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Piezometric and Hydrochemical Dynamics of Alluvial Aquifer in Timia Valley, Aïr Mountains, Semi-Arid Region (Agadez, Niger)

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Abstract The alluvial aquifer of the Timia valley provide the supply of water to the population, but also the need for irrigation water. This important aquifer is highly dependent on precipitations and sometimes it dries out before the return of rainy season leading to drought. Also, the increase of agricultural activities has led to the deterioration of water quality in places but also to the depletion of this alluvial aquifer. The objective of this study is to contribute to understanding the quantitative and qualitative dynamics of this limited extension aquifer. A methodological approach based on piezometric and hydrochemical methods has revealed that the alluvial aquifer is renewed from the arrival of first floods of Timia valley and the main flow directions that are globally NE-SW. It show too an increase concentration of cations Ca^{2+}, Mg^{2+}, Na^{+} and stability of K^{+} during the rainy season. However, for anions a low increase of HCO_3^-, Cl^-, SO_4^{2-} and NO_3^- during the dry season is observed.

Keywords: *alluvial aquifer, piezometrie, hydrochemical dynamic, Niger, Aïr Mountains*

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1. Introduction

Water is an essential resource to all forms of life. In arid areas, the water resource available and mainly represented by groundwater. Since the late 1960s, the Sahelian areas know a deep climate change characterized by big significant decrease of precipitation [1,2,3]. Groundwater resources of the Sahel areas, and more particularly those of the basement regions of Aïr massif, arid region of Niger, know more and more qualitative and quantitative degradation, due to climate and anthropogenic actions [2,4]. However, in the Timia area, irrigated agriculture is the main activity of the population. Groundwater from the alluvial aquifer of the Timia valley ensures the supply of water to the population and irrigation. With the increase of the population combined with a heavy occupation of space for irrigation at the first valley increased the need for water. In addition, the development of vegetable crops (citrus fruits, cereals, potatoes, onions, etc.) in the Aïr valleys and their modernization with the use of motor pumps, have increased water withdrawals from these alluvial aquifers of limited extension. This high demand for water, combined with population growth, has led to a drastic drop in the level of these aquifers, resulting in their almost total depletion before the return of rains. This situation observed in several localities of Aïr, Timia, Tabelot, Tin Telouste, Boughoule, compromises the water supply of the populations and a small irrigation, as well as the sustainable management of the fragile ecosystems of this zone [5]. To this problem of depletion of reserves, is added the uses of chemical fertilizers and pesticides, resulting in the degradation of the water quality of these surface aquifers, requiring the exploitation of deeper aquifers.

It therefore seems urgent to improve the knowledge of water potential of alluvial aquifer of Timia, in particular for an integrated and sustainable management of said resources. It is in this perspective that the present study, whose main objective is to characterize the alluvial aquifer of Timia watershed, in order to better match the needs and resources available in mountainous semi-arid environment.

2. Material and Methods

2.1. Study Area

Timia is located between 18° and 19° north latitude, 8° and 11° east longitude. It is located in the Department of Arlit, region of Agadez. It is located 224 km southeast of the capital of Arlit Department and 220 km northeast of

Agadez capital region. It is limited by six (6) rural municipalities which are Tabelot in the south, Dabaga in southwest, Iférouane in north, Dannat in West, Gougaram in the Northwest and Fachi in the East. The rural municipality of Timia covers an area of 32,000 km^2, of which about 70% is occupied by mountain ranges [6].

Timia watershed, covering an area of about 267.5 km^2, occupiez the central part of the municipality of Timia. It is located between 17°50' and 18°15' north latitude and 8°30' and 9°00' east longitude (Figure.1). This area is bounded by three mountains ranges including: Egalagh to the north, Aroyan to the east and Iskou to the south, culminating respectively at 1855m, 1134 m and 1708 m altitude [7]. The climate of Timia area is of the Sahelian type, marked by alternation of two distinct seasons: a dry season from october to june, and a rainy season from july to september [8]. Rainfall at Timia station in 2009 and 2008 was 101.58 mm and 117.02 mm, respectively. We observe that 2009 was less rainy than 2008.

Regarding temperatures, the lowest are observed in july and august (rainy season) and december-february (cold season) where they can fall below 15°C. On the other hand, the high temperatures recorded in april-june (dry season) Similarly, temperatures can reach 45°C during the months of october and november [8,9].

