



EVALUATION OF CONVENTIONAL, ACTIVATED CARBON, REVERSE OSMOSIS, UV AND BIOSAND WATER TREATMENT METHODS BASED ON PHYSICOCHEMICAL WATER QUALITY PARAMETERS

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Abstract

The effectiveness of different water treatment methods was evaluated by comparing their ability to reduce major physicochemical water-quality parameters. Five treatment methods—conventional treatment (M1), activated carbon filtration (M2), reverse osmosis (M3), ultraviolet treatment (M4), and biosand filtration (M5)—were assessed using turbidity, electrical conductivity (EC), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total hardness, alkalinity, chloride, sulphate, nitrate, fluoride and iron. Treatment performance was expressed as the mean concentration after treatment and percentage removal relative to the corresponding untreated water. Among the five methods, reverse osmosis demonstrated the highest overall treatment efficiency, with a mean removal of 87.89%. It achieved particularly high removal of turbidity (91.85%), EC (88.67%), TDS (88.01%), BOD (80.30%), COD (77.99%), total hardness (90.50%), alkalinity (81.56%), chloride (89.02%), sulphate (89.67%), nitrate (88.04%), fluoride (89.06%) and iron (89.88%). Conventional treatment showed an overall mean removal of 33.71%, while activated carbon, biosand and UV showed mean removals of 33.55%, 29.86% and 12.46%, respectively. The results indicate that RO was the most effective treatment for simultaneous reduction of dissolved and particulate contaminants in the investigated water, whereas UV showed limited effects on physicochemical parameters, as expected for a primarily disinfection-oriented process. Activated carbon and biosand filtration demonstrated intermediate performance and may be particularly useful as components of treatment trains rather than as universal stand-alone processes. The findings emphasize the importance of selecting water-treatment technologies according to the specific contaminant profile and treatment objective.

Keywords: Water treatment, reverse osmosis, activated carbon, biosand filter, UV treatment, conventional treatment, water quality, contaminant removal, physicochemical parameters.

1. Introduction

Access to safe and acceptable-quality water is essential for public health, domestic use and sustainable development. Raw water may contain suspended particles, dissolved salts, organic matter, nutrients, hardness-forming ions and trace metals. The concentration and composition of these contaminants vary



according to source characteristics, land use, domestic discharge, agricultural activities, industrial inputs and seasonal conditions.

Water-treatment technologies differ substantially in their mechanisms and contaminant-removal capabilities. Conventional treatment generally involves processes such as coagulation, flocculation, sedimentation and filtration and is particularly useful for reducing suspended and particulate matter. Activated carbon treatment operates primarily through adsorption and can improve water quality by reducing several organic contaminants, colour and taste- and odour-producing compounds. Biosand filtration combines physical filtration with biological processes and can substantially improve turbidity and microbiological quality. WHO notes that biosand filters can consistently reduce turbidity, although additional disinfection may be desirable because of possible post-treatment contamination. The selection of an appropriate treatment process therefore requires evaluation of both the quality of the raw water and the treatment objectives. WHO's treatment-performance guidance emphasizes that treatment processes should be selected according to their ability to address particular contaminants and water-quality requirements.

In the present paper comparison of five treatment approaches—conventional treatment, activated carbon, reverse osmosis, UV and biosand filtration—using a common set of physicochemical water-quality parameters. The objective was to determine the relative removal efficiency of each method and identify the treatment technology providing the greatest overall improvement in the investigated water quality.

2. Objectives

The study was undertaken with the following objectives:

1. To evaluate the effectiveness of five water-treatment methods using physicochemical water-quality parameters.
2. To compare the removal efficiency of conventional, activated carbon, RO, UV and biosand treatment.
3. To determine the most effective treatment method based on mean percentage removal.
4. To assess the individual treatment performance for turbidity, EC, TDS, BOD, COD, hardness, alkalinity, chloride, sulphate, nitrate, fluoride and iron.
5. To identify treatment methods that may be suitable for targeted contaminant removal or integrated treatment systems.

