water

Article

Evaluating the Influence of Reverse Osmosis on Lakes Using Water Quality Indices: A Case Study in Saudi Arabia

Mohammed T. Aljassim *, **Abdulaziz A. AlMulla**, **Mahmoud M. Berekaa** and **Abdulmalik S. Alsaif**

Department of Environmental Health, College of Public Health, Imam Abdulrahman Bin Faisal University (IAU), P.O. Box 1982, Dammam 31441, Saudi Arabia
* Correspondence: mtaljassim@iau.edu.sa

Abstract: A drastic level of resource degradation was revealed through a preliminary evaluation (completed in 2016) of water quality in a recreational lake in the second industrial city in Dammam, Saudi Arabia. The primary signs were a foul smell, algal bloom, high turbidity, and lack of aquatic life. This study aims to evaluate the influence of reverse osmosis (RO) on lake water quality. The recreational lake consists of two connected lakes (Lakes 1 and 2), which receive treated effluent from an industrial wastewater treatment plant. Composite samples were collected from the lakes to analyze their physiochemical parameters. Descriptive analyses were performed, and two water quality indices were developed to observe the variations in water quality conditions between the two periods (2016 and 2021). The results indicated that the water parameters of total dissolved solids (TDS), sulphate (SO_4^{2-}), biological oxygen demand (BOD), and dissolved oxygen (DO) in 2016 (3356, 4100, 516, and 1.32 mg/L, respectively) were significantly improved in 2021 (2502, 1.28, 9.39, and 7.79 mg/L, respectively). The results of the water quality index (WQI) and comprehensive pollution index (CPI) indicated that the water quality in Lake 1 was significantly enhanced in 2021 (WQI = 85, CPI = 1) in comparison with assessment data from 2016 (WQI = 962, CPI = 8). However, the data from Lake 2 revealed higher pollution levels in 2021 (WQI = 1722, CPI = 18) than those recorded in 2016 (WQI = 1508, CPI = 13). As indicated by the absence of bad smells, algal blooms, and restoration of aquatic life, the RO intervention successfully improved the water quality in Lake 1. The WQI and CPI were helpful tools for evaluating lake water quality.

Keywords: reverse osmosis water quality index; comprehensive pollution index; industrial wastewater; sustainability

check for updates

Citation: Aljassim, M.T.; AlMulla, A.A.; Berekaa, M.M.; Alsaif, A.S. Evaluating the Influence of Reverse Osmosis on Lakes Using Water Quality Indices: A Case Study in Saudi Arabia. *Water* **2024**, *16*, 1351. https://doi.org/10.3390/w16101351

Academic Editor: Andrea G. Capodaglio

Received: 25 March 2024
Revised: 4 May 2024
Accepted: 5 May 2024
Published: 10 May 2024

1. Introduction

Water is an essential element for all living organisms. It plays a crucial role in their development on the Earth's surface [1–4]. There is escalating concern about the deterioration of water resources, raising interest in the challenging issue of water quality on national and international levels [5–7]. Water pollution from different sources, primarily industrial and anthropogenic activities, amplifies the need for well-established policies and regulations, particularly for evaluating water quality [8–10].

Worldwide industrial development has increased the amount of industrial pollutants dumped into the environment [11]. The improper discharge of untreated industrial wastewater is a significant concern for human health and the environment, leading to serious health hazards and environmental pollution [12]. The disposal of untreated wastewater from industrial areas to various water bodies can cause environmental problems such as a significant concentration of pathogenic microorganisms or toxic chemicals, large amounts of nutrients and organic compounds, and malodorous gases. These can lead to eutrophication, dissolved oxygen deficiency, and water contamination, eventually harming aquatic life and degrading water quality [13].

Among the primary goals of the second industrial city in Dammam is the obligation toward social responsibilities and accountabilities in various environmental protection activities. For this reason, this industrial city has established a recreational lake, which is considered the most prominent industrial lake in the Kingdom of Saudi Arabia. Significant attention has been directed toward sustainable development and environmental sustainability. Under the umbrella of laws and mechanisms for environmental sustainability, the conservation of natural resources has become a primary sustainable development goal in Saudi Arabia. Therefore, the second industrial city has moved toward adopting best practices so that bodies of water may be renewable resources.

Due to significant concern about water deterioration, its impact on the environment, and its economic threat, several methods have been developed to assess water quality. Several scholars have proposed the WQI globally to evaluate water quality within different water bodies [14–18]. The WQI is advantageous in its capacity to enable researchers to evaluate water quality in specific locations and compare it between different locations [19]. The CPI uses a statistical formula to assess the level of pollution in bodies of water [20] and has been used for the same purpose as the WQI in several studies [21–24].

The lake in the current study consisted of two lakes that were industrial lagoons in the ancient past. In 2016, many complaints were made about the lake's condition, including its foul smell, algal bloom, high turbidity, and lack of aquatic life. Therefore, in 2019, an RO treatment unit was retrofitted as a further treatment step before discharging the wastewater into the lake. A study showed that RO significantly influences water quality through dilution [25].

The main objective of this research was to evaluate the impact of RO intervention as a tertiary industrial wastewater treatment method on improving water quality in the second industrial city lake in Dammam, Saudi Arabia. Emphasis was given to assessing various water quality parameters and developing the WQI and CPI to assess the magnitude of improvement from 2016 to 2021.

2. Materials and Methods

2.1. Study Area

The second industrial city in Dammam (26°13′32.8″ N 49°58′38.4″ E), located in the Eastern Province of Saudi Arabia, contains a recreational lake. It was developed to meet the increasing need for industrial lands, to achieve industrial growth, and boost the economy [26]. The lake is considered the largest recreational lake in the kingdom and receives effluent from an industrial wastewater treatment facility. The lake is designed as two partially connected lakes (see Figure 1). The first (labeled Lake 1) is bottom-isolated and receives effluent from the wastewater treatment plant. The second (labeled Lake 2) is non-isolated and is partially connected to Lake 1.

