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Hydrodynamic Characterization of the Water Table of the Upper Dallol Maouri Basin (Niger)

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Abstract

The Dallol Maouri is a valley of an ancient tributary of the Niger River. The groundwater in this area of the upper Dallol Maouri is little known because of the weakness of the data. The purpose of this study is to make a hydrodynamic characterization of the water table of the upper dallol Maouri by piezometric approach. A piezometric monitoring network made up of 65 points (54 wells and 11 piezometers) was set up. Six (6) piezometric measurement campaigns were carried out from June 2018 to June 2021. The piezometric survey is carried out once every six months: in January and June corresponding respectively to the high and low water period. The results show that the water table is multi-layered in places with a combination of alluvial and Continental Terminal 3 (CT3) aquifers, or perched aquifers and inferoflux aquifers around permanent ponds. The flow direction of the Continental Terminal 3 (CT3) aquifer is mainly North-East/South-West. The piezometric levels are around 219 m (in the South-West part) and 281 m (in the North-East part). The hydraulic gradient varies from 0.018‰ to 1.83‰. The recharge zones are located in the outcrop zone of the aquifer and in the valleys. A lack of recharge is observed on the plateaus despite the presence of numerous permanent ponds. The recharge coefficient in 2020 is estimated at 25% of the total rainfall recorded.

Keywords

Aquifer, Piezometry, Pond, Recharge, Isotopic

1. Introduction

Food self-sufficiency in the Sahel requires the development of irrigated crops in the valleys. Satisfying water needs for consumption and irrigation requires increasing demands on aquifers. The left bank of the Niger River is characterized by a multitude of ancient valleys that once drained the waters of the Aïr. Formerly very rich in water resources, these valleys have experienced a process of desertification in recent decades. The Dallol Maouri is one of these valleys. Its valley is cut into a plateau whose limit is marked by steep escarpments, formed by thick armor with however regional variations. The upper Dallol Maouri, area of this study, is characterized by a low surface water potential which is very limited (only in the rainy season and in the form of ponds in certain depressions). Groundwater is therefore the main source of drinking water for populations and livestock, but also and above all for crop irrigation. The water table is the most exploited because it can be easily mobilized due to its proximity to the ground surface. The interrelation between the different aquifers in the area on the one hand and between surface water and groundwater on the other hand remains poorly understood. According to isotopic studies carried out by [1] [2] and [3], only the groundwater contains recent water. The underlying aquifers (CT2, CT1) are fossil waters (not renewed), infiltrated under a more humid and cold climate than the current climate. In the Dallol Maouri, the water table is the most exploited because of its accessibility by wells and more than 80% of the water points exploit the water table [4]. With population growth and the need to increase irrigated agriculture to meet food needs, catchment works have multiplied.

The water table of the upper Dallol Maouri has not been the subject of a piezometric study since the work of B [5] [4] and [1]. The piezometric monitoring network of the Regional Directorate of Hydraulics and Sanitation of Dosso only slightly touches the upper Dallol Maouri. In this area, the water table is characterized by sudden variations in lithologic facies and numerous perched aquifers ([4] and [1]). Inferoflux sheets are found in most sandy valleys, fed by the rains of the year [6]. The morphology of its piezometric surface is complex [5]. Recharge occurs locally from runoff concentration points ([7] [8] [9] and [1]). In the north of the basin and on the plateaus, diffuse recharge is low or even non-existent. The objective of this study is to analyze the hydrodynamic characteristics of the water table in the upper Dallol Maouri basin.

2. Material and Methods

2.1. Presentation of the Study Area

The Dallol Maouri is a fossil valley of a tributary of the Niger River, stretching north-south and covering the departments of Doutchi, Dioundou and Gaya in the Dosso Region. Dallol is a name given by the Fulani to a valley, so etymologically "Dallol Maouri" would then mean the Maouri valley and "Maouri" which represents an ethnic group from Niger. Currently, these waters can no longer flow very far and infiltrate fairly quickly towards the water table of the Continental Terminal [3].

The upper Dallol Maouri belongs to the vast basin of the Iullemmeden. It is located between longitude 3˚46' and 5˚07' East and latitude 13˚53' and 14˚56' North (**Figure 1**). Its watershed covers an area of 10,210 km^2 and is located in the north of the department of Dogondoutchi straddling 2 municipalities and a department, namely the rural municipalities of Dogon kirya, Soukoukoutan and the department of Bagaroua. In this area, the surface water potential is limited and consists of semi-permanent and permanent ponds threatened by climate change and human activities. Groundwater resources are therefore the main sources of water supply for populations, livestock and withdrawals for irrigated crops.

The climate in the study area is of the Sahelo-Sudanian type, characterized by the alternation of a short rainy season, from May to September with an annual cumulative rainfall of around 400 mm; and a longer dry season, from October to April. Temperatures vary greatly throughout the year with the highest recorded in April and May ranging from 40˚C to 47˚C. This high temperature causing intense evaporation would be the reason for the early drying up of many surface waters [10]. The lowest temperatures observed in December and January fluctuate between 15˚C and 20˚C [11].

