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Seasonal Variations of Phytoplankton Community and Physico-Chemical Characteristics of Water Desalination Plants at Red Sea Governorate, Egypt

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Desalination of seawater offers a promising solution to local water shortages and provides safe drinking water. Reverse osmosis (RO) is currently the most widely used method for seawater desalination. This study monitored five RO desalination plants: El Yosr, Safaga, and Shalateen (which use open intake for feed water), and Qusser and Marsa Alam (which use shore well feed water). Over the course of a year, seasonal samples were collected to observe the abundance of phytoplankton in relation to the physicochemical quality of Red Sea water. Various physicochemical parameters were analyzed, and phytoplankton communities were identified. The analysis revealed that the type of feed water significantly influenced water quality, with shore well feed water showing better physicochemical characteristics compared to open intake feed water. This difference contributes to longer RO membrane lifespans and improved desalination efficiency. A total of thirty-two algal species from four distinct phytoplankton groups were identified: Bacillariophyceae (23 species), Dinophyceae (4 species), Chlorophyceae (3 species), and Cyanophyceae (2 species). The RO technique demonstrated excellent performance in maintaining water quality within Egyptian standards, effectively reducing or eliminating algae in the permeate water. Throughout all research seasons, bacterial loads remained low due to the high salinity of Red Sea water. All sites were free of fecal coliforms, and the permeate water met the quality standards set by the Egyptian Ministry of Health's Decision 458/2007 for drinking water and domestic use.

Keywords: Desalination plants, Marine water, Physicochemical state, Phytoplankton, Red Sea, Reverse osmosis (RO)

INTRODUCTION

Global water needs by 2030 will increase from 4,500 billion m^3 to 6,900 billion m^3, making seawater usage an alternative solution to address freshwater shortages (Abdul Ghani et al., 2021). The Red Sea holds a unique position among basins due to its geographic location and relative isolation from open oceans (Halim, 1984). The natural habitats of the Red Sea are of significant natural and international interest because of their beauty and diversity (Jameson et al., 1995). Recently, various man-made activities, such as fishing ports, urban agglomeration, marine shipping, phosphate industry operations, recreational resorts, and limited freshwater and sewage resources, have directly impacted the Red Sea shores of Egypt (Abdelmongy & El-Moselhy, 2015). The dynamics of the Red Sea and its geographic location both influence its physico-chemical properties. River runoff does not significantly contribute to the nutrient supply of the Red Sea, which is essential for phytoplankton growth (Krom et al., 1992). Chemical contamination in the Red Sea is largely confined to areas near industrial sites and facilities that frequently discharge their wastewater into the sea. These industries include oil production and transportation facilities, phosphate mining, desalination units, and chemical industrial infrastructure (Povlesen et al., 2003). Reverse osmosis (RO)-based seawater desalination plants are considered vital components of the social infrastructure (Takabatake et al., 2021). By employing reverse osmosis technology, any colloidal or dissolved materials can be rejected from the aqueous solution, resulting in a stream of concentrated brine and purified water (Fritzmann et al., 2007; Xavier et al., 2020). One of the major challenges associated with desalination using RO membranes is fouling, which negatively impacts process performance by reducing permeate flow and quality (Matin et al., 2011). Additionally, it leads to an increase in operating pressure over time (Baker, 2012; Joo & Tansel, 2015), consequently shortening the membrane's lifespan. Furthermore, silicate salts affect the structure of the RO membrane, leading to a shortened operating time (Xavier et al., 2020). Proper pretreatment minimizes scaling on the RO membrane, helping to maintain permeate flow and extend the membrane's operating life (Tharamapalan et al., 2013; Xavier et al., 2020). Coagulation is a crucial step in the pretreatment process for RO (Edzwald & Haarhoff, 2011), preventing the membrane from fouling due to particulate matter (Fritzmann et al., 2007). This process can also remove turbidity-causing agents, including oils (Dincer et al., 2008), clays (Annadura et al., 2004), and microorganisms (Zhidong et al., 2009). Typically, this step is followed by traditional sand filtering after a sedimentation process that eliminates residual particles (Voutchkov, 2010). The quality of the feed water matrix determines the pretreatment strategy to be implemented (Harvey et al., 2020). Generally, desalination plants include cartridge filters, multimedia filters, coagulation-flocculation steps, and reverse osmosis (Xavier et al., 2020). Previous studies have reported that the discharge from desalination plants into marine ecosystems can have potential environmental impacts on marine life (Nasr et al., 2019). Salinity stress may adversely affect coral reef growth and reproduction, leading to the death of plankton, fish, and other mobile species (APHA, 2005; Nasr et al., 2019). This investigation aims to explore the distribution of phytoplankton, assess bacteriological quality, and analyze the physico-chemical characteristics of the Red Sea water in relation to reverse osmosis (RO) desalination plants within the Red Sea Governorate. The study specifically compares the potential of open intake feed sources versus shore well feed sources for producing drinking water, providing insights into the environmental and operational advantages of each.

This research is of significant importance due to its innovative approach in examining the complex interplay between marine ecosystems and desalination processes. By focusing on both biological and chemical aspects of the Red Sea water, the study not only addresses the sustainability of using seawater for desalination but also offers novel insights into optimizing water quality for human consumption. The comparative analysis of open intake versus shore well sources is particularly crucial, as it evaluates key factors such as contamination risks, energy efficiency, and long-term sustainability. The findings of this work could serve as a cornerstone for enhancing desalination practices, potentially improving water availability and quality in regions heavily reliant on desalination technologies.

MATERIALS AND METHODS

Study area

The investigation was carried out to provide a comprehensive physico-chemical, psychological, and bacteriological assessment of the primary water source in the Red Sea governorate. It was conducted throughout the Red Sea governorate, from Hurghada to Shalateen, as indicated on the map (Figure 1). The coastline of the Red Sea governorate measures 1,080km, stretching from the Gulf of Suez at a latitude of 29 degrees north to the Sudanese borders at a latitude of 22 degrees north. Collection sites included the El Yosr desalination plant in Hurghada (latitude 27.23, longitude 33.84), the Safaga desalination plant (latitude 26.77, 33.92), the Qusser desalination plant (latitude 26.12, 34.27), the Marsa Alam desalination plant (latitude 25.07, 34.89), and the Shalateen desalination plant (latitude 23.15, longitude 35.61). The type of feed water source, the treatment process steps, and the added chemicals used in the five desalination plants are presented in Table 1.

Sample collection

The water samples were taken and brought to the lab in one-liter, air-bubble-free glass bottles (triplicate for each sample). Samples were collected during the study from April 2019 to March 2020 including all seasons.