2.2. Sample Collection

The samples were collected from four different points in each lake (26°13′32.8″ N 49°58′38.4″ E) in February of 2016 and 2021. For water analysis, three independent replicates were collected in clean, sterilized, 250 mL plastic bottles from each point (N = 24 for each year). All water samples were cooled to 4 °C and immediately transferred to the laboratory within 24 h to preserve water properties.

Figure 1. The study area shows the second industrial city lakes (Lakes 1 and 2).

2.3. RO Membrane Specifications

As shown in Table 1, the membrane type used in the treatment plant was a thin film composite (TMC) (cross-linked fully aromatic polyamide composite).

Table 1. RO membrane specifications.

Membrane Type	Cross-Linked Fully Aromatic Polyamide Composite
Membrane Diameter (inch)	8
Membrane Area (m^2)	37
Salt Rejection (%)	99.8
Flow Rate (m^3/day)	39.7
Maximum Feed Water Temperature	45 °C
Maximum Feed Water SDI (15 min)	5
Feed Water pH Range	2–11
Maximum Operating Pressure (psi)	600

2.4. Analytical Methods

pH, TDS, and electrical conductivity (EC) were measured with standard electrodes directly immersed into the samples [27] and an Orion™ 3-Star Benchtop pH Meter device (Thermo Scientific™, USA). Turbidity and free chlorine were measured by transferring 10 mL of deionized water or the sample into the turbidity sample cells [28] and using an LTC-3000we Turbidity Meter and a Chlorine Benchtop Meter (LaMotte Company, Newark, DE, USA). DO and BOD were measured using a 5-day-long BOD test [28]. The chemical oxygen demand (COD) test was conducted using the closed reflux titrimetric method [28]. Sulfate (SO_4^{2-}) was measured using the turbidimetric method [28]. Phosphate (PO_4^{3-}) was measured using the ammonium molybdate–stannous chloride method [28]. Iron (Fe) and manganese (Mn) were measured with an iCAP 6300 Duo Inductively Coupled Plasma–Optical Emission Spectrophotometer (ICP-OES, Thermo Fischer Scientific, Waltham, MA, USA) [29]. Alkalinity and hardness were measured by titration [28].

2.5. Statistical Analysis

The data in this assessment were statistically analyzed using an Excel sheet to calculate the mean and the standard error of the mean. The Excel sheet was also used to generate multiple charts to compare levels of water quality parameters between 2016 and 2021, and to compare the results of the different water quality indices used in this study. R studio 4.2.2 was used to calculate Pearson's correlation coefficients and generate the plots.

2.6. Water Quality Index (WQI)

Eleven water quality parameters, shown in Table 2, were included in the calculation of the WQI. Similar studies have used four steps to calculate the index [24,30,31].

Table 2. Analysis of water quality parameters of the lakes from 2016 to 2021.

Parameter	**Lake 1**		**Lake 2**		**RO [1] Intervention**		**SD [2] (NCEC) [3]**	**AW_i [4]**	**RW_i [5]**	**Indices (i)**
	2016	2021	2016	2021	Before	After				
pH	9.22	8.13	8.7	7.51	7.74	6.93	8	5	0.128	1
TDS (mg/L)	3356	2502	67,665	100,373	3161	148	5000	4	0.102	2
Conductivity (ms/cm)	3.34	3.49	76.8	205.49	3.64	0.2	5	3	0.076	3
Turbidity (NTU)	0.5	0.3	15	48.83	0.69	0.33	30	4	0.102	4
DO (mg/L)	1.32	7.79	1.12	47.25	8.07	6.5	5	5	0.128	5
BOD (mg/L)	516	9.39	660	8.83	7	7.7	10	5	0.128	6
COD (mg/L)	30	53.07	197	2128	79.73	35.47	25	5	0.128	7
SO_4^{2-} (mg/L)	4100	1.28	4200	45	3.77	0.11	200	3	0.076	8
PO_4^{3-} (mg/L)	8.9	0.12	12.6	0.925	2.4	0.11	1	3	0.076	9
Fe (mg/L)	0.03	0.01	0	0.241	0.13	1.63	0.5	1	0.025	10
Mn (mg/L)	0.02	0.4	0	4.20	0.57	0.4	0.1	1	0.025	11
Free chlorine (mg/L)	1758	0.03	56,813	0.29	0.28	0.04	-	-	-	-
Alkalinity (mg/L)	340	153.75	320	2079	346.67	28.33	-	-	-	-
Hardness (mg/L)	2540	921	14,500	17,908	910	70	-	-	-	-

Notes: [1] (RO) reverse osmosis; [2] (SD) standard values; [3] (NCEC) National Center for Environmental Compliance, Saudi Arabia; [4] (AW_i) assigned weight; and [5] (RW_i) relative weight.

Step 1: For each parameter, an assigned weight (AW_i) was set (1 to 5), where 1 was the least significant parameter and 5 was the highest (Table 3). This was based on the purpose of the model, the nature of the study area, and the combined opinions of experts from previous studies [32–35]. The WQI model is based primarily on the relative weights of water quality parameters, so there is no universally accepted WQI [36]. Available indices have many variations and limitations based on the number of water quality parameters used. All of the developed indices worldwide have variations and limitations based on the water quality variables involved in the model [34].

Table 3. Categories of water quality for WQI and CPI.

Water Quality Condition	WQI [31]	CPI [31]
Clean	<50	<0.20
Sub-clean	50–100	0.21–0.40
Slightly polluted	100–200	0.41–1.00
Medium polluted	200–300	1.01–2.00
Highly polluted	>300	>2.01

Step 2: The following equation was used to calculate a relative weight (RW_i) for each parameter:

$$RW_i = \frac{AW_i}{\sum_{i=1}^{n} AW_i} \quad (1)$$

where RW_i is the relative weight of each parameter, AW_i is the assigned weight of each parameter, and n is the number of parameters.

Step 3: The following equation was used to calculate a quality rating scale (Q_i) for all of the parameters except for DO and pH:

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \quad (2)$$

where C_i is the measured value of the parameter, and S_i is the standard value of the parameter.