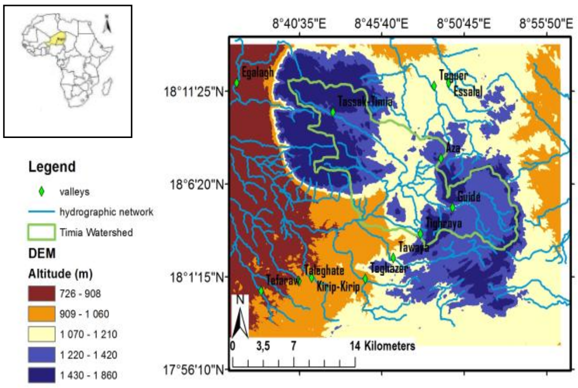

Figure 1. Location of study area

2.1.1. Geological and Hydrogeological Context

The Aïr massif corresponds to the SE part of the Touareg shield (**Figure 2**) and extends over a length of 382km with a width of 178 km approximately [10]. From a geomorphological point of view, the Aïr massif presents a very contrasted relief ranging from 505 m (southern edge) to 1022 m (Mount Bagzan). Hydrologically, the Aïr Massif is crossed by important seasonal valleys that constitute the main oases of this area. Among these oases, those of Timia connected by a large stream commonly know as "Tassak". Geologically, the base consists of ancient granites, gneiss, micaschiste and marble, intruded by ring complexes of young granites such as Greboun, Tamgak Bagzan and Taraoudji [11-14].This ring-shaped complex constitutes the various mountains of the locality, elongated along an N-S axis. These mountains are commonly called "Mont Bagzan". This annular complex, considered "anorogenic" [10,15] finds its equivalence in the Damagarm-Mounio (southern Niger) [16,17,18] and in the Jos sector (Plateau state, central eastern Nigeria) [17,18]. The geological formations of the Aïr Massif include [10] of (i) eburnian gneiss containing amphibolites, quartzites, diopside marbles (ii) granitoids of Precambrian anatexia related to pan-African tectonics (iii) sub-volcanic and hyperalkaline volcanic complexes("younger granites") [19] with annular structures intersecting the whole, and which were set up in the Ordovician and Silurian [20,21]. According to [9,22] four accident families cut the massif according to the directions NW-SE, N80°, N45° and N120°-N150°.

In Timia area, the deep aquifer is represented by fractured basement aquifers contained in fractured granites and cracked gneiss. Its depth varies from 90 m to 120 m and captured by boreholes, their flow varies from 1 to 8 m^3/h and shows a high mineralized water. The piezometric level is high goes up showing that these aquifers are under pressure. Today, several boreholes have been drilled with a relatively high failure rate around 30% [23].

The medium depth aquifer is contained in the basement alterites.These aquifers of alterites are located in altered zones of basement, they are mainly captured by boreholes and cemented wells with large diameter and their average depth are around 22 m. The water salinity is average, for most of them.

The surface aquifer is constitute of alluvium of valley. These aquifers are located on the edges, and at the bottom of the valley which generally cut the young massifs to the foothills from which the springs and "aguilmames" are found [22] [24]. These aquifers are captured by shallow wells (6 to 18 m). The water of these aquifers have low salinity.

2.2. Methodology

2.2.1. Piezometric Follow-ups

Static level surveys were carried out on wells serving as pitfalls on the extent of the alluvial aquifer. Also, the static level survey network was constituted by the wells capturing the alluvial aquifer. Indeed, it has relatively well distributed wells throughout the valley, in addition some of them are considered as "piezometer wells".

2.2.2. Elaboration of Piezometric Maps

The piezometric levels were determined by differentiating between the altitudes from the DEM and the static levels of wells.

Given the complexity of discontinuous flows of basement and the limited number of boreholes, the piezometric maps developed focused only on alluvial aquifer. These maps were made from the geographical coordinates and the piezometric coasts of the works using the Surfer.11 software by Kriging (geostatistical interpolation method). The two piezometrics maps of the alluvial aquifer concern the period of high and low water.

