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Assessing the Quality of Treated Wastewater for Irrigation: A Case Study of Ain Sefra Wastewater Treatment Plant

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Abstract: This study aimed to assess the water quality parameters in the wastewater treatment plant (WWTP) of Ain Sefra, southwestern Algeria. Various methods were employed to analyze the performance and suitability of the WWTP for irrigation. The results revealed effective removal of nitrates, with levels below the limit set for irrigation water. The dissolved oxygen content showed efficient biological processes and good degradation of organic matter. Phosphate levels were found to be within FAO and Algerian irrigation standards. However, elevated ammonia levels were observed, exceeding typical ranges for irrigation. The suitability of groundwater for irrigation was evaluated by calculating groundwater suitability indices. These indices categorized all samples as either excellent or good based on their Sodium Adsorption Ratio (SAR) and Kelly's ratio. However, the sodium percentage values raised concerns about potential negative effects on the soil. Some samples were deemed unsuitable for irrigation because of high magnesium hazard and potential salinity values. These findings offer valuable insights into the performance and suitability of treated wastewater for irrigation in the Ain Sefra region. They can inform decision makers and stakeholders involved in agriculture and water management.

Keywords: wastewater quality effluent; Sodium Adsorption Ratio; groundwater contamination; reusing treated wastewater; irrigation suitability; Ain Sefra

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1. Introduction

Ensuring sufficient access to water resources is crucial for promoting sustainable progress [1]. Freshwater is limited globally [2]. Climate change, population growth, economic expansion, and environmental concerns are all contributing to this issue [3]. According to the report by the United Nations World Water Development [4], climate change is introducing greater uncertainty regarding the future availability of clean water, which could cause irreversible desertification in various regions worldwide. Water supplies are expected to decline and demand is expected to rise because of rising temperatures and reduced precipitation [5]. The MENA (Middle East and North Africa) region is globally recognized as the driest and most water deprived [6]. Despite having only 7.5% of the global population, it has the lowest availability of freshwater resources [6]. Algeria, one of the largest countries in the MENA region, experiences severe water scarcity [7]. Despite a population of over 43 million people, Algeria faces significant constraints in terms of freshwater resources [8]. The annual renewable water supply per person in the country is estimated to be around 1000 m^3, which is lower than the recognized water scarcity benchmark of 1700 m^3 per individual per year [8]. This limited availability of freshwater sources in Algeria can be attributed to its arid and semiarid climate, characterized by irregular rainfall patterns and high evapotranspiration rates [9]. A major challenge faced by Algeria is the irregularity of rainfall, with some regions experiencing prolonged droughts while others have more regular precipitation [10]. This spatial disparity in rainfall patterns adds complexity to water availability and management across different areas of the country. The situation has been exacerbated by climate change, resulting in more frequent and severe droughts, leading to crop failures, food insecurity, and water scarcity [11–13]. Agriculture is the largest consumer of water resources in Algeria, as in many other countries, and this can be attributed to the long-term decrease in water availability witnessed in recent decades [14]. To address the water shortage, farmers are exploring the potential of wastewater as an alternative source of irrigation water [15,16]. It is crucial to ensure that the quality of wastewater is suitable for agricultural purposes and does not contain contaminants that could pose risks to crops or public health [17]. Countries such as the US, China, France, and Mexico pioneered the use of wastewater in agriculture in the late 19th century [18]. Both treated and untreated wastewater are commonly used for irrigation, with the extent of this practice varying depending on geographical and economic factors. However, developing countries rely more heavily on untreated wastewater for irrigation [19]. Untreated wastewater is prevalent in peri-urban and urban agriculture, accounting for eleven percent of the world's irrigated croplands [20]. In the 1990s, there was a notable increase in using wastewater for irrigating crops and urban green spaces, such as parks and golf courses. Many countries, including the US, Australia, Mediterranean regions, and Spain, have embraced this approach [21]. A proposed method aims to assess the feasibility of using treated wastewater by considering potential investments and expected savings [22].

Currently, there is a growing global interest in the reuse of wastewater as a strategy to ensure a consistent water supply for agriculture [23,24]. Many studies have been conducted to evaluate the effectiveness of this technique [25,26]. In Algeria, an active policy has been implemented to address water scarcity by mobilizing water resources and adopting alternative management approaches, including the use of wastewater in agriculture [27]. The National Sanitation Office (ONA) plays a crucial role in managing multiple wastewater treatment plants across the country, producing high-quality treated wastewater suitable for agricultural irrigation [28]. The implementation of wastewater treatment plants in Algeria serves several objectives, including improving water resource quality, protecting public health from pathogens, reducing pollution from sanitation activities, preserving water resources, and providing a reliable water supply for agriculture. This is in line with Algeria's ratification of the Barcelona Convention, a set of international agreements for the protection of the Mediterranean Sea [29]. Despite being designed for reuse in irrigation, the treated wastewater from the Ain Sefra WWTP has not been used, representing a missed opportunity to ease water scarcity in the region and support sustainable agriculture. This study will evaluate the quality and suitability of the treated wastewater for irrigation.

The adopted method in this study aims to provide a comprehensive understanding of the treated wastewater quality. The collected data allow for a detailed analysis of wastewater characteristics, to decide if it can be used for irrigation. Several indices, including the Sodium Adsorption Ratio (SAR), Permeability Index (PI), Kelly's Ratio (KR), Sodium Percentage (Na%), Potential Salinity (PS), and Magnesium Hazard (MH), are used to evaluate the suitability of the treated wastewater for irrigation. The SAR index assesses the relative amounts of sodium, calcium, and magnesium in the irrigation water, providing insights into the risk of soil degradation because of sodium accumulation.

This study aims to assess the quality of treated wastewater from the Ain Sefra WWTP with laboratory measurements and suitability indices. The paper intends to answer the following questions: (i) Which is the potential of reusing treated wastewater in agriculture? (ii) Is treated water in WTTP meeting the acceptable standards? (iii) Which are the values obtained for each measurement? (iv) Is there any problem making impossible their use for irrigation? (v) What about the nitrate and nitrite levels? (vi) How can the practitioners solve the hypothetical problems in the future? The findings will show how treated wastewater can be reused safely and sustainably for irrigation in the study area, as well as any improvements needed for meeting the standards. Assessing the efficiency of the Ain Sefra WWTP, this study fills the knowledge gap regarding the quality assessment of treated wastewater from the Ain Sefra WWTP for irrigation. It seeks to provide important data for the secure, sustainable reuse of treated wastewater. This research will offer valuable insights for water resource managers and policymakers to promote sustainable irrigation practices and reduce negative effects of wastewater.

2. Materials and Methods

2.1. Study Area

The Ain Sefra WWTP is in the arid zone of Ain Sefra in the southwestern region of Algeria, at coordinates 27.0514° N, 0.2285° W (Figure 1). The area experiences a hot and arid climate, with an annual precipitation of below 190 mm and an average yearly temperature of around 18 °C [30]. This city has a population of approximately 75,000 residents and is at an elevation of 1078 m above sea level [31].