The C_i for DO and pH was calculated using the following equation:

$$Q_i = \left(\frac{C_i V_i}{S_i V_i}\right) \times 100 \quad (3)$$

where V_i is the ideal value (14.6 for DO and 7.0 for pH).

Step 4: Before calculating the WQI, the sub-indices (SI_i) for each parameter were calculated using the following equation:

$$SI_i = RW_i \times Q_i \quad (4)$$

Finally, the WQI was calculated using the following equation:

$$WQI = \sum_{i=1}^{n} SI_i \quad (5)$$

The WQI values were classified into different categories according to Son [24] (Table 3).

2.7. Comprehensive Pollution Index (CPI)

The CPI was used to assess the pollution level of the lakes. Like the WQI, eleven water quality parameters (shown in Table 2) were included in the CPI calculations. The index was calculated using the following formula [20].

$$CPI = \frac{n}{1}\sum_{i=1}^{n} PI_i \quad (6)$$

where CPI is the comprehensive pollution index, n is the number of parameters, and PI_i is the pollution index for a single water quality parameter.

Finally, the PI_i was calculated according to the following equation:

$$PI_i = \frac{C_i}{S_i} \quad (7)$$

where C_i is the measured value of the parameter, and S_i is the standard value of the parameter.

3. Results

Several water quality parameters were investigated to assess the influence of RO treatment on lake water quality (see Table 2).

3.1. Water Quality Parameters in the Influent and Effluent of the RO Unit

As shown in Table 2, the levels of multiple water quality parameters were significantly improved after RO intervention. These parameters include TDS, COD, alkalinity, and hardness. Their concentrations before RO treatment were 3161, 79.73, 346.67, and 910 mg/L, which then reduced to 148, 35.47, 28.33, and 70 mg/L, respectively, after treatment.

3.2. Water Quality Parameters in the Lakes

Multiple water quality parameters improved in 2021 (see Figure 2). As shown in Table 2, pH readings in the lakes decreased from 2016 to 2021. In 2016, the pH in Lake 1 was 9.22, compared to 8.13 in 2021. The pH in Lake 2 was 8.7 in 2016, and 7.51 in 2021. In general, observations showed a higher concentration of TDS in Lake 2 than in Lake 1. In Lake 1, the TDS value was 3354 mg/L in 2016, and was reduced to 2502 mg/L in 2021. However, in Lake 2, it increased from 67,665 mg/L in 2016 to 100,373 mg/L in 2021. The results showed a significant variation in EC readings in Lake 2 compared to Lake 1. This may be due to the significant increase in the concentration of TDS in Lake 2. The EC in Lake 1 was 3.34 ms/cm in 2016, and 3.49 ms/cm in 2021. In Lake 2, it was 76.8 ms/cm in 2016, which increased to 205.49 ms/cm in 2021. As illustrated in Table 2, the turbidity was higher in Lake 2 than in Lake 1. In 2016, it was 0.5 NTU in Lake 1, which decreased to 0.3 NTU in 2021, while in Lake 2, the turbidity reading was 15 NTU in 2016, which increased significantly to 48.83 NTU in 2021.

The study results show that the concentration of DO was lower in 2016 and elevated in 2021 in both lakes. In 2016, it was 1.32 mg/L in Lake 1 and 1.12 mg/L in Lake 2. By contrast, it increased to 7.79 mg/L in Lake 1 and 47.25 mg/L in Lake 2 in 2021. Interestingly, the BOD level decreased significantly in 2021 compared to 2016. In 2016, it was 516 mg/L and 660 mg/L in both lakes, respectively, whereas in 2021, it was 9.39 mg/L in Lake 1 and 8.83 mg/L in Lake 2. COD had a higher concentration in Lake 2 than in Lake 1. In Lake 1, it was 30 mg/L in 2016, which increased to 53.07 mg/L in 2021. In Lake 2, it was 197 mg/L in 2016, which increased significantly to 2128 mg/L in 2021.

The $SO_4{}^{2-}$ level was much higher in 2016 than in 2021 in both lakes. In 2016, it was 4100 mg/L in Lake 1 and 4200 mg/L in Lake 2, whereas in 2021, it decreased radically to 1.28 mg/L and 45 mg/L in Lake 1 and Lake 2, respectively. As shown in Table 2, the $PO_4{}^{3-}$ level decreased significantly from 2016 to 2021 in both lakes. In 2016, it was 8.9 mg/L in Lake 1 and 12.6 mg/L in Lake 2, whereas in 2021, readings of 0.12 mg/L in Lake 1 and 0.925 mg/L in Lake 2 were obtained. The study observations indicated a significant reduction in free chlorine levels in both lakes. In 2016, it was 1758 mg/L in Lake 1 and 56,813 mg/L in Lake 2, whereas in 2021, measurements were obtained of 0.03 mg/L and 0.29 mg/L in Lake 1 and Lake 2, respectively.

The study results show that the alkalinity in Lake 1 was 340 mg/L in 2016, which decreased to 153.75 mg/L in 2021. On the other hand, the alkalinity of Lake 2 was 320 mg/L in 2016, and increased to 2079 mg/L in 2021. In Lake 1, the hardness level was 2540 mg/L in 2016, which decreased to 921 mg/L in 2021. However, in Lake 2, it was 14,500 mg/L in 2016, which increased to 17,909 mg/L in 2021. Like alkalinity and hardness, the Fe concentration decreased in Lake 1 and increased in Lake 2. In Lake 1, it was 0.03 mg/L in 2016 and decreased to 0.01 mg/L in 2021. In Lake 2, it was not detected in the 2016 sample, but it was 0.24 mg/L in 2021. As shown in Table 2, Mn measurements were higher in 2021 than in 2016 in both lakes. In Lake 1, it was 0.02 mg/L in 2016, which increased to 0.4 mg/L in 2021. By contrast, in Lake 2, it was not detected in the 2016 sample, but in 2021, it was 4.21 mg/L.

(**a**) (**b**) (**c**) (**d**)

Figure 2. (**a**) Lake 1 before (2016) and (**b**) after (2021) the RO intervention; (**c**) Lake 2 before (2016) and (**d**) after (2021) the RO intervention.

