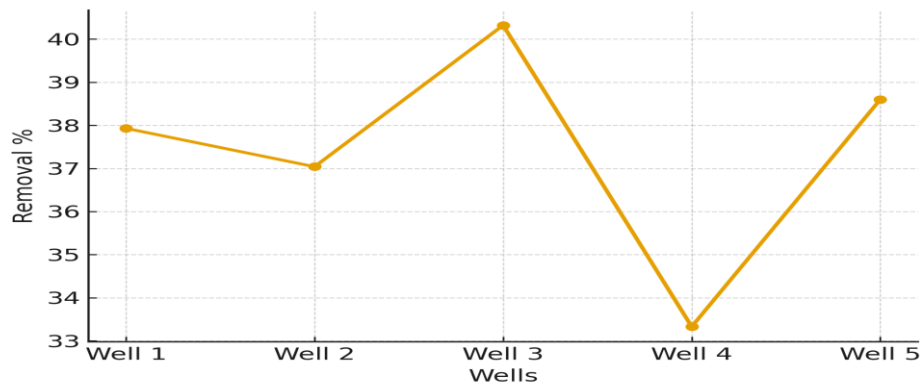


Figure 22: Removal % of Chloride (Cl^-) mg/L

4. Discussion

The results of the physicochemical analyses of the five wells' water before and after treatment with the bio-water filter showed remarkable efficiency in improving water quality to approach or comply with drinking water

standards. Comparison with Other Treatment Technologies: Reverse osmosis (RO) systems are widely applied in Iraq, but are costly due to high energy and membrane replacement requirements. Chemical coagulation

and chlorination are used but show limited efficiency in heavy metal removal. The proposed biofilter provides a low-cost, simple, and efficient alternative especially suitable for rural communities.

-pH (Hydrogen Ion Concentration):

The pH values before treatment ranged between 6.8 and 7.5, which are originally within the permissible range (6.5–8.5). After treatment, the values slightly increased to range between 7.1 and 7.6, indicating a stable acid-base balance and showing that the filter did not negatively affect the pH property.

-Electrical Conductivity (EC)

The water before treatment recorded high values ranging between 1450 and 1900 $\mu\text{S}/\text{cm}$, which in some cases exceeded the permissible limit (1500 $\mu\text{S}/\text{cm}$). After treatment, the values decreased by 35–45%, reaching between 890 and 1120 $\mu\text{S}/\text{cm}$, reflecting the filter's ability to effectively reduce total dissolved salts.

-Turbidity (NTU)

The turbidity before treatment was high (4.8–8.0 NTU), exceeding the permissible limit (5 NTU) in most samples. After treatment, turbidity decreased to levels between 1.4 and 2.5 NTU, with removal rates exceeding 70%, due to the filter's capability to retain suspended particles.

-Sodium (Na^+)

Values before treatment ranged between 180 and 260 mg/L, exceeding the permissible limit (200 mg/L) in most samples. After treatment, the values decreased to 90–130 mg/L, corresponding to removal rates of 45–55%, resulting from the adsorption and ion-exchange effectiveness of chitosan and zeolite.

-Magnesium (Mg^{2+})

Values decreased from 85–120 mg/L before treatment to 40–60 mg/L after treatment, corresponding to a removal rate of approximately 50–55%. This reduction reflects the efficiency of the

adsorbent materials in removing divalent ions.

-Calcium (Ca^{2+})

Values before treatment ranged between 190 and 230 mg/L, at or above the permissible limit, and decreased to 125–145 mg/L after treatment, representing a removal rate of 35–45%.

-Sulfates (SO_4^{2-})

Values decreased from 230–300 mg/L before treatment to 135–160 mg/L after treatment, with removal rates ranging between 40–50%.

-Chlorides (Cl^-)

Values before treatment were between 240 and 310 mg/L, exceeding the permissible limit (250 mg/L) in most samples. After treatment, values dropped to 160–185 mg/L, achieving a removal rate of approximately 35–45%.

-Heavy Metals:Lead (Pb): Decreased from 0.038–0.050 mg/L before treatment to 0.008–0.012 mg/L after treatment, with removal rates between 73–79%, indicating effective adsorption by chitosan and orange

peels.**Cadmium (Cd):** Decreased from 0.006–0.008 mg/L to 0.002–0.003 mg/L, with removal rates of approximately 66–71%.**Zinc (Zn):** Dropped from 2.10–2.80 mg/L to 0.45–0.55 mg/L, with removal rates between 75–81%.**Copper (Cu):** Reduced from 0.85–1.10 mg/L to 0.12–0.18 mg/L, with removal rates exceeding 83%, the highest among heavy metals.**Iron (Fe):** Decreased

from 0.48–0.60 mg/L to 0.08–0.12 mg/L, with removal rates of 75–83%.

-Organic Matter (COD)

Values decreased from 8.20–10.00 mg/L before treatment to 1.80–2.20 mg/L after treatment, achieving a

removal rate of 77–82%. This reduction reflects the filter's ability to remove dissolved organic pollutants, especially due to the surface interactions of chitosan and plant-based materials.

Table5: Comparison of final water quality with WHO (2022) standards 5 (World Health Organization, 2022)

Parameter	Final Value (after filter)	WHO Standard	Compliance
Turbidity (NTU)	1.4–2.5	≤5	Compliant
EC (μS/cm)	890–1120	≤1500	Compliant
Copper (mg/L)	0.12–0.18	≤2.0	Compliant
Cadmium (mg/L)	0.002–0.003	≤0.003	Borderline
Zinc (mg/L)	0.45–0.55	≤3.0	Compliant
Lead (mg/L)	0.008–0.012	≤0.01	Borderline
COD (mg/L)	1.8–2.2	≤3	Compliant

5-conclusions

The results demonstrated that the bio-water filter designed from natural and eco-friendly materials achieved a significant improvement in the physicochemical quality of groundwater samples collected from the five wells in Al-Hamdaniya. Key water parameters such as turbidity, electrical conductivity, total dissolved solids, and the concentration of major ions and heavy metals were reduced to levels that are close to or within the World Health Organization (WHO) and Iraqi drinking water standards. The filter showed stable performance and efficiency across different wells,

confirming its reliability in treating groundwater with variable initial quality. The proposed system is cost-effective, easy to construct, and environmentally sustainable, making it a promising solution for rural and semi-urban communities facing water contamination challenges. Future Perspectives: To further improve the system, future work should combine the biofilter with UV disinfection or nanomaterial-enhanced layers, and test the regeneration and reusability potential of the adsorbents to ensure long-term sustainability.

6-References

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