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MONITORING OF GROUNDWATER QUALITY IN A SEMI-ARID REGION, TEBESSA BASIN (NORTH-EAST OF ALGERIA): USING POLLUTION INDEX OF GROUNDWATER

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Abstract: *The study area is characterized by low rainfall and a significant outcrop of salt formations, which significantly compromises the use of water for consumption and other purposes (agriculture and industry). Groundwater contamination affects both water quality and human health. Hence it is essential for continuous monitoring of the quality of groundwater so that contamination can be minimized. Application of pollution index of groundwater (PIG) to the problem of estimating groundwater contamination with respect to their drinking water quality standards has been done by the investigation of 58 water sample. The computed values of Pollution Index of Groundwater (PIG) for the study area vary from 0,457 to 8.190. Spatial variation map has been prepared using GIS. The variation map shows that most of the study area accounts for high and very high pollution zones, which is mainly due to geogenic, anthropogenic factors and also it is compounded due to mining activities. Geochemical ratios (Na^+: Cl^-, HCO_3^- : Cl^-, Na^+: Ca^{2+} and Mg^{2+}: Ca^{2+}) also form the quantitative basis of the index. This manuscript synthesizes a set of data that allowed us to make a classification of the contamination zones, using PIG tool, of the study area.*

Keywords: *Drinking-water, pollution index of groundwater, semi-arid area, Tebessa, Algeria.*

1. Introduction

Water is considered as rare, precious and indispensable source in many domains, such as: industry, agriculture, construction, etc. Water chemistry can be used to help understand effects natural and human activities. The hydrochemical composition of water inside an aquifer is normally controlled by elements such as: lithology, weathering, dissolution, precipitation or ion exchange. The Algerian climate is a transitional climate. It varies from the Mediterranean type in the north to the desert type in the Sahara.

The climatic conditions and the lithology of arid zones are contributing in the modification of the physic-chemical properties of the waters. In this context, several researches have been conducted on groundwater to assess the hydro chemicalprocesses, groundwater quality and water suitability for the irrigation of this region. They have shown that groundwater hydrochemistry depends ontwo important resources: natural and anthropogenic processes. In this context, several researches have been conducted on groundwater to assess the hydrochemicalprocesses, groundwater quality and water suitability for the irrigation of this region. They have shown that groundwater hydrochemistry depends

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on two important resources: natural and anthropogenic processes [1] and [2].
Tebessa Basin is among the semi-arid areas, where the increased forage yield is the main source of water consumption in drinking and irrigation. Nevertheless, the northern part of the region is an area of active and abundant mines which constitute about 83% of the total Algerian iron production [3]. Due to its abundance and availability nexus the water source static levels, their geological constituents cause realistic challenge on groundwater quality. Moreover, its ecological function has great impact on public health and on flora diversity [4]. The increasing population as well as industrial and agricultural demands renders the protection and preservation of groundwater resources all the more important.
The aim of the present paper is to characterize the groundwater quality by using a pollution index of groundwater (PIG) for groundwater contamination quantificationin the study area (Figure 1), and the determination of pollution zones for proposing remedial solutions at a specific site.

