



Groundwater quality assessment using water quality index and geographic information system based in Sebou River Basin in the North-West region of Morocco

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Abstract

The assessment of groundwater quality in regions with high economic activities is crucial for sustainable water resource management. The pressures on groundwater in the Sebou river basin are many and increasingly affecting the quality and the availability of groundwater. The identification of areas with groundwater of degraded quality is important for actions to be taken to reduce the pollution. The aim of this research is to assess and spatialize, using GIS, the groundwater quality in view of delineating polluted hotspots to be controlled by water resource managers. A water quality index (WQI) developed in Morocco has been applied to 81 water-quality monitoring stations with database of five water quality parameters from 1989 to 2017. The result indicated that the overall WQI, in most parts of the basin, was classified as medium to very bad. There were only small areas that showed good to excellent water quality. Three water quality parameters (NO_3^- , Cl^- and electrical conductivity (EC)) underlie the degradation of groundwater quality as these parameters have shown very high correlation coefficients with the overall water quality index and minimum relative values of their sub-indices as 0.00 (very bad) for NO_3^- , as 0.00 (very bad) for EC and 11.7 (very bad) for Cl^- . Intensive agricultural activities, untreated industrial and domestic wastewater and landfills could be responsible for degradation of groundwater quality in this area.

Keywords Groundwater quality · Water quality index · Nitrate · Pollution

Introduction

Groundwater is the main source of water supply for domestic consumption, agricultural, industrial, and other uses in the everyday life within every society. Unfortunately, this vital resource is under pressure due to the lack of sanitation installations, excessive use of Agro inputs, irrigation, landfills and wastewater discharges, population growth and economic development (Sullivan 2011; Wanda et al. 2015; Yang et al. 2016; WHO 2017; UN 2019). At the pace of economic development, population growth and climate change, maintaining an acceptable water quality for drinking purposes and other water-dependent activities, is a challenge for water management bodies (UNESCO 2015). United Nations (UN)

has made it one of its goals to achieve in Agenda 30 and the Millennium Development Goals to provide safe drinking water for all by 2030 (Srebotnjak et al. 2012; Nelly and Mutua 2016; WHO 2017). Currently, several countries are now making great efforts in this direction, as the effect of deteriorating groundwater quality is increasingly being felt despite the various actions taken in the fight against pollution (UNEP 2018). All this implies is that more effective and well-considered action needs to be taken to offset groundwater pollution. Morocco is subjected to a high level of pollution in certain localities, especially in the Sebou river basin. Nutrients and toxic elements from agricultural activities, urban and industrial development (Hayzoun et al. 2015) are the sources of water pollution in the Sebou Basin. Domestic wastewater are usually discharged into rivers and spilled on the land untreated (Koukal et al. 2004; Essahale et al. 2010; Hayzoun et al. 2015), with only 20% being treated before discharging into rivers and streams (Perrin et al. 2014). Industrial activities are also considered a source of pollution in this basin. In the light of these various challenges, policy and decision-makers commonly rely on WQI to determine

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the water quality of supply sources and, at the same time, assess the effectiveness of programs and actions undertaken to improve groundwater quality. WQI combines physical, chemical and biological water quality parameters to form a composite index, easy to understand and interpret to decision makers (Brown et al. 1970; Abbasi and Abbasi 2012; Gitau et al. 2016; Tian et al. 2019). Since WQIs are used to assess water quality policies and managements (Nabizadeh et al. 2013). Some of these parameters in excess concentration in water can cause severe health concerns to such an extent of being the root cause of some serious illnesses, particularly certain cancer cases in humans and animals (Morris 1995; Cantor 1997). For others, even though high concentrations are not harmful to human and animal health, they seriously impair taste (Sadat-Noori et al. 2013). A wide range of water quality indices combining several water quality parameters have been developed in the assessment of water quality, including NSF's index (Brown et al. 1970), the Canadian Council of Ministers of the Environment (CMME)'s index (CMME 2001), the Oregon's index (Cude 2001), the Said's index (Said et al. 2004), Swame and Tyagi's Index (2007), etc. These indices with their advantages and disadvantages resulting during the process of index development and in particular the way in which water quality parameters are aggregated are documented in Kanga et al. (2019a). Accordingly Kanga et al. (2019b) proposed a new water quality assessment index using Moroccan water quality standards (which are close to WHO standards) and has already been applied in parts of this basin (Kanga et al. 2019b). In this study, the Moroccan Index was used to assess and spatialize groundwater quality in view of identifying areas to be monitored by water resource managers. This assessment was based on data from 1989 to 2017 with twin sampling per year. The data of water quality was collected from Sebou basin hydraulic agency in June 2019 and the analysis was carried out in March 2020 in Morocco.