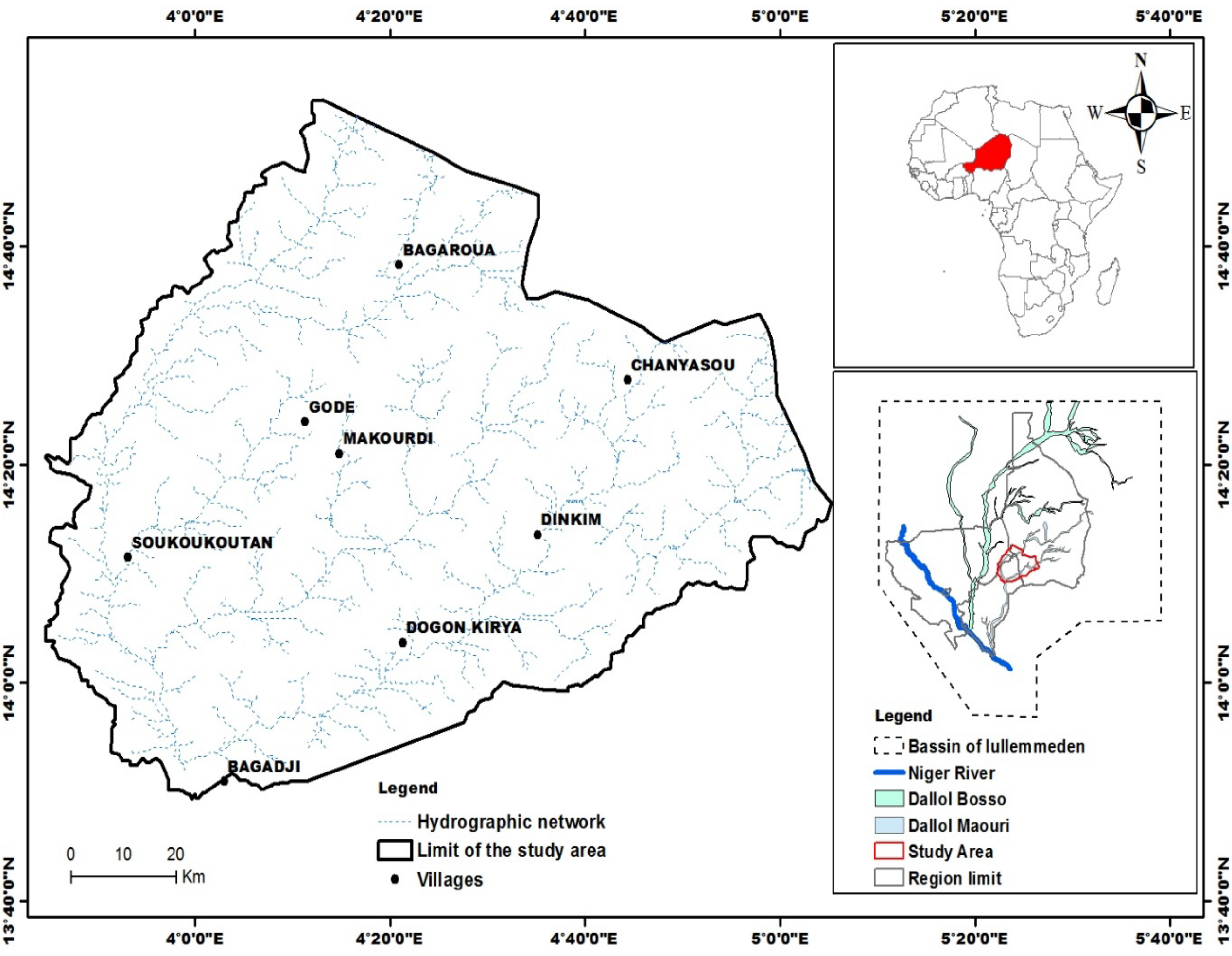

Figure 1. Location of the study area.

- ***Geology and geomorphology***

The geology of the study area is characterized by crystallophyll formations and sedimentary formations (**Figure 2**). The filling of the sedimentary formations consists mainly of sandstone, sand and silts with clayey intercalation dating from the Silurian to the Quaternary [12]. We observe from bottom to top [1]:

- The Continental intercalaire (CI) and Continental Hamadien (CH) series made up of fine to coarse sandstones and medium to coarse sands;
- The series of Paleocene/Ypresian marine deposits made up of marl and limestone, the Continental Terminal 1 (CT1) series which rests on the marine formations of the Paleocene/Ypresian (the facies is essentially sandy with clay passages and soft gray sandstones green sandstone, clayey sand);
- The Continental Terminal 2 (CT2) series consisting of two layers of gray clay with lignite and peat sandwiching a layer of sand in which thin past clay layers appear;
- The Continental Terminal 3 (CT3) series, essentially made up of sand, hetero-granular sandstone and more or less clayey silts, and finally the alluvial aquifer series, essentially made up of alluvial sand.

The relief of the study area is made up of plateaus, intermediate zones and Dallol plains with altitudes varying from 232 to 390 m above sea level (**Figure 2**).

