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Impacts of Climate Change on Seawater Temperature and Total Dissolved Solids: Challenges and Sustainable Solutions for Reverse Osmosis Desalination in the Arabian Gulf Region

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Abstract

This article examines the influence of seawater temperature and total dissolved solids (TDS) on reverse osmosis (RO) desalination in the Arabian Gulf region, with a focus on the impact of climate change. The study highlights the changes in seawater temperature and TDS levels over the years and discusses their effects on the efficiency and productivity of RO desalination plants. It emphasizes the importance of monitoring TDS levels and controlling seawater temperature to optimize water production. The article also suggests various solutions, including intensive pre-treatment, development of high-performance membranes, exploration of alternative water sources, and regulation of discharges into the Gulf, to ensure sustainable water supply in the face of rising TDS levels and seawater temperature. Further research and comprehensive monitoring are recommended to understand the implications of these findings and develop effective strategies for the management of marine resources in the Arabian Gulf.

Keywords

Climate Change, Temperature, Reverse Osmosis, Seawater, Total Dissolved Solids, Desalination

1. Introduction

Climate change has considered as one of the most challenges to our environment and ecosystems. The accumulation of greenhouse gases in the atmosphere, created a global concern that impacts our plant's ecosystem and resources [1]. The indirect impacts of climate change extended to resources managements, such as in water supply solutions.

Globally, desalination is considered a key solution for providing a fresh water resource, especially in water scarcity regions [2]. The Arabia Gulf is one major basin of desalination that supplies approximately up to 60% of the regional demand [3]. The seawater in the eastern region of Saudi Arabia exposed to high rate of changes due to the expansion of industrial growth and increase in human infrastructure with other activities. In addition to global increase in atmospheric temperature, the Arabian gulf considered a shallow water body, average depth of 36 meter, which makes the consequence of changes in temperature patterns noticeable and more significant [4] [5].

The properties of seawater have a significant impact on the efficiency and productivity of Reverse Osmosis (RO) desalination technology. Factors such as seawater temperature, total dissolved solids (TDS) levels, and other water quality parameters play a crucial role in determining the performance and operational costs of RO desalination plants [6].

Since in RO technology are currently replacing other desalination technology shares [7], and due to its sensitivity to the feed quality, the understanding the influence of seawater properties on desalination process is essential for optimizing plant operations, improving energy efficiency, and ensuring the long-term sustainability of water supply in region.

This article aims to highlight the changes in seawater temperature and total dissolved solids (TDS) in the Arabian Gulf over the years. It also discusses the influence of global climate change on seawater temperature and TDS patterns, with a specific focus on their impact on the production of reverse osmosis (RO) desalination in the Arabian Gulf region. Long-term solutions and recommendations will be presented to address these challenges and ensure sustainable water production.

2. Climate Change and Reverse Osmosis Desalination

The global temperature patterns become gradually noticeable. The gradual increase in global temperatures is primarily attributed to human activities, specifically the emission of greenhouse gases such as carbon dioxide (CO_2) into the atmosphere. These greenhouse gases trap heat from the Sun within the Earth's atmosphere, causing a warming effect known as the greenhouse effect [8]. The rise in global temperature causes deviation in seawater physical, chemical, and biological properties. These influences can impact seawater parameters, such as temperature and total dissolved solids. The water surface temperature and total dissolved solids (TDS) in seawater are essential factors for desalination plants, especially with current shift toward Reverse Osmosis (RO) technology. This technology based on pressurizing pre-treated seawater into membranes that separates salt and allows fresh water to pass though [9]. Thus, as higher TDS level as more pressure required to remove salts and other substances. As well as, more energy would be required to pressurize the water flux through the membranes. Therefore, it is essential to monitor TDS levels in seawater to ensure the effectiveness of water production (**Figure 1**).

On the other hand, seawater temperature has a direct effect to the RO productivity. The high seawater temperatures promote the growth of marine organisms, including algae and bacteria. Consequently, these organisms can adhere to the RO membranes, leading to fouling, reducing membrane efficiency, and causing higher frequency of membrane cleaning and replacement. As a result, the operational cost of RO system increases, while productivity declines [11]. In addition, membranes topically are made out of polymer material. The elevation of temperature causes thermal expansion to the membrane sheets surface. The polymer breakdown can lead to changes in the membrane's structure, including pore size and distribution, ultimately affecting its porosity. The changes in membrane material structure and porosity have substantial effect to membrane rejection rate, which lead to lower the permeate quality [12].

