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Water Quality Assessment Using the Water Quality Index, and Geographic Information Systems in Nador Canal, Morocco

Driss Hammoumi[1], Hefdhallah S. Al-Aizari[2*], Zaid Alkhawlani[3], Saïd Chakiri[1], Zohra Bejjaji[1]

[1] *Laboratory of Geosciences, Department of Geology, Faculty of Science, Ibn Tofail University, Kenitra, BP 133, Morocco*

[2] *Department of Chemistry, Faculty of Education, Dhamar University, Dhamar, PO Box 87246, Yemen*

[3] *Laboratory of Research in Informatics (LaRI), Faculty of Science, Ibn Tofail University, BP 133, Kenitra, Morocco*

ABSTRACT

In recent decades, water pollution has emerged as a significant concern, posing a threat to both humans and natural ecosystems. This study aimed to assess the spatial variations in water quality in the Nador Canal, Morocco using the water quality index combined with multivariate statistical techniques and geographic information systems (GIS). The parameters examined were then compared to the maximum permissible limit values recommended by Moroccan surface water standards and the World Health Organization. The results indicated that the WQI of Nador Canal is generally suitable for irrigation and unsuitable for drinking. It indicated that the quality of surface water in the Nador Canal is affected by organic pollutants, and this is evidenced by low levels of dissolved oxygen, the levels of elements were high, especially chlorine and sodium, in addition to a high concentration of ammonia, nitrate, and phosphate in some of the stations studied. Principal component analysis (PCA) results revealed that PC1–PC3 collectively accounted for 73% of the variation in surface water quality within the study area. The cluster analysis also proves that the water quality is relatively polluted. Potential contributing factors to surface water pollution include changes in the hydrological regime, household waste discharges, and agricultural activities. These findings furnish essential insights into water quality, particularly its suitability for irrigation, and contribute to enhancing the water quality management system of the Nador Canal in the Gharb region of Morocco.

Keywords: Samples; Water quality index; Surface water; GIS

*CORRESPONDING AUTHOR:
Hefdhallah S. Al-Aizari, Department of Chemistry, Faculty of Education, Dhamar University, Dhamar, PO Box 87246, Yemen; Email: alaizari2@gmail.com

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1. Introduction

Ensuring the quality of surface water is a matter of paramount importance in numerous countries due to its direct link to drinking water and its profound impact on human and environmental well-being. Surface water, encompassing rivers, lakes, and streams, serves as a vital source for many communities drinking water needs. Any contamination or degradation of its quality can pose significant health risks to humans and disrupt ecosystems [1,2]. Surface water quality is exceptionally sensitive to changes and pollution, as even minor alterations can result in harmful consequences. Polluted surface water can lead to unsafe drinking water, affecting human health and ecosystems. Therefore, regular assessment and monitoring of surface water quality are imperative. This ongoing evaluation is essential to detect pollution, ensure safe drinking water supplies, and protect the health of aquatic life. In summary, maintaining the purity of surface water is vital to safeguarding public health and the environment, necessitating diligent and continuous quality assessment and management [3,4]. Human activities often lead to the pollution and deterioration of surface water quality, diminishing its suitability for a range of vital purposes, including industry, agriculture, recreation, and more. Pollutants from sources like industrial discharge and agricultural runoff can contaminate these water bodies, making them unsuitable for use in industrial processes and irrigation, thereby affecting productivity. Furthermore, recreational activities like swimming and boating may become unsafe due to polluted water. These adverse effects underscore the need to manage human activities and their impact on surface water to ensure its continued viability for various applications while safeguarding both the environment and public health [5,6].

Morocco's water resources are increasingly at risk due to human activities, primarily linked to agriculture. The widespread use of fertilizers and pesticides in farming, while beneficial for crop production, is causing water contamination. These chemicals can infiltrate the soil, eventually reaching and polluting water sources. As a result, the quality and safety of water for various purposes, including drinking and irrigation, are compromised. The Nador Canal is situated in the western plain of northwestern Morocco, cutting across an agricultural region deeply influenced by both human and agricultural activities. Furthermore, it serves as a common disposal site for agricultural waste generated by nearby residents, with the Esbou River also flowing into it. This canal passes through an area teeming with agricultural and human endeavors. The accumulation of agricultural waste, along with the inflow of the Esbou River, poses potential risks to water quality, ecosystem well-being, and overall environmental sustainability. Hence, the imperative lies in closely monitoring water quality, implementing measures to prevent pollution, and ensuring the preservation and protection of this vital resource from contamination.

Many studies have employed the Water Quality Index (WQI) method to assess water suitability for irrigation. Utilizing standard criteria for water characterization, the Water Quality Index is recognized as a crucial tool for classifying surface water. It provides an overarching perspective on water usage and quality. The WQI utilizes a mathematical formula to condense extensive water data into a single numerical value [7–12].

GIS and multivariate statistical methods are gaining prominence in enhancing our comprehension of water quality and ecological conditions. Given their capacity to handle extensive datasets spanning both geography and time across multiple monitoring locations. Within the realm of scientific research, various statistical techniques, such as principal component analysis (PCA) and, cluster analysis (CA), have been applied to these investigations. These methods are well-suited for assessing temporal and spatial variations in water quality and identifying potential sources of water contamination [7,10,12,13].

In Morocco, Several studies have recently been conducted on the sources of pollution in many rivers, which indicate the deterioration of water quality due to various human activities [14–23]. CA, PCA, FA, and DA were used to assess temporal/spatial differences in surface water quality, identify potential sources of pollution, and assemble river monitoring stations. PCA and CA are utilized to group testing locales and recognize the wellspring of likely tainting. The vast majority of the investigations showed that the factual strategies of PCA and CA are significant apparatuses for deciding the fundamental connections between water quality principles, distinguishing contamination sources, and gathering comparative observing stations into bunches with comparative attributes [24–31]. This study aimed to assess the spatial variations in water quality in the Nador Canal, Morocco using the water quality index (WQI) and combined with multivariate statistical techniques and geographic information systems (GIS).