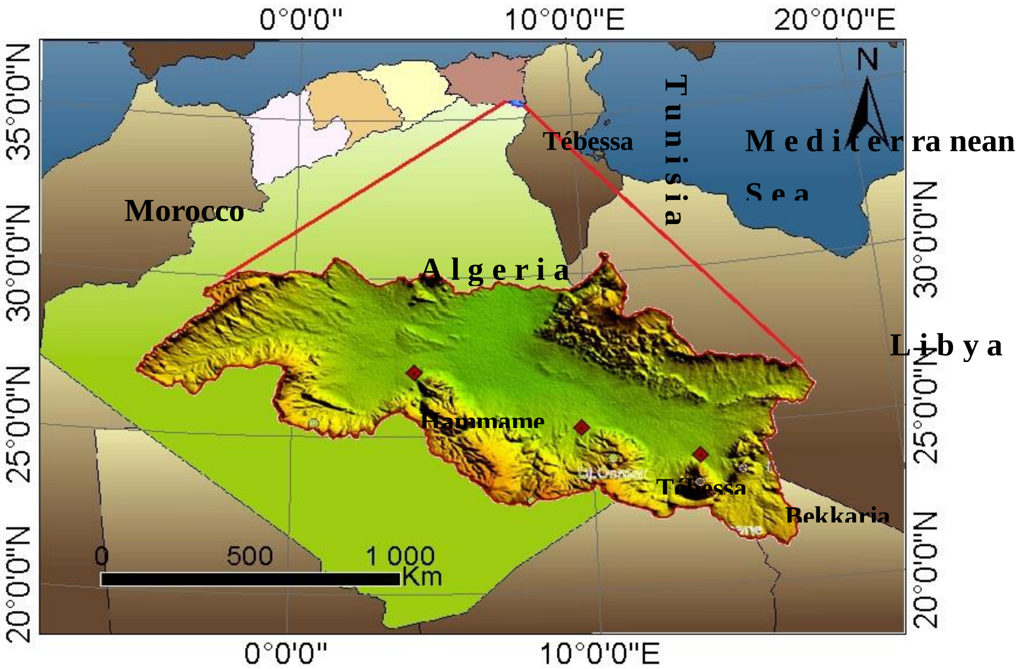

Fig. 1. Geographic situation of the study area

2. Characteristics of the study area

The Tebessa basin is an agricultural region located in the north east of Algeria, within the semi-arid zones of the country and characterized by a precipitation of less than 400 mm per year (Figure1). The basin of Tebessa is a flat plain surrounded by several mountains with different altitudes such as: Djebel Troubia, Djebel Serdiess in the West, by Djebel Kouif and Bouremane in the East, and by Djebel Dyr and Belkfif in the North and by Djebel Doukkane, Tezbent and Essen to the South, respectively, as it described by the Figure 2.
The hydrogeological system of Tebessa basin consists of Mio-plio-quaternary and Cretaceous aquifer. The superficial unit of the Mio-plio-quaternary is constituted from

unconsolidated materials, consisted by actual and recent alluvial deposits, conglomerates, gravels and sandstones, which form an alluvial aquifer.

