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Water Quality Assessment Using a New Proposed Water Quality Index: A Case Study from Morocco

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Abstract**—***Excellent or very poor water quality depends of its physicochemical and biological parameters. However, the assessment of water quality relies on the water quality index (WQI) used, because some indices in their form of application may underestimate or overestimate the overall water quality. For instance, to avoid the problem of underestimation of water quality index, a new WQI is proposed in this study. In order to develop this new WQI, data from 29 water quality monitoring stations, including 3 surface water stations and 26 groundwater stations, spanning over1988 -2017 , were collected from the Sebou Hydraulic Basin Agency (ABHS).The water quality parameters were standardized and then aggregated into a composite water quality index, using Moroccan water quality standards. The application of this new WQI showed that 37.9% of the stations have bad or very bad water quality, 13.8% have medium quality, 41.4% have good quality and that only 6.9% have excellent quality. The poor surface water quality, characterized by high levels of BOD_5 and COD, low dissolved oxygen and high levels of fecal coliforms is mainly due to industrial and domestic activities. The poor groundwater quality marked by nitrate leaching from agricultural lands is chiefly due to industrial and domestic activities. The comparison between this new WQI and the method used by ABHS showed a satisfactory agreement of the results (R^2 =0.70, at the 95% confidence level) for the 26 groundwater stations.*
Keywords**— WQI, Water Quality Index, Sebou Basin, Physicochemical Parameters, Water Quality Parameters.***

I. INTRODUCTION

In the daily lives of living things, water resources play a very important role in keeping the body alive. This precious resource is present in all human activities. However, water quality can quickly deteriorate, following human activities and become unusable for consumption. In a world where climate change is affecting all sectors, water resources are not spared and are increasingly vulnerable. Recently, throughout the world, several cases of problems related to water quality or scarcity due to drought must alert all global stakeholders in water resources management. Among other things, water problems have been reported all over the world: In 2014, the city of Sao Paulo (Brazil) could have been deprived of water because of drought and pollution of the reservoirs supplying the city. In 2016, the city of Ouagadougou (Burkina Faso) experienced a very severe water shortage, where districts stayed 3 to 4 days without seeing a drop of water in the taps, and even when water is available, it is so turbid. In 2014, the city of Zinder (Niger) experienced a severe water shortage to the point of depriving the population of food since there is no water for cooking. In 2016, the government of Bolivia declared a state of emergency due to the severe drought in the country. The City of Cape Town in South Africa have experienced the so called " Day Zero" in June 2018, the day when the army would take over the distribution of water, which would be limited to 25 liters per day per person.

In Morocco, in addition to the spectra of water scarcity profiling, it is one of the African countries most threatened by water resource pollution [5]. For example, the Sebou basin, being the study site, is considered the most polluted in the country [3, 9]. The origins of pollution are diverse and several researchers report 3 to 4 main sources of pollution. Agricultural practices, urban and industrial development through the induction of nutrients and toxic elements [9] are the sources of pollution of water resources. Domestic water discharges are often injected directly into rivers and spread on land without any treatment [14, 9, 5], and only 20% are treated before being discharged into rivers [20]. Industrial

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activities are also considered as one of the sources of pollution in this watershed. The main branches of this activity are agro-food industries such as sugar factories, paper mills and olive oil mills generating large quantities of organic matter that degrade dissolved oxygen in the water. Agricultural activities are also very important in the area and represent the main economic activity.

The use of fertilizers and phytosanitary products causeleaching of some 900 T/year of nitrogen, 220 T/year of phosphates according to the Sebou Watershed Agency (ABHS) in 2013. Landfills also generate leachate to surface water and groundwater [2, 5, 13]. In this basin, several researchers [14, 2, 6, 3, 9,5] have attempted toassess the quality of water resources,using different water quality parameters and different methods. Beyond the parameters elected for water quality assessment, the methods used to assess overall water quality may also affect the outcome of the assessment. In regard to this, several researchers have listed a number of problems related to the application of water quality assessment methods. Kanga et al. (2019)[12] report that some water quality index methods may either overestimate the deterioration of water quality or underestimate the best water quality due to the forms of aggregation of water quality parameter values. The purpose of this study is to assess the quality of water resources in the Sebou basin,usingthe water quality parameters proposedby the Sebou hydraulic Basinagency (ABHS) and to propose a new water quality index to avoid underestimation or overestimation of water quality using Moroccan water quality standards.

II. METHODS

2.1. Study Area

The study area is located in the large Sebou catchment area and extends over two aquifers: the Fez-Meknes aquifer and the aquifer of the Barren limestone plateau. It covers an area of 5,849 Km2 and spans over7 provinces and 64 municipalities. The economy of the area is mainly based on agriculture and industry. Water resources are used for drinking water supplies and for irrigating crops. The study area is composed of agricultural lands in the northern part of the area. A large part is covered by forested lands in the extreme south of the area. There are approximately 208,860 farms in the study Area, operating overmore than 2 million hectares of agricultural lands. The use rate of agri-inputs is very high and averaged 66.5% of farms in 1996. There are 51 potential sources of pollution in the study area, namely 9 quarries, 18 landfills, 8 industries, 13 liquid discharges and 3 industrial areas. Much of the study area laysonclayey soil texture, especially in the northwest, north and northeast parts. The eastern and central parts are made up of sand-clayey textures. The western part of the study area consists of sand-clay textured soils. The western part of the study area consists of sand-silt textured soils and rock outcrop. The deep aquifer of Fez-Meknes includes dolomitic limestone formations of the Lias, which are highly fractured. The thickness of this aquifer varies from a few meters inthe center to 760 m north of the study area. However, the water level is 50 m deep on average in the captive part of the aquifer and 250 m deep in the non-captive part. The aquifer of the Barren limestone plateauis juxtaposed with the Fes-Meknes water tableand consists of the calcareous-basaltic aquifer of Lias and the basaltic aquifer of the Quaternary. Groundwater rechargeof is provided by the infiltration of rainfall. Wells and boreholes are the means of exploiting groundwater in this area. Annual precipitation in the study area is highly variable and mean annual rainfall between 1988 and 2017 ranged from479 mm in the north and northeast to 800 mm in the south. The inventory of water bodies in the study area shows some natural riversand lakes: Fez river, Guigou river (flow rate: 0 to 54 m3/s), Boufekrane river, Tizguit river, Agay river, and Aoua, Ifrah and hachlaf lakes.

2.2. Data sources

Data on water quality, over 30 years were collected at the Sebou Hydraulic Basin Agency and the Secretariat of State for Water (SEE), two water resources management bodies in Morocco. These data includes29 water quality-monitoring stations that were sampled twice a year from 1988 to 2017. Figure1 shows the localization of water quality station and surrounding cities in the study area. Some stations are older than others are, so the data may show discontinuities in the recording. The 29 stations are composed of 3 surface water-monitoring stations and 26 groundwater stations.