Materials and methods

Description of the study area

The study was carried out in the Sebou Basin, located in northwest Morocco. It is a large catchment with a total surface area of 40,000 Km² covering 6% of the Moroccan national territory. According to the Sebou Hydraulic Basin Agency, this catchment mobilizes 30% of the potential of surface water resources and 20% of groundwater in the country. In the upper part of the catchment is bounded by the Rif Mountains in the North, and by the Middle Atlas Mountains in the South. The plateau of Saï's is located between these two mountain ranges, within the perimeter of Fés-Meknès. In the lower part of the catchment,

towards the sea, the Sebou sub-basin consists of a large alluvial plain known as the Gharb plain. The Rif highlands are mainly characterized by impermeable Cretaceous clayey–marly formations, while the Gharb plain and Saï's plateau are shaped by permeable Tertiary and Quaternary materials. The Atlas domain consists chiefly of permeable Jurassic limestones and calcareous materials from the Lias. Rainfall data (1980–2003) showed a high variation in annual and intra-annual rainfall, typical of semi-arid climate (Perrin et al. 2014). The average rainfall in the Sebou Basin is 600 mm/year, with a maximum of 1000 mm/year in the Rif highlands and a minimum of 300 mm/year in the upper Sebou. The average potential evapotranspiration (PET) is rather high in the basin. It varies from 1600 mm in the coast to 2000 mm inlands. PET is at its highest on July–August at almost 300 mm/month and is at its lowest on December–January at under 50 mm/month. Its population of 6.2 million inhabitants is very active in the socio-economic context, in which agriculture is deemed its main vocation. The potential irrigated areas are estimated at 375,000 ha, of which 269,600 are currently irrigated according to the Sebou Hydraulic Basin Agency. Industrial activities play a major economic role and the most important industrial units are: sugar mills, paper mills, oil mills, tanneries, cement works and the textile industry. Figure 1 displays the geographic location of the Sebou Basin along with the water monitoring stations.

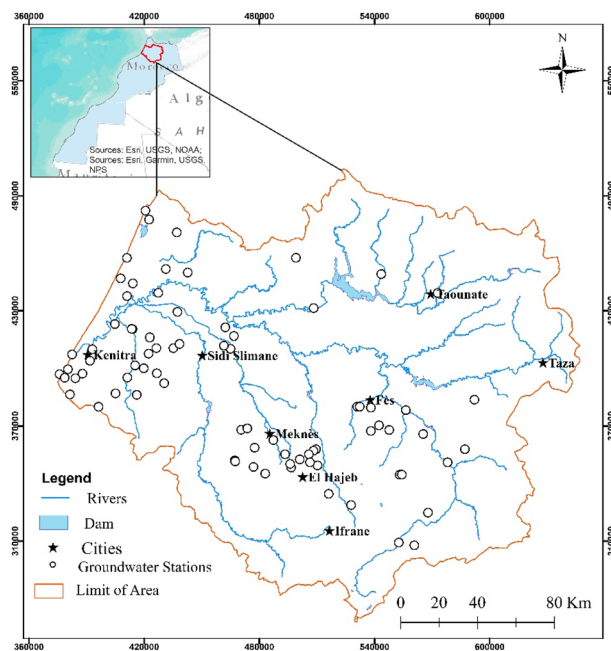


Fig. 1 Geographic setting of the Sebou Basin along with the water monitoring stations

Data collection

Twenty-eight (28) years of water quality data from 81 groundwater-quality monitoring stations were collected from the Sebou Hydraulic Basin Agency (ABHS). Some groundwater-quality monitoring stations are more ancient than others, resulting sometimes in data not being as old as 1989, and may have some discontinuity in the timeline between years. The monitoring stations were made up of wells and boreholes located in the various aquifers of the Sebou Basin (Fig. 1). Table 1 showed water quality parameters and their related units.