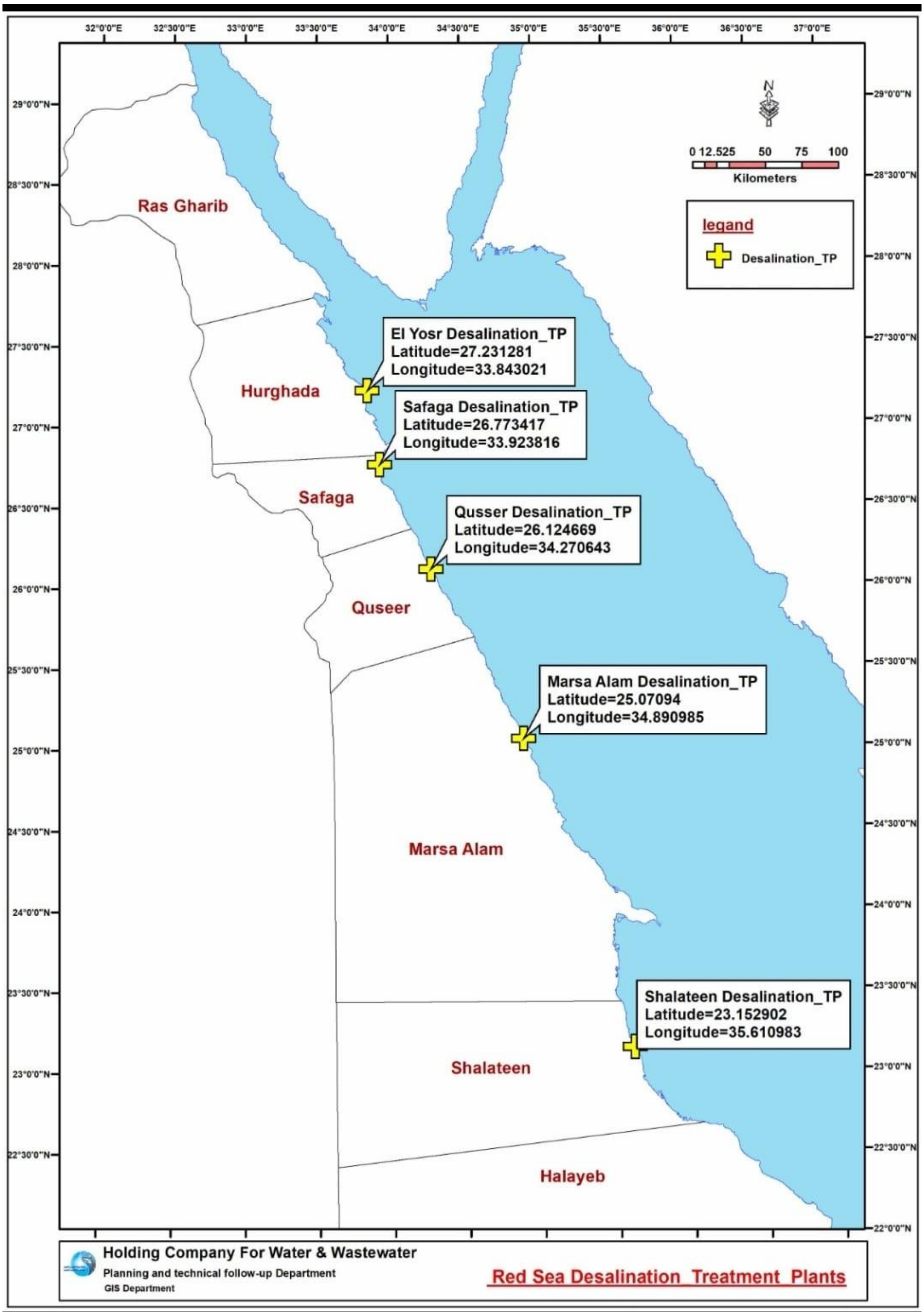

Figure 1. Map showing the locations of study sites along the Red Sea Governorate, from Hurghada in the north to Shalateen in the south

Table 1. The five desalination plants under study illustrating the type of feed water source, the treatment process steps, and the added chemicals

Desalination plant	Feed intake	Treatment steps	Added chemicals
Al Yosr (Hurghada)	Open intake	Feed water Tank Multimedia Filters Cartridge Filters First RO unit Second RO unit Permeate Water Tank	Ferric Chloride Antiscalent Sodium metabisulfite (SMBS) CO_2 Gas Calcide Final Chlorination by Chlorine Gas Costic Soda if required
Safaga	Open intake	Feed water Tank Multimedia Filters Cartridge Filters RO unit Permeate Water Tank	Antiscalent Final Chlorination by Calcium Hypochlorite addition
Qusser	Shore Wells	Feed water Tank Multimedia Filters Cartridge Filters RO unit Permeate Water Tank	Soda ash if required Antiscalent Final Chlorination by Calcium Hypochlorite addition
Marsa Alam	Shore Wells	Feed water Tank Multimedia Filters Cartridge Filters RO unit Permeate Water Tank	Antiscalent Final Chlorination by Calcium Hypochlorite addition
Shalateen	Open intake	Feed water Tank Multimedia Filters Cartridge Filters RO unit Permeate Water Tank	PreChlorination(by Hypo) Ferric Chloride Sodium metabisulfite (SMBS) Antiscalent Final Chlorination by Calcium Hypochlorite addition

Physico-chemical analysis of water

The physical and chemical characteristics of the water samples were estimated and the procedures were detailed in the standard method recommended by the APHA (2005) and the manual of seawater analysis (Parsons et al., 1984).

Phycological analysis

After being collected in one-liter dark glass bottles, the water samples were promptly preserved at the sampling site by adding Lugol's solution, and they were then transported to the lab in an icebox at 4°C. The well-mixed samples were centrifuged for 20min at 1500 rpm. After concentration, the samples were placed in dark 100ml bottles to allow for the counting and identifying of phytoplankton according to Streble & Krauter (1978); APHA (1992); Al-Kandari et al. (2009) using a Sedgwick-Rafter (S-R) counting chamber. 50 fields were randomly counted after the S-R cell was left to settle the plankton for at least 15 minutes. The final results, which were expressed as organisms per liter, were computed using the following formula:

$$\text{Number of counted organisms/ml} = \frac{\text{C} \times 1000\ \text{mm}^3}{\text{A} \times \text{D} \times \text{F}}$$

where, C represents the number of organisms / A is the field area (mm^2) /D is the S-R cell depth (mm) / F is the number of fields counted.

For adjustment of sample dilution or concentration, the number of cell per milliliter was multiplied or divided by a correction factor as following:

$$\text{Algal Count (Organism/ml)} = \left(\frac{\text{Actual field}}{\text{Count Fields}}\right) \times \left(\frac{\text{Net volume}}{\text{Sample volume}}\right) \times \text{No. of counted algae}$$

Bacteriological assessment

To counteract the bactericidal action of any chlorine in the water, an aqueous solution of sodium thiosulfate (3% $Na_2S_2O_3$ w/v) was added to the one-liter sterilized, well-stoppered autoclavable plastic (polypropylene) bottles from which the water samples were taken. To allow the water to flow to waste for a few minutes, the sample point was flamed and fully opened. After labeling, each sample was transported to the lab in an icebox at 4 °C. Using Sartorius sterile, gridded, 47mm in diameter, 0.45µm pore size cellulose nitrate membrane filters, the collected samples were immediately examined upon arrival at the laboratory using the heterotrophic plate count (poured plate) and membrane filtration technique (MF), in accordance with Standard Methods for the examination of Water and Wastewater (APHA, 1998).

Verification test

The lactose fermentation test was used to determine the total number of fecal coliforms. From each plate of m-Endo Agar LES, five typical colonies were chosen at random, put in lauryl tryptose broth (LTB), and cultivated for 48h at 35.5°C. The colony was identified as a coliform within 48 hours after gas formed in the LTB and was verified in brilliant green lactose bile broth (BGLB). Within 48h at 35°C, the gas formation in LTB broth and EC broth confirmed the presence of fecal coliform colonies.

