
Food safety and Public health

Optimization of Drinking Water Quality Produced from Reverse Osmosis Systems in Menoufia Governorate, Egypt.

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ABSTRACT

Reverse osmosis (RO) stands as a crucial membrane-based technology for addressing water scarcity through desalination and purification processes. Water quality produced from different compact plants was assessed. This technology is applied in many places all over the world and helpful for drinking water production in seven cities of Menoufia governorate, Egypt. To ensure acceptable drinking water quality, ensuring the quality of the raw water source is crucial, and treatment plants must be rigorously evaluated for their effectiveness. Raw water resources either groundwater or surface one was assessed, where compact units abstract their waters. Comparisons were made between various sites using different compact units. The average TDS of source water of El-Khatatba was higher than Quesina as 1200 and 560 mg/L, respectively. To describe RO of neutral solutes, we utilize the solution-diffusion (SF) model, which closely resembles the classical sieving or pore flow model. Also, the maximum and minimum of obtained drinking water have similar trend. This could potentially illustrate the variability in removal efficiency across the entire range of water plant capacities as successful investigated tools for evaluation. Next improvements of drinking water quality of small-scale unit are followed up. In this view, the new protocol emphasized the characteristics of the raw water source and aimed to maximize the removal efficiency of physical and chemical contaminants during the treatment process.

Keywords: Reverse osmosis; Drinking; Water quality; Compact units; Resources; Local plants.

1.INTRODUCTION

Meeting the growing demand for safe water is a major challenge in many

water-stressed nations (Kabeel, 2009; Alkaisi et al., 2017; Abdelkareem et al., 2018). The United Nations forecasts that by 2025, approximately 20% of countries will face critical water scarcity, with 2.7 billion people globally lacking access to safe drinking water. Access to potable water is crucial not only for human survival but also for key sectors like agriculture, energy, tourism, recreation, and construction. Global urbanization is driving up annual water consumption, exacerbating the problem of water pollution and making direct human consumption increasingly problematic. These critical needs across various sectors underscore the urgent necessity of producing clean, safe water to sustain human populations and support water-dependent activities (Wong and Pecora, 2015).

Approximately 97.5% of the Earth's available water is saltwater, with another 2% locked in polar ice caps and glaciers. Consequently, less than 0.5% of the total water supply exists as accessible freshwater for human and ecosystem needs (Kabeel, 2009). Recognizing this scarcity, significant efforts are underway to develop and scale up alternative water production technologies to mitigate the global water crisis. Simultaneously, governmental bodies and scientific communities are collaborating to raise public awareness about the crucial need for effective water management and conservation practices to ensure access to safe and clean water (Goosen and Shayya, 1999).

Desalination refers to the purification of saline water through the removal of dissolved minerals (Chen et al., 2020). It is a prominent technology employed to generate potable water from seawater or brackish sources for both human

consumption and various other applications requiring purified water (Zaidi and Saleem, 2021; Suwaileh et al., 2020; Saud et al., 2022). Among desalination approaches, thermal and membrane-based separation are the most prevalent (Nassrullah et al., 2020). Large- and medium-scale thermal desalination commonly utilizes techniques such as multistage flash distillation (MSF), multi-effect distillation (MED), and vapor compression (VC). With the exception of VC, thermal desalination processes generally require two forms of energy input: low-grade thermal energy to elevate the temperature of the incoming saline water and electrical energy to power the associated pumps (Al-Karaghoul and Kazmerski, 2013).

While numerous membrane-based desalination methods exist, reverse osmosis (RO) and electrodialysis (ED) are the most widely applied. Both RO and ED require electrical power; in RO, this energy drives the pumping process, whereas in ED, it's essential for applying a direct current across electrodes to facilitate ion separation through membranes (Zarzo and Prats, 2018). RO technology has been implemented in several large-scale, modern desalination facilities globally, including the recently established Tuas plant in Singapore and the Ashkelon plant in Israel (Bakly et al., 2022; Saleem et al., 2022). The Ashkelon facility, recognized as one of the largest RO plants worldwide, provides desalinated seawater for municipal use, boasting a daily production capacity of 395,000 m³ (Isaias, 2001).

Our study aims to monitor the appropriate small-scale local RO desalination plants to evaluate their produced waters quality in seven

different cities, Menoufia governorate, Egypt. The acquired cities were Quesna, El-Bagour, Minuf, Ashmoun, El-Khataba, Kafr Dawood, and Sadat city which are distributed along. Proposed of this study be assessed where the compact units abstract their water. At the same time, comparison between different treatments steps of different compact units have be investigated.