WQI calculation and spatialization

Kanga et al. (2019b) have proposed a water quality index for Morocco that takes into account water quality standards developed in three main steps: the adoption of water quality parameters, the transformation of parameter values

into sub-indices and the combination of sub-indices into an overall index. The adoption of water quality parameters was based on the same parameters used by the Sebou Hydraulic Basin Agency as follows: ammonium, chloride, fecal coliforms, nitrate and electrical conductivity. The normalization of the parameters was carried out using linear segmented equations for each water quality parameter resulting in sub-indices. Table 2 displayed normalizations functions. The sub-indices were combined to form an overall water quality index using a multiplicative equation form, as many researchers (Swamee and Tyagi 2007; Abbasi and Abbasi 2012; Kanga et al. 2019a) think that geometric mean aggregation can avert some of the problems encountered with conventional WQIs, such as eclipsing, ambiguity, compensation, etc.

$$WQI = \prod_{i=1}^n (I_i)^{\frac{1}{n}}, \tag{1}$$

where I_i represents the sub-index of the first parameter, n the number of parameters and WQI the overall water quality index.

The sub-index and overall index values have been categorized into five quality classes according to the decree 1275-02, which regulates the classification of water quality in Morocco. Table 3 shows the range of values and their interpretation.

Correlation matrices were established between water quality parameter sub-indices and overall WQI, and water quality parameter sub-indices with each other for all stations. The data were spatialized using ArcGIS by interpolating the average value of sub-indices and the overall WQI using the

Table 1 Water quality parameters, their associated units, and data chronology

Parameter	Unit	Number of samples	Data period
EC	μS/cm	81	1988–2017
NO ₃ ⁻	mg/l	81	1988–2017
NH ₄ ⁺	mg/l	81	1988–2017
FC	number/100 ml	81	1988–2017
Cl ⁻	mg/l	81	1988–2017

Table 2 Normalization equations of water quality parameters

NH ₄ ⁺ (mg/l)	Cl ⁻ (mg/l)	FC (number/100 ml)
$I_{NH_4^+} = -100x + 100$ $\forall 0 \leq x < 0.1$ (1)	$I_{Cl^-} = -0.05x + 100$ $0 \leq x \leq 200$ (6)	$I_{FC} = -0.5x + 100$ $0 \leq x < 20$ (11)
$I_{NH_4^+} = -67.5x + 96.75$ $\forall 0.1 \leq x \leq 0.5$ (2)	$I_{Cl^-} = -0.27x + 144$ $200 < x \leq 300$ (7)	$I_{FC} = -0.005x + 90.1$ $20 \leq x \leq 2000$ (12)
$I_{NH_4^+} = -8.67x + 67.33$ $\forall 0.5 \leq x \leq 2$ (3)	$I_{Cl^-} = -0.028x + 71.67$ $300 < x \leq 750$ (8)	$I_{FC} = -0.0007x + 64.44$ $2000 \leq x \leq 20000$ (13)
$I_{NH_4^+} = -2x + 54$ $\forall 2 \leq x \leq 8$ (4)	$I_{Cl^-} = -0.048x + 86$ $750 < x \leq 1000$ (9)	$I_{FC} = 0, \forall x > 20000$ (14)
$I_{NH_4^+} = 0, \forall x > 8$ (5)	$I_{Cl^-} = 0, \forall x \geq 1000$ (10)	
NO ₃ ⁻ (mg/l)		CE (μS/cm)
$I_{NO_3^-} = -x + 100$ $\forall 0 \leq x < 10$ (15)		$I_{CE} = -0.013x + 100$ $0 \leq x < 750$ (19)
$I_{NO_3^-} = -1.8x + 108$ $\forall 10 \leq x \leq 25$ (16)		$I_{CE} = -0.049x + 126.81$ $750 \leq x < 1300$ (20)
$I_{NO_3^-} = -0.52x + 76$ $\forall 25 \leq x \leq 50$ (17)		$I_{CE} = -0.0093x + 75.07$ $1300 \leq x < 2700$ (21)
$I_{NO_3^-} = 0, \forall x > 50$ (18)		$I_{CE} = -0.04x + 158$ $2700 \leq x < 3000$ (22)
		$I_{CE} = 0, \forall x \geq 3000$ (23)