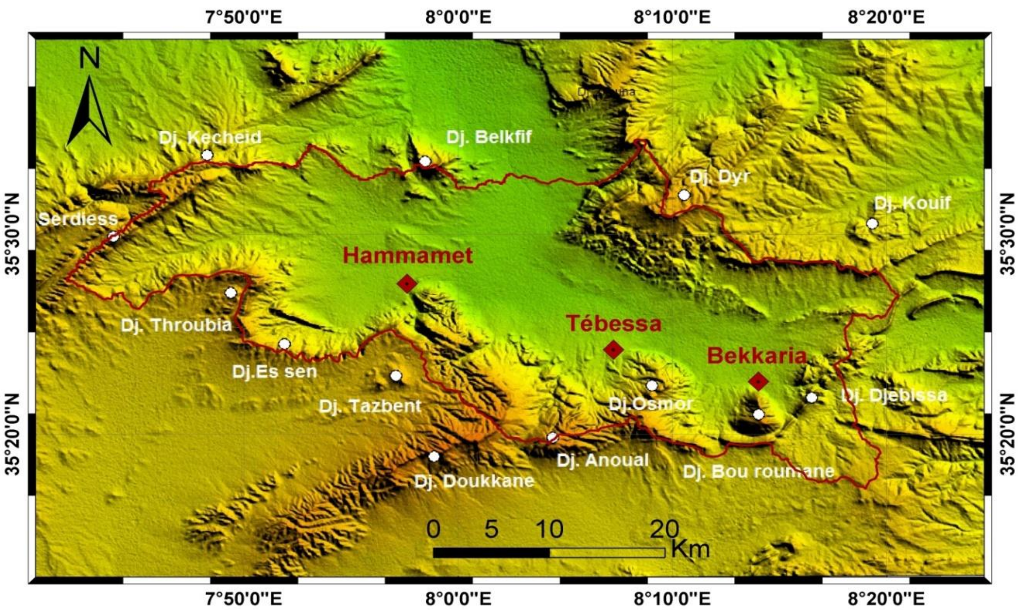

Fig. 2. Natural boundaries of the study area

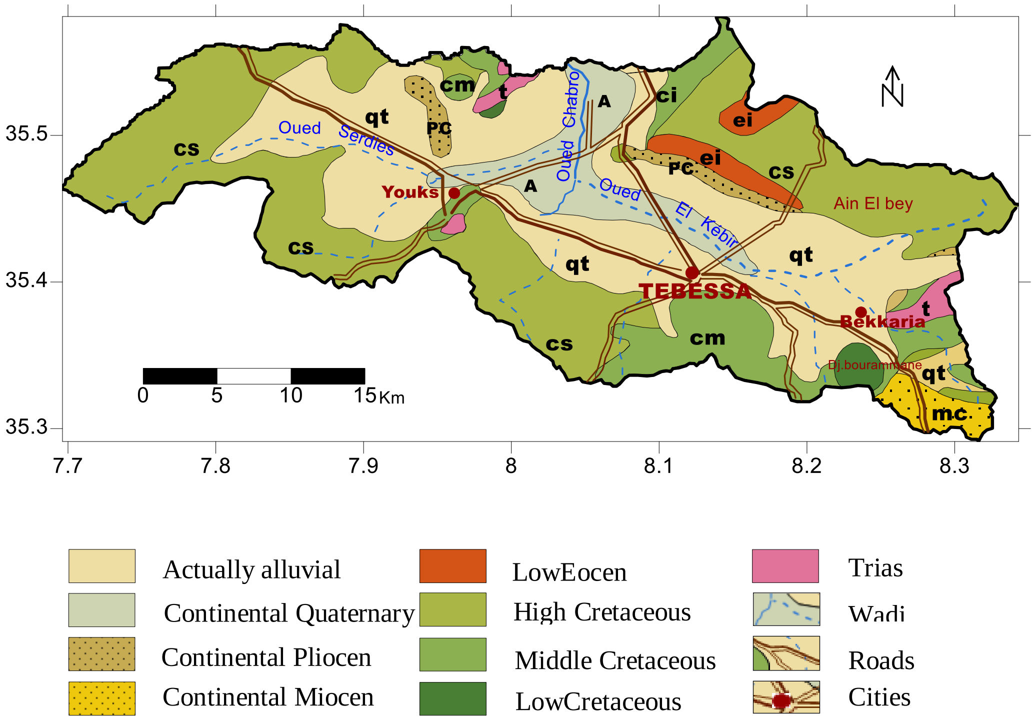

Fig. 3. Geological map of the study area

The Cretaceous units forming a series of anticlines and synclines.The stratigraphic sequence is presented in the form of alternation of carbonated formations of limestones, marly-limestones and argillaceous marls forming a very important karstic aquifer [5] [6]. It is noted the presence of Triassic evaporitic outcrops (clay and gypsum), which stand above the eastern borders of the study area (figure 3).

3. Hydrochemical data

3.1 Field work

A survey was carried in Tebessa basin, and 58 samples were collected from open dug wells during February 2020 (fig.4). Water samples were collectedin clean polythene bottles, washed thoroughly with dilute nitric acid then rinsed with distilled water, and again rinsed with representative water samples. The physical parameters of the water sources, such as pH, electrical conductivity (EC), and total dissolved solids (TDS) were measured in the field.

