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Water Quality Assessment of Reverse Osmosis (RO) Plants and Municipal Supply Water in Al-Muthanna Governorate: A Comparative Physicochemical, Bacteriological, and Statistical Study

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Abstract

The research project was performed in Al-Muthanna Governorate in May 2024 to assess the physicochemical parameters. The effect of physicochemical variables such as pH, turbidity, electrical conductivity was determined in samples from six various commercial water treatment plants located in the governorate, and samples were also collected from the public water supply of the city to compare the quality of water in commercial treatment facilities to the one from municipal network. It was found out that samples taken from the commercial plants met Iraqi standards, while water from municipal supply exceeded the permissible levels set by the regulations, excluding only the sample from the area of Al-Samawa, where the parameters were within the normal range.

Keywords
Al-Muthanna,
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Introduction

One of the main causes of water pollution is the introduction of foreign substances that are harmful to humans and animals. Among these pollutants there are industrial waste and domestic sewage, pesticides, fertilizers, and pathogens, including bacteria and viruses, which deteriorate the quality of water (Farouha, 1989). It should be noted that the first analysis of water quality was based on characteristics such as taste, odour, and colour; however, with the development of science, it became clear that it is possible to assess water quality using various techniques (Mahmoud, 1988).

The wide knowledge of environmental specialists regarding drinking water regulations, standards, and specifications enables them to choose proper sources of raw water, stages of treatment, design parameters, and prepare budget estimates for their work. Moreover, it is necessary to consider the changes made to specifications (Tebbutt, 1989). In the last century, scientists discovered the connection between drinking water and diseases, thus opening the door for numerous technologies that made water treatment more efficient and affordable. These technologies include different processes aimed at providing the highest level of water purity (Hammer, 1996). In order to make drinking water pollution-free, raw water undergoes a series of three treatments: chemical (chemical sedimentation by adding alum), negligible physical treatment (sand filtration), and bacteriological (chlorination to kill bacteria).

As for the required treatment procedures, they depend on the type of water and its pollution degree by waste and microorganisms (AWWA, 1989). Since it has become problematic to obtain clean drinking water from municipal taps and people are concerned about its purity, they started using drinking water from treatment plants (Shalouf et al., 2018).

- Materials and Methods

This study was conducted on six drinking water Reverse Osmosis (RO) plants distributed across three sectors of Al-Muthanna Governorate: Al-Samawah, Al-Rumaitha, and Al-Khidr. Two samples were collected from each sector, spaced apart. The public water supply—sourced from the Al-Rumaitha and Al-Muthanna water projects, which in turn rely on the waters of Shatt Al-Rumaitha—serves as the primary water source for the population for all uses; the governorate's desalination plants also rely on this same source (see Map No. ...).

- Sample Collection Methods

Samples were collected during May 2024 from six locations, along with a sample from the water supply line serving these plants. One-liter plastic containers were used for collection; these were rinsed twice with distilled water and sealed tightly after filling. Some tests were performed on-site, while the remaining samples were transported to the Environment Center for analysis.

- Laboratory Analysis of Physical and Chemical Properties

1- pH:

Water acidity (pH) was measured using a pH meter.

2- Total Dissolved Solids (TDS) and Electrical Conductivity:

Measurements of dissolved solids and electrical conductivity were performed directly on the water samples using a conductivity meter (EcoSense EC300).

3- Turbidity:

Turbidity was measured using a turbidity meter.

4- Total Hardness:

Hardness was determined by measuring calcium and magnesium levels in the water according to the following equation:

$T.H = 2.5\ Ca + 4.1\ Mg$

5- Magnesium and Calcium:

Calcium and magnesium ions in water samples were determined according to the method described by Lind (1979).

6- Sodium:

Sodium concentrations were measured using a flame photometer.

7- Chloride:

The chloride concentration was found by titration with a standard silver nitrate solution and potassium chromate based on the procedure explained by Jackson (1958).

