Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2021, Volume 12, Issue 8, Page 1046-1056

http://www.jmaterenvironsci.com

Groundwater quality assessment, using pollution index of groundwater *(PIG)* from a semi-arid basin, Tebessa region (north-east of Algeria)

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Received 06 Sept 2020,
Revised 25 July 2021,
Accepted 01 Aug 2021

Keywords
- ✓ Drinking-water,
- ✓ pollution index of groundwater,
- ✓ geochemical process,
- ✓ Tebessa,
- ✓ Algeria.

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Abstract

Groundwater is a most precious natural resource, providing reliable water supplies for population of Tebessa region. Also, groundwater quality needs greater attention because it is the alternative source of water for domestic and agricultural purposes. In this paper, a pollution index of groundwater *(PIG)* is proposed for quantification of water contamination. PIG quantifies the status of concentrations of water quality measures with respect to their drinking water quality standards. The computed values of Pollution Index of Groundwater *(PIG)* for Tebessa basin vary from 0,457 to 8.190. The variation map depicts that most of the study area accounts for high and very high pollution zones is mainly due to geogenic, anthropogenic factors and also it is compounded due to mining activities. The present study paves the way to implement appropriate management strategies at a specific site to circumvent the pollution. As the classification of the pollution zones with PIG depends upon the drinking water quality standards, it becomes a universal assessment tool for groundwater contamination at any test area.

1. Introduction

Water dissolves minerals present in soil and rock portions during its flow, which deteriorates groundwater quality by natural processes of geogenic origin and mining activities. In the Tebessa area, local population largely depends on water from shallow aquifer. Agricultural activity and untreated domestic wastewaters cause a degradation of a quality of groundwater [1]. Contaminants can easily reach the groundwater through soils and are rapidly transported over large distances [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]. On the other hand, because of the recent globalization, a number of industries are coming up to establish their activities in the country. As most of the industries are not adhering to the strict environmental norms, the industrial activities can overtake the impacts of agricultural practices, municipal and mining waste waters on groundwater quality, leading to severe groundwater pollution.

Pollution not only affects water quality but also threatens human health and socioeconomic development. Assessment of groundwater pollution is, thus, an important aspect for proper civilization and also for development of database for future planning of water resources developmental strategies [5]. In view of this, an attempt has been made to propose a pollution index of groundwater (PIG) for quantification of contamination by choosing a case study of Tebessa Basin, North-East of Algeria, (Figure 1). This helps to disseminate the pollution zones for implementing remedial measures at a specific site.

2. Characteristics of the study area

2.1 Location

The study area is a part of a narrow trough which forms a large portion of the great plio-quaternary tectonic depression of Tebessa-Morsott which is located between the latitude 35° - 36° N and Longitude 7° 45' - 8° 20' E (Fig.1). The region is bound by 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 Es sen to the South, respectively, as it described by the Fig.2. The annual precipitation ranges between 350 and 400 mm, ranking the location among the semi-arid areas, in Algeria. Ambient temperature can rise in the summer by reaching the average of about 45°C causing dryness which affect negatively the drawdown of water resource, especially during the last decade due to the high weakness in the renewal of these resources. The dry climate, the atmospheric dust and low intensity of precipitation has also great impact on groundwater quality where an increased salt content is emerged [6].