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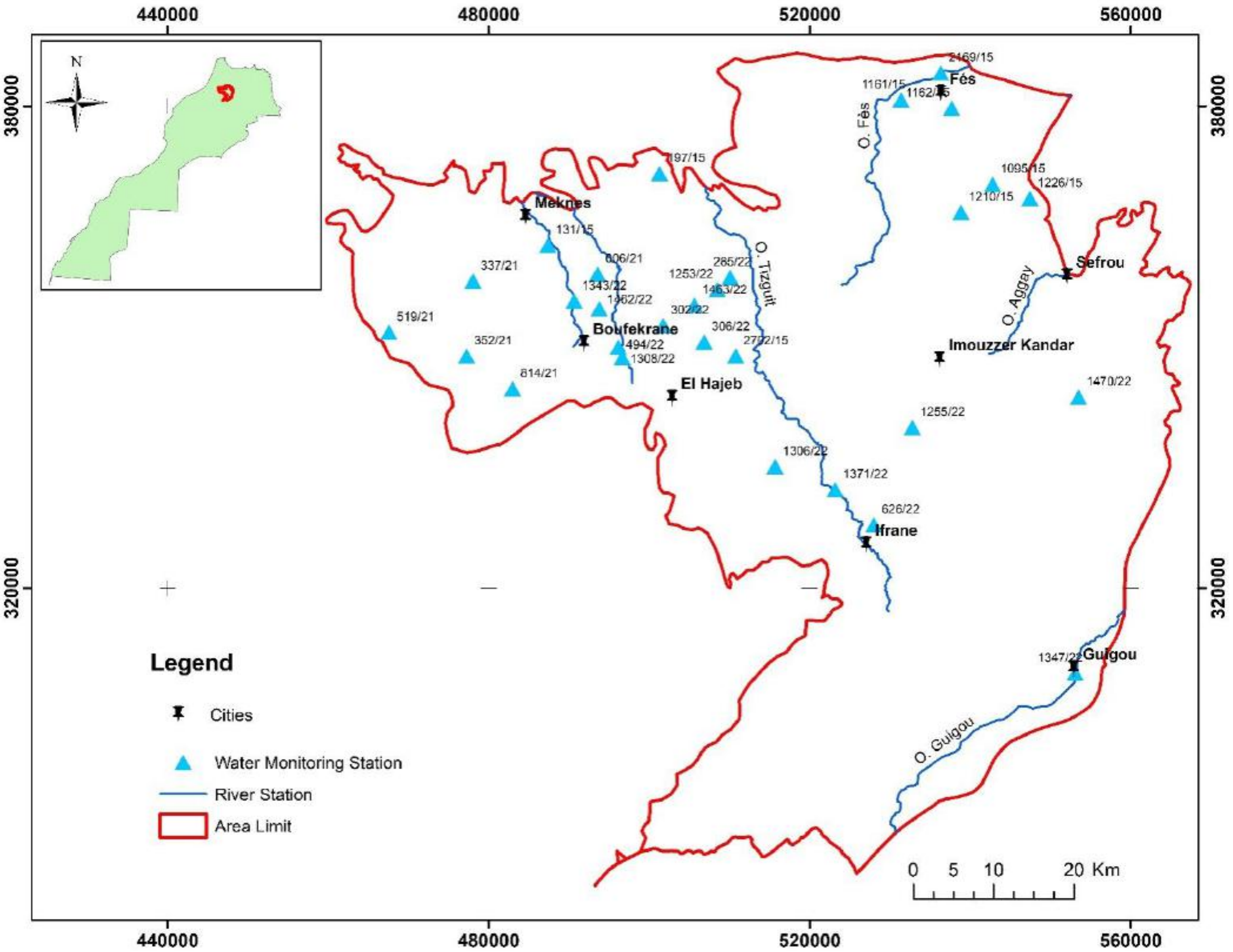

Fig.1: Localization of monitoring water quality stations in study area

A land cover map has been developed to understand the environmental characteristic and the surrounding area of water sources that can influence the water quality. The Secretariat of State for water provided the inventory of potential point sources of pollution. Land use map was established using supervised classification of a Sentinel A2 image with high resolution (10 m X 10 m), dated December 10, 2018.The sentinel 2 image is multispectral imager that provides images featuring 13 spectral bands with high resolution vary from 10 m to 60 m depending on the band using. A Kappa index (K) [4] of 0.68 (meaning strong agreement)was achieved using the XLSTAT statistical tool. The map was validated by creating randomized points on Google Earth, which were imported into the ArcGIS environment to find the classes.

2.3. Calculation of WQI

The ABHS uses a water quality assessment method (Act 10-95 of 16 August 1995, Act 36-15 of 6 October 2016 and Decree 1275-02 of 17 October 2002). This method consists of subdividing water quality into 5 different classes (Excellent, Good, Average, Poor, and Very Poor). According to the standards set out in Order 1275-02, the samples of the various water quality parameters, i.e. the measured values, are classified into their corresponding classes. The overall class at a station tends to be the most deteriorated class in terms of quality. Several water quality parameters are measured in a water sample; however, ABHS uses 6 parameters for both groundwater and surface water quality assessment. These parameters are, for surface water: dissolved oxygen (O_2), biochemical oxygen demand for 5 days (BOD_5), chemical oxygen demand (COD), ammonium (NH_4^+), total phosphorus (P) and fecal coliforms (CF). For groundwater, these parameters are considered: Electrical conductivity (EC), Chloride (Cl), Nitrate (NO_3^-), Ammonium (NH_4^+) and Fecal Coliforms (CF). Yet, ABHS method has some disadvantages when it comes to determining water quality over a given period because of the appreciative nature of the overall water quality. In other words, the overall water quality is in the form of qualitative classes, which makes

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any addition or multiplication operation difficult. For this reason, themethod we are proposingto assess water quality uses the same water quality standards to normalize the values of the various water quality parameters. Two main steps characterize the new method: normalization of water quality parameter values into sub-indexes and aggregation of sub-indexes into water quality index (WQI).

2.3.1. Normalization of water quality parameters

The normalization is the transformation of variables that are in different units and dimensions into a common scale [1, 8, 22]. Water quality parameters are not measuredinthe same unit. For example, the unit of $BOD_5$is expressed in milligrams per liter (mg/l), fecal coliforms in number per 100 ml of water, electrical conductivity in micro or milli Siemens per cm (µS/cm or mS/cm). This difference in units results in the failure to aggregate parameter values without normalizing them. In addition, often the variables do not have the same effect on water quality. While other variables are proportional to water quality, others are inversely proportional to water quality [22]. In other words, variables such as dissolved oxygen,variesin the same direction as water quality, the higher the value, the better the water quality.Unlikely, fecal coliforms have the opposite effect, the higher the value, theworsen the water quality. It is therefore mandatory to standardize these values so that the final water index couldrepresent all the parameters chosen with the relative contribution of the strength of each parameter. According to Abbassi and Abbassi,(2012)[1], there are 4 ways to normalize the values of the quality parameters into sub-indices: linear function sub-indices, segmented linear function sub-indices, non-linear function and segmented non-linear function. The normalization of parameter values into sub-indices was implemented basedon Moroccan water quality standards (decree 1275-02) and segmented linear functions. The general equation for normalizing a parameter [1] is described as follows:

$$I_i = (x - a_i)\left(\frac{b_{i+1} - b_i}{a_{i+1} - a_i}\right) + b_i,\ a_i \le x \le a_{i+1}\ \text{and} b_i \le ClasseI \le b_{i+1}. \quad (1)$$

With I_i, the sub-index of the ith parameter, $a_i$the measured value of the ith parameter, b_i the ith corresponding a class according to the simplified grid of the decree 1275-02 in this context. Five (5) classes are determinedto classify water quality in Morocco: Excellent, good, medium, bad, very bad. For each value of a water quality parameter, the sub-index transformation is performed using the linear equation above and has a value between 0 (Very Poor) and 100 (Excellent). Table 1 shows the distribution of classes with numerical values as follows:

Table 1: Classification of water resources based on the proposed WQI

Numerical Value	Description of the Class	Color Code
90-100	Excellent	
63-90	Good	
50-63	Medium	
38-50	Bad	
0-38	Very Bad	

For example, BOD5 measurements that are strictly less than 3 mg/l are considered "Excellent" in terms of water quality description and correspond to the range of numerical values {90 to 100}. To normalize this class, simply do:

$$\begin{cases} 0 \le x \le 3\ mg/l \\ 100 \ge I_{DBO_5} \ge 90 \end{cases} I_{DBO_5} = (x - 0)\left(\frac{90-100}{3-0}\right) + 100\ ;$$

$$I_{BOD_5} = -3.33x + 100, \quad (2)$$

$$\forall\ x, 0 \le x \le 3$$

Table 2 displays the sub-indices of the water quality parameters. For each class, a linear equation was developed to quantitatively estimate water quality instead of a qualitative description.

Table 2: Normalization equations of water quality parameters

Dissolve Oxygen (DO) (mg/l)	Biochemical Oxygen Demand for 5 days DBO_5 (mg/l)	Chemical Oxygen Demand (DCO) (mg/l)
$I_{OD} = 11.366x \forall, 0 < x \le 8.8$ (3) $I_{OD} = 100, six > 8.8$ (4)	$I_{BOD_5} = -3.33x + 100 \forall\ x, 0 \le x \le 3$ (5) $I_{BOD_5} = -13.5x + 130.5 \forall\ x, 3 < x \le 5$ (6) $I_{BOD_5} = -1.85x + 72.28 \forall\ x, 5 < x \le 10$ (7) $I_{BOD_5} = -0.8x + 58 \forall\ x, 10 < x \le 25$ (8) $I_{BOD_5} = 0, \forall\ x > 25$ (9)	$I_{COD} = -0.5x + 100$ $\forall x, 0 < x \le 20$, (10) $I_{COD} = -5.4x + 198 \forall\ x, 20 < x \le 25$, (11) $I_{COD} = -0.86x + 84.66 \forall\ x, 25 < x \le 40$, (12) $I_{COD} = -0.3x + 62 \forall\ x, 40 < x \le 80$(13) $I_{COD} = 0, \forall x \ge 80$ (14)
Ammonium ($NH^+{}_4$) (mg/l)	Total Phosphorus TP (mg/l)	Fecal Coliforms (CF) (number/100 ml)

