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ARTICLE

Physicochemical and Bacteriological Quality Assessment of Water Downstream of the Kaddoussa Dam in Boudnib, Morocco

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ABSTRACT

This study addresses the pressing need to evaluate the quality of water resources in the Oued Guir watershed, highlighting the importance of monitoring both surface water and groundwater in the context of environmental and public health. It focuses on the evaluation of physicochemical and bacteriological water quality downstream of the Kaddoussa Dam, as well as the characterization of wastewater from the Boudnib treatment plant discharged into Oued Guir. The goal is to assess the health of aquatic ecosystems and understand the impact of anthropogenic activities on these sensitive environments. A comprehensive analysis was conducted at 15 selected stations during a sampling campaign in November 2023. Groundwater and surface water were assessed using 10 physicochemical parameters, while bacteriological quality was evaluated based on fecal coliforms and *Escherichia coli*. In addition, 38 parameters were studied to characterize the wastewater discharge. All analyses followed standard procedures and the results were compared to Moroccan and World Health Organization (WHO) standards. The study revealed that surface water and groundwater in the study area exhibited strong mineralization, with Electrical Conductivity (EC) exceeding 1400 µS/cm at all stations. Nitrogen quality, in terms of Nitrates (NO_3^-), was moderate across stations, while Ammonium (NH_4^+) quality was consistently excellent. Physicochemical parameters of surface waters indicated overall excellent quality. Bacteriological analysis showed minimal contamination by fecal coliforms and *Escherichia coli*, with levels deemed negligible. However, wastewater from the Boudnib treatment plant exceeded Moroccan standards for organic load, presenting a potential environmental risk.

Keywords: Water Quality; Wastewater; Boudnib; Oued Guir; Kaddoussa Dam; Anthropogenic Activities

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ARTICLE INFO

Received: 31 October 2024 | Revised: 17 November 2024 | Accepted: 20 November 2024 | Published Online: 7 January 2025

DOI: https://doi.org/10.30564/jees.v7i1.7643

CITATION

Albou, E.M., Abdaoui, A., Boughrous, A.A., 2025. Physicochemical and Bacteriological Quality Assessment of Water Downstream of the Kaddoussa Dam in Boudnib, Morocco. Journal of Environmental & Earth Sciences. 7(1): 503–513. DOI: https://doi.org/10.30564/jees.v7i1.7643

1. Introduction

Water quantity and quality pose significant challenges for humanity in the 21st century [1, 2]). The wellbeing of both humans and crop production is directly impacted by water quality, which affects soil health, harvests, and the overall ecosystem [3]. Water quality is a crucial consideration in various sectors, including water supply, wastewater treatment, industry, agriculture, aquaculture, aquatic ecology, and human and animal health [4]. Human activities are responsible for contaminating and polluting different ecosystems [5–8]. These anthropogenic activities severely impact aquatic ecosystems, which are also under growing pressure from population growth, urban development, and unsustainable water resource exploitation [9]. The expanding population and rapid urbanization further strain freshwater resources, leading to increased water scarcity and stress [10–12]. Agriculture is identified as a significant contributor to excessive water consumption and the degradation of water quality [13]. The impact of agriculture on water quality originates from multiple sources, including crop cultivation, livestock farming, and aquaculture, which have expanded and intensified to meet the rising food demand driven by population growth and changing dietary patterns [14]. Fertilizers and pesticides are the primary contaminants associated with agricultural practices [15, 16]. Furthermore, the process of irrigation can contribute to the transportation of accumulated salts in soils into nearby water bodies through drainage water. This can lead to the phenomenon of salinization, where the increased salt content negatively impacts the water quality of these receiving bodies [14, 17].

In Morocco, the water sector continues to confront numerous challenges, primarily stemming from water scarcity attributed to a confluence of factors, including the impacts of climate change and the escalating overexploitation of groundwater resources, notably driven by the agricultural sector. Additionally, there are various factors contributing to the deterioration of water quality, such as pollution. This issue is particularly important, especially in arid regions such as oasis regions [18]. However, the study area is one of the oasis areas affected by these constraints, especially the sudden development of agricultural activities after the installation of the Kaddoussa dam. Agricultural activities and municipal sewage pose significant threats to the water quality of Boudnib. The expansion of agricultural activities in the region, especially in the date palm sector facilitated by the establishment of the Kaddoussa dam, has led to the excessive use of chemical fertilizers and pesticides. Consequently, these substances have the potential to permeate the soil, resulting in the contamination of water bodies, particularly groundwater sources [15, 16, 19, 20]. This presents a substantial environmental concern, posing potential risks to both water quality and the health of aquatic ecosystems [15, 16, 19, 20].

In recent years, several case studies have focused on the impact of human activities on water quality. For instance, Sarker [21] investigated the effects of agricultural runoff on river systems in South Asian countries, showing level of pesticides contamination in the major river systems. In contrast, a study by Mukate [22] examined the influence of industrial and agricultural land uses on groundwater quality in semiarid region of Solapur, India, revealing significant contamination of water quality due to land uses activities. These case studies underscore the need for integrated water quality assessments that consider both natural and anthropogenic influences.

Wastewater may contain harmful substances, such as pathogens, heavy metals, and chemicals, which can seep into groundwater. However, it can negatively affect groundwater quality, potentially threatening ecological stability and human health [23–25].