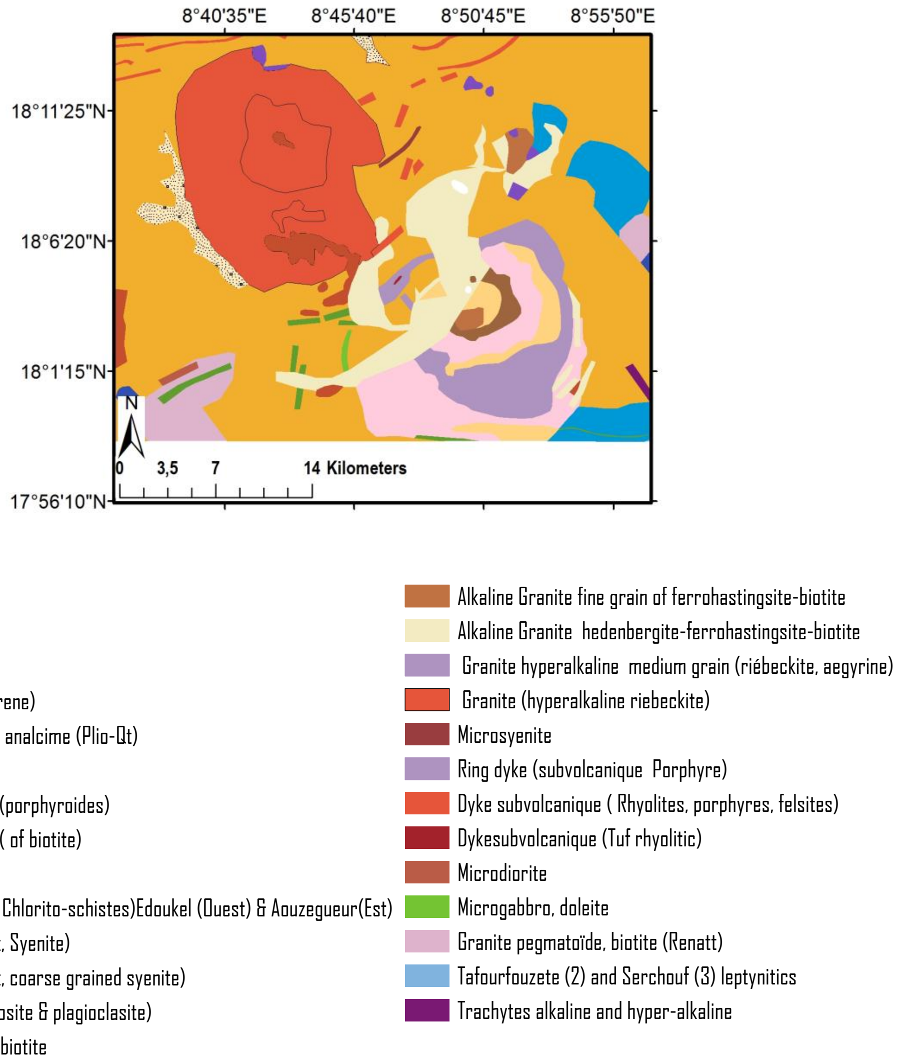

Figure 2. Geological map of study area

2.2.3. Sampling

A total of 25 water samples were collected during two campaigns in march 2020 (low water period) and october 2020 (high water period).

The first sampling campaign for chemical is realized in march 2020, corresponding to the period of low water, (piezometric levels of alluvial aquifer) and twenty five (25) samples were taken. The second sampling campaign for chemical is realized in october 2020, corresponding to the high piezometric level, twenty five (25) wells were sampled.

The sampling sites were selected on the basis of the hydrogeological characteristics of Timia valley, and in order to sample the alluvial aquifer in the area. All sites are geo-referenced, which allowed their carry-over on the cartographic funds (Figure 3).

