Journal of Environmental & Earth Sciences
https://journals.bilpubgroup.com/index.php/jees

ARTICLE

Ten-Year Analysis of the Dynamics of the Goulbi'N Maradi Alluvial Aquifer from 2013 to 2022 in Niger

Abdel Kader Hassane Saley [1*] , ***Issoufou Sandao*** [1] , ***Inaytoulaye Saidou Garba*** [2]

[1] *Department of Geology, Faculty of Science and Technology, Abdou Moumouni University, Niamey 10662, Niger*

[2] *Information and Research Department, Regional Center of AGRHYMET, Niamey BP 11011, Niger*

ABSTRACT

In the Maradi region, the alluvial aquifer of the Goulbi'N Maradi rests on the aquifers of the Continental Hamadien. It represents an essential reserve for irrigation and drinking water supply. However, due to its high demand and the excessive use of chemical fertilizers and pesticides in irrigation, a ten-year analysis of the dynamics of this alluvial aquifer has proven necessary. Hence, this study, based on hydrodynamic and hydrochemical approaches, aims to improve knowledge of the dynamics of the alluvial aquifer from 2015 to 2023. The novelty of this study lies in its comprehensive coverage of the entire Goulbi N'Maradi valley in Niger, employing a multidimensional approach. The data used were composed of water samples taken from forty-five structures, piezometric monitoring sheets, and digital terrain models. The results reveal that the Goulbi'N Maradi aquifer exhibits continuous piezometry, characterized by a general flow pattern from south to northwest and a relatively strong hydraulic gradient in the southern part, indicating recharge from recent infiltration of rain and floodwaters. The water balances calculated at a monthly time step showed that only July and August had surpluses, with average infiltrations of 25.4 mm and 23.9 mm for 2018 and an RFU of 50 mm. For 2021, the average infiltrations were 30.8 mm and 6.6 mm, respectively, for August and September, and for the same RFU. The water conductivity values between 115 and 800 $\mu S \cdot cm^{-1}$. The hydrogen potential varied between 5 and 7 pH units, giving the water an acidic character that makes it corrosive to equipment.

Keywords: Goulbi'N Maradi; Alluvial Aquifer; Hydrodynamics; Climate Change; Niger

*CORRESPONDING AUTHOR:
Abdel Kader Hassane Saley, Department of Geology, Faculty of Science and Technology, Abdou Moumouni University, Niamey 10662, Niger; Email: hassanesaleyak@gmail.com

ARTICLE INFO
Received: 2 July 2025 | Revised: 18 August 2025 | Accepted: 27 August 2025 | Published Online: 16 September 2025
DOI: https://doi.org/10.30564/jees.v7i9.10849

CITATION
Saley, A.K.H., Sandao, I., Garba, I.S., 2025. Ten-Year Analysis of the Dynamics of the Goulbi'N Maradi Alluvial Aquifer from 2013 to 2022 in Niger. Journal of Environmental & Earth Sciences. 7(9): 45–60. DOI: https://doi.org/10.30564/jees.v7i9.10849

1. Introduction

In Niger, a Sahelian country, water remains a determining factor in agro-sylvo-pastoral production. In fact, the recurrence of food crises linked to natural and anthropogenic phenomena in recent decades has become structural in the Sahelian space. Thus, the development of irrigation and livestock farming in such an area requires the mobilization of groundwater resources because surface water resources are unpredictable due to the instability of the rainfall regime[1,2]. In the Maradi Region, the alluvial aquifer of Goulbi'N Maradi is highly sought after for drinking water supply and irrigation because of its high productivity and shallow depth. However, the intensive use of chemical fertilizers, phytosanitary products, and pesticides, as well as the proliferation of boreholes capturing this water table, significantly influences the dynamics of this alluvial aquifer[3]. Several studies have been conducted to estimate the amount of recharge/runoff in Niger and elsewhere in the world[4–7]. These studies compare the amount of recharge/runoff using different methods. Groundwater recharge through precipitation is a key factor in the water balance of an aquifer[8–14]. Despite these multiple previous studies, knowledge of the dynamics of the alluvial aquifer of Goulbi N'Maradi in the study area remains insufficient. This confirms the urgency of studying the dynamics of the Goulbi N'Maradi alluvial aquifer through the water balance and the physical parameters of the water. The main objective of the study was to analyze the ten-year dynamics of the Goulbi'N Maradi alluvial aquifer from 2013 to 2022. The specific objectives consist of interpreting the hydro-climatic, geometric, lithological, and hydrodynamic characteristics of the aquifer, estimating average infiltration using RFU = 50 mm, and assessing the physical parameters of the water. All the acquired data were processed using various specific software, including ArcGIS 10.2.2 for mapping and Adobe Illustrator CS6 for drawings.

2. Study Area

The Goulbi'N Maradi Basin, the area of this study, is a transboundary basin located in the southern part of the Maradi Region in Niger and the northern part of Katsina State in Nigeria. Covering an area of 10,115.40 km^2, it lies between 12°22' and 13°51' North Latitude and between 6°26' and 7°55' East Longitude (**Figure 1**). The relief is low to moderate, with altitudes ranging from 271 m to 612 m.

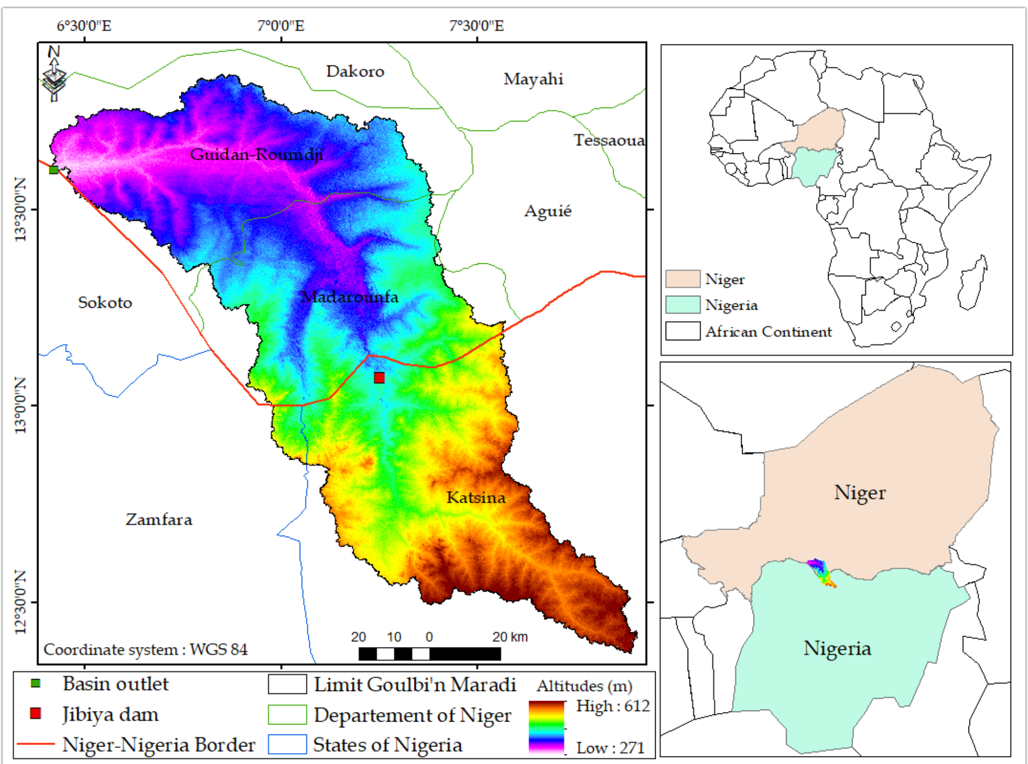

Figure 1. Location map of the study area.

The Goulbi'N Maradi is a seasonal river (July to September) that originates in Katsina State, Nigeria. Its hydrographic network, which is quite dense and well-developed, is based on eruptive, intrusive, and metamorphic rocks in Nigeria and on sandstones covered with alluvium in the bed in Niger, extending up to the N'Yelwa station [15].

The annual flow is estimated to be more than 200 million m^3 at the N'Yelwa station. However, its regime is currently affected by the decline in rainfall and the construction of the Jibiya Dam in 1989 in Nigeria (**Figure 2**). The main river, classified as order 7, measures 206.10 km, and its outlet is located in Niger, in the village of Souloulou, in the department of Guidan Roumdji, where it flows into the Rima River of Sokoto, a tributary of the Niger River. The climate, classified as semi-arid tropical, is characterized by three seasons: a dry and cold season from October to February; a dry and hot season from March to May; and a rainy season from June to September, with annual precipitation, which is poorly distributed in time and space, varying between 350 mm and 600 mm with high intensities. Potential evapotranspiration (**Figure 3**) is at its maximum in March (448 mm), with an average annual accumulation of 3,530 mm. Regarding air humidity, it ranges from a minimum of 15% during the dry and cold period to a maximum of 76% in the rainy season.