RESULTS AND DISCUSSION

Physicochemical characteristics

In this study, the physico-chemical characteristics of raw water (the Red Sea) and permeate water (desalinated water) were estimated (Tables 2-6). The physical parameters revealed that the temperature of feed water varied between 19.8°C in winter at Marsa Alam and 33.3°C in summer at Shalateen, while permeate water had the lowest temperature of 19°C in winter at Marsa Alam and the highest of 32.1°C in summer at Shalateen. Turbidity data for feed water were very low and did not exceed 1 NTU, indicating extremely clear permeate water. The pH values of raw water ranged around 7.6 in winter at Quseer and 8.3 at Safaga, Hurghada, and Shalateen, indicating the slightly alkaline nature of the raw water. For permeate water, the pH ranged from neutral to slightly alkaline, fluctuating between 7.02 in spring at Safaga and 8.2 in summer at Shalateen. During winter, feed water exhibited the lowest conductivity (48330µs/cm) at Marsa Alam, while the highest value was found at Shalateen in summer (66100µs/cm). In contrast, permeate water showed lower conductivity, recorded in winter at Hurghada (552µs/cm) and in summer at Quseer (985µs/cm). Shalateen feed water recorded the highest total dissolved solids (TDS) in summer (33100mg/L), while Marsa Alam had the lowest in winter (24600mg/L). For permeate, Hurghada reflected the minimum measurement in winter (248mg/L) and the maximum in summer (445mg/L). Salinity (%) in Quseer and Marsa Alam (shore wells) was lower than in El Yosr, Safaga, and Shalateen (open intake), with feed water ranging between 34.2% in winter at Marsa Alam and 45.81% in summer at Shalateen, while permeate salinity fluctuated between 0.26% in winter at Hurghada and 0.41% in summer at Hurghada, Quseer, and Shalateen. Red Sea chloride contents varied from 19498mg/L in winter at Marsa Alam to 26120mg/L in summer at Shalateen, while chloride values in drinking water ranged between 148 mg/L in winter and 236mg/L in summer, both at Hurghada. Quseer feed water recorded the lowest alkalinity during fall, while Safaga had the highest during winter. For permeate, Safaga (5mg/L) and Hurghada (72mg/L) represented the two extremes of alkalinity readings. Calcium ion concentrations in feed water varied from 416mg/L at Shalateen in spring to 1552mg/L at Marsa Alam in fall, whereas permeate values ranged from 0.01mg/L at Quseer to 19.85mg/L at Hurghada in summer. Magnesium levels were 1120.14mg/L at Hurghada feed water in spring and 2709.6mg/L at Shalateen feed water in fall, whereas desalinated water showed values of 0.04mg/L in summer at Hurghada and 6.24mg/L in fall at Shalateen. In all investigated sites, the lowest sodium ion concentration (7074mg/L) in feed water occurred in spring at Marsa Alam, while the highest (15430mg/L) was noted in winter at Shalateen. Permeate water had a minimum sodium concentration (38.62mg/L) in spring at Quseer but the highest value (198mg/L) in summer at Marsa Alam. Seasonal variations of potassium ion concentrations in feed water were 170mg/L at Marsa Alam in summer and 575mg/L at Safaga in spring, while permeate water reached maximum potassium values (7.5mg/L) in fall at Safaga. The feed water from shore wells had the lowest potassium ion concentrations. The average sulfate concentrations in raw water were 356mg/L during spring at Shalateen and 4142mg/L during spring at Marsa Alam. For permeate water, sulfate values ranged from 0.001mg/L in summer at Marsa Alam to 211mg/L in winter at Safaga. The presence of nitrogen compounds, NH_3, $NO_{2,}$ and $NO_{3,}$ was analyzed. The minimum values for all nitrogen compounds in feed were recorded in winter, while the maximum levels occurred in summer for ammonia (with the exception of

Marsa Alam, where values peaked in spring) and nitrite, and during spring for nitrate. Results of nitrogen compounds in drinking water adhered to Egyptian standards and WHO guidelines. The highest concentration of dissolved phosphate was observed during spring at all sites studied, except for Shalateen, where the highest values occurred in summer. These values were significantly low in permeate water, not exceeding 0.006mg/L. In contrast to previous parameters, feed water from shore well intakes exhibited higher levels of dissolved silica compared to those from open intake feed water. At Hurghada, Safaga, and Shalateen, the maximum silica value occurred in spring, whereas maximum values were recorded in winter at Quseer and Marsa Alam.

Table 2. Physico-chemical characteristics of Al Yosr (Hurghada) desalination plant from April 2019 to March 2020

Parameter \ Site	Hurghada (Feed)				Hurghada (Permeate)			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Temperature (°C)	25.30	29.4	24	21.3	24.20	28.5	23.5	20.5
Res. Chlorine (mg/L)	---	---	---	---	1.80	1.5	1.5	1.5
Turbidity (NTU)	0.18	0.3	0.47	0.18	0.01	0.01	0.01	0.03
pH	8.20	8.1	7.8	8.3	7.36	8	7.4	7.7
Conductivity (µs/cm)	59703	61430	59330	58100	674	889	774	552
T.D.S (mg/L)	29900	31000	29660	29100	323	445	426	248
Salinity (%)	41.5	43.14	41.1	40.25	0.38	0.41	0.4	0.26
Chloride (mg/L)	23660	24594	23431	22947	216.07	236	226	148
Alkalinity (mg/L)	135	144	129.6	142.5	52	72	36	46
Calcium (mg/L)	485.63	480	532	571.2	16.32	19.85	17.4	13.96
Magnesium (mg/L)	1120.14	1477	1588.8	1596.7	1.62	0.04	0.53	2.64
Sodium (mg/L)	9450	12748	10981	14231	45.14	94	58	72
Potassium (mg/L)	525.34	379	442	404	3.35	3.16	4	3.5
Sulphate (mg/L)	3206.56	3093	1187.16	448	7.44	1.24	172.7	98
Ammonia (mg/L)	1.15	1.57	0.013	0	0.01	0.003	0	0
Nitrite (mg/L)	0.01	0.36	0.005	0	0.01	0.004	0.003	0
Nitrate (mg/L)	6.50	4.9	5.8	1.4	0.30	0.02	0.06	0.08
Phosphate (mg/L)	0.21	0.13	0	0.016	0	0.001	0	0.006
Silicate (mg/L)	0.28	0.07	0	0	0.01	0	0	0
Iron (mg/L)	6.5	0.08	0.003	0.353	0.06	0.02	0.005	0.009
Manganese (mg/L)	0	0	0	0.069	0	0	0	0
Boron (mg/L)	6.10	4.97	3.68	3.9	1.10	1	1.4	0.8
Fluoride (mg/L)	7.35	0.76	9.5	12.8	0.20	0.02	0.4	0.65
Lithium (mg/L)	0.08	1.11	0	0	0.01	0.002	0	0
Zinc (mg/L)	2.55	4.73	0.88	0.091	0	0	0	0
Cupper (mg/L)	0	0	0.09	0.119	0	0	0	0
Dissolved Oxygen (mg/L)	6.90	5.3	6.7	8.6	7.90	6.5	7.2	8.7
COD (mg/L)	19.5	17.2	18.7	20.2	6.7	5.2	6.4	7.3
BOD (mg/L)	10.50	7.9	10	11.3	3.40	2.5	3.1	3.7

Table 3. Physico-chemical characteristics of Safaga desalination plant from April 2019 to March 2020