3.3. Water Quality Indices

3.3.1. Water Quality Index (WQI)

As shown in Figure 3, the WQI for Lake 1 improved significantly in 2021 to the sub-clean condition (85), while in 2016, it was highly polluted (962). By contrast, Lake 2 was highly polluted in both years, with a noticeable increase in the index value in 2021 (1722) compared to 2016 (1508).

3.3.2. Comprehensive Pollution Index (CPI)

As shown in Figure 3, the CPI results indicated that the water quality in Lake 1 improved from highly polluted (8) in 2016 to slightly polluted (1) in 2021. Lake 2 remained highly polluted in both years, as the CPI value was 13in 2016 and increased to 18in 2021.

3.3.3. Pearson's Correlation Matrix between Water Quality Parameters

As presented in Figure 4, the correlation matrix indicated numerous significant correlations between water quality parameters for Lake 1 in 2021. There was a positive correlation between turbidity and COD. Likewise, EC showed a positive correlation with free chlorine, SO_4^{2-}, and Fe. Hardness was positively correlated with pH. Additionally, there was a positive correlation between Mn and TDS.

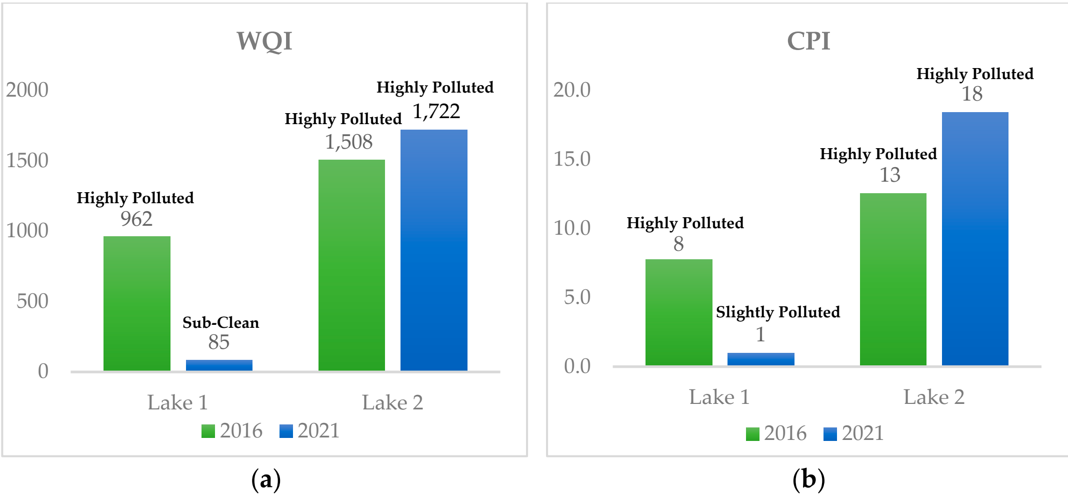

Figure 3. (**a**) WQI for Lakes 1 and 2 for 2016 and 2021; (**b**) CPI for Lakes 1 and 2 for 2016 and 2021.

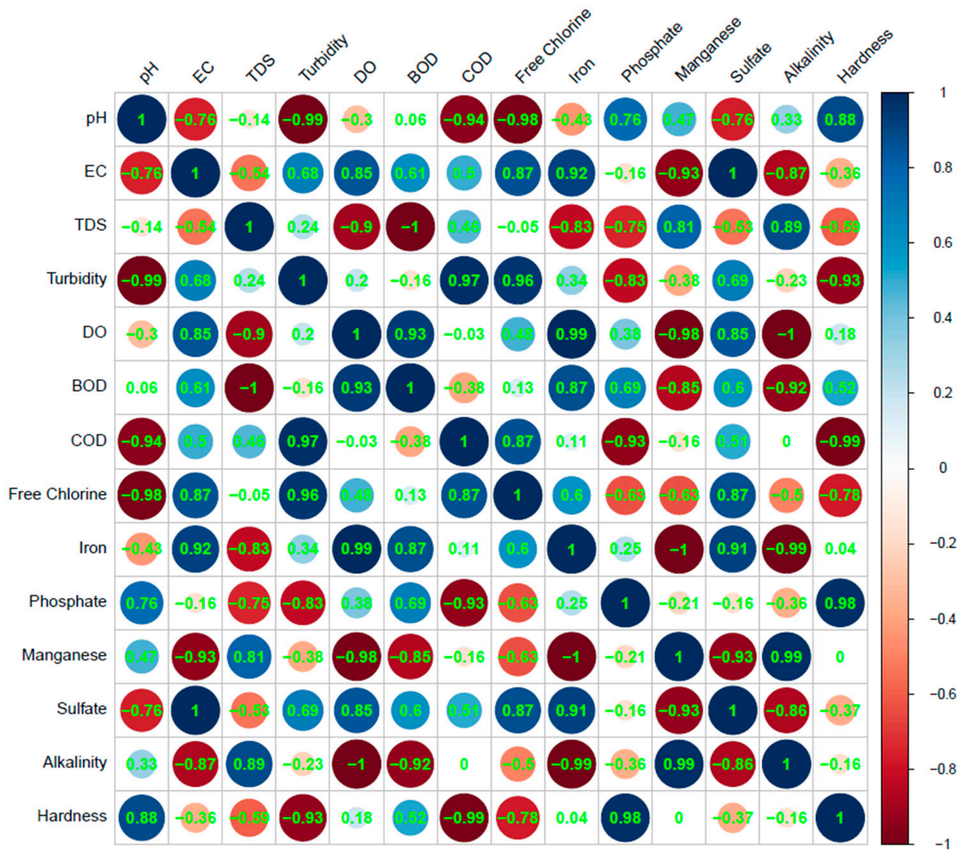

Figure 4. Pearson's correlation matrix between water quality parameters for Lake 1 in 2021.

Moreover, a negative correlation was found between pH and turbidity. Alkalinity was negatively correlated with BOD and Fe. TDS showed a negative correlation with DO.