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$I_{NH_4^+} = -100x + 100\ \forall x, 0 \leq x < 0.1$ (15) $I_{NH_4^+} = -67.5x + 96.75\ \forall x, 0.1 \leq x \leq 0.5$ (16) $I_{NH_4^+} = -8.67x + 67.33 \forall x, 0.5 \leq x \leq 2$ (17) $I_{NH_4^+} = -2x + 54 \forall x, 2 \leq x \leq 8$ (18) $I_{NH_4^+} = 0, \forall\ x > 8$ (19)	$I_{TP} = 100 - 100x \forall x, 0 \leq x < 0.1$ (20) $I_{TP} = -135x + 103.5 \forall\ 0.1 \leq x \leq 0.3$ (21) $I_{TP} = -65x + 82.5 \forall\ 0.3 \leq x \leq 0.5$ (22) $I_{TP} = -4.8x + 52.4 \forall\ 0.5 \leq x \leq 3$ (23) $I_{TP} = 0, \forall\ x > 3$ (24)	$I_{FC} = -0.5x + 1000 \leq x < 20$ (25) $I_{FC} = -0.005x + 90.120 \leq x \leq 2000$ (26) $I_{FC} = -0.0007x + 64.442000 \leq x \leq 20000$ (27) $I_{FC} = 0, \forall\ x > 20000$ (28)
Nitrate (NO_3^-) (mg/l)	Chloride (Cl) (mg/l)	Electrical conductivity (CE)(µS/cm)
$I_{NO_3^-} = -x + 100\ \forall\ 0 \leq x < 10$ (29) $I_{NO_3^-} = -1.8x + 108\ \forall\ 10 \leq x \leq 25$ (30) $I_{NO_3^-} = -0.52x + 76\ \forall\ 25 \leq x \leq 50$ (31) $I_{NO_3^-} = 0, \forall\ x > 50$ (32)	$I_{Cl} = -0.05x + 1000 \leq x \leq 200$ (33) $I_{Cl} = -0.27x + 144200 < x \leq 300$ (34) $I_{Cl} = -0.028x + 71.67300 < x \leq 750$ (35) $I_{Cl} = -0.48x + 86750 < x \leq 1000$ (36) $I_{Cl} = 0, \forall x \geq 1000$ (37)	$I_{CE} = -0.013x + 1000 \leq x < 750$ (38) $I_{CE} = -0.049x + 126.81750 \leq x < 1300$ (39) $I_{CE} = -0.0093x + 75.071300 \leq x < 2700$ (40) $I_{CE} = -0.04x + 1582700 \leq x < 3000$ (41) $I_{CE} = 0, \forall x \geq 1000$ (42)

2.3.2. Aggregation

The normalized sub-indices are aggregated to form a composite water quality index. Researchers use several types of methods for aggregating sub-indices. Kanga et al.(2019) [12] report 6 aggregation methods: the arithmetic mean, geometric mean, square root function, logarithmic function, fuzzy inference function, and minimum or maximum operator. The methods for aggregating the sub-indices are diverse: additive methods (linear sum-index, weighted linear sum-index, sum index at root power), multiplicative methods (weighted product), logic methods (maximum operator, minimum operator) [1]. To avoid problems encountered in other indices related to the aggregation of sub-indexes such as eclipsing, ambiguity, compensation and rigidity [12], the multiplicative form especially the product to power has been adopted. The following equation is the form used to aggregate the different values of the water quality parameters.

$$WQI = \prod_{i=1}^{n} (I_i)^{\frac{1}{n}} \quad (43)$$

Where I_i, represents the sub-index of the i[th] parameter, and n, the number of parameters, WQI, the overall water quality index.

To apply the WQI aggregation formulae on data, a Microsoft excel spreadsheet is used. In addition, the statistical analyses (correlation matrices, regression equation, graph plotting and curve fitting, etc.) were conducted under a Microsoft Excel.

III. RESULT AND DISCUSSION

In this study, water quality was assessed for human consumption purposes. In accordance with the legislative framework for water management governed by the country water management agencies, this WQI has been developed for human consumption purposes. Data from 29 water quality-monitoring stations (surface and groundwater) showed variations in water quality as a result of land use. For each station, this developed WQI was applied using the above steps. Each water quality parameter was transformed into a sub-index with values between 0 (very bad) and 100 (Excellent). Once the parameters normalized, a water quality index was calculated for each sampling. In addition, the average values of the parameter sub-indexes were calculated as well as the average values of the overall water quality for each station, based on multiple years of water quality analyses. Table 3 shows the 31-year average quality status for the 29 water quality monitoring stations within the study area. Fig.2 displaysthe spatial distributionof water quality interpretation of the 29 monitoring stations.

Table 3: Water quality status of the 29 stations

Water Resources	**Station ID**	**WQI**	**Interpretation**
Surface Water stations	1343/22	63.79	Good
	2169/15	52.86	Medium
	1371/22	80.08	Good
	197/15	41.17	Bad
	1210/15	48.93	Bad

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Groundwater stations	1095/15	80.99	Good
	131/15	30.51	Very Bad
	1161/15	55.60	Medium
	1162/15	69.41	Good
	1226/15	49.04	Bad
	2702/15	20.12	Very Bad
	352/21	58.16	Medium
	519/21	77.95	Good
	814/21	38.88	Bad
	337/21	27.53	Very Bad
	606/21	81.17	Good
	285/22	8.21	Very Bad
	1253/22	66.35	Good
	302/22	26.28	Very Bad
	1462/22	68.13	Good
	1463/22	67.14	Good
	306/22	28.67	Very Bad
	1308/22	73.55	Good
	494/22	62.81	Medium
	1306/22	49.77	Bad
	626/22	95.93	Excellent
	1347/22	70.93	Good
	1470/22	79.54	Good
	1255/22	94.20	Excellent

Table 4 shows the ratios of different water quality classes according to their locations. The figure 2 displays the land cover and surrounding of the water monitoring sites. The stations are located mainly in forester area, urban area and agricultural land.

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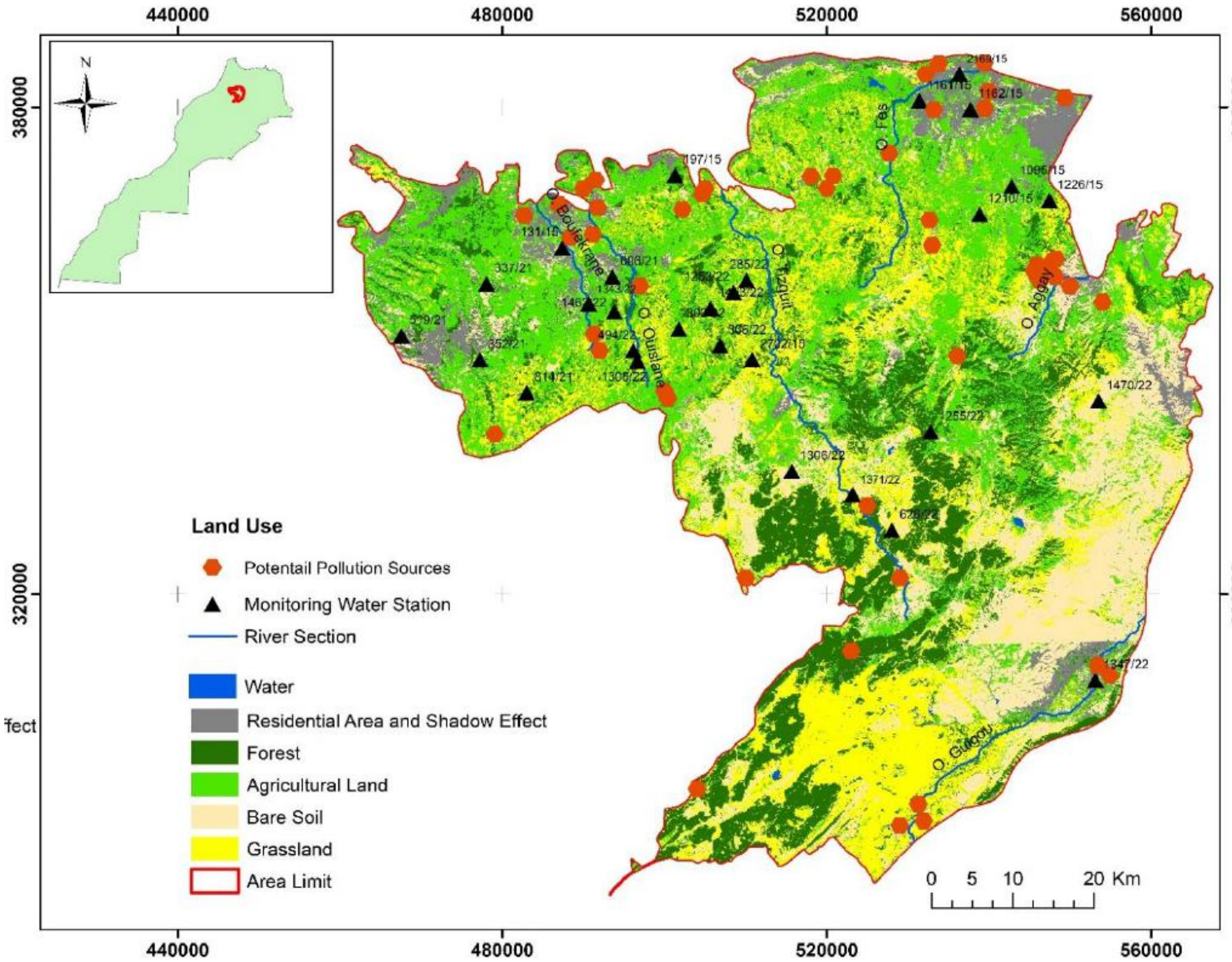