Parameter \ Site	Safaga (Feed)				Safaga (Permeate)			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Temperature (°C)	25.30	31.5	24.8	22.5	24.50	30.6	24.2	21.2
Res. Chlorine (mg/L)	---	---	---	---	1.60	1.3	2	1.8
Turbidity (NTU)	0.52	0.34	0.38	0.49	0.02	0.01	0.04	0.03
pH	8	8.3	8.1	8.07	7.02	7.4	7.5	7.7
Conductivity (µs/cm)	63800	65200	62420	61320	765	810	799	765
T.D.S (mg/L)	32100	33000	31420	31020	388	430	402	375
Salinity (%)	43.18	44.5	42.33	41.8	0.37	0.39	0.38	0.32
Chloride (mg/L)	24617	25370	24133	23831	210	222	215	180
Alkalinity (mg/L)	139	147	127.2	183.5	10	5	9.6	13.7
Calcium (mg/L)	484	477	504	524.4	2.41	1.55	3	3.8
Magnesium (mg/L)	1552.81	1508	1586.4	1524.2	3.46	2.04	1.6	2.83
Sodium (mg/L)	10253	12785	11020	15016	52.32	193	84	142
Potassium (mg/L)	575	386	475	412	7.22	6.2	7.5	5.9
Sulphate (mg/L)	3800	3161	1069.7	423	3.23	3.94	159	211
Ammonia (mg/L)	0.02	6.82	0	0	0	0.56	0	0
Nitrite (mg/L)	0.01	2.70	0.003	0	0.01	0.016	0.002	0
Nitrate (mg/L)	6.31	6.22	5.7	1.7	0.14	0.011	0.01	0.005
Phosphate (mg/L)	0.12	0.05	0	0	0	0.001	0	0
Silicate (mg/L)	2.79	0	0	0.133	0	0	0	0.047
Iron (mg/L)	3.18	0	0	0.359	0.06	0.04	0.009	0
Manganese (mg/L)	0	0	0	0.067	0	0	0	0
Boron (mg/L)	5.10	5.25	4.81	4.5	1.40	1.2	1.4	0.6
Fluoride (mg/L)	4.22	1.69	5.3	8	0.09	0.007	0.14	0.28
Lithium (mg/L)	0.04	0.29	0	0	0	0.003	0	0
Zinc (mg/L)	0.72	1.12	0.38	0.08	0.01	0.04	0.017	0.006
Cupper (mg/L)	0	0	0.04	0.117	0	0	0	0
Dissolved Oxygen (mg/L)	6.41	4.7	6.2	8.4	6.71	7.9	6.7	8.9
COD (mg/L)	22.5	19.7	20.3	22.8	7.5	6.3	7.2	8.2
BOD (mg/L)	12.41	12.15	13.8	14.5	3.42	2.5	3.4	4

Table 4. Physico-chemical characteristics of Qusser desalination plant from April 2019 to March 2020

Site / Parameter	Qusser (Feed)				Qusser (Permeate)			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Temperature (°C)	23.5	29.5	23.9	21.8	23.10	28.1	23.4	21.1
Res. Chlorine (mg/L)	---	---	---	---	2	2.5	1.3	1.5
Turbidity (NTU)	0.58	0.52	0.62	0.75	0.27	0.01	0.48	0.33
pH	7.76	7.65	7.9	8	7.41	7.6	7.35	7.6
Conductivity (µs/cm)	52810	55500	52300	52090	641	985	815	630
T.D.S (mg/L)	26600	28202	26400	26100	335	443	394	314
Salinity (%)	35.5	37.2	35.32	35	0.34	0.41	0.4	0.32
Chloride (mg/L)	20239	21208	20136	19954	191	235	228	181
Alkalinity (mg/L)	100	137	91.8	123	49	15	6.4	13.3
Calcium (mg/L)	476	484	600	483.6	2.24	0.01	1.8	1.52
Magnesium (mg/L)	1538.41	1303	1492.8	1439	5.76	1.58	2.7	3.58
Sodium (mg/L)	7562	11157	8524	11805	38.62	143	51	98
Potassium (mg/L)	325	225	330	212	2.42	1.32	2.9	1.1
Sulphate (mg/L)	3417	2945	1275.8	359	10.68	3.57	176.2	134
Ammonia (mg/L)	0.01	37.77	0.016	0	0.01	0.14	0	0
Nitrite (mg/L)	0.01	1.20	0.005	0	0.01	0.0003	0.002	0
Nitrate (mg/L)	9.32	7.52	6.2	2.3	0.84	0.0024	1.34	0.4
Phosphate (mg/L)	0.19	0.18	0.11	0.17	0	0.0032	0	0.005
Silicate (mg/L)	0.69	2.4	1.84	4.17	0.34	0.05	0	0
Iron (mg/L)	2.78	0.09	0.002	0.313	0.15	0.05	0.014	0
Manganese (mg/L)	0	0	0	0.063	0	0	0	0
Boron (mg/L)	6.82	5.4	6.38	4.3	1.11	1.1	1.8	1
Fluoride (mg/L)	5.91	0.24	7.4	9.7	0.12	0.06	0.28	0.53
Lithium (mg/L)	0.05	3.50	0	0	0	0.0058	0	0
Zinc (mg/L)	1.45	1.99	0.41	0.087	0.02	0.01	0.01	0.01
Cupper (mg/L)	0	0	0.06	0.111	0	0	0	0
Dissolved Oxygen (mg/L)	6.41	5.8	6.4	8.8	7.51	6.8	6.8	9.6
COD (mg/L)	23	21.2	22	24.1	13	11	12.9	14.5
BOD (mg/L)	11.3	10.2	11	11.9	6.81	5.8	7.2	8.5

Table 5. Physico-chemical characteristics of Marsa Alam desalination plant from April 2019 to March 2020

Site / Parameter	Marsa Alam (Feed)				Marsa Alam (Permeate)			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Temperature (°C)	27.2	32.5	23.7	19.8	26.40	31	23	19
Res. Chlorine (mg/L)	---	---	---	---	1.90	1.8	1.9	1.9
Turbidity (NTU)	0.40	0.38	0.47	0.52	0.03	0.15	0.36	0.42
pH	7.90	8	8	8.04	7.31	7.3	7.5	7.33
Conductivity (µs/cm)	52400	53820	49870	48330	779	805	796	575
T.D.S (mg/L)	26230	27200	25400	24600	329	403	394	283
Salinity (%)	35.3	36.32	34.8	34.2	0.32	0.38	0.33	0.30
Chloride (mg/L)	20125	20706	19840	19498	180	218	190	173.03
Alkalinity (mg/L)	120	92	101.8	109.7	45	7	9	13
Calcium (mg/L)	1411.14	1334	1552	1189.2	5.77	2.48	3.2	3.12
Magnesium (mg/L)	1239.95	1240	1375.2	1315.4	5.11	2.53	0.43	1.3
Sodium (mg/L)	7074	9598	7557	10697	110.30	198	90	106
Potassium (mg/L)	285.38	170	255	198	4.45	3.02	3.9	3.6
Sulphate (mg/L)	4142	3449	1126.9	570	11.06	0.001	192.2	201
Ammonia (mg/L)	0.80	0.49	0	0	0.01	0.20	0	0
Nitrite (mg/L)	0.01	1.04	0.002	0	0.03	0.009	0	0
Nitrate (mg/L)	14.30	7.42	5.5	0.9	0.68	0.052	0.005	0
Phosphate (mg/L)	1.40	0.68	0.33	0.7	0	0.001	0	0
Silicate (mg/L)	0.13	14.53	10	16.76	0.02	0.01	0	0.126
Iron (mg/L)	6.30	0.07	0.002	0.304	0.08	0.093	0.01	0
Manganese (mg/L)	0	0	0	0.087	0	0	0	0
Boron (mg/L)	4.70	5.92	6.2	4.5	1	1.89	1.6	0.4
Fluoride (mg/L)	11.52	0.92	13	16.7	0.13	0.012	0.35	0.57
Lithium (mg/L)	0.19	0.44	0	0	0	0.004	0	0
Zinc (mg/L)	2.11	3.4	1.45	0.08	0	0	0	0
Cupper (mg/L)	0	0	0.07	0.118	0	0	0	0
Dissolved Oxygen (mg/L)	6.10	5.1	6.4	8	7.20	6.9	6.6	8.5
COD (mg/L)	22	20.8	21.6	22.5	11	9	11.7	12.8
BOD (mg/L)	9.9	9	11	12.3	1.10	2.8	4.2	4.8

Table 6. Physico-chemical characteristics of Shalateen desalination plant from April 2019 to March 2020