On each site, the physicochemical parameters (Electrical Conductivity, Temperature and pH) are measured in situ, before rinsing plastic bottles of 500 ml polyethylene and carried to SOMAÏR laboratory for the chemical analyses. The cations (Ca^{2+},Mg^{2+}, Na^{+} and K^{+}) are determined by atomic flame absorption. The analyses of nitrates (NO_3^{-}) and chlorides (Cl^{-}) were made by direct potentiometric titration, whereas carbonate ions (CO_3^{2-})

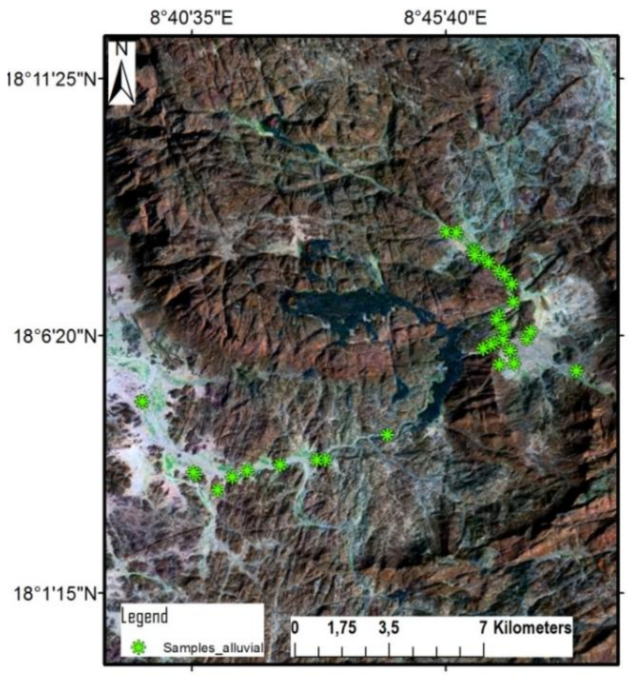

Figure 3. Sampling wells distribution

and bicarbonated (HCO_3^-) are obtained by the calculation after determination of pH and complet alkalimetric title.

The validity of analyses results was verified by calculating ion balances (IB) determined by the following formula:

$$IB(en\ \%) = \frac{\sum \mathbf{cations} - \sum \mathbf{anions}}{\sum \mathbf{cations} + \sum \mathbf{anions}} * 100$$

With: $\sum C^+ = [Ca^{2+}] + [Mg^{2+}] + [Na^+] + [K^+]$; $\sum A^- = [HCO3^-] + [SO_4^{2-}] + [Cl^-] + [NO_3^-]$.

The concentrations of major chemical elements anions and cations used are in meq/L. For an analysis to be considered acceptable, the ion balance must be less than or equal to 6% [25,26].

2.2.4. Basic statistics

These are calculations of Maximum, Minimum, Means, Medians and the coefficients of variation (cv) of physicochemical parameters. The cv is the ratio of standard deviation to mean of variable. It highlights the homogeneity or heterogeneity of variables considered. Thus, when a cv tends towards 1, the variable studied is heterogeneous, while a cv tends towards 0, indicates that the variable is homogeneous. To account for certain dissolved elements in water, in addition to cations and anions, total mineralization (MT) was calculated in each samples. These calculations were made using the statistical software SPSS.

2.2.5. Diagram

The hydrogeochemical classification water was achieved through the diagram of Piper. The latter is frequently used for the types of water. Chemical elements considered for this treatment concern the cations Ca^{2+}, Mg^{2+}, ($Na^+ + K^+$) and anions HCO_3^-, ($Cl^- + NO_3^-$) and SO_4^{2-}). Thus, the geochemical facies of water are obtained in function of predominance of cations and anions in solution.

3. Results and Discussion

3.1. Spatial Variations of Piezometry

3.1.1. Low Water Piezometry

The piezometric map of the alluvial aquifer in low water (Figure 4) shows that isopiezes vary from 840 to 1100m. This map highlights the areas of piezometric depressions characterized by the lowest levels located at the level of: Tamechite (840 m), Inwanissan (920 to 860 m) and Ayastchine (980 to 940 m). These piezometrics depressions observed in the south and west, would be explained respectively by evapotranspiration due to the resurgence of the groundwater, and by pumping. For the piezometrics domes (1100 to 1096 m) located in north, upstream of Timia valley (1100 m) and Guidé valley in the east (1080 m), they are probably linked to a supply of alluvial aquifer. The main flow directions (Figure 4) that are globally NE-SW appear to be controlled by fracturing [6].

In the north-East part, upstream of valley, the isopiezes are spaced, which could be due to an increase in permeability, and a low hydraulic gradient. On the other hand, in the south, in Ayastchine area, the isopiezes are tightening, which reflects a strong hydraulic gradient.