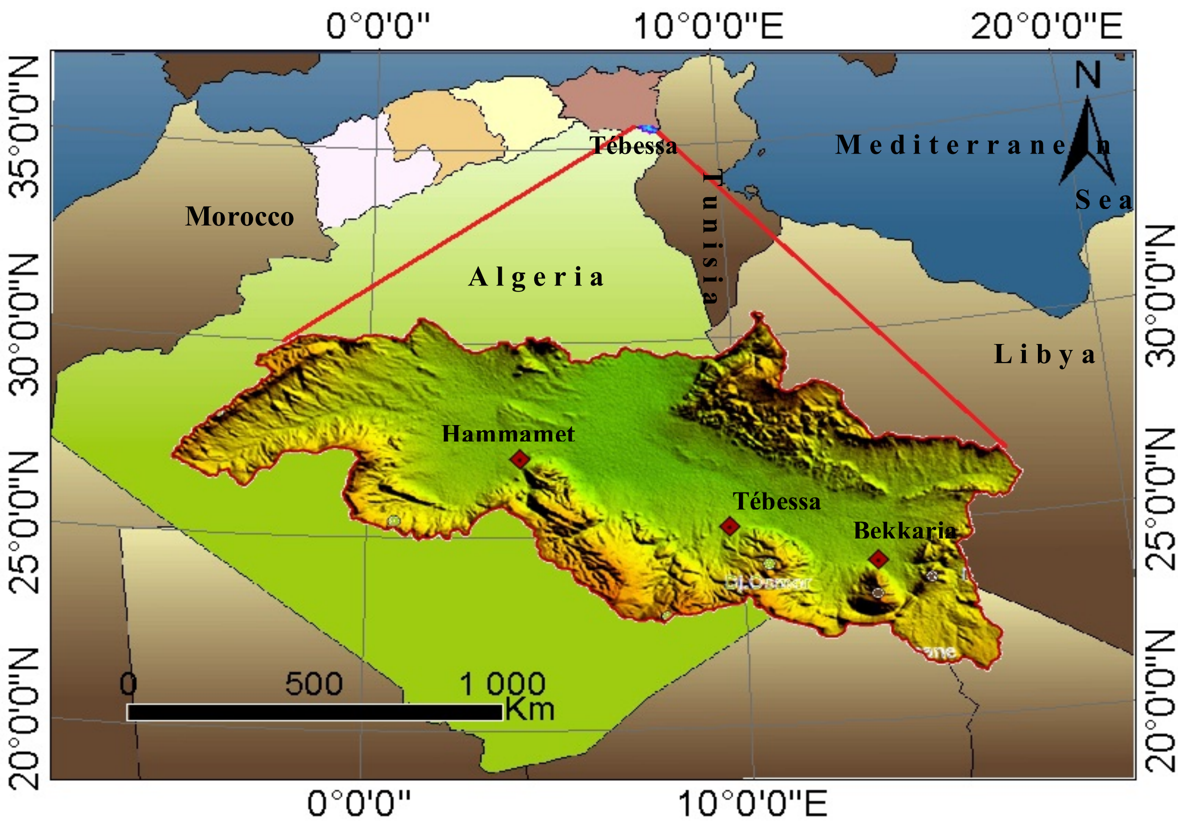

Figure 1 : Geographic situation of the study area.

2.2. Geological and hydrogeological setting

The geology of study area was studied by several authors [7]. The micropaleontologic and biostartigraphic analysis has showed that from the stratigraphic point of view, the study area covers the plio-quaternary tectonic depression of Tebessa. This depression separates the highlands of Dyr situated in the North from the one of Doukkane and Mestrie highlands in the South.