Site / Parameter	Shalateen (Feed)				Shalateen (Permeate)			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Temperature (°C)	30.2	33.3	25.2	23.4	29.50	32.1	24.7	22.5
Res. Chlorine (mg/L)	---	---	---	---	1.8	1.8	1.5	1.5
Turbidity (NTU)	0.21	0.64	0.49	0.57	0.02	0.26	0.09	0.13
pH	7.97	8.2	8.3	8.3	7.31	8.2	7.9	8
Conductivity (µs/cm)	64800	66100	65000	63700	723	814	795	702
T.D.S (mg/L)	32530	33100	32720	32000	356	402	395	344
Salinity (%)	44.2	45.81	44.5	43.3	0.39	0.41	0.40	0.39
Chloride (mg/L)	25199	26120	25370	24686	225	235	229	220.2
Alkalinity (mg/L)	130	158	115.6	122.5	46	6.29	7	14.3
Calcium (mg/L)	416	487	492	528	3.12	0.6467	3	5.8
Magnesium (mg/L)	1435.21	1515	2709.6	2517.36	5.33	1.61	6.24	3.6
Sodium (mg/L)	9452	12773	10890	15430	40.81	143	68	173
Potassium (mg/L)	488	370	470	398	3.12	2.31	3.7	2.6
Sulphate (mg/L)	356	3203	1145.3	420	7.35	2.86	181.9	95
Ammonia (mg/L)	0.01	24.20	0	0	0	0.1	0	0
Nitrite (mg/L)	0.02	0.96	0.018	0	0.02	0.008	0.003	0
Nitrate (mg/L)	14.72	4.12	2.7	0.91	0.31	0.0001	0.005	0
Phosphate (mg/L)	0.18	0.74	0	0	0	0.0042	0	0
Silicate (mg/L)	2.62	0.02	0	0.184	0.09	0	0	0.008
Iron (mg/L)	0.97	0.09	0.004	0.367	0.06	0.01	0	0
Manganese (mg/L)	0	0	0	0.062	0	0	0	0
Boron (mg/L)	6	3	5.34	8.6	1.31	1.79	2.4	3.3
Fluoride (mg/L)	5.32	1.6	7	11.92	0.14	0.0019	0.37	0.68
Lithium (mg/L)	0.03	3.37	0	0	0.01	0.0056	0	0
Zinc (mg/L)	0.87	1.48	0.78	0.09	0.01	0.07	0.05	0.02
Cupper (mg/L)	0	0	0.06	0.12	0	0	0	0
Dissolved Oxygen (mg/L)	6.50	4.6	6.3	8.5	7.21	7.1	6.9	8.8
COD (mg/L)	25	23.1	23.7	26	14	12.5	14.1	16
BOD (mg/L)	13.3	12.7	13.7	14.5	7.91	4.1	6.2	7

Regarding the content of microelements like iron and manganese, Fe^{+2} recorded a maximum value of 6.5mg/L during spring at Hurghada for raw water, while the maximum for desalinated water was 0.15mg/L during spring at Quseer. The iron values were reduced to very low concentrations with the help of reverse osmosis technologies. The study showed poor representation of manganese ion content. Boron levels in feed water ranged from 3 to 8.6mg/L, with minimum and maximum readings noted at Shalateen during summer and winter, respectively. For permeate water, the results were 0.4mg/L during winter at Marsa Alam and 3.3mg/L during winter at Shalateen. Fluoride concentration in feed water varied between 0.24mg/L (at Quseer during summer) and 16.7mg/L (at Marsa Alam during winter), while the permeate readings were 0.001mg/L at Shalateen in summer and 0.68mg/L at Shalateen in winter. Observations of heavy metals indicated that lithium was not detected in the water during fall and winter; meanwhile, zinc had the lowest value during winter. The highest values for lithium (3.5mg/L at Quseer) and zinc (4.73mg/L at Hurghada) were recorded in summer. Copper was not detected at any sites during summer and spring, but the highest reading for copper (0.12mg/L at Shalateen) was noted in winter. The presence of these heavy metals in desalinated water was minimal across all sites surveyed. Contamination indicators were considered in our assessment. For raw water, the results for dissolved oxygen, chemical oxygen demand, and biological oxygen demand showed the lowest values in summer and the highest in winter across all sites. The dissolved oxygen levels for the feed water varied from 4.6 mg/L at Shalateen to 8.8mg/L at Quseer, while chemical oxygen demand fluctuated between 17.2mg/L at Hurghada and 26mg/L at Shalateen. Additionally, biological oxygen demand records showed a minimum of 7.9mg/L at Hurghada during summer and a maximum of 14.5mg/L at Safaga and Shalateen during winter. For permeate, dissolved oxygen ranged from 6.5 to 9.6mg/L at Hurghada during summer and Quseer during winter, respectively. Chemical oxygen demand varied from 5.2mg/L (at Hurghada in summer) to 16 mg/L (at Shalateen in winter), while biological oxygen demand ranged from 1.1 to 8.5mg/L at Marsa Alam in spring and Quseer in winter, respectively. Water temperature is thought to be the most significant environmental factor influencing organisms and waterborne biological and chemical reactions. It greatly affects the biological characteristics of the marine environment, particularly algae (Khedr et al., 2019). Temperature fluctuations are caused by several factors, including wind, depth, air temperature, seasonal volatility, and heat exchange resulting from waves in shallow coastal waters. The temperature levels in our study align with earlier investigations (Dorgham et al., 2012; Abdelmongy & El-Moselhy, 2015). Our maximum and minimum result values matched those found by Ansari et al. (2015), who reported maximum values during summer and minimum values during winter.

Turbidity or suspended particulate matter is regarded as a significant aspect of the coastal ecosystem that is tracked by several systems. To assess the material fluxes from river to sea, the geographic distribution of turbidity is thought to be crucial for examining the patterns of deposition and erosion. The turbidity readings in our assessment were less than 1.0 NTU, which agreed with Ghobashy et al. (2022). High turbidity values were recorded during winter in some sites, that agreed with Jafar-Sidik et al. (2017).

The type and concentration of ions present in the solution determine the electrolyte conductivity. The high levels were during summer, but the lowest were during winter (Emara et al., 2013). Values of feed water that has open intake were near 60000µs/cm, which agreed with Abdel-Aal et al. (2015). While those of shore wells intake were slightly lower in their conductivity values.

The potential of pollutants is measured by pH, which correlates with the concentration of various chemicals, particularly weakly dissociated acids and bases. One of the most significant environmental factors influencing the physiology, metabolism, growth, and survival of aquatic species, as well as various chemical processes, is pH (Ramanathan et al., 2005). Water pH is regulated by dissolved oxygen, water temperature, the breakdown of organic matter, photosynthetic activity, and sewage outflow (Nassar & Hamed, 2003). The pH data from the current study indicate the alkaline nature of raw water, aligning with previous reports (Ibraheem et al., 2014; El Gammal et al., 2017; Al-Taani et al., 2020). In comparison to our study results, a positive correlation was observed between pH and water temperature, indicating that high pH values during summer and rising temperatures often enhance the photosynthetic activity of phytoplankton, which increases carbon dioxide consumption and elevates pH (Abdalla et al., 1995). Conversely, Ganesan (1992) supported our findings of a negative correlation between pH and water temperature due to the accelerated decomposition of organic matter induced by microbial respiration, which can increase carbon dioxide levels and decrease pH levels.

The trace levels of organic materials and inorganic salts in solution are referred to as TDS. TDS levels in typical seawater are around 35,000mg/L. Saeed et al. (2019) achieved comparable outcomes.

The discharges of contaminated post-mining water are the way that chloride enters the aquatic environment (Sikorski, 2021). The lowest value of chloride concentration in seawater was in winter at Marsa Alam, while the highest was in summer at Shalateen, which agreed with the results obtained by Emara et al. (2013) and not agreed with the results of Abdel-Aal et al. (2015).