- Reverse Osmosis Process:

A natural process according to which water moves from the area of high concentration to where the concentration is lower through a semi-permeable membrane. Mechanical energy is applied to the concentrated solution in order to increase the level of osmotic pressure. Under natural conditions, when a homogeneous solution and a salt solution separated from each other by means of a permeable membrane are observed, they tend to equalize and lead to pure water coming from the homogeneous solution to the salt solution (Al-Shablawi & Jasim, 2018). Compared to thermal alternatives, reverse osmosis becomes more popular due to its low power consumption (Fritzmann et al., 2007). - Reverse Osmosis Equipment and Applications

Currently, osmosis technologies are used in various spheres of business including the separation, purification and concentration in the food industry, which can be used for the concentration of juices from fruits and vegetables and from milk. It is also employed for providing communities with clean water (Wenten, 2016).

Salman (2013) states that reverse osmosis equipment consists of four major components:

- Pre-treatment system: The purpose of this system is to remove suspension present on the membrane so that scaling and growth of organisms will be avoided.

- High-pressure pump: The objective of the pump is to create pressure allowing water to go through the membrane and leaving salts on the surface.

- Membrane system: This is a pressure vessel containing a semi-permeable membrane that enables diffusion to occur.

- Post-treatment system: At this stage, the quality of water is improved by means of adjusting its pH and other parameters.

- Results and Discussion

First: Physical and Chemical Characteristics

Table (1) presents the Iraqi standard specifications, while Table (2) shows the results of laboratory analyses for selected reverse osmosis (RO) plants in Al-Muthanna Governorate and for municipal tap water. The results indicate that none of the desalinated water samples exceeded the limits permitted by Iraqi standards; in fact, they fell below the maximum limits set by these standards—unlike the municipal tap water. These results will be discussed through a comparison with the Iraqi specifications.

Table (1) Iraqi Standard Specifications for Drinking Water

Local Standard	Item Name
8.5-6.5	PH
2000	EC
5	TU
1000	TDS
500	TH
150	Ca
100	Mg
200	Na
12-10	K
350	Cl
(CFU)100/ml	Aerobic Plate count(A.P.C)1 ml
0	Total coliform (T.C)100 ml
0	Total coliform (F.C)100 ml
0	E.coli_100 ml

Ministry of Planning and Development Cooperation. Central Organization for Standardization and Quality Control. (2009). "Standard Specification No. 417 – Drinking Water – Second Update." Baghdad.

Table (2): Results of physical and chemical laboratory analyses of RO water and municipal water in Al-Muthanna Governorate.

Source:

											RO
Cl	K	Na	Mg	Ca	TH	TDS	TU	EC	pH		Sample
20	0.0	2.4	0.0	0.6	0.4	120	1.50	80	7.0	W1	Al-Samawah Sector
20	0.5	2.0	0.5	0.4	3.1	96	1.10	79	7.0	W2	
30	0.2	6.8	0.2	4.3	2.4	80	1.42	69	7.1	W3	Al-Rumaitha Sector
20	0.4	8.1	0.4	2.1	1.0	120	1.20	87	7.0	W4	
35	1.4	8.1	1.4	1.6	1.1	110	1.51	76	6.9	W5	Al-Khidr Sector
30	1.9	5.0	1.9	0.9	0.2	120	1.21	82	7.2	W6	
											Mains water / Piped water supply
Cl	K	Na	Mg	Ca	TH	TDS	TU	EC	pH		Sample
46	399	7.1	141	46	129	1100	7	1842	7.0	W1	Al-Samawah Sector
37	379	6.6	132	37	111	995	4.3	1550	6.9	W2	
232	854	26	450	232	139	1316	9.1	2800	7.5	W3	Al-Rumaitha Sector
200	730	40	501	200	159	1320	8.0	2980	7.4	W4	
201	870	38	400	201	144	1044	8.8	1638	7.7	W5	Al-Khidr Sector
182	805	29	406	182	175	1340	9.2	3007	7.4	W6	