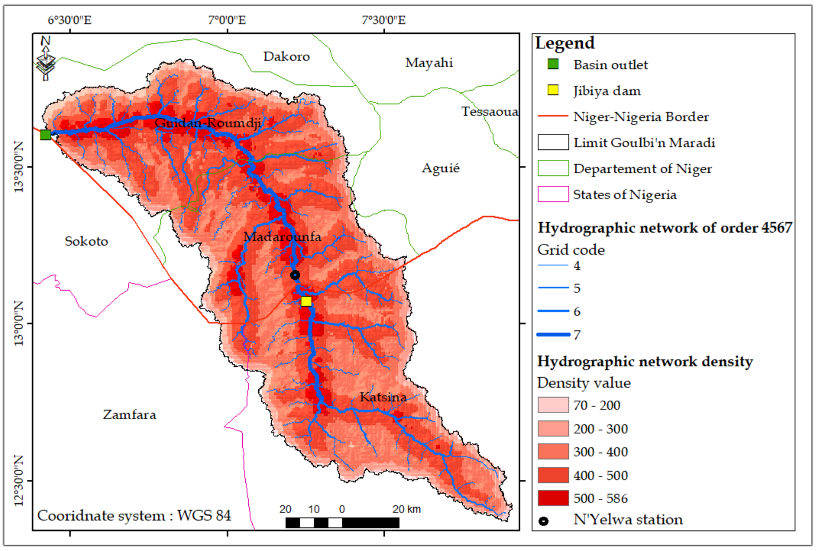

Figure 2. Map of the Goulbi'N Maradi hydrographic network.

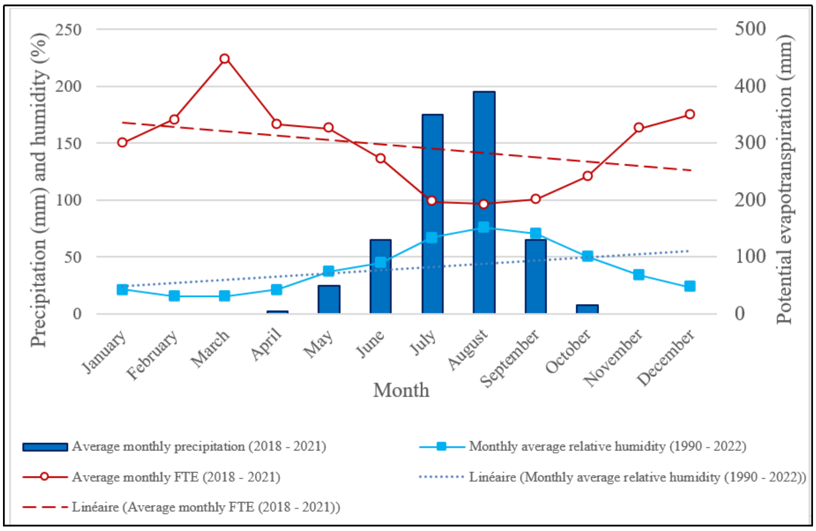

Figure 3. Relationship between monthly averages of precipitation, relative humidity, and potential evapotranspiration (2018–2021) in the study area.

Three groups of geological formations characterize the area from bottom to top[10,11] (**Figure 4**):

- Crystalline basement, consisting mainly of granite, gneiss, schists, and leptynite. In the center, the basement of North Nigeria has undergone a deep alteration of the substratum, leading to the kaolinization of aluminous silicates, an uplift of the basement, and the clearing of the alteration products, which are deposited downstream in a piedmont slope[16].
- Continental Hamadien, of Upper Cretaceous age, has a detrital lithology characterized by rapid variations of facies laterally and vertically[17,18]. It rests in a major unconformity on the crystalline basement and is covered by the Quaternary formations.
- Quaternary, composed of ancient stony alluvium consisting of variegated sandstone, sand, pebbles, and clay banks filling the Goulbi valley, along with recent alluvium, essentially fine sands and extremely tangled clays 5 to 10 m thick, and wind-induced coatings resulting from the erosion of the basement reliefs, covering the old ones downstream of Madarounfa.

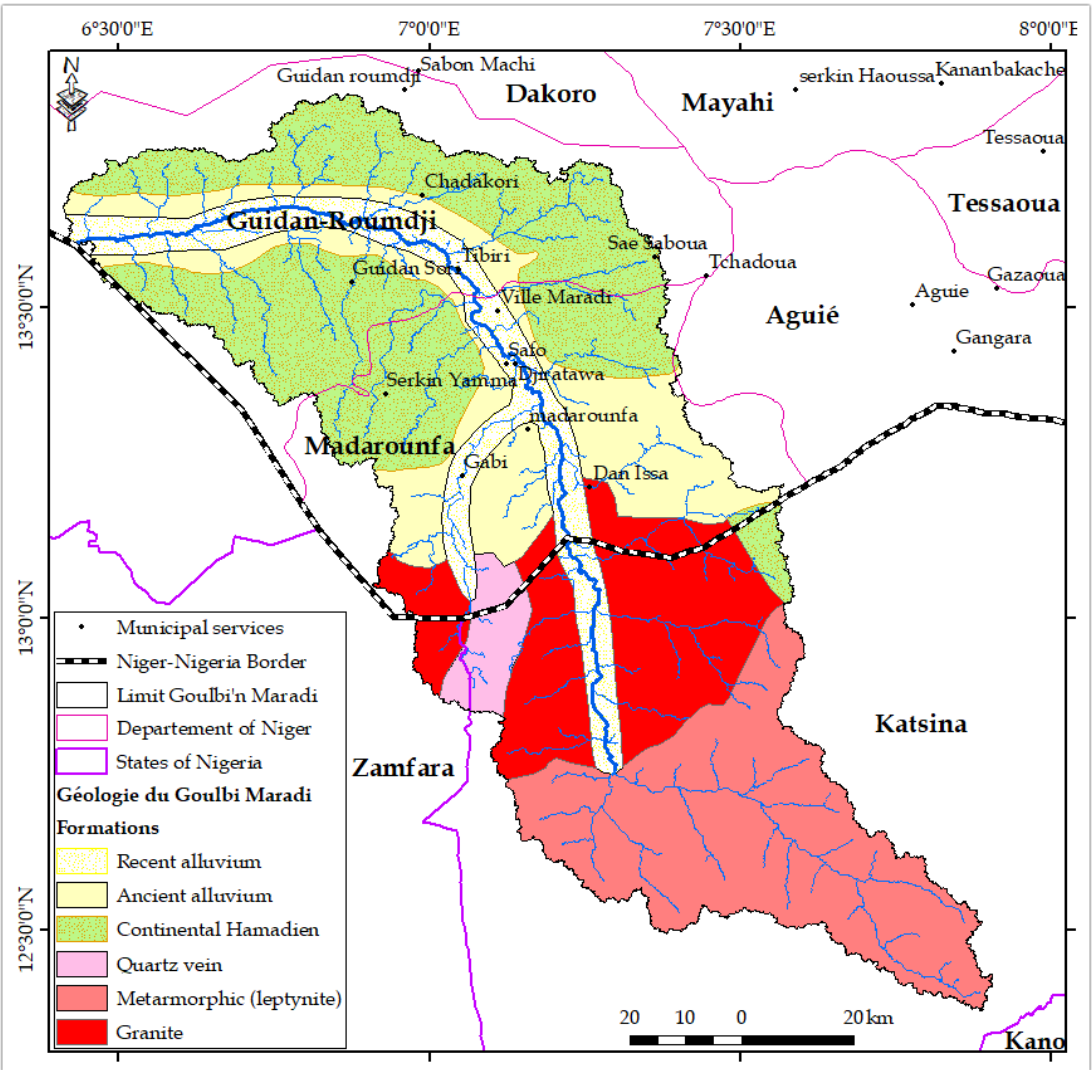

Figure 4. Geological map of the Iullemeden Basin[12].

Hydrogeology shows, from bottom to top, the following aquifers:

- The Basement aquifer, with flow rates of 0.5 to 2 m^3/h and water of good physicochemical quality;
- The Continental Hamadien aquifer, free in the Maradi region, with collection depths between 20 and 80 m.

Flow rates range from 5 m^3/h to more than 50 m^3/h locally, with generally fresh water. Some elements, such as fluorine, may be found in abnormal concentrations (Tibiri arc, Fissataou, Chadakori, Baban Kori, Malan Kaka, Sabon Machi), and nitrates towards Maïjirgui;

- Alluvial aquifers, free and located in the valley in discordance with the sand, with static levels varying between 1 and 18 m. The average conductivities are of the order of 150 µS/cm[3].