Table 3 Class grouping of sub-indices and the overall water quality index

Description	Very bad	Bad	Medium	Good	Excellent
Interval	0–38	38–50	50–63	63–90	90–100

inverse distance weighting (IDW) technique. The concept of IDW is based on the notion that the value of an unsampled point is the weighted average of the sampling point values of its nearest neighbors, whereby these weights are inversely proportional to the distances between the prediction point and the sampled points (Muzenda et al. 2019). It is important to mention that IDW provides satisfactory results when the data is uniformly distributed in an area (ESRI 1992).

Results and discussion

The summary of the descriptive statistics (minimum, maximum, mean, standard deviation) of sub-indices of the groundwater parameters are presented in Table 4. The overall scores of groundwater quality index for the monitoring stations are presented in Fig. 2. The minimum, maximum and mean values of sub-indices for all the monitored stations are respectively 0.00 (very bad), 94.91 (excellent) and 76.61 (good) for electrical conductivity. The sub-index of Nitrate concentrations had values of 0.0 (very bad), 97.53 (excellent) and 54.66 (medium). The sub-index of fecal coliform counts indicated values of 76.2 (good), 99.37 (excellent) and 91.46 (excellent). The chloride concentration sub-index values showed 11.76 (Very Bad), 99.44 (excellent) and 85.44 (good). And the sub-index of ammonium concentrations had values of 80.35 (good), 98.83 (excellent) and 93.98 (excellent).

Table 4 Descriptive statistics of sub-indices of water quality parameters

Sub-index of parameter	Minimum	Maximum	Mean	Standard deviation
EC	0.00	94.91	76.61	18.93
NO ₃ ⁻	0.00	97.53	54.66	25.33
NH ₄ ⁺	80.35	98.83	93.98	4.25
FC	76.20	99.37	91.46	4.46
Cl ⁻	11.7	99.44	85.44	17.11

The study showed that, in general, groundwater quality in the Sebou Basin was classified as very degraded during this period of investigation (1989–2017) in several monitoring stations. The overall water quality is characterized as very bad at 28.4% of the stations, bad at 11.1%, medium at 14.8%, good at 38.3% and excellent at only 7.4%. These figures are consistent with the national assessment of groundwater quality conducted by Hssaisoune et al. (2020), in which the categorical distribution is as follows: 17%, 14%, 22%, 35%, and 12% for very bad, bad, medium, good, and excellent, respectively.

Water quality parameters spatialization

The spatial variation of groundwater quality based on individual parameters (sub-indices) for the 81 water-quality monitoring stations is presented in Fig. 3.

Chloride

The analysis of the chloride map (Fig. 3a) showed that groundwater quality varied from good to excellent in