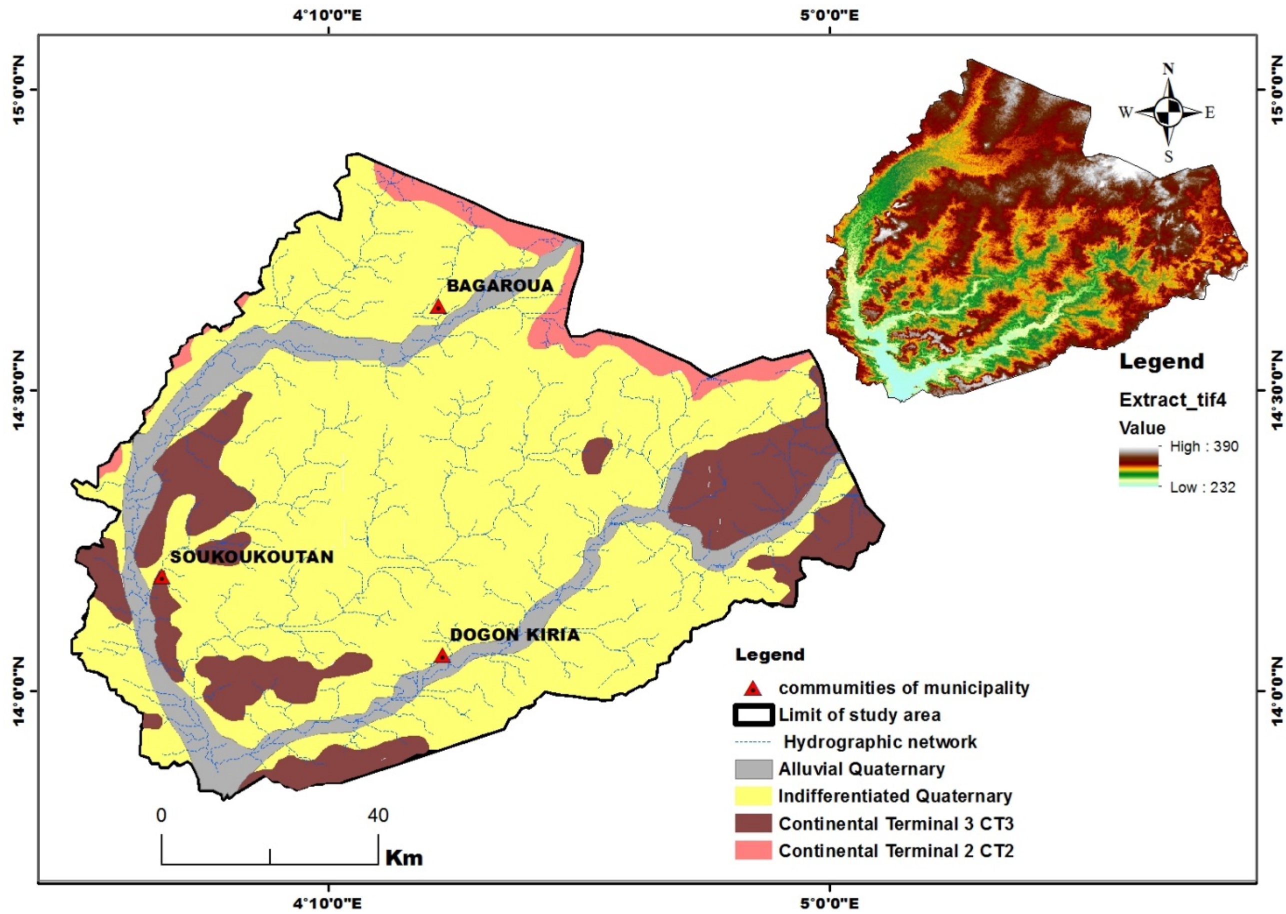

Figure 2. Geological map of the upper Dallol Maouri watershed.

The lowest altitudes are found in the valleys and the highest are observed in the northeast on the plateaus with altitudes not exceeding 390 m.

The general morphology of the study area is a plateau slightly inclined from North-East to South-West and strongly cut by the valley of the Dallol Maouri and several koris which collected rainwater and surface water flows are random [13].

- ***Hydrogeology***

The hydrogeology of the area is characterized by several superposed aquifers: alluvial aquifers, CT3, CT2, CT1 aquifers and CI/CH aquifers [14]. The impermeable layers separating the different aquifers become sandy or thin in places, thus promoting communication between the aquifers [1]. The water table, the most exploited, is characterized by sudden variations in lithologic facies. According to [5] the morphology of its piezometric surface is complex. In the North of Dallol and under the plateaus, diffuse recharge is low or even non-existent. It is carried out in a localized manner from points of concentration of runoff, permanent ponds and streams ([7] [8] and [9]).

The Dallol Maouri is one of the valleys where the availability of water (the alluvial water table is less than 25 m deep) makes it possible to envisage a good development of irrigated crops, after the rainy season and before the arrival major periods of heat in April and May [15]. Also on the plateaus, the impermeable ferruginous armor can support a few narrow pools of short duration, where the sandy cover is the most important.

2.2. Material

The materials used consist of tools and data.

The tools used in this work are:

- A Garmin-type GPS for taking geographical coordinates of the various piezometric monitoring points;
- A tape measure for measuring the diameters and heights of the copings of the measuring structures;
- A light and sound piezometric probe for measuring static levels in the various structures;
- Software ARGIS 10.5 was used to produce the thematic maps;

The data used in this work are:

- Previous reports on the study area;
- Geological maps and satellite images.

2.3. Methodology

2.3.1. Data Collection

- The piezometric monitoring network used consists of 65 water points, including 55 piezometers and 10 wells (**Figure 3**). The monitoring works were chosen at their geographical locations: in the valleys, on the channels and on the plateaus (**Figure 1**).
- Data collection was carried out for three (3) years, on a semi-annual basis: in

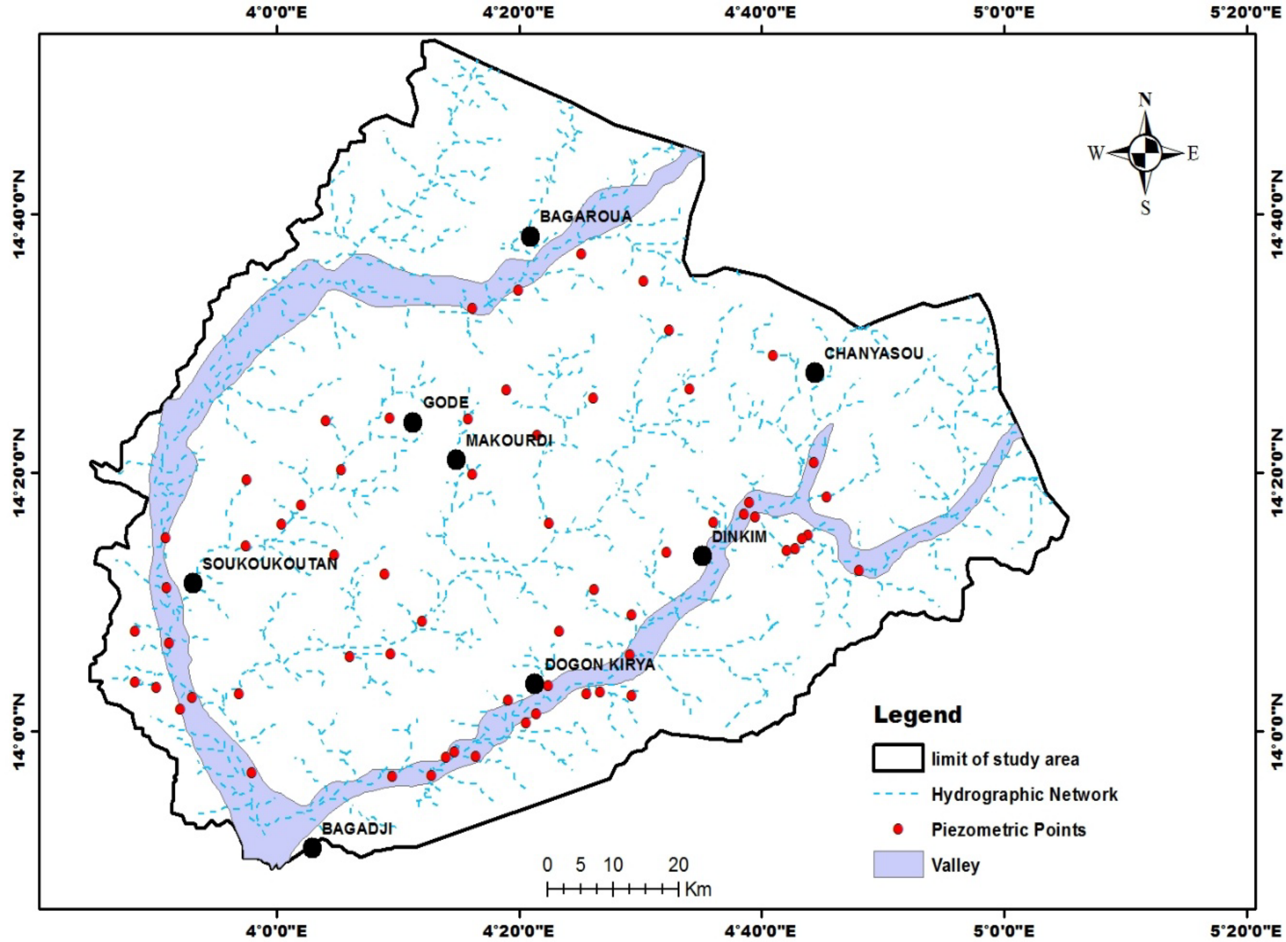

Figure 3. Geographical distribution of water points monitored by the water table

January and June corresponding respectively to the high water period and the low water period.