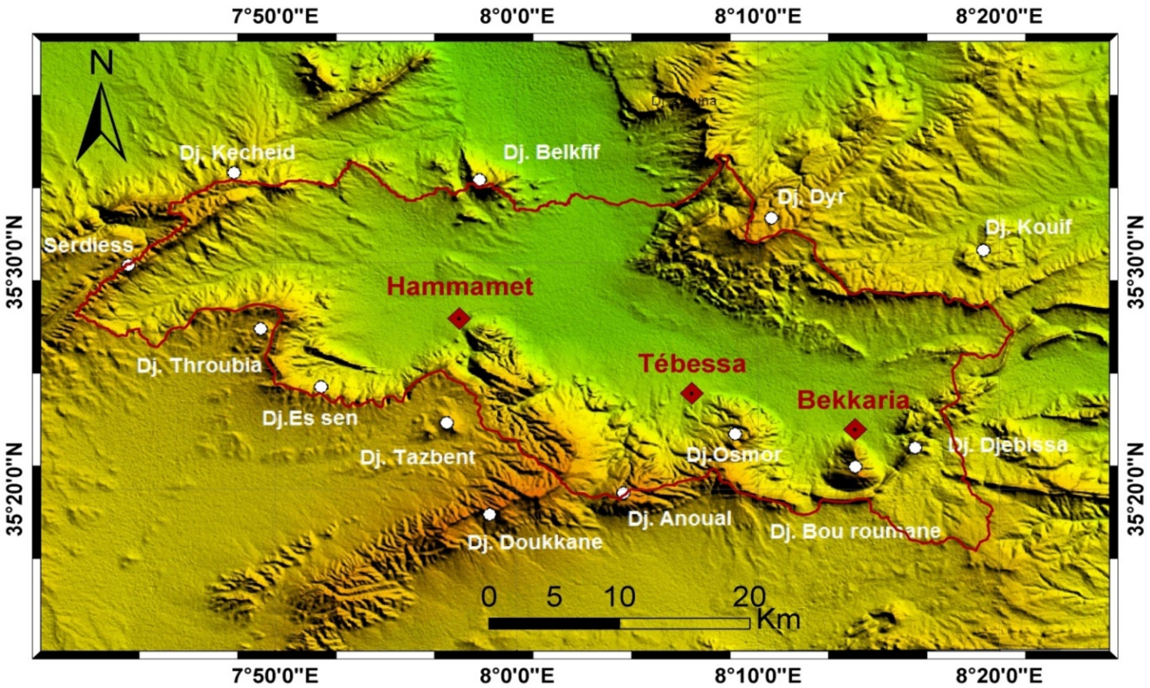

Figure 2 : Natural boundaries of the study area.