Prepared by the researcher based on analyses conducted at the Soil and Water Laboratory, College of Agriculture, University of Al-Muthanna, and the Environmental Analysis Laboratory, Al-Muthanna Environment Directorate, on May 22, 2024.

pH Level:

Monitoring of the pH of water samples taken from sea-water desalination plants as well as from piped water sources indicates that the pH ranged from 6.9 to 7.5 (as demonstrated in Table 2). The pH of all collected samples is within the limits of drinkable water used in Iraq (6.5–8.5). One of the reasons behind mild pH values is chlorination. In addition, it is known that high level of carbon dioxide affects it. More specifically, desalination membranes are able to eliminate carbonates and bicarbonates but do not have an ability to remove carbon dioxide, which negatively affects product water.

EC is the next measure.

The study results show that a, ll the desalinated water samples are within allowable limits provided by Iraqi standards (2000 mg/L) and have the levels of 69 to 87 mg/L. Among samples from pipes, there are significant differences: W6 shows the highest level (3007), whereas W2 has the lowest level of the content.

Total Dissolved Solids (TDS) is the indicator of the water value. If TDS is high, water becomes unfit for economical use (Aoun, 2002). In terms of the study of the TDS of desalination water, it should be said that TDS of all samples collected comply with the standards of maximum allowed amount in drinkable waters in Iraq (1,000 mg/L). At the same time, sampled water from municipalities has high indexes, with Water Sample W2 being the only exception (995 mg/L).

Turbidity (Turb)

Turbidity is an important measure of drinking water quality (Dhiab, 2016); it is effectively used as an indicator of the quality changes that occur in drinking water treatment facilities, such as bends and pipes. Turbidity is caused by the presence of some substances, including soil, clays and sands, organic and inorganic materials along with biological agents (Al-Mufarji & Al-Azzawi, 1991). The Iraqi standards set a turbidity limit value equal to 5, and all samples from the desalinated water plants remained under this limit because turbidity indices went from 1.10 to 1.51. With municipal water, except for W2 with a value of 4.3 (less than the limit), all other values of the measured samples exceeded the limit.

Hardness (T.H.)

The results of the hardness tests, which are presented in Table 2, show that hardness indices for the desalinated water remain within the applicable range according to Iraqi standards where the maximum amount should be 500 mg/L, and the values were in the range of 20-40 mg/L for the desalination plant samples. As for the water that flows through pipes, hardness indices were varied, and the one with the highest index was (W6) with an index of 175 mg/L (above the limit), while (W2) turned out to be wet with the lowest figure (111 mg/L).

Calcium (Ca):

High calcium levels in the water lead to some problems (Al-Mahdi et al., 2025). At the same time, calcium is a necessary element for the development of bones and teeth and the enzyme activity (Owaida, 2004).According to Table (2), calcium concentration in the desalinated water of the three sectors ranged between 0.2 and 3.1 mg/L, which was lower than the limit according to Iraq standard specifications. This is unlike the water supplied through pipes, where the concentrations of calcium varied, and some samples—namely (W1, W2, W3, and W5)—had concentrations lower than the permissible level. The above concentration of calcium in the piped water was between 111 and 144 mg/L, while the rest was above the permissible concentration.

Magnesium (Mg)

High concentrations of magnesium in the water may cause problems in the intestines of consumers (Omar, 2000). Iraq standards define the limit for magnesium at 100 mg/L. The desalinated water had concentrations within limits according to these standards, as its concentrations were between 0.4 and 4.3 mg/L. On the other hand, the piped water had concentrations of magnesium recorded within the permissible levels in samples W1 and W2 (with concentrations between 37 and 46 mg/L), while other samples had concentrations above the permitted limit, such as sample W3, which was found to be at a maximum concentration of 232 mg/L.