2.3.2. Data Processing

The piezometric maps are produced by the geostatistical analyst and spatial analyst extensions of the ARGIS software.

The hydraulic gradients were calculated using the following formula:

$$i = \Delta H / L. \quad (1)$$

With i = the hydraulic gradient, ΔH = the difference between the hydraulic heads of two structures located on the same streamline in the direction of the groundwater flow and L= the distance separating the two structures.

Groundwater recharge was estimated by analyzing seasonal fluctuations (WTF: Water Table Flux). To determine the porosities of the aquifer reservoirs, previous data on the alluvial and CT3 aquifers were used: 8% for the CT3 aquifer [1] and 20% for the alluvial aquifer [4]. Cumulative rainfall for 2020 was used. The recharge was calculated using the following formula [16]:

$$R\left(t_j\right)_{averge} = \Delta h\left(t_j\right)_{average} * S \quad (2)$$

With: $R\left(t_j\right)_{averge}$ = average recharge between a time t0 and tj;

$\Delta h\left(t_j\right)_{average}$ = difference between the maximum piezometric level of the season at time tj and the assumed lowest level;

S = storage coefficient or effective porosity for unconfined aquifers.

The recharge rate or recharge coefficient was calculated using the following formula [16]:

$$\alpha = R_{average} / P_{average}\,(\text{mm}) \tag{3}$$

With: $R_{average}$ = the average annual recharge;

$P_{average}$ = the average rainfall.

3. Results and Discussion

3.1. Results

3.1.1. Spatial Variation of the Piezometric Levels of the CT3 Aquifer

Figure 4 shows the spatial variation of static levels. The piezometric levels vary from less than 1 m (the outcrop zone of the water table where the structures have shallow depths) to 79 m (under the plateaus where the structures have great depths). The static levels are strongly influenced by the depth of the structures linked to the topography. Field visits revealed several structures that capture perched aquifers and inferoflux aquifers around the ponds (**Photo 1**). These

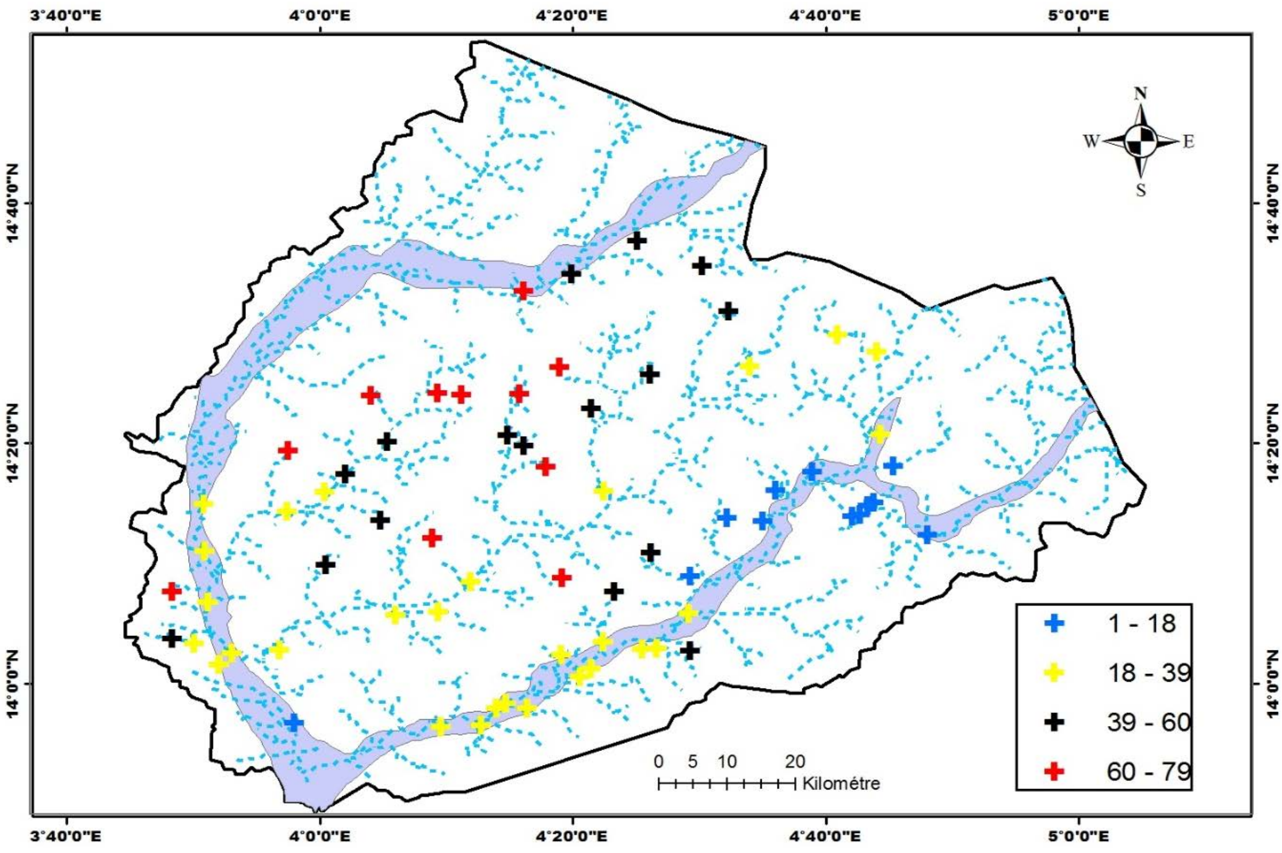

Figure 4. Spatial distribution of the piezometric levels of the water table.

Photo 1. Perched and inferoflux aquifers.

structures have low piezometric levels compared to the water table itself. According to the analysis of the existing geological sections next to these structures, these aquifers are not in hydraulic continuity with the CT3 aquifer. These structures are exploited just one to two months after the rainy season before they subsequently become dry. These small localized aquifers are present in several places (in the valleys, the chimneys of the hydraulic network, under the plateaus and near the ponds).