2.MATERIALS AND METHODS

The most common technology that depend on membrane processes were used in our area are the reverse osmosis (RO) ones that used for groundwater desalination. But only in small scale potable, RO competes with distillation processes for desalination of water production as a small villages and different communities (Kalogirou,

2005).

2.1 Water sampling

Water samples, including raw, clarified-filtered, and treated water, were sampled from Badr drinking water treatment plants across seven cities within the Menoufia Governorate, Egypt. Sampling spanned five full seasons, from November 2021 to December 2022, adhering to standard water and wastewater examination protocols (APHA, 2017). Weekly collections were conducted for a range of physicochemical analyses, as well as experiments to determine residual chlorine dosages (breakpoint chlorination). The geographical distribution of the sampled cities within the Menoufia Governorate, Egypt, is illustrated in Figure 1.

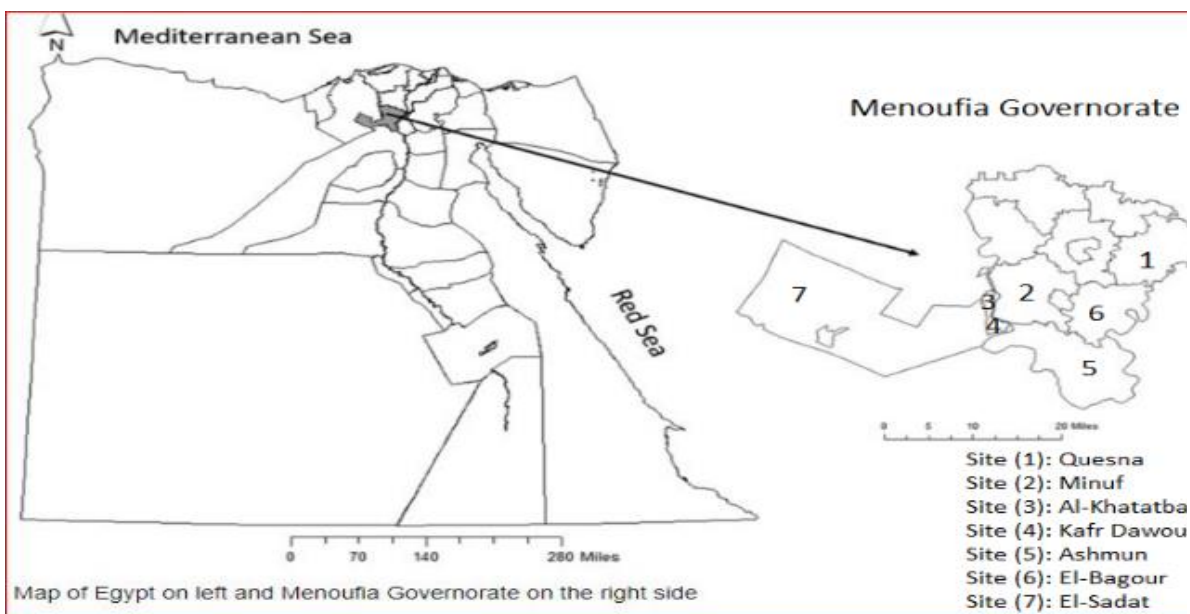


Fig. (1): Map of Sampling Locations and Study Area

2.2 Water chemical analyses

Water quality was assessed by measuring several key parameters: pH, turbidity, electrical conductivity (EC), and total dissolved solids (TDS). The concentrations of trace

elements, specifically aluminum, iron, and manganese, were determined using ICP-MS, with results expressed in milligrams per liter (mg/L). All physical and chemical analyses were performed in

duplicate, adhering to the established protocols in accordance with Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

2.3 Heavy metals determination by ICP-MS

Heavy metal analysis was conducted at the Environment and Food Biotechnology Laboratory within the GEBRI at the Sadat City- University. The analysis encompassed over 663 samples of both raw and treated drinking water. Water samples were initially filtered through 0.2-micron disposable Polytetrafluoroethylene syringe filters (Advantech, Tokyo, Japan) to remove particulates. Metal concentrations in the filtered samples were subsequently measured using inductively coupled plasma-mass spectrometry (ICP-MS) with an iCAP instrument from Thermo Fisher Scientific, Germany. Certified reference materials obtained from Merck, Germany, were included in the analysis to ensure accuracy and precision. Data processing and statistical analysis (including calculations of average, standard deviation, and relative standard deviation) were performed using Qtegra software (APHA, 2017). The laboratory maintains accreditation through EGAC/ILAC (under accreditation No. 021706). Metal recovery rates were within acceptable limits of the certified reference materials (Goher et al., 2021).