Salinity is one of the most important ecological variables that affect some chemical processes, as it had a storage influence on nutrients in the coastal regions (Ospar, 1997). The level of salinity at Qusser and Marsa Alam (shore wells) was lower than those of El Yosr, Safaga, and Shalateen (open intake). For feed water ranged between 34.2% in winter and 45.81 % in summer at Marsa Alam and Shalateen, respectively, where permeate ones varied from 0.26% at Hurghada in winter to 0.41% at Hurghada, Qusser, and Shalateen in summer. El Gammal et al. (2017) and Khedr et al. (2019) also found the highest value of salinity at summer.

Alkalinity measures the ability of water to neutralize acid or to absorb hydrogen ions without changing pH value (Emara et al., 2013). Concerning alkalinity, the high levels were observed in summer and the minimum in winter, which contrasted with results of Emara et al. (2013).

Calcium concentrations rose as a result of the Red Sea's surface evaporation (Ansari et al., 2015). During this study, the lowest reading of calcium was noted in spring at Quseer and Shalateen and in summer at Hurghada, Safaga and Marsa Alam. On the other side, the highest value was obtained during winter at Hurghada, Safaga and Shalateen and during autumn at Quseer and Marsa Alam. More or less similar results were obtained by Somashekar et al. (2023).

The magnesium concentration during our study ranged between 1120.14-2709.6mg/L. Somashekar et al. (2023) observed nearly the same concentrations of magnesium (1000-2000mg/L).

The sodium concentration recorded fluctuated values between 7074 and 15430mg/L. Similar results were recorded previously. Abdel-Aal et al. (2015) reported that sodium content in the water of the Red Sea was 12339mg/L and Ghobashy et al. (2022) had the same ranges of sodium in their study from various Tabuk locations around the Red Sea Coast of Saudi Arabia (12524-13547mg/L).

Seasonal variations of potassium ion concentration in feed water were observed and recorded 170mg/L in summer at Marsa Alam and 575mg/L in Safaga during spring, where its concentrations in permeate water reached maximum values in fall season in most of sites under study. Feed water that of shore wells intake has lower values of potassium ion concentration. These findings are consistent with earlier findings by Abdel-Aal et al. (2015).

Sulphate values of the Red Sea water in our study ranged between 359 and 4142mg/L. In this context, Somashekar et al. (2023) reported that sulphate concentration range between 2700-3400mg/L, while, Ibraheem et al. (2014) observed the average value of sulphate concentration was 3244mg/L, and Ghobashy et al. (2022) stated that the sulphate results were less than 2000mg/L.

The rapid production and processing of ammonia by the bacterial breakdown of organic waste makes it a useful indicator of water pollution (Abu Hilal & Abu Alhaija, 2010). Guerrero & Jones (1996) stated that by nitrifying microorganisms, light inhibits the oxidation of ammonium and this agreed with our findings where high concentrations of ammonia were during summer and the low ones were during winter.

When phytoplankton assimilate nitrogen, the intermediate oxidation state between ammonia and nitrates can be eliminated from the water, making it beneficial to monitor the content of nitrite in seawater (Khedr et al., 2019). However, if it is present in foods in a noticeable amount, it has the greatest toxicological relevance for human health (Abdelmongy & El-Moselhy, 2015). In our study, the high levels of nitrite were during summer, while previous results on the Red Sea water obtained by Abdelmongy & El-Moselhy (2015) reported the greatest levels of nitrite during winter.

Nitrate is the most stable form of inorganic nitrogen in oxygenated water and the byproduct of the nitrification process in natural water (Khedr et al., 2019). According to them, as a result of both the denitrification process and plant assimilation, the summer season had the highest seasonal mean of nitrate, while the fall season had the lowest ones. Also, Abdelmongy & El-Moselhy (2015) noted the maximum level of nitrate was observed during winter.

The majority of organic phosphorus originates from the waste products of protein metabolism and how humans eliminate them as phosphates in their urine. The remainder is mostly derived from detergents. Due to its ability to drive eutrophication, phosphorus plays a significant role in the marine environment (Redouane & Mourad, 2017). In accordance with phosphates function as a major nutrient, it is a limiting nutrient for phytoplankton development, and its contents are lower during the season of higher primary production (Conkright et al., 2000). This could be the cause of the low phosphate levels in the spring and summer (Abdelmongy & El-Moselhy, 2015) because of the absorption by primary producers and phytoplankton (Al-qutob et al., 2002). The sorption and deposition of phosphate on iron-born dust carried to the basin from the nearby mountains and deserts may be the cause of the low phosphate concentrations. It was asserted, however, that phosphate does not restrict the primary production of maritime ecosystems (Perry & Eppley, 1981). The greatest contents of phosphate in most of the sites under this investigation were during spring. Abdelmongy & El-Moselhy (2015) observed low values of phosphate during spring and summer. According to Saeed et al. (2019) the maximum level of phosphate was noted during autumn, and the minimum one was noticed during summer. Khedr et al. (2019) emphasized that the most crucial factor regulating phytoplankton growth and reproduction is phosphate, which is also thought to be the most easily absorbed form by algae. According their results, the highest concentration of phosphate was in summer while the lowest one was during winter. For the present study, shore wells intake feed had also the maximum during summer, but those of the open intake feed had the maximum was during spring.

According to Fahmy (2003), the primary determinants of the distribution of dissolved silica in the coastal waters of the Red Sea in Egypt are: 1. biological composition 2. Decomposition of organic substances 3. The partial disolution of clay and quartz particles carried by sandstorms from the nearby desert to the sea 4. The migration of dissolved silica via the Bab El-Mandab Straight in the Red Sea. Phosphate is an essential macronutrient, along with silicate and nitrogen (Raymont et al., 1980). In contrast to all the previous parameters the feed water of shore wells intake has more values of dissolved silica than had those of open intake feed water.

Boron is widely distributed across the earth’s hydrosphere and lithosphere. Seasonal factors and geographic location have an impact on its concentration. One of the seven micronutrients necessary for healthy plant growth is boron. Boron concentration is a remarkable parameter for seawater and is found with high concentrations and considered one of the limiting factors for seawater treatment success (Escarabajal-Henarejos et al., 2021). Boron elimination from seawater is a crucial and challenging process (Baransi-Karkaby et al., 2019). Approximately 98% of salts and other solutes in seawater are removed by reverse osmosis (RO), which successfully produces freshwater with a satisfactory grade. The single-pass RO system cannot eliminate boron and other trace pollutants. At seawater’s typical pH (7–8), boron rejection level in the single-pass RO process was frequently reported to range between 40% and 78% (Alkhudhiri et al., 2020). The minimum and maximum boron concentrations were noted at Shalateen during summer and winter, respectively. Landsman et al. (2020) stated that boron concentration is highly affected by temperature. The RO membrane lowered the high values of boron to be under the criteria of treated water according to the decision of the Minister of Health No. 458/2007.

Flouride can be found in igneous rocks (granite) as cryolite, in sandstone and limestone rocks as fluorspar (Cox, 1964).

During the study, the metals concentration was very low. This could be attributable to the dilution of the effluent and the water exchange between the coast and the main sea (Omar et al., 2013). Zinc is found naturally and known to be a contaminant in the residues of pesticides, anti-corrosion paints and food waste (Al-Mur, 2020). Also the solubility of cupper is greatly affected by the solubility of iron (Al-Mur, 2020). According to Ali et al. (2019), the following descending order describes the concentration of heavy metals in seawater: Mn > Cu > Zn. While, the order of heavy metals concentration in the present investigation was Zn > Cu > Mn. The oxidation process of Fe^{+2} to iron hydroxides may be the reason for the drop in iron and manganese concentrations as water salinity increases (Hariri & Abu-Zied, 2018).