Fig.2: Land use classes, monitoring water quality stations and potential sources of pollution in study area

Table 4: Water quality status as a function of land use

	Forested land	**Agricultural land**	**Urban Area**	**Total**
Monitoring sites	3/29 (10.34 %)	23/29 (79.32%)	3/29(10.34 %)	100 %
Excellent	2/29 (6.90 %)	0 (0 %)	0 (0 %)	6.90 %
Good	1/29 (3.45 %)	10/29 (34.48 %)	1/29 (3.45 %)	41.38 %
Medium	0 (0 %)	2/29 (6.90 %)	2/29 (6.90 %)	13.79%
Bad	0 (0 %)	6/29 (20.69 %)	0 (0 %)	20.69 %
Very Bad	0 (0 %)	5/29 (17.24 %)	0 (0 %)	17.24 %

The water quality of the stations in the forested areas varied from good to excellent. Out of the 3 stations in the forested area, 2 have excellent qualities. Forests have a positive effect on water quality because of their purification ability [24]. Frequent deforestation in Brazil on the river banks has deteriorated the quality of the Murucupi and Parà rivers [17]. The majority of monitoring stations are located in agricultural areas (79.3%). In addition, 47.8% of the water quality of these stations in the agricultural zone has qualities ranging from bad to very bad; moreover, 8.7% have medium qualities. Only 43.5% of these stations have good water quality. Due to the abusive application of fertilizers in the study area, agriculture stands up as the main sources of water pollution due to nitrate and phosphorus leaching [5, 19]. Water quality in urban areas varies from medium to good. Of the 3 stations located in urban areas, 2 exhibit medium qualities. Landfills and domestic wastewater discharges constitute the causes of water quality degradation [18, 6] due to large quantities of leachate and ETMs contained in wastewater [2, 14].

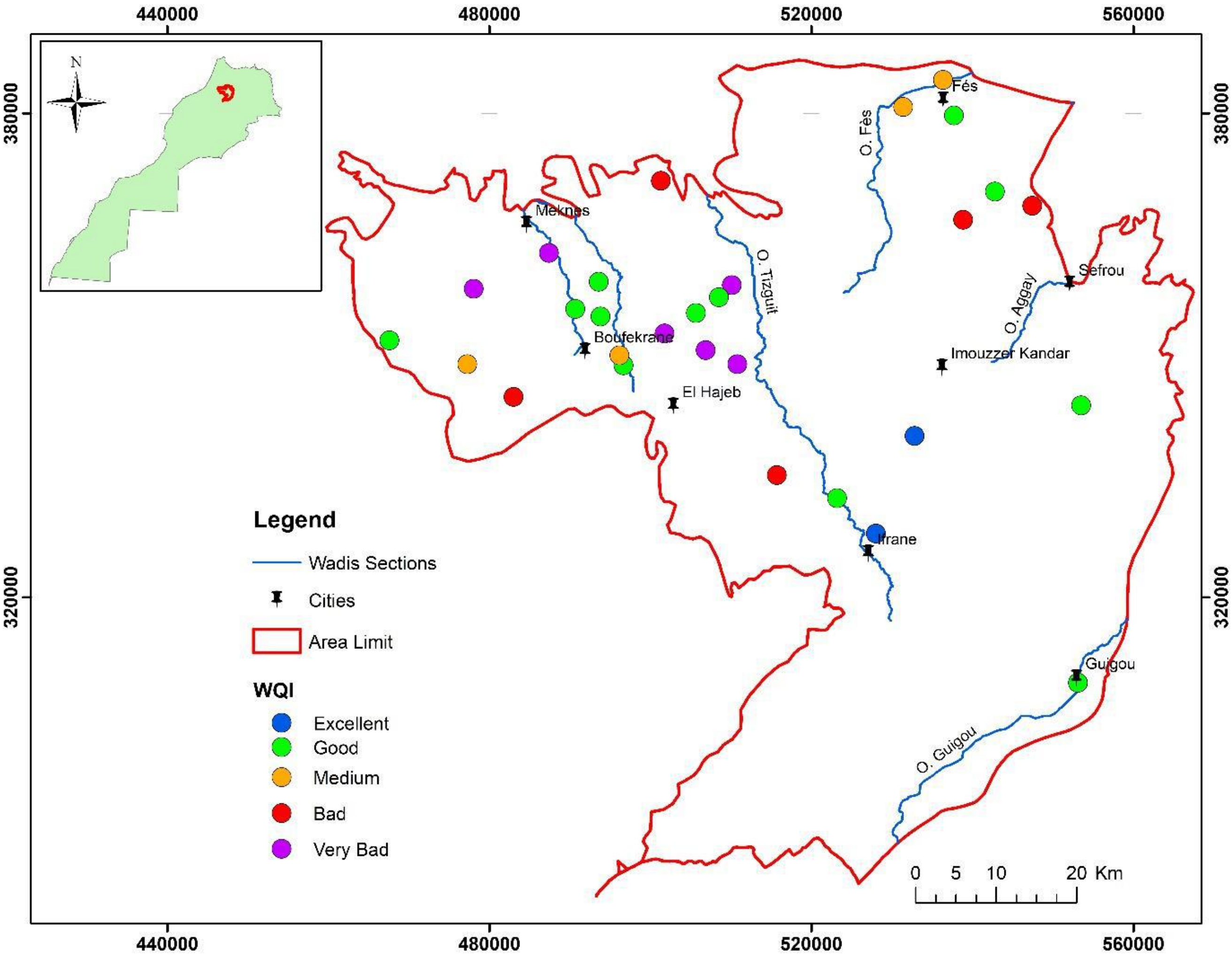

Fig. 3: Mapping of water quality status of 29 stations in the study area

3.1. Surface water monitoring stations

3.1.1. Station 1343/22 (Boufekrane River)

The different values of water quality parameters transformed into the corresponding sub-indices were aggregated into a final water quality index (fig. 4).Results at this station show a resemblance in the variation of the curves of WQIand fecal coli form sub-index. Over time when the water wasof poor quality, the fecal coli form sub-index dropped to zero, indicating that its value exceeded the acceptability limit. In addition to fecal coli form, total phosphorus sub-index has varied following the same pattern as the final water quality index. The correlation matrix between these parameters and the final water quality index shows a high correlation (r=0.84 at 95% confidence level) between the total coliform sub-index and WQI. The poor water quality at this station, lobserved in summer samples, is mainly due to the high quantity of fecal coliform. In contrary water is of good quality during winter of the same year. This station is located upstream Boufekrane Riverat about 5 kilometers north of the cityof Meknes. The proximity to the town of Boufekrane to the river streamisat the root of these high levels of fecal coliforms. El Ouali et al. (2011)[5] observed moderate to significant bacterial contamination in this area, particularly due to fecal coliforms of human and animal origin. Norat-Ramírezet al. (2019)[19] showed ina study conducted, in a Southern California watershed, that the concentration of bacteria in runoff water increases as a function of land use. In this sense: they affirm that a horse barn emits more bacteria than an agricultural area with animal fertilizer, and that the latter emits more than an urban area and more than a green space.

