Introduction

Reverse osmosis (RO) is a wide spread technique used to supply potable water from seawater and brackishwater. There are different types of membranes used in RO structure such as: micro porous, symmetric, non-porous symmetric, asymmetric and thin film composite (TFC). Most companies synthesis TFC membranes that have a lot of advantages including durability with long lifetime in spite of sensitivity to chlorine (Bouchareb et al., 2019). Membrane life is an important factor to determine the economic efficiency of RO systems (Metcalf & Eddy et al., 2007). Process of RO has simple design, easy operation, and able to remove organic and inorganic pollutants. Therefore, RO is more environmentally friendly option (Garud, Kore, Kore & Kulkarni, 2011; Al-Hotmani, Al-Obaidi, John, Patel & Mujtaba, 2020). The most disadvantages of RO include the requirement for high pressure and adding of chemicals against scaling and fouling.

A number of researchers have evaluated the performance of RO process based brackishwater desalination as follows. Makki (2009) studied the performance of RO in Dura – Iraq power station. The study examined RO with TFC membrane constructed as spiral wound module, and concluded that TFC membrane has higher productivity and durability to chemicals with TDS removing percentage reached 96%.

El-Harrak et al. (2013) evaluated the performance of RO process for irrigation purpose in Dokkala – Morocco. The results showed that the performance of RO system decreases after few months. The study included illumination of chlorine and sodium bisulfate for the feed water. Al-Bayati (2015) outlined the efficiency of five brackish water desalination plants for drinking purpose at Salahaldin province – Iraq. The research
The performance assessment of reverse osmosis stations at Al-Mahalabea area included examination of 17 samples of well water and more than 17 parameters for each sample were analysed. The research concluded that the permeate water were within the permissible standards and the TDS removal percentage reached 98.18%.

Abdel-Fatah, El-Gendi and Ashour (2016) studied a RO system which has flush cycle for the treatment of saline water in Cairo University – Egypt. The study showed that the resulted water has low concentration in TDS which equals to 100 ppm while the feed water concentration exceeds 10,000 ppm.

Al-Jilil (2017) studied the reduction of TDS concentrations from wastewater using Nano Filtration NF and RO in Saudi Arabia. The study found that RO removes mono valent ions such as Cl− reaching rejection efficiency 94.4%.

Haider (2017) evaluated the brackishwater at each component of RO system in Buraydah, Qussim – Saudi Arabia during the year 2016. The research used fuzzy AHP to extract the weights of five main variables and fuzzy weighted sum method to evaluate the average monthly performance. The results showed high performance of the system and meets drinking water limits.

Bouchareb et al. (2019) outlined the RO performance which have TFC membrane type (TW30-2540) for desalination brackish water at Alpine region in the north of Algeria. The results showed that this type of membrane has less cost and high rejection efficiency reaches 97% of salts.

The study aims to assess the performance of four RO stations at different sites within Al-Mahalabea area in Nineveh governorate – Iraq. Besides, a ranking of RO stations performance is conducted according to their rejection efficiency (at zero time of operation and after ten weeks of operation) by using the SAW and the TOPSIS techniques, and identifying the higher removal percentage parameters. The collected data of the feed water can be used as a feedback for groundwater quality database for Nineveh governorate.

Material and methods

The studied area

The studied area is located about 35 km south west of Mosul city. Its area is about 888 km². Table 1 illustrates the names of RO stations’ sites. Also, the locations of the RO stations can be seen in Figure 1.

The components of used RO stations

The studied RO system is consisted of the following components; working pressure pump (4 bar), flow rate gage, flow meter, RO system, flush cycle, filtration system, and specialized environmental crew.

| Table 1. Reverse osmosis stations within the studied area |
| --- | --- | --- | --- |
| RO station | Site name | Longitude | Latitude | Management |
| RO1 | Ain Alwah, | 42°37'08" | 36°14'16" | specialized environmental crew |
| RO2 | Misherfa Altaha | 42°48'20" | 36°05'15" | specialized environmental crew |
| RO3 | Ghiziel | 42°40'34" | 36°02'39" | untrained labours |
| RO4 | Misherfa | 42°52'42" | 36°11'57" | untrained labours |
pH gage, TH gage, pH equalization device, in addition to chemical cleaning system. Feed water flow rate capacity is 18 m$^3$·h$^{-1}$.

Pretreatment system includes the following components; tanks of reclaimed water, sand filter, activated carbon filter, cartridge 5–10 $\mu$m. Permeate capacity is 10 m$^3$·h$^{-1}$. Model of RO is Trust CRO-8/12 and the membrane model is AG-8040, noting that all the stations have the same model. The membranes brand name is GE Desal (USA). The diameter and length of the membrane is 8 and 40 inches respectively. The post-treatment system includes the following units: UV unit, in-line storage tanks and ozone unit. Schematic diagram of the studied RO station and the units of the pre and post treatment of groundwater is explained in Figure 2.