Finally, isopiezes 1060 seems to compartmentalize the aquifer in two parts. A high zone whose average value of piezometric coasts is about 1100 m and another low where this average is 840 m. This would be related to the Plio-Quaternary basaltic flow, characterized by important slopes and falls (Timia waterfall), constituting a natural barrier to underground flows. Indeed, beyond this flow, the geometry of the water level and the piezometric level, varying from 980 to 840 m, is normalized.

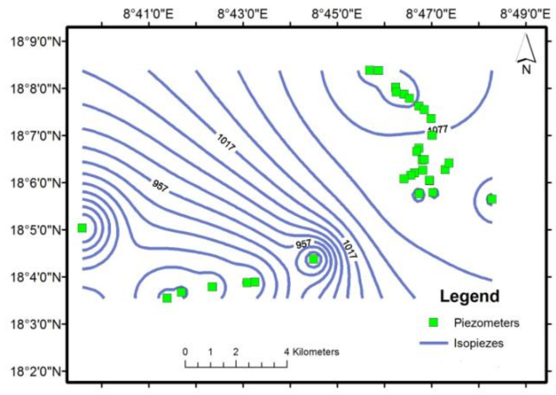

Figure 4. Piezometric map of alluvial aquifer of Timia (low water)

3.1.2. High Water Piezometry

The piezometric map of high water level (Figure 5) shows that the piezometrics curves are between 1104 m in the northwest and 1084 m in the southeast. The piezometrics domes are located north (1104 m) and center (1098-1102 m). These piezometrics domes could correspond to a possible recharge of the groundwater that can come from flows upstream of valley.

On the other hand, the piezometrics hollows located in the southeast (1086-1084 m), would be explained by a possible evapotranspiration, of groundwater located less than 6 m deep at this place. The underground flows are generally to NW-SE direction.

Finally, the piezometric differences between high and low water can reach 4 m in the northeast, and 3 m in the center. That is due to lack of measurements, the low water piezometric map only takes into account the northern part of piezometric level.

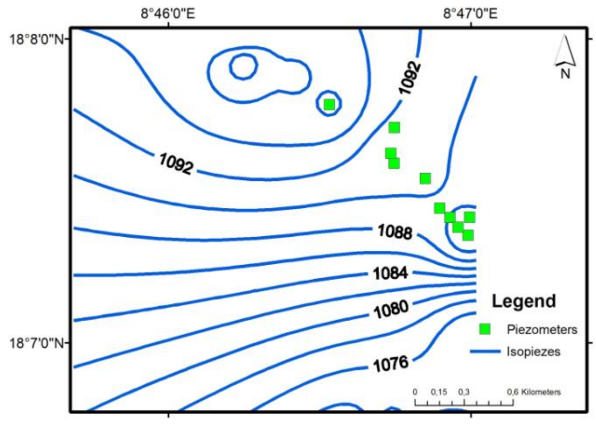

Figure 5. Piezometric map of alluvial aquifer of Timia (high water)

3.1.3. Temporal Evolution of Piezometric Levels

The piezometric level fluctuation curves (Figure 6) of piezometers P_1 and P_2 are identical. They shows:

- gradual decline in piezometric level from september to june. This is increasing between april and june (dry season);
- rise in piezometric level at the beginning of the rainy season (july-august). It begins when the first floods arrive. The reactions of piezometers P_1 and P_2 are almost identical, reflecting a homogeneous behavior of groundwater. Maximum piezometrics levels are observed in july and september (rainy season);
- amplitudes of piezometric fluctuations between low water (april-june) and high water (july-september) vary from year to year and in proportion to the size and numbers of floods. Thus, in 2012 and 2015, the rise in piezometric levels reached respectively 11m (P_1) for a flood and 12 m (P_2) for two floods, a rise of 2 m for P_1 and 7 m for P_2.

Moreover, this quickly reaction of groundwater following floods and varying from one piezometer to another could be explained by the nature of the alluvial environment and the existence of possible fractures at depth. The last hypothesis seems to be confirmed by the fact that in some places, the piezometric level only reacts when the floods come from the main valley (Tassakh), located on major fractures. While for floods from secondary valley, located on relatively small fractures, the reaction of piezometric level is weak or almost zero.