2. Materials and methods

2.1 Study area location

The Nador Canal is situated at the northwestern end of Sahel al-Gharb, just south of the village of Marja al-Zarqa in the coastal region of Moulay Bousselham (**Figure 1**). It is located 70 km north of the city of Kenitra and 35 km south of Larache, extending until Sidi Allal al-Tazi, which is part of the Kenitra province [20]. The annual rainfall in the area varies between 200 mm and 400 mm, averaging 320 mm. The region receives effective rainfall for seven months, from October to April, and endures a hot and dry season lasting five months, from March to November. The average highest temperature recorded is 27 °C, while the average lowest is 21 °C. The geological features of the study area are linked to the Rharb Basin, located between two major structural regions: the Meseta and the Rif. Tectonic instabilities, triggered by geophysical events, have caused subsidence that contributed to the basin's formation. Throughout the Tertiary period, the basin was predominantly formed by the deposition of marine sediments, such as marl and sand. During the Quaternary period, further geological developments occurred [32].

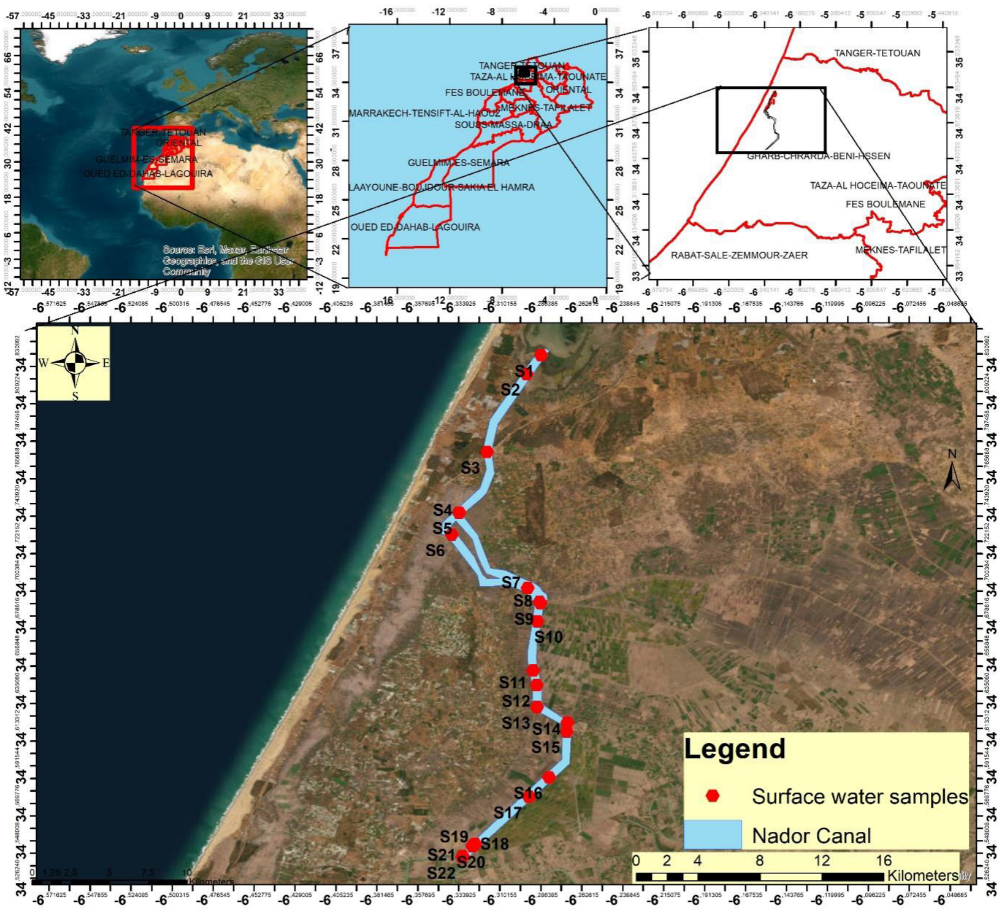

Figure 1. The study area is in Nador Canal, Morocco.

2.2 Water sample collection

In the summer of 2022, 44 of surface water samples were collected from 22 stations along the Nador channel, each at a depth of fifty centimeters. This depth was chosen as representative of the entire channel. All samples were carefully collected in dry polyethylene bottles and were then transported to the laboratory, maintained at a temperature of 4 °C. All samples were taken from the Nador Canal, which passes through areas with agricultural activities.

2.3 Physicochemical analysis of surface water samples

The physicochemical parameters of water samples were obtained utilizing the Rodier techniques, as outlined in the guidelines provided by WHO [33]. The pH value was determined employing a pH meter (WTW Inolab), while electrical conductivity (EC) was assessed using a conductivity meter (Thermo ORION 3 STAR). The levels of magnesium (Mg^{2+}) and calcium (Ca^{2+}) were ascertained through complexometric titration using EDTA. potassium (K^+) and Sodium (Na^+) concentrations were measured employing a flame photometer (JENWAY PFP7). Chlorides (Cl^-) were measured through a titration process with silver nitrate in the presence of a potassium chromate solution. Sulfates (SO_4^{2-}) were assessed using a spectrophotometer (V-1100). The determination of nitrate (NO_3^-) and ammonium (NH_4^+) involved a distillation procedure with the inclusion of specific catalysts, notably magnesium oxide and a DEVA GDR alloy. The NH_4^+ was subsequently captured in a boric acid solution and then measured by titration with H_2SO_4, utilizing the east distillation apparatus (VELP Scientifica, UK).

2.4 Determination of water quality index

The WQI is widely recognized as an effective way to provide a comprehensive assessment of water quality by combining various water quality parameters into a singular, dimensionless numerical value. It offers an effective way to condense various water quality parameters into a single numerical representation, making it easier to interpret water quality [34,35]. The WQI was initially proposed by Horton, primarily for the evaluation of drinking water quality. This concept has since been widely applied to water quality assessment, as demonstrated by studies such as those by Brown et al [36]. Furthermore, an alternative WQI methodology was proposed by Pesce and Wunderlin [37], which has gained significant recognition among researchers. Different countries have also devised their versions of WQIs, including the Florida Stream Water Quality Index (FWQI), the National Sanitation Foundation Water Quality Index (NSFWQI) in the USA, the British Columbia Water Quality Index (BCWQI) in the United Kingdom, the Canadian Water Quality Index (CWQI) [38], and the Oregon Water Quality Index (OWQI) as detailed by Cude (2001) [39].