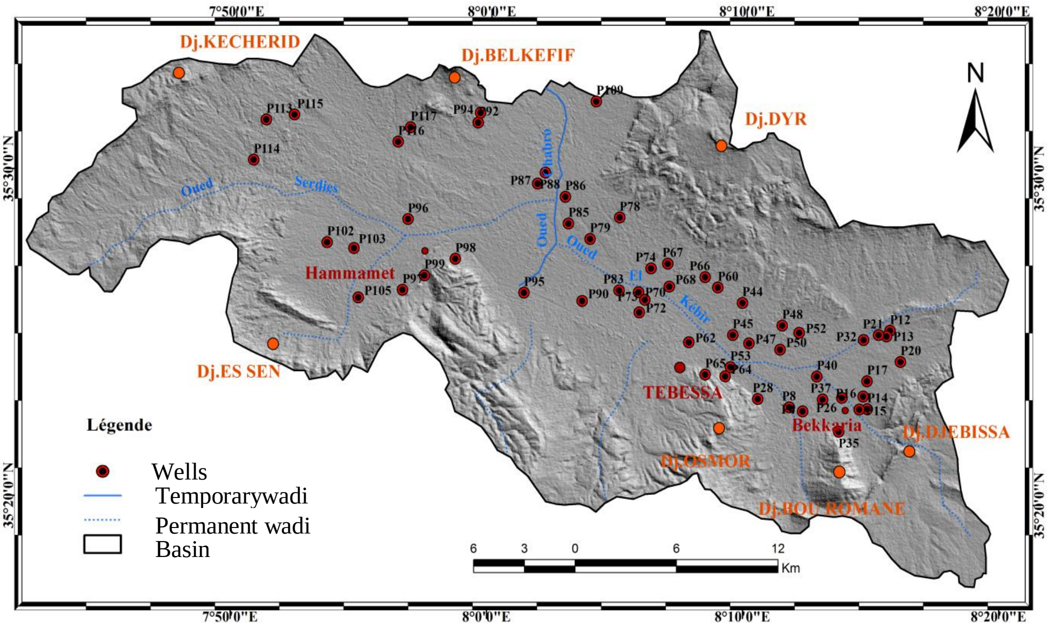

Fig. 4. Map of sampled wells – Tebessa Basin

3.2 Laboratory work

The chemical parameters of the groundwater samples like major cations, calcium (Ca^{++}), magnesium (Mg^{++}) were determined by EDTA titration method. Sodium (Na^{+}) and potassium (K^{+}) were determined by flame photometric method. Anions like bicarbonate (HCO_3^-) were measured by titration to the methyl orange end point. The amount of chloride (Cl^-) present in groundwater samples was determined by titration and precipitation of AgCl until silver chromate appears. Sulfate (SO_4^{2-}) was determined by precipitation of $BaSO_4$ and then measuring the absorbency with spectrophotometer. Trace metals namely iron (Fe), copper (Cu), lead (Pb) and manganese (Mn) were analyzed using atomic absorption spectrophotometer (AAS).Organic matter such as phosphate (PO_4), nitrite (NO_2), ammonium (NH_4) and nitrate (NO_3) was measured by the phenol disulfonic acid method.

The analyzed data (Table 1) has been used in the computations. The standards for drinking purposes as recommended by WHO and BIS have been considered for the calculation of Pollution index of ground water (PIG) [7]. There are different steps for computing PIG which includes assigning a weight to each chemical parameter according to its relative importance in the overall quality.

Table 1.

Chemical composition of groundwater in the Tebessa Basin

Water qualitymeasure	Units	Minimum	Maximum	Moyenne	Standard deviation
pH		6.140	8.220	7.186	0.300
TDS	mg/l	6.070	11550.000	3345.357	2619.367
RS	mg/l	420.000	18501.000	2511.847	2670.277
Ca	mg/l	39.360	793.280	258.251	169.925
Mg	mg/l	13.520	243.870	86.878	57.135
Na	mg/l	28.000	1560.000	375.441	395.859
K	mg/l	1.000	38.000	4.271	5.382
Cl	mg/l	40.000	2025.000	448.475	451.330
SO4	mg/l	22.000	3820.000	851.966	806.846
NO3	mg/l	0.000	275.000	47.746	54.847
HCO3	mg/l	30.500	939.400	298.475	128.108

4. Computation of pollution index of groundwater (*PIG*)

PIG is an arithmetic scale, quantifying the degree of water contamination. It represents a complex influence of individual water quality measures on general water quality of aquifer. The steps to compute PIG is given as follows:

4.1 Relative Weight (Rw)

A relative weight (Rw) for each chemical parameter is assigned a weight age by keeping its impact on human health into consideration. The range of numerical magnitude of Relative weight ranges from 1 to 5 (Table 2).

Table 2.

Weighting scheme for drinking water quality standard with respect to water quality measures

Water quality measure	Units	Relative weight (Rw)	Weightparameter (Wp)	Drinking water quality standard (Ds)*
pH		5	0.139	7.5
TDS	mg/l	5	0.139	500
Ca	mg/l	2	0.056	75
Mg	mg/l	2	0.056	30
Na	mg/l	4	0.111	200
K	mg/l	1	0.028	10
Cl	mg/l	4	0.111	250
SO4	mg/l	5	0.139	150
NO3	mg/l	5	0.139	45
HCO3	mg/l	3	0.083	300
Sum ∑		36	1.000	

*Davis and Dewiest (1966), Holden (1970), and BIS (2003)

For instance, the value of 5 of the Rwis assigned to pH, TDS, NO_2, NH_4, and NO_3; 4 to Na^+, Cl^-, PO_4, Fe, Mn and Pb; 3 to HCO_3^-; 2 to Ca^{++} and Mg^{++} and 1 to K^+. The lower values of *Rw*indicate lesser impact of respective chemical parameters on health and higher values have more impact over human health.

4.2 Computation of Weight Parameter (Wp)

Weight parameter is the ratio of *Rw*of every water quality measure to the sum of all relative weights. Weight parameter helps to know about the relative share of each water quality measure on overall water quality. The *Wp*is given by the equation:

$$Wp = Rw / \Sigma Rw \qquad (1)$$

4.3 Status of concentration (SC)

The Sc is computed by dividing the concentration (C) of each water quality measure of every water sample by its respective drinking water quality standard.