3. Materials and Methods

3.1 Study design

The investigation was designed as a comparative treatment-performance study. Water was subjected to five different treatment methods:

- **M1 – Conventional treatment**



- **M2 – Activated carbon**
- **M3 – Reverse osmosis**
- **M4 – UV treatment**
- **M5 – Biosand filtration**

3.2 Treatment methods

M1 – Conventional treatment

Conventional treatment represents a treatment train based on physical and physicochemical processes such as coagulation, flocculation, sedimentation and filtration. Such processes are commonly used to reduce suspended solids and turbidity and can also reduce a proportion of organic matter and associated contaminants.

M2 – Activated carbon treatment

Activated carbon was considered as an adsorption-based treatment. Its high surface area allows adsorption of several dissolved organic compounds and other contaminants. Activated carbon can complement other treatment processes and is commonly incorporated into treatment trains.

M3 – Reverse osmosis

RO treatment uses pressure to force water through a semipermeable membrane. The membrane retains a substantial fraction of dissolved substances while producing a lower-solute permeate. RO is therefore particularly suitable when reduction of dissolved salts, hardness and other inorganic constituents is required.

M4 – UV treatment

UV treatment was evaluated as a disinfection-oriented process. Its principal function is microbial inactivation rather than removal of dissolved minerals. Therefore, relatively small changes in EC, TDS, hardness and major ions would be expected.

M5 – Biosand filtration

Biosand filtration combines physical filtration and biological activity within a sand-filter medium. WHO reports that biosand filters can consistently reduce turbidity and may contribute to improved microbiological quality, while safe storage and/or supplementary disinfection may remain important.

3.3 Water-quality parameters

The following parameters were considered:

- Turbidity (NTU)
- Electrical conductivity ($\mu\text{S}/\text{cm}$)
- Total dissolved solids (mg/L)
- Biochemical oxygen demand (mg/L)
- Chemical oxygen demand (mg/L)



- Total hardness (mg/L)
- Alkalinity (mg/L)
- Chloride (mg/L)
- Sulphate (mg/L)
- Nitrate (mg/L)
- Fluoride (mg/L)
- Iron (mg/L)

3.4 Calculation of removal efficiency

Removal efficiency was calculated using the standard expression:

$$\text{Removal Efficiency (\%)} = \{(C_i - C_f) / C_i\} \times 100$$

where:

- (C_i) = concentration before treatment
- (C_f) = concentration after treatment.

The overall mean removal reported in the dataset was used to compare the five treatment methods.

4. Results

4.1 Overall treatment performance

Table 1: The overall mean removal efficiencies were:

Treatment	Mean Removal (%)	Overall Rank
M3 – Reverse Osmosis	87.89	1
M1 – Conventional	33.71	2
M2 – Activated Carbon	33.55	3
M5 – Biosand	29.86	4
M4 – UV	12.46	5

The results clearly demonstrate the superior overall performance of RO. Its mean removal efficiency of 87.89% was substantially higher than that of conventional treatment (33.71%), activated carbon (33.55%), biosand filtration (29.86%) and UV treatment (12.46%).

4.2 Comparative physicochemical results

Table 2: Mean concentration after treatment

Parameter	M1 Conventional	M2 Activated Carbon	M3 RO	M4 UV	M5 Biosand
Turbidity (NTU)	3.07	4.23	1.15	10.51	2.01
EC (µS/cm)	650.46	634.96	80.00	690.21	670.78
TDS (mg/L)	470.10	460.44	60.00	490.29	481.10



BOD (mg/L)	2.46	1.93	1.08	4.84	3.17
COD (mg/L)	16.80	10.37	7.07	28.84	19.96
Total hardness (mg/L)	251.41	282.41	29.05	300.10	275.39
Alkalinity (mg/L)	190.94	206.53	40.11	215.09	204.55
Chloride (mg/L)	125.94	120.78	14.43	130.03	127.29
Sulphate (mg/L)	95.60	97.91	11.24	107.52	100.08
Nitrate (mg/L)	22.46	21.90	2.99	24.73	22.02
Fluoride (mg/L)	0.89	0.87	0.10	0.94	0.92
Iron (mg/L)	0.11	0.17	0.06	0.60	0.16

RO produced the lowest post-treatment concentration for **all 12 measured parameters** in the supplied dataset.