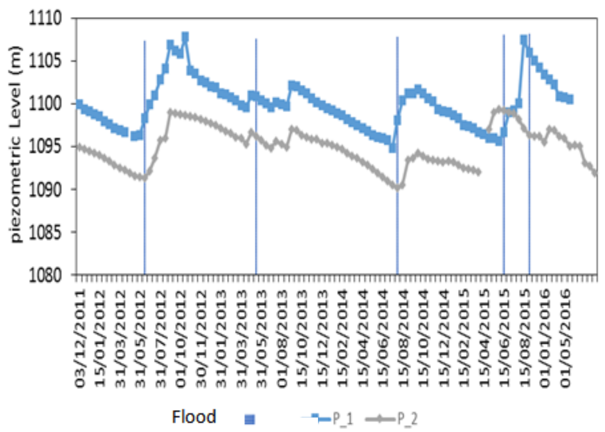

Figure 6. Variations of piezometric levels of wells in the alluvial aquifer (and floods indicated only by the date of their arrival)

3.1.4. Variations in Piezometric Heights

The monitoring of the piezometric levels of five structures during the period 2020-2021 (Figure 7) shows an increase of piezometric levels during this phase. Indeed, for the wells located on the sector of secondary arm, groundwater of sub-watershed of Guidé, this increase is of 0.73 m Amer piezometer, while for the wells capturing the alluvial aquifer of main valley of Timia, this increase reaches, to the piezometers Tass, Gig, Ifer, and Agh, 2 m, 1 m, 0.97 m and 0.5 m respectively.

The analysis of the piezometric map shows that the flow of groundwater is in the directions NE-SW and NW-SE. As for temporal evolution of the piezometrics levels, it shows that the level of groundwater grows from the arrival of the first flood.

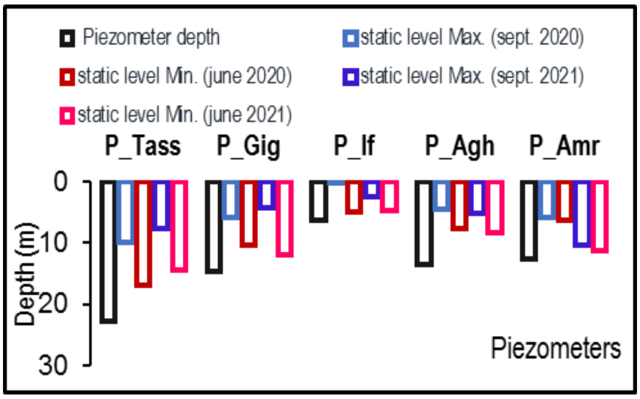

Figure 7. piezometric levels variation in 2020 and 2021

3.1.5. Physico-Chemical Parameters of Groundwater

Table 1 show that the water temperature of the alluvial aquifer is close to that of the air (26.9 °C) and shows that the surface aquifers are subject to seasonal variations in air temperature [24,27,28]. The pH values measured in the samples water range from 6.4 to 8.2, with an average of 7.3 and a standard deviation of 0.5.

The high pH values, above 8 pH units, measured in the alluvium reservoirs is basic and may be related to a possible closure of these aquifer systems (Table 1). For other waters, pH values are slightly acidic to neutral. This seems to be in agreement with the geological nature of generally acidic aquifers (sands) for the alluvial aquifer. Nevertheless, contact with the atmosphere and/or possible pollution is not excluded for these pH values [29]. In addition, the standard deviation value is higher (0.5).

The alluvial aquifer shows low conductivity values ranging from 107 to 521 µS/cm, with an average of 256 µS /cm and a standard deviation of 119.

These low EC values of the alluvial aquifer reflect a quickly renewal of alluvial aquifer compared to other systems.

Table 1. Physico-chemical parameters of groundwater (alluvial aquifer)

	Parameters	T°C	pH	EC(µS/cm)
Alluviums N=25	Average	26.5	7.3	256.3
	Medium	26.5	7.3	228.0
	Ecart-type	0.9	0.5	119.2
	Min	24.7	6.4	107
	Max	28.3	8.2	521
	CV(%)	3.4	6.3	46.5

3.1.6. Chemical Parameters of Groundwater

In the alluvial aquifer (Table 2), total mineralization ranged from 2.68 meq/l to 14.26 meq/l, with an average of 5.7 meq/l, showing that the waters are low mineralized as a whole. The coefficient of variation and 45.6 (< 50%). In the samples of the alluvial aquifer, it happens that calcium predominates giving the following ionic formula: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. For anions, the order of abundance is $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > F^-$. HCO_3^- is the dominant ion, it represents 83% of the total anionic charge [23].