$$(Ds): Sc = C / Ds \qquad (2)$$

4.4 Overall water quality (OW)

The overall water quality is computed by taking the product of each water quality measure with its corresponding status of concentration. Ow reflects overall water quality and also enables to understand the nature of weight parameter with respect to concentration of each water quality measure. Ow is calculated by:

$$Ow = Wp * Sc \text{ (Table 3)}. \qquad (3)$$

4.5 Pollution index of groundwater (PIG)

Pollution index of groundwater is calculated by adding all values of Ow contributed by measures ofall water quality of each sample of groundwater. PIG is given by:

$$PIG = \Sigma Ow \qquad (4)$$

4.6 PIG Classification

The classification of PIG is based on water quality standard for drinking purpose. PIG classification could also be used in the assessment of groundwater contamination. When both the values of quality of particular water sample and concentration of water quality measure are same then their impact on health could be insignificant. With an account of this, when the PIG value is less than 1.0, it could be considered as a non-pollution index and when PIG exceeds more than 1.0, it is probably dueto the contribution of additional concentrations of water quality measures into groundwater by the direct pollution of the aquifer. The intensity of PIG is as follows:

PIG values	PIG intensity
PIG<1.0	Insignificant pollution
1.0<PIG<1.5	Low pollution
1.5<PIG<2.0	Moderate pollution
2.0<PIG<2.5	High pollution
PIG>2.5	Very high pollution

When Ow is more than 0.1 (which represents 10% of 1.0 of PIG value), the relative contribution of concentration of water quality measure of each water sample is taken into consideration. This gives an idea on impact of pollution on groundwater.

5. Results and discussion

5.1 Groundwater movement and evolution

The piezometricmap shows that the direction of groundwater movement must be moving as represented in Fig. 5 from the east towards the center in one path and the other path is from the western part towards the center part.Groundwater movement show that the Tebessa basin is divided in two aquifer system, at the east this system is recharged through carbonate formations outcropping from Bouromane mountains and in the west part this aquifer system have a direct alimentation from Meastrichtian fractured limestone from Hammamet and Doukkane mountains.

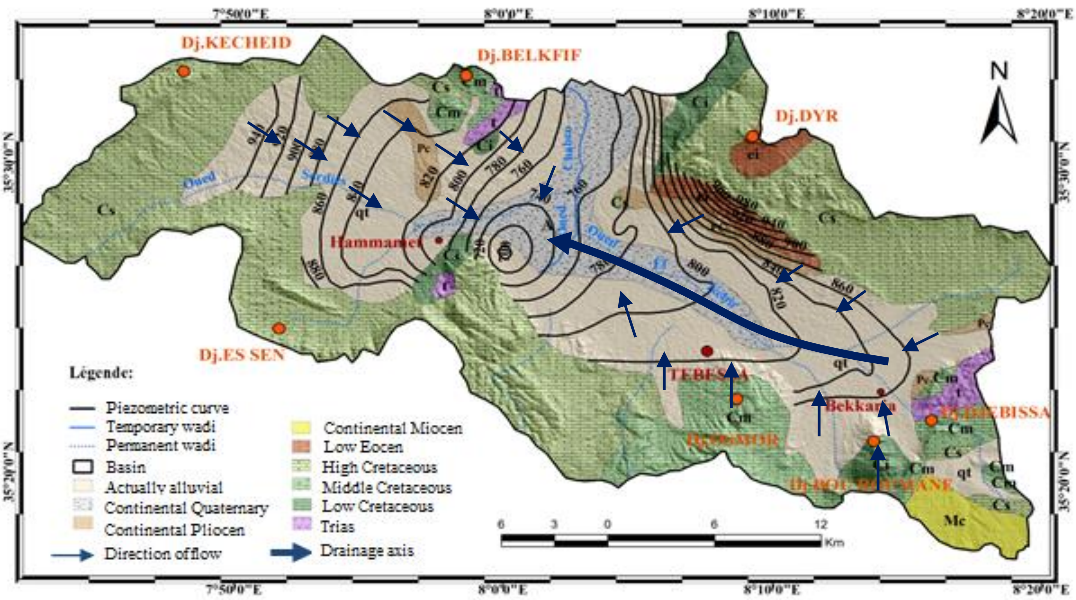

Fig. 5.Piezometric map –TebessaBasin

5.2 Water quality

The value of physical parameters (pH, EC and TDS) of the water samples collected from Tebessa Basin changes from 6.9 to 7.6, 1500 to 3320 µs / cm and 1060 to 1960 mg/l, with mean values of 7.39, 2652.73 µs / cm and 1489.09 mg/l respectively (Table 1). The concentrations (mg/l) of major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), major anions (HCO_3^-,Cl^- and SO_4^{2-}),and Organic matter (NO_3^-) are in the range of (39.36 to 793.28,13.52 to 243.87, 28 to 1560 and 1.00 to 38.00), (30.50 to 939.4, 40.00 to 2025.00 and 22 to 3820), and (0 to 275).Statistical parameter of the analytical results of groundwater is given in Table 1.