4.3 Percentage removal efficiency

Table 3: Percentage removal achieved by each treatment

Parameter	M1 Conventional	M2 Activated Carbon	M3 RO	M4 UV	M5 Biosand
Turbidity	78.19	70.00	91.85	25.40	85.76
EC	7.85	10.05	88.67	2.22	4.98
TDS	6.07	8.00	88.01	2.04	3.87
BOD	55.00	64.67	80.30	11.66	42.01
COD	47.73	67.74	77.99	10.27	37.88
Total hardness	17.81	7.68	90.50	1.90	9.97
Alkalinity	12.19	5.02	81.56	1.09	5.93
Chloride	4.14	8.06	89.02	1.02	3.11
Sulphate	12.13	10.00	89.67	1.17	8.01
Nitrate	10.27	12.52	88.04	1.21	12.00
Fluoride	5.43	8.18	89.06	0.93	2.93
Iron	81.95	72.20	89.88	3.55	74.69
Mean removal	33.71	33.55	87.89	12.46	29.86

5. Parameter-wise Interpretation

5.1 Turbidity: The removal of turbidity was highest with RO (91.85%), followed by biosand filtration (85.76%), conventional treatment (78.19%) and activated carbon (70.00%). UV treatment showed only 25.40% removal. The strong performance of conventional and biosand treatment is consistent with their filtration-based mechanisms. Biosand filtration is specifically recognized for its ability to reduce turbidity.



The post-treatment turbidity values were 3.07 NTU for M1, 4.23 NTU for M2, 1.15 NTU for M3, 10.51 NTU for M4 and 2.01 NTU for M5.

5.2 Electrical conductivity: RO demonstrated an exceptionally high EC removal of 88.67%, reducing the mean EC to 80.00 $\mu\text{S}/\text{cm}$. In contrast, conventional, activated carbon, UV and biosand treatment produced only 7.85%, 10.05%, 2.22% and 4.98% removal, respectively. This result is expected because EC reflects the concentration of dissolved ionic substances, whereas RO is specifically designed to separate dissolved constituents through a semipermeable membrane.

5.3 Total dissolved solids: TDS removal followed a pattern similar to EC. RO achieved 88.01% removal, compared with 8.00% for activated carbon, 6.07% for conventional treatment, 3.87% for biosand and 2.04% for UV. The post-treatment TDS concentration after RO was only 60.00 mg/L. This provides strong evidence that RO was particularly effective in reducing dissolved mineral content.

5.4 BOD: BOD removal was highest for RO (80.30%), followed by activated carbon (64.67%), conventional treatment (55.00%) and biosand filtration (42.01%). UV achieved only 11.66%. The results indicate that RO and activated carbon provided stronger reduction in the organic-load indicator than the other treatments in this dataset.

5.5 COD: COD removal was 77.99% for RO and 67.74% for activated carbon. Conventional treatment achieved 47.73%, biosand 37.88% and UV 10.27%. The comparatively high performance of activated carbon is consistent with its adsorption-based mechanism, while RO provides broad removal of dissolved constituents.

5.6 Total hardness: RO was clearly the most effective treatment for hardness, achieving 90.50% removal and reducing the mean concentration to 29.05 mg/L. The remaining treatments showed considerably lower removal: Conventional: 17.81%, Activated carbon: 7.68%, UV: 1.90%, Biosand: 9.97%. The strong RO performance is consistent with the ability of membrane processes to remove dissolved ions contributing to hardness. EPA describes RO as useful for a broad range of dissolved inorganic contaminants.

5.7 Alkalinity: RO achieved 81.56% removal of alkalinity, considerably exceeding conventional treatment (12.19%), biosand (5.93%), activated carbon (5.02%) and UV (1.09%). The reduction in alkalinity further demonstrates the ability of RO to reduce dissolved ionic constituents.

5.8 Chloride: RO removed 89.02% of chloride, reducing the post-treatment concentration to 14.43 mg/L. Activated carbon achieved 8.06%, conventional treatment 4.14%, biosand 3.11% and UV only 1.02%. The result demonstrates the substantially different mechanisms of membrane separation compared with adsorption, filtration and UV disinfection.

5.9 Sulphate: The highest sulphate removal was observed with RO (89.67%), while conventional treatment, activated carbon, biosand and UV achieved 12.13%, 10.00%, 8.01% and 1.17%, respectively. The post-RO sulphate concentration was 11.24 mg/L.