The WQI is established through chemical assessments of the Nador Canal surface water. Typically, the generation of the WQI involves a four-step process that takes into account numerous parameters. These parameters include the weighting (wi) of thirteen factors. Specifically, the parameters under consideration include pH, electrical conductivity (EC in s/cm), turbidity (TUR), bicarbonate (HCO_3^-), dissolved oxygen (DO), potassium (K^+), sodium (Na^+), chloride (Cl^-), sulfate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and nitrate (NO_3^-) as presented in **Table 1**. To determine the WQI parameter, three equations are required, with the initial equation involving the computation of relative weight as follows [37]:

First, the relative weight (Wi) is computed as equation (1):

$$Wi = \Sigma(wi) / n \tag{1}$$

Where wi represents the weights assigned to each parameter, Wi represents the relative weight, and n is the total number of parameters (**Table 1**).

Next, the quality rating scale (qi) for each parameter is determined as equation (2):

$$qi = (Ci / Si) * 100 \tag{2}$$

Where qi represents the quality rating scale for a specific parameter, Ci represents the measured concentration of that parameter (**Tables 2 and 3**), and Si represents the standard limits for that parameter.

The sub-quality index (SIi) for each parameter is calculated by multiplying the quality rating (qi) by its relative weight (Wi) as equation (3):

$$SIi = Wi * qi \tag{3}$$

Finally, the overall WQI is determined by summing the sub-quality indices for all parameters as equation (4):

$$WQI = \Sigma(SIi) \text{ from } i=1 \text{ to } n \tag{4}$$

This series of equations (1–4) provides a comprehensive framework for calculating the WQI based on various parameters and their relative importance.

2.5 Data processing and statistical analysis

Statistical analysis was done using the Statistical Package for the Social Sciences (Minitab version 2020). The spatial and reverse data of the data were performed by ArcGIS (10.8) by IDW which includes a specific spatial geographical analysis technique known as the reverse distance weight (IDW). The application of principal components analysis (PCA) aimed to discern correlations among surface water parameters, as well as correlations among various sampling sites. This statistical analysis facilitates the identification of connections between intricate quantitative data and the relationships among different parameters [25]. Correlation analysis is a frequently utilized technique for evaluating the association between two variables. It commonly utilizes the simple correlation coefficient to quantify the predictive ability of one variable with the other. This coefficient serves as a measure to assess the extent of correlation between two variables, especially when one (independent variable 'y') predominantly influences the other (dependent variable 'x'), and vice versa [30].

3. Results and discussion

3.1 Physicochemical characteristics of water samples collected from Nador Canal

The results of the analyses encompass the physical and chemical parameters of Nador Canal water and are presented in **Table 2** with a basic statistical summary.

Table 1. Relative weight (RW) of each parameter.

Chemical parameter	WHO and MSWQ standards	Weight (wi)	Relative weight (Wi)
			WI = ∑ni=1 wi
pH	6.5–8.5*	4	0.108
Electrical conductivity (µs.cm $^{-1)}$	750*	4	0.108
Dissolved oxygen(mg. L^{-1})	7*	4	0.108
Calcium(mg. L^{-1})	75**	2	0.054
Magnesium(mg. L^{-1})	45**	1	0.027
Sodium(mg. L^{-1})	200**	2	0.054
Potassium(mg. L^{-1})	12**	2	0.054
Bicarbonate(mg. L^{-1})	0.1*	3	0.081
Chloride(mg. L^{-1})	200*	3	0.081
Sulphate(mg. L^{-1})	100*	4	0.108
Nitrate(mg. L^{-1})	10*	5	0.135
Phosphate(mg. L^{-1})	0.1*	3	0.081
Total	-	37	1.000

Note: Moroccan surface water quality (MSWQ) *; World Health Organization (WHO, 2011) **

Table 2. Statistical summary of the physicochemical parameters of the Nador Canal water.

Variable	Unit	Minimum	Maximum	Mean	Standard deviation
T	-	27.00	39.00	29.92	3.03
PH	-	7.79	8.72	8.10	0.20
EC	µS/cm	960.00	2720.00	1849.55	507.84
TUR	-	33.15	221.00	112.32	55.80
DO	-	1.00	2.82	1.85	0.45
HCO_3^-	mg/L	94.7	531.2	362.18	217.20
SO_4^{2-}	mg/L	68.18	133.65	102.90	21.11
Cl^-	mg/L	184.35	907.59	537.59	204.70
NO_3^-	mg/L	0.27	37.90	5.04	7.78
Ca^{2+}	mg/l	50.78	111.77	79.55	17.34
Mg^{2+}	mg/L	21.10	45.10	34.66	7.17
K^+	mg/L	3.10	5.79	4.13	0.69
Na^+	mg/L	122.05	343.90	239.62	64.00
NH_4^+	mg/L	0.23	0.62	0.30	0.08
PO_4^{3-}	mg/L	0.2	1.97	0.14	0.4
WQI	-	85.26	248.43	135.56	37.64

The pH values in the Nador Canal ranged from 7.79 to 8.72, (**Figure 2a**). It indicates alkaline water influenced by tributary inflow and organic decomposition. This classifies the water as excellent to good for irrigation as per Moroccan standards, though one station showed moderate pollution. pH levels significantly impact water quality and usability [40,41]. The correlation analysis of pH reveals a strong negative correlation between pH and most of the parameters, except for nitrates, phosphates, turbidity, and bicarbonates (**Table 3**). The water temperature values (**Figure 2b**) varied from 27 to 39 °C. The increase in temperature during the summer period can be attributed to an increase in air temperature. The temperature is high in most of the sampled sites, which suggests that there is a general trend of elevated temperatures in those areas. This observation could be due to various factors, such as geographic location, climate, time of the year, or local weather patterns. The daily thermal regime is influenced by various weather conditions, including climate, sunlight, and more. Water temperature plays a crucial role in enhancing chemical activity, bacterial activity, and water evaporation [15,40]. Dissolved oxygen measurements obtained from water samples in the Nador Canal ranged between 1 and 2.82 mg/L (**Figure 3a**). According to Moroccan standards, all samples indicated low levels of dissolved oxygen at all locations in the Nador Canal, suggesting pollution. The optimal dissolved oxygen value for good water quality is 4 to 6 mg/L dissolved oxygen, to ensure healthy aquatic life in the water [28]. The turbidity values (**Figure 3b**) for the water samples ranged from 33 to 210 NTU. Turbidity values can vary greatly depending on bodies of water and current conditions. For example, a clear mountain stream may have a turbidity of about 1 TFU, while a large river may have a turbidity of about 10 TFU in dry weather, which can increase dramatically during runoff events. Regular monitoring of turbidity is crucial in understanding and managing the quality of water bodies [42]. The (EC) of surface water in the study ranged from 962 to 2720 µS/cm, (**Figure 3c**). Although these values stay within the Moroccan permissible limit of 2,700 µS/cm, an increase in ion content from pollutants like agricultural residues and sewage waste has been observed. EC is pivotal as it measures the water's ability to conduct electricity, indicating mineralization levels. This parameter is essential for assessing the presence of dissolved salts such as chlorides, sulfates, calcium, sodium, magnesium, bicarbonate, and potassium. High EC values can signal elevated levels of dissolved solids and potential contamination in surface waters [43].