Table 2. Statistical results of groundwater chemistry (N=25), (meq/L)

Ions	Aver.	Med.	Ecart.	Min	Max	CV(%)
$Ca^{2}+$	1.34	1.25	0.4	0.65	2.05	29.92
$Mg^{2}+$	0.58	0.5	0.22	0.25	1.33	36.89
Na^{+}	0.83	0.57	0.85	0.3	4.17	101.47
K^{+}	0.09	0.08	0.05	0.03	0.23	57.48
HCO_3^{-}	2.08	1.77	1.2	0.59	5.34	57.49
F^{-}	0.05	0.04	0.03	0.01	0.12	69.63
Cl^{-}	0.35	0.28	0.21	0.14	1.01	58.15
SO_4^{2-}	0.25	0.19	0.19	0.04	0.79	75.53
NO_3^{-}	0.14	0.11	0.09	0.03	0.32	5.92
MT	5.73	4.93	2.61	2.68	14.26	45.63

3.1.7. Piper Diagram

The alluvial layer of Timia is characterized mainly by a chemical facies of calcium bicarbonate and magnesian type (88%) (Figure 8), apart from three samples of which two (2) are chlorinated/calcium sulfated and magnesian (8%) (Aghya and Teguère wells) and the other type bicarbonated sodium and potassium (4%) (Billa Well 1). This variation of facies within the alluvial aquifer could be explained by the fact that the well Téguère1 is located on the tributary of the main valley while Amer1 is in the area of confluence of two valleys. For the Aghya well, although it is in the right of the main valley, it has high chloride and sulfate contents. This particularity seems to be linked to the presence of a small pond that refills this well. The presence of chloride and sulfate anions suggest an anthropogenic character [30,31].

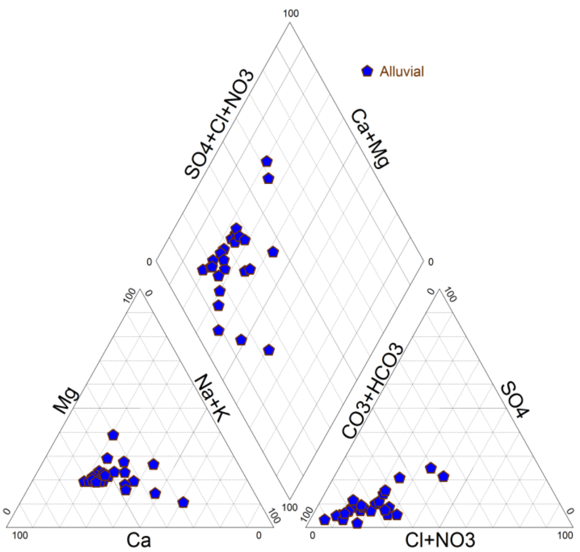

Figure 8. Alluvial aquifer Piper Diagram

3.2. Temporal Evolution of Ions

3.2.1. Temporal Variation of Cations

Variations in the concentration of the various chemical elements in the alluvial aquifer (Figure 9) show:

- a very high concentration of Ca^{2+} ions in high water except the Tanout well or these are higher in dry seasons;
- an increase in the contents of Mg^{2+} ions during high water period at (Mintina, Tanout and Infassassan) wells, while the opposite phenomenon is observed at Lima well. For other these remained relatively stable during the two seasons;
- an increase of Na^{+} concentration in high water for majority of wells with the exception of well (Lima) where the contents change in the opposite direction. On the other hand, such as Infassassan and Tanout, any variation in these contents is observed during two seasons;
- K^{+} content stability for all wells is observed, apart from those of (Lima) and (Tanout) where K^{+} concentrations increase respectively in low water and high water.

These observations show a very remarkable variations of ions within the alluvial aquifer in different seasons depending on their location relative to the recharge zones.