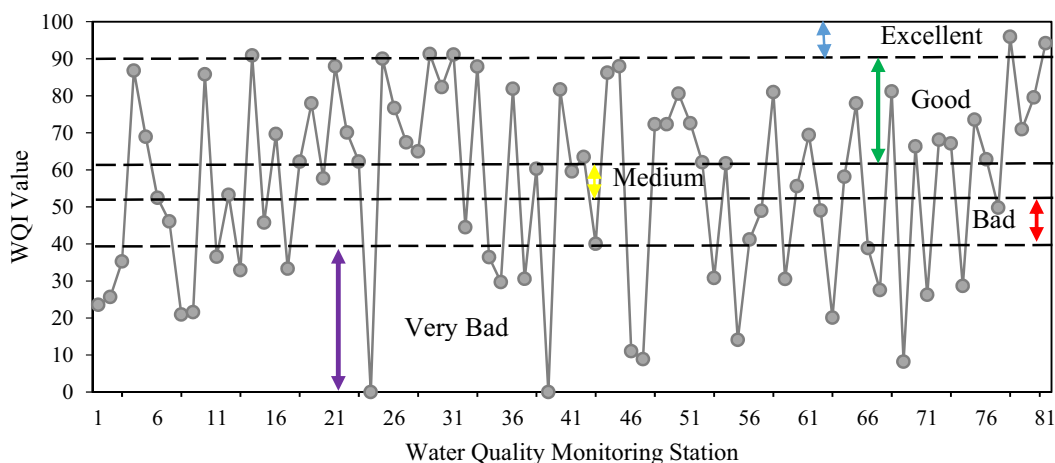
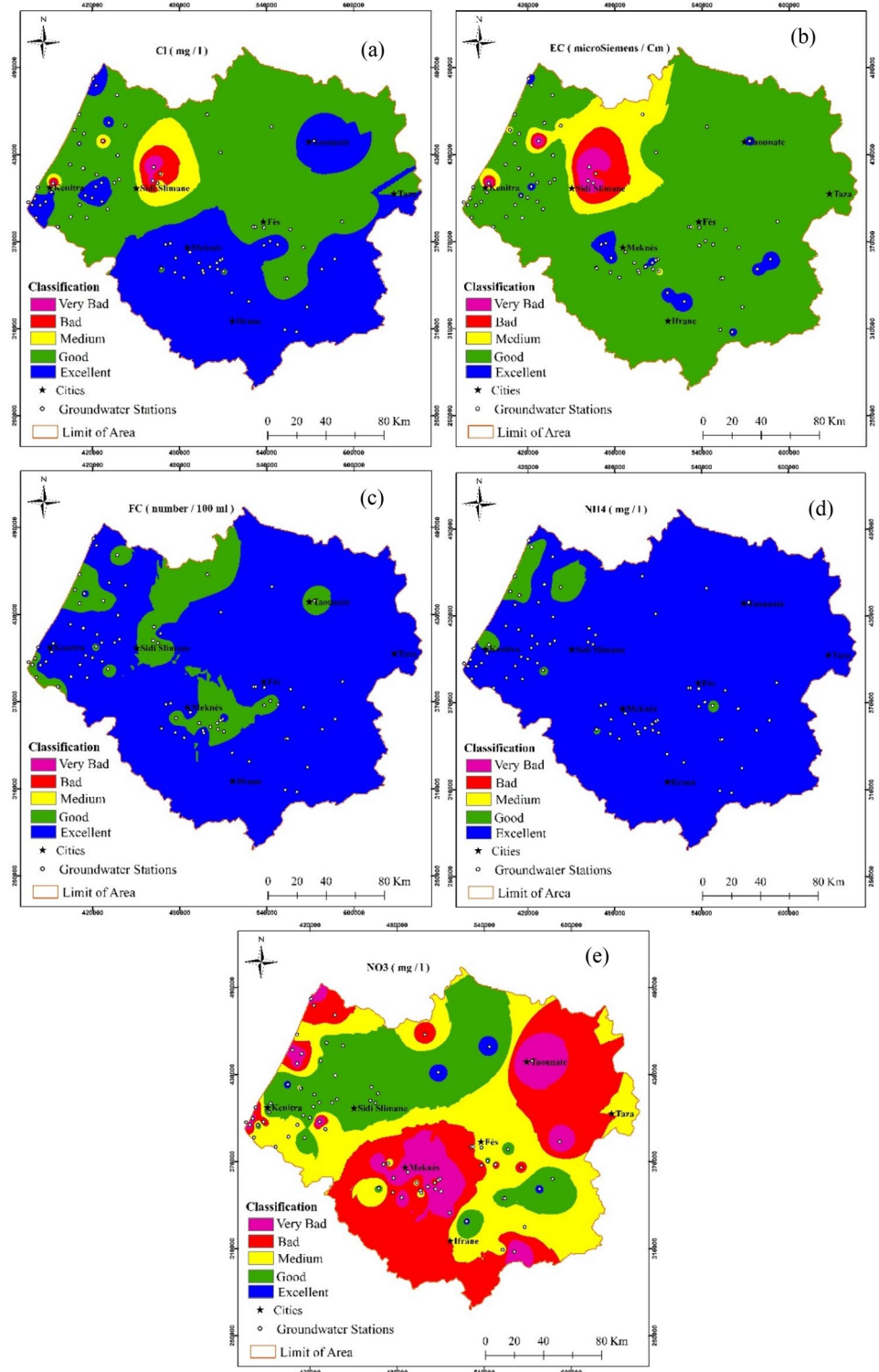