Concentrations of bicarbonate (HCO_3^-) in water samples varied from 94.7 to 531.2 mg/L, (**Table 1** and **Figure 4a**). Most samples remained within the Moroccan standard of 400 mg/L, though levels at five stations approached this upper limit. Bicarbonates enhance the alkalinity and buffering capacity of water. This is likely due to the absence of carbonate-rich rocks, such as crystalline limestone, dolomite limestone, calcareous granite, and caliche (a lime-rich layer overlying carbonate rocks), which are major contributors to carbonate weathering. The concentration of sulfate (SO_4^{2-}) ranged from 36.18 to 133.57 mg/L. Consequently, all the values observed at the sample sites meet the Moroccan standards (250 mg/L) as displayed in **Table 1** and **Figure 4b**. The primary origins of sulfate stem from the breakdown of

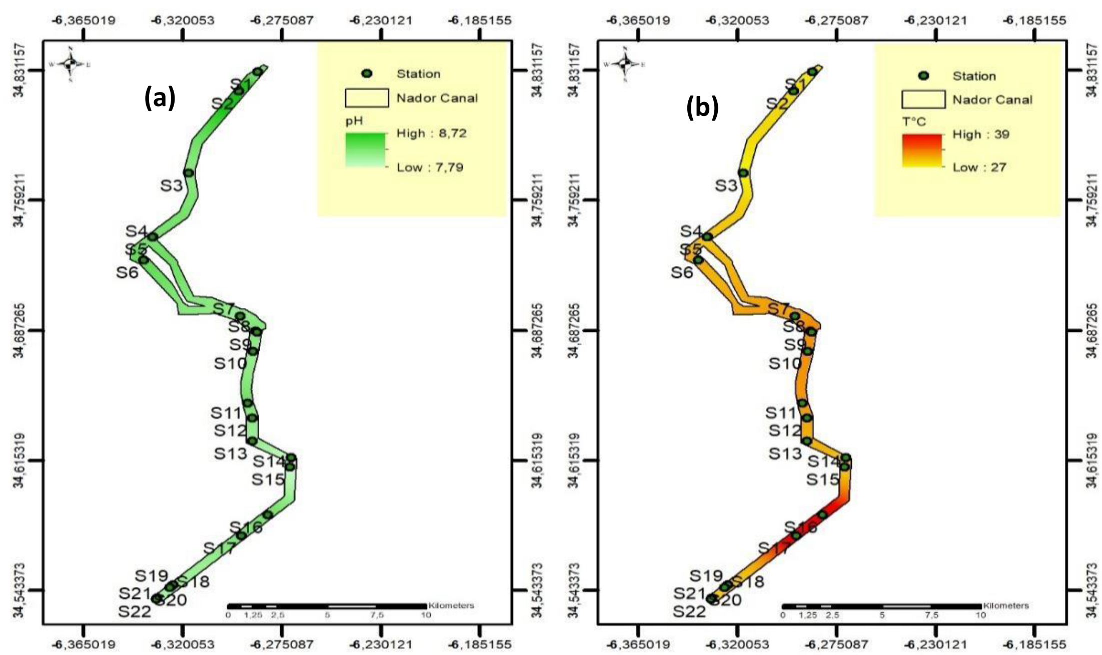

Figure 2. The spatial distribution of pH (**a**) and temperature, T (**b**) in Nador Canal, Morocco.

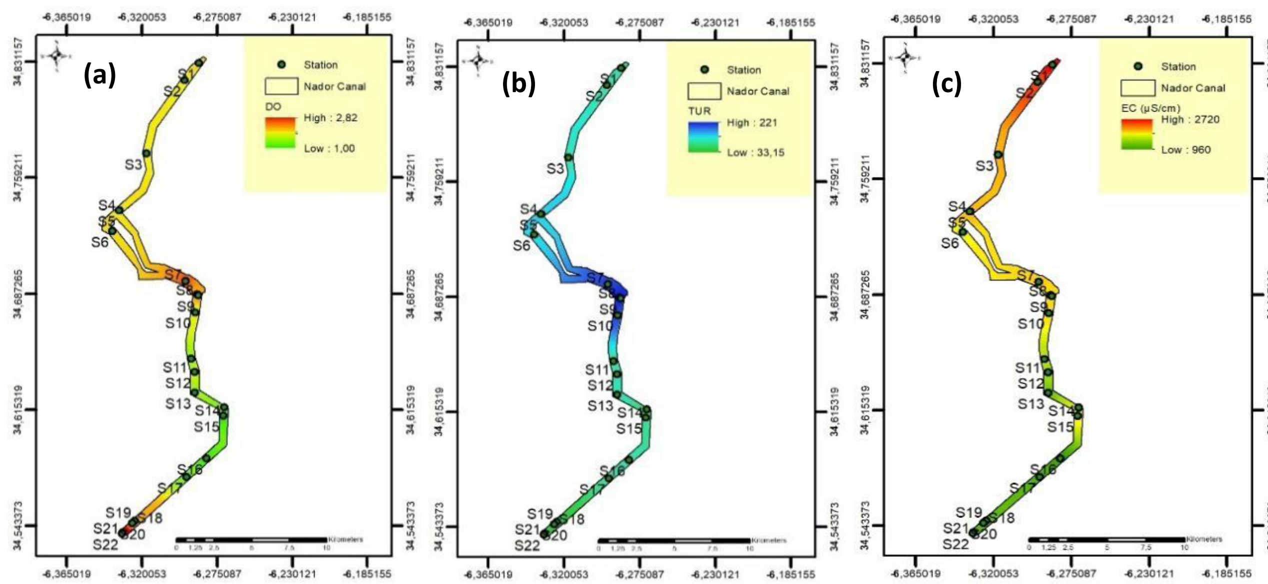

Figure 3. Spatial variation of dissolved oxygen, DO (**a**), turbidity, TUR (**b**), and electrical conductivity, EC (**c**) in Nador Canal, Morocco.

organic matter in the soil, the use of fertilizers containing sulfates, and the microbial oxidation of sulfur compounds [44]. The chloride (Cl^-) concentration in Nador Canal water showed a variation ranging from 184.3 to 907.6 mg/L (**Table 1** and **Figure 4c**). The highest chloride levels were recorded in most sites. High chloride concentration in the Nador Canal is due to the discharge of domestic water and sewage, as well as human activities, agricultural waste, and excessive use of fertilizers. The typical nitrate concentration in surface water is low, but there is the potential for it to increase due to leaching from agricultural land [45]. The concentrations of nitrate (NO_3^-) ranged between 0.28 and 37.09 mg/L (**Figure 4d**). The highest concentration of nitrate was at the end of the Nador Canal according the Moroccan standards, and this indicates the accumulation of agricultural and human waste in this location. The presence of nitrates and phosphates in surface waters results primarily from human-related activities, including improper waste disposal, the presence of sanitary landfills, overuse of fertilizers, and inadequate manure management practices, among others.