Sodium (Na)

The concentrations of sodium in samples of the desalinated water from all three stations were below their permissible limit of 200 mg/L standard in Iraq, which means that the desalination units are capable of eliminating sodium. The piped water had concentrations of Na above the permissible limit; its concentrations were found to be between 400 and 501 mg/L except for those from Samawah, which were below this standard with concentrations between 132 and 141 mg/L.Although potassium is an important mineral in humans if its concentration is balanced, its

excess concentration might have adverse symptoms in patients suffering from heart-related diseases, diabetic patients or hypertensive patients (Laflouf, 2019). The water results published in table no (2) show that desalinated water samples obtained from different places comply with the Iraqi standard level of potassium concentration in drinking water (10-12 mg/L). However, the piped water samples vary in potassium concentration with water sample w4 showing the highest concentration of 40 mg/L while w5 followed with 38 mg/L. The concentration of potassium in the water samples numbered w1 and w2 was recorded to be 6.6 mg/L and 7.1 mg/L respectively while still lying within the permissible range of the Iraqi standard.

Concentration of Chlorides:

The chloride concentration in water impacts its taste and results in salinity of water (Molana et al., 2021). The data in table (2) shows that the concentration of chlorides in all water samples remains in the range of 20 to 35 mg/L meaning that the samples obtained from the desalinated water do not exceed the limit of the Iraqi standard which is 350 mg/L. On the other hand, the concentration of chloride in piped water remains higher than the allowable limit with the maximum concentration being observed in w5 sample, which is equal to 870 mg/L and the minimum concentration being equal to that of 379 mg/L from sample w2.

Second Bacteriological Tests:

The bacteriological water tests are the key analysis in terms of testing the presence of pathogenic bacteria in water.More specifically, researchers analyzed the Total Plate Count (T.P.C.) of aerobic bacteria. Testing T.P.C. is one of the established tests in water analysis. T.P.C. is an important test that helps in verifying the effectiveness of sterilization in producing safe drinking water, and that has become a standard in assessing safety of water (Al-Shammari, 2005). Moreover, T.P.C. also helps to assess the total bacterial count in one sample (Al-Nadawi, 2010).

In addition to that, researchers examined the Total Coliform (T.C.) bacteria, which is one of the most important and relevant microbial indicators of water contamination because of their convenience and distribution (Hamilton et al., 2003). Researchers analyzed Fecal Coliform (F.C.) bacteria since the presence of these organisms points to the occurrence of fed contamination resulting from human waste (Al-Douri, 2012). Moreover, the researchers examined *Escherichia coli* (*E. coli*), since this bacterium is considered the organism that can be used as an indicator of the presence of fecal contamination (Sasakova et al., 2018).

The biological analysis showed (Table 3) that some samples of water supplied through the network exceeded the microbial limits set by the Iraqi standards. Therefore, there is a need to regulate the quality of water supplied to people and improve the treatment methods used in purification plants. More specifically, the samples taken from Rumaitha (w4) and Al-Khidr (w6) sectors exceeded the limit for Aerobic Plate Count (APC) according to the Iraqi standards, since APC is set at 100 CFU/ml. The values of APC in these two sectors were 1.29 and 4.31. In the case of Total Coliforms (TC) and Fecal Coliforms (FC) and *Escherichia coli* (E. coli), the values recorded by the researchers were between 2.2 and 5.1. The remaining samples complied with the standards set for quality. This difference is caused by several factors, such as the transportation of water through the pipes that are known to be contaminated. Most of the contaminants come from the daily human activities, such as household waste, hospital waste, and others, which mix with sewage and leak into the water supply system. Moreover, the problem can be attributed to the presence of poorly efficient sterilization processes in the treated plants and lack of qualified specialists who could conduct high-quality sterilization.

Table (3): Bacteriological analyses of treated water supply

Total count	Fecal	Coliform	Aerobic bacteria	Sample	No.
0	0	0	0.32	W1	1
0	0	0	0.54	W2	2
0	0	0	0.57	W3	3
2.2	2.2	2.2	1.29	W4	4
0	0	0	0.41	W5	5
5.1	5.1	5.1	4.31	W6	6

Source: Prepared by the researcher based on analyses conducted at the Soil and Water Laboratory, College of Agriculture, University of Al-Muthanna, and the Environmental Analysis Laboratory, Al-Muthanna Environment Directorate, on May 22, 2024.