3. Materials and Methods

3.1. Material

The material used in this study consists of data and tools. The data mainly comprised theses, study reports, climatic data, piezometric data, hydrodynamic sheets, geological maps, and digital terrain models with a resolution of 30 meters. The tools included static level recorders from the Global Logger and 3 Driver brands, a Garmin GPS, a Rossignole SEBA light-sound probe (for certain piezometric level measurements), and a HI 991301 multifunction conductivity meter with direct reading (for measuring EC, temperature, and pH of the water). In addition, various software programs were used, including Adobe Illustrator (for drawing), ArcGIS 10.2.2 (for mapping), and Statistica (for statistical analyses).

3.2. Data Acquisition

The collection of bibliographic data was conducted at the documentary and archiving centers of the regional technical services of Maradi, as well as from projects and design offices. The piezometric surveys during the year 2023 were carried out in two periods (low water and high water) and involved the 105 piezometers in the Goulbi'N Maradi piezometric monitoring network (**Figure 5**). During these piezometric monitoring campaigns, in the low water (May 2023) and high water (November 2023) periods, the total depths of the structures and the physical parameters of the water were measured. Thus, forty-five (45) structures were selected and sampled after a mesh of the piezometer park for the measurements of the physical parameters of the water.

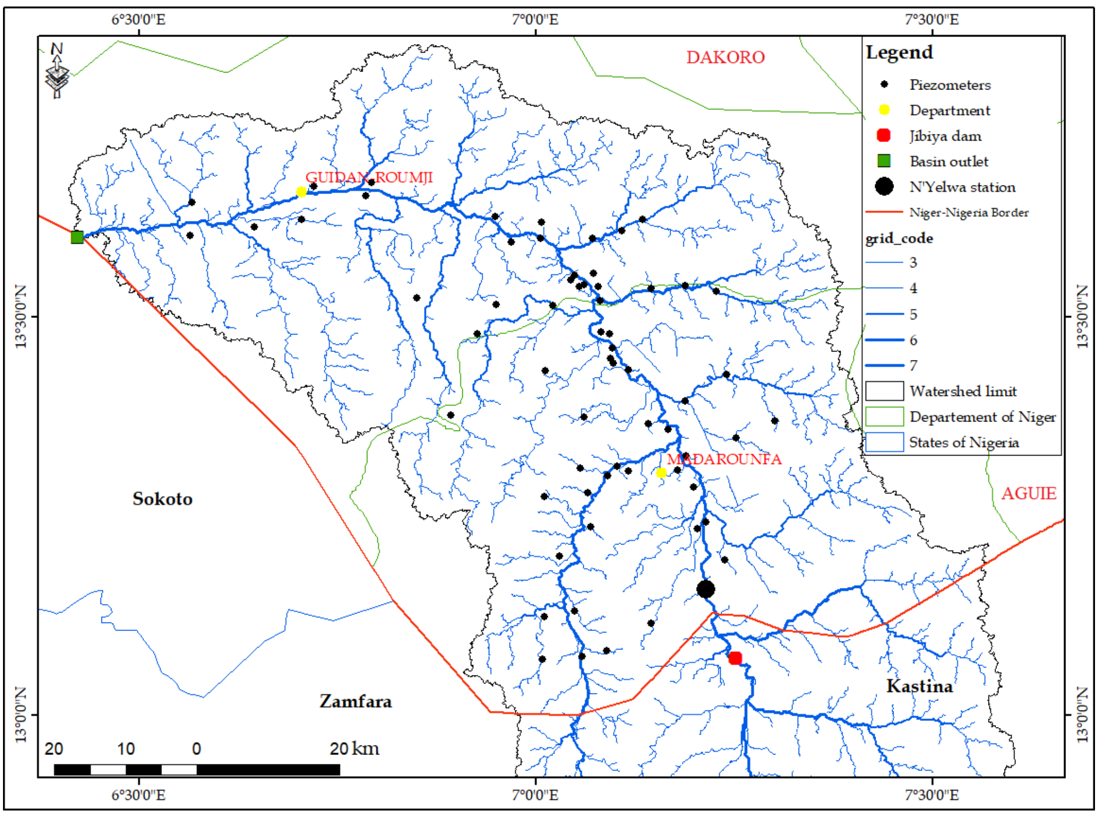

Figure 5. Piezometric monitoring network of the Goulbi'N Maradi valley.

3.3. Data Processing

3.3.1. Precipitation Analysis

The data used in this study to analyze rainfall were collected from the Maradi Airport Station, Guidan Roumdji, and Madarounfa for the period from 1990 to 2022. The evolution of rainfall was assessed using the standardized rainfall index (SPI), developed by McKee et al.[19], which has the following Equation (1):

$$\text{IPS} = \frac{\text{Pluie annuelle} - \text{pluie moyenne interannuelle}}{\text{écart type}} \quad (1)$$

Table 1 provides the various drought classes according to the IPS value.

Table 1. Drought classes based on SPI values.

IPS Values	Drought Type
2.0 and above	Extremely humid
1.99 to 1.5	Very humid
1.49 to 1.0	Moderately humid
0.99 to −0.99	Close to normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Very dry
−2 and less	Extremely dry

3.3.2. Evaluation of the Recharge

The hydrological balance was used to establish the relationship between water inputs and outputs of a defined hydrological unit over a given period. This balance is based on Equation (2):

$$\text{P} = \text{ETR} + (\text{I} + \text{R} + \Delta\text{RU}) + \Delta\text{S} \quad (2)$$

Where:
P = precipitation;
ETR = actual evapotranspiration;
I = deep infiltration;
R = runoff;
ΔRU = variation in the Useful Reserve;
ΔS = variation in the Surface Water Stock.

For a sandy soil like that of Goulbi'N Maradi, a value of RFU = 50 mm (Easily Usable Reserve) is retained. Finally, the annual recharge was estimated using the following Equation (3)[20]:

$$\text{Ra} = \text{D} \times \text{S} \times \text{ne and D} = \text{P}_\text{b} - \text{P}_\text{h} \quad (3)$$

Where,
D: difference in the volume of water stored between the low water period and the high water period;
Pb: the depth of the lowest piezometric level of the year;
Ph: the depth of the highest piezometric level of the year;
S: surface area of the Goulbi;
ne: the effective porosity of the alluvium.

3.3.3. Piezometric Maps

The piezometric heights of the water points were calculated by finding the difference between the altitudes of the water points (extracted from the DTMs in ArcMap 10.2.2) and the in-situ measurements of the static levels relative to the ground at the water points. The heights were used to create piezometric maps of the Goulbi'N Maradi alluvial aquifer for high and low water levels. These maps reflect the morphology of the water surface of the aquifer at the time of the piezometric campaign, allowing for the definition of the direction of water flow.

4. Results

4.1. Interannual Variation in Rainfall

The analysis of the spatio-temporal variability of the annual rainfall indices and their average for the Guidan Roumdji station, calculated from data from 1990 to 2022, shows a heterogeneous distribution of rainfall, materialized by three main periods (**Figure 6**): (i) two dry periods characterized by deficit years. The first runs from 1991 to 1997, with an exceptionally wet year (1994) and an interannual rainfall average of 258 mm. The second period extends from 2002 to 2018, with an interannual rainfall average of 300 mm; (ii) a wet period, from 1998 to 2001, characterized by surplus years, with an interannual rainfall average of 630 mm; (iii) a normal period marked by the alternation of surplus and deficit years, which spans from 2018 to 2022, with an interannual rainfall average of 430 mm. For the Madarounfa station, the annual rainfall indices and their average, calculated from data from 1990 to 2022, also show a heterogeneous distribution of rainfall in three main periods (**Figure 7**): a first normal period marked by the alternation of surplus and deficit years, spanning from 1990 to 1994, with an interannual rainfall average of 550 mm; a second dry period characterized by deficit years, from 1995 to 2015, with an interannual rainfall average of 270 mm; and finally, a third wet period, from 2016 to 2022, characterized by surplus years, with an interannual rainfall average of 675 mm.

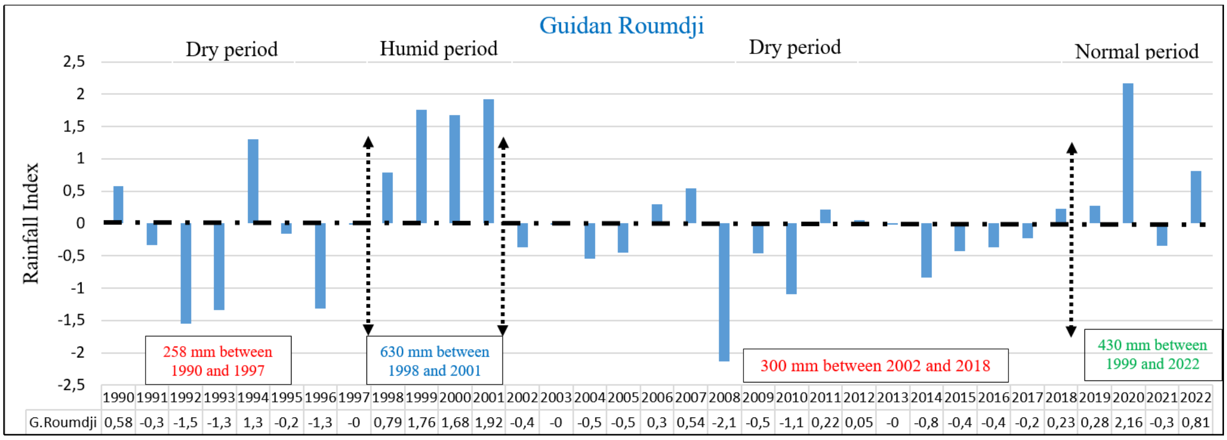

Figure 6. Rainfall index of Guidan Roumdji from the period 1990 to 2022.