Methodology

The studied parameters

Two groups of samples were taken from feed and permeate water and analysed into two periods: the first is at zero time of operation, while the second period occurred after 10 weeks of operation (this period was the recommended period used by the supplied company). A number of parameters were laboratory analysed for each sample and then compared with local and international standards and examined according to standard methodology (APHA, 2005) in the laboratory of the college of the Environmental Sciences and Technology, Mosul University – Iraq, as in Table 2. The studied parameters are: TH, SO$_4$, TDS, TA, Mg, Ca, Cl, Na, pH, turbidity and NO$_3$. 

FIGURE 1. The studied area and locations of the operating RO stations
Methods used to determine RO stations performance

Two methods are used to determine RO stations performance: the Simple Additive Weight (SAW) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). As follows a summary of each method.

The SAW method is firstly used by (McDuffie & Haney, 1973). This method recaps the studied parameters values in one index. A relative weight \( w_i \) is given...
to each parameter depending on its importance. Sum of these relative weights must equal 1. The quality rating (q) is calculated by equation: 
\[ q_i = \left( \frac{C_i}{S_i} \right) \times 100 \]
where \( C_i \) refers to the concentration of a certain parameter, \( S_i \) is the depended values limits. Sub-index (\( S_{ij} \)) of a parameter is calculated by multiplying the \( w_j \) by \( q_i \). Index value is gained from summation of sub-indices which has five ranges: excellent 0–25, good 26–50, poor 51–75, very poor 76–100, and unsuitable > 101 (Afshari, Mojahed & Yusuff, 2010; Al-Ozeer & Ahmed, 2019).

The TOPSIS method is a mathematical method used in ranking the alternatives. It is a goal-based decision making technique for finding the alternative that is closest to the ideal solution (Behzadian, Otaghsara, Yazdani & Ignatius, 2012; Tahyudin, Rosyidi, Ahmar & Haviluddin, 2018). In this study, this method is used to rank the performance of four stations.

The main steps of the TOPSIS method can be summarized as follows (Tsaur, 2011):

Step 1: Input decision matrix as in Table 3, where \( X_{ij} \) represents the feature value, where: \( i = 1, \ldots, M \) and \( j = 1, \ldots, 7 \).

Step 2: Normalized a decision matrix, as in
\[ R_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} [x_{ij}^2]}} \]

Step 3: \( W_j \) (the weights), noting that, the values of the weights which are inserted in the two methods are the same, and these weights are determined according to the importance of each parameter.

Step 4: Construct the weighted normalized matrix \( (V_{i,j}) \) by multiplying each column by \( W_j \).

Step 5: The highest value in the column \( V_{i,j}^+ \).

Step 6: The lowest value in the column \( V_{i,j}^- \).

Step 7: Determined the \( S^+ \);
\[ S^+ = \sqrt{\sum_{j=1}^{m} (V_{i,j}^+ - V_j^+)^2} \]

Step 8: Determined the \( S^- \);
\[ S^- = \sqrt{\sum_{j=1}^{m} (V_{i,j}^- - V_j^-)^2} \]

Step 9: Calculate closeness to ideal solution (\( C_i \));
\[ C_i = \frac{S_i^-}{(S_i^+ + S_i^-)} \]

Step 10: Rank all sites according to the results of Step 9.

Results

Data of feed and permeate water in two periods and the calculated rejection \( R \) efficiency are tabulated in Tables 4, 5, 6 and 7. The rejection \( R \) is calculated by the formula \( \%R = (1 - P/F) \times 100\% \), here \( F \) and \( P \) represent feed and permeate water concentrations.

| \( W_j \) | 0.15 | 0.12 | 0.12 | 0.1 | 0.1 | 0.1 | 0.06 | 0.05 | 0.05 | 0.05 |
|----------|------|------|------|-----|-----|-----|------|------|------|------|
| Parameter | TDS | Mg | Ca | Cl | NO₃ | SO₄ | TH | turbidity | pH | Na | TA |
| Site 1 | X11 | X12 | X13 | X14 | X15 | X16 | X18 | X19 | X110 | X111 | X112 |
| Site 2 | X21 | X22 | X23 | X24 | X25 | X26 | X28 | X29 | X210 | X211 | X212 |
| Site 3 | X31 | X32 | X33 | X34 | X35 | X36 | X38 | X39 | X310 | X311 | X312 |
| Site 4 | X41 | X42 | X43 | X44 | X45 | X46 | X48 | X49 | X410 | X411 | X412 |
TABLE 4. Rejection values of RO1 parameters