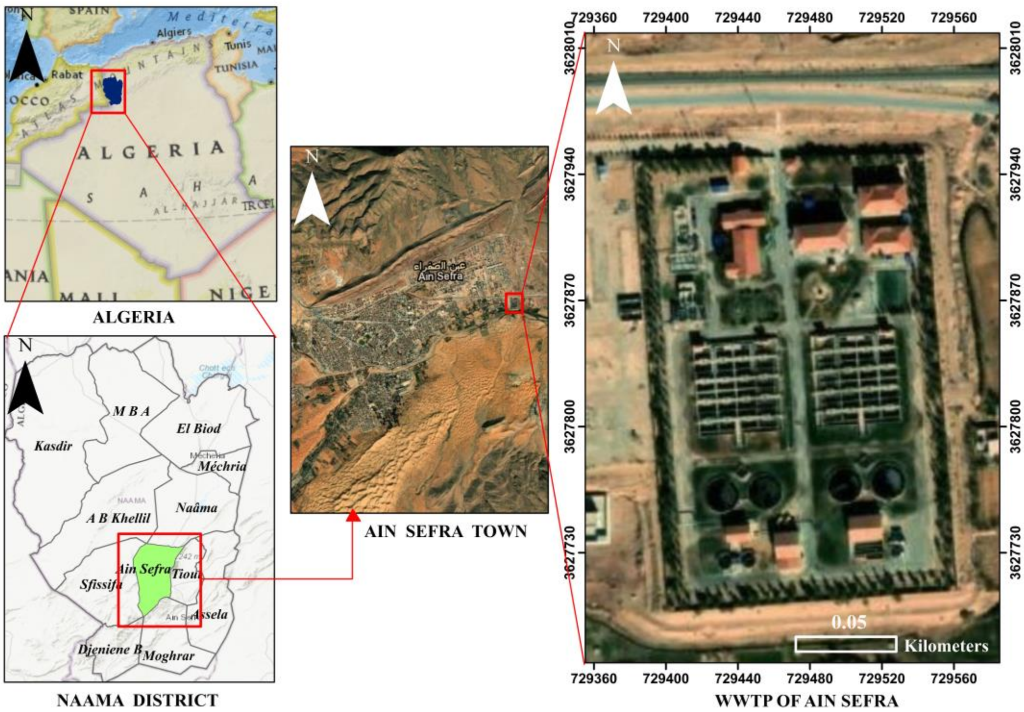

Figure 1. Study area.

Ain Sefra has a unitary sewer system that collects wastewater and stormwater in a single network. The plant is an activated sludge type covering an area of 7 hectares and has a processing capacity of 11,760 m^3/day [32]. Currently, the plant processes 6838 m^3/day, representing a use rate of 58.14% of its capacity [32]. The National Sanitation Office (ONA) manages and operates the plant. The influent wastewater at the WWTP typically consists of organic matter, nutrients, suspended solids (organic and inorganic particles), pathogens (bacteria, viruses), and trace amounts of heavy metals.

2.2. The Treatment Process of WWTP of Ain Sefra

The Ain Sefra WWTP incorporates several structures that remove pollutants from the wastewater effectively (Figure 2). The treatment process comprises two major chains: the first chain includes pre-treatment, biological treatment, clarification, and disinfection, while the second chain focuses on sludge treatment. Treatment begins at the receiving well with wastewater collection. This well acts as a barrier, preventing large solids from entering the treatment process. It has an overflow level height of 840 m^3/h. The WWTP is equipped with two screening channels, each containing three inclined screens, to remove large solids and debris. The pumping station plays a vital role by lifting and injecting the water into the treatment circuit at a steady flow rate. This ensures a consistent and controlled process. Sand and oil removal is also incorporated into the treatment process at the Ain Sefra WWTP to protect equipment. The WWTP uses an aerated longitudinal sand and oil separator, which effectively separates sand and sticky organic matter from the water. The biological treatment stage comprises three consecutive tanks, each with a capacity of 1800 m^3. These tanks employ aerobic bacteria to break down organic matter present in the wastewater. They are equipped with a perforated pipe system that facilitates diffused aeration. Wastewater enters the first tank, where organic pollutants are reduced. The water is treated and released according to standards.

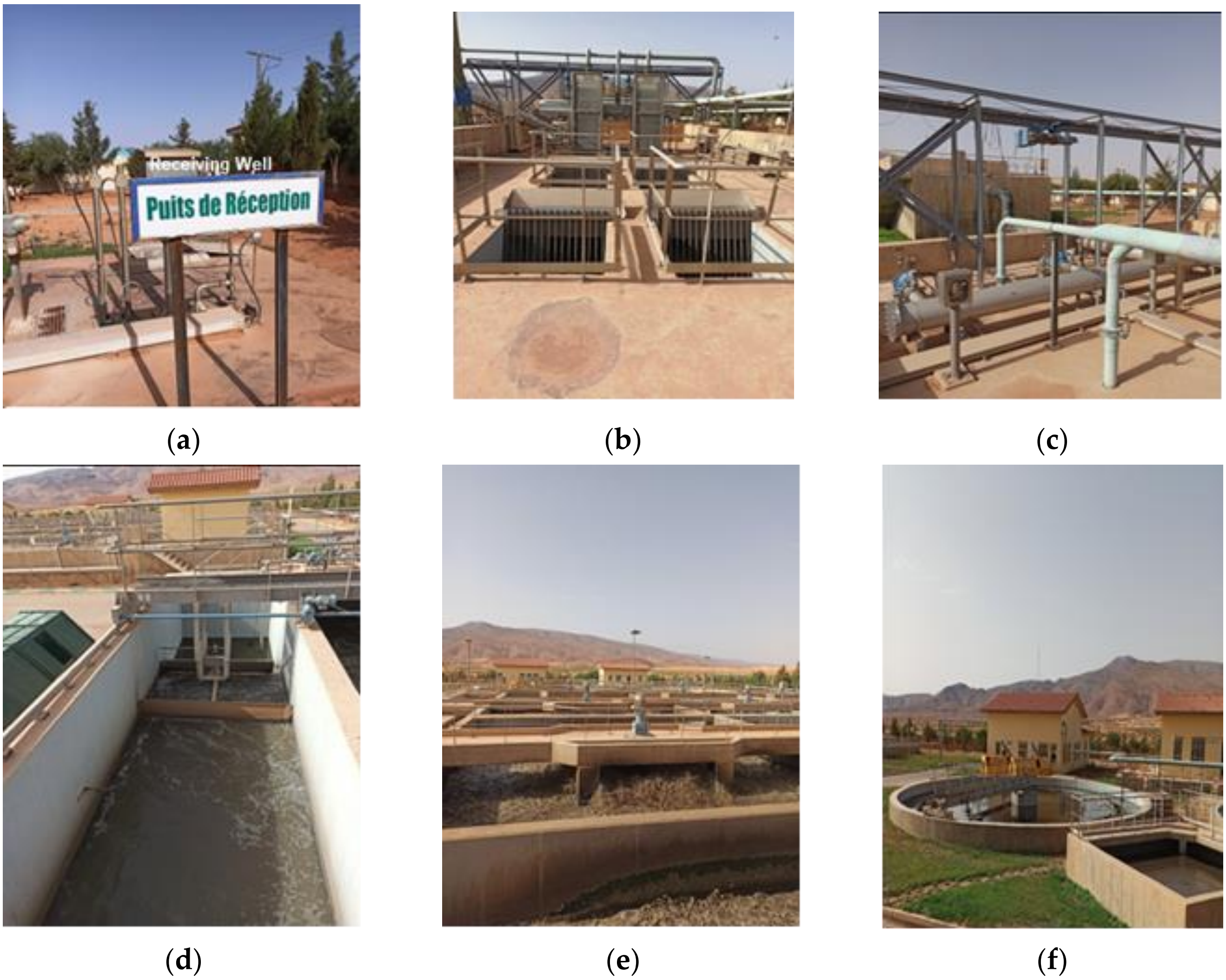

Figure 2. Treatment Processes of the WWTP of Ain Sefra ((**a**): receiving well; (**b**): screening; (**c**): pumping station; (**d**): sand and oil removal; (**e**): aeration tank; (**f**): clarification basin).

2.3. Assessment of Water Quality

In 2021, 252 water samples were collected from the Ain Sefra WWTP to assess the quality of treated wastewater. The laboratory at the Ain Sefra WWTP conducted analyses of various physicochemical parameters. Temperature, pH, and electrical conductivity (EC) were measured daily to monitor their variations. Total suspended solids (TSSs), dissolved oxygen (DO), and biochemical oxygen demand (BOD_5) were analyzed three days per week, while chemical oxygen demand (COD) was evaluated once a week. Phosphate (PO_4), nitrate (NO_3), and ammonia (NH_4) levels were assessed monthly.

Cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+) ions, as well as anions including bicarbonate (HCO_3^-), chloride (Cl^-), and sulfate (SO_4^{2-}) ions, were analyzed once a week at the research laboratory of the University Center of Naama and the laboratory of the Algerian Water Unit of Naama (ADE). All water samples were collected in PP bottles, which were previously rinsed. This pre-rinsing process was implemented to minimize potential contamination from the bottles themselves. After collection, the water samples were stored in a portable cooler during transportation from the sampling site to the laboratory. The portable cooler maintained a low temperature, typically around 4 °C, to preserve the samples and minimize any changes in their composition.