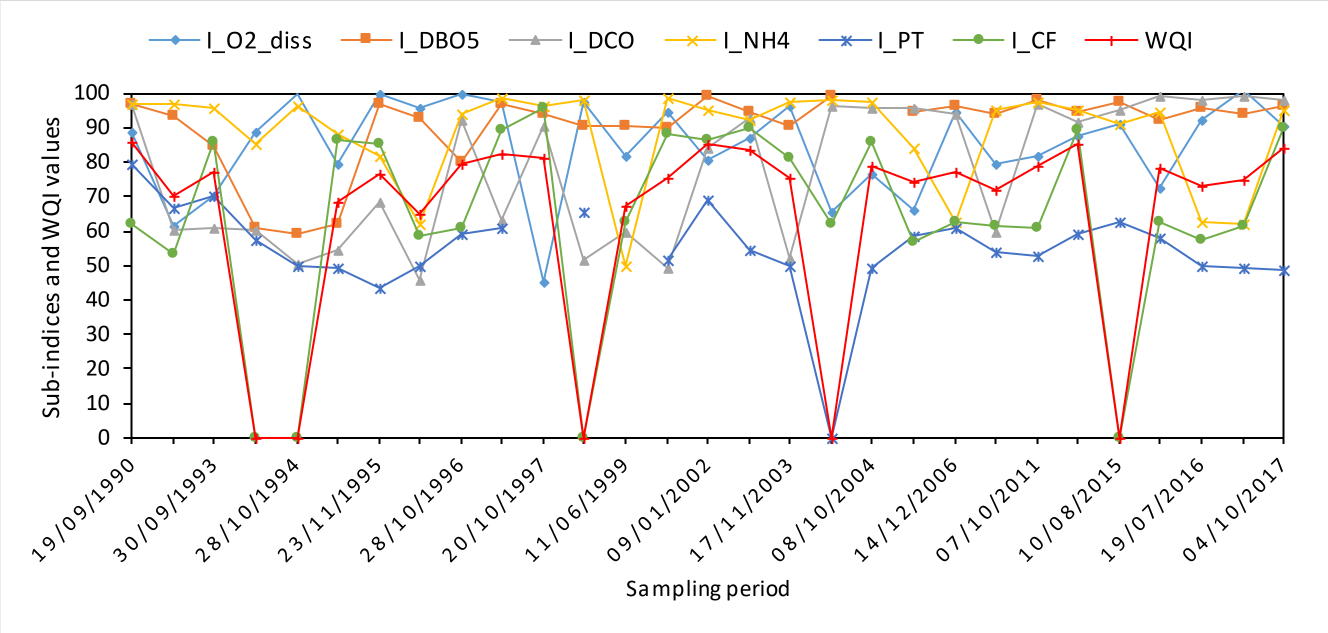

Fig. 4: Variation of water quality in station 1343/22 during the period 1990-2017.

I_O2: Dissolved oxygen sub-index; I_BOD5: bub-index pf biochemical oxygen demand for 5 days, I_COD: chemical oxygen demand sub-index; I_NH4: ammonium sub-index, I_TP: total phosphorus sub-index; I_CF: fecal coliforms sub-index; I_EC: Electrical conductivity sub-index; I_CL: Chloride sub-index; I_NO3: Nitrate sub-index.

Table 5: Correlation matrix of water quality parametersat station 1343/22

	I_O2_diss	I_DBO5	I_DCO	I_NH4	I_PT	I_CF	WQI
I_O2_diss	1						
I_DBO5	-0.14	1.00					
I_DCO	-0.21	0.48	1.00				
I_NH4	-0.25	-0.06	-0.02	1.00			
I_PT	0.11	-0.02	-0.08	0.07	1.00		
I_CF	-0.25	0.39	0.18	0.08	-0.09	1.00	
WQI	-0.11	0.41	0.25	-0.08	0.31	0.84	1

3.1.2. Station 2169/15 (Fès River)

Located downstream and north ofthe city ofFez, this stationis placedon Fez River. Figure 5 presentsthe variation ofwater quality atthis station. The analysis of results shows low values for sub-indexes of dissolved oxygen, total phosphorus, ammonium, and biological and chemical oxygen demand. Over time, the variation in water quality is chiefly explained by the levels of quality parameters. The correlation matrix of water quality parameter sub-indexes and the final quality index shows a high correlation between BOD_5sub-indexes and WQI(r=0.85), COD and WQI(r=0.71),NH_4^+ and WQI(r=0.59), PT and WQI(r=0.53). The evolution of these sub-indexes shows the same trend, especially when thefinalwater quality index was of poor water quality. In addition to being within the urban area of Fèz, this station is also bordered by farms. The high correlation between BOD_5 and COD sub-indices and WQI revealssignalsof organic pollution from industrial and domestic wastewater discharges. Dissolved oxygen sub-index has shown low values, especially in summer when temperatures are high. The dissolved oxygen content in water decreases when temperatures are high [5, 11]. Poor water quality isobserved during summer sampling periods [16, 10, 21, 23].

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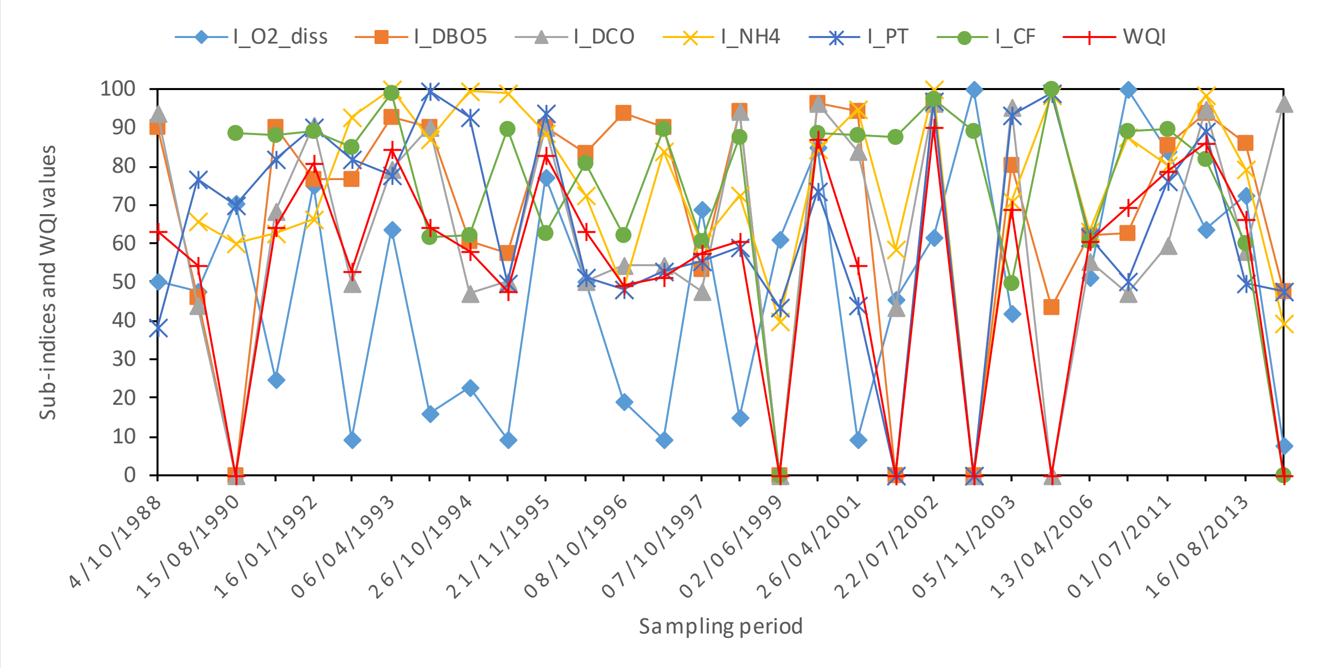

Fig. 5: Variation of water quality in station 2169/15 during the period 1988-2016

Table 6: Correlation matrix of water quality parameters at station 2169/15

	I_O2_diss	I_DBO5	I_DCO	I_NH4	I_PT	I_CF	WQI
I_O2_diss	1.00						
I_DBO5	-0.22	1.00					
I_DCO	-0.22	0.78	1.00				
I_NH4	-0.19	0.60	0.39	1.00			
I_PT	-0.06	0.49	0.34	0.62	1.00		
I_CF	0.17	0.25	0.00	0.43	0.11	1.00	
WQI	0.15	0.85	0.71	0.59	0.53	0.32	1.00

3.1.3. Station 1371/22 (Tizguit river)

Located in the mountains of the middle Atlas at 10 Km northwest of the town of Ifrane, analysis of the results at this station has generally shown good water quality over time. From 1990 to 2016, the water quality index value dropped to zero only twice in the winter of 2004 due to high levels of total phosphorus and BOD_5, and in the summer of 2016 due to high levels of fecal coliform. Overall, water quality is good at this station. The correlation matrix shows a very high correlation between the values of the PT and WQI sub-indexes (r=0.85), this is due in the fact that the sub-index of PT exceeded the permissible level on October 2004. The correlation is high between the CF and WQI (r=0.71) because the sub-index of CF exceeded the permissible level on Jun 2016. The correlation is also high between the BOD_5 and WQI (r=0.65) because the sub-index of BOD_5 exceeded the permissible level in October 2004. And the sub-index of the dissolved oxygen and WQI (r=0.68) showed a high correlation. That said, the different variations in water quality at this station are explained by the contents of these different water quality parameters. Fig.6 shows the water quality variation in this station.