In contrast, the population in the study area continues to rely on traditional sanitation systems in the form of septic systems within the ksours (traditional villages). Wastewater effluent from these systems is discharged into the Oued Guir. Similarly, the treated municipal wastewater from the treatment plant is directly released into the Oued Guir. Globally, approximately 80% of municipal wastewater is released into water bodies without undergoing any treatment [26]. The discharge of polluted waters into the Oued Guir may pose a potential risk of contaminating both surface water and groundwater sources. This contamination can have detrimental effects on human health [27], particularly considering that a significant portion of the population relies on wells and Khettaras as their source of drinking water. The release of wastewater from various sources leads to contamination of underground and surface water as well as the soil [26, 28]. This contamination, in turn, affects the safety of food and drinking water. When individuals consume water and food that have been contaminated, it poses a serious risk to human health, contributing to significant health problems and even epidemics [27]. The evaluation of wastewater quality parameters, such as pH (potential of hydrogen), biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended sediments, plays a crucial role in the effective and dependable operation of wastewater treatment plants. These variables provide essential information for monitoring and maintaining the efficiency of treatment processes [29, 30].

Effectively addressing water pollution arising from agricultural activities and untreated municipal wastewater requires the implementation of robust water resource management frameworks. These frameworks should integrate comprehensive approaches for managing both land and water utilization, incorporating strategies for water reuse. Indeed, the primary objective of this study was to provide insights into water quality in the region and offer relevant recommendations.

2. Material and Methods

2.1. Study Area

Boudnib, situated on the southeastern border of Morocco, encompasses the Oued Guir valley, extending approximately 60 kilometers from the Kaddoussa dam site to the downstream Sahli perimeter (**Figure 1**). Positioned 60 km southeast of Gourrama and 80 km east of Errachidia, Boudnib became part of the Draa-Tafilalet region following the administrative division of 2015. The region includes seven Ksours (traditional villages) and two communes: the rural commune of Oued Naam and the urban commune of Boudnib. As of the 2014 general population census, Boudnib had a total population of 16,713 (RGPH, 2014). In terms of water potential, the Boudnib region is characterized by two main aquifers: the quaternary aquifer and the Senonian aquifer. Additionally, the study area boasts an ingenious hydraulic heritage known as Khettaras—draining galleries that channel groundwater to the surface by gravity for irrigation and drinking water. Presently, six khettaras are still in use in the Boudnib area. Given this abundance of groundwater, the agricultural sector serves as the driving force behind local development in the study area.

2.2. Hydrology of Guir Watershed

The study area belongs to the Guir hydraulic basin. The watershed of Oued Guir has its source in the High Atlas, which is a region with higher rainfall than that of Boudnib. According to geological studies, Guir watershed is formed essentially by permeable to semi-permeable soils, which occupy almost the whole of the area of the basin, which promotes the infiltration of surface water [31]. The annual rainfall pattern in the high Guir basins is marked by two distinct rainy seasons: autumn and spring. The average annual rainfall in the upper basin reaches approximately 250 mm, while in the downstream area of the basin, it amounts to around 112 mm [31]. Concerning Oued Guir, it is considered as one of the longest Oued in North Africa. Its total area is around 17500 km^2 in Moroccan territory [32]. At the exit of the Boudnib area, Oued Guir joins Oued Bouanane. Several tributaries feed Oued Guir before arriving at the Kaddoussa dam. In Moroccan territory, the main tributaries of Oued Guir are Oued Assefti, Oued Aït Aïssa and Oued Zelmou. Before the construction of the Kaddoussa dam, Oued Guir, along its course in the study area, is fed by resurgences of the alluvial aquifer, by small Oueds and by perennial sources of low flow, with flows of a few liters per second) or temporary (associated with heavy rains at high altitude [33]. Despite the extent of the Guir watershed, a high flow velocity given the presence of steep slopes characterizes the floods of Oued Guir. Indeed, they are classified in the category of torrential floods of small mountain basins [33]. In 2008 the study area experienced violent and catastrophic flooding, causing the destruction of many habitats. Following these floods, the measures adopted to restore the balance is the construction of the Kaddoussa dam. The construction work on this dam was completed in 2021.

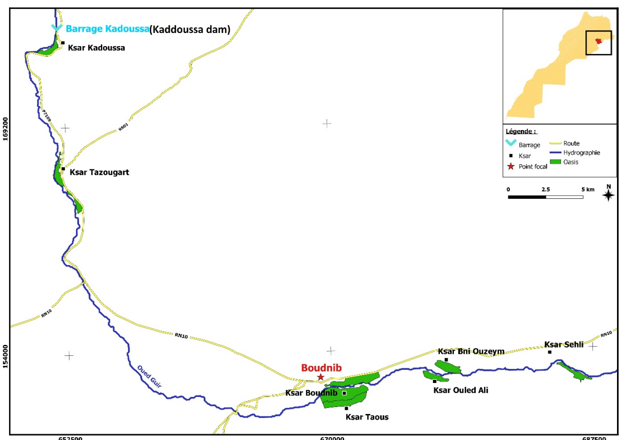

Figure 1. Geological location of the study area: Boudnib, Morocco.
Source: own study.

2.3. Climatic Characteristics

The climate of the region is semi-arid continental type, marked by the scarcity of rainfall. Temperatures are characterized by large seasonal and daily variations with peaks varying between –5 °C in winter and 50 °C in summer. The precipitation recorded is generally weak and uneven in time and space. The average annual rainfall is 100 mm in the plains and 150 mm in the mountainous areas. Monthly and annual means have a special significance of randomness due to the large variations in rainfall patterns. The prevailing winds have a direction from northeast to southwest [32].