The calculated values of PIG in our study region are between 0,457 to 8.190 (Figure 6).

According to the classification of PIG, 22.41 % of the all groundwater samples which represent moderate to high pollution zone and about 43.10% as very high pollution zone.

Spatial distribution map of zones of PIG has been prepared using GIS (Map-2). The variation map (Figure 7) depicts a pollution zone insignificant observed in the extreme southern part, this part of the study area is characterized by a very high topography (upstream area). Low pollution zone is observed and clearly dominate the central part. Moderate pollution zone is spread in the eastern, western and northern parts of the study area. High pollution zone is observed in the northern and western part. Very high pollution zone is spread in the extreme northern part, where the topography is low (downstream area). Thus, the spatial distribution map of PIG zones shows a gradual increasing of PIG values from upstream to downstream.

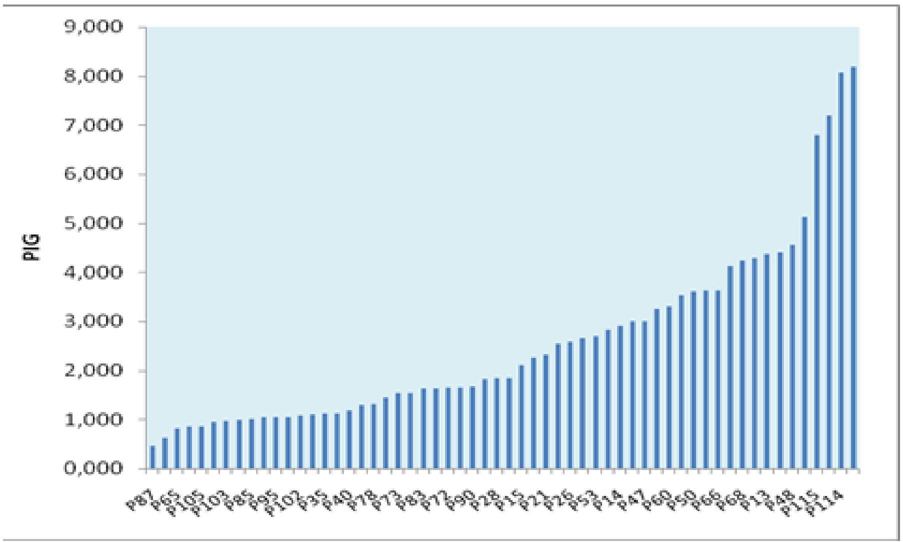

Fig. 6. Sample-wise PIG values

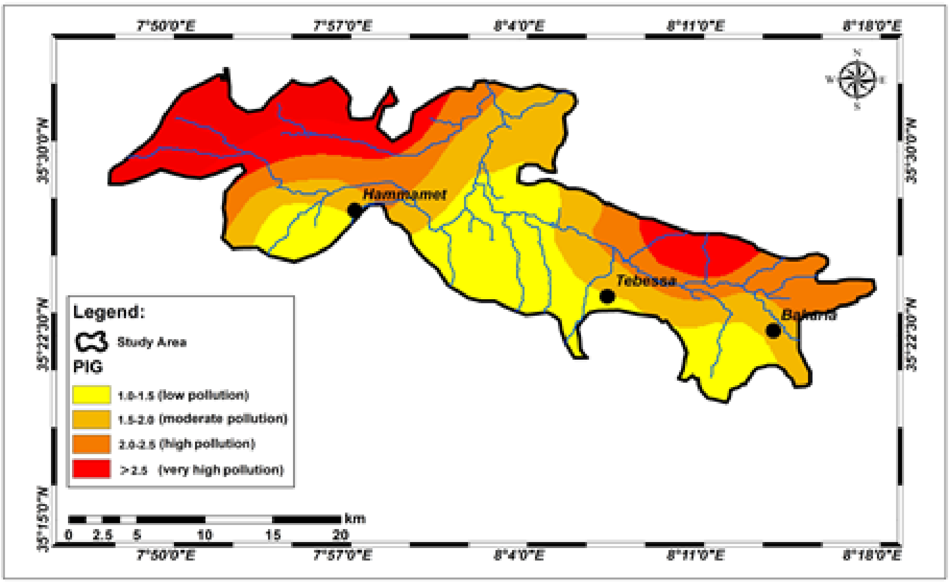

Fig. 7. Spatial distribution of groundwater pollution zones in the case study area (Tebessa Basin) based on PIG