Fig. 2 Variation of the overall groundwater quality index for 81 monitoring stations

Fig. 3 Spatial distribution of the sub-indices of chloride (a), electrical conductivity (b), fecal coliforms (c), ammonium (d) and nitrate (e)



almost the entire basin. Some areas (near Sidi Slimane and Kénitra) showed water quality classified as very bad to medium. Chloride concentrations were very high and exceeded the permissible limit of the water quality standards. Chloride is naturally present in water (Brandt et al.

2016) but its excess in groundwater is mostly caused by human activities (Khan and Ali 2018), like wastewater and leachate from public discharges. Domestic and industrial wastewater (oil mills, sugar mills, paper mills, etc.) are usually discharged into rivers and spilled on the

landuntreated. About 130 Million m³ of wastewater per year is discharged into water sources in the study area. Chloride can be introduced from seawater intrusion, irrigation or agricultural discharges, runoff from urban waters due to industrial discharges and from landfills (Brandt et al. 2016; Khan and Ali 2018; Mukate et al. 2019). Agriculture is widespread in areas where chloride concentrations have been high, particularly in areas close to cities. Excessive chloride concentration induces a salty taste in water (Sadat-nori et al. 2013; Brandt et al. 2016) and may act as a laxative for someone not accustomed to its consumption (Sadat-nori et al. 2013). In Morocco, some researchers (Elgettafi et al. 2011; Najib et al. 2016; Hssaisoune et al. 2020) observed that groundwater salinity in the area results from seawater intrusion, and naturally from the dissolution of Permo-Triassic evaporites and from irrigation.

Electrical conductivity (EC)

The analysis of the EC map (Fig. 3b) showed that groundwater quality was good throughout almost the entire basin, as well as excellent in some discrete portions of the basin. EC-related water quality in the north-central part of the catchment varied from medium to very bad. The EC concentration in groundwater is high and has exceeded permissible levels for several years. EC is defined as the ability of water to conduct electrical current, which is dependent on the presence of ions in dissolved solution, indicating indirectly the total dissolved solids or directly the salts dissolved in water (Sadat-nori et al. 2013; Brandt et al. 2016). This high concentration can result from the type of rocks in the area (Sadat-nori et al. 2013) or from landfills (Kawo and Karuppanan 2018). Within the area with high EC values, marly materials with calcite and clay formed the aquifers (Amraoui 2005).

Fecal coliforms (FC)

The analysis of the fecal coliform map (Fig. 3c) showed that the spatial distribution of water quality was classified as excellent over almost the whole area. Some areas are classified as good quality, including part of the Sais plateau (between Fés and Meknès), the northern part of Sidi Slimane city, the area surrounding the city of Taounate and the coastal areas in the west. Fecal coliform represents the amount of coliform population present in the water reflecting pathogenic contamination by fecal matter (Muzenda et al. 2019). In fine there is no geographic pattern that explains the actual distribution of fecal coliform content in the basin. However, none of the wells and/or boreholes are located near septic systems or human and/or animal feces deposits.

Ammonium ion

The ammonium map (Fig. 3d) showed that the spatial distribution of water quality was excellent over a substantial part of the basin, except for some space-limited sites in the south. Ammonium is not highly toxic and can originate mainly from agricultural, domestic and industrial activities. Due to its positive charge, NH₄⁺ can be easily fixed to the topsoil, (Chen 1997; Wang and Alva 2000; Ao et al. 2020), particularly with clay–humic complex, which would limit its deep penetration. Clayey soil, marl and calcareous materials mainly characterize the soils and subsoils of the Sebou basin (Amraoui 2005). According to data from the Sebou hydraulic basin agency, the depths to water table vary from 10 m to more than 100 m in the extreme south and center of the basin, 4–8 m deep in the extreme west and the north-west. Ammonium adsorption is greater at soil surface than at subsurface (Wang and Alva 2000).