2.4. Sampling

The selection of stations aimed to cover the entire perimeter of Boudnib, starting from the Kaddoussa dam and extending to Sahli, which represents the last point downstream (**Figure 2**).

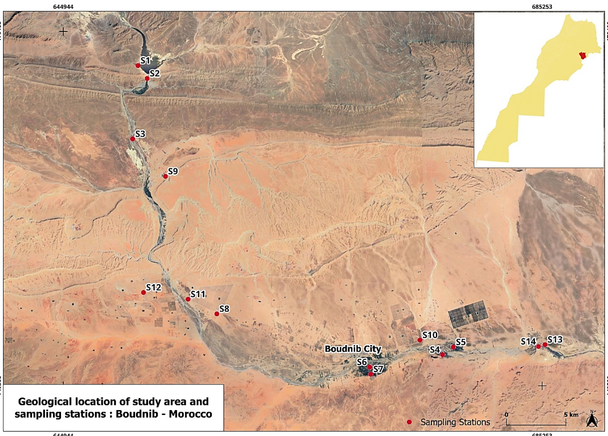

Figure 2. Geological location of sampling stations.

Source: own study.

2.4.1. Groundwater Sampling

Groundwater samples were collected from eleven wells and boreholes located in the ksours (traditional villages) and farms. Electric pumps were used for the groundwater sampling, as it is a practical and widely employed technique for this purpose. In cases where stations did not provide a continuous flow of water, such as in modern farms, a flow of water was initiated for one hour before directly sampling the water sample. This step ensured representative sampling of the groundwater.

2.4.2. Surface Water Sampling

Surface water sampling was done manually in three water points using a sampling pole.

2.4.3. Wastewater Sampling

Direct sampling of the wastewater that comes out of the canal, coming from the Boudnib wastewater treatment plant, which discharges into the natural environment (Oued Guir).

2.5. Physicochemical Parameters

Water temperature, pH, electrical conductivity and dissolved oxygen, these parameters were measured in situ using portable devices. The samples were packaged in bottles, and transported to the laboratory in order to carry out the rest of the analyses. Additional indicators were analyzed according to the analysis methods recommended by AFNOR [34] and Rodier [35]. The results found were compared with Moroccan standards for surface water and groundwater (Direction de la recherche et de la planification de l'eau, 2014a), and with the standards of the World Health Organization [36]. For wastewater, the recorded results were compared with the general discharge limit values applicable to discharges of wastewater, which do not have specific limit values [37].

2.6. Bacteriological Parameters

The samples were put in sterilized bottles, after they were transported to the laboratory. Two indicators were analyzed: fecal coliforms and *Escherichia coli*. The count of these bacteria indicating fecal contamination was carried out based on the technique recommended by Rodier [35]. The results found were compared with Moroccan standards for surface water and groundwater, also compared with the standards of the World Health Organization [18, 36].

2.7. Statistical Analysis

In conducting the statistical analysis for this study, data processing was meticulously executed through the utilization of SPSS 10.0.5 software.

3. Results and Discussion

3.1. Physicochemical Parameters of Groundwater and Surface Water

The results of the physicochemical analyzes of surface water and groundwater are summarized in the following table (**Table 1**):

Table 1. The results of the physicochemical analyzes of surface water and groundwater.

		Physicochemical Analysis										Geographic Coordinates	
ID Unit	**Water Nature** -	**T** °C	**pH** pH Unit	**NH_4^+** mg/l	**NO_3^-** mg/l	**Dissolved Oxygen** mg O2/l	**Total Phosphorus** mg P/l	**CDO** mg/l	**BOD5** mg/l	**Electrical Conductivity (EC)** µS/cm	**Fluorides** mg/l	**X**	**Y**
S1	Surface water	22.7	8.9	0.07	10.02	4.43	<0.1	<30	<3	1600	0.25	651227.92	176520.90
S2	Ground water	22.9	8.2	<0.005	41.07	-	-	-	-	3460	0.33	651998.07	175431.59
S3	Surface water	20.03	9	<0.005	12.8	4.33	<0.1	<30	<3	1980	0.21	650780.70	170331.56
S4	Ground water	24.01	7.3	<0.05	4.48	-	-	-	-	1965	0.2	676868	152127
S5	Ground water	23	7.5	<0.05	9.29	-	-	-	-	1716	0.25	677772	152767
S6	Ground water	22.1	7.2	<0.05	7.24	-	-	-	-	1771	0.2	670728	151078
S7	Ground water	23.5	7.3	<0.05	6.54	-	-	-	-	1809	0.13	670823	150479
S8	Ground water	22.2	7.7	<0.05	1.69	-	-	-	-	1934	<0.1	657865.66	155570.11
S9	Ground water	22.2	8	<0.05	10.82	-	-	-	-	1637	0.22	653541.23	167171.71
S10	Ground water	23.5	8.1	<0.05	5.53	-	-	-	-	1921	0.22	674962	153361
S11	Ground water	23.2	7.76	<0.02	11.65	-	-	-	-	1500	0.23	655444	156806
S12	Ground water	24.1	7.9	<0.05	0.87	-	-	-	-	2460	<0.1	651693	157376
S13	Surface water	20.7	8.8	0.09	9.36	4.55	<0.1	<30	<3	1935	0.15	685490.22	152978.34
S14	Ground water	18.4	7.8	<0.05	2.7	-	-	-	-	3300	0.15	684946.27	152815.69

Note. All abbreviations used in this article are defined below.
S - Station; T - Temperature; COD - Chemical Oxygen Demand; BOD5 - Biochemical Oxygen Demand, 5-day.