The analysis of the piezometric surface (**Figure 5**) indicates that the hydraulic heads vary from 219 m in the western part to 281.55 in the eastern part with hydraulic gradients varying from 0.01816‰ in the south to 1.83‰ in the North. The high values are located in the north where the aquifer is deep and the low values are located in the southern part. These gradients are similar to those

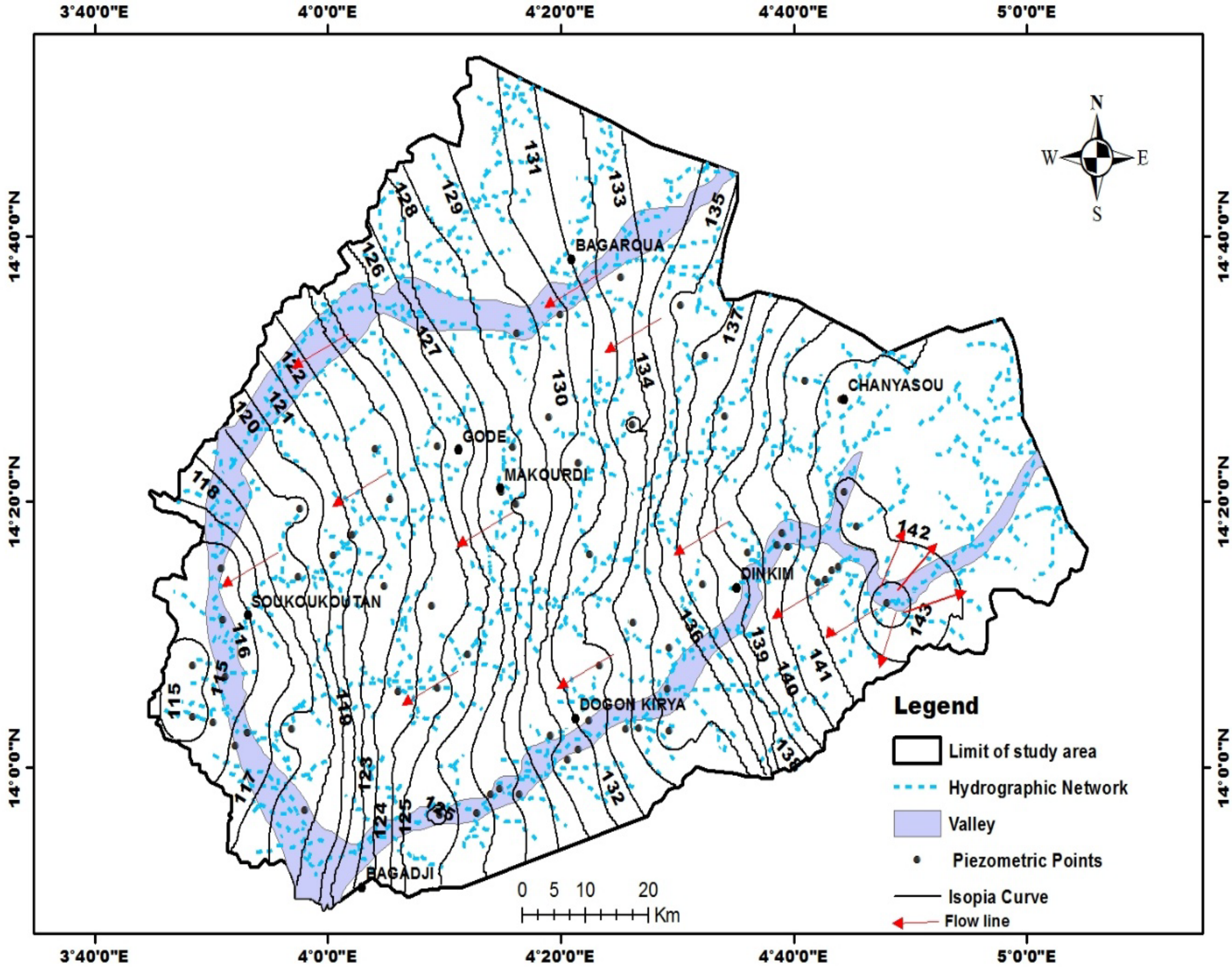

Figure 5. Piezometric map of the water table (CT3).

obtained (1% to 1.5%) in 1965 by [5] in [17]. Thus the average directions of water flows from the CT3 aquifer are mainly North-East/South-West.

3.1.2. Temporal Variation of the Piezometric Levels of the Groundwater Phreatic

1) Seasonal fluctuation of piezometers in the eastern part

Figure 6 presents the seasonal variation of the piezometric levels. It shows that all piezometers react to precipitation and variations between seasons of the piezometric levels are well marked. The pace of curves of the piezometric levels of all the piezometers (6) monitored is quite similar.

2) Seasonal fluctuation of piezometers located in the valleys

Figure 7 presents the inter-seasonal variation of piezometric levels. The analysis of this figure shows that all the piezometers have recorded variations in the piezometric levels, but this variation is less marked between two consecutive seasons. Indeed, there is a slight drop in piezometric levels from the high water period (January-February) to the low water period (May-June). However, an exception is observed at the right of the Maiguebé well where a strong increase