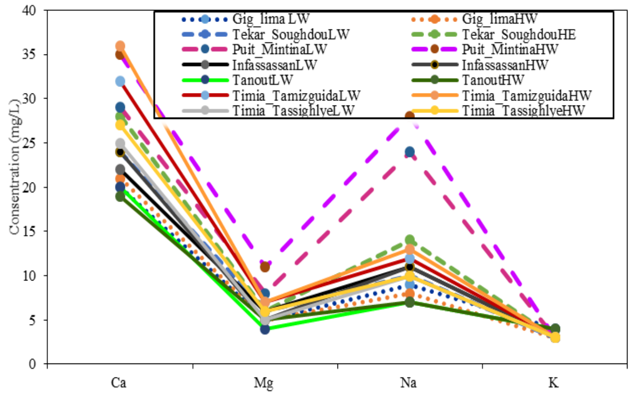

Figure 9. Temporal variation of cations in groundwater

3.2.2. Temporal Variation of Anions

The evolution of anion contents in the water of alluvial aquifer (Figure 10) shows a slight increase in the contents of HCO_3^-, Cl^- and SO_4^{2-} ions in periods of low water (dry season). Those NO_3^- ions are also high in low water for some wells, and high water for others. Variations in the concentrations of these ions would reflect an external input during high water and evaporation during low water except for NO_3^- where this increase could be due to anthropogenic activities [31,32].

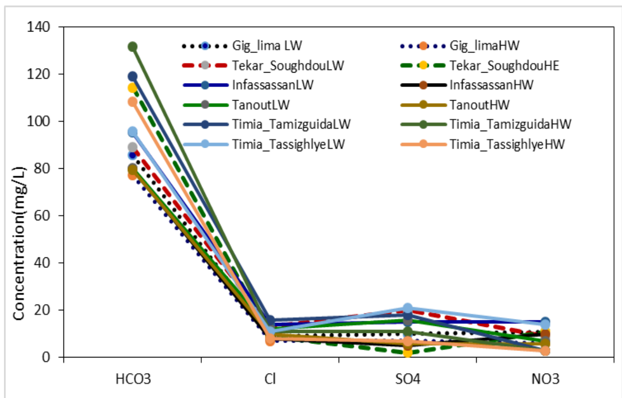

Figure 10. Temporal variation of anions in groundwater

3.2.3. Evolution of Chemical Facies

The evolution of geochemical facies of alluvial aquifer according to the seasons (Figure 11) shows that these remain relatively stable. Indeed, the waters have remained calcium bicarbonate and magnesian.

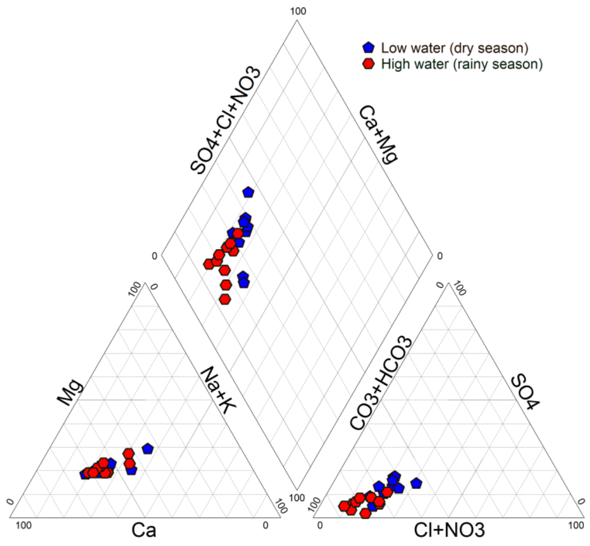

Figure 11. seasonal variation of the water types of alluvial aquifer (Piper diagram)

4. Conclusion

The analysis of piezometrics maps shows that the flow of alluvial aquifer is in the directions NE-SW and NW-SE. As for the temporal evolution of piezometric levels, it shows that the level of alluvial aquifer grows from the arrival of the first flood.

The alluvial groundwater shows temperatures of 26℃ close to ambient air and the pH values are between 6.4 and 8.2. In the alluvial aquifer the values of EC vary from 107.4 to 521.0 µS/cm and show low mineralized water.

The water of alluvial aquifer are predominantly (88%) calcium and magnesium bicarbonated, calcium and magnesium chlorinated/sulfated and to a lesser extent sodium and potassium bicarbonated.

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