The method adopted in this study is depicted in Figure 3.

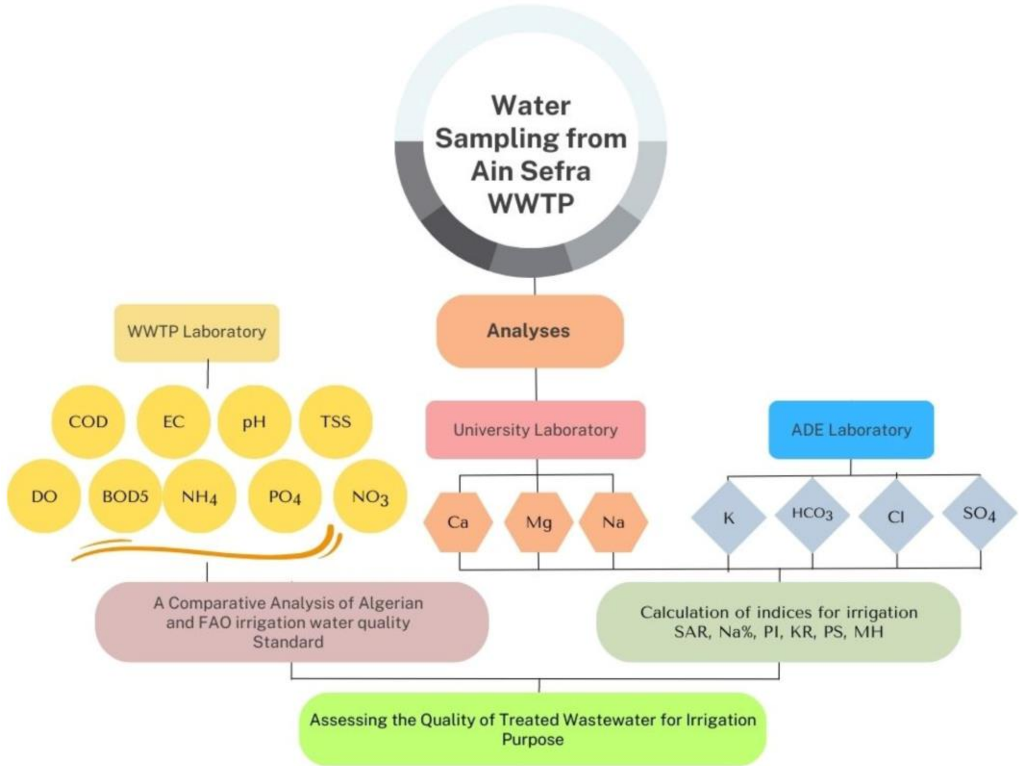

Figure 3. The method adopted in this study.

Colorimetry was employed as a common method to measure nitrate (NO_3) levels in the treated water. A reagent was added to the sample, causing a reaction with the nitrates and generating a color. The intensity of the resulting color was measured using a spectrophotometer (DR-3900; HACH; Loveland, CO, USA). The concentration of nitrates in the water was then calculated based on the absorbance of the color. For measuring phosphorus (PO_4), a spectrophotometer (DR-3900; HACH; Loveland, CO, USA) was used. Initially, the samples were treated with reagents that produce a colored compound upon reacting with phosphorus. The spectrophotometer measured the intensity of the color, which was proportional to the amount of phosphorus in the sample. The results were reported in milligrams per liter (mg/L).

To analyze the cations and anions, the methods described in the EPA-600/4-79-020 protocol were used [33]. Titrations (Figure A1e in Appendix A) were conducted to determine the levels of magnesium (Mg^{2+}), calcium (Ca^{2+}), and bicarbonate (HCO_3^-). Atomic absorption spectrometry was employed to measure sodium (Na^{2+}) and potassium (K^+) concentrations. The Mohr method was used to determine chloride (Cl^-) concentrations. Additionally, levels of sulfates (SO_4^{2-}) were measured using a UV-Vis spectrophotometer (Figure A1f). After conducting the tests, the obtained results will be compared with the standards set by the Food and Agriculture Organization (FAO) as outlined by Ayers and Westcot [34], as well as the Algerian Standards [35], as presented in Table 1.

Table 1. Algerian water quality standards and FAO irrigation water quality guidelines.

Parameters	Unit	Algerian	FAO
		Limits	Limits
Ph		6.5–8.5	6–8.5
Total Suspended Solids	mg/L	30	-
Conductivity	µS/cm	3000	3000
Bicarbonate	meq/L	8.5	10
Chemical Oxygen Demand	mg/L	90	-
Biochemical Oxygen Demand	mg/L	30	-
Chloride	meq/L	10	30
Nitrogen	mg/L	30	-
Magnesium	meq/L	-	5
Calcium	meq/L	-	20
Sodium	meq/L	-	40
Potassium	mg/L	-	2
Sodium Adsorption Ratio	meq/L	-	15
Sulphate	meq/L	-	20
Ammonium-Nitrogen	mg/L	-	5
Nitrate-Nitrogen	mg/L	-	10
Phosphate-Phosphorus	mg/L	-	2

2.4. Suitability Indices for Irrigation

Suitability indices are used to assess the appropriateness of water for irrigation. These indices include the SAR, PI, KR, Na%, PS, and MH. The SAR index determines the relative amounts of sodium, calcium, and magnesium in irrigation water. The PI assesses the potential of irrigation water to cause soil structure issues. KR examines the balance between cations and anions in irrigation water. Na% represents the percentage of sodium in the total cations of irrigation water. The PS measures the total dissolved salts in irrigation water and is expressed in electrical conductivity. Last, the MH evaluates the potential of irrigation water to cause magnesium-related problems in soil structure.

In this study, the formulas listed in Table 2 (Equations (1)–(6)) applied to calculate the indices. All ion concentrations were expressed in meq/L, except for PI and Na%, which were expressed as percentages.

Table 2. Irrigation water's qualitative formulas and classifications.

Parameter	Formula Adopted	Classification	Type		References
Sodium adsorption ratio *(SAR)*	$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+}+Mg^{2+})}{2}}}$	SAR > 26 18 < SAR < 26 10 < SAR < 18 SAR < 10	Unsuitable Doubtful Good Excellent	(1)	[36]
Permeability Index *(PI)*	$PI = \frac{\left(Na^+ + \sqrt{HCO_3^-}\right)}{(Ca^{2+}+Mg^{2+}+Na^+)} \times 100$	<25% >75% 25–75%	Unsuitable Good Suitable	(2)	[37]
Kelly's ratio *(KR)*	$KR = \frac{Na^+}{Ca^{2+}+Mg^{2+}}$	<1 >1	Unsuitable Suitable	(3)	[38]
Sodium percentage *(Na%)*	$Na\% = \frac{(Na^+ + K^+)}{(Ca^{2+}+Mg^{2+}+Na^+)}$	80–100 60–80 40–60 20–40 <20	Unsuitable Doubtful Permissible Good Excellent	(4)	[39]

Table 2. *Cont.*

Parameter	Formula Adopted	Classification	Type		References
Potential salinity *(PS)*	$PS = Cl^- + \frac{SO_4^{-2}}{2}$	>10 5–10 <5	Unsatisfactory Good to Injurious Excellent to good	(5)	[37]
Magnesium Hazard *(MH)*	$MH = \frac{Ca^{2+}}{Ca^{2+}+Mg^{2+}} \times 100$	>50% <50%	Unsuitable Suitable	(6)	[40]

3. Results

3.1. Physicochemical Parameters

Table 3 summarizes the physical limits and results of the chemical analysis for the sampled waters in the study area. The table presents both the range and mean values of the parameters.

Table 3. Summary of the physicochemical parameters of samples at the outlet of the WWTP of Ain Sefra.