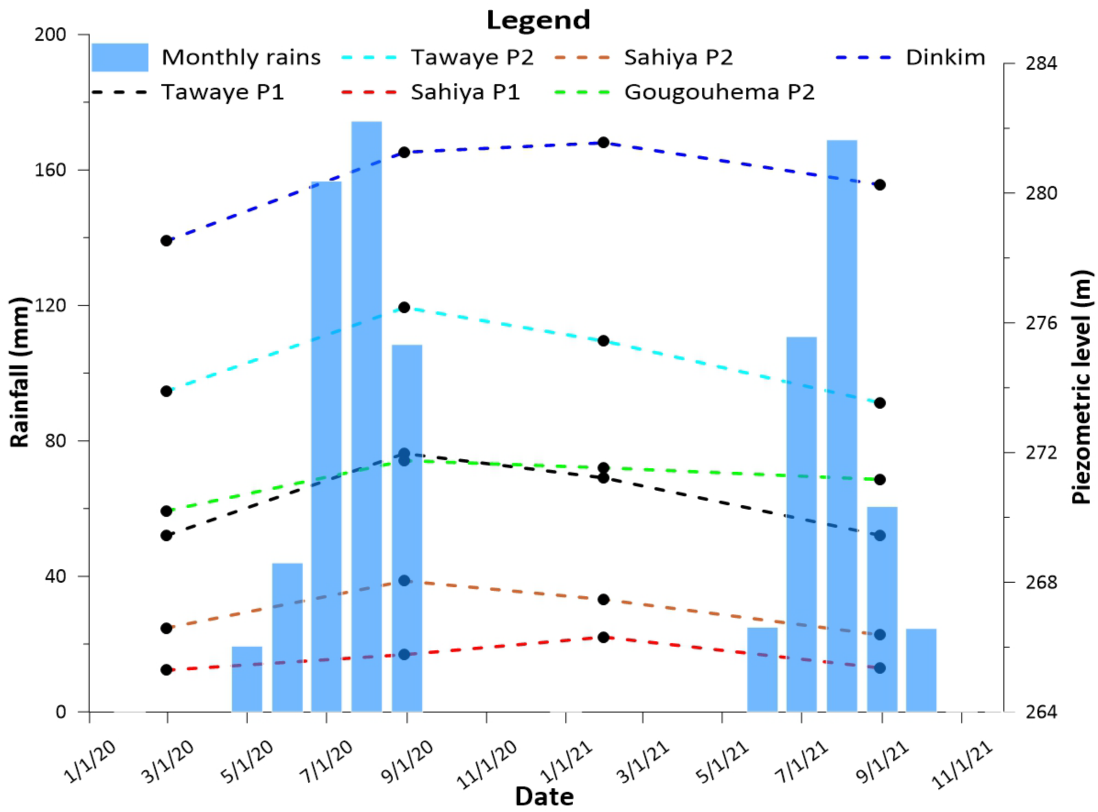

Figure 6. Inter-seasonal variation of piezometric levels in the CT3 outcrop area.

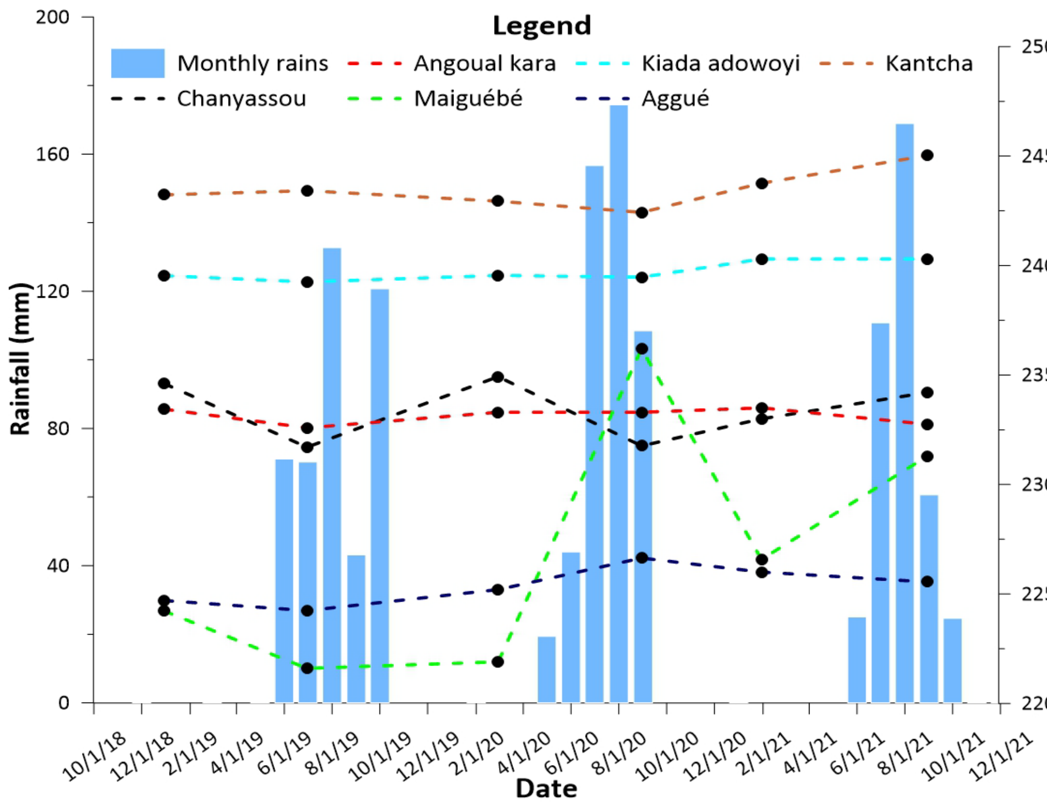

Figure 7. Inter-seasonal variation of CT3 aquifers located in the valleys.

(14.3 m) in the piezometric level was from the third campaign to the fourth campaign. This sharp increase is linked to flooding during the rainy season. During our visit in August 2020, we observed lateral intrusions of rainwater via cracks in the well casings, these intrusions are materialized inside the well by water jets (**Figure 8**). These observations were made in the villages of Maiguébé and Koutoumbou

3) Seasonal fluctuation of piezometers located under the plateaus

Figure 9 shows the seasonal evolution of piezometric levels. It can be seen that the wells did not record significant variations. This highlights a lack of recharge to the rights of these wells located on the plateaus. This lack of recharge is linked on the one hand to the great depth of the aquifer (more than 60 m) and to the lithological nature of the top of the aquifer, consisting of a large fringe of clay which moreover places the aquifer places under pressure (Intiga-Tsadoura Fana sector).

4) Seasonal fluctuation of the aquifer located in the southern part capturing the alluvial aquifer

Figure 10 shows the seasonal variation of the water table located in the southern part of the basin. The analysis of this figure shows that the piezometers capturing the alluvial aquifer show a slight decrease in level during the low water period and a slight increase during the high water period. However, the piezometric levels of Godabawa, Kakadim and Maddata recorded an increase during the fourth season (period of low water), unlike the piezometers of Taramna and Dangari where this increase was not recorded despite their shallow depths. This increase in these three wells is probably due to the groundwater response in August.

Figure 8. Flooding by lateral intrusion.