This suggests a progressive increase of pollution from insignificant level to significant level.
Insignificant pollution zone is principally characterized by the following values: TDS (0.167), pH (0.133), and SO_4^{2-} (0.14) corresponding to Ow values more than 0.1 (Table 3). The rest of water quality measures, Ca^{2+} (0.081), Mg^{2+} (0.057), Na^+ (0.033), K^+ (0.003), Cl^- (0.038), HCO_3^- (0.075), and NO_3^- (0.091), are considered as principal contributors under natural conditions, because their Ow values are less than 0.1. pH variation from 6.14 to 8.22 (Table 1) is due to the concentration of HCO_3^-.The groundwater aquifer system is in permanent contact to soil CO_2, this last one coming, generally,from organic matter and root respiration. The CO_2 combined to the rainwater infiltration form bicarbonates$^-$, leading to a mineral dissolution [8]. All dissolved ions in the groundwater area direct result of the total dissolved salts TDS [9].
In the low pollution zone,the water quality measures, pH (0.135), TDS (0.251), SO_4^{2-} (0.25) and NO_3^- (0.1),Ow values are more than 0.1 (Table 3). They have higher Ow values compared with those values of the water quality measures Ca^{2+} (0,096), Mg^{2+} (0.083), Na^+ (0.07), K^+ (0.01), Cl^- (0.06) and HCO_3^-(0.09) .Weathering of gypsum is the main source of SO_4^{2-} in the study area [10]. Ion exchange and precipitation of $CaCO_3$ are also the mainly causes for increased Ca^{2+} [11] and [12]. Anthropogenic sources (chemical fertilizers, irrigation return flows, poor drainage conditions and leakage of septic tanks), lead to the presence NO_3^- in the groundwater.
The water quality measures, pH (0.13), TDS (0.38), Ca^{2+} (0.16), Mg^{2+} (0.13), SO_4^{2-} (0.45) and NO_3^- (0.13), show Ow values more than 0.1 in the moderate pollution zone (Table 3), due to the geological and anthropogenic origin. They have more Ow values compared with those values of Na^+ (0.08), K^+ (0.02), Cl^- (0.1) and HCO_3^- (0.1) in the same pollution zone (Table 3). The higher values of Ow in the groundwater samples are observed in the very high pollution zone compared with those of water quality measures in the moderate to high pollution zone (Table 3).
The value of Ow of NO_3^- is more than 0.1 in the high pollution zone, which is probably due to role of anthropogenic activities on the groundwater aquifer system in the high pollution zone. Furthermore, the Ow value of bicarbonatesisless than that of Cl^-, while that of sodium is less than that of chloride. This confirms that the geogenic source is the main detrimental factor in the control of groundwater quality.
In the insignificant, low, moderate, high pollution zones and the very high pollution zone (Figure 8), the geochemical ratio of Na^+-Cl^- is more than one (1.00 to 1.45) this is probably due to the meteoric source of groundwater in the very old zones.
The ratio HCO_3^-: Cl^- is more than unity in the insignificant (1.87) and low (1.41) pollution zones and is less than unity in the moderate (0.92), high (0.40) and very high pollution (0.19) zones (Figure 8). This is due to a meteoric source of groundwater in the old part of the aquifer and dissolution of triasic formations in the shallow zones.
The ratio HCO_3^-:Cl^- is rapidly dropped to 0.19 in the very high pollution zone.This suggest that the groundwater is mainly influenced by evaportitic formations in the very high pollution zone.
The ratios Na^+ : Ca^{2+} are observed to be more than unity (1.11 to 1.53) for high and very high pollution zone (Figure 9),This suggests a precipitation of $CaCO_3$ and less than one (0.5 to 0.8) in the insignificant, low and moderate pollution zone (Figure 9), showingthe geogenicorigin (influence of Triassic formations). The ratios Mg^{2+}: Ca^{2+}isless than one (0.235 to 0.288) in the

pollution zones (Figure 9). This is due probably to $CaCO_3$ precipitation and ionic exchanges. However, thevalue of the Mg^{2+}: Ca^{2+} ratio is almost similar in all pollution zones.

This shows the sameorigins of Mg^{2+} and Ca^{2+} ions, as is also observed from the ratio of Na^{+}: Cl^{-} (Figure 8).The differences in the geochemical ratios explain the different factors controlling concentrations changes of water quality measures in all zones (Table 3).