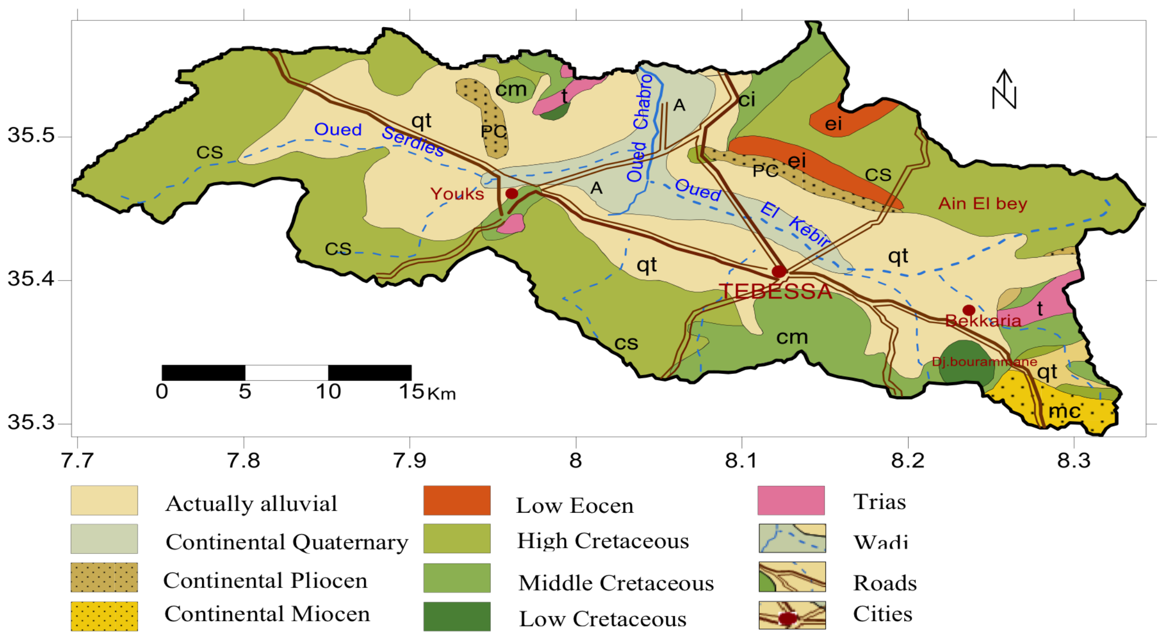

Figure 3: Geological map of the study area

The study area is constituted in the major part by cretaceous formations (fig.3), forming a series of anticlines and synclines. The stratigraphic sequence is presented in the form of alternation of carbonated formations of limestone, marly-limestones and argillaceous marls [8]. The plio-quaternary and quaternary terrains occupy the central part; they are consisted by actual and recent alluvial deposits, conglomerates, gravels, sandstones…etc. The summary analysis of the stratigraphic column of the study area shows the presence of three (03) aquiferous formations among them the formation of plio-quaternary one. This aquifer of great extension occupies the major part of the tectonic depression, limited at the West and at the East by two great faults of NW-SE orientation. It is consisted very varied deposits such as, alluvial fans, silts, calcareous crust, conglomerates and gravels. This aquifer plays an important role in the supply of drinking water for the inhabitants of this area [9].

3. Materials and Methods

3.1 Field work

A survey was carried in Tebessa basin, and 58 samples were collected from open dug wells during February 2020 (fig.3). Water samples were collected in 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.

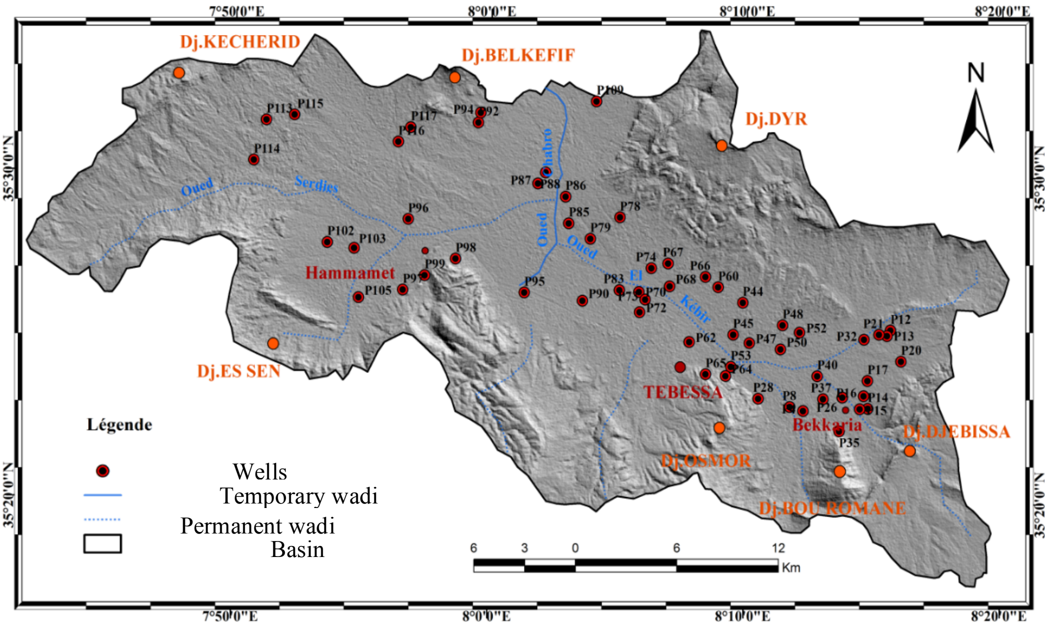

Figure 4 . Map of sampled wells – Tebessa Basin –

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 endpoint. 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 BaSO4 and then measuring the absorbency with spectrophotometer. Organic matter such as nitrate (NO_3) was measured by the phenol disulfonic acid method (Table I).

The analyzed data 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) [10]. 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.

3.3 Computation of pollution index of groundwater PIG

PIG is a numerical scale, quantifying the extent of contamination. It reflects a composite influence of individual water quality measures on overall water quality of aquifer. The algorithm to compute PIG is given as follows:

Step I: 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 II). For instance, the value of 5 of the Rw is 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.