With respect to Table (4), which shows the biological water quality assessment of the Reverse Osmosis (RO) plants, the results clearly indicate that water from almost all of the units involved in the investigation is mostly free of bacteria, even if certain sources of water may be unsuitable. This implies that the studied units had a considerable positive effect on the water quality and safety. However, with regard to the sample of the vegetable sector (W6), the unit was not able to provide the safe and bacteria-free water. The inability of the system to comply with the sanitary norms in the production and storage of water may explain the problem. Particularly, it has been proven that packing water in plastic bottles leads to development of bacteria much faster than that in glass bottles (Health Canada, 2006).

Table (4): Bacteriological analyses of Reverse Osmosis (RO) systems.

Total count	Fecal	Coliform	Aerobic bacteria	Sample	No.
0	0	0	0.5	W1	1
0	0	0	0	W2	2
0	0	0	0.2	W3	3
0	0	0	0	W4	4
0	0	0	0.4	W5	5
3.1	3.1	3.1	4.1	W6	6

Source: Prepared by the researcher based on analyses conducted at the Soil and Water Laboratory, College of Agriculture, University of Al-Muthanna, and the Environmental Analysis Laboratory, Al-Muthanna Environment Directorate, on May 22, 2024.

Third: Statistical Analysis

Data analysis and descriptive statistics methods were used to analyze RO water and mains water samples and their physicochemical properties, as well as to determine the variations and homogeneity of samples. The following statistical indicators were obtained for this purpose: arithmetic mean, standard deviation (SD), minimum and maximum values, and coefficient of variation (CV%). Descriptive statistics form the first step in analyzing water quality data, allowing for quantitative data description and identification of general trends and variations before proceeding to inferential testing (Montgomery & Runger, 2018).

The application of these indicators on RO water and mains water samples allows for a descriptive comparison of these two types of water in terms of their element and salt concentrations, as well as physicochemical properties, and analysis of the uniformity of results across samples. Comparing the RO water to the mains water is very valuable when assessing the quality of the waters from different sources and the efficiency of the treatment process (Al-Gayyim & Al-Asady, 2023).

In Table (5), a number of physicochemical properties of water before and after the reverse osmosis (RO) process are presented in terms of arithmetic mean, standard deviation, range, and coefficient of variation (CV%). The obtained results indicated some notable distinctions between the water from the reverse osmosis (RO) system and the municipal water supply, which can be attributed to the effectiveness of the reverse osmosis process in the removal of different ions and dissolved salts and the improvement of some physical characteristics of the water.

Table (5): Statistical analysis of RO water and municipal supply water samples.

Liquefaction CV%	Liquefaction Max	Liquefaction Min	Liquefaction SD	Liquefaction Mean	RO CV%	RO Max	RO Min	RO SD	RO Mean	variable
4.10	7.70	6.90	0.30	7.32	1.42	7.20	6.90	0.10	7.03	pH
27.38	3007.00	1550.00	630.52	2302.83	7.67	87.00	69.00	6.05	78.83	EC
12.81	1340.00	995.00	151.89	1185.83	15.33	120.00	80.00	16.51	107.67	TDS
28.07	9.20	4.30	2.17	7.73	13.64	1.51	1.10	0.18	1.32	Turbidity
17.32	175.00	111.00	24.74	142.83	83.94	3.10	0.20	1.15	1.37	TH
50.71	232.00	37.00	75.88	149.67	87.88	4.30	0.40	1.45	1.65	Ca^{2+}
48.30	501.00	132.00	163.43	338.33	102.69	1.90	0.00	0.75	0.73	Mg^{2+}
28.28	870.00	379.00	190.30	672.83	102.69	1.90	0.00	0.75	0.73	K^{+}
54.40	40.00	6.60	13.30	24.45	50.54	8.10	2.00	2.73	5.40	Na^{+}
50.71	232.00	37.00	75.88	149.67	25.74	35.00	20.00	6.65	25.83	Cl^{-}

Source: Prepared by the researcher based on SPSS software outputs.