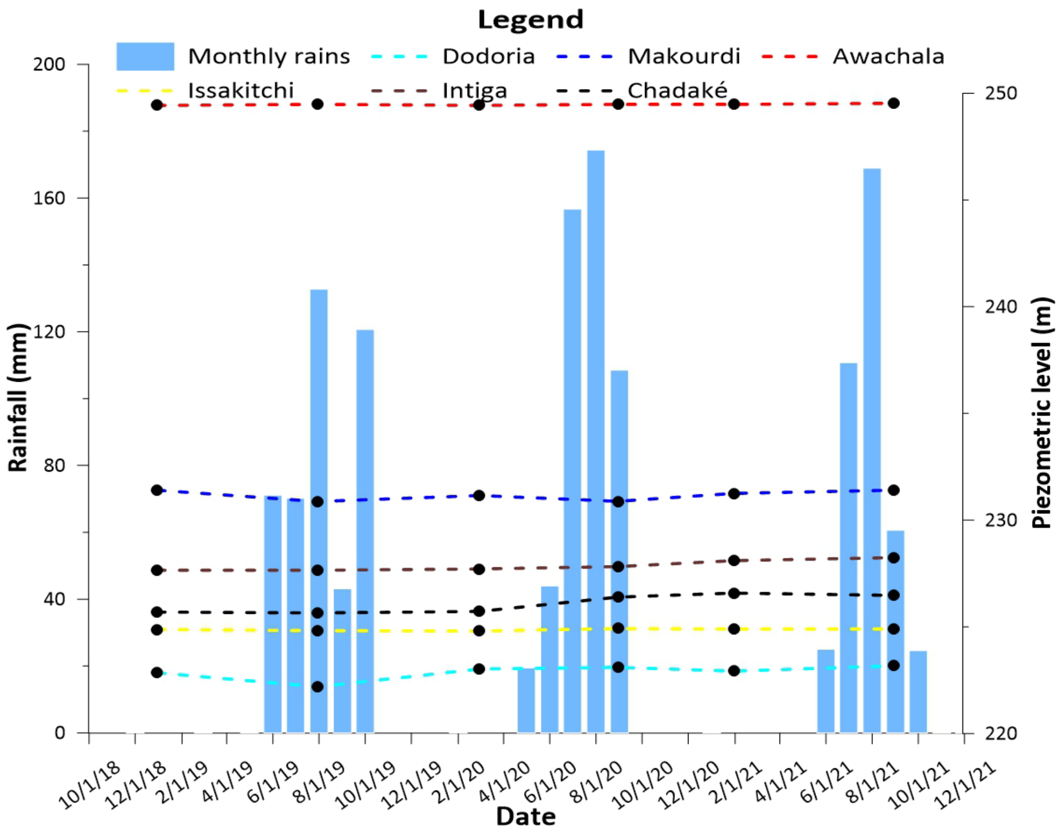

Figure 9. Inter-seasonal variation of piezometric levels of the water table located on the plateaus.

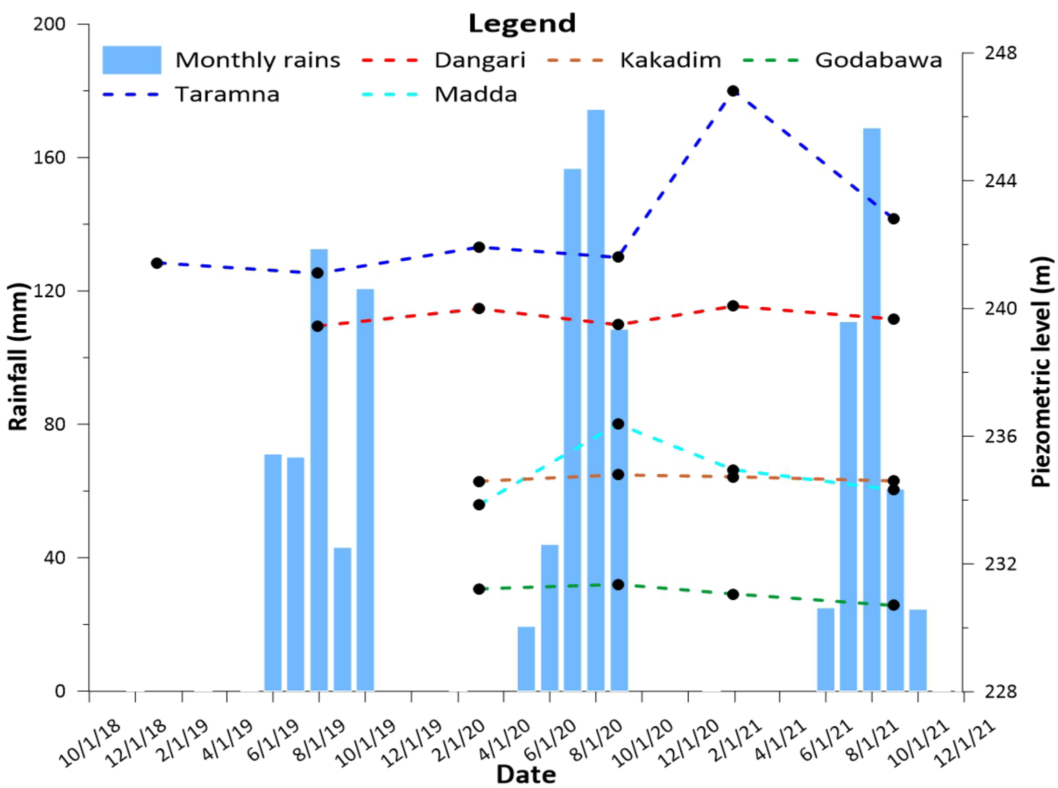

Figure 10. Inter-seasonal variation of the alluvial water table.

3.1.3. Test to Estimate CT3 Recharge and Alluvial Aquifer

Table 1 presents the recharge in the 3 zones of the basin. It can be seen that the recharge varies according to the location of the aquifer: 151 mm/year in the outcrop zone, 127 mm/year in the alluvial aquifer and 110 mm/year in the CT3 aquifer of the valleys.