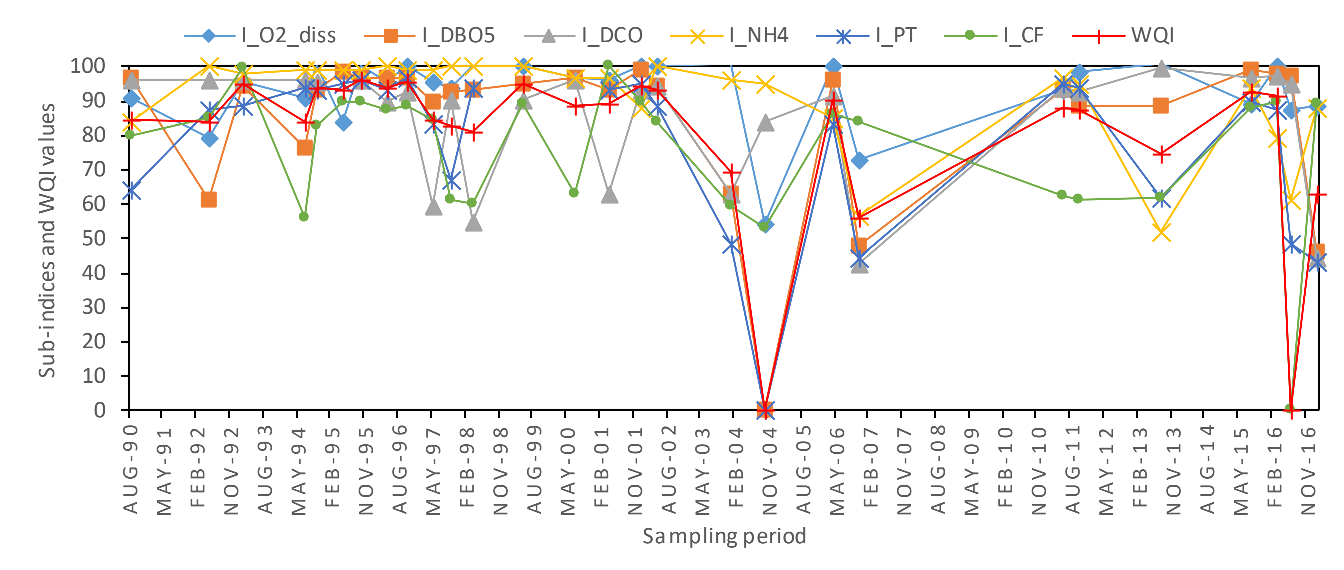

Fig. 6: Variation of water quality in station 1371/22 during the period 1988-2016

Table 6: Correlation matrix of water quality parameters at station 1371/22

	I_O2_diss	I_DBO5	I_DCO	I_NH4	I_PT	I_CF	WQI
I_O2_diss	1.00						
I_DBO5	0.80	1.00					
I_DCO	0.21	0.44	1.00				
I_NH4	0.16	0.11	0.09	1.00			
I_PT	0.68	0.80	0.35	0.44	1.00		
I_CF	0.20	0.16	-0.11	0.34	0.43	1.00	
WQI	0.68	0.65	0.22	0.46	0.85	0.71	1.00

3.1.4. The average values at the 3 stations: surface water

The average for the data for each sub-index was performed for each station to estimate the average water quality over the 30 years (1988-2017). Water quality varies from medium to good for the 3 stations. The fig.7 shows the average values of the WQI and the values of sub-indices for the stations. The station of the Fez river (2169/22) has water of medium quality but must be monitored by the water management authorities since this water is close to poor quality (WQI = 52.83 while the interval for poor quality water is {50 -38}). Perrin et al. [20] have already observed severe pollution at some measurement points in the Fez River, particularly high levels of total nitrate, total phosphorus, and chromium due to the influence of domestic and industrial wastewater discharges. Koukal et al. (2004)[14] report that the poor quality of Sebou river is mainly due to the low dissolved oxygen content in water and high turbidity, ammonium, organic matter, and severe chromium and copper pollution from industrial plants and urban public and domestic landfills. The station on Boufekrane river (1343/22) has approximately good quality water (WQI = 63.79) while the range for medium water quality is {63 - 50}). Finally, the station located on Tizguit river (1371/22) presents good quality water with a WQI = 80.08 close to excellent ({90 -100}). The application of the ABHS method showed medium water quality for the station (1343/22), poor quality for the Fez river station (2169/22) and good quality for the Tizguit river station (1371/22). This difference at the two stations is that the ABHS method consists in averaging the values for all samples over a period and classifying the parameters into different classes based on the simplified Moroccan standards grid. Then the final water quality index tends towards the worst class. As a result, if only one measure has absurd data, the final water quality index would be affected. This was the case for the Fez river station where the sample for the summer of 2016 showed a value of 2 million/100 ml for fecal coliforms.This was the same for the Boufekraneriver station where some parameters showed absurd data that affected the averages for the 31 years. The analysis of the mean value correlation matrix showed strong correlations between the dissolved oxygen

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sub-indexes (r=0.89), the ammonium sub-index (r=0.89), and the COD (r=0.94) with the final WQI. This means that variations in water quality at these different stations are explained by variations in the concentrations of these parameters. Koukal et al. (2004) [14], Perrin et al. (2014) [20], El Ouali et al. (2011)[5] have identified these parameters as the main pollutants in the Sebou basin.

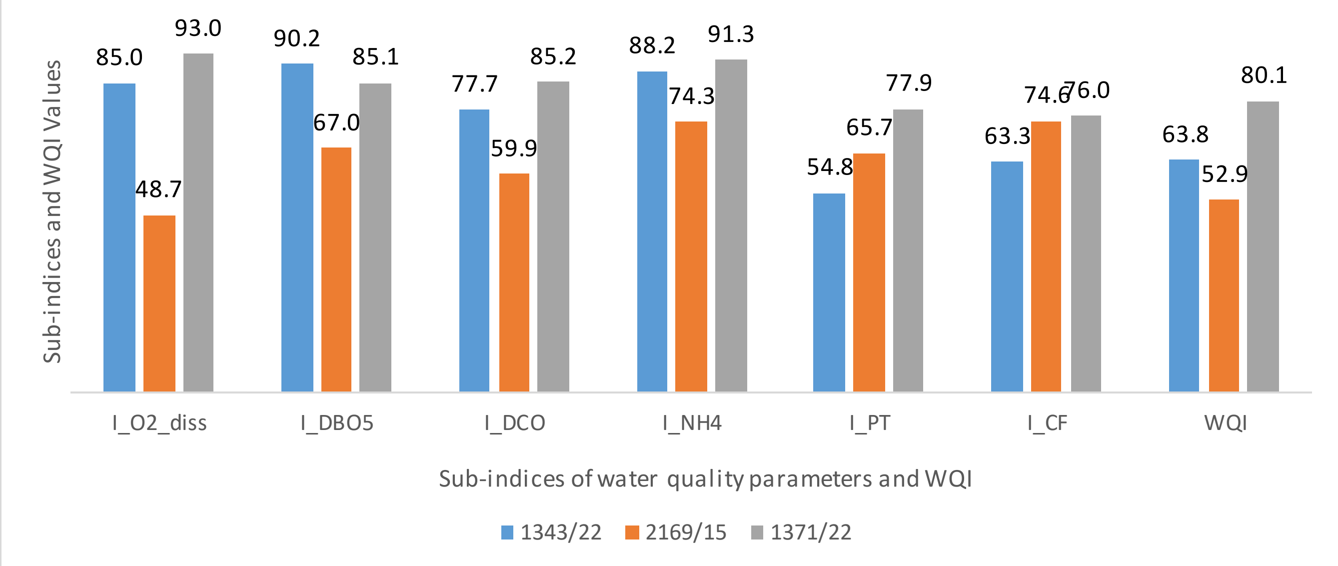

Fig. 7: Variation of water quality inthe 3stationsofsurface water during the period 1988-2017

Table 7: Correlation matrix of water quality parameters at the 3stations of surface water

	I_O2_diss	I_DBO5	I_DCO	I_NH4	I_PT	I_CF	WQI
I_O2_diss	1.00						
I_DBO5	0.93	1.00					
I_DCO	0.99	0.88	1.00				
I_NH4	1.00	0.93	0.99	1.00			
I_PT	0.20	-0.17	0.32	0.20	1.00		
I_CF	-0.25	-0.59	-0.13	-0.25	0.90	1.00	
WQI	0.89	0.66	0.94	0.89	0.62	0.21	1.00