The physicochemical analysis results of groundwater and surface water were examined to assess the quality of water in the study area. The data presented in **Table 1** provide a comprehensive overview of the key water quality indicators, including temperature, pH, ammonium (NH_4^+), nitrates (NO_3^-), dissolved oxygen, total phosphorus, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), electrical conductivity (EC), and fluorides, among others.

To assess the quality of this water, the recorded values were compared with Moroccan standards and WHO standards in points where the water is drinkable.

3.1.1. Temperature

The recorded temperatures vary between 18 °C and 24 °C. The temperature influences the other parameters, such as the case of dissolved oxygen and electrical conductivity. High temperatures leading to degradation of water quality [38, 39].

3.1.2. pH

The waters in the study area are characterized by an alkaline **pH**. The recorded values vary between 7.2 and 9. The values recorded in the points where the water is drinkable are within Moroccan standards (between 6.5 and 8.5). Regarding surface waters (S1, S3 and S13), the recorded values exceed a pH level of eight. Generally, pH values in waters have a dynamic relationship with other water quality parameters [40].

3.1.3. Electrical Conductivity (EC)

Conductivity is a parameter used to assess the mineral load in water. It is an indicator of inorganic pollution. The recorded values range between 1500 µS/cm (S11) and 3460 µS/cm (S2). The findings indicate that the water sources in the study area, particularly the Quaternary groundwater, exhibit high mineralization levels. Specifically, two stations, Kaddoussa (S2) and Sahli (S14), demonstrate inadequate mineralogical quality in terms of electrical conductivity, as per the standards established by the national system for assessing overall groundwater quality (Direction de la recherche et de la planification de l'eau, 2014a). The values recorded in these two stations exceed the values set by the WHO (less than 2000 µS/cm). On the other hand, the remaining stations exhibit an average mineralogical quality. The high mineralization of groundwater observed in the study area can be attributed to several potential factors, including the composition of the source rock, the use of fertilizers contributing to increased electrical conductivity, irrigation practices involving water with high levels of dissolved salts or salinity, and the presence of soils with elevated levels of dissolved salts or salinity [41–44].

3.1.4. Ammonium (NH_4^+)

Ammonium (NH_4^+) is a main indicator of pollution that can be caused by polluted discharges [45]. The nitrogen quality in terms of Ammonium (NH_4^+) is excellent for all stations. The S2 and S3 recorded the lowest levels of ammonium content. Ammonium levels do not exceed the values established by the national system for evaluating the overall quality of groundwater [18]. The values recorded are less than 0.1 mg/l, which is lower than the permissible limit of the WHO, that is, 1.5 mg/l [36].

3.1.5. Nitrates (NO_3^-)

The nitrogen quality, specifically in terms of nitrates (NO_3^-), is generally classified as good to excellent at most stations, with the exception of the Kaddoussa point where the quality is average. The recorded nitrate concentrations range from 0.87 mg/l to 41.07 mg/l. The Kaddoussa station (S2) exhibits the highest nitrate content (41.07 mg/l) compared to the other stations. While, the lowest nitrates contents were recorded in the (S12), that is, 0.87 mg/l. However, the recorded values do not exceed the maximum permissible limit for drinking water, which is set at 50 mg/l [36]. The potential causes of the high nitrate content at the Kaddoussa point can be attributed to the use of nitrogen fertilizers, animal waste, manure, or domestic wastewater in the area [46].

3.1.6. Fluorides

Fluoride levels recorded at all the stations comply with the WHO standard (1.5 mg/l) (WHO, 2008). Fluoride is a naturally occurring element and can be found in various geological formations, including rocks and soils. It can also enter water sources through the weathering of minerals or human activities such as industrial discharges, agricultural runoff, and the use of fluoride-containing fertilizers [47, 48].

3.1.7. Surface Waters: Additional Parameters

For the three specified stations - Kaddoussa dam (S1), surface waters of Tazougart (S3), and Sahli (S13) - an extensive analysis included additional parameters. These parameters encompassed dissolved oxygen (registering below 5.6 at all three stations), total phosphorus (measuring less than 0.1 mg/l of P at all three stations), chemical oxygen demand (COD) (recording less than 3 mg/l at all three stations), and 5-day biochemical oxygen demand (BOD5) (noting values below 30 mg/l at all three stations). The recorded values consistently adhere to Moroccan quality standards for high-quality surface water, stipulating dissolved oxygen greater than 7, total phosphorus not exceeding 0.1, BOD5 below 3, and COD below 30, respectively [18].

The inclusion of these additional parameters is paramount, as they constitute essential measurements in evaluating and quantifying the extent of water pollution within a specific water body [49].

3.2. Physicochemical Parameters of Wastewater

The results of the physicochemical analyzes of wastewater, discharged from the Boudnib wastewater treatment plant, are summarized in the following table (**Table 2**):

Table 2. The results of the physicochemical analyzes of wastewater.