The concentrations of calcium (Ca^{2+}) varied from 50.78 to 111.77 mg/L in the study area. The highest concentration of calcium was measured at location S17. This value exceeded the Standard limit (**Figure 5a**). The concentrations of magnesium ranged from 21.1 to 45.1 mg/L (**Figure 5b**). The concentrations of sodium (Na^+) varied from 122 to 343.9 mg/L

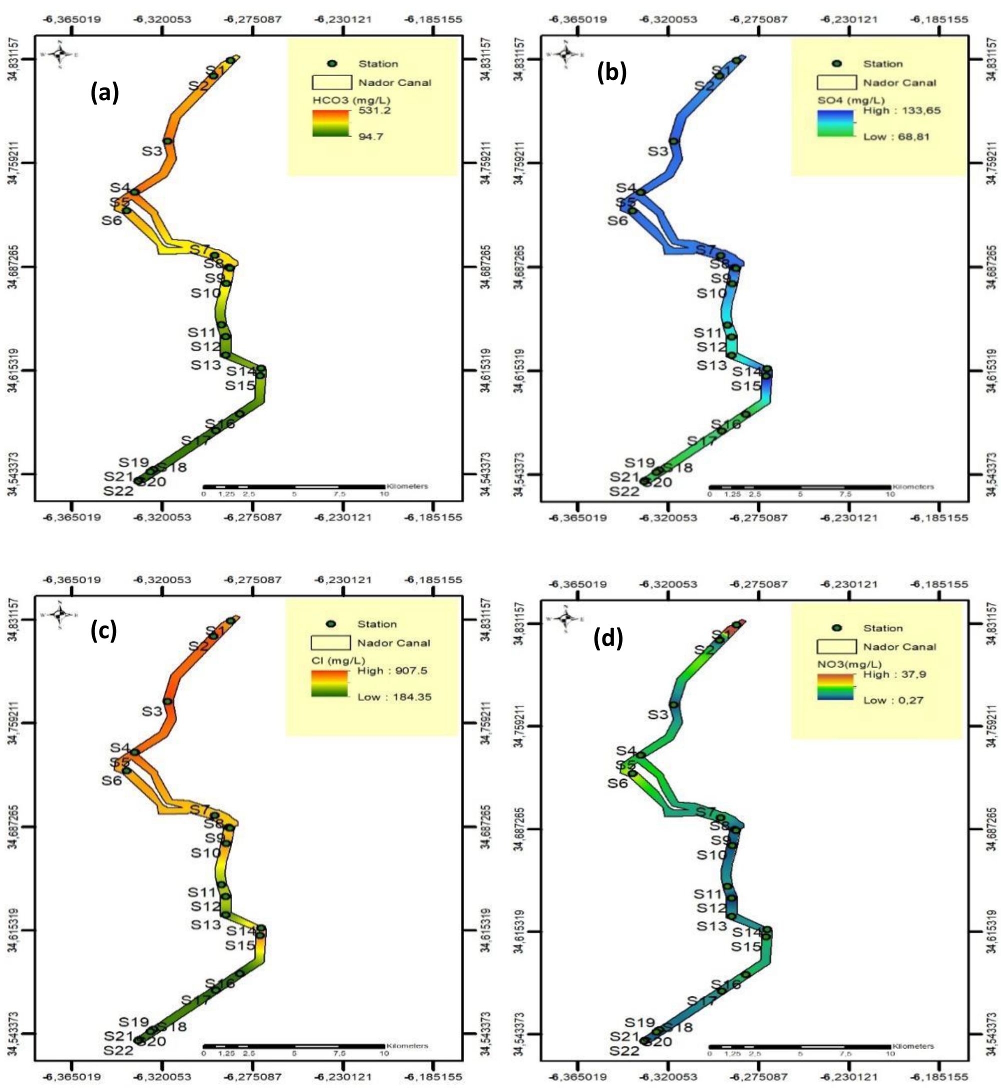

Figure 4. The spatial distribution of bicarbonate, HCO_3^- (**a**), sulfate, SO_4^{2-} (**b**), chloride, Cl^- (**c**), and nitrate, NO_3^- (**d**) in Nador Canal, Morocco.

in the study area (**Figure 5c**). According to WHO standards, the highest Na concentrations were observed in locations S1 to S15. The primary sources of Na^+ in surface water typically include geological weathering of sodium-containing rocks, agricultural run-off from sodium-based fertilizers, industrial discharges, and wastewater effluents. The concentration of potassium (K^+) in water samples was between 3.1 and 5.79 in the study area (**Table 2**), (**Figure 5d**). The concentration of ammonia (NH_4^+) ranged from 0.9 to 7.02 mg/L (**Figure 5e**). According to Moroccan standards, all samples were within the permissible. Ammonia, a gaseous substance that can dissolve in water when found in significant quantities can be indicative of contamination from sources, such as emissions from human activities, industrial facilities (including chemical industries, nitrogen fertilizer production, coking plants, ice factories, and textile manufacturing [44]. The concentration of phosphate (PO_4^{3-}) was from 0.02 to 1.97 mg/L, which indicates the absence of human activities in the region.