3.2. Groundwater stations

The average for the data for each sub-index was performed for each station of the 26 stations to estimate the average water quality over the 31 years (1988-2017). A ratio of 42.3% of the stations have very poor to poor water quality and all are located in agricultural areas. The inventory of point sources (fig. 2) of pollution shows that these stations are also close to potential sources of pollution such as liquid discharges, industrial waste, public landfills, and industrial areas. Only 38.46% of the stations show good water quality, 7.69% excellent quality and 11.53% have medium quality. The establishment of the correlation matrix for the 26 stations (Table 8) between the sub-indices of the various parameters and the final water quality index showed a very high correlation between the nitrate sub-index and the final WQI for all stations where water quality varies from very poor to poor. The correlation of the nitrate sub-index with the WQI for water stations is r=0.96. Nitrates have agricultural origins, resulting from the application of fertilizers and livestock breeding, reaching groundwater after leaching [5]. The presence of nitrates in groundwater is generally from agricultural, landfill and industrial sources [13]. However, nitrate is not the only cause of the degradation of the quality of these stations. At 5 stations, the sub-index of electrical conductivity with WQI is high: 197/15 (r=0.59), 1210/15 (r=0.56), 1226/15 (r=0.79), 2702/15 (r=0.56), 1306/22 (r=0.62). In addition to electrical conductivity, the chloride sub-index showed a strong correlation with WQI at 2 stations: 1210/15 (r=0.60), 1226/15 (r=0.68). The high content of electrical conductivity shows the presence of salts in groundwater [5]. Salts can be of natural or anthropogenic origin through irrigation in agricultural areas. Three stations presented water of average quality. The variation of the chloride sub-index with the WQI showed a high correlation for station 352/21. Chloride can be naturally occurring or present in groundwater through industrial activities, wastewater discharges, and landfills. Since most groundwater, pollution comes from surface water pollution [5]. Fig. 8 and 9 show the variation in the values of the quality parameter sub-indexes and the WQI for the 26 stations. Nitrate curves and WQI have the same variations for stations, including those with good to excellent water quality. The high nitrate content due to agricultural activities explains this variation in the overall water quality.

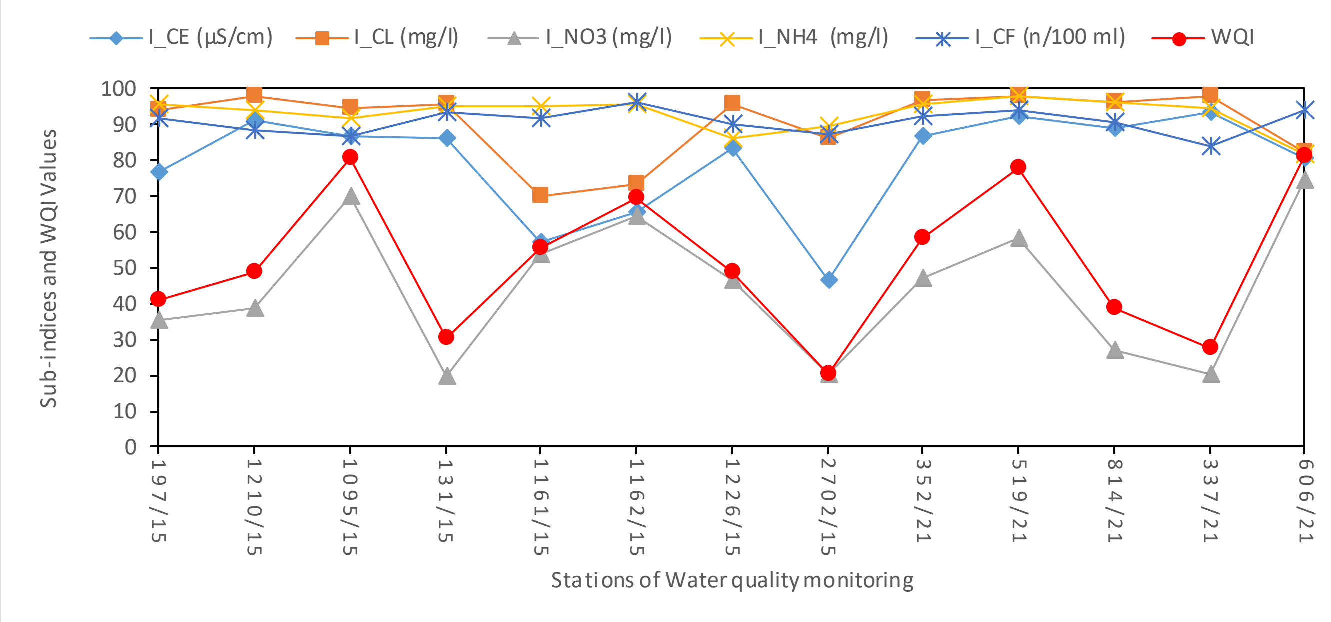

Fig. 8: Variation of water quality in26 stations of groundwater during the period 1988-2017

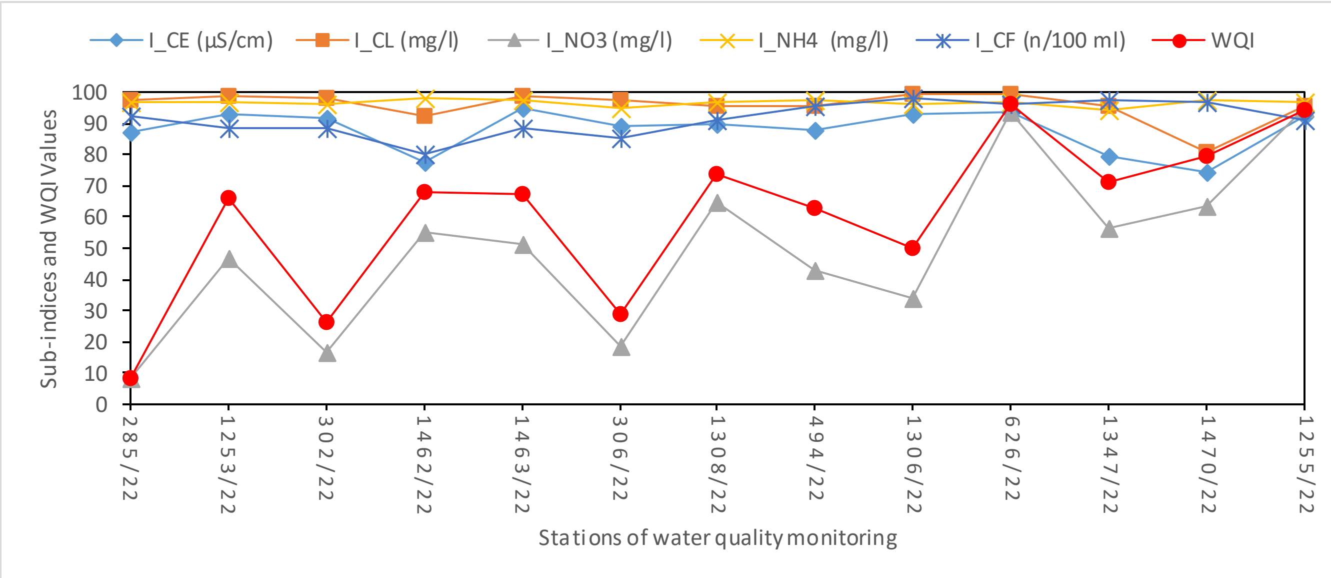

Fig.9: Variation of water quality in26 stations of groundwater during the period 1988-2017

Table 8: Correlation matrix of water quality parameters at the 26 stations of groundwater

	I_CE (µS/cm)	I_CL (mg/l)	I_NO3 (mg/l)	I_NH4 (mg/l)	I_CF (n/100 ml)	WQI
I_CE (µS/cm)	1.00					
I_CL (mg/l)	0.80	1.00				
I_NO3 (mg/l)	0.04	-0.24	1.00			

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I_NH4 (mg/l)	0.28	0.24	-0.05	1.00		
I_CF (n/100 ml)	-0.02	-0.20	0.29	0.06	1.00	
WQI	0.14	-0.15	**0.96**	0.05	0.31	1.00

3.3. Comparison between the ABSH method and the proposed WQI

Fig. 10 shows the comparison of the ABHS method and this proposed WQI for the 26 stations for the 5 water quality classes. Other researchers such as Lermontov et al. (2009)[15], Gharibi et al. (2012)[7] have made comparisons with one of the other methods to validate proposed water quality indices. Mathematically, the ABHS method is expressed as follow: $water\ quality\ index =$ $\min\{class_1, class_2, \ldots, class_i\}$ (44), with min: the most deteriorated class of the ith parameter; class$_i$, the water quality class corresponding to the ith parameter.