Parameters	Unit	Results	General Discharge Limit Values Applicable to Waste Water Discharges that Do Not Have Specific Discharge Limit Values
Temperature	°C	19	30
pH	Unit pH	7.9	5.5–9.5
Electrical conductivity at 20’C	µs/cm	2661	2700
Suspended matter	mg/I	26	100
COD	mg/I	326.40	500
Sulphates	mg/I	266.80	600
Total phosphorus	mg P/I	11.38	15
Nitrogen Kjeldahl	mg N/I	112.08	40
Phenol index	mg/I	<0.1	0.5
BOD5	mg/I	109.60	100
Anionic detergents	mg/I	0.87	3
Cationic detergents	mg/I	0.09	3
Ionic detergents	mg/I	0.12	3
Hydrocarbons by infrared	mg/I	4.54	15
Hexavalent chromium	mg/l	ND	0.2
Active chlorine	mg/I	<0.1	0.2
Oils and Fats	mg/I	185	30
Free cyanides	mg/I	<0.01	0.5

Table 2. *Cont.*

Parameters	Unit	Results	General Discharge Limit Values Applicable to Waste Water Discharges that Do Not Have Specific Discharge Limit Values
Fluorides	mg/I	0.78	20
Free sulfides	mg/I	0.03	1
Chlorine dioxide	mg/l	0.02	0.05
AOX	µg/I	<0.01	5
Arsenic (As)	mg/I	<0.0005	0.1
Barium (Ba)	mg/I	0.04	1
Cadmium (Cd)	mg/l	<0.0005	0.25
Copper (Cu)	mg/I	0.02	2
Manganese (Mn)	mg/I	0.09	2
Nickel (Ni)	mg/I	0.02	5
Lead (Pb)	mg/I	<0.0005	1
Selenium (Se)	mg/I	<0.0005	0.1
Chromium (Cr)	mg/I	0.03	2
Mercury (Hg)	mg/I	<0.0005	0.05
Aluminum (Al)	mg/l	0.04	10
Cobalt (Co)	mg/I	<0.0005	0.5
Tin (Sn)	mg/I	<0.0005	2.5
Iron (Fe)	mg/I	0.17	5
Zinc (Zn)	mg/I	0.02	5
Silver (Ag)	mg/I	<0.0005	0.1

Note. All abbreviations used in this article are defined below.
COD - Chemical Oxygen Demand; BOD5 - Biochemical Oxygen Demand, 5-day; AOX - Halogenated Organic Compounds.

A total of 38 parameters were examined to evaluate the quality of the wastewater that is discharged from the Boudnib wastewater treatment plant.

Discharge limit values are predefined thresholds for specific pollution indicators. They represent the maximum allowable levels of certain parameters in wastewater or other discharges. Non-compliance with these limit values indicates a deterioration in water quality. These values can be general, applicable to a wide range of activities, or specific to particular industrial or domestic activities. The purpose of these limit values is to regulate and control the discharge of pollutants into water bodies, ensuring the protection of water resources and the environment [37].

The largest proportion of waste released into Oued Guir is attributed to sewage. Sewage comprises a combination of municipal and domestic wastes, including waste from bathing, laundry, kitchen activities, and human fecal matter.

Based on the analysis of the liquid effluent discharged from the Boudnib treatment plant, it has been determined that three measured parameters exceed the general discharge limit values [37]. The liquid discharge exhibits elevated concentrations of organic matter, specifically Kjeldahl nitrogen (112.08 mg/l), BOD5 (109.6 mg/l), and oils and fats (185 mg/l). The respective applicable limit values for these parameters are 40 N mg/l for Kjeldahl nitrogen, 100 mg/l for BOD5, and 30 mg/l for oils and fats [37]. The observed exceedance of these limits signifies a concern as it indicates the presence of significant organic pollution in the discharged effluent, posing potential environmental risks to the receiving ecosystem, which is Oued Guir. Ensuring that wastewater discharge is within regulated limits for parameters such as Oils and Fats, Heavy Metals, and Detergents will help prevent contamination of surrounding water bodies.

In the analysis of the liquid effluent, it is commonly observed that there is a low concentration of metals such as nickel (Ni), cadmium (Cd), lead (Pb), cobalt (Co), copper (Cu), mercury (Hg), silver (Ag), zinc (Zn), chromium (Cr), iron (Fe), tin (Sn), arsenic (As), selenium (Se), barium (Ba), manganese (Mn), and aluminum (Al). The recorded levels do not exceed the applicable limit values [37]. Wastewater not only contributes to organic pollution, but it is also a significant source of chemical pollution from heavy metals. The discharge of wastewater leads to an increased presence of heavy metals in the ecosystem, which can accumulate in aquatic life, animals, and ultimately in the human body [50–52].

3.3. Bacteriological Analysis of Groundwater and Surface Water

The summarized results of the bacteriological analysis conducted on surface water and groundwater are as follows (**Table 3**):

Table 3. The results of the bacteriological analysis of surface water and groundwater.

	Bacteriological Analysis	
ID	**Fecal Coliforms**	***Escherichia Coli***
Unit	**CFU/100 ml**	**CFU/100 ml**
S1	<1	<1
S2	<1	<1
S3	$1.1*10^1$	<1
S4	<1	<1
S5	<1	<1
S6	<1	<1
S7	<1	<1
S8	<1	<1
S9	<1	<1
S10	<1	<1
S11	<1	<1
S12	<1	<1
S13	<1	<1
S14	<1	<1

Note. All abbreviations used in this article are defined below.
CFU - Colony-Forming Unit.