Step II: 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 enables to know about the relative share of each water quality measure on overall water quality. The *Wp* is given by the equation;

$$\mathbf{Wp = Rw / \Sigma Rw} \qquad (1)$$

Step III: Status of concentration (*SC*)

The status of concentration (Sc) of water quality measure of each water sample, with respect to its drinking water quality standard (Ds). 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

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

Step IV: 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:

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

Step IV: Pollution index of groundwater (PIG)

Pollution index of groundwater is computed by adding all values of Ow contributed by all water quality measures of every water sample. PIG is given by:

$$\mathbf{PIG = \Sigma\, Ow} \qquad (4)$$

Step VI: 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 can be taken into account as contribution of additional concentrations of water quality measures into groundwater by entering of foreign matter into an aquifer due to pollution.

Knowledge base for intensity of PIG:

If $PIG<1.0$

Then Insignificant pollution

If $1.0<PIG<1.5$

Then Low pollution
If 1.5<PIG<2.0
Then Moderate pollution
If 2.0<PIG<2.5
Then High pollution
If PIG>2.5
Then Very high pollution

Table I. Chemical composition of groundwater in the Tebessa Basin

Water quality measure	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
SO_4	mg/l	22,000	3820,000	851,966	806,846
NO_3	mg/l	0,000	275,000	47,746	54,847
HCO_3	mg/l	30,500	939,400	298,475	128,108

Table II. Weighting scheme for drinking water quality standard with respect to water quality measures

Water quality measure	Units	Relative weight (Rw)	Weight parameter (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
SO_4	mg/l	5	0.139	150
NO_3	mg/l	5	0.139	45
HCO_3	mg/l	3	0.083	300
Sum ∑		36	1.000	

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

The relative contribution of concentration of water quality measure of each water sample is taken into consideration, if Ow is more than 0.1 (which is the 10% of the value of 1.0 of PIG). This gives a clear picture on impact of pollution on groundwater system. In this method, if a number of water quality measures are taken, the value of PIG is 1.0, because the classification of PIG depends upon the water quality standards allowed for drinking purpose. Thus, the classification of PIG would be the same for assessment of groundwater contamination at any test area.

4. Results and discussion

4.1 Groundwater movement and evolution

Two piezometric highs are recognized in the study area. One has a static water level of 860 m and is located near Bekkaria. The second is in the west of the study area and has a static water level of 940 m at the El Hammamet. The piezometric map suggests that the direction of groundwater movement must be moving as shown 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 subsidized in two hydrogeolgic aquifer system, at the east this system is recharged through carbonate outcropping from Bouromane highlands and in the west part this aquifer system has a direct alimentation from Meastrichtian fracturated limestone.