As for the discussion of pH, the results were quite similar between the RO water and feed water, which means that the average pH for RO water was measured at 7.03 and the average pH of feed water was found to be 7.32. On its own, it shows that the treatment process does not surely affect the quality of the water in terms of acidity and alkalinity. The pH of the RO water is characterized as having a very small coefficient of variation (V), which is equal to 1.42% compared to feed water which has V equal to 4.10%.

When it comes to the electrical conductivity of the RO water, it is equal to 78.83 µS/cm while the feed water has a bigger value which is equal to 2302.83 µS/cm that is confirmed by low coefficient of variation for electrical conductivity values (which is 7.67%) which indicates successful removal of ions and other electrically conductive materials using RO pipes.

The next quality indicator that can be discussed is turbidity, where it is estimated as 7.73 NTU in the feed water while in the case of RO water it dropped down to 1.32 NTU. Therefore, it shows a big change in terms of improvement of water quality after the process of treatment and considerable decrease in standard deviation from 2.17 to 0.18.

Finally, we can state that TDS was measured as 107.67 mg/L for RO water.The coefficient of variation for both types of water is fairly low. The RO water has a coefficient of variation of 15.33% while mains water has a coefficient of variation of 12.81%. That is, it shows good stability in the concentration of Total Dissolved Solids (TDS) in different samples.

The mean value of Total Hardness (TH) for the RO water is equal to 1.37 (standard deviation: 1.15) while for mains water, it is 142.83 (standard deviation: 24.74) which indicates a significant reduction in this value because of the use of the RO technique that removes the hardness ions from the water such as calcium and magnesium. It is important to mention that the coefficient of variation for mains water is still rather low, equal to 17.32%, compared to other values.

Speaking of calcium (Ca^{2+}) in both types of water, this parameter shows a decrease from 149.67 in mains water to 1.65 in RO water. It also means that the standard deviation decreased from 75.88 to 1.45. This means that the calcium ions that are responsible for water hardness were effectively removed.

Magnesium (Mg^{2+}) value, on the contrary, dropped from 338.33 in mains water to 0.73 in RO water.The high value of the coefficient of variation for RO water (increased to 102.69%) indicates a low average value and existence of values close to zero; however, it may not mean the presence of important fluctuations of the proportions in absolute terms.

As for sodium (Na^{+}), its average was recorded at 5.40 for RO water, while the average in mains water was 24.45 alongside with a decrease of standard deviation from 13.30 to 2.73. This means that the RO technology did not just minimize the concentration of sodium ions, but equalized their concentrations in different samples.

The average concentration of potassium (K^{+}) in RO water amounted to 0.73 against 672.83 measured in mains water. The differences confirm the substantial reduction of potassium concentration in treated water. The coefficient of variation is very high at 102.69% and is explained by low average concentration and small values, as the low arithmetic mean affects the coefficient of variation much.

Regarding the concentration of chloride ion (Cl^{-}), its mean value in RO Water made 25.83 with the standard deviation of 6.65, while for mains water it took 149.67 and a standard deviation of 75.88. This indicates that the concentration of chloride ions in RO water is reduced—that is not a surprise taking into account a high level of removal of dissolved ions by the membrane of reverse osmosis. Besides this, the coefficient of variation in mains water (50.71%) is higher comparing to RO water samples (25.74%), which means that there is a bigger variability of chloride

concentration across the different samples of mains water.

Fourth: Removal Efficiency Using Reverse Osmosis (RO) Technology

When the descriptive analysis is done, the removal efficiency (%) is calculated as well. The percentage allows getting a better understanding about the efficiency of the treatment of physical and chemical characteristics of water after passing through the reverse osmosis system.