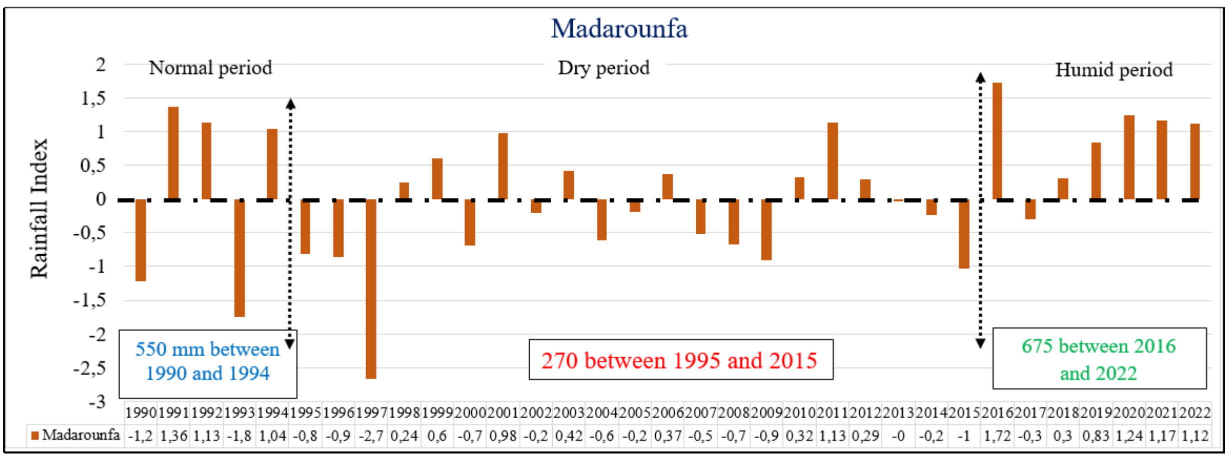

Figure 7. Madarounfa rainfall index from 1990 to 2022.

Potential evapotranspiration is highest in March (over 420 mm), with an average annual accumulation of 3,450 mm (**Table 2**). It decreases regularly in parallel with the increase in atmospheric humidity caused by the rise of the Inter-Tropical Front (ITF).

The lowest values are recorded in July (180 mm) and September (200 mm). It is during this period that the Goulbi records its highest water levels.

The water balances calculated for the study area at a monthly time step, based on the monthly average values of ETP and precipitation heights (2018–2021), are presented in **Tables 3** and **4**. The results of these two tables indicate that only two months (August and either July or September) show a surplus for the value of RFU = 50 mm, depending on the year. The average infiltrations obtained were 25.4 mm and 23.9 mm, respectively, for August and September 2018, and 30.8 mm and 6.6 mm, respectively, for August and September 2021. These surpluses represent the portion of precipitation likely to contribute to the recharge of the water table.

Table 2. ETP (in mm) at the Maradi station (average from 2018 to 2021).

Month	January	February	March	April	May	June	July	August	September	October	November	December	Annual Cumulative Totals
2018	281.3	336.6	420.4	324.4	325.5	280.0	187.1	161.9	189.9	205.4	351.1	345.2	3408.8
2019	320	339.5	480.1	340.1	319.5	262.3	260.6	209.9	205.8	285.1	321.6	380.8	3725.3
2020	290.8	330.1	452.5	322.1	308.2	255.7	182.7	203.8	210.4	248.3	301.2	318.8	3424.6
2021	310.5	360.5	440.8	345.5	350.0	289.8	158.2	198.4	199.8	225.1	328.8	356.1	3860.8
Average	1202.6	1366.7	1793.8	1332.1	1303.2	1087.8	788.6	921.1	956.1	963.9	1302.7	1400.9	14,419.5

Table 3. Water balance for the year 2018 at the Maradi Airport Station (RFU = 50 mm).

Month	Jan-uary	Febru-ary	March	April	May	June	July	August	Septem-ber	Octo-ber	Novem-ber	Decem-ber	Annual Cumulative Totals
Annual rainfall (mm)	0	0	0	4.9	12.3	91.2	125.8	187.3	213.8	1.5	0	0	636.80
Monthly ETP (mm)	281.3	336.6	420.4	324.4	325.5	280	187.1	161.9	189.9	205.4	351.1	345.2	3408.8
Value (P-ETP)	-	-	-	-	-	-	-	+	+	-	-	-	49.3
Value RFU								50					50
Monthly ETR (mm)	0	0	0	4.9	12.3	91.2	125.8	161.9	189.9	1.5	0	0	521
Infiltration (mm)								25.4	23.9				49.3

Table 4. Water balance for the year 2021 at the Maradi Airport Station (RFU = 50 mm).

Month	Jan-uary	Febru-ary	March	April	May	June	July	August	Septem-ber	Octo-ber	Novem-ber	Decem-ber	Annual Cumulative Totals
Annual rainfall (mm)	0	0	0	0	32	57	189	205	78	5	0	0	566
Monthly ETP (mm)	310.5	360.5	440.8	345.5	350	289.8	158.2	198.4	199.8	225.1	328.8	356.1	3563.5
Value (P-ETP)	-	-	-	-	-	-	+	+	-	-	-	-	37.4
Value RFU							50	50					100
Monthly ETR (mm)					32	57	158.2	198.4	78	5	0	0	566
Infiltration (mm)							30.80	6.60				-	37.4

4.2. Hydrodynamic Parameters

4.2.1. Static Levels

The piezometric readings in the upper parts of the South (Samey, blue curve), the average in the center (Angoual Mata, red curve), and the low in the North (Hannou Gazané, green curve) of Goulbi'N Maradi from 2014 to 2022 show considerable variation in static levels (**Figure 8**). Indeed, in Samey, they varied between 2.31 and 3.91 m, respectively, for low and high water; in Angoual Mata, they varied between 8.35 and 11.05 m; and in Hannou Gazané, between 4.44 and 7.69 m. These structures had the lowest levels in April-May, corresponding to the low water period in the area.

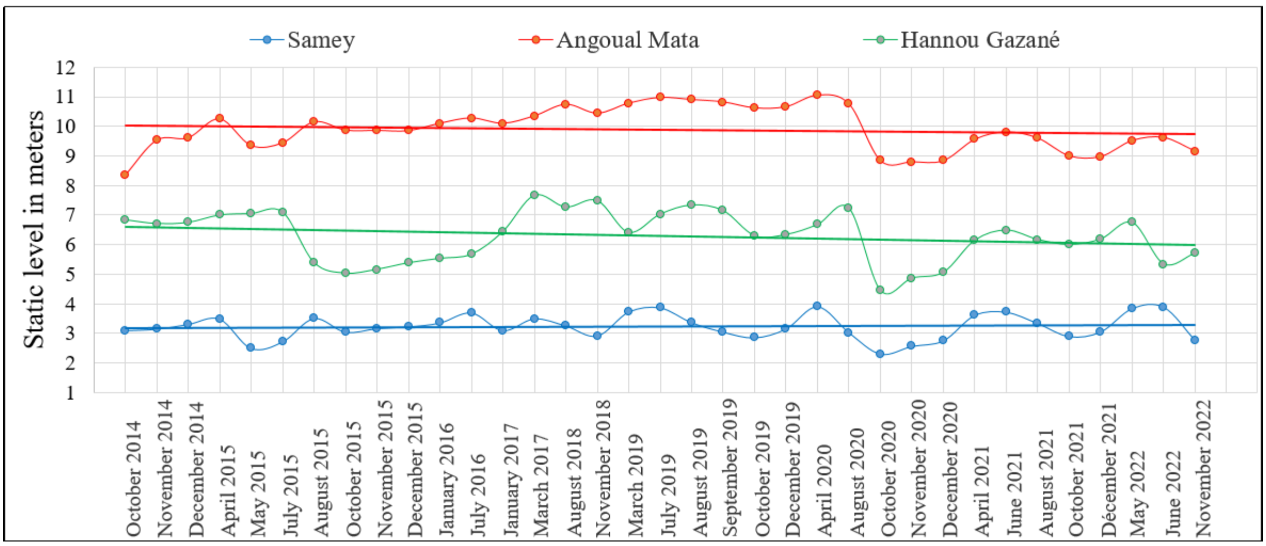

Figure 8. Variation in static levels of the Goulbi'N Maradi water table from 2014 to 2022.