Several studies have underscored the distinctive characteristics of the Arabian Gulf, emphasizing its elevated salinity levels and accelerated rate of seawater surface temperature increase. Research indicates that the average salinity of seawater worldwide stands at approximately 35 parts per million (ppm), while the Arabian Gulf exhibits a significantly higher salinity level of around 45 ppm. Moreover, studies assessment on surface sea water temperature rising in the Arabian Gulf found that the average warming rate is more than three times the global average rise [13] [14]. These findings are of particular significance in the context of the study as they shed light on the unique challenges faced by desalination processes in this region and emphasize the need for sustainable solutions to ensure the viability and effectiveness of reverse osmosis desalination systems.

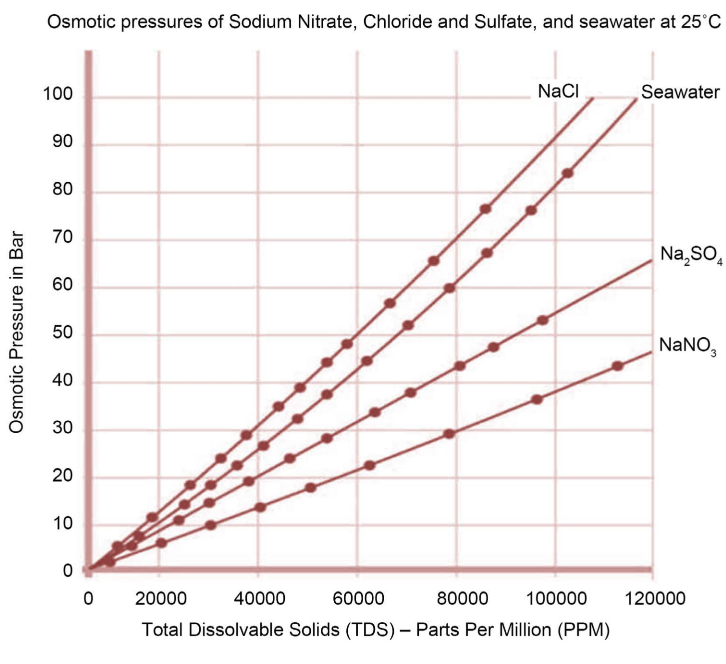


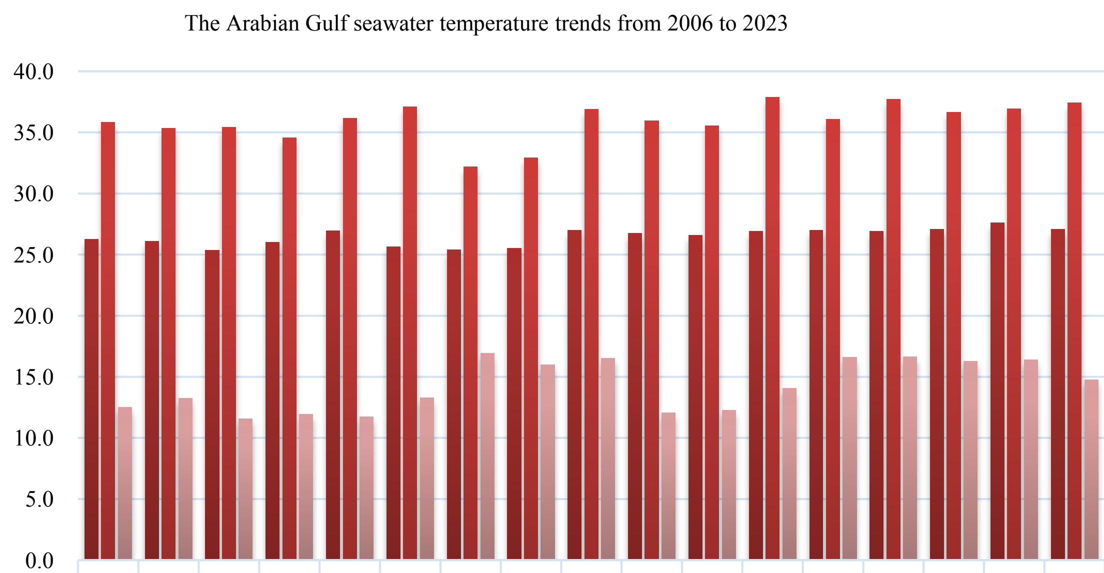
Figure 1. Effect of total dissolved solids on osmotic pressure [10].