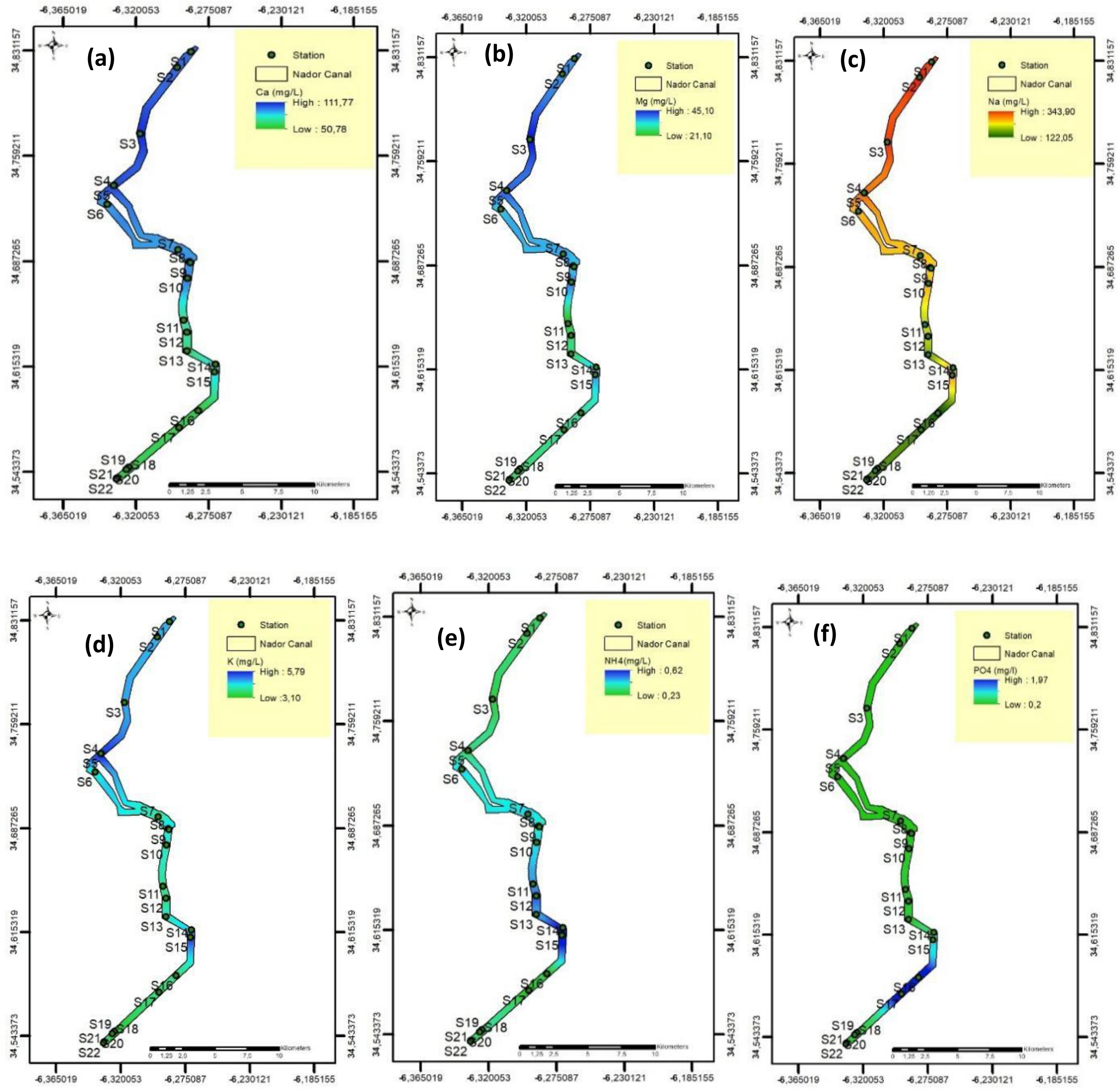

Figure 5. The spatial distribution of calcium, Ca^{2+} (**a**), magnesium, Mg^{2+} (**b**), sodium, Na^+ (**c**), potassium, K^+ (**d**), ammonium, NH_4^+ (**e**), and PO_4^{3-}(**f**) in Nador Canal, Morocco.

3.2 Multivariate analysis

Correlation analysis

Table 3 presents the correlation values obtained at all well points. The relationship between the variables becomes stronger the closer the value is to 1. The matrix indicates the strong correlation between the following variables: To obtained results indicate a very strong positive correlation between Ca^{2+} with Mg^{2+}, Na^{+}, Cl^{-}, K^{+}, and SO_4^{2-}. also very positive correlation between Mg^{2+} with Na^{+}, Cl^{-}, K^{+}, and SO_4^{2-}. also between Na with Cl^{-} and SO_4^{2-}. also Cl^{-} with SO_4^{2-}. Other elements such as TUR, NH_4^{+}, and PO_4^{2-} show moderate positive correlation. While pH, DO, HCO_3^{-}. and T show weak and very weak positive correlations with all parameters and weak and negative correlations with other parameters.

Principle component analysis

Multivariate is a (PCA) for quantitative data analysis. Multivariate analysis has been developed by many different disciplines. There are major multivariate methods among which are (PCA) which we will use in this study. The objective of PCA is to extract brief and important information from a large amount of data. **Table 4** shows the results of the principal component analysis of surface water quality in the study area. (PCA) was performed on a data matrix consisting of Twenty-two stations and sixteen variables. Three principal components extracted eigenvalues that were more than 1 that explained nearly 73.4% of the cumulative data in the hydroponic data set (**Table 4** and **Figure 6a**). It is evident that PC1 dominantly contains Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, NO_3^{-}, and PO_4^{2-}.The variables are exclusively hadrochemical in nature and are believed to have their origins in geological processes. signifying geogenic sources. PC2 contains T, HCO_3^{-}, DO as dominant variables. and PC3 contains pH, NH_4^{+} and SO_4^{2-}as dominant. PC1 of the samples is primarily characterized by high values of acidity, Alkalinity, hardness, and Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, Cl^{-}, NO_3^{-}, and PO_4^{2-}. These variables are distinctly hadrochemical in nature and are attributed to geogenic sources. likely originating from geological processes. (**Figure 6b**) illustrates the mineralization processes. depicting the enrichment of groundwater with sodium (Na) and chloride (Cl) ions in the initial scenario. Over time, the chlorides present in the Nador canal could originate from diverse channels, such as leaching from sedimentary soils, the infiltration of saltwater. the discharge of domestic and agricultural waste, rock alteration, and so on.

Table 3. Correlation between all parameters.