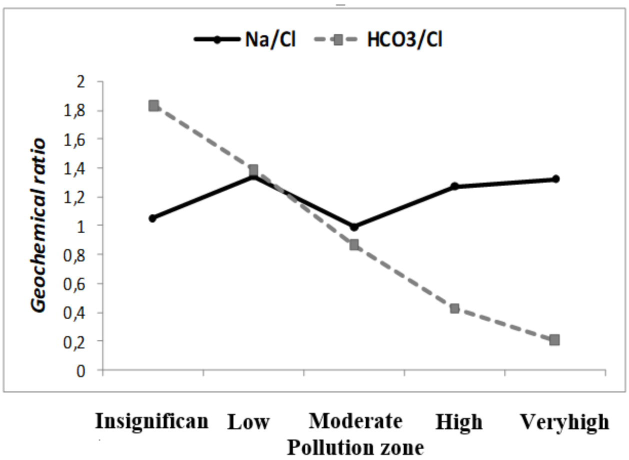

Fig. 8. Ratios of Na^{+} : Cl^{-} and HCO_3^{-} : Cl^{-} with respect to pollution zones

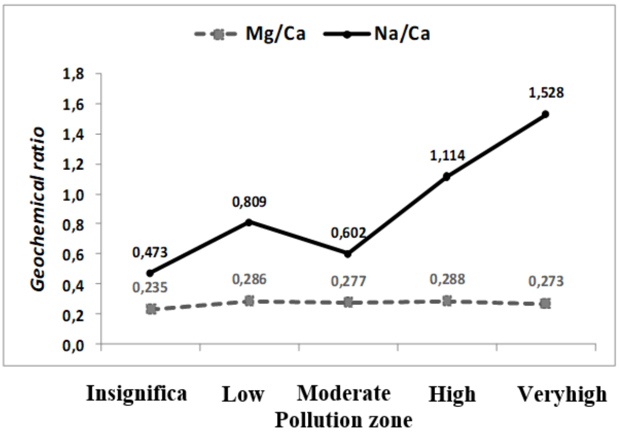

Fig.9. Ratios of Mg^{2+} : $Ca^{2+}$and Na^{+-} : Ca^{2+} with respect to pollution zones

Table III. Discrimination of TebessaBasin samples into graded pollution zones, using the pollution index of groundwater

PIG	PH		TDS		Ca^{2+}		Mg^{2+}		Na+		K+		Cl^{-}		SO_4^{-}		No_3^{-}		HCO_3^{-}	
	Units	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow	mg/l	Ow
Insignificant pollution zone																				
0,816	7,15	0,133	599.945	0,167	108.630	0.081	30.65	0,057	59.12	0,033	1.313	0.004	86.25	0,038	148.5	0,14	29.37	0,091	272.2	0,075
Low pollution zone																				
1.145	7.27	0.135	902.075	0.251	129.013	0.096	44.32	0.083	120.1	0.07	2.63	0.01	137.5	0.06	270.7	0.25	33.67	0.10	328.4	0.09
Moderate pollution																				
1.69	7.17	0.13	1375.34	0.38	216.86	0.16	72.11	0.13	150.2	0.08	5.95	0.02	232.5	0.10	484.8	0.45	40.9	0.13	344.0	0.10
High pollution																				
2.23	7.13	0.13	1891.86	0.53	225.04	0.17	77.74	0.15	288.3	0.16	6.33	0.02	348.3	0.15	744.7	0.72	44.33	0.14	254.2	0.07
Very High pollution																				
4.18	7.15	0.13	3776.78	1.05	396.00	0.30	129.9	0.25	695.9	0.39	5.10	0.01	813.0	0.36	1528	1.42	63.68	0.20	280.3	0.08

Note: Water quality measure is an average value

6. Conclusion

This paper presents integrated approaches for characterizing hydrochemistry and suitability of groundwater quality in the Tebessa Basin (North East of Algeria). Based on PIG method; and the major objective of the study was to disseminate the groundwater contamination zonesand characterize the status of concentrations of water quality measures with respect to their water quality standards. This study comes as the first attempt in applying PIG tool to assist water planners and managers in the study area to better understand the water quality determinants influencing the attractiveness of groundwater users. The proposed index computed from the study area varies from 0.46 to 8.19.

The distribution of pollution zones, in the study area, suggests that the geogenic origin (triasic evaporate formations) is the main controlling factor of groundwaterquality, but it can be changed by the influences of some anthropogenic activities. As the index is calculated and validated, the study throws light to undertake remedial solutions at anysite to control the activity of pollution.

7. Acknowledgments

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