Al-Khobar Site Survey

The Arabian Gulf region is experiencing rising temperatures, heatwaves and extended periods of high temperatures are becoming more frequent [15]. To evaluate the Gulf seawater temperature, data was collected for seventeen years period from (2006 to 2022) for Al-Khobar area (SWCC-Phase 3-intake seawater temperature analyzer-unit 11). The annual average seawater temperature was in range of 25.6˚C to 27.6˚C. The maximum detected temperature was 37.89˚C on 2017, while the lowest degree was 11.57˚C on 2008.

The average seawater temperature was fluctuation over year, though, notably from 2018 the pattern started by show slightly higher range (**Figure 2**).

Considering the impacts of temperature to dissolved solids concentration, data collected for total dissolved solids from the same location (SWCC-Al Khobar-Phase 3—intake sample point) and were analyzed for two periods: (2005-2006) and (2020-2022). During the first period (2005-2006), the average TDS was recorded as 53,396 ppm, while in second period (2020-2022), the level was 55,990 ppm, representing a 5% increase. The maximum TDS value observed during the first period was 56,540 ppm, and the minimum was 47,690 ppm. In the later period, the maximum TDS increased by 6% to reach 59,920 ppm, and the minimum value recorded was 50,000 ppm, which is 5% higher than the first period's data (**Figure 3**). These findings indicate a significant increase in the TDS levels of the seawater over the analyzed periods. This increase in TDS could be attributed to various factors, including the global warming influences such as the rise in temperature and other climate change consequences.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Avg. Temp. (oC)	26.24	26.08	25.36	26.03	26.96	25.67	25.39	25.54	26.98	26.75	26.60	26.91	27.02	26.92	27.09	27.59	27.05
Max. Temp. (oC)	35.84	35.35	35.42	34.56	36.18	37.10	32.18	32.92	36.88	35.93	35.53	37.89	36.09	37.71	36.68	36.92	37.42
Min. Temp. (oC)	12.49	13.23	11.57	11.93	11.72	13.28	16.92	16.00	16.54	12.06	12.29	14.06	16.61	16.63	16.29	16.38	14.76

Figure 2. The Arabian Gulf seawater temperature trends from 2006 to 2023.

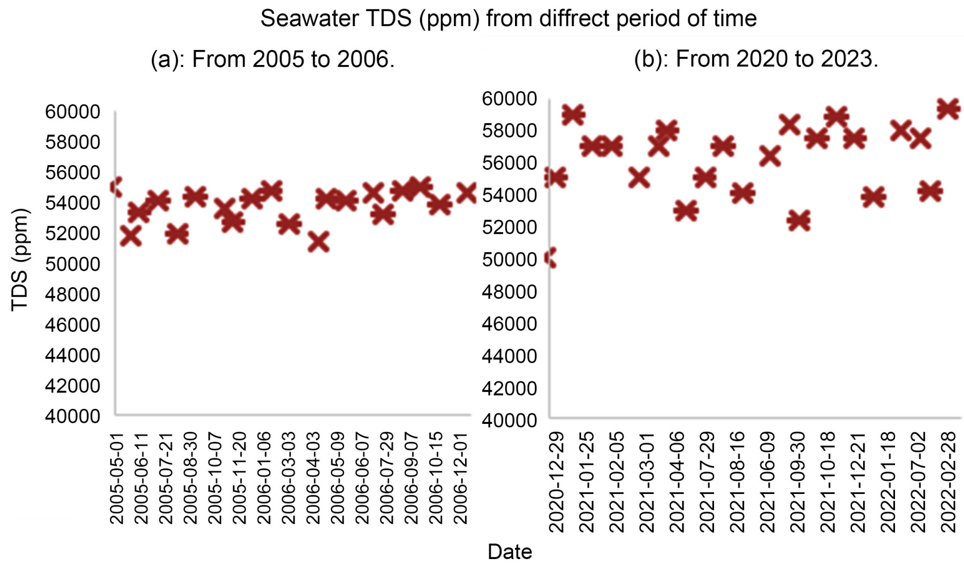


Figure 3. The Arabian Gulf seawater TDS: (a) TDS measurement from 2005 to 2006. (b) TDS measurement from 2020 to 2023 [16].