2.4 Pollution Indices

To assess the environmental quality of the water samples, pollution indices were employed. Specifically, this involved calculating the contamination-degree (CD), the pollution load-index (PLI), and the potential ecological risk-index (RI) (Qingjie et al., 2008). Ideally,

the concentrations of the studied metals should be compared to pre-industrial background levels. However, in this study, the composition of the upper continental crust was used as a proxy for these pre-industrial reference levels of trace and heavy metals.

2.5 Data analysis

Data analysis was conducted using SPSS Statistics (Version 17, IBM Corp., Chicago, IL). Descriptive statistics were calculated initially, followed by one-way ANOVA to assess group differences. To pinpoint specific differences between groups, Duncan's post-hoc test was employed. Statistical significance was determined at a significance level of $\alpha = 0.05$.

3.RESULTS AND DISCUSSION

Access to sufficient, safe, and readily available drinking water is fundamental for human life. Consequently, enhancing drinking water quality is a global priority for safeguarding public health (WHO, 2004). Over recent decades, regulations governing water quality have become increasingly rigorous, coinciding with greater public awareness and more discerning attitudes towards the quality of their drinking water (Zhang et al., 2021). The European Directive 98/83/EC sets the standard for drinking water quality. It defines drinking water as any water, whether untreated or treated, intended for use in drinking, cooking, food preparation, or other household purposes. This definition encompasses water from all sources, including that supplied through distribution networks, tankers, or bottled (European Commission, 1998).

Table 1 and Figure 2 present a comparison of water treatment plant performance across seven cities in the governorate, showing the number of

plants meeting and not meeting the Egyptian drinking water standards (Decree 458/2007). All samples analyzed (Table 1) demonstrated notable improvements in turbidity, with no samples exhibiting turbidity levels that would preclude their use as drinking water. Similarly, no concerning odors or pH values were detected. The treatment systems yielded substantial improvements in water appearance across all samples, particularly in sedimentation. While filtered effluent from groundwater-dependent plants showed reduced total dissolved solids, these levels remained within acceptable limits and comparable to Egyptian drinking water standards (El-Masry et al., 1995).

This study assessed the performance of local reverse osmosis (RO) desalination plants in producing potable water across seven cities in Menoufia Governorate, Egypt: Quesna, El-Bagour, Minuf, Ashmoun, El-Khataba, Kafr Dawood, and El-Sadat. These cities have groundwater as their primary source for drinking water and other human needs. Data were collected from multiple sites within these cities between October 2021 and November 2022. All analyzed parameters were evaluated against the Egyptian drinking water standards (Decree 458/2007). The removal efficiencies of the studied plants generally followed a similar pattern.

Table (1): No. of plants status complies according to Egyptian law 458/2007.

#	Cities	No of plants	Plant status for outlet results							
			TDS		Fe		Mn		Al	
			C	NC	C	NC	C	NC	C	NC
1	Quesina	65	51	14	64	1	58	7	50	15
2	El-Bagour	53	28	25	52	1	53	0	53	0
3	Minuf	19	9	10	10	9	18	1	3	16
4	Ashmoun	48	33	15	29	19	24	24	2	46
5	El- Khatatba	24	14	10	21	3	16	8	7	17
6	Kafr Dawood	11	7	4	11	0	9	2	5	6
7	Sadat city	6	3	3	5	1	3	3	4	2