4.2.2. Piezometric Map of the CI/CH Aquifer System

The piezometric maps produced in October of 2015 and 2023 (**Figure 9**) for the Goulbi N'Maradi aquifer show simple and regular piezometric surfaces across the entire valley for both years. The isopiezial curves decrease in altitude from south to northwest, from 425 m to 305 m on both maps, thus defining a main flow direction for the water. However, there was a slight shift towards the northern part of the curves across the entire basin on the 2023 map, indicating a decline in the water table level over time (between 2015 and 2023). The spacing between the isopiezoid curves allows for the distinction of two main zones of recharge and circulation that are identical on the two maps: (i) a south-north direction with a relatively strong hydraulic gradient, indicating that the water table is recharged from recent infiltration of rainwater and upstream flooding, and (ii) a southeast to northwest direction with a weak hydraulic gradient, confirming the recharge of the water table at this level from the flow of water in the basin.

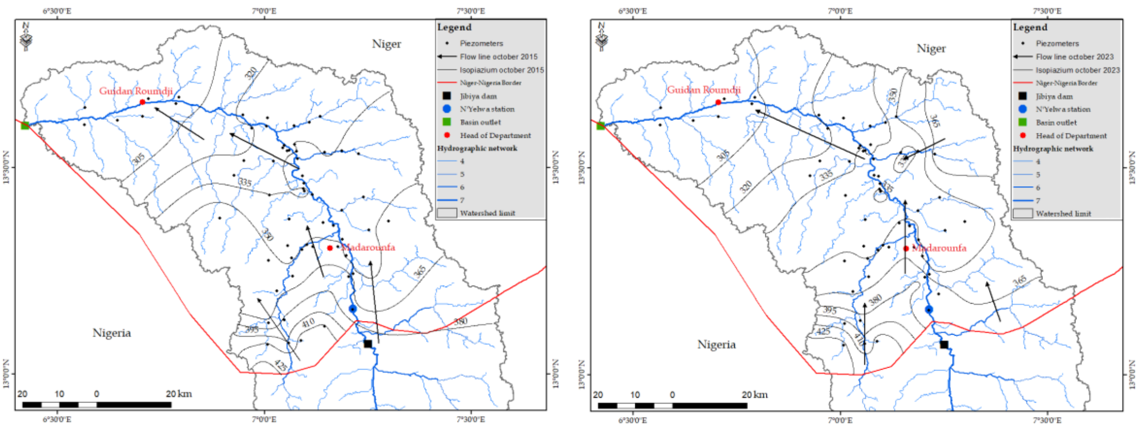

Figure 9. Piezometric map of the Goulbi'N Maradi aquifer, October 2015 and 2023.

4.3. Physicochemical Parameters of Water

Physical Parameters

Temperature

The values of the water temperature of the free water table varied between 26.6 °C and 34.4 °C, with an average of 31.5 °C in Hannou Gazané; between 29.6 °C and 33.7 °C, with an average of 31.53 °C in Angoual Mata; and between 27.04 °C and 33 °C, with an average of 29.44 °C in Samey. The groundwater temperature graphs (**Figure 10**) for May 2023 (blue curve) and November 2023 (red curve) show that the groundwater temperatures of Goulbi N'Maradi measured in November 2023 are lower than those measured in May 2023.

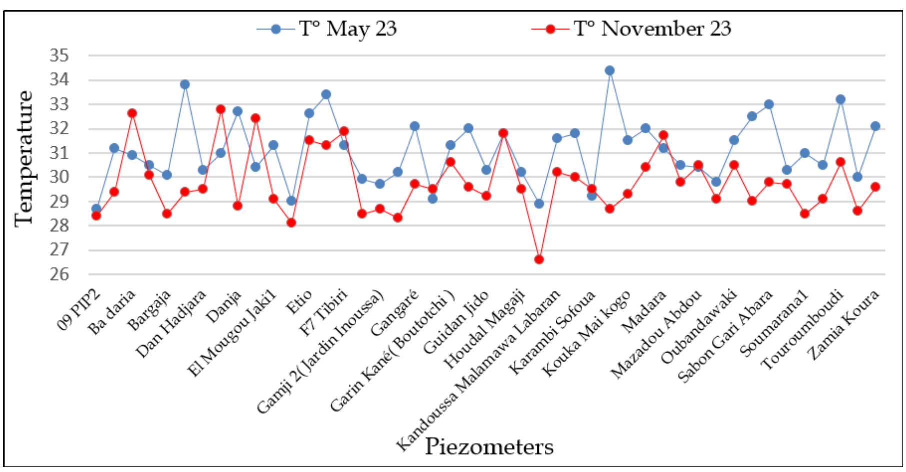

Figure 10. Water temperature of the Goulbi'N Maradi aquifer at low and high water levels.

Hydrogen Potential (pH)

The values of the hydrogen potential (n = 45) of the alluvial aquifer waters varied between 5 and 7 pH units (**Figure 11**). These low pH values observed in the alluvial aquifer are explained by their contact with CO_2 from the atmosphere and soils. Most of the waters had values that do not meet the WHO standard (< 6.5 pH units), whether during the low water period (in blue) or the high water period (in red). The acidic nature of the waters has a corrosive effect on equipment, pumping systems, and metal water pipes. Hence, there is a need to use stainless steel or HDPE plastic materials for water distribution or storage.

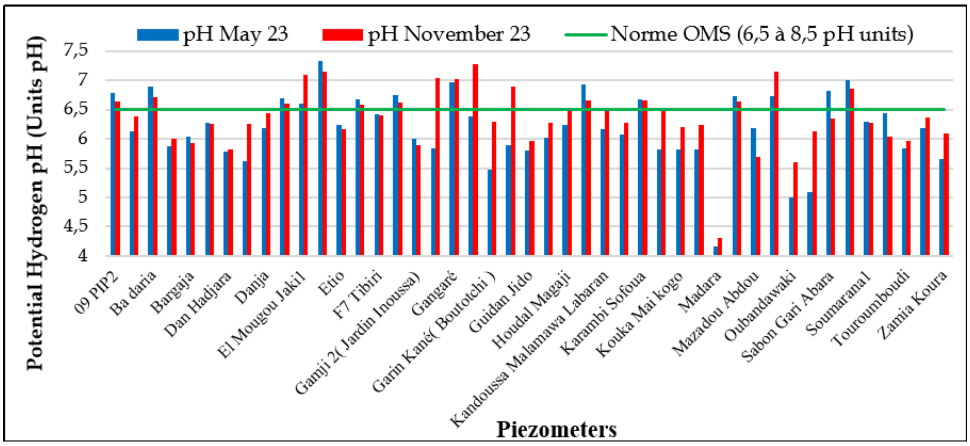

Figure 11. Hydrogen potential of the waters of the Goulbi'N Maradi aquifer.

The spatial distribution of pH values of the waters of the Goulbi'N Maradi alluvial aquifer, measured during the high water period of November 2023 (**Figure 12**), highlighted three groups of water: waters with a pH lower than 5.5 units (in blue), waters with a pH between 5.5 and 6.5 units (green), and finally, waters with a pH between 6.5 and 8 units (red). Thus, only the waters represented in red circles comply with WHO potability standards. In addition, it can be seen that these so-called standard-compliant waters are largely located on major river networks.