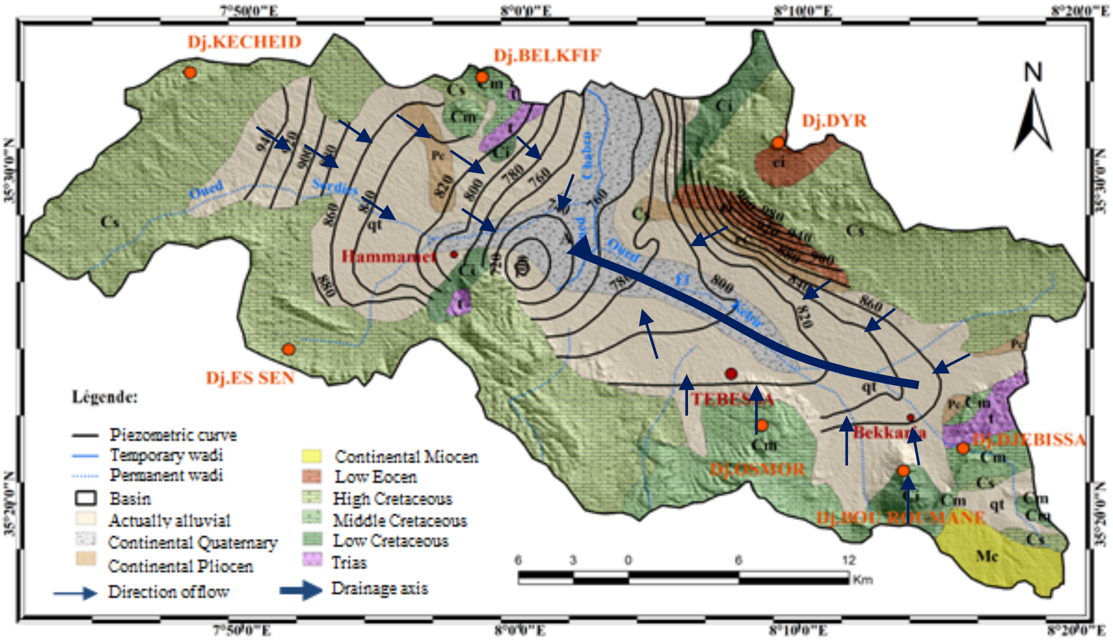

Figure. 5. Piezometric map .-Tebessa Basin- .

4.2 Water quality

The value of physical parameters (pH, EC and TDS) of the groundwater samples collected from Tebessa Basin varies 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 I). The concentrations (mg/l) of major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}), major anions (HCO^{-}_{3}, Cl^{-} and SO^{2-}_{4}), 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 I.

The computed values of PIG in this case study area are between 0,457 to 8.190 (Fig 6, Tab III). According to the classification of PIG, 22.41 % of the total groundwater samples represent moderate to high pollution zone and about 43.10% as very high pollution zone.

The relative contribution of concentration of water quality measure of each water sample is taken into consideration, if *Ow* is more than 0.1(which is the 10% of the value of 1.0 of *PIG*). This gives a clear picture on impact of pollution on groundwater system.

Spatial distribution map of zones of PIG has been prepared using GIS (Map-2). The variation map (Fig 7) depicts insignificant pollution zone is observed from the extreme southern part, where the topography is high (upstream area). Low pollution zone is predominant in the central part. Moderate pollution zone is spread in the eastern, western and northern parts. High pollution zone is recorded in the northern and western part. Very high pollution zone is noticed in the extreme northern part, where the topography is low (downstream area). Thus, the spatial distribution of zones of PIG is increased gradually from upstream to downstream. This suggests a progressive increase of pollution from its insignificant level to significant level by a combination of Ow values of various concentrations of water quality measures.