Dissolved oxygen monitoring is a valuable indicator of ecosystem stability and water quality in coastal locations (Abdel-Halim & Aly-Eldeen, 2016). Additionally, it is among the most crucial factors influencing the biological processes, activity, and survival of all aquatic biota (Goher et al., 2018). It is an excellent tool that illustrates how pollution influence aquatic ecosystems wherever harmful substances are present (Lester, 1975). It also has an impact on the nutrients' solubility and availability. Low dissolved oxygen concentrations influence the aquatic ecosystem's productivity by facilitating the release of nutrients from sediments (Abdelmongy & El-Moselhy, 2015). A high dissolved oxygen level in the water column signifies good mixing (Girgis, 1980). The maximum dissolved oxygen values were recorded during winter which is consistent with the fact that low temperature values in winter, increase the solubility of gasses (Calliari et al., 2005). Comparable data were attained by Shrestha & Kazama (2007). The obtained values of chemical oxygen demand not exceed the national standard (120mg/L) (Redouane & Mourad, 2017). Biological oxygen demand is considered as a vital factor in the aquatic environment. Its concentration can be raised by increased organic pollutants as that from wastes of industrial activities, sewage and disposal of fishing ships. Our study showed high BOD values during winter. In contrast, Abdelmongy & El-Moselhy (2015) found a positive relationship between temperature and BOD. The recorded values obtained during the present study not exceed the national standard (40mg/L) (Redouane & Mourad, 2017).

Algae enumeration and identification

Thirty two species belonging to four phytoplankton groups were recorded. With a clear dominance of Bacillariophyceae (23 species) followed by Dinophyceae (4 species), Chlorophyceae (3 species) and finally Cyanophyceae (2 species). From the obtained results, there was a noticeable difference between the open intake and the shore wells intake feed water. Also, Cyanophycean species disappeared in the feed water of the shore wells intake (Tables 7- 9).

The identification and enumeration of algae showed that the most dominant species in Bacillariophyceae were *Thalassiosira subtilis, Cocconeis pellucida, Pseudo-Nitzschia brasiliana* and *Thalassionema bacillare* which appeared at all sites under study followed by *Cyclotella striata* which appeared in four sites during the four seasons, *Climacosphenia moniligera* and *Melosira juergensii* were recorded in four sites during three seasons. Concerning Dinophyceae, the most dominant species were *Gymnodinium aureolum* which appeared in all sites during all seasons, followed by *Alexandrium minutum* which found in all sites during three seasons and *Gonyaulax polygramma* was identified in all sites during two seasons. The chlorophyte *Pyramimonas amylifera* was the dominant member and appeared in three sites during fall and winter, followed by *Oocystis parva* which appeared in two sites during the fall season, finally, *Scenedesmus acutus* was found in one site (El Yosr feed water) during spring. Chlorophytes disappeared completely at Marsa Alam. Only two species of Cyanophyceae *Chroococcus turgidus* was found at two sites (Hurghada during summer and Shalateen during fall) and *Trichodesmium erythraeum,* which appeared only at Hurghada during spring. For permeate water, it contained species of only two groups Bacillariophyceae and Dinophyceae. The dominant Bacillariophytes species were *Climacosphenia moniligera* which found at three sites during fall and spring followed by *Cyclotella striata* which found at three sites during only spring, while Dinophyceae represented by *Gymnodinium aureolum* that appeared in Safaga and Shalateen sites during fall season and *Alexandrium minutum* appeared at Marsa Alam during spring season.

Table 7. Annual variations in the total phytoplankton count (Organism/L) at the five desalination plants

Division \ Sites	Al Yosr (Hurghada)		Safaga		Qusser		Marsa Alam		Shalateen	
	Feed	Permeate	Feed	Permeate	Feed	Permeate	Feed	Permeate	Feed	Permeate
Bacillariophyceae	40947	1665	47942	666	5661	666	5661	1665	39452	1665
Dinophyceae	5026	0	3996	333	1332	0	3663	333	5196	666
Chlorophyceae	999	0	666	0	333	0	0	0	333	0
Cyanophyceae	718	0	0	0	0	0	0	0	333	0
Total	47690	1665	52604	999	7326	666	9324	1998	45314	2331

Table 8. Seasonal variations of different algal taxa in feed intake at the five desalination plants

Algal species	Feed				
	Al Yosr (Hurghada)	Safaga	Qusser	Marsa Alam	Shalateen
Bacillariophyceae (Diatoms)					
Climacosphenia moniligera Ehrenberg	S	Sp&S&F	Sp	-	Sp&S&F
Thalassiosira subtilis (Ostenfeld) Gran	S	Sp&S	S	S&F	Sp&S
Amphora turgida W.Gregory	-	Sp	-	Sp	-
Cocconeis pellucida Grunow	Sp&F	Sp&S&F	S	Sp	A
Cyclotella striata (Kützing) Grunow	Sp&S&W	Sp&S&F	-	Sp&S	S&F
Pseudo-nitzschia brasiliana Lundholm, Hasle & G.A.Fryxell	A	A	F	S	Sp&S&F
Nitzschia vitrea G.Norman	F	W	-	-	F&W
Grammatophora oceanica Ehrenberg	S	S	-	-	Sp&S
Melosira juergensii C.Agardh	W	S&W	-	W	Sp&S
Leptocylindrus danicus Cleve	S	S	-	Sp	Sp&S
Navicula distans (W.Smith) Brébisson	F	F	-	-	-
Navicula cancellata Donkin	-	-	-	-	W
Cylindrotheca closterium (Ehrenberg) Reimann & J.C.Lewin	F&W	S	-	-	S
Asterionella japonica Cleve	F	F	-	-	F
Chaetoceros compressus Lauder	F	-	-	-	F
Proboscia alata (Brightwell) Sundström	Sp	-	-	-	-
Fragilaria striatula Lyngbye	F	-	-	-	-
Cymbella ventricosa (C.Agardh) C.Agardh	S	S	S		S&W
Thalassionema bacillare (Heiden) Kolbe	S	S	F	S&F	S&F
Amphiprora gigantea Grunow	-	F	-	-	F&W
Striatella unipunctata (Lyngbye) C.Agardh	-	-	-	F	-
Pleurosigma angulatum (J.T.Quekett) W.Smith	-	-	F	-	-
Guinardia flaccida (Castracane) H.Peragallo	W	W	-	-	-
Dinophyceae					
Gymnodinium aureolum (Hulburt) Gert Hansen	Sp&S	Sp&F&W	Sp	Sp&F	Sp&S&F
Alexandrium minutum Halim	Sp&S	F	Sp	Sp&S	F
Gonyaulax polygramma F.Stein	Sp&S	S	Sp&S	Sp&S	Sp&S
Prorocentrum gracile F.Schütt	-	Sp	-	-	Sp
Chlorophyceae					
Scenedesmus acutus Meyen	Sp	-	-	-	-
Oocystis parva West & G.S.West	F	-	F	-	-
Pyramimonas amylifera Conrad	F	W	-	-	F
Cyanophyceae					
Chroococcus turgidus (Kützing) Nägeli	S	-	-	-	F
Trichodesmium erythraeum Ehrenberg ex Gomont	Sp	-	-	-	-

Species recorded during the autumn/fall (F), winter (W), spring (Sp), summer (S), during all seasons (A) and absent (–).