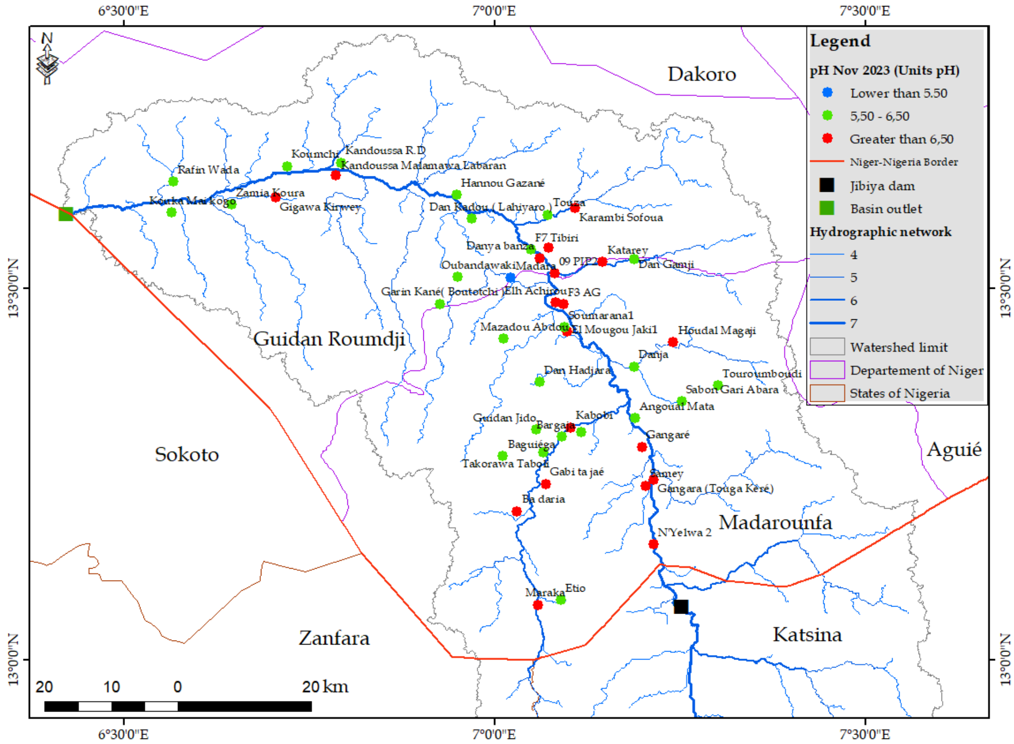

Figure 12. Distribution of pH values of the waters of the Goulbi'N Maradi aquifer.

Electrical Conductivity

The electrical conductivity values range from 115 to 800 µS·cm^{-1}, indicating weakly mineralized waters and conforming to WHO standards for potability, except for those of Gangara (red circle), which is 2250 µS·cm^{-1}. This high content is mainly due to the stagnation of water coming from the village. The conductivity values of the waters of the Goulbi'N Maradi aquifer varied very little during different campaigns but were quite variable from one site to another (**Figure 13**). There is a slight increase in the average value of water conductivity at the end of the rainy season (October). The spatial distribution of the electrical conductivity values (**Figure 13**) shows that the mineralization of the waters is lower during periods of low water (May) than during periods of high water.

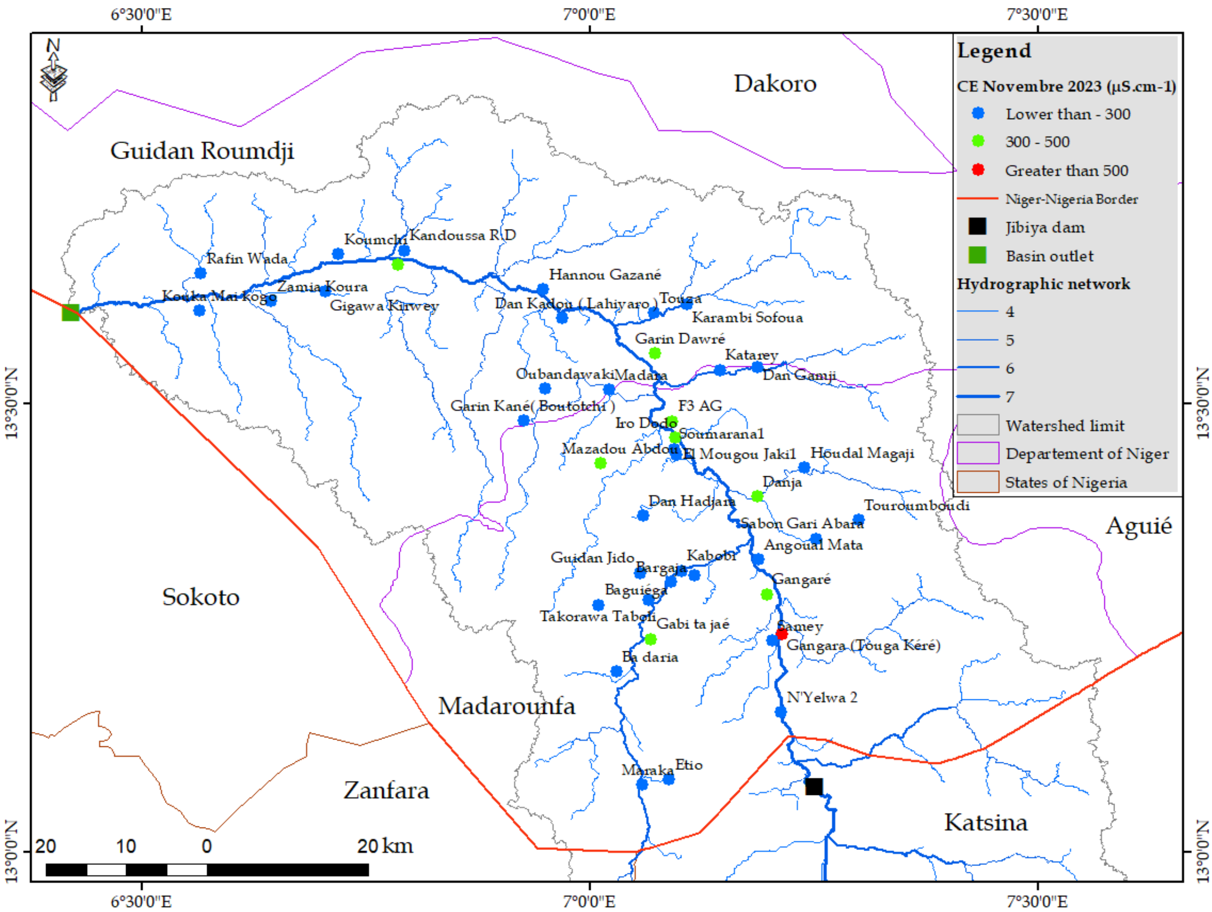

Figure 13. Distribution of electrical conductivity of alluvial water table waters.

4.4. Climate Impacts on Water Table Dynamics

The analysis of average annual rainfall and static levels of the reference piezometers (Samey and Angoual Mata) showed that during the rainy season, there is an initial rise in the water table due to recharge, which ends a few weeks after the rains stop. **Figure 14** illustrates that the rise in the static level is not only linked to the amount of annual rainfall but also to the spatiotemporal distribution of rainfall. At the beginning of the dry season, the water table begins to fall and continues to decline throughout the season until the end of June, the low water period. At Samey, the trend is toward stability of the static level over the decade, while at Angoual Mata, the static level varies considerably, linked to the intense withdrawals occurring in the irrigated areas. The graphs indicate a progressive decline in the water table from October 2014 until April 2020, which is due to the deficit of rainy seasons in the area. However, the rise in the water table observed in October 2020 can be attributed to the significant rainfall during that year.

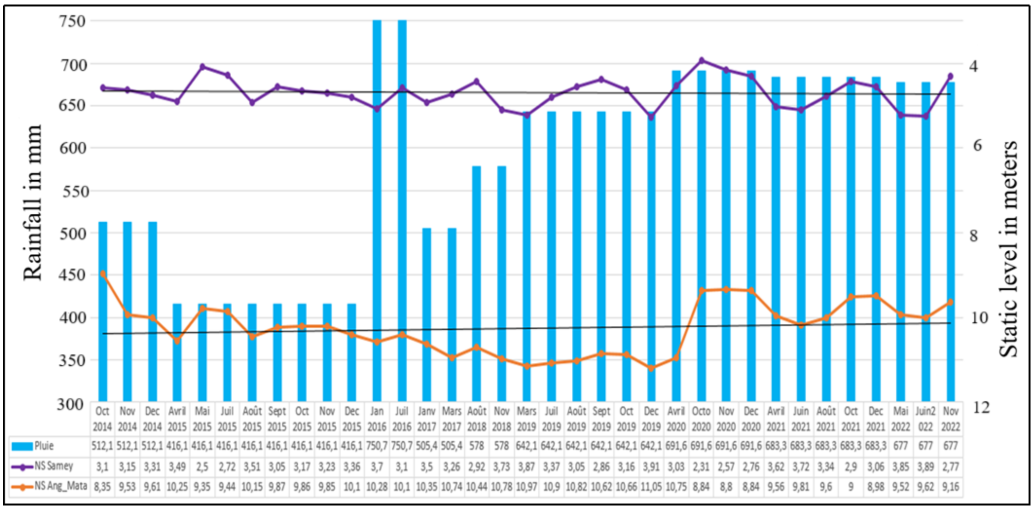

Figure 14. Evolution of the NS and the average annual rainfall in Samey and Angoual Mata.