Parameter	Unit	Min	Max	Average ± SD	Algerian Standards	FAO Standards
Temperature	(°C)	13.40	24.80	19.51 ± 3.60	25	25
pH		7.40	7.92	7.77 ± 0.15	6.5–8.5	6–8.5
Conductivity	(µS/cm)	2430.00	3126.00	2784.25 ± 244.63	3000	3000
TSS	(mg/L)	7.89	23.00	12.47 ± 4.96	30	30
COD	(mg/L)	22.00	52.60	33.97 ± 9.95	90	40
BOD_5	(mg/L)	7.92	38.33	21.78 ± 8.75	30	10
$NH_4^+ - N$	(mg/L)	0.11	28.90	6.33 ± 5.89	-	5
$NO_3 - N$	(mg/L)	0.23	6.55	2.03 ± 1.86	30	10
$NO_2 - N$	(mg/L)	0.02	2.50	0.63 ± 0.50	1	1
PO_4^{-3}	(mg/L)	0.22	2.46	0.75 ± 0.60	2	2
O_2	(mg/L)	1.20	3.10	2.23 ± 0.51	-	5
Mg^{++}	(meq/L)	5.14	8.29	6.94 ± 0.92	-	5
Ca^{++}	(meq/L)	6.06	7.30	6.55 ± 0.46	-	20
K^+	(meq/L)	0.87	1.57	1.23 ± 0.20	-	2
Na^+	(meq/L)	21.16	28.47	23.86 ± 2.84	-	40
SO_4^{-2}	(meq/L)	10.87	16.57	14.41 ± 1.65	-	20
Cl^-	(meq/L)	7.70	9.88	8.78 ± 0.73	10	30
HCO_3^-	(meq/L)	8.50	10.91	9.63 ± 0.84	8.5	10

3.1.1. Temperature

A thermometric probe was immersed into the water sample to measure the temperature in the wastewater treatment plant. The temperature was recorded once the thermometer had stabilized (Figure A1a). Temperature is important as it affects other parameters. It also influences the reactions of organic matter degradation and mineralization. The temperature values of the treated water (Figure 4a) ranged from 13.40 °C to 24.80 °C, with an average of 19.51 °C. These results show that the temperature of the treated water was lower than the recommended limit of 25 °C for irrigation water according to Algerian standards [35].

3.1.2. pH

The determination of the pH value of the water was performed by a pH meter (TruLab pH 1310; YSI; OH, USA) (Figure A1a). The pH values of treated wastewater (Figure 4b) were close to neutrality, ranging from 7.40 to 7.92, showing no harm to the soil or crops. The recommended pH range for irrigation water ranges between 6.5 and 8.5 by Algerian standards [35] and between 6 and 8.5 by Ayers and Westcot [34].

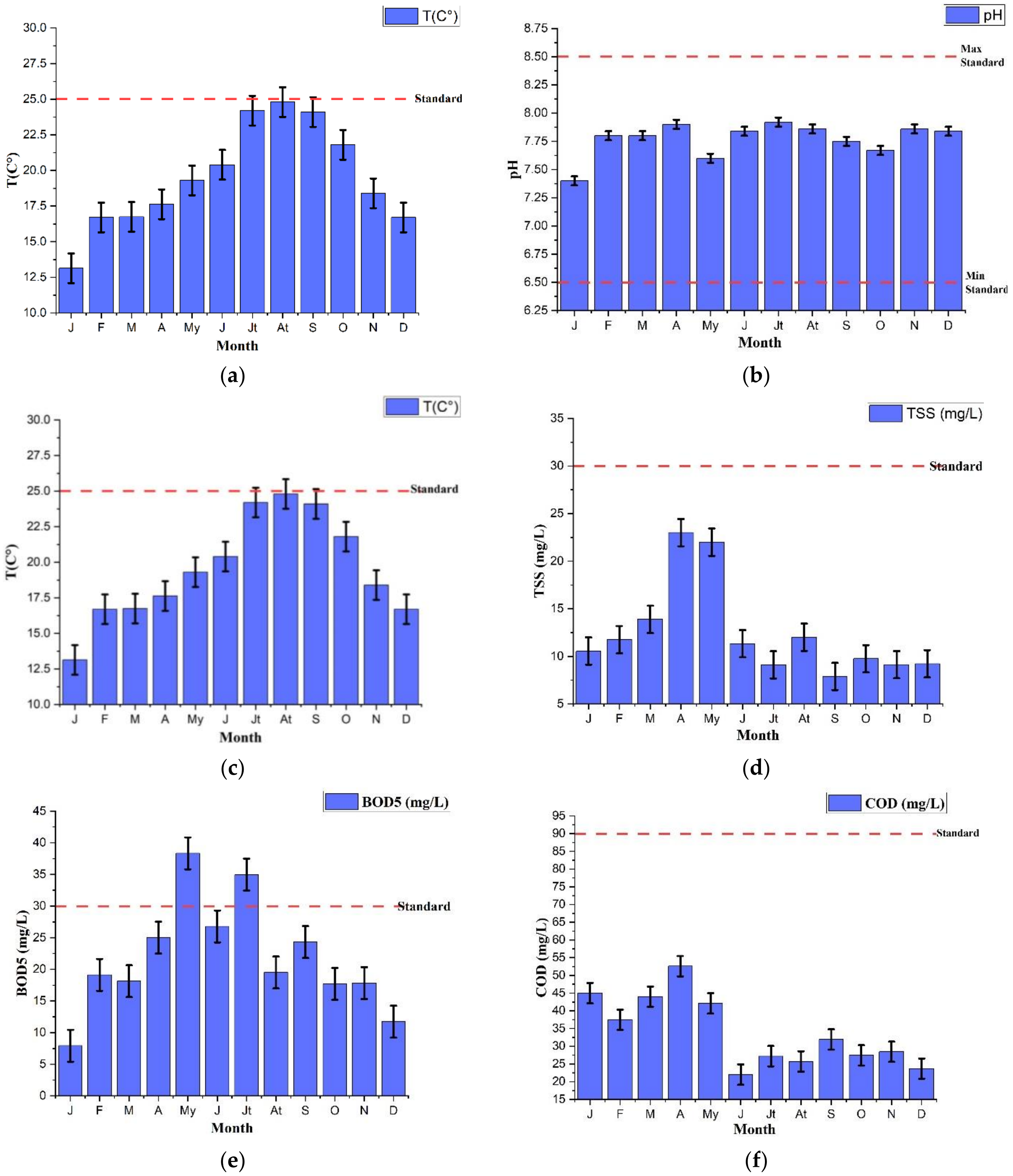

Figure 4. Monthly variation of physicochemical parameters at the outlet of the WWTP of Ain Sefra. ((**a**): temperature, (**b**): pH, (**c**): EC, (**d**): TSS, (**e**): BOD_5, (**f**): COD).

3.1.3. Electrical Conductivity

The conductivity of the treated water was measured at 20 °C using a conductivity meter (in-oLab/Cond-7110; WTW; Weilheim, Germany) (Figure A1b). Conductivity is a measure of the concentration of salts dissolved in the water. The treated water exhibited high electrical conductivity (Figure 4c), ranging from 2430 to 3126 µS/cm, with an average of 2784.25 µS/cm. This classification shows that the water is highly saline. The soluble salt content in terms of NaCl was 1500 mg/L. Despite its salinity, it could still be used in agriculture. Djeddi and Rahmoune [41] categorized water quality based on conductivity and corresponding salt content into four categories. "Excellent": water with a conductivity of less than 250 μS/cm and a corresponding salt content of less than 160 mg/L. This water is considered to be of excellent quality and is suitable for various uses, including irrigation. "Low salinity": water with a conductivity between 250 and 750 μS/cm and a corresponding salt content between 160 and 500 mg/L. This water is considered to have low salinity and is also suitable for various uses. "High salinity": water with a conductivity between 750 and 2250 μS/cm and a corresponding salt content between 500 and 1500 mg/L. This water has high salinity and may be useful, but strategies are needed to prevent soil salinization and crop damage. "Very high salinity": water with a conductivity between 2250 and 5000 μS/cm and a corresponding salt content of 1500 and 3600 mg/L. This water is considered to have extremely high salinity levels and is unsuitable for various applications, including irrigation, unless comprehensive management and treatment measures are implemented. Based on this classification, the electrical conductivity of the treated water in the study fell within the "Very High Salinity" category, indicating a significant soluble salt content estimated at 1500–3600 mg/L of NaCl [37].