3.3.1. fecal coliforms

Based on the analysis of the bacteriological examination results for fecal coliforms, it has been observed that the contamination of the analyzed waters is very low and can be considered negligible (less than 1 CFU/100 ml). This indicates a relative absence of significant fecal contamination. Overall, the bacteriological quality in terms of coliforms is excellent. The surface waters of Tazougart (S3) recorded the highest number of fecal coliforms ($1.1*10^1$ CFU/100 ml). Furthermore, it should be noted that the waters in this particular location are not suitable for drinking. They are designated solely for irrigation purposes. However, all the results obtained from the stations comply with the values set by the national system for evaluating the overall quality of ground and surface water [18]. For the two stations (S7) and (S9), which are commonly utilized as sources of drinking water, the recorded results meet the guide values for the verification of microbial quality set by the World Health Organization [36].

3.3.2. *Escherichia Coli*

Based on the analysis of the results from the bacteriological examination of *Escherichia coli*, it has been determined that the contamination of the analyzed waters is very low and can be considered negligible (less than 1 CFU/100 ml). In terms of microbiological quality, all the stations, including both surface water and groundwater, meet the established standards [18, 36].

The bacteriological analysis shows that both fecal coliforms and *Escherichia coli* are generally absent or present at very low concentrations, suggesting minimal fecal contamination across all water samples. This indicates a good level of water safety for most of the samples in terms of microbial health risks.

3.4. Overview of Water Quality Assessment across Study Stations

The water quality across most stations in the study area meets the acceptable limits for pH, ammonium, and nitrate levels, as per both WHO and Moroccan standards. However, two stations, S2 and S14, exhibit higher electrical conductivity, suggesting increased mineralization. Bacteriological analyses show minimal contamination, with fecal coliforms and *Escherichia coli* either absent or present at very low concentrations, indicating that the water quality poses minimal health risks. In terms of wastewater discharge, the Boudnib plant exceeds limit values for several parameters, including BOD5, Kjeldahl nitrogen, oils, and fats, pointing to significant concerns about organic pollution. The mineralization and contamination of the waters in the studied region are influenced by both natural and anthropogenic factors. Naturally, the dissolution of minerals from surrounding rock formations contributes to elevated levels of dissolved solids, including ions such as calcium, magnesium, and sodium. Anthropogenic activities, particularly agricultural practices and wastewater discharge from urban centers like Boudnib, increase the concentrations of nitrates, ammonium, and organic pollutants. The high electrical conductivity observed at certain stations reflects the geogenic influence of the region's geological formation. Additionally, bacteriological contamination, such as the presence of fecal coliforms and *E. coli*, is likely linked to untreated or inadequately treated wastewater effluents, especially in areas with poor sanitation infrastructure. The variation in water quality across stations highlights the spatial differences in contamination levels, with stations located closer to urban areas experiencing higher levels of pollution compared to more remote locations. Furthermore, multivariate analysis methods, as demonstrated in the study by Nouayti [53], indicate that the quality of groundwater in the upper Guir basin is controlled by three major phenomena: anthropogenic activities, rainfall, and the leaching of soils and hydrolysis of rock minerals, further supporting the complex interplay of natural and human-induced factors in the mineralization and contamination of the groundwater in this region.

4. Conclusions

The study assessed the physicochemical and bacteriological quality of surface water, groundwater, and wastewater in the study area. The results indicate generally good water quality, with minimal fecal contamination and moderate mineralization in surface water. However, some groundwater samples exhibited elevated nitrate concentrations, suggesting potential contamination from agricultural or anthropogenic activities. Additionally, wastewater analysis revealed exceedance in certain discharge parameters, particularly nitrogen and organic load, posing potential environmental risks.

To ensure sustainable water quality management, it is recommended to improve wastewater treatment, focusing on reducing nitrogen and organic pollutants. Continued monitoring of groundwater, especially for nitrates, is essential to track potential contamination sources. Regular water quality assessments will be crucial for maintaining ecosystem health and ensuring safe water resources in the region.

Author Contributions

Writing—original draft, validation, supervision, software, resources, project administration, methodology, investigation, data curation, conceptualization, E.M.A.; writing—review and editing, validation, software, resources, methodology, conceptualization, A.A.; writing—review and editing, visualization, validation, methodology, A.A.B.

Funding

The research received no external funding.

Institutional Review Board Statement

The study does not require ethical approval.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request. All relevant data are included in the manuscript.

Acknowledgements

The authors acknowledge the Laboratory of Analyzing and Agricultural Studies - Agro-Food and Environment (AGRI-LABO) for their collaboration in conducting specific physico-chemical analyses on the water under investigation.

Conflict of Interest

The authors certify that there is no conflict of interest to declare.

References

[1] Grey, D., Garrick, D., Blackmore, D., et al., 2013. Water Security in One Blue Planet: Twenty-first Century Policy Challenges for Science. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences. 371(2002), 20120406.

[2] Cooley, H., Ajami, N., Ha, M.L., et al., 2013. Global Water Governance in the 21st Century. Pacific Institute: Oakland, CA. p. 34.

[3] Khatri, N., Tyagi, S., 2015. Influences of Natural and Anthropogenic Factors on Surface and Groundwater Quality in Rural and Urban Areas. Frontiers in life science. 8(1), 23–39.

[4] Boyd, C.E., 2015. Water Quality: An Introduction. Springer Science and Business Media: New York, NY. p. 330.

[5] Ogidi, O.I., Akpan, U.M. 2022. Aquatic Biodiversity Loss: Impacts of Pollution and Anthropogenic Activities and Strategies for Conservation. In Biodiversity in Africa: potentials, threats and conservation. Springer Nature Singapore: Singapore. pp. 421–448.

[6] Bashir, I., Lone, F.A., Bhat, R.A., et al., 2020. Concerns and Threats of Contamination on Aquatic Ecosystems. Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation. 1–26.