Nitrate

Water quality based on nitrate map (Fig. 3e) ranged from medium to very bad across a large part of the basin. A significant portion in the southern part of the basin; the Sais plateau as well as a part of the Atlas domain (near the city of Ifrane), indicated very bad and bad water quality classes. In the eastern part, within Taounate and Taza perimeters, the nitrate concentration was very high, exceeding the permissible limit resulting in bad and very bad quality. In the western part, towards the coastal area, some areas showed bad and very bad water quality. Nitrate resulted mainly from agricultural activity, but can also be derived from industrial discharge, domestic activity like septic systems (Hayzoun 2014) and landfills (Kawo and Karuppanan 2018; Mukate et al. 2019). The areas with high nitrate concentration are intensively cultivated with often overuse of fertilizers.

Overall WQI spatialization

The mean values of the overall water quality index revealed that groundwater quality in the Sebou Basin is severely degraded. Figure 4 showed the spatial distribution of the overall groundwater quality. On the large scale, the water quality of wells and boreholes was decreasingly variable from medium to very bad. There were some good to excellent zones along just a few areas. Table 5 showed the correlation matrix between the mean values of sub-indices and the mean values of overall water quality indices.

The correlation coefficient is very high between the sub-index of nitrate and the overall groundwater quality index with $r_{\text{WQI} - \text{NO}_3} = 0.79$. This correlation coefficient was considerably high for the stations with very bad, bad