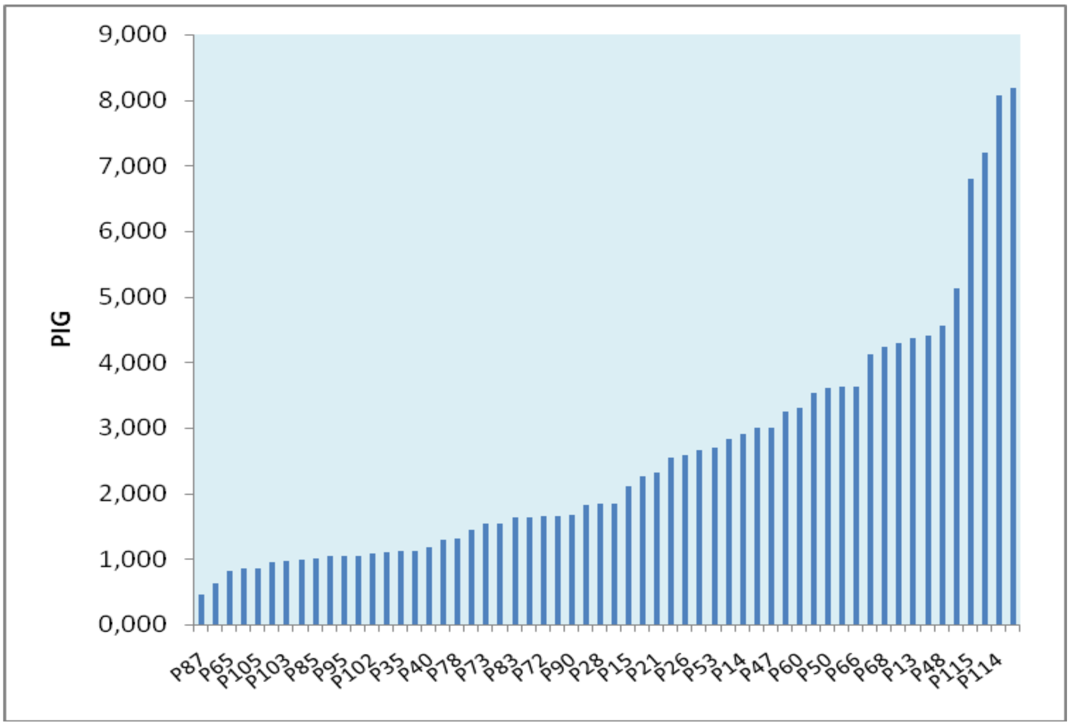

Figure 6. Sample-wise PIG values.

For example, insignificant pollution zone is mainly by pH (0.129 to 0.136), TDS (0,098 to 0.210), Ca^{2+} (0,114) and SO_4^{2-}, (0.02 to 0.226) which are characterized by Ow values more than 0.1 (Table III). The remaining water quality measures, Mg^{2+} (0.025 to 0.096), Na^{+} (0.016 to 0.049), K^{+} (0.003 to 0.007), Cl^{-} (0.0222 to 0.06), HCO_3^{-} (0.059 to 0.086), and NO_3^{-} (0.00 to 0.136), are considered as nominal contributors under natural conditions, as their Ow values are less than 0.1. The variation of pH from 6.14 to 8.22 (Table I) is mainly due to HCO_3^{-} . The groundwater system is open to soil CO_2, which results from the decay of organic matter and root respiration. This CO_2 combines with rainwater to form HCO_3^{-} , leading to a mineral dissolution [11]. All dissolved ions in the groundwater are, thus, a result of TDS [12].

The water quality measures, pH (0.129 to 0.152), TDS (0.208 to 0.318), Ca^{2+} (0,089 to 0.130) , SO_4^{2-}, (0.107 to 0.410) and NO_3^{-} (0.0 to 0.207), show Ow values more than 0.1 in the low pollution zone (Table III). They have more Ow values compared with those values of the water quality measures Mg^{2+} (0.057 to 0.109), Na^{+} (0.033 to 0.186), K^{+} (0.003 to 0.022), Cl^{-} (0.0178 to 0.1288), HCO_3^{-} (0.059 to 0.260) . Gypsum weathering (geogenic source) is the main source of SO_4^{2-}, [13]. Ion exchange (due to occurrence of clay horizons derived from the country rocks) and precipitation of CaCO3 in the study area are also cause for increased Ca^{2+} [14]. Another reason for NO_3^{-} in the groundwater is anthropogenic source (chemical fertilizers, irrigation return flows, poor drainage conditions and leakage of septic tanks).

Table III. Discrimination of Tebessa Basin samples into graded pollution zones, using the pollution index of groundwater (PIG)

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

The sources of geogenic and anthropogenic origin can also be caused for the water quality measures, pH (0.128 to 0.139), TDS (0.341 to 0.554), Ca^{2+} (0,128 to 0.241) and SO_4^{2-}, (0.107 to 0.410), show Ow values more than 0.1 in the low pollution zone (Table III). They have more Ow values compared with those values of the water quality measures Mg^{2+} (0.057 to 0.109), Na^+ (0.058 to 0.191), K^+ (0.003 to 0.106), Cl^- (0.055 to 0.179), HCO_3^- (0.068 to 0.138) and NO_3^- (0.0 to 0.389) in the same pollution zone (Table III). However, the differences in the sources of geogenic and anthropogenic origins between the low and moderate to high pollution zones could be the main controlling factors for higher Ow values of water quality measures in the latter zone.

The groundwater shows the higher values of Ow of TDS (0.517 to 2.182), Ca^{2+} (0,078 to 0.557), Mg^{2+} (0.115 to 0.455), Na^+ (0.072 to 0.827), Cl^- (0.1332 to 0.89), SO_4^{2-}, (0.630 to 3.06), and NO_3^- (0.0 to 0.849) excepting pH (0.114 to 0.146), K^+ (0.007 to 0.039), and HCO_3^- (0.008 to 0.154), in the very high pollution zone compared with those of water quality measures in the moderate to high pollution zone (Table III).