C: comply NC: Not comply

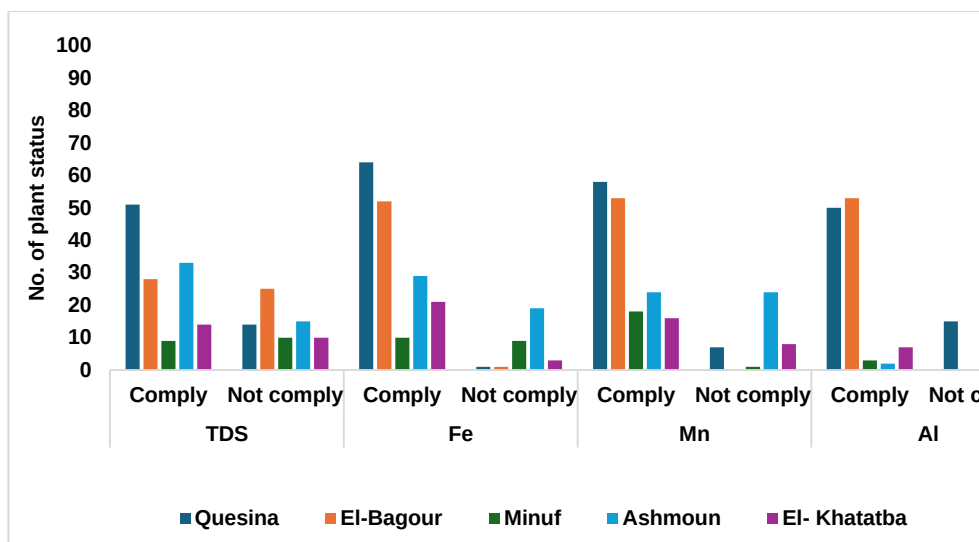


Fig. (2) No. of plants status complies according to Egyptian law 458/2007

The RO plants' feedwater originated from two sources: groundwater and the municipal distribution network. The city water, sourced from the Nile River and its distributaries, undergoes preliminary treatment involving rapid mixing with pre-chlorination, sedimentation and coagulation, rapid sand filtration, and post-chlorination. Pre-treatment is crucial for the selected RO plants due to the high fouling potential of the source water. Consequently, these RO systems were fed with treated municipal effluent, with samples augmented using stock solutions to achieve desired target concentrations. Similar to the methodology described by Benler et al. (2021), a stock solution was diluted with RO permeate in a stirred tank with a capacity of 600–700 L. The flow rate through the RO pilot system was 9.7

m³/h. Further details regarding the feedwater characteristics and a schematic diagram of the pilot setup are available.

In regions experiencing low rainfall and insufficient surface water resources, groundwater has become a primary water source for agriculture (Adimalla, 2021). Irrigation, a practice responsible for 30% of global agricultural output, requires a dependable supply of usable-quality water. Consequently, groundwater reservoirs have been extensively tapped as a potentially valuable alternative for irrigated agriculture (Bamigboye et al., 2020). However, a significant portion of these groundwater resources exhibit high salinity levels, which can contribute to increased soil salinity (Abbasnia et al., 2019).

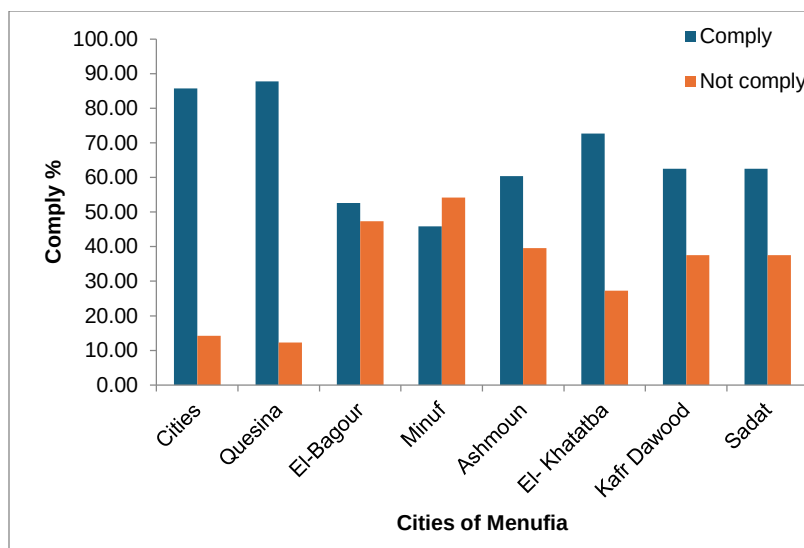


Fig. (3): % of Plants status in different city of Menoufia governorate complies according to Egyptian law 458/2007.

Figure 3 illustrates the percentage of water samples from different plants that met the Egyptian standard 458/2007 for drinking water: 59.9% for TDS (Total Dissolved Solids), 82.9% for Iron (Fe), 76.1% for Manganese (Mn), and 48.3% for Aluminum (Al). Despite the relatively small scale and higher operating costs associated with the present application, the resulting water quality is generally superior to that of larger governmental plants. Furthermore, even with these cost considerations, the use of electricity for these smaller plants

remains economically competitive with diesel-generated power in local settings such as small cities.