Table 9. Seasonal variations of different algal taxa in permeate water at the five desalination plants

Algal species	Permeate				
	Al Yosr (Hurghada)	Safaga	Qusser	Marsa Alam	Shalateen
***Bacillariophyceae (Diatoms)**					
Climacosphenia moniligera Ehrenberg		F	Sp		Sp&F
Amphora turgida W.Gregory				Sp	
Cocconeis pellucida Grunow	Sp			Sp	
Cyclotella striata (Kützing) Grunow	Sp	Sp		Sp	
Pseudo-nitzschia brasiliana Lundholm, Hasle & G.A.Fryxell	F				F
Leptocylindrus danicus Cleve				Sp	
Navicula distans (W.Smith) Brébisson	F				F
Thalassionema bacillare (Heiden) Kolbe			F	F	F
***Dinophyceae**					
Gymnodinium aureolum (Hulburt) Gert Hansen		F			F
Alexandrium minutum Halim				Sp	

Species recorded during the autumn/fall (F), winter (W), spring (Sp), summer (S), during all seasons (A) and absent (–).

Following a certain succession, the floristic composition of phytoplankton is regulated by the water physico-chemical characteristics, such as pH, DO, temperature, salinity, and nutrients (Buzzi, 2002; Touliabah et al., 2016). Also, the turbidity was negatively correlated with algal count. Turbidity determines how many photons are available for photosynthesis in the water column (Jafar-Sidik et al., 2017). On agreement with our results, Kebede & Ahlgren (1996) found the maximum algal growth during summer. Touliabah et al. (2010) stated that pH 8 is the ideal growth pH for Bacillariophyceae, Dinophyceae, and Cyanophyceae. In our investigation, algae prefer pH>8. The data in the present investigation showed a positive relation between algal count and salinity. Similar results were obtained by El Gammal et al. (2017). Also, Schumann et al. (2006) elucidated that the phytoplankton diversity was influenced by salinity. The uptake of iron by microorganisms and plants is explained by two theories; the first one is the reductive way and the second one is through the siderophore-mediated mechanisms. Those two theories are used by some marine algae (Sutak et al., 2012). This phenomenon explains the negative relationship between iron concentration and algal count. Many algae and aquatic plants can directly use ammonia, a biologically active substance that is found in most water, as a natural biological degradation product of organic nitrogen (UNESCO, 1988). Also, nitrate is the most considerable state and predominant state in seawater, which is naturally created as a byproduct of the nitrogen cycle and promotes the growth of plankton and water weeds, which serve as fish food (Al-Qutob et al., 2002). In addition, phosphorus is regarded as one of the essential nutrients that control both the growth and reproduction of algae (Abdelmongy & El-Moselhy, 2015). Furthermore, silica is considered a skeletal material for marine diatoms, in addition to the fact of being one of the most important nutrients (Abdel-Halim & Aly-Eldeen, 2016). This explains the negative relation observed during the study between dissolved silica and algal count. It appears that boron is not universally necessary for algae. Fernández et al. (1984) did not demonstrate the need for boron in green algae, although there was evidence that marine diatoms required it (Miller et al., 2016). High fluoride values cause inhibition of diatoms, dianoflagellates while other algal groups were not affected. The harmless complexes that fluoride forms with one or more seawater ions may be the reason for its lack of toxicity (Masoud et al., 2006). During the present investigation, the total algal count was negatively related to fluoride concentration. The maximum fluoride value was observed in winter (the lowest algal growth), while the minimum fluoride value was found in summer (the highest algal growth).

Algae are recognized as a trustworthy indicator for tracking the levels of heavy metals in aquatic environments (Mourad & Abd El-Azim, 2019). The intake of metals by algae to a great level is influenced by a lot of parameters like salinity, pH, and metal concentration of seawater (Morrison et al., 2008). The bioaccumulation of metals is highly controlled by the biological factors, which are natural components of the marine environment (Al-Mur, 2020). Trace metals are of two divisions, the first one includes Co, Cu, Fe, Mn, and Zn, which are of great importance to the biochemical process may also be toxic at high levels. While, Hg, Cd, Cr, and Pb are of no biological role but are more and more dangerous contaminants for the aquatic marine environment (Omar et al., 2013). Zinc is found naturally and is known to be a contaminant in the residues of pesticides, anti-corrosion paints, and food waste (Al-Mur, 2020). The distribution of dissolved minerals is highly related to the phytoplankton through adsorption. Also, copper solubility is greatly influenced by the solubility of iron (Al-Mur, 2020). From the obtained results during the present research, the lowest concentrations were during spring and summer, but the highest ones were during autumn and winter. The copper concentration was negatively correlated with algal count. In addition, dissolved oxygen concentrations were negatively related to the total algal count. These results agreed with those reported by El Gammal et al. (2017).

Bacteriological assessment

Removal of microorganisms to lower the risk of illness is one of the main objectives of drinking water treatment. To determine the water quality and guarantee its compliance with the Ministry of Health's 458/2007 decision, the following quantitative analyses of bacteria are advised: total bacterial count (HPC bacteria), total coliform, and fecal coliform. HPC bacteria measure all the common bacteria that found in the water. The quality of the water system is better if those bacteria are less prevalent (Rusin et al., 1997). For feed analysis, the highest value of HPC was at El Yosr during winter (367cfu/ml), and the lowest was at Marsa Alam during spring (20 cfu/ml). In fact, the positive occurrence of total coliform was accompanied with the absence of fecal coliform, which is considered unacceptable (El-Sheekh & Hamoud, 2021). The results fluctuated between too numerous to count (T.N.T.C) at two sites El Yosr (during winter) and Safaga (during fall and winter) to < 1 at all the sites under investigation. Throughout the investigation period, fecal coliform was absent from every collected sample. Regarding permeate water, all the collected samples from all the sites comply with the standards suggested by WHO guidelines (2008) and the Egyptian Ministry of Health's 458/2007 decision (Table 10).

Table 10. Seasonal variations of the bacteriological analysis at the five desalination plants

Parameter	Spring		Summer		Autumn		Winter	
	Feed	Permeate	Feed	Permeate	Feed	Permeate	Feed	Permeate
Al Yosr (Hurghada)								
Total Bacterial Count (CFU/ml)	85	<1	148	<1	67	4	367	14
Total Coliform (CFU/100ml)	8	<1	41	<1	<1	<1	T.N.T.C	<1
Fecal Coliform (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free
Safaga								
Total Bacterial Count (CFU/ml)	68	<1	110	<1	98	3	298	<1
Total Coliform (CFU/100ml)	2	<1	17	<1	T.N.T.C	<1	T.N.T.C	<1
Fecal Coliform (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free
Qusser								
Total Bacterial Count (CFU/ml)	22	<1	40	<1	68	5	39	1
Total Coliform (CFU/100ml)	2	<1	1	<1	1	<1	3	<1
Fecal Coliform (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free
Marsa Alam								
Total Bacterial Count (CFU/ml)	20	<1	25	<1	100	<1	88	13
Total Coliform (CFU/100ml)	2	<1	1	<1	<1	<1	5	<1
Fecal Coliform (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free
Shalateen								
Total Bacterial Count (CFU/ml)	43	<1	39	<1	30	7	48	7
Total Coliform (CFU/100ml)	5	<1	3	<1	<1	<1	2	<1
Fecal Coliform (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free

CONCLUSION

This investigation compared two types of intake systems used in desalination plants within the Red Sea Governorate: open intakes and shore wells. The results showed that shore wells provide superior water quality compared to open intakes, which helps protect reverse osmosis membranes, extending their lifespan and offering significant economic benefits. Additionally, our study provides an overview of the seasonal variations in marine microalgae across various Red Sea sites, with a particular focus on the physicochemical characteristics of the water.

Recommendations: Given the critical importance of the Red Sea as an alternative drinking water source, regular water quality monitoring is recommended, with a focus on seasonal variations to mitigate operational risks in desalination plants. Based on the findings of this study, we recommend that future desalination plant locations prioritize the use of shore well intakes. This approach should be considered during the planning phase, as shore wells offer significant economic benefits by reducing operational issues and ensuring the production of high-quality water. Implementing this strategy will enhance the efficiency and sustainability of desalination operations in the region.

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