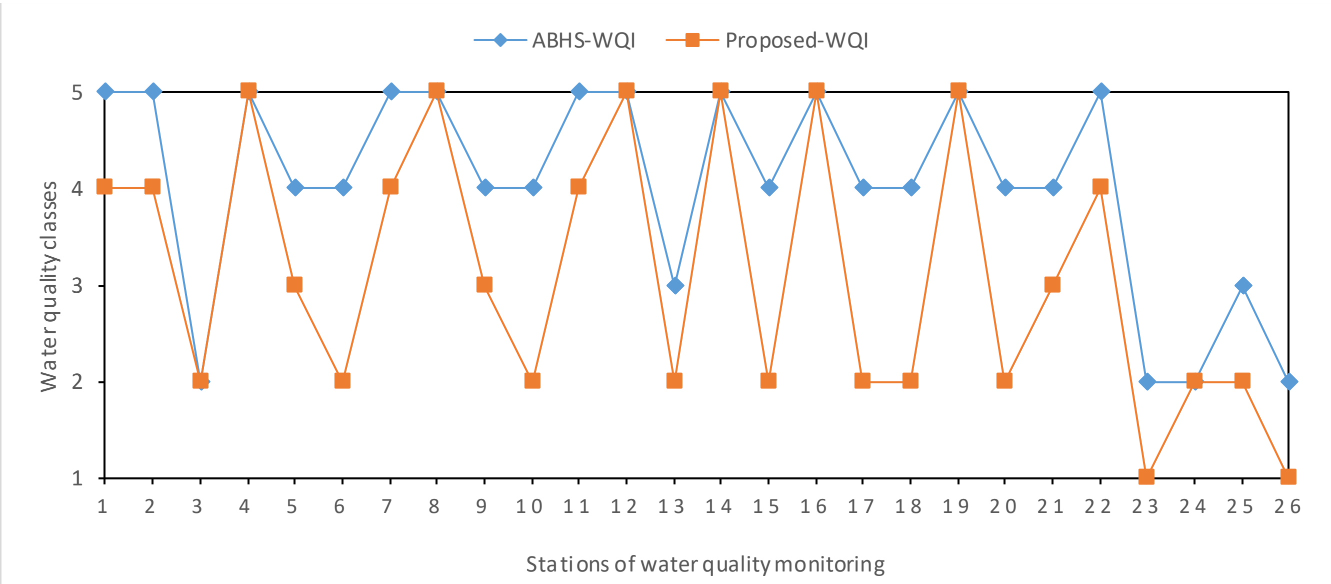

Fig. 10: Comparison of ABHS method and this method proposed for the 26 stations of groundwater. 1: excellent, 2: good, 3: medium, 4: bad and 5: very bad.

Analysis of this curve shows that the ABHS method tends to overestimate the deterioration in water quality. For example, for stations 1 and 2, the proposed method indicates that they are of class 4 quality, which means poor water quality, while the ABSH method indicates that they are of class 5, which means very poor water quality. In addition, this is also the case for station 26, where the proposed method indicates excellent water quality; the ABHS method indicates good water quality. This is because the ABHS WQI always tends towards the most deteriorated class in terms of water quality, i.e. the worst or very bad class, etc. In other words, if all the parameters have shown very good water quality, in the application of the simplified grid standards (Moroccan standards), with the exception of one quality parameter which has shown water of medium quality, the overall water quality is indicated as medium. While the proposed method uses the contribution of all sub-indices, i. e. the normalized values of the various parameters to determine the final water quality index. For stations where both methods indicate the same class, this means that at least one parameter has exceeded the permissible water quality limit, i.e. the limit at which if this parameter is present in water, the water is no longer usable for consumption, for example, this limit is 50 mg/l for nitrate (Moroccan standards and WHO). This proposed method is more flexible than the ABHS method because it does not tend towards the bad or the excellent of the parameter classes that compose it, unlike the ABSH method, which always tends towards the minimum of the classes of the parameters that compose it.Determining water quality for a time series of data may be difficult by applying the ABHS method because of the qualitative nature of the overall water quality. In other words, unless the data are averaged for each water quality parameter, it is impossible to determine a mean class for the quality time series. In addition, if there is only one outlier for a quality parameter during any sampling, this will affect the entire assessment, as it would mean averaging over a given period, and therefore affect overall water quality, although for the same station the concentration of a parameter can vary significantly between two sampling points. The proposed method is the contribution of all water quality parameters and has the advantage of presenting the values of the different variables quantitatively before being presented in classes because of the forms of normalization and aggregation of the WQI. Figure 11 shows the regression equation between the ABHS water quality index and the proposed WQI using the same data and water quality parameters. Moreover, it shows that there is a positive correlation between the two methods at r = 0.84 at a 95% confidence level.

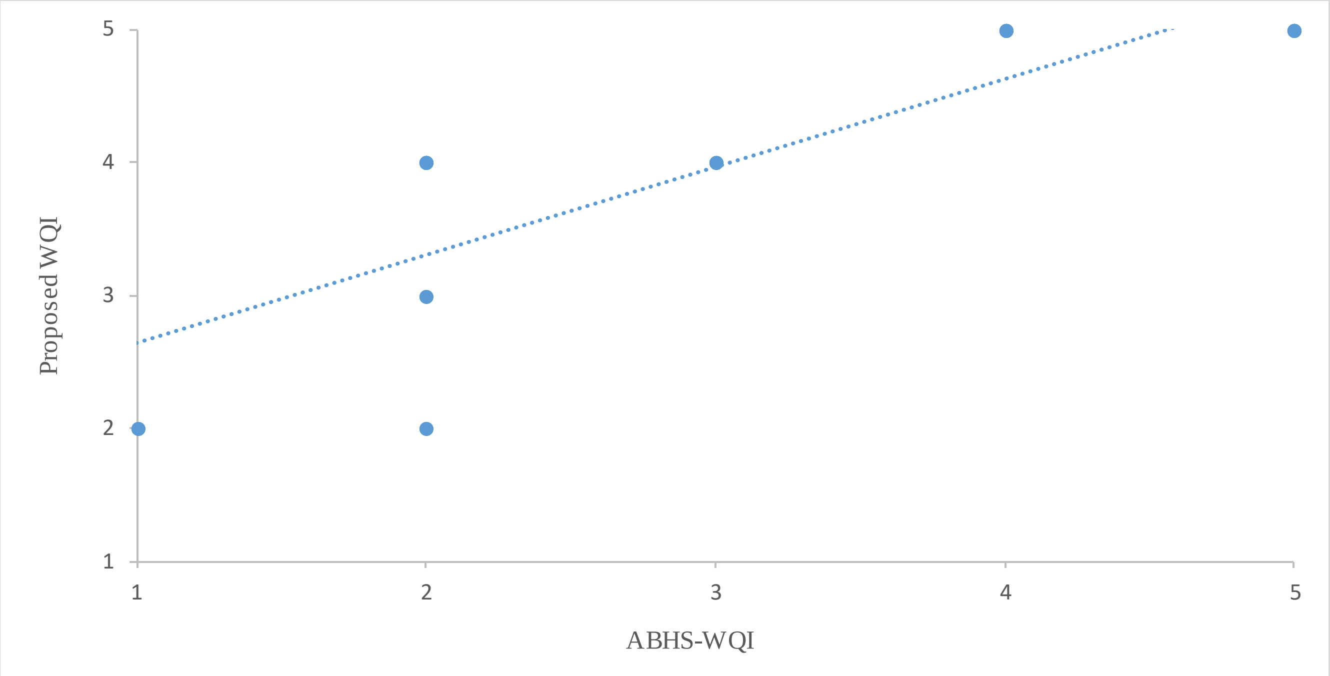

Fig. 11: Regression fitbetween results of the ABHS method and results of theproposed WQI (R^2=0.7, at the 95% confidence level) for the 26 groundwater stations.

IV. CONCLUSION

A water quality index is a practical tool for appreciating the general status of water quality. The proposed WQI was developed to remedy the observed gaps in the Sebou Hydraulic Basin Agency index, although the comparison of the two methods showed a positive agreement for the studied stations. The new WQI is different from those used in Morocco because it uses mathematical equations to normalize water quality parameters and presents it quantitatively instead of using a simplified grid that gives classes and always tends towards the minimum value, i.e. towards the most deteriorated class. The flexibility of operation with the proposed WQI is a great asset for water resource managers since it will facilitate for them the interpretation of results, especially if it is necessary to calculate water quality over multiple campaigns. This WQI could be further developed into smartphone or laptop application that will directly determine water quality and interpret results, thus facilitating water resource management. The proposed WQI uses Moroccan standards to normalize the observed values of water quality parameters. Therefore, its use in another locality, outside Morocco would need the upgrade of normalization equations of parameters using the standards values of water parameters of this locality.

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