Figure 4 presents the percentage of water samples from different plants complying with Egyptian standard 458/2007 for the following cities in Menoufia Governorate: Quesina (85.77%), Minuf (87.74%), El-Bagour (52.63%), Ashmoun (45.83%), El-Khatatba (60.41%), Kafr Dawood (72.72%), and Sadat City (62.50%).

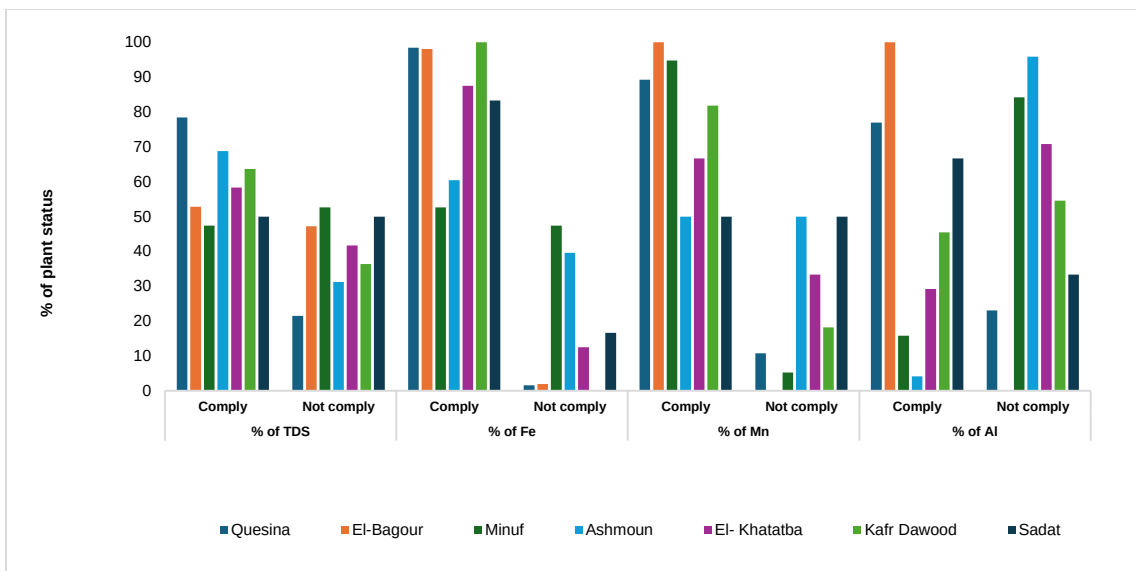


Fig. (4): % of Plants status complies according to Egyptian law 458/2007.

The data from the RO treatment plants suggests a consistent trend in water quality for certain cities. The observed stepwise decrease in source water quality arises from the practice of supplementing insufficient inlet water from a primary source with secondary or tertiary sources to meet demand. This supplementation, however, leads to a disproportionate increase in costs even with relatively small increases in demand.

Elevated feedwater temperature can increase membrane pore size, thereby reducing resistance to the passage of neutral solutes (Bouaroudi et al., 2019; Ibrahim, 2019). A comparison of micropollutant (MP) passage at two different temperatures revealed that while higher temperatures generally affect the passage of all compounds, the impact varied depending on the specific MP. For example, a lower temperature enhanced the removal of 4-Methyl-1H-benzotriazole, resulting in a 63% improvement in removal efficiency compared to the higher temperature ($T = 19^{\circ}\text{C}$). Conversely, the removal of acesulfame-K was only marginally

improved (0.1%) by the lower temperature. Discerning the specific removal mechanisms for each MP at different temperatures is complex and warrants further research (Alemu and Desta, 2017). Statistical analysis using a paired t-test indicated that the temperature-related differences in removal were most significant for benzotriazoles, chlortoluron, chloridazon, diuron, and guanyl urea. Maintaining a consistent feedwater temperature throughout the treatment process is therefore crucial.

Further pilot-scale testing is strongly advised to thoroughly assess the RO membrane's susceptibility to fouling. Given the potential for chemical, physical, and biological fouling in the processes examined within this work, a long-term operational study using water with representative characteristics would be beneficial in predicting the likelihood and rate of fouling. Fouling is a critical economic consideration in reverse osmosis due to the substantial cost of membrane replacement. Such a study should also investigate various pretreatment strategies, including the use

of antiscalants and biocides. Furthermore, effective membrane cleaning protocols should be established for instances where fouling occurs. The discussion and literature review on fouling presented herein highlight the inherent challenges in maintaining clean membrane surfaces.

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