Fig. 4 Overall groundwater quality

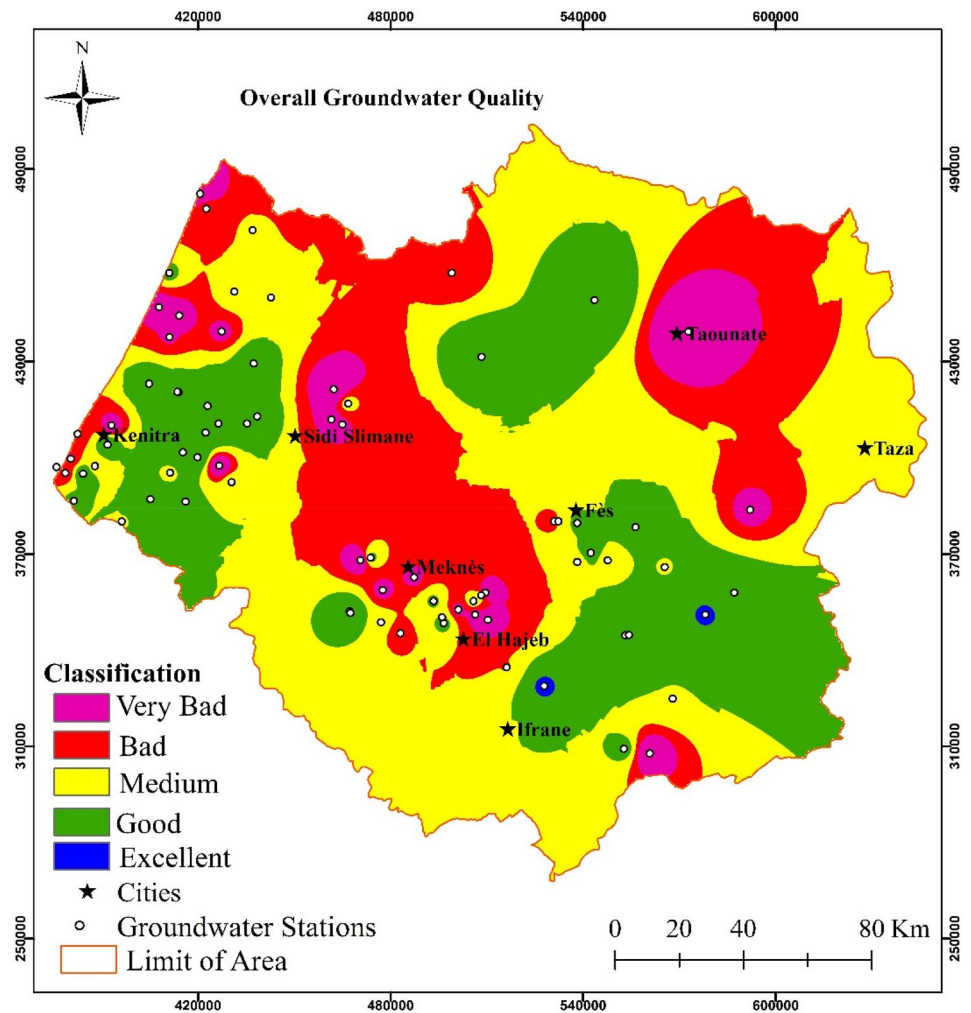


Table 5 Correlation matrix between sub-indices and the overall WQI

	EC ($\mu\text{S/cm}$)	NO_3^- (mg/l)	NH_4^+ (mg/l)	FC (n/100 ml)	Cl^- (mg/l)	WQI
EC ($\mu\text{S/cm}$)	1.00					
NO_3^- (mg/l)	-0.24	1.00				
NH_4^+ (mg/l)	0.26	-0.05	1.00			
FC (n/100 ml)	0.16	0.25	0.15	1.00		
Cl^- (mg/l)	0.95	-0.33	0.25	0.13	1.00	
WQI	0.29	0.79	0.15	0.32	0.22	1.00

and medium water qualities. The average correlation coefficient for these three categories of quality classes was $r_{\text{WQI}-\text{NO}_3} = 0.93$. Similarly, other water quality parameters such as EC and chloride were found to have high correlation coefficients with the overall WQI, relatively high correlation coefficients were obtained from the correlation of the mean values of WQI and sub-indices. The mean correlation coefficient for stations with medium, bad and very bad water quality was $r_{\text{WQI}-\text{EC}} = 0.74$ for electrical conductivity and $r_{\text{WQI}-\text{Cl}} = 0.71$ for chloride. The correlation among

sub-indices did not show high values, except for the correlation between EC and Cl^- ($r_{\text{EC}-\text{Cl}} = 0.95$). This indicated that Cl^- and EC both have the same origin and their presence in water might determine the degree of salinity.

This means that changes in overall groundwater quality in the Sebou Basin was attributable to the concentrations of nitrate, electrical conductivity and chloride. It has already been shown by Gamar et al. (2018) that chloride, nitrate and electrical conductivity are major pollutants of groundwater within parts of Sebou river basin in the surroundings area of

the city of El Hajeb, and further stated that these pollutants originated from leachate of uncontrolled landfills and agricultural activities. Intensive agricultural activities within the basin released high amount of nitrates, which infiltrated after rainfall into the groundwater. Nitrates can also be released from industrial discharges and leachate from public landfills, which was generated after precipitation. Chloride and electrical conductivity all occur naturally in water, but excess values of chloride and electrical conductivity in groundwater are human-induced as a result of agricultural and industrial activities, landfills and wastewater discharges.

Conclusion

Groundwater quality was considered to be impaired in the Sebou Basin since, within the large area of the basin, groundwater quality decreases from medium to very bad, while good or excellent in only some limited spots. Correlation analysis of the values of sub-indices and the overall WQI in the basin revealed evidence of nitrate, electrical conductivity and chloride as the basis of deteriorating groundwater quality. Spatialization of the WQI using GIS can provide a useful tool for decision-makers to evaluate the effectiveness of water management projects and to undertake actions to reduce the impacts of anthropogenic activities on groundwater. Increasing the number of water-quality monitoring stations can improve the accuracy of the mapping of the WQI, precisely in the Northeast side of the basin.

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Author contributions KIS conducted the research, manuscript writing. NM corrections, reading, writing. CM corrections, reading, writing.

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Availability of data All data are available for transparency.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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