3.2. Discussion

Overall, the piezometric levels of the water table vary from less than 1 m (the outcrop zone of the water table where the works have shallow depths) to 79 m (under the plateaus where the works have large depths). In fact, low values are encountered in the valleys and chimneys of the hydrographic network, while high values are observed under the plateaus. This reflects the influence of topography on static levels. This phenomenon was observed by [18] in the water table of the Tillaberi region. This great spatial variability of the depths of the groundwater table induces a strong variability of the statistical levels and the mechanisms of groundwater recharge [4] [1]. However, several structures were observed capturing perched sheets and inferoflux sheets around the ponds. These structures have low piezometric levels compared to the piezometric levels of the water table itself. These small localized aquifers are present in several places (in the valleys, the chimneys of the hydraulic network, under the plateaus and near the ponds). This suggests that the water table of the upper Dallol Maouri basin is multi-layered in places. Elsewhere, in Grand Yaréré, North Cameroon, This phenomenon similar to ours was highlighted by [19], through the isotopes of the water molecule, he showed that the water table is bilayer, considered for a long time as a single-layer generalized water table. Thus, to avoid establishing a piezometric map consisting of static levels of the CT3 and those of the alluvial, perched aquifers and the inferoflux aquifers around the ponds, the structures capturing the alluvial aquifers, the perched aquifers and the inferoflux aquifers around ponds, which are not in hydraulic continuity with the CT3 aquifer according to the analysis of the lithological sections, have been removed from the points used to draw up the piezometric map. By including these points, the morphology of the piezometric surface could be complex. Moreover in 1965, Boeck [5] established the piezometric map at the scale of the generalized water table of the Iullemmeden basin in Niger from existing works and he indicated that the morphology of the piezometric surface is very complex. This complexity could be linked to the presence of numerous lenticular aquifers [4] which have

Table 1. Groundwater recharge and recharge coefficient.

	CT3 outcrop zone	CT3 aquifer in the valleys	Alluvial aquifer
Mean piezometric rise (in mm)	1.89	1.37	1.59
Recharge (in mm/year)	151	110	127
Recharge coefficient (%)	30	22	25

no hydraulic continuity with the general groundwater table. The average directions of water flows from the CT3 aquifer are mainly North-East/South-West. It is observed that the underground flow has the same direction and the same direction as the surface flow oriented North-East/South-West [6]. This direction of groundwater flow is in agreement with the results of previous work [5] [1]. In addition, this direction is in perfect agreement with the dips of the geological layers (North-East/South-West) of the Continental Terminal [12].

The piezometers located in the eastern part (outcrop area of CT3) all react to precipitation and the piezometric levels experience a clear inter-seasonal variation in the piezometric levels. The shape of the curves of the piezometric levels of all the piezometers (6) monitored are quite similar. The overall analysis shows that after the rainy season all the piezometers recorded an increase in piezometric levels. This increase is linked to the contribution of the rainfall of the year. However, some contrasts are observed between the piezometers. The piezometric levels of the piezometers located closer to the permanent ponds are stationary until February while those located a little far from the ponds record a slight drop at the end of the rainy season. This highlights respectively the significant support of permanent ponds to the aquifer and the influence of pumping on the aquifer (for the supply of populations, livestock and agricultural activities) at the level of piezometers not close to the ponds.

The piezometric levels of the structures in the valleys capturing the CT3 aquifer varied little between two consecutive seasons. Indeed, there is a slight drop in piezometric levels from the high water period (January-February) to the low water period (April-May). However, some exceptions are observed at the right of the Maiguebé well. At the level of this well, there is a strong increase (14.3 m) in the piezometric level from the third campaign to the fourth campaign. This sharp increase is linked to flooding during the rainy season. During our visit in August 2020, we observed lateral intrusions of rainwater via cracks in the well casings, these intrusions are materialized inside the well by water jets (**Figure 8**). Indeed, according to the information received and testimonies from the local populations, during the sinking of the well, an alluvial aquifer was encountered by the well diggers. This horizon (reservoir of the alluvial aquifer) was cased in order to continue and reach CT3. Indeed, in the rainy season, the water quickly infiltrates the alluvial groundwater (dry during the dry season) and enters the well through the cracks in the casings. This phenomenon is frequently encountered in the area, especially in the north (Maiguebé-Koutoumbou sector) in the valley bed.

The piezometric levels of the piezometers capturing the CT3; have not recorded significant variations. This translates into an absence of recharge at the rights of these wells located on the plateaus. This corroborates the results obtained in the water table of Dallol Maouri by [1] which indicate the plateaus are characterized by an absence of piezometric level fluctuations. This lack of recharge is linked on the one hand to the great depth of the aquifer (more than 60

m) and to the lithological nature of the top of the aquifer, consisting of a large fringe of clay which moreover places the aquifer places under pressure (Intiga-Tsadoura Fana sector).

The piezometers (wells) located in the southern part (in the arms of the valley) where the piezometers (wells) capture the alluvial aquifer.

A significant diffuse recharge is recorded at the level of the wells located in the minor bed of the valley (wells of Taramna and Dangari) and in the channels of the hydrographic network. There is also a strong increase in the piezometric level (5.22 m) in Taramna from the fourth campaign to the fifth campaign. This particularity is linked to the high rainfall in 2020 and the location of the structure near the permanent pond of Taramna (100 m). This highlights the contribution of this pond to the recharge of the water table, which reflects a localized recharge near the ponds. This phenomenon is similar to that described by [1] in Kolefou not far (about 4 km) from Taramna. It indicates that the Kolefou piezometer located about 150 m from a permanent pond, records annual piezometric amplitudes greater than 2 m, reaching 4.2 m in 1994.

4. Conclusion

The piezometric study made it possible to characterize the local hydrodynamic behavior of the water table. It is established that four types of piezometers are identified according to the monitoring points of the water table: The piezometers located in the eastern part of the zone (CT3 outcrop zone) where the piezometers show a recharge of the water table, translated by a significant seasonal fluctuation of the piezometric levels; the piezometers of the valleys also showing piezometric fluctuations where the structures capturing the CT3 aquifer; The piezometers (wells) located in the southern part where the piezometers capture the alluvial aquifer and the piezometers of the plateaus where there is an absence of recharge resulting in an absence of fluctuation of the piezometric levels. The main directions of water flow from the CT3 aquifer are oriented from North-East to South-West in accordance with the dips of the sedimentary layers. The hydraulic gradients of the CT3 aquifer are weak in the southern part and strong in the northern part where the aquifer is deep. The water table is multi-layered in places, consisting of the alluvial water table, perched water tables, inter-flow water tables around the permanent ponds and the recharge areas of the CT3 water table are located in the eastern part, the outcrop area of the aquifer by forming large continuous pools (Ambagoura-Dinkim-Dan-Doutchi Sector) and in the valleys. The recharge rates of the CT3 aquifer vary respectively by 22% and 30% of the total rainfall for 2020 (502 mm) in the eastern part and in the valleys where the structures capture the CT3 aquifer. As for the alluvial aquifer, its recharge rate is 25% of the total rainfall.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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