5.10 Nitrate: RO achieved 88.04% nitrate removal. The remaining treatments achieved substantially lower removal: Activated carbon: 12.52%, Biosand: 12.00%, Conventional: 10.27%, UV: 1.21%. The result demonstrates the importance of selecting a treatment technology specifically capable of reducing dissolved nitrate when nitrate is a water-quality concern.

5.11 Fluoride: RO achieved 89.06% fluoride removal, reducing the mean fluoride concentration to 0.10 mg/L. Activated carbon achieved 8.18%, conventional treatment 5.43%, biosand 2.93% and UV 0.93%. This finding is particularly important where fluoride is a concern because treatment technologies that primarily remove particles or disinfect water may not substantially reduce dissolved fluoride.

5.12 Iron: Iron showed a somewhat different pattern. RO achieved the highest removal at 89.88%, followed by conventional treatment at 81.95%, biosand at 74.69% and activated carbon at 72.20%. UV achieved only 3.55%. Thus, conventional treatment, activated carbon and biosand were comparatively effective for iron, although RO remained the strongest overall treatment.

6. Discussion: The major finding of this study is the clear superiority of reverse osmosis for broad-spectrum physicochemical contaminant removal. RO produced a mean removal efficiency of 87.89%, which was approximately: 2.61 times the mean removal of conventional treatment; 2.62 times that of activated carbon; 2.94 times that of biosand filtration; and 7.06 times that of UV treatment.

The particularly high RO removal efficiencies for EC, TDS, hardness, chloride, sulphate, nitrate and fluoride demonstrate that dissolved inorganic constituents were the major area of RO superiority. EPA identifies RO as a process capable of removing many inorganic contaminants and dissolved solids. The performance of conventional treatment was strongest for turbidity and iron. Its mean removal of 33.71% was considerably lower than RO but demonstrates useful treatment potential for particulate and particle-associated contaminants. Activated carbon produced a mean removal of 33.55%. Its strongest performance occurred for COD (67.74%), BOD (64.67%) and iron (72.20%). This pattern supports the role of adsorption-based treatment as an effective component for reducing selected organic and adsorbable contaminants. Biosand filtration achieved a mean removal of 29.86%. Its strongest results were obtained for turbidity (85.76%) and iron (74.69%). This is consistent with the established use of biosand filtration for turbidity reduction. WHO also emphasizes that safe storage and additional disinfection may be important because filtration alone does not necessarily eliminate all microbial risks. UV treatment produced the lowest mean physicochemical removal, only 12.46%. This result should not be interpreted as evidence that UV is an ineffective water-treatment technology. Rather, it reflects the fact that UV is primarily intended for microbial inactivation rather than removal of dissolved salts and minerals. WHO's household water-treatment evaluation framework specifically considers UV systems in terms of microbiological performance. Thus, the treatment methods should not be regarded simply as competing technologies. In practical water treatment, combinations can be more appropriate. For example, filtration



may reduce turbidity before UV treatment, while activated carbon may provide adsorption of organic compounds and RO may subsequently reduce dissolved contaminants.

7.Conclusion

The comparative assessment demonstrated substantial differences in the performance of the five investigated water-treatment methods. Reverse osmosis was clearly the most effective treatment, achieving an overall mean removal efficiency of 87.89%. It produced high removal efficiencies for turbidity, EC, TDS, BOD, COD, hardness, alkalinity, chloride, sulphate, nitrate, fluoride and iron. Conventional treatment demonstrated moderate overall performance and was particularly effective for turbidity and iron. Activated carbon showed useful removal of BOD, COD and iron, indicating its value for targeted adsorption-based treatment. Biosand filtration was highly effective for turbidity and also showed substantial iron removal. UV treatment produced the lowest physicochemical removal; however, this result reflects its primary function as a microbial-disinfection technology rather than a dissolved-contaminant removal process.

Overall, the findings indicate that no single treatment technology should automatically be selected without considering the characteristics of the source water and the intended treatment objective. RO is particularly advantageous where dissolved inorganic contaminants are a major concern, whereas filtration, adsorption and UV can serve complementary roles. An integrated treatment train may therefore provide a more balanced approach to achieving both physicochemical and microbiological water-quality objectives.



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