3.1.4. Total Suspended Solid (TSS)

Solid particles can be removed from wastewater through sedimentation and filtration. TSS can comprise various materials, including organic matter, inorganic matter, and microorganisms. TSS is typically measured in milligrams per liter (mg/L) and serves as an important indicator of wastewater quality. In the Ain Sefra WWTP, TSS levels were determined using a colorimeter (DR-890; HACH; Loveland, CO, USA) (Figure A1c). This device measures the absorbance of light by suspended solids in a sample. Higher absorbance indicates a higher concentration of suspended solids. The colorimeter converts this information into a TSS measurement in mg/L. The treated water from the WWTP exhibited a low concentration of TSS (Figure 4d), ranging from 7.89 to 23.00 mg/L, with an average of 12.47 mg/L. These results show the effectiveness of the process following biological treatment. They indicate that there are no issues related to the transportation or distribution of the treated water. There are no concerns about clogging in irrigation systems since the measured TSS value of 30 mg/L in the treated water falls well within the permissible limit set by Algerian regulations for irrigation water.

3.1.5. Biochemical Oxygen Demand (BOD_5)

BOD_5 is a measure of the oxygen required by microorganisms to decompose organic matter in water over a five-day period. It is a crucial parameter used in wastewater treatment to assess the level of organic pollution in water. To measure BOD_5, a wastewater sample was taken and analyzed using a spectrophotometer (DR-3900; HACH; Loveland, CO, USA) (Figure A1d). The sample was incubated for five days at a controlled temperature of 20 °C, and the dissolved oxygen concentration was measured at the beginning and end of the incubation period. These two measurements give the oxygen consumed by microorganisms, used to calculate the BOD_5. BOD_5 is expressed in milligrams of oxygen per liter (mg/L O_2). According the FAO [34], and Algerian regulations [35], the acceptable limit for BOD_5 in irrigation water is 30 mg/L. The results for BOD_5 in the treated water from the Ain Sefra WWTP ranged from 7.92 to 38.33 mg/L, with an average of 21.78 mg/L (Figure 4e). These values were below the limit set for irrigation water, except for May and June, when some measurements exceeded the limit. However, it is important to note that the treated water was still considered safe for crops as it did not pose a risk in terms of biodegradable organic pollution. Implementing biological treatment in the wastewater showed significant efficacy in ensuring the suitability of the water for irrigation.

3.1.6. Chemical Oxygen Demand (COD)

COD is a measure of the amount of organic matter in water that can be oxidized by a chemical oxidizing agent. It represents the oxygen required to break down the organic matter in water. A higher COD value indicates a higher level of organic contaminants and pollution in the water. COD is expressed in milligrams of oxygen per liter (mg/L O_2) and is typically measured using a spectrophotometer (DR-3900; HACH; Loveland, CO, USA) (Figure A1d). Algerian regulations state that the COD level should not exceed 90 mg/L [35]. Figure 4f shows that the COD level in the treated water from the Ain Sefra WWTP was unstable, with variations ranging from 22 to 52.60 mg/L. However, these values did not exceed the upper limit set for agricultural reuse. While the COD levels fluctuated, they remained within an acceptable range for the treated water to be suitable for irrigation according to Algerian regulations.

3.1.7. Nitrates (N-NO_3) and Nitrites (N-NO_2)

In a WWTP, NO_3 is a form of nitrogen that can be present in the treated water. Nitrates in surface waters can cause eutrophication. High nitrates can disrupt the disinfection process for drinking water. Algerian regulations set a cap of 30 mg/L on nitrate concentration in irrigation water to prevent groundwater pollution [35]. However, the treated water examined in this study, as shown in Figure 5a, displayed nitrate levels ranging from 0.23 to 6.55 mg/L, which is below the irrigation limit. Nitrification-denitrification bacteria convert ammonia into nitrites. Nitrites are unstable but can accumulate if there is a deficiency of oxidants. The average concentration of nitrites in the treated water (Figure 5b) was 0.63 mg/L, adhering to the standards set by (<1 mg/L) [35]. Figure 5b illustrates a notable increase in nitrate content during the months of February and March. Several factors can contribute to these elevated nitrate levels. First, seasonal variations in agricultural activities need to be considered. February and March are planting and fertilization seasons. This agricultural practice can lead to increased nitrates in the wastewater reaching the treatment plant during these months. Weather conditions such as heavy rainfall can contribute to the leaching of nitrate from the surrounding soil into the wastewater, further increasing its concentration. The nitrate and nitrite levels of the treated water from the Ain Sefra WWTP are lower than the acceptable limits for irrigation.

3.1.8. Dissolved Oxygen (DO)

DO in water refers to the amount of oxygen that is dissolved and available for aquatic organisms. It is an important parameter to assess the water's quality and its ability to support aquatic life. The measurement of DO was conducted using an oximeter (HQ1130; HACH; Loveland, CO, USA), which uses probes placed in the water sample to measure the concentration of dissolved oxygen. The oximeter's screen displays the reading in milligrams per liter (mg/L) or parts per million (ppm). The treated water from the Ain Sefra WWTP exhibited dissolved oxygen levels, as shown in Figure 5c, with an average content of 2.23 mg O_2/mL. This value falls within the standard limit of 5 mg O_2/mL, as stated by Algerian standards [34]. The results show that the biological treatment process in the WWTP was efficient, and the degradation of organic matter was satisfactory [42,43]. Maintaining adequate levels of dissolved oxygen in the treated water is crucial for the survival of aquatic organisms. Meeting the standard limit ensures that the treated wastewater is suitable for irrigation, as it provides a favorable environment for plant growth and minimizes potential ecological affects.

3.1.9. Phosphate

Phosphorus (PO_4) is a nutrient essential for plant and microorganisms' growth. Excess phosphorus in wastewater can lead to eutrophication. It can lead to the growth of algae and other aquatic plants, which deplete the oxygen in the water and harm aquatic life. Phosphate escapes biological treatment processes in wastewater treatment plants. However, the treated wastewater in this study (shown in Figure 5d) had an average of 0.75 mg/L of phosphate, which complies with the FAO standards for irrigation use [34]. The reason for the reduction in phosphate levels could be attributed to consuming phosphate by bacteria in the course of the treatment process [42,43].