3. Solution and Recommendation

The increased in seawater TDS and temperature pose additional challenges for RO desalination. More energy input required to achieve freshwater production. This not only impacts the operational costs but also affects the overall sustainability of desalination processes. To address the challenges of rising seawater temperature and TDS levels in RO desalination, several recommended solutions can be implemented:

- Intensive Pre-Treatment required to decrease the load of dissolved and suspended solids on membrane. Such as enhanced coagulation, flocculation, and remove of suspended solids and organic compounds before entering RO system. This can include techniques such as using pretreatment filtration technologies (Ultra-filtration or Nano-filtration) to minimize the impacts on membrane performance.

- Using proper chemicals treatments to overcome the environmental difficulties such as utilize appropriate antiscalant chemicals to mitigate scaling issues caused by elevated TDS levels. In addition, injecting the biocide chemical 2,2-dibromo-3-nitrilopropionamide (DPNBA) in a RO system can be an effective approach to control microbial growth and mitigate fouling issue. These chemicals can help prevent the precipitation and deposition of mineral scales and biofilm organics on the membrane surface, reducing the frequency of cleaning and minimizing the impact on system performance.

- Research and development efforts should prioritize the development of high-performance membranes with improved resistance to fouling and scaling. Innovative membrane materials and coatings can be employed to enhance salt rejection efficiency and mitigate the impacts of elevated TDS concentrations.

- Exploring an alternative water sources or diluting the original feed, like mixing feed with treated wastewater, brackish water (well water) or even recycling portion of permeate water, can help reduce the reliance on high-TDS seawater for desalination. This would contribute to a more sustainable water supply strategy and management.

- Deep comprehensive expert study of the region's discharged and outfall into the Gulf is critical to effectively manage the overload rate that can lead to an increase in TDS levels. By implementing proactive measures and adopting a strategic approach, the Arabian Gulf region can ensure the long-term viability of its marine ecosystem.

- Further in-depth analysis and extensive monitoring of TDS levels required, along with a comprehensive study investigating the factors influencing the observed changes, are necessary to fully understand the implications of these findings and develop appropriate strategies for the sustainable management of the Arabian Gulf's marine resources.

4. Conclusions

This article highlights the challenges posed by climate change in the Arabian Gulf region, specifically in relation to seawater temperature and total dissolved solids (TDS) levels, and their impact on reverse osmosis (RO) desalination processes. The study emphasizes the importance of monitoring and understanding these factors to optimize water production, improve energy efficiency, and ensure long-term sustainability. The research findings suggest that seawater temperature variations and increasing TDS levels in the Arabian Gulf have significant implications for RO desalination. Higher temperatures can affect the quality and efficiency of membranes, leading to reduced salt rejection and lower permeate quality. Additionally, the rise in TDS concentration necessitates greater energy input to overcome osmotic pressure during the desalination process.

To address these challenges, the article proposes several solutions and recommendations. These include implementing intensive pre-treatment methods to reduce the load of dissolved and suspended solids, developing high-performance membranes resistant to fouling and scaling, practicing a proper chemicals the lower tendency of scaling and biofouling, exploring alternative water sources or dilution options, regulating and managing the discharge and outfall of the region, and conducting further in-depth analysis and monitoring of TDS levels.

By implementing these strategies, the Arabian Gulf region can enhance the efficiency and sustainability of RO desalination processes, ensuring a more secure and affordable water supply. Additionally, a comprehensive understanding of the factors influencing seawater temperature and TDS changes will contribute to the effective management of marine resources in the Arabian Gulf.

Overall, this article underscores the need for proactive measures, research, and ongoing monitoring to address the challenges posed by climate change and ensure the long-term viability of water production in the region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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