4. Discussion

The water analysis results indicate that RO has significantly improved the quality of the influent from the tertiary treatment plant. A previous study indicated that cross-linked polyamide TFC membranes efficiently removed organic contaminants in wastewater treatment [37]. These polyamide TFC membranes are commonly used for RO applications in industrial wastewater [38]. The RO treatment significantly improved the water quality in Lake 1 by the dilution mechanism. The impaired water within the lake was diluted with high-quality treated water [25,39,40].

In this study, water quality parameters were monitored in the two lakes during 2016 and 2021. The results shown in Table 2 indicate a noticeable improvement, particularly in Lake 1. After implementing the RO as a tertiary treatment unit, improvements were made in the physical, chemical, and biological properties of Lake 1.

Generally, the TDS of industrial wastewater improves by approximately 95% after RO, as reported by [41,42]. Fortunately, the TDS in Lake 1 improved by 25%, from 3356 mg/L to 2502 mg/L, after tertiary treatment. In contrast, the TDS in Lake 2 increased by about 48%. A possible explanation for this increase might be because Fe and Mn salts were added to remove PO_4^{3-}. This also explains the increase in Fe and Mn levels in Lake 2 in 2021. In reviewing the literature, several methods have been used to reduce phosphorus in wastewater, as reported by [43]. The efficient use of iron chloride to remove phosphorus from Dianchi Lake was demonstrated by [44]. Oxides of metals (e.g., Fe) have also been used to remove phosphorus from industrial wastewater [45].

Hardness values also increased in Lake 2 and decreased in Lake 1. The efficient removal of TDS in Lake 1 with the RO method reduced the hardness levels in Lake 1. Zhao [46] has demonstrated the enhanced removal of hardness from saline water by electrocoagulation pretreatment before RO.

Another finding that stands out from these results is that a drastic decrease in BOD and a significant increase in DO were observed in both lakes. According to [47], BOD and DO are inversely related. Given the negative correlation found in Lake 1 between TDS and DO, the increase in DO could be explained by the decrease in TDS, which led to a decrease in the BOD level.

In 2016, the SO_4^{2-} concentration in both lakes was highly elevated, which could have resulted from the direct wastewater discharge from several industries [48]. However, SO_4^{2-} levels improved significantly in 2021. RO successfully lowered the SO_4^{2-} concentration of the two lakes. Research has shown [49,50] that nanofiltration and RO are promising techniques for lowering high SO_4^{2-} concentrations in water.

The results show that the free chlorine concentration in both lakes was elevated. Interestingly, tertiary treatment with RO led to a drastic decrease in the free chlorine level. According to [51,52], the use of RO is effective in reducing chloride levels in wastewater.

The primary purpose of developing water quality indices is to compare changes in water quality over different periods. Unsurprisingly, the results of the WQI indicate that the water quality in Lake 1 improved, while Lake 2 remained highly polluted. This result was expected, as the initial results for some water quality parameters in Lake 2 were elevated, which indicated poor water quality.

When comparing water quality parameters from 2021 and 2016 in Lake 1, this study showed that TDS, turbidity, DO, BOD, SO_4^{2-} concentration, PO_4^{3-} concentration, free chlorine, alkalinity, and hardness had all improved. On the other hand, in Lake 2, the study results showed that the levels of TDS, electrical conductivity, turbidity, COD, alkalinity, hardness, Fe, and Mn had increased between 2016 and 2021, which explains the highly polluted status indicated by the WQI and CPI for both study periods. One of the factors that improved water quality in Lake 1 is that the bottom of the lake was constructed with insulation material. This material has the advantage of preventing the pollutants from accumulating at the bottom of the lake, which in turn contributes to reducing turbidity, TDS, and other unwanted contaminants.

In contrast, the bottom of Lake 2 is not isolated. Therefore, there is a possibility that the water pollution increased due to mixing water with the accumulated pollutants in the soil at the bottom of the lake. Another reason for the degraded level of water quality parameters in Lake 2 is that RO effluents are directly discharged into Lake 1. Since the two lakes are partially connected, this obstructs water flow from Lake 1 to Lake 2. In this case, the dilution process in Lake 2 would be minimal compared to Lake 1. Nevertheless, foam was noticed in some parts of Lake 2 (see Figure 2). This foam might be due to an unknown source of untreated wastewater that Lake 2 may receive, especially since both lakes were industrial lagoons in the past.

The primary purpose of performing the correlation analysis between the parameters was to explore the nature of the relationships between them, with the aim to help explain the reasons for the abnormal levels of some water quality parameters within the lake. The analysis of correlation in our study indicated that there is a positive relationship between turbidity and COD. High levels of COD indicate the presence of pollutants such as organic matter, industrial effluents, and solid waste. These pollutants usually increase turbidity in water bodies; thus, when COD increases, the turbidity also increases. Therefore, eliminating the contaminants that increase the COD level will reduce the lake's turbidity. COD is a significant concern in both lakes, which is expected since the lakes receive effluent from industrial wastewater treatment plants.

Another positive correlation was explored in the analysis between EC and free chlorine, SO_4^{2-}, and Fe. According to [53], it was found that the presence of inorganic dissolved solids, including cations (such as Fe) and anions (such as chloride and SO_4^{2-}), affects the conductivity of water, because conductivity increases when the concentration of dissolved solids increases. These findings are interesting since the EC level in Lake 1 was within the acceptable limit, as was the case with free chlorine, SO_4^{2-}, and Fe. This study also indicated a positive correlation between hardness and pH. A possible explanation for this result is that hard water (with a high concentration of minerals) usually has a high pH (above 8.5). This finding indicates the importance of maintaining the permitted levels of minerals to achieve an acceptable pH within the lake. This result is consistent with the findings of [54]. Furthermore, Mn and TDS were found to have a positive correlation. Mn is classified as one of the dissolved solids in water; therefore, TDS increases proportionally with Mn [55]. Consistent with this study's results, ref. [56] demonstrated that DO is inversely related to TDS.