| After 10 weeks | At zero time | Unit | Parameter |
|----------------|--------------|------|-----------|
| %R         | P   | F  | %R         | P   | F  |
| 92.3        | 154 | 2 019 | 94.7       | 105 | 2 010 | mg l⁻¹ as CaCO₃ | TH |
| 95.7        | 78  | 1 812 | 96.2       | 67  | 1 800 | mg l⁻¹           | SO₄ |
| 90.5        | 226 | 2 400 | 91.8       | 228 | 2 800 | mg l⁻¹           | TDS |
| 51.4        | 68  | 140  | 70.1       | 40  | 134  | mg l⁻¹ as CaCO₃  | TA |
| 92.3        | 26  | 340  | 92.0       | 26  | 326  | mg l⁻¹           | Mg |
| 90.4        | 24  | 250  | 92.2       | 21  | 269  | mg l⁻¹           | Ca |
| 55.5        | 16  | 36   | 60.0       | 12  | 30   | mg l⁻¹           | Cl |
| 58.6        | 12.4| 30   | 61.8       | 10.3| 27   | mg l⁻¹           | Na |
| –           | 7.1 | 7.3  | –          | 7   | 7.2  | –                | pH |
| 90.0        | 0.28| 2.8  | 95.7       | 0.2 | 4.75 | NTU turbidity    |
| 89.2        | 0.97| 9.0  | 92.6       | 0.63| 8.5  | mg l⁻¹           | NO₃ |

TABLE 5. Rejection values of RO2 parameters

| After 10 weeks | At zero time | Unit | Parameter |
|----------------|--------------|------|-----------|
| %R         | P   | F  | %R         | P   | F  |
| 96.50       | 70  | 1 995 | 96.8       | 66  | 2 086 | mg l⁻¹ as CaCO₃ | TH |
| 97.83       | 39  | 1 800 | 98.05      | 35  | 1 800 | mg l⁻¹           | SO₄ |
| 95.42       | 96  | 2 100 | 97.5       | 70  | 2 812 | mg l⁻¹           | TDS |
| 72.66       | 41  | 150  | 93.3       | 12  | 180  | mg l⁻¹ as CaCO₃  | TA |
| 95.1        | 16.3| 335  | 97.9       | 7.6 | 365  | mg l⁻¹           | Mg |
| 90.45       | 21  | 220  | 91.06      | 21  | 235  | mg l⁻¹           | Ca |
| 62.14       | 21.2| 56   | 75.86      | 7   | 29   | mg l⁻¹           | Cl |
| 78.46       | 8.4 | 39   | 83.46      | 4.3 | 26   | mg l⁻¹           | Na |
| –           | 7   | 7.3  | –          | 6.9 | 7.7  | –                | pH |
| 90.00       | 0.2 | 2    | 96.55      | 0.2 | 5.8  | NTU turbidity    |
| 90.1        | 0.8 | 8.9  | 94.4       | 0.53| 9.5  | mg l⁻¹           | NO₃ |
### TABLE 6. Rejection values of RO3 parameters

| After 10 weeks | At zero time | Unit  | Parameter |
|----------------|--------------|-------|-----------|
| %R  | P  | F  | %R  | P  | F  | |
| 91.3 | 130 | 1 500 | 95.7 | 65 | 1 535 | mg l⁻¹ as CaCO₃ | TH |
| 94.7 | 106 | 2 010 | 97.8 | 42 | 1 910 | mg l⁻¹ | SO₄ |
| 87.7 | 144 | 1 170 | 91.8 | 90 | 1 100 | mg l⁻¹ | TDS |
| 67.7 | 40 | 124 | 77.0 | 30.8 | 134 | mg l⁻¹ as CaCO₃ | TA |
| 89.8 | 28 | 275 | 97.7 | 6 | 265 | mg l⁻¹ | Mg |
| 90.3 | 49 | 507 | 96.8 | 16 | 507 | mg l⁻¹ | Ca |
| 61.1 | 11.7 | 30 | 80 | 6 | 30 | mg l⁻¹ | Cl |
| 58.6 | 8.7 | 21 | 78.2 | 4.5 | 20.7 | mg l⁻¹ | Na |
| – | – | 7.6 | – | 6.6 | 7.6 | – | pH |
| 90.0 | 0.4 | 4 | 93.0 | 0.27 | 3.9 | NTU | turbidity |
| 94.3 | 0.73 | 12.8 | 97.6 | 0.32 | 13.6 | mg l⁻¹ | NO₃ |