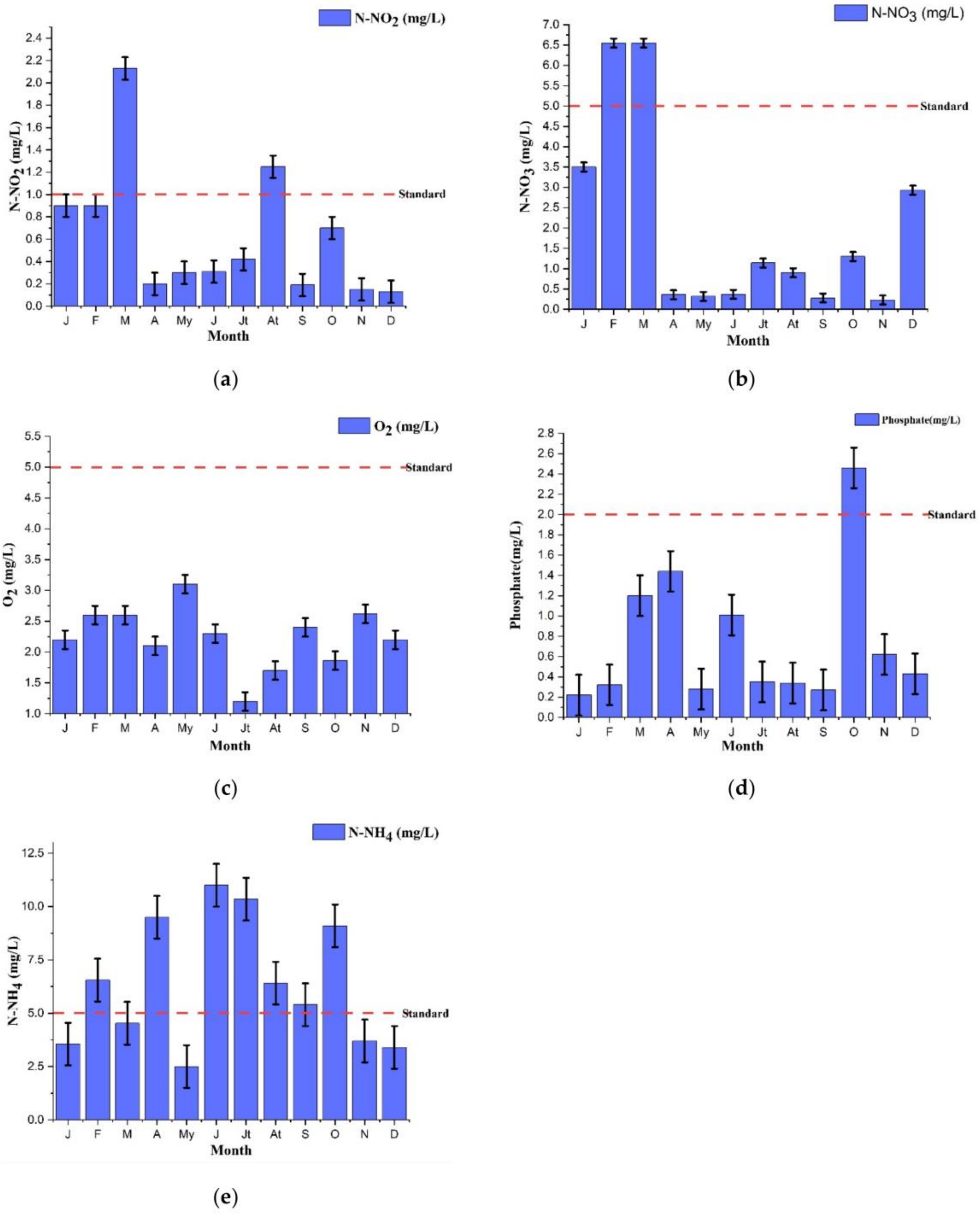

Figure 5. Monthly variation of physicochemical parameters at the outlet of the WWTP of Ain Sefra. ((**a**): N-NO_2, (**b**): N-NO_3, (**c**): DO, (**d**): PO_4, (**e**): N-NH_4).

3.1.10. Ammonia Nitrogen (NH_4^+)

NH_4^+ is nitrogen that can be present in wastewater. It is produced through the decomposition of organic matter by bacteria. Ammonia nitrogen measurement was performed using a colorimetric method and a spectrophotometer (DR-3900; HACH; Loveland, CO, USA). According to Figure 5e, the treated water from the Ain Sefra WWTP had an average ammonia nitrogen concentration of 6.33 mg/L, which falls within the typical range for water intended for irrigation (0–5 mg/L) according to Ayers and Westcot [34]. April's values exceeded standards, potentially impacting agricultural use. Elevated ammonia levels during this period may have implications for crop health and productivity. The significant increase in ammonium nitrogen observed in April can be attributed to various factors. Seasonal variations (temperature and rainfall) influence microbial activity and decomposition. An influx of organic waste or biomass in April caused an increase in ammonium nitrogen concentrations at the wastewater treatment plant. Changes in aeration and nutrient dosing in the treatment plant can affect ammonium nitrogen levels. Further investigation is needed to understand the increase in ammonia levels. Excessive concentrations of ammonia can negatively impact plant growth and cause stress or toxicity, especially in sensitive crop species [44]. High levels of ammonia can increase nitrogen in the soil, potentially affecting soil fertility and groundwater quality [45]. Factors such as nitrification processes, influent characteristics, and treatment performance can affect ammonia levels [46].

3.2. Suitability Indices for Irrigation

Table 4 presents a summary of the results of different water irrigation indices adopted in this study. The table displays a range of values and the mean values for each parameter.

Table 4. Summary of irrigation water's qualitative limits at the outlet of the WWTP of Ain Sefra.

	Unit	Min	Max	Average
SAR	meq/L	8.00	10.29	9.17
$Na\%$	%	63.16	69.24	66.52
PI	%	84.54	93.17	89.67
MH	meq/L	46.13	55.50	48.71
KR	meq/L	1.52	1.97	1.77
PS	meq/L	14.16	18.17	15.98

The obtained samples exhibited a SAR ranging from 8.00 to 10.29, with an average of 9.17 (Table 4). All samples were classified as excellent and suitable for irrigation, with SAR values ranging from 0 to 18. Figure 6, illustrating the Richards plot on the US salinity diagram [36], employed EC to assess salinity hazard and SAR to evaluate alkalinity hazard. The diagram showed that 33.33% of the sampled water fell into the C4-S3 category, signifying a very high salinity hazard and high alkalinity hazard [36]. Consequently, while the water may be suitable for irrigation, it requires careful management and monitoring to prevent soil degradation and potential reductions in crop yield [36]. Additionally, 25.00% of the sampled water fell into the C3-S2 category, showing a high salinity hazard and a medium alkalinity hazard [36]. Precautions should be taken to avert salt accumulation in the soil when using this water for irrigation [36]. The remaining 41.67% of the sampled water fell into the C3-S3 category, showing a moderate salinity hazard and a moderate to high alkalinity hazard [36]. This suggests that the water may be appropriate for irrigation, but precautions need to be implemented to prevent salt accumulation in the soil [36].

The Na% values of the samples ranged from 63.16 to 69.24% (Table 4). All samples were classified as doubtful for irrigation and have the potential to harm the soil. High sodium concentrations (>60%) can negatively affect the physical properties of the soil. The results of Na% are depicted in the Wilcox diagram [47] in Figure 7.

The PI values of the samples ranged from 84.54 to 93.17 meq/L, with a mean value of 89.67 meq/L (Table 4). According to the classification by Doneen [33], samples with PI values above 75 fall into Class 1, which is acceptable for irrigation. Samples with PI values between 25 and 75% are classified as Class 2, showing good suitability for irrigation [30]. Therefore, all samples in the study area with PI values falling within Class 1 and 2 are suitable for irrigation.

The Magnesium hazard values ranged from 46.13 to 55.50% (Table 4). Samples with Magnesium hazard values exceeding 50% are unsuitable for irrigation. Among all the samples, only two had Magnesium hazard values above 50%, indicating their unsuitability for irrigation [48].

KI values ranged from 1.52 to 1.97, with an average of 1.77 (Table 4). Water with KI values greater than one is considered to contain excessive sodium and is unsuitable for irrigation [49]. In the study area, all samples had KI values less than one, showing their suitability for irrigation [29].

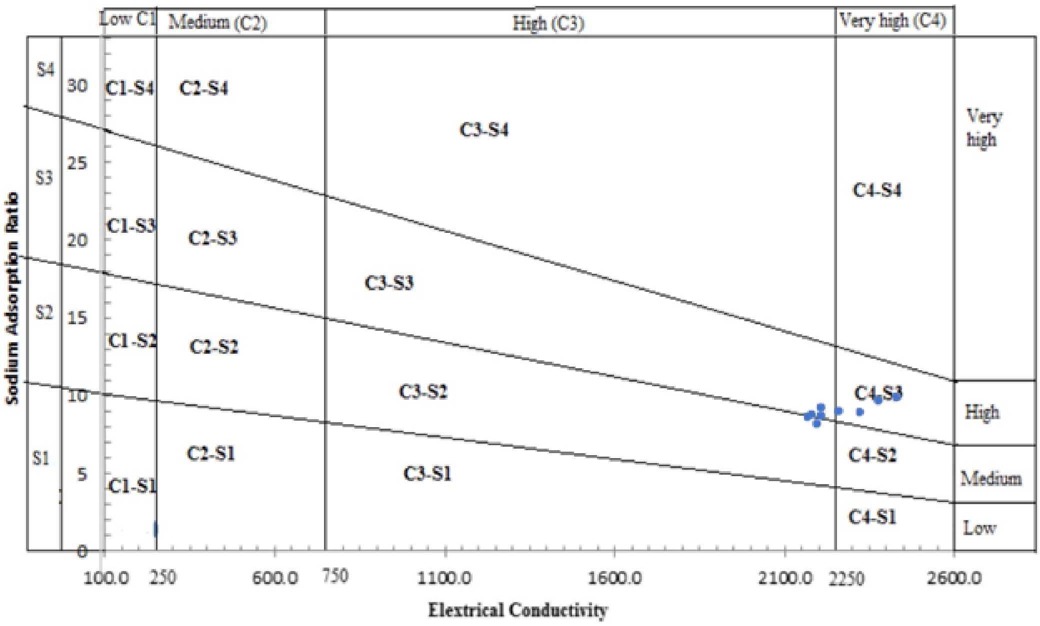

Figure 6. Classification of irrigation water suitability using USSL diagram based on SAR and EC according to Richards.