	T	PH	HCO_3	DO	NH_4^+	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	NO_3^-	SO_4^{2-}	PO_4^{2-}
T	1												
PH	0.15	1											
HCO_3	0.1	–0.12	1										
DO	–0.4	0.07	0.25	1									
NH_4	–0.18	–0.37	–0.06	–0.48	1								
Ca^{2+}	–0.37	0.26	–0.57	–0.09	0.08	1							
Mg^{2+}	–0.43	0.07	–0.58	–0.27	0.39	0.92	1						
K^+	–0.31	0.11	–0.43	–0.22	0.5	0.74	0.77	1					
Na^+	–0.43	0.19	–0.58	–0.2	0.28	0.96	0.98	0.79	1				
Cl^-	–0.4	0.22	–0.62	–0.16	0.25	0.97	0.96	0.81	0.99	1			
NO_3^-	–0.12	0.11	–0.18	0.04	–0.08	0.26	0.23	0.24	0.26	0.21	1		
SO_4^{2-}	–0.31	0.22	–0.41	–0.2	0.38	0.79	0.84	0.76	0.81	0.81	0.18	1	
PO_4^{2-}	0.66	0.08	–0.28	–0.25	–0.02	–0.33	–0.36	–0.12	–0.35	–0.27	0.02	–0.32	1

Table 4. Rotated matrix of components for chemical data from the stations.

Variable	PC1	PC2	PC3
T	–0.162	0.561	0.079
PH	0.07	0.13	0.528
HCO_3	0.213	0.291	0.197
DO	–0.241	–0.278	–0.113
NH_4^+	–0.09	–0.466	0.365
Ca^{2+}	0.134	0.047	–0.655
Mg^{2+}	0.373	–0.025	0.173
K^+	0.386	–0.019	–0.066
Na^+	0.326	0.011	–0.16
Cl^-	0.386	–0.035	0.026
NO_3^-	0.384	–0.005	0.061
SO_4^{2-}	0.104	–0.026	0.188
PO_4^{2-}	0.348	0.003	–0.028
Valeur propre	6.4615	2.0909	1.7288
Proportion	0.462	0.149	0.123
Cumulative	0.462	0.611	0.734

The Cluster analysis of wells on the basis of the physico-chemical quality of the water from the sources has allowed us made it possible to distinguish three groups of stations (**Figures 7 and 8**): Group 1: This group is made up of 11 stations S1, S2, S3, S4, S5, S6, S7, S8, S9, S10 and S15 which provide water of physical and chemical quality characterized by high levels of T, NH_4^+ and PO_4^-. This can be explained by human and agricultural activities around this water point. Temperatures rise in this case due to summer weather. Group 2: This group is made up of 8 stations: S22, S21, S20, S19, S18, S17, S13. The water is characterized by an average physical and chemical quality. while the water from these stations is very rich in NO_3^-. Cl^- and Na^+ ions. Group 3: This group is composed of 3 terminals S14, S12, and S11 and contains DO TNH_4^+, PO_4^{2-}. This results in water of poor physical and chemical quality, particularly with low dissolved oxygen levels, and low DO threatens the life of aquatic organisms present in the water.

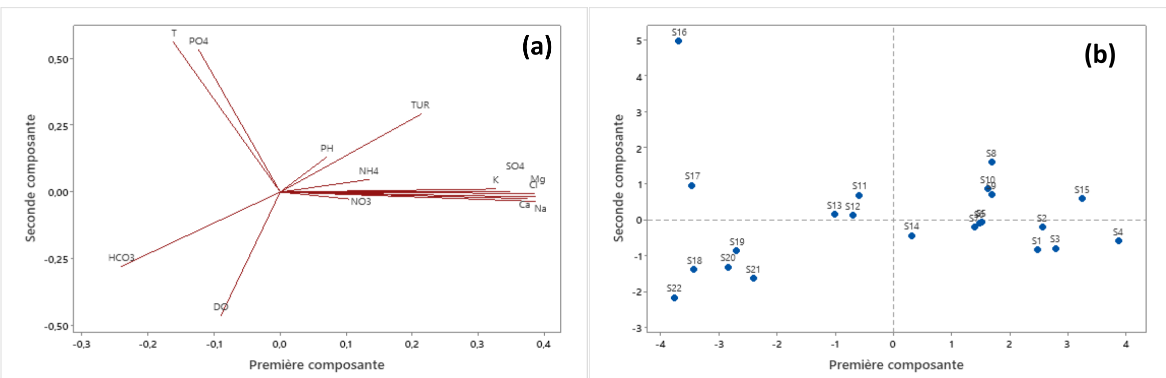

Figure 6. PCA loadings of parameters of the PC1/PC2 (**a**) and PCA loadings of Stations axes (PC1–PC2) (**b**).

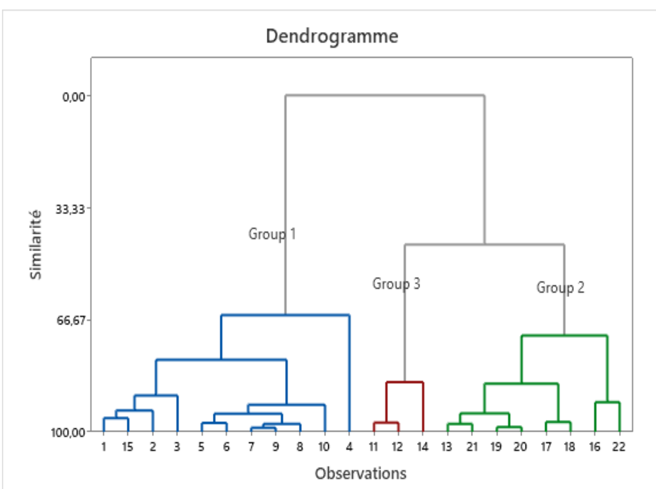

Figure 7. The Cluster analysis of wells.

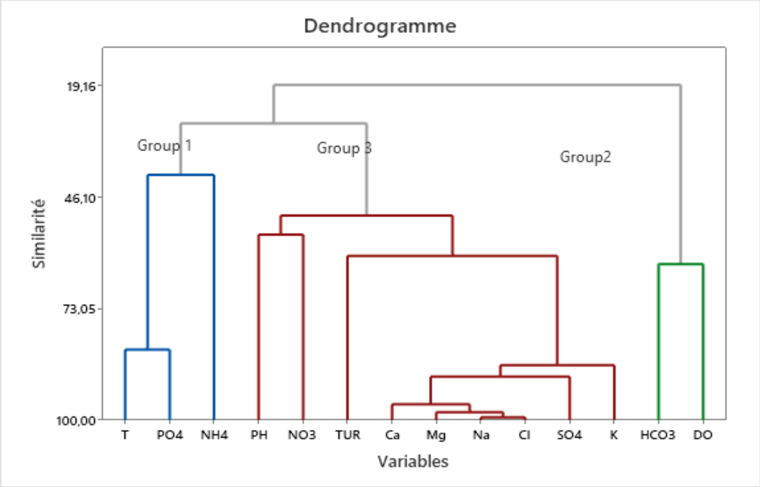

Figure 8. The cluster analysis of parameters.