### TABLE 7. Rejection values of RO4 parameters

| After 10 weeks | At zero time | Unit  | Parameter |
|----------------|--------------|-------|-----------|
| %R  | P  | F  | %R  | P  | F  | |
| 94.9 | 627 | 1 230 | 97.2 | 30 | 1 100 | mg l⁻¹ as CaCO₃ | TH |
| 97.0 | 207 | 690 | 98.4 | 12 | 770 | mg l⁻¹ | SO₄ |
| 94.3 | 91.7 | 1 610 | 96.9 | 46 | 1 518 | mg l⁻¹ | TDS |
| 77.3 | 60.3 | 266 | 95.9 | 10 | 245 | mg l⁻¹ as CaCO₃ | TA |
| 94.7 | 7.6 | 144 | 97.8 | 2.4 | 112 | mg l⁻¹ | Mg |
| 95.7 | 25.8 | 600 | 98.7 | 8 | 624 | mg l⁻¹ | Ca |
| 65.8 | 45.5 | 133 | 78.3 | 8.2 | 38 | mg l⁻¹ | Cl |
| 78.6 | 16.6 | 77.7 | 88.3 | 6.4 | 55 | mg l⁻¹ | Na |
| – | 7.1 | 7.4 | – | 7 | 7.1 | – | pH |
| 85.4 | 0.55 | 3.8 | 91.2 | 0.35 | 4 | NTU | turbidity |
| 91.2 | 1.1 | 12.6 | 96.0 | 0.47 | 11.8 | mg l⁻¹ | NO₃ |
A number of calculations were done to determine the RO stations performance as in Table 8 according to the SAW method. The results show that performance at Ain Alwah RO1, Misherfa Altaha RO2, Ghiziel RO3, and Misherfa RO4 were 98.3, 97.9, 95.3 and 86.3%, respectively.

The ranking performance resulted from TOPSIS are 99.95, 99.92, 40.2 and 17.99%, respectively as in Table 9.

After comparing the performance results of the SAW and the TOPSIS methods, it was seen that the stations’ performance can be ranked from high to low as follows: RO1: Ain Alwah, RO2: Misherfa Altaha, RO3: Ghiziel, and RO4: Misherfa.

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Discussion

Figure 3 shows a comparison between the SAW and the TOPSIS results. There is a difference in values between them. And this is due to the principles applied by the two methods themselves, where the SAW occupies weighted average, whereas the TOPSIS focuses on maximizing distance from the negative ideal solution, and minimizing the distance from the positive ideal solution. The SAW gives more convenient values than the TOPSIS method. The result of this study is a good agreement with the findings of the studies of Thor, Ding and Kamaruddin (2013) and Tahyudin et al. (2018).
It was seen that the overall performance shows an excellent rejection efficiency reaching 90% in the following set of parameters; SO$_4$, TDS, Ca, Mg, NO$_3$, Ca, turbidity and TH, however, the other set of parameters CL, and Na show a less rejection efficiency between 60 and 85%, as in Figure 4. It was shown that the divalent cations have higher percentage removal than monovalent anions.

Assessing the performance of RO stations is carried out where RO1 was the best station while RO4 was the worse one. Although the RO system model and the membrane model were the same, the operating conditions of these stations were different. Mismanagement of RO stations (untrained labours) with low maintenance and the lack of frequent washing of the membrane can be considered as the main reason in decreasing (RO3 and RO4) station’s performance.

**Conclusions**

Total dissolved solids plays a vital role in determining the suitability of the drinking water, where the feed wa-
water TDS concentrations ranged between 1,100 and 2,800 mg·l⁻¹, while the permeate water ranged between 46 and 228 mg·l⁻¹ and it was within the permeable standards of drinking water for all stations. The removal efficiency of TDS ranged between 92 and 97%.

It can be observed that the SAW occupies weighted average and its mathematically easier while, the TOPSIS presents a priority of ranks with an optimal station. Therefore, both methods provide an integrated viewpoint of RO stations performance.

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Summary

The performance assessment of reverse osmosis stations at Al-Mahalabea area. The present study assesses RO stations at four sites in Al-Mahalabea area – Nineveh governorate, Iraq during the summer of 2013. The performance of RO stations are ranked by two methods: the Simple Additive Weight (SAW) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Two groups of samples were collected from feed and permeate water for two periods (at zero time of operation and after ten weeks of operation) with eleven parameters for each sample were analysed. The highest overall rejection $R$ efficiency appeared with the first set of parameters more than 90% (SO$_4$, TDS, NO$_3$, TH, and turbidity), while the second set was the least (Cl, Na, and total alkalinity – TA) ranged between 65 and 85%. It is observed that both the SAW and the TOPSIS methods are accurate to predict the performance efficiency.

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