[7] Schweitzer, L., Noblet, J., 2018. Water contamination and pollution. In Green chemistry (pp. 261–290). Elsevier: Amsterdam.

[8] Hampel, M., Blasco, J., Segner, H., 2015. Molecular and cellular effects of contamination in aquatic ecosystems. Environmental science and pollution research. 22, 17261–17266.

[9] Akhtar, N., Syakir Ishak, M.I., Bhawani, S.A., et al., 2021. Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review. Water. 13(19), 2660.

[10] Mulwa, F., Li, Z., Fangninou, F.F., 2021. Water Scarcity

in Kenya: Current Status, Challenges and Future Solutions. Open Access Library Journal. 8(1), 1–15.
[11] Chakraborti, R.K., Kaur, J., Kaur, H., 2019. Water Shortage Challenges and A Way Forward in India. American Water Works Association. 111(5).
[12] El Kharraz, J., El-Sadek, A., Ghaffour, N., et al., 2012. Water Scarcity and Drought in WANA Countries. Procedia Engineering. 33, 14–29.
[13] Mateo-Sagasta, Javier., Zadeh, S.M., Turral, H., et al., 2017. Water Pollution from Agriculture: A Global Review. Executive summary. Rome, Italy: FAO; Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 1–35.
[14] FAO. 2014. Area Equipped for Irrigation. Infographic. Aquastat: FAO's Information System on Water and Agriculture. Food and Agriculture Organization of the United Nations (FAO): Rome.
[15] Umer Shah, Z., Parveen, S., 2020. A review on pesticides pollution in aquatic ecosystem and probable adverse effects on fish. Poll Res. 39(2), 309–321.
[16] Häder, D.P., Banaszak, A.T., Villafañe, V.E., et al., 2020. Anthropogenic Pollution of Aquatic Ecosystems: Emerging Problems with Global Implications. Science of the Total environment. 713, 136586.
[17] Hakeem, K.R., Bhat, R.A., Qadri, H., 2020. Bioremediation and Biotechnology Sustainable Approaches to Pollution Degradation, 1st ed. Springer International Publishing: Cham.
[18] Direction de la recherche et de la planification de l'eau, 2014. Etat de la qualité des ressources en eau au Maroc, année 2009–2012, Available from: http://www.abhatoo.net.ma/maalama-textuelle/developpement-durable/environnement/eau-douce/approvisionnement-en-eau-potable/traitement-de-l-eau/etat-de-la-qualite-des-ressources-en-eau-au-maroc-annee-2009-2012 (cited 19 December 2024).
[19] Craswell, E., 2021. Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. SN Applied Sciences. 3(4), 518.
[20] Srivastav, A.L., 2020. Chemical Fertilizers and Pesticides: Role in Groundwater Contamination. In Agrochemicals Detection, Treatment and Remediation. Butterworth-Heinemann. 143–159.
[21] Sarker, S., Akbor, M.A., Nahar, A., et al., 2021. Level of Pesticides Contamination in the Major River Systems: A Review on South Asian Countries Perspective. Heliyon. 7(6).
[22] Mukate, S.V., Panaskar, D.B., Wagh, V.M., et al., 2020. Understanding the Influence of Industrial and Agricultural Land Uses on Groundwater Quality in Semiarid Region of Solapur, India. Environment, Development and Sustainability. 22, 3207–3238.
[23] Gündoğdu, S., Mihai, F.C., Fischer, E.K., et al., 2023. Micro and Nano Plastics in Groundwater Systems: A Review of Current Knowledge and Future Perspectives. Trac Trends in Analytical Chemistry. 165, 117119.
[24] Silori, R., Shrivastava, V., Singh, A., et al., 2022. Global Groundwater Vulnerability for Pharmaceutical and Personal care products (PPCPs): The Scenario of Second Decade of 21st Century. Journal of Environmental Management. 320, 115703.
[25] Pradhan, B., Chand, S., Rout, P.R., et al. 2023. Emerging Groundwater Contaminants: A Comprehensive Review on Their Health Hazards and Remediation Technologies. Groundwater for Sustainable Development. 20, 100868.
[26] WWAP, 2017. United Nations World Water Assessment Programme, the United Nations World Water Development Report 2017: Wastewater, the Untapped Resource. 22 March 2017.
[27] Karri, R.R., Ravindran, G., Dehghani, M.H., 2021. Wastewater—sources, toxicity, and their consequences to human health. In Soft computing techniques in solid waste and wastewater management (pp. 3–33). Elsevier: Amsterdam.
[28] Singh, P.K., Deshbhratar, P.B., Ramteke, D.S., 2012. Effects of Sewage Wastewater Irrigation on Soil Properties, Crop Yield and Environment. Agricultural Water Management. 103, 100–104.
[29] Waqas, S., Harun, N.Y., Sambudi, N.S., et al., 2023. Effect of Operating Parameters on the Performance of Integrated Fixed-film Activated Sludge for Wastewater Treatment. Membranes. 13 (8), 704.
[30] Harrou, F., Dairi, A., Sun, Y., et al., 2018. Statistical Monitoring of A Wastewater Treatment Plant: A Case Study. Journal of Environmental Management. 223, 807–814.
[31] Aït Hssaine, Ali. 2008. Éléments sur l'hydrologie de la partie atlasique de l'oued Guir (Maroc sud-oriental) et sur l'inondation catastrophique du 10 octobre 2008. Physio Géo. 337–354.
[32] ABHGZR, 2011. Étude de modélisation hydrodynamique du système aquifère du bassin Crétacé Errachidia-Boudnib. 1–15.
[33] Riad, S., 2003. Typology and Hydrological Analysis of Surface Waters Based on Selected Representative Watersheds in Morocco [Doctoral Thesis]. 3rd cycle, joint supervision between the University of Science and Technology of Lille and the University of Ibno Zohr of Agadir. p. 147.
[34] AFNOR, 1983. Association Française de Normalisation: Eaux, méthodes d'essai, 2ème édition. AFNOR, Paris-La Défense. pp. 1–622.
[35] Rodier, J., 1984. L'analyse de l'eau, eaux naturelles, eaux résiduaires, eau de mer: chimie, physico-chimie, bactériologie, biologie. Place of Publication: Paris. 1 vol. (XLVII-1383 p.): ill.; 25 cm.
[36] World Health Organization (WHO), 2008. Guidelines for Drinking Water Qualité, 3rd ed., World Health Or-