Turbidity was found to be negatively correlated with pH. According to [57], high-pH conditions in water enable colloids to deposit in the bottom of lakes due to the colloidal particle's opposite charge. Therefore, the increased pH value is a determinant for low turbidity due to sedimentation, which causes water turbidity to decrease. This observation suggests a solution for controlling turbidity, which is one of the main issues in both lakes. This finding is consistent with ref. [58]. Alkalinity and BOD were found to be negatively correlated. Interestingly, alkalinity was found to be negatively correlated with iron concentration. This might be explained by the fact that water with a high Fe concentration usually has a low pH level, meaning that an increase in Fe may cause alkalinity to decrease [59].

5. Conclusions

The main goal of the current study was to evaluate the impact of RO intervention that was implemented to improve water quality in the second industrial city lake. The most prominent finding from this study is that water quality has been enhanced, primarily in Lake 1, as indicated by the absence of bad smells, the disappearance of algal blooms, and the return of aquatic life. Despite this improvement, further modifications should be applied to maximize the enhancement in the water quality of Lake 1. The results also revealed that more studies are needed to investigate the possible application of novel remediation strategies to improve water quality in Lake 2.

One of this study's limitations is that temporal variations regarding the development of water quality indices should have been examined. Consequently, a further limitation was that this study needed to analyze the correlation between water quality parameters and indices. Further modifications should be applied to maximize the water quality of Lake 1. Additional studies are required to investigate the impact of further interventions on the water quality of the lakes.

Author Contributions: Conceptualization, M.M.B. and M.T.A.; methodology, M.T.A. and A.S.A.; sampling, A.A.A. and M.T.A.; lab works, A.A.A. and M.M.B.; data curation, A.A.A.; formal analysis, M.T.A. and A.S.A.; investigation, M.T.A. and M.M.B.; writing—original draft preparation, M.T.A.

and A.A.A.; writing—review and editing, M.M.B. and A.S.A.; visualization, M.T.A. and A.S.A.; supervision, M.T.A.; project administration, A.S.A.; funding acquisition, M.T.A. and A.A.A. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Deanship of Scientific Research, Imam Abdulrahman Bin Faisal University (IAU), Saudi Arabia, grant number (2020-103-CPH).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available, due to restrictions.

Acknowledgments: The authors acknowledge the financial support from the Deanship of Scientific Research (DSR), Imam Abdulrahman Bin Faisal University (IAU), Saudi Arabia (Grant Application No. (2020-103-CPH). The authors acknowledge the great support of the "Second Industrial City" in Dammam for the administrative support in conducting the study.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Falkenmark, M. Water resilience and human life support-global outlook for the next half century. *Int. J. Water Resour. Dev.* **2020**, *36*, 377–396. [CrossRef]
2. Jéquier, E.; Constant, F. Water as an essential nutrient: The physiological basis of hydration. *Eur. J. Clin. Nutr.* **2010**, *64*, 115–123. [CrossRef] [PubMed]
3. Molden, D. *Water for Food Water for Life: A Comprehensive Assessment of Water Management in Agriculture*; Routledge: Oxfordshire, UK, 2013.
4. Strang, V. *The Meaning of Water*; Routledge: Oxfordshire, UK, 2020.
5. Johnson, B.L.; Lichtveld, M.Y. *Environmental Policy and Public Health*; CRC Press: Boca Raton, FL, USA, 2017.
6. Landrigan, P.J.; Fuller, R.; Acosta, N.J.; Adeyi, O.; Arnold, R.; Baldé, A.B.; Bertollini, R.; Bose-O'Reilly, S.; Boufford, J.I.; Breysse, P.N. The Lancet Commission on pollution and health. *Lancet* **2018**, *391*, 462–512. [CrossRef] [PubMed]
7. Schwarzenbach, R.P.; Egli, T.; Hofstetter, T.B.; Von Gunten, U.; Wehrli, B. Global water pollution and human health. *Annu. Rev. Environ. Resour.* **2010**, *35*, 109–136. [CrossRef]
8. Danquah, L.; Abass, K.; Nikoi, A.A. Anthropogenic pollution of inland waters: The case of the Aboabo River in Kumasi, Ghana. *J. Sustain. Dev.* **2011**, *4*, 103. [CrossRef]
9. Halder, J.N.; Islam, M.N. Water pollution and its impact on the human health. *J. Environ. Hum.* **2015**, *2*, 36–46. [CrossRef]
10. Zhang, L. Different methods for the evaluation of surface water quality: The Case of the Liao River, Liaoning Province, China. *Int. Rev. Spat. Plan. Sustain. Dev.* **2017**, *5*, 4–18. [CrossRef] [PubMed]
11. Shindhal, T.; Rakholiya, P.; Varjani, S.; Pandey, A.; Ngo, H.H.; Guo, W.; Ng, H.Y.; Taherzadeh, M.J. A critical review on advances in the practices and perspectives for the treatment of dye industry wastewater. *Bioengineered* **2021**, *12*, 70–87. [CrossRef] [PubMed]
12. Okereke, J.N.; Ogidi, O.I.; Obasi, K.O. Environmental and health impact of industrial wastewater effluents in Nigeria-A Review. *Int. J. Adv. Res. Biol. Sci.* **2016**, *3*, 55–67.
13. Nahiun, K.M.; Sarker, B.; Keya, K.N.; Mahir, F.I.; Shahida, S.; Khan, R.A. A review on the methods of industrial waste water treatment. *Sci. Rev.* **2021**, *7*, 20–31. [CrossRef]
14. Gaur, N.; Sarkar, A.; Dutta, D.; Gogoi, B.J.; Dubey, R.; Dwivedi, S.K. Evaluation of water quality index and geochemical characteristics of surfacewater from Tawang India. *Sci. Rep.* **2022**, *12*, 11698. [CrossRef] [PubMed]
15. Mammeri, A.; Tiri, A.; Belkhiri, L.; Salhi, H.; Brella, D.; Lakouas, E.; Tahraoui, H.; Amrane, A.; Mouni, L. Assessment of Surface Water Quality Using Water Quality Index and Discriminant Analysis Method. *Water* **2023**, *15*, 680. [CrossRef]
16. Şener, Ş.; Şener, E.; Davraz, A. Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Sci. Total Environ.* **2017**, *584*, 131–144. [CrossRef] [PubMed]
17. Tian, Y.; Jiang, Y.; Liu, Q.; Dong, M.; Xu, D.; Liu, Y.; Xu, X. Using a water quality index to assess the water quality of the upper and middle streams of the Luanhe River, northern China. *Sci. Total Environ.* **2019**, *667*, 142–151. [CrossRef] [PubMed]
18. Tripathi, M.; Singal, S.K. Use of principal component analysis for parameter selection for development of a novel water quality index: A case study of river Ganga India. *Ecol. Indic.* **2019**, *96*, 430–436. [CrossRef]
19. Bhateria, R.; Jain, D. Water quality assessment of lake water: A review. *Sustain. Water Resour. Manag.* **2016**, *2*, 161–173. [CrossRef]
20. Liu, S.; Zhu, J.P.; Jiang, H.H. Comparison of several methods of environment quality evaluation using complex indices. *Environ. Monit.* **1999**, *15*, 33–37.
21. Abdulkareem, I.A.; Abbas, A.A.; Dawood, A.S. Modeling Pollution Index Using Artificial Neural Network and Multiple Linear Regression Coupled with Genetic Algorithm. *J. Ecol. Eng.* **2022**, *23*, 236–250. [CrossRef]
22. Döndü, M.; Özdemir, N.; Demirak, A.; Doğan, H.M.; Dincer, N.G.; Keskin, F. Seasonal assessment of the impact of fresh waters feeding the Bay of Gökova with water quality index (WQI) and comprehensive pollution index (CPI). *Environ. Forensics* **2022**, *25*, 68–80. [CrossRef]
23. Mishra, S.; Kumar, A.; Shukla, P. Study of water quality in Hindon River using pollution index and environmetrics, India. *Desalination Water Treat.* **2016**, *57*, 19121–19130. [CrossRef]