Table (6) shows that in general RO systems are capable of high performance in case of the parameters investigated, though the levels of efficiency may differ among them. This difference is due to the nature of the ions and impurities to be removed, as well as the properties of the membranes, and the operational conditions and state of the membranes.

Table (6): Pollutant removal efficiency rates in RO water samples.

Mean	W6 %	W5 %	W4 %	W3 %	W2 %	W1 %	Variabe
96.3	97.3	95.4	97.1	97.5	94.9	95.7	EC
82.0	86.8	82.8	85.0	84.4	74.4	78.6	Turbidity
90.8	91.0	89.5	90.9	93.9	90.4	89.1	TDS
98.9	99.9	99.2	99.4	98.3	97.2	99.7	TH
98.9	99.5	99.2	99.0	98.1	98.9	98.7	Ca^{2+}
99.8	99.5	99.6	99.9	100.0	99.6	100.0	Mg^{2+}
75.2	82.8	78.7	79.8	73.8	69.7	66.2	Na^{+}
99.9	99.8	99.8	99.9	100.0	99.9	100.0	K^{+}
74.3	83.5	82.6	90.0	87.1	45.9	56.5	Cl^{-}

Source: Prepared by the researcher based on SPSS software outputs.

For the potassium ion (K^{+}), all six systems It was exhibited that, the systems were 99.8% to 100.0%, average of 99.9% for potassium removal rate. The systems lead to the excellent comparison of potassium removal as highest stability of potassium removal through RO membranes. The RO membranes exhibit the capability to prevent the passage of dissolved ions from the membranes to a great extent under optimum conditions of operation. The amount of post-treatment potassium concentration was also found to be very near zero, which means the removal efficiency was almost 100%.

In case of magnesium (Mg^{2+}), efficiency of 99.5% to 100.0% was shown with average of 99.8 %. The phenomenon is chemically justifiable as magnesium ion is a di-valent ion. This implies that RO membranes are very effective in eliminating multivalent ions contrary to the monovalent ions. The limited variability across the systems W1– 6 indicates that magnesium removal was stable, and the efficiency across systems was not affected much by operational differences.

For calcium (Ca^{2+}), the removal efficiency ranged from 98.1% to 99.5%. The results demonstrate that RO membranes were highly effective in eliminating calcium. It is important because calcium is one of the major contributors to water hardness, and high calcium removal leads to decreased total hardness of water. The results were totally aligned with the Total Hardness (TH) results where calcium removal ranged fromIt is important to highlight that W2 has the lowest rate of TH efficiency removal of 97.2%, whereas W6 was the leading system that has the

highest TH removal efficiency of 99.9%. There was a huge variance in result, but, overall, the systems show great performance concerning water hardness.

As far as Electrical Conductivity is concerned, the removal efficiency has varied between 94.9% and 97.5%, with an average of 96.3%. The process shows large reduction in ions that can conduct electricity. Besides, the values for W1-W6 remain constant, which shows some stability of the overall system concerning the ionic load of the water. The best EC efficiency indicator was obtained by W3 (97.5%), while the worst was noted for W2 (94.9%).

Concerning Total Dissolved Solids values, efficiency varied from 89.1% to 93.9%, and the average TDS efficiency was equal to 90.8%. The final numbers suggest successful operation of the project within all systems, and there is practically no difference in effectiveness of different systems. The best result was noted for W3 with 93.9% efficiency, while the worst efficiency was obtained by W1 (89.1%), which can be related to some reasons such as feed water characteristics, membrane condition, water flow rate, operating pressure, and effectiveness of proto-treatment stages in the process.

As far as chloride is concerned, the highest fluctuation was observed in this regard. The efficiency varied from 45.9% (W2) to 90.0% (W4), with the average level of W2 being 74.3%. This indicates the relatively worse efficiency of the process in terms of chloride removal compared to availability of other ions.This may be associated with the characteristics of the chloride ion being a monovalent ion, as well as the effects of membrane characteristics, feed salt concentration, operating pressure, recovery rate and the state and age of the membrane. Also, the less efficient performance of system W2.