ganization: Geneva. p. 668.

[37] Direction de la recherche et de la planification de l'eau, 2014. Préservation de la qualité des ressources en eau et lutte contre la pollution; Valeurs Limites de Rejet à respecter par les déversements (Normes de pollution). Available from: http://www.abhatoo.net.ma/maalama-textuelle/developpement-durable/environnement/eau-douce/deterioration-des-eaux-douces/pollution-de-l-eau/preservation-de-la-qualite-des-ressources-en-eau-et-lutte-contre-la-pollution-valeurs-limites-de-rejet-a-respecter-par-les-deversements-normes-de-pollution (cited 19 December 2024).

[38] Gupta, P., Singh, J., Verma, S., et al., 2021. Impact of climate change and water quality degradation on food security and agriculture. In Water Conservation in the Era of Global Climate Change (pp. 1–22). Elsevier: Amsterdam.

[39] Dahm, C.N., Candelaria-Ley, R.I., Reale, C.S., et al., 2015. Extreme Water Quality Degradation Following A Catastrophic Forest Fire. Freshwater Biology. 60(12), 2584–2599.

[40] Saalidong, B.M., Aram, S.A., Otu, S., et al., 2022. Examining the Dynamics of the Relationship between Water pH and Other Water Quality Parameters in Ground and Surface Water Systems. Plos one. 17(1), e0262117.

[41] Senarathne, S., Jayawardana, J.M.C.K., Edirisinghe, E.A.N.V., et al., 2021. Geochemical and Isotope Evidence for Groundwater Mineralization in A Semi-arid River Basin, Sri Lanka. Applied Geochemistry. 124, 104799.

[42] Modibo Sidibé, A., Lin, X., Koné, S., 2019. Assessing Groundwater Mineralization Process, Quality, and Isotopic Recharge Origin in the Sahel Region in Africa. Water. 11(4), 789.

[43] Fadili, A., Najib, S., Mehdi, K., et al., 2016. Hydrochemical Features and Mineralization Processes in Coastal Groundwater of Oualidia, Morocco. Journal of African Earth Sciences. 116, 233–247.

[44] Nkot, S.N.B., Tandia, B.K., Ndje, Y., et al., 2015. Origin of Mineralization of Groundwater in the Tongo Bassa Watershed (Douala-Cameroon). Research Journal of Environmental and Earth Sciences. 7(2), 29–41.

[45] Zhang, Z., He, W., Shen, J., et al., 2019. The Driving Forces of Point Source Wastewater Emission: Case Study of COD and NH4-N Discharges in Mainland China. International Journal of Environmental Research and Public Health. 16(14), 2556.

[46] Garzon-Vidueira, R., Rial-Otero, R., Garcia-Nocelo, M.L., et al., 2020. Identification of Nitrates Origin in Limia River Basin and Pollution-determinant Factors. Agriculture, Ecosystems and Environment. 290, 106775.

[47] Malago, J., Makoba, E., Muzuka, A.N., 2017. Fluoride Levels in Surface and Groundwater in Africa: A Review. American Journal of Water Science and Engineering. 3(1), 1–17.

[48] Vithanage, M., Bhattacharya, P., 2015. Fluoride in the Environment: Sources, Distribution and Defluoridation. Environmental Chemistry Letters. 13, 131–147.

[49] World Health Organization (WHO), 2016. Protecting Surface Water for Health: Identifying, Assessing and Managing Drinking-water Quality Risks in Surface-water Catchments.

[50] Mokarram, M., Saber, A., Sheykhi, V., 2020. Effects of Heavy Metal Contamination on River Water Quality due to Release of Industrial Effluents. Journal of Cleaner Production. 277, 123380.

[51] Tytła, M., 2019. Assessment of Heavy Metal Pollution and Potential Ecological Risk in Sewage Sludge from Municipal Wastewater Treatment Plant Located in the Most Industrialized Region in Poland—Case Study. International Journal of Environmental Research and Public Health. 16(13), 2430.

[52] Vardhan, K.H., Kumar, P.S., Panda, R.C., 2019. A Review on Heavy Metal Pollution, Toxicity and Remedial Measures: Current Trends and Future Perspectives. Journal of Molecular Liquids. 290, 111197.

[53] Nouayti, N., Nouayti, A., Khattach, D., et al., 2020. Characterization of the Mineralization of the Groundwater in the High Basin of Guir (Morocco) by Geochemical and Geostatistical Methods. E3S Web of Conferences 150, 01003 (2020). The Seventh International Congress "Water, Waste and Environment" (EDE7-2019).