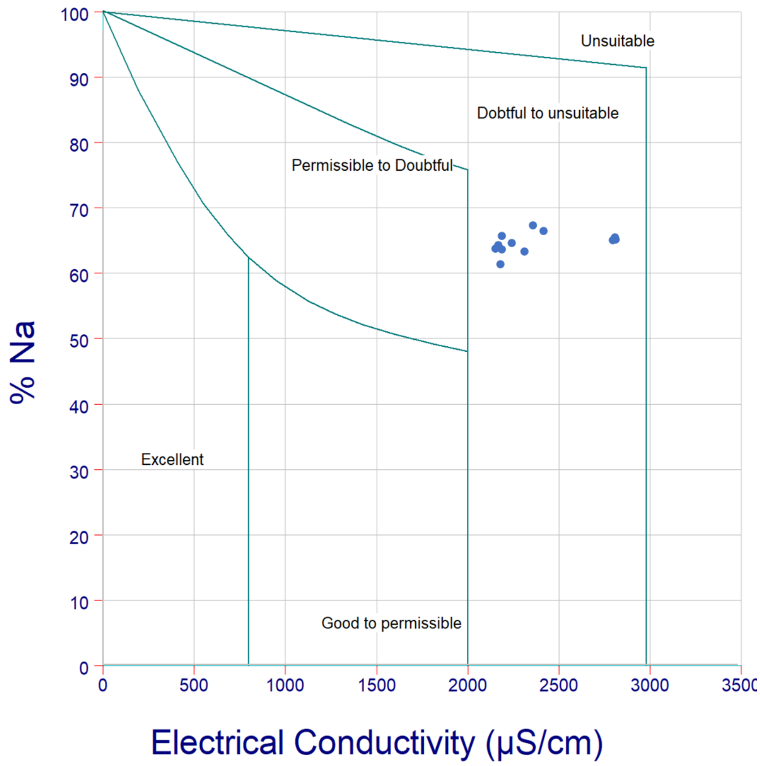

Figure 7. Water samples Suitability for Irrigation depicted by Wilcox Diagram.

The PS values of the samples ranged from 14.16 to 18.17 meq/L, with an average value of 15.98 meq/L. Based on their PS values, all samples were classified as "Injurious" to "Unsatisfactory" for irrigation.

4. Discussion

This study's treated water had higher salinity levels than Mariehamn, Sweden's moderate levels. In Mariehamn, Sweden, moderate salinity levels ranging from 580 to 1370 µS/cm were reported. A study conducted in Abu Dhabi reported high salinity levels. 4700 µS/cm [50], unlike our findings. Variability in electrical conductivity and salinity levels was observed across WWTPs.

Our study's findings on TSS differ because of wastewater characteristics and treatment processes. For instance, a study conducted in Kolea's WWTP in northern Algeria reported similar values of 14.8 mg/L for TSS concentration in the treated effluent [51]. In Madrid, Spain, TSS concentrations range from 28.4 to 79.4 mg/L in the treated effluent [52]. Our study showed how climate affects settling and the removal of suspended solids, compared to Madrid's context.

Our findings show the BOD_5 levels in the treated water from the Ain Sefra WWTP are comparable or lower than other studies in Algeria. For example, a study conducted in Medea's WWTP reported BOD_5 levels reaching a maximum value of 352.33 mg/L in the treated effluent, which exceeds our findings [53]. WWTPs worldwide typically report BOD_5 levels between 10–50 mg/L [54–56]. These results show that the biological treatment process implemented at the Ain Sefra WWTP effectively reduces biodegradable organic pollution, ensuring the suitability of the treated water for irrigation.

COD results differ depending on treatment processes and influent wastewater. COD levels in M'rirt City exceeded our study's range, with readings of 450 to 1265 mg/L [57]. Similarly, a study conducted in Ouargla, Algeria, reported COD levels ranging from 260 to 380 mg/L in the treated wastewater [58]. It is important to note that acceptable COD limits for agricultural reuse may vary between countries and regions. The COD levels for agricultural reuse remained within acceptable limits (90 mg/L) according to Algerian regulations [35]. Despite fluctuations in COD levels, the treated water from the Ain Sefra WWTP can still be suitable for agricultural use.

Examining studies conducted in different WWTPs in Madrid, Spain, by Colmenarejo et al. [52] found nitrate levels in the treated effluent in Madrid, Spain ranged from 1.06 to 6.58 mg/L, which is in line with our results. Similarly, a study conducted in Ain Temouchent by Haidara et al. [43] reported nitrate concentrations in the treated wastewater ranging from 3.65 to 10.20 mg/L, also within the permissible limit for irrigation. Nitrate level variations across WWTPs are highlighted, emphasizing the importance of effective treatment processes. The Ain Sefra WWTP's findings show lower nitrate levels. This proves the effectiveness of the nitrification–denitrification processes implemented in the treatment facility. Through oxidation, the plant efficiently converts ammonia into nitrites. The remarkable ability of the Ain Sefra WWTP to achieve such minimal levels of nitrate and nitrite can be attributed to the successful implementation of biological treatment methods and the overall efficiency of the treatment processes. These results indicate the plant's efforts to prevent groundwater contamination, especially in areas with permeable soil. The study conducted by Colmenarejo et al. [52] in different WWTPs in Madrid, Spain, also reported similar results, with nitrate levels in the treated effluent ranging from 1.9 to 6.4 mg/L. The Ain Sefra WWTP results show successful degradation of organic matter through the biological treatment process. These findings are consistent with previous studies conducted by Hachi et al. [59] and Haidara et al. [43], which examined similar WWTPs in different regions and reported comparable levels of dissolved oxygen in the treated effluent. For example, Haidara et al. [43] documented dissolved oxygen values ranging from 6.39 mg/L to 9.26 mg/L in the treated water of a WWTP in Ain Temouchent, northwestern Algeria. Similarly, Hachi et al. [59] observed an average dissolved oxygen concentration of 4.89 mg/L in the effluent of a WWTP in M'rirt, Morocco. These comparative studies underscore the superior performance of the Ain Sefra WWTP, consistently showing its effectiveness compared to other wastewater treatment plants.

When examining phosphate levels, a comparison of the outcomes concerning phosphate removal throughout the treatment procedure exhibits discrepancies. Phosphate is difficult to remove from wastewater because of its inclination to elude biological processes. Nevertheless, the decrease in phosphate levels observed in the treated wastewater of this study implies the efficacy of the treatment process in alleviating phosphate contamination. This reduction can be attributed to the consumption of phosphate by bacteria during the treatment process, as reported in a previous study conducted by Bachi et al. [60], which investigated a similar WWTP in Ouargla, Algeria. The study found phosphate values ranging from 5.92 mg/L to 8.46 mg/L in the treated wastewater. These comparative findings highlight the consistent phosphate removal capabilities of the Ain Sefra WWTP and underscore the effectiveness of the treatment process in mitigating phosphate contamination.

The results obtained from the Ain Sefra WWTP provide evidence for the effectiveness of the biological treatment process used, demonstrating successful degradation of organic matter. These findings agree with Rekrak and Fellah [61] and Hachi et al. [59], who found similar levels of dissolved oxygen. For example, Rekrak and Fellah [61] documented dissolved oxygen values ranging from 6.39 mg/L to 9.26 mg/L in the treated water of a WWTP in Ain Temouchent, northwestern Algeria. Similarly, Hachi et al. [59] observed an average dissolved oxygen concentration of 4.89 mg/L in the effluent of a WWTP in Oued Tighza, Morocco. These comparative studies underscore the superior performance of the Ain Sefra WWTP, consistently showing its effectiveness compared to other wastewater treatment plants. The results show varying phosphate levels. Biological processes can have difficulty removing phosphate from wastewater. This reduction can be attributed to the consumption of phosphate by bacteria during the treatment process, as reported in a previous study conducted by Hachi et al. [59], which investigated a similar WWTP in Ouargla, Algeria. The study found phosphate values ranging from 5.92 mg/L to 8.46 mg/L in the treated wastewater. These comparative findings highlight the consistent phosphate removal capabilities of the Ain Sefra WWTP and underscore the effectiveness of the treatment process in mitigating phosphate contamination.