3.3 Water quality assessment using water quality index (WQI)

WQI values can be categorized as follows: excellent water (25), good water (25 to 50), poor water (50 to 75), very poor water (75 to 100), and unsuitable water (> 100) [46]. **Table 5** shows the computed WQI values for surface water samples in Nador Canal. Water quality index values ranged between 85.26 and 248.43 with an average of 135.5. Based on this WQI rating, all stations are non-potable. While it is suitable for agricultural purposes (**Figure 9**). The elevated values of the WQI are primarily attributed to factors including the excessive use of fertilizers, the disposal of agricultural waste into the canal (as it is situated in an agricultural area), sewage leakage from adjacent areas, and the impact of rain, which plays a significant role in transporting and accumulating waste in the canal, contributing to its pollution (**Table 5**). The occurrence may result from factors such as ion discharge, coastal zone development, seawater intrusion, agricultural input contamination, human waste, or sewage from homes and septic tanks, among other causes [47]. Additionally, this phenomenon is linked to rock salt, as gypsum-containing rock formations are prone to infiltration and dissolution due to the aforementioned factors [48–50].

Table 5. Type of water quality using water quality index (WQI).

Station	WQI	Type of water		Station	WQI	Type of water	
		Drinking	**Irrigation**			**Drinking**	**Irrigation**
S1	183.877532	Unsuitable	suitable	S12	116.403954	Unsuitable	suitable
S2	144.946131	Unsuitable	suitable	S13	110.159732	Unsuitable	suitable
S3	145.660099	Unsuitable	suitable	S14	130.087517	Unsuitable	suitable
S4	155.214084	Unsuitable	suitable	S15	184.711444	Unsuitable	suitable
S5	139.596366	Unsuitable	suitable	S16	248.432254	Unsuitable	suitable
S6	144.832974	Unsuitable	suitable	S17	91.2106243	Very poor	suitable
S7	134.165312	Unsuitable	suitable	S18	95.4747257	Very poor	suitable
S8	132.232116	Unsuitable	suitable	S19	100.897309	Unsuitable	suitable
S9	129.307892	Unsuitable	suitable	S20	94.9760507	Very poor	suitable
S10	139.396099	Unsuitable	suitable	S21	104.643384	Unsuitable	suitable
S11	108.226236	Unsuitable	suitable	S22	85.2617079	Very poor	suitable

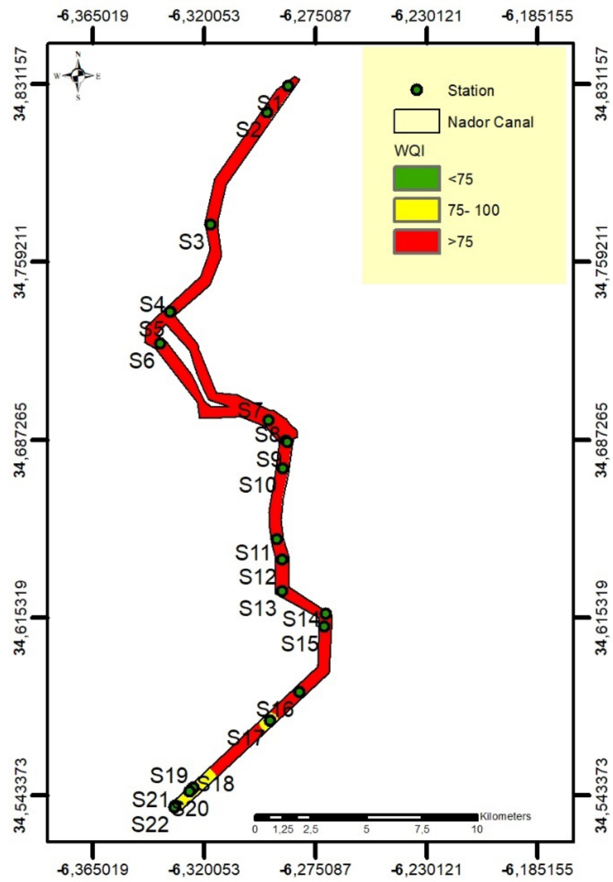

Figure 9. Spatial variations of water quality index (WQI).

4. Conclusion

This study aimed to evaluate the spatial variations in water quality at 22 different locations along the Nador Canal, Morocco, during the summer season. We employed the Water Quality Index (WQI), combined with multivariate statistical techniques and Geographic Information Systems (GIS), to analyze the data. The results indicated that the surface water quality of the Nador Canal is adversely affected by organic pollutants, as demonstrated by low DO levels and high total suspended solids. Elevated nutrient levels of Na^+, Cl^-, NH_4^+, NO_3^-, and PO_4^{3-}, along with increased salinity marked by high chloride and sodium concentrations, were also observed. The WQI values suggest that the canal water is generally suitable for irrigation but unsuitable for drinking. (PCA) revealed that the first three components accounted for 73% of the variation in water quality, highlighting issues such as contamination with sodium and calcium (PC1), low DO and bicarbonate levels (PC2), and high temperatures (PC3). Cluster Analysis (CA) corroborated the relative pollution levels, aligning with the PCA findings.

Author Contributions

Conceptualization and Methodology: Driss Hammoumi and Hefdhallah S. Al-Aizari; Software: Zaid Alkhawlani; Validation: Driss Hammoumi and Hefdhallah S. Al-Aizari, Mohamed Tayebi and Saïd Chakiri; Formal analysis: Driss Hammoumi; Investigation: Driss Hammoumi; Resources: Driss Hammoumi; Data curation: Driss Hammoumi and Hefdhallah S. Al-Aizari; Writing original draft preparation: Driss Hammoumi and Hefdhallah S. Al-Aizari; Writing review and editing: Driss Hammoumi and Zohra Bejjaji; Visualization: Driss Hammoumi and Zohra Bejjaji; Supervision: Zohra Bejjaji; All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

Data will be available on request from the corresponding authors.

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