Apparently, the value of Ow of NO_3^- is exceeding 0.1 in the high pollution zone. This suggests that the role of anthropogenic activity on the groundwater system in the high pollution zone is as influential as not in the low and moderate pollution zones. Furthermore, the differences in the sources of pH, K^+ and HCO_3^- could be a cause for their lower Ow values in the high pollution zone than those in the moderate pollution zone. Another important point is that the Ow value of HCO_3^- is less than that of Cl^-, whereas that of Cl^- is higher than that of Na^+. This indicates that the geogenic source is the main detrimental factor in the control of groundwater quality, but it is subsequently modified by the influence of the source of the anthropogenic origin. However, it may not be a dominant factor like in the low and moderate pollution zones. Thus, the value of Ow of NO_3^- (0.0 to 0.849) is higher in the high pollution zone than those in the insignificant pollution zone.

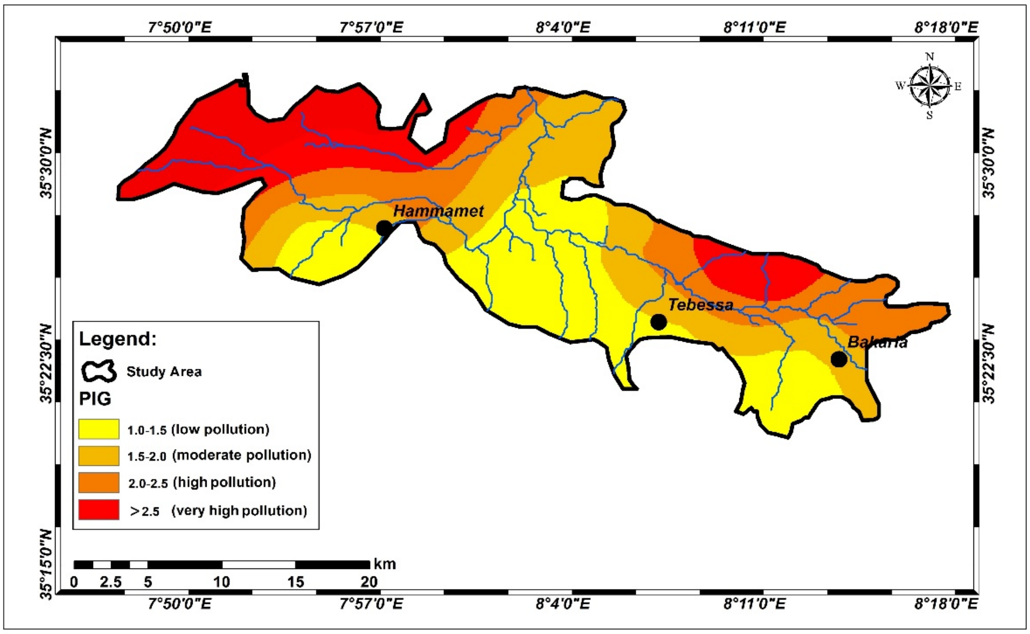

Figure 7. Spatial distribution of groundwater pollution zones in the case study area (Tebessa Basin) based on PIG

Conclusion

Tebessa Basin is chosen as the area of a case study to disseminate the groundwater contamination zones, using the proposed PIG. This is a simple tool of universal classification to explain the status of concentrations of water quality measures with respect to their water quality standards allowed for drinking. The proposed index computed from the study area varies from 0.46 to 8.19.

The index classifies the area as insignificant (PIG <1.0), low (PIG: 1.0 to 1.5), moderate to high (PIG: 1.5 to 2.0), and very high (PIG > 2.5) pollution zones, following the topography. Groundwater in the whole pollution zones is characterized by SO_4^-. Spatial distribution of pollution zones indicates that the geogenic origin (triasic evaporate formations) is the main controlling factor of the quality of groundwater, but it is subsequently modified by the influences of some anthropogenic activities in the study area.

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