5. Discussion

The analysis of rainfall heights for the period 1990–2022 at the stations in the study area shows that 85% to 90% of the rainfall between June and September, with maximums in August (195 mm), followed by July (175 mm), and June and September in last position with a rainfall height of 65 mm. This is directly related to the thickness of the monsoon over the area, in accordance with similar studies in Niger[21–24]. In general, the 2022 seasonal accumulation (July, August, and September), compared to the climatological normal of the last thirty years, is in excess in the study area (1990 to 2022), and the annual rainfall follows the same trend: an increase in temperature from south to north, a decrease in rainfall from south to north, and an increase in interannual variability, a shortening of the rainy season, and more violent rainy episodes due to the evolution of maximum daily rainfall. These results are similar to those found by Yahouza et al.[3] in the area. These heavy daily rainfall events could then cause flooding phenomena with harmful consequences for the ecosystem. As for the irregularity of rainfall in the area, it results in the continued migration of isohyets toward the south. The calculated water balances showed that only two months of the year are in surplus in the area for the value of RFU = 50 mm. These surpluses constitute the share of precipitation likely to contribute to the recharge of the water table and are mainly linked to the rainfall regime of the area.

Piezometric surveys in the Goulbi'N Maradi from 2014 to 2022 show considerable variation in static levels. In Samey, the level varies between 2.31 and 3.91 m; in Angoual Mata, it varies between 8.35 and 11.05 m; and in Hannou Gazané, between 4.44 and 7.69 m, respectively for low and high water. These structures have the lowest levels in April and May, corresponding to the low water period across the entire valley, in accordance with the results of Yahouza et al.[3]. Similar results are observed in other valleys of the Niger, such as the Tarka[25], the dallol Maouri[26], and Korama[24], as well as at the level of the dallol Bosso[24,27,28]. Thus, the more rain and floods there are in the Goulbi, the greater the recharge, and the higher the piezometric level rises to continue its flow. The piezometry for the years 2015 and 2023 of the alluvial aquifer shows simple and regular piezometric surfaces throughout the valley for both years, with a main direction of flow for the water. There are two main recharge zones: a south-north direction with a relatively strong hydraulic gradient, showing that the aquifer is recharged by the infiltration of rainwater and floodwater upstream, and a second southeast to northwest direction with a weak hydraulic gradient, confirming the recharge of the aquifer at this level by the flow of water in the basin. This variation in the hydraulic gradient along the Goulbi'N Maradi basin results from the variation in hydraulic conductivity and, therefore, in the flow rate of groundwater, as well as from the intensification of the abusive exploitation of this water table in places (Djirataoua and Angoual Mata). These results are in perfect agreement with those found in the Goulbi N'Kaba by Yahouza[3].

The water temperature values of the Goulbi vary between 26.6 °C and 34.4 °C. These values reflect the average atmospheric temperatures observed in arid and semi-arid zones for unconfined aquifers, in accordance with the findings of Guero et al.[29]. They are also similar to those found for the alluvial aquifers of the Bosso Dallol[27,28]. Additionally, these values are comparable to those found in the Goroubi basin by Djahadi et al. and Dégbey et al.[16,30]. However, they are slightly higher than the temperatures of the effluents from the city of Nouakchott, which vary between 23 °C and 26.3 °C[31], and those obtained by Dégbey et al.[30], Lagnika, et al.[32], and Seki et al.[33] for the drinking water of the city of Aboisso. It is also noted that the groundwater temperatures measured in November 2023 are lower than those measured in May 2023. This corroborates the fact that the temperature of the waters in the alluvial aquifer is controlled by atmospheric temperature, as April and May are the hottest. The pH values of the hydrogen potential of the alluvial aquifer water vary between 5 and 7 units. This low pH observed in the alluvial aquifer is explained by its contact with CO_2 from the atmosphere and the soil. The acidic character of the waters gives them a corrosive nature regarding equipment, pumping means, and metal water pipes. Hence, there is a need to use stainless steel or HDPE plastic materials for water distribution or storage. These results are similar to those found in the various alluvial aquifers of Niger[20,22]. A large portion of the pH values is below the WHO recommended potability standards ($6.5 < pH < 8.5$) and therefore does not comply with the WHO potability standards. The electrical conductivity values range from 115 to 800 µS/cm, except for those of Gangara (2250 µS/cm). These waters, which are weakly mineralized, are below the WHO potability standards (1000 µS/cm). On the other hand, the high content observed in Gangara is attributed to the stagnation of water coming from the village. At the end of the rainy season, there is a slight increase in the average value of water conductivity. This seems to indicate that the infiltration of water into the water table influences the temporal evolution of conductivity. This differentiation could be explained by the leaching of soils by runoff water. These results are close to those found by Oumarou[26] in the Maouri Dallol. However, they are lower than those obtained by Bouselsal[34] for the waters of the El-Oued aquifers in Algeria, in the Sahara, which oscillate between 2170 and 47150 µS/cm, or even those of Algerian groundwater[35].

The analysis of the relationship between average annual rainfall and reference piezometers shows that during the rainy season, the water table begins to rise due to recharge, which ends a few weeks after the rains stop (early October). At the beginning of the dry season (late October), the water table begins to decline and remains low throughout the season until the end of June, marking the low-water period. The trend is toward stability of the NS in Samey (2014–2022); however, in Angoual Mata, the static level varies considerably. This variation is linked to the intense withdrawals carried out in the irrigated areas, but it has begun to rise slightly since the 2020s.

6. Conclusion

The study aimed to analyze the decadal dynamics of the Goulbi'N Maradi alluvial aquifer from 2013 to 2022. Thus, this study provides important information on these dynamics and the physical parameters of the water. The results reveal that climate change has created a spatio-temporal variation in rainfall in the area covering the Goulbi'N Maradi valley, leading to a decrease in the recharge of the aquifer and, therefore, in piezometric levels. This decrease in rainfall and runoff, coupled with local overexploitation of the aquifer, has had a direct impact on the local population, whose main source of water, accounting for more than 90%, is rainwater that flows into the valley between July and September. The volume of water carried is largely dependent on rainfall, resulting in significant annual fluctuations. This regime seems to have changed in recent years, with the wet period beginning in June instead of May. It should also be noted that since the construction of the Jibia dam in 1989, there has been insufficient spreading, which has negative consequences for the recharge of the alluvial aquifer and the growth of flood recession crops. The slightly acidic pH characterizes the waters of the sandy and free aquifers. The spatial distribution of water conductivity values shows that it decreases from south to north, indicating that recharge waters (rain, flood) are more mineralized. Additionally, this area constitutes one of the regions with high agricultural activity. For a better understanding of the functioning of the Goulbi N'Maradi and improved management of these water resources, several recommendations are made. These include strengthening the quantitative and qualitative monitoring system of the Goulbi alluvial aquifer by expanding its monitoring network;

developing a hydrological and hydrogeological model of the Goulbi N'Maradi; and informing and raising awareness among various stakeholders and users about the issues related to groundwater resources.

Author Contributions

Conceptualization, A.K.H.S. and I.S.; methodology, A.K.H.S., I.S., and I.S.G.; writing—original draft preparation, A.K.H.S.; writing—review and editing, A.K.H.S., I.S., and I.S.G. All authors have read and agreed to the published version of the manuscript.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data was collected in the field and from state technical services in documents or UBS keys. There is no possible link to access the data used.

Acknowledgments

This work was conducted with the non-financial assistance of the Department of Geology at Abdou Moumouni University in Niamey, Niger.

Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] Bouselsal, B., 2017. Groundwater Quality in Arid Regions: The Case of Hassi Messaoud Region (SE Algeria). Journal of Fundamental and Applied Sciences. 9(1), 528–541. DOI: https://doi.org/10.4314/jfas.v9i1.30 (in French)

[2] Nazoumou, Y., Favreau, G., Adamou, M.M., et al., 2016. Small-Scale Irrigation Using Groundwater, a Sustainable Solution to Poverty and Food Crises in Niger? Cahiers Agricultures. 25(1), 15003. DOI: https://doi.org/10.1051/cagri/2016005 (in French)

[3] Yahouza, L., Issoufou, S., Abdou, B.M.S., et al., 2018. Contribution of Stable Isotopes of Water (18 O and 2 H) to the Characterization of Goulbi N'kaba Valley Aquifer, Region of Maradi in the Republic of Niger. International Journal of Hydrology. 2(5), 560–565. DOI: https://doi.org/10.15406/ijh.2018.02.00126

[4] Mizyed, A., 2025. Assessment of Water Balance Dynamics and Resource Stress in the Gaza Strip, Palestine. Journal of Energy and Power Technology. 7(2), 007. DOI: https://doi.org/10.21926/jept.2502007

[5] Mushtaha, A.M., Van Camp, M., Walraevens, K., 2019. Evolution of Runoff and Groundwater Recharge in the Gaza Strip Over the Last Four Decades. Environmental Earth Sciences. 78, 32. DOI: https://doi.org/10.1007/s12665-018-7999-9

[6] Aish, A.M., 2022. Estimation of Spatial Groundwater Recharge and Surface Runoff in the Gaza Coastal Aquifer Using GIS-Based WetSpass Model. International Journal of Geoinformatics. 18(6), 25–32. DOI: https://doi.org/10.52939/ijg.v18i6.2457

[7] Hamad, J.T., Eshtawi, T.A., Abushaban, A.M., et al., 2021. Modeling the Impact of Land-Use Change on Water Budget of Gaza Strip. Journal of Water Resource and Protection. 4(6), 325–333.