24. Son, C.T.; Giang, N.T.H.; Thao, T.P.; Nui, N.H.; Lam, N.T.; Cong, V.H. Assessment of Cau River water quality assessment using a combination of water quality and pollution indices. *J. Water Supply: Res. Technol.—AQUA* **2020**, *69*, 160–172. [CrossRef]
25. Trishitman, D.; Cassano, A.; Basile, A.; Rastogi, N.K. Reverse osmosis for industrial wastewater treatment. In *Current Trends and Future Developments on (Bio-) Membranes*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 207–228.
26. Ibrahim, A.O.; Bashir, F.M.; Ojobo, H.; Dodo, Y.A.; Abdulmumin, I.; Christian, O.I. Opting for Enriching Saudi Arabia's Tourism Attraction Sites towards the Realization of Vision 2030. *Elem. Educ. Online* **2021**, *20*, 4101–4114.
27. AlMulla, A.A.; Jones, D.; Roberts, P. Substrate influences temperature sensitivity of dissolved organic carbon (DOC) and nitrogen (DON) mineralization in arid agricultural soils. *Soil Syst.* **2018**, *2*, 28. [CrossRef]
28. Baird, R.; Rice, E.; Eaton, A. *Standard Methods for the Examination of Water and Wastewaters*; American Public Health Association: Washington, DC, USA, 2017.
29. AMulla, A.A.; Saber, O.; Ezzeldin, M.F.; Berekaa, M.M.; El-Azab, W.I. Dual-Functional Nanostructures for Purification of Water in Severe Conditions from Heavy Metals and *E. coli* Bacteria. *Water* **2022**, *14*, 3010. [CrossRef]
30. Kükrer, S.; Mutlu, E. Assessment of surface water quality using water quality index and multivariate statistical analyses in Saraydüzü Dam Lake, Turkey. *Environ. Monit. Assess.* **2019**, *191*, 71. [CrossRef] [PubMed]
31. Maansi; Jindal, R.; Wats, M. Evaluation of surface water quality using water quality indices (WQIs) in Lake Sukhna, Chandigarh, India. *Appl. Water Sci.* **2022**, *12*, 2. [CrossRef]
32. Brown, R.M.; McClelland, N.I.; Deininger, R.A.; Tozer, R.G. A water quality index-do we dare. *Water Sew. Work* **1970**, *117*, 339–343.
33. Soleimani, H.; Nasri, O.; Ojaghi, B.; Pasalari, H.; Hosseini, M.; Hashemzadeh, B.; Kavosi, A.; Masoumi, S.; Radfard, M.; Adibzadeh, A. Data on drinking water quality using water quality index (WQI) and assessment of groundwater quality for irrigation purposes in Qorveh&Dehgolan, Kurdistan, Iran. *Data Brief* **2018**, *20*, 375–386. [PubMed]
34. Tyagi, S.; Sharma, B.; Singh, P.; Dobhal, R. Water quality assessment in terms of water quality index. *Am. J. Water Resour.* **2013**, *1*, 34–38. [CrossRef]
35. Wu, Z.; Wang, X.; Chen, Y.; Cai, Y.; Deng, J. Assessing river water quality using water quality index in Lake Taihu Basin, China. *Sci. Total Environ.* **2018**, *612*, 914–922. [CrossRef]
36. Sutadian, A.D.; Muttil, N.; Yilmaz, A.G.; Perera, B.J.C. Development of river water quality indices—A review. *Environ. Monit. Assess.* **2016**, *188*, 1–29. [CrossRef] [PubMed]
37. Rastgar, M.; Shakeri, A.; Karkooti, A.; Asad, A.; Razavi, R.; Sadrzadeh, M. Removal of trace organic contaminants by melamine-tuned highly cross-linked polyamide TFC membranes. *Chemosphere* **2020**, *238*, 124691. [CrossRef] [PubMed]
38. Li, Q.-M.; Ma, H.-Y.; Hu, Y.-N.; Guo, Y.-F.; Zhu, L.-J.; Zeng, Z.-X.; Wang, G. Polyamide thin-film composite membrane on polyethylene porous membrane: Fabrication, characterization and application in water treatment. *Mater. Lett.* **2021**, *287*, 129270. [CrossRef]
39. Priyanka, M.S.; Mohapatra, S.; Menon, N.G. Chapter 23—Hybrid membrane technology: An alternative to industrial wastewater treatment. In *Membrane-Based Hybrid Processes for Wastewater Treatment*; Shah, M.P., Rodriguez-Couto, S., Eds.; Elsevier: Amsterdam, The Netherlands, 2021; pp. 481–501, ISBN 978-0-12-823804-2.
40. Venzke, C.D.; Rodrigues, M.A.S.; Giacobbo, A.; Bacher, L.E.; Lemmertz, I.S.; Viegas, C.; Striving, J.; Pozzebon, S. Application of reverse osmosis to petrochemical industry wastewater treatment aimed at water reuse. *Manag. Environ. Qual. Int. J.* **2017**, *28*, 70–77. [CrossRef]
41. Li, L.; Li, S.; Dong, Y.; Yang, P.; Wang, R. Pilot Study on the Deep Treatment of Sulfuric-Acid–Titanium-Dioxide Wastewater Using an Ultrafiltration/Reverse Osmosis Process. *Processes* **2023**, *11*, 1626. [CrossRef]
42. Elhady, S.; Bassyouni, M.; Mansour, R.A.; Elzahar, M.H.; Abdel-Hamid, S.; Elhenawy, Y.; Saleh, M.Y. Oily wastewater treatment using polyamide thin film composite membrane technology. *Membranes* **2020**, *10*, 84. [CrossRef] [PubMed]
43. Bunce, J.T.; Ndam, E.; Ofiteru, I.D.; Moore, A.; Graham, D.W. A review of phosphorus removal technologies and their applicability to small-scale domestic wastewater treatment systems. *Front. Environ. Sci.* **2018**, *6*, 8. [CrossRef]
44. Li, S.; Jiang, F.; Lei, T.; Ren, Z.; Wang, S.; Yang, X. Phosphorus removal by in situ sprayed ferric chloride in Dianchi Lake: Efficiency, stability, and mechanism. *Process Saf. Environ. Prot.* **2019**, *131*, 320–328. [CrossRef]
45. Fish, D.H.; Dietz, J.M. *Use of Iron Oxides Produced from the Treatment of Coal Mine Drainage as Adsorbents to Remove Phosphorus from Secondary Wastewater Effluent*; Final Report for OSM PA (AMD-04) Grant; Pennsylvania Department of Environmental Protection: Harrisburg, PA, USA, 2008.
46. Zhao, S.; Huang, G.; Cheng, G.; Wang, Y.; Fu, H. Hardness, COD and turbidity removals from produced water by electrocoagulation pretreatment prior to reverse osmosis membranes. *Desalination* **2014**, *344*, 454–462. [CrossRef]
47. Mishra, A.P.; Kumar, S.; Patra, R.; Kumar, A.; Sahu, H.; Chandra, N.; Pande, C.B.; Alshehri, F. Physicochemical Parameters of Water and Its Implications on Avifauna and Habitat Quality. *Sustainability* **2023**, *15*, 9494. [CrossRef]
48. Tejada-Tovar, C.; Villabona-Ortíz, Á.; Gonzalez-Delgado, A.D.; Herrera, A.; Viera De la Voz, A. Efficient sulfate adsorption on modified adsorbents prepared from Zea mays stems. *Appl. Sci.* **2021**, *11*, 1596. [CrossRef]
49. Sawadogo, B.; Konaté, Y.; Sossou, S.K.; Ado Saidou, N.F.; Nouhou Moussa, A.W.; Karambiri, H. Removal of Sulphate Ions from Borehole Water Using Nanofiltration and Reverse Osmosis. *Water* **2022**, *14*, 3422. [CrossRef]
50. Yang, Z.; Zhou, Y.; Feng, Z.; Rui, X.; Zhang, T.; Zhang, Z. A review on reverse osmosis and nanofiltration membranes for water purification. *Polymers* **2019**, *11*, 1252. [CrossRef] [PubMed]