Comparative studies conducted in Algeria have revealed variations in ammonia nitrogen concentrations in treated wastewater among different WWTPs. For example, a study by Hamaidi-Chergui et al. [62] in Beni Messous, east of Algiers, reported an average ammonia concentration of 2.65 mg/L in the treated effluent, slightly lower than the findings of the present study. Another study by Karef et al. [53] in Medea, northern Algeria, observed an average ammonia level of 3.46 mg/L in the treated wastewater, showing lower concentrations compared to the Ain Sefra WWTP. Similarly, studies conducted in other countries have reported different ammonia concentrations in treated wastewater. For instance, a study by Ewida et al. [63] in Qalyubia, Egypt, found an average ammonia concentration of 14 mg/L, indicating higher concentrations compared to the current study. These comparative findings highlight the variations in ammonia concentrations observed across different WWTPs in Algeria and internationally. They emphasize the influence of treatment technologies, influent characteristics, and operational parameters on ammonia removal. Continued research and data sharing between WWTPs in different regions can contribute to identifying effective treatment strategies for ammonia removal and optimizing wastewater treatment processes.

The study assessed various water irrigation indices in the study area. The results indicate that the water samples exhibit both suitable and unsuitable characteristics for irrigation. The SAR values and Permeability Index suggest that the samples are suitable for irrigation. However, the %Na, Magnesium hazard, KI, and PS values highlight potential limitations and risks associated with using the water for irrigation. To ensure sustainable irrigation practices and prevent soil degradation, proper management and monitoring are crucial in the study area.

It is important to acknowledge certain limitations of this study. First, the lack of long-term data restricts the analysis to a specific period, potentially overlooking seasonal variations and trends. Results may not be comparable due to differences in wastewater, treatment processes, and environmental conditions. The study does not account for the potential influence of agricultural practices or soil properties on the suitability of the treated water for irrigation. Further research is needed to understand the implications of treated wastewater irrigation.

5. Conclusions

The study highlights the potential of reusing treated wastewater in agriculture as a solution to water scarcity. It specifically focuses on assessing the physical and chemical characteristics of treated wastewater at the Ain Sefra WWTP.

The results answer the questions planned, indicating that:

(i). The findings show that the treated water meets acceptable standards in terms of temperature and pH levels for irrigation. Water irrigation indices showed varying degrees of suitability for irrigation, with some parameters raising concerns about soil deterioration. This emphasizes the importance of assessing water sources used in irrigation to prevent soil degradation and ensure sustainable agricultural practices.

(ii). Treated water in WTTP meets the acceptable standards in Algeria. The concentration of total suspended solids in the treated water is low, posing no challenges for water distribution. The levels of BOD_5 were below the limit for irrigation, except for specific months where they exceeded the limit. The levels of COD fluctuated but remained below the maximum limit for agricultural reuse.

(iii). The high electrical conductivity classifies the water as highly saline, which may have implications for its use in irrigation.

(iv). Nitrate and nitrite levels were also below the irrigation limits, ensuring no risk of groundwater contamination.

(v). Long-term monitoring should be incorporated to evaluate seasonal variations, compare with other wastewater treatment plants, assess effects on soil and crops, and explore emerging contaminants. Further studies on the optimization of treatment processes could help us better understand the reuse of reclaimed wastewater in agriculture.

It is important to note the limitations of the study, such as its focus on a specific period, which may not capture seasonal variations and trends. Because of differences in wastewater characteristics, treatment processes, and environmental conditions, comparing the results with other wastewater treatment plants worldwide may be limited.

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

Appendix A

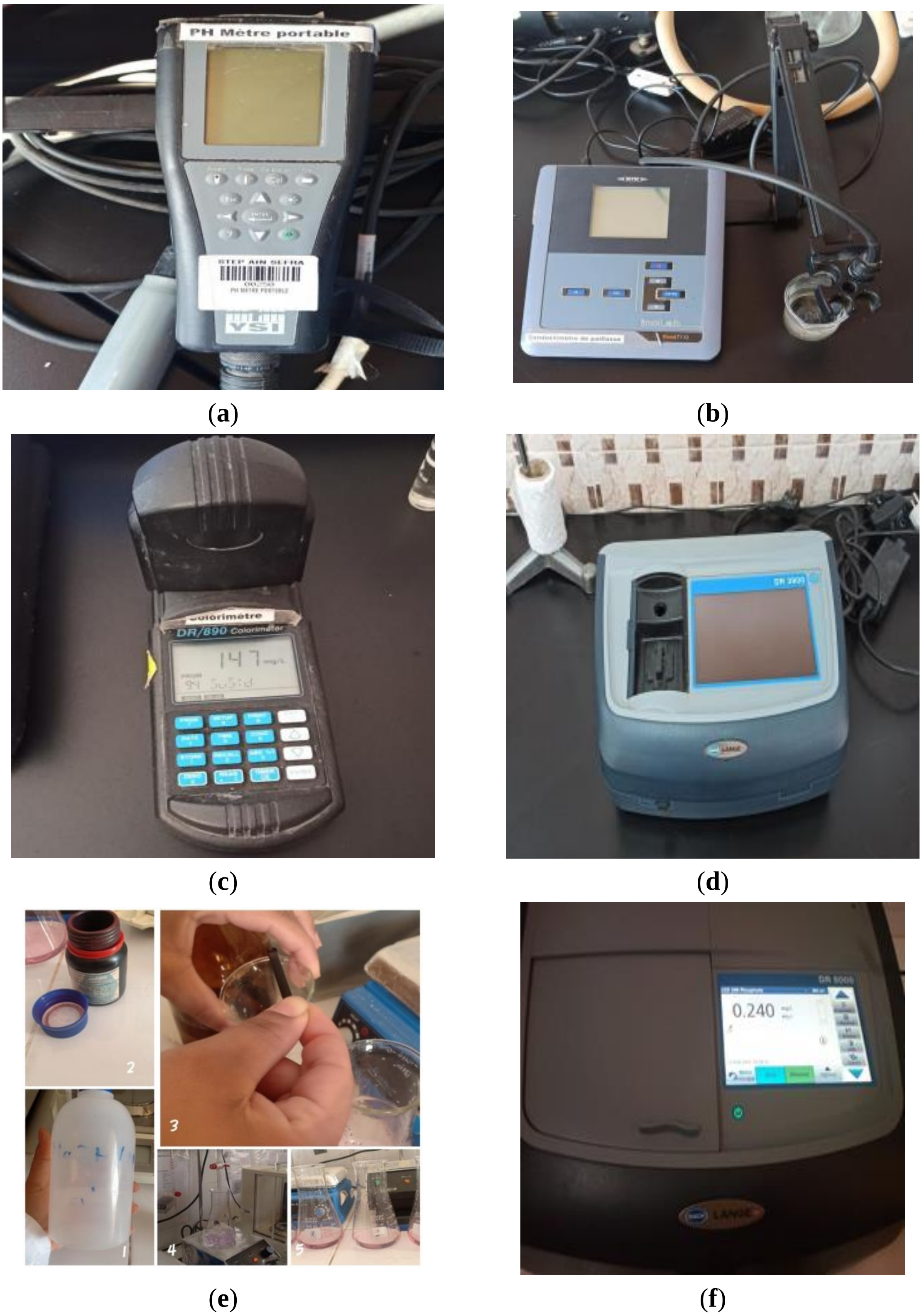

Figure A1. Analyses methods ((**a**): temperature and pH measurements, (**b**): EC determination, (**c**): TSS determination, (**d**): spectrophotometer (HACH DR-3900), (**e**): titration method (Total hardness, calcium, and magnesium determination), (**f**): UV-VIS spectrophotometer (Nitrate and sulphates determination).

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