[8] Aish, A.M., Batelaan, O., De Smedt, F., 2010. Distributed Recharge Estimation for Groundwater Modeling Using WetSpass Model: Case Study—Gaza Strip, Palestine. Arabian Journal for Science and Engineering. 35(1), 155–163.

[9] Mushtaha, A.M., Van Camp, M., Walraevens, K., 2019. Quantification of Recharge and Runoff From Rainfall Using New GIS Tool: Example of the Gaza Strip Aquifer. Water. 11(1), 84. DOI: https://doi.org/10.3390/w11010084

[10] Mizyed, A.G., Moghier, Y., Hamada, M.S., 2025. Factors Affecting the Crop's Water Footprint to Optimize the Water Use Efficiency in the Gaza Strip, Palestine. Journal of Water and Climate Change. 16(4), 1443–1458. DOI: https://doi.org/10.2166/wcc.2025.558

[11] Baba, M.E., Kayastha, P., Huysmans, M., et al., 2022. Evaluation of the Groundwater Quality Using the Water Quality Index and Geostatistical Analysis in the Dier al-Balah Governorate, Gaza Strip, Palestine. Water. 12(1), 262. Available from: https: //www.researchgate.net/publication/338662037

[12] Weinthal, E., Vengosh, A., Marei, A., et al., 2005. The Water Crisis in the Gaza Strip: Prospects for

Resolution. Groundwater. 43(5), 653–660. DOI: https://doi.org/10.1111/j.1745-6584.2005.00064.x

[13] Aish, A.M., 2014. Estimation of Water Balance Components in the Gaza Strip With GIS-Based WetSpass Model. Civil and Environmental Research. 6(11), 77–84.

[14] Al-Yaqubi, A., Aliewi, A., Mimi, Z., 2007. Bridging the Domestic Water Demand Gap in Gaza Strip-Palestine. Water International. 32(2), 219–229. DOI: https://doi.org/10.1080/02508060708692202

[15] Chaperon, P., 1971. Hydrological Note on the Goulbi of Maradi and Lake Madarounfa (Niger). ORSTOM: Paris, France. (in French)

[16] Djahadi, S.D., Sandao, I., Ahmed, Y., et al., 2021. Physico-Chemical Characteristics of the Groundwater of the Basement of the Goroubi Watershed in the Commune of Torodi/Liptako Niger. International Journal of Biological and Chemical Sciences. 15(6), 2715–2729. DOI: https://doi.org/10.4314/ijbcs.v15i6.35 (in French)

[17] Boeckh, E., 1965. Contribution to the Hydrogeological Study of the Sedentary Zone of the Republic of Niger. Bureau de Recherches Géologiques et Minières: Dakar, Senegal. (in French)

[18] Greigert, J., 1978. Atlas of Groundwater of the Republic of Niger. State of Knowledge. Bureau de Recherches Géologiques et Minières: Orléans, France. (in French)

[19] McKee, T.B., Doesken, N.J., Kleist, J., 1993. Study of Rainfall and Hydrological Droughts in Tropical Africa: Characterization and Mapping of Drought by Indices in the Upper Senegal River Basin. Physio-Géo. Géographie Physique et Environnement. 9, 17–35. DOI: https://doi.org/10.4000/physio-geo.4388 (in French)

[20] Saley, A.K.H., Sandao, I., Michelot, J.L., et al., 2019. Contribution of the Physicochemical Parameters of the Waters to the Improvement of the Knowledge of the Continental Intercalaire/Continental Hamadien Aquifer of the Tahoua Region (Iullemeden Basin, Niger). European Scientific Journal. 15(12), 444–468. DOI: https://doi.org/10.19044/esj.2019.v15n12p444 (in French)

[21] Guillaume, L., 2007. Temporal Variations of Hydrological Changes in the Eastern Pacific Area. Geochemical, Isotopic And Micropaleontological Approaches [PhD Thesis]. Aix-Marseille University: Aix-en-Provence, France. pp. 1–350. (in French)

[22] Saley, A.K.H., Sandao, I., Dossou, P.D.L., et al., 2025. Study of the Quality of the Water of the Alluvial Aquifer in the Northern Part of the Dolol Bosso: Departments of Balleyara and Filingué. International Journal of Biological and Chemical Sciences. 19(1), 367–383. DOI: https://doi.org/10.4314/ijbcs.v19i1.27 (in French)

[23] Ozer, P., Bodart, C., Tychon, B., 2005. Climate Analysis of the Gouré Region, Eastern Niger: Recent Changes and Environmental Impacts. European Journal of Geography. 308, 1–24. DOI: https://doi.org/10.4000/cybergeo.3338 (in French)

[24] Sandao, I., 2013. Hydrodynamic, Hydrochemical and Isotopic Studies of the Groundwater of the Korama/South Zinder Watershed, Niger: Impacts of Climate Variability and Human Activities [PhD Thesis]. Université de Niamey: Niamey, Niger. pp. 1–250. (in French)

[25] Adamou, M.M., 2012. Characterization of Agriculture, Interpretations and Consolidated Analyses of Resource Monitoring Data in the Sub-Basin of the Lower Tarka-Niger Valley. Provisional Report. Section 2: Interpretation and Analysis of the Alluvial Aquifer Monitoring Data. Unpublished. (in French)

[26] Oumarou, H.S.A.S., 2022. Hydrogeophysical Study of the Exchanges Between the Niger River and Sedimentary and Basement Aquifers in Niger [PhD Thesis]. Université Abdou Moumouni de Niamey: Niamey, Niger. pp. 1–242. (in French)

[27] Ambarka, M.B., 2019. Dynamics of the Alluvial Aquifer of the Northern Part of Dallol Bosso and Assessment of Water Potential for Small-Scale Irrigation: Departments of Baleyara and Filingué [Master's Thesis]. Université Abdou Moumouni: Niamey, Niger. pp. 1–78. (in French)

[28] Maigary, I., 2018. Assessment of the Potential of Water Resources of the Dallol Bosso Alluvial Aquifer and Their Evolution in the Square Degree of Filingué (Tillabery Region in Niger) [PhD Thesis]. Université Abdou Moumouni de Niamey: Niamey, Niger. pp. 1–215. (in French)

[29] Guero, A., Marlin, C., Leduc, C., et al., 2003. Use of Environmental Isotopes (18O, 2H, 3H, 14C) and Hydrodynamic Modelling to Highlight Groundwaters Mixing in the South-Western Part of the Iullemmeden Basin (Niger). In Proceedings of the International Symposium on Isotope Hydrology and Integrated Water Resources Management, Vienna, Austria, 19–23 May 2003; pp. 28–30.

[30] Dégbey, C., Makoutode, M., Ouendo, E.M., et al., 2008. The Quality of Well Water in the Municipality of Abomey-Calavi in Benin. Environnement, Risques et Santé. 7(4), 279–283. DOI: https://doi.org/10.1684/ers.2008.0161 (in French)

[31] N'Diaye, A.D., Kankou, M.O.S.O., Lo, B., 2010. Study of the Salinity of Wastewater Used in Irrigation in the Market Gardening Area of Sebkha, Nouakchott. International Journal of Biological and Chemical Sciences. 4(6), 2060–2067. DOI: https://doi.org/10.4314/ijbcs.v4i6.64964 (in French)

[32] Lagnika, Ibikounle, Montcho, J.P.C., et al., 2014. Physico-Chemical Characteristics of Well Water in

the Commune of Pobè (Benin, West Africa). Journal of Applied Biosciences. 79, 6887–6897. DOI: https://doi.org/10.4314/jab.v79i1.13 (in French)

[33] Seki, T.O., Yapo, W.T., Kpaibé, S.A.P., et al., 2024. Physicochemical and Microbiological Characterization of Drinking Well Water in the City of Aboisso (South-East of Côte d'Ivoire). International Journal of Biological and Chemical Sciences. 18(1), 311–325. DOI: https://doi.org/10.4314/ijbcs.v18i1.26 (in French)

[34] Bouselsal, B., Zeddouri, A., Belksier, M.S., Fenazi, B., 2015. Contribution of the Intrinsic Vulnerability GOD Method to the Study of Free Aquifer Pollution in Ouargla (SE Algeria). International Journal for Environment and Global Climate Change. 3(4), 92–99. (in French)

[35] Satouh, A., Bouselsal, B., Chellat, S., et al., 2021. Determination of Groundwater Vulnerability Using the DRASTIC Method in Ouargla Shallow Aquifer (Algerian Sahara). Journal of Ecological Engineering. 22(6), 12–19. DOI: https://doi.org/10.12911/22998993/137680