51. Panwattanakul, S.; Kasikun, K.; Musikavong, C.; Sinyoung, S. Reduction Of Chloride in Raw Water by Nanofiltration and Reverse Osmosis. In Proceedings of the IOP Conference Series: Materials Science and Engineering; IOP Publishing: Bristol, UK, 2021; Volume 1163, p. 012026.
52. Simonič, M. Reverse osmosis treatment of wastewater for reuse as process Water—A case study. *Membranes* **2021**, *11*, 976. [CrossRef] [PubMed]
53. USEPA Water: Monitoring & Assessment. Available online: https://archive.epa.gov/water/archive/web/html/vms59.html (accessed on 6 August 2023).
54. Arimoro, F.O.; Ikomi, R.B.; Iwegbue, C.M. Water quality changes in relation to Diptera community patterns and diversity measured at an organic effluent impacted stream in the Niger Delta, Nigeria. *Ecol. Indic.* **2007**, *7*, 541–552. [CrossRef]
55. Ruiz-Ramírez, J.; Arnau, J.; Serra, X.; Gou, P. Relationship between water content, NaCl content, pH and texture parameters in dry-cured muscles. *Meat Sci.* **2005**, *70*, 579–587. [CrossRef] [PubMed]
56. Momin, S. Statistical Analysis of Physico-Chemical Parameters. *Int. Res. J. Adv. Sci. Hub* **2020**, *2*, 118–122. [CrossRef]
57. Mohammed, S.S. Effect of pH on the Turbidity Removal of Wastewater. *Open Access Libr. J.* **2015**, *2*, 1. [CrossRef]
58. Khatoon, N.; Khan, A.H.; Rehman, M.; Pathak, V. Correlation study for the assessment of water quality and its parameters of Ganga River, Kanpur, Uttar Pradesh, India. *IOSR J. Appl. Chem.* **2013**, *5*, 80–90. [CrossRef]
59. Roosta, H.R. Interaction between water alkalinity and nutrient solution pH on the vegetative growth, chlorophyll fluorescence and leaf magnesium, iron, manganese, and zinc concentrations in lettuce. *J. Plant Nutr.* **2011**, *34*, 717–731. [CrossRef]