...as distinct from the rest of the systems, may refer to differences in membrane efficiency or operating conditions; however, it is not possible to say exactly as to what specific reasons.

In the case of sodium (Na^+), the removal efficiency was from 66.2% to 82.8%, giving an average of 75.2%, which indicates that sodium removal is lower than calcium and magnesium removal, which can be explained by the nature of RO membranes that are generally considered to work better with multivalent ions than with monovalent ions and also gives the evidence of the increase of sodium removal efficiency from system W1 to W6.

With regards to turbidity, removal efficiency was between 74.4% and 86.8%, totaling an average of 82.0%. System W6 had the highest turbidity removal efficiency, whereas the lowest one belonged to W2 and this indicates an improvement of water quality in general, though the difference among the systems can be attributed to the type of water being treated, the performance of pre-filtration, and the state of the membranes.It should be acknowledged that, besides RO membranes, there are also other stages involved in controlling turbidity. Particularly, efficiency of pretreatment as well as pre-membrane filtration should be highlighted in reducing particles and suspended solids. When looking at the systems in general, it is worth mentioning that W3 performed the best as for a number of parameters after an analysis, where the highest removal efficiency for TDS (93.9%) and EC (97.5%) was recorded in the system. It is worth mentioning that 100 % effectiveness was achieved in terms of removing K^+ and Mg^{2+} ions. This shows that the system is very efficient in respect to ionic load and dissolved substances. W4 also performed really well in terms of removing Cl^- (90.0%) as well as in cases of calcium ions and TH removal. On the other hand, W6 recorded the highest performance level during Na^+ and turbidity removal as well as during TH and Ca^{2+} removal.

However, overall, W2 showed the most heterogeneous result where it achieved the lowest removal of Cl^- (45.9%), TH (97.2%), and turbidity (74.4%). Nevertheless, the system is still able to efficiently operate in terms of K^+, Mg^{2+}, and Ca^{2+} removal, which proves that having low efficiency for certain parameters does not imply poor working or functioning of the systems; rather it could be caused by specific

characteristics of the membrane, feed water as well as operational conditions.

CONCLUSIONS:

1. Thus, the physicochemical concentrations in the collected water samples are in line with the standards for desalinated water. 2- The process of desalination, by means of reverse osmosis, brought about a substantial reduction in the concentration of chemicals and sediments resulting in the water quality resembling that of distilled water. Drinking water low in mineral salt can have adverse effects on human beings, and it requires augmentation of the mineral content in water.

3- Results of the analysis confirmed the fact that the concentration in the municipal water samples was above the Maximum Permissible Concentration. This is due to the shape of pipeline network that suffers from damage and breakages due to lack of maintenance; also pollution coming from the Euphrates River plays a role in influencing the quality characteristics of water.

4- It can be said that the six RO systems performed well in terms of treatment effectiveness, demonstrating good results in removal of divalent ions as well as total hardness and high efficiency in TDS and EC reduction, while the efficiency in removal of Cl^- and Na^+ is lower and is subject to more considerable variations between different systems.

5- The values shown in the table represent the efficiency of removal for every system as well as the figures for average values, which reflect the very performance of RO systems. The question regarding presence of statistically significant difference between such systems as W1-W6 should be answered with the help of application of a proper inferential test for the data on efficiency of removal, such as One-way ANOVA test (if the requirements concerning normality of distribution and equality of variances are satisfied), or Kruskal-Wallis test (in case the mentioned requirements are not satisfied).

Recommendations:

1. Raise awareness of the employees and owners of Reverse Osmosis (RO) desalination plants about the significance of making potable water using modern sterilization and purification methods.

2. Cautions the owners of the units that they should not remove all mineral substances from the water.

3. Enhance the regulatory body approach in terms of carrying out the supervision of compliance of plant owners with respect to carrying out periodic physical and chemical analysis.

4. Reiterate the importance of regular maintenance and replacement of damaged pipes with good quality ones that can withstand the conditions of running the operation.

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