*International Research Journal of Environmental Sciences*_____ ISSN 2319–1414
Vol. **15(4),** 53-65, October **(2026)** *Int. Res. J. Environmental Sci.*

Technical Feasibility Study of a Simplified Drinking Water Supply System (SDWSs) Based on Geological, Hydrogeological and Geophysical Investigations in Tchintabaraden, Niger

HAROUNA Souley[1], MAMAN HASSAN Abdourazakou[2*], ELHADJI DAOU IBRAHIM[3], Mahamane Moustapha Sanda Chékaraou[4], Badamassi Kadri Mahaman Mansour[5], Karimou Laouali Idi[6] and BOUBACAR AMADOU Adama[2]

[1]Department of Civil Engineering, School of Mines, Industry and Geology of Niamey (EMIG), Niamey, Niger
[2]Department of Mines-Geology, School of Mines, Industry and Geology of Niamey (EMIG), Niamey, Niger
[3]Department of Mining Engineering and Environment, School of Mines, Industry and Geology of Niamey (EMIG), Niamey, Niger
[4]Djibo Hamani University of Tahoua, Faculty of Education Sciences, Department of Discipline Didactics, Tahoua-Niger
[5]Dept. of Geological and Environmental Sciences, Faculty of Sciences and Techniques, André Salifou University of Zinder (UAS), Zinder, Niger
[6]Department of SVT, Abdou Moumouni University, Higher Normal School, Niamey, Niger
abdourazakoum@gmail.com

Available online at: www.isca.in, www.isca.me
Received 9th August 2026, revised 18th September 2026, accepted 12th October 2026

Abstract

Groundwater resources represent a strategic component for securing water supply in arid and semi-arid regions, particularly in northern Niger where population growth and pastoral activities increase pressure on available water resources. This study aims to assess groundwater potential and identify suitable borehole locations for sustainable water supply in the Tchintabaraden and Infagagane areas. The methodology combined geological, hydrogeological, geophysical, and socio-economic approaches. Geological investigations revealed that the study area belongs to the sedimentary domain of the Iullemmeden Basin, characterized by Upper Cretaceous marine formations, Continental Intercalaire, Continental Terminal, and Quaternary deposits. Hydrogeological analysis highlighted the importance of deep confined aquifers, particularly the Upper Cretaceous marine aquifer, as the main groundwater target. Electrical Resistivity Tomography (ERT) surveys identified conductive anomalies interpreted as potential aquifer zones. At Tchintabaraden, groundwater targets were located between 320 and 400 m depth, while at Infagagane they were identified between 220 and 300 m depth. Based on the integrated interpretation, three potential borehole locations were proposed at each site. The socio-economic assessment showed that the population of Tchinta Nord is projected to increase from 2695 inhabitants in 2025 to 5781 inhabitants by 2050, resulting in a significant increase in water demand. Total water requirements, including domestic and livestock consumption, are expected to rise from 104 m³/day in 2025 to 166 m³/day in 2050, requiring a production capacity of approximately 209 m³/day at the design horizon. The results demonstrate the effectiveness of integrating geological, hydrogeological, and geophysical methods for groundwater exploration in sedimentary basins and provide a reliable framework for developing sustainable water supply systems in semi-arid environments.

Keywords: Groundwater exploration, Electrical Resistivity Tomography, Iullemmeden Basin, Hydrogeology, Sustainable water supply.

Introductıon

Access to safe drinking water remains one of the most pressing sustainable development challenges in the Sahel region, where climatic constraints, high rainfall variability, and rapid population growth intensify pressure on available water resources. Despite significant progress achieved under Sustainable Development Goal 6 (SDG 6), Sub-Saharan Africa continues to exhibit the lowest levels of access to safely managed drinking water services worldwide[1]. Recent estimates from the WHO/UNICEF Joint Monitoring Programme indicate that only 31% of the population in Sub-Saharan Africa has access to safely managed drinking water services, while millions of people still depend on unimproved or distant water sources[1,2]. This situation is particularly critical in rural Sahelian areas, where surface water resources are scarce and highly seasonal[3].

In Niger, a country characterized by arid to semi-arid climatic conditions and a strong dependence on groundwater resources, challenges related to drinking water supply are further exacerbated by climate change, increasing temperatures, and growing rainfall irregularities[4]. Climate projections suggest that extreme events, including prolonged droughts and heat waves, may significantly affect aquifer recharge processes and water availability throughout the Sahel region[4,5]. Consequently, groundwater constitutes the primary source of water supply for rural communities, livestock production, and local socio-economic activitie[5,6].

The municipality of Tchintabaraden, located in the Tahoua Region of Niger, exemplifies these challenges. In recent years, the area has experienced a substantial influx of refugees and internally displaced populations resulting from ongoing security and humanitarian crises across the Sahel. This demographic expansion has considerably increased pressure on existing water supply infrastructures, which are often insufficient to meet the domestic and livestock water demands of both host and displaced communities[7]. In humanitarian settings, access to reliable drinking water services is a fundamental priority for protecting public health, reducing waterborne diseases, and maintaining social stability[1,8]. Several studies have reported that refugee-hosting communities frequently face inadequate water supply systems, long distances to water points, and overexploitation of existing hydraulic facilities[2].

From a hydrogeological perspective, the Tahoua region belongs to the extensive Iullemmeden Basin, one of the largest groundwater reservoirs in West Africa[9,10]. The principal exploitable groundwater resources are associated with the Continental Intercalaire and Continental Hamadien formations, which consist of multilayered sandstone aquifers whose productivity varies according to local lithological and structural characteristics[5,10]. Previous investigations within the Iullemmeden Basin have highlighted the critical role of diffuse recharge processes, fractured zones, and sedimentary heterogeneity in controlling groundwater flow and borehole productivity[5,11].

However, identifying productive groundwater zones in arid environments remains a complex task requiring appropriate investigation techniques. Geophysical methods have become indispensable tools for groundwater exploration and for optimizing borehole siting[12]. Among these methods, Electrical Resistivity Tomography (ERT) has emerged as one of the most effective techniques for characterizing subsurface structures, locating saturated horizons, and identifying fractured zones favorable for groundwater accumulation[13,14]. Several recent studies conducted across West Africa have demonstrated the effectiveness of ERT in detecting deep aquifers and improving drilling success rates[12,15].

Beyond groundwater resource identification, the sustainable design of drinking water supply systems requires accurate estimation of future water demand. In Sahelian regions, demographic growth, pastoral activities, and population displacement dynamics strongly influence water consumption patterns and infrastructure sizing requirements[1-3]. Hydraulic modeling tools such as EPANET are increasingly employed to simulate water distribution networks, optimize system performance, and assess long-term sustainability under various demographic growth scenarios[16].

Within this context, the present study aims to assess the technical feasibility of a Simplified Drinking Water Supply System (SDWSS) for the Tchinta Nord refugee site located in the municipality of Tchintabaraden, Tahoua Region, Niger. The study integrates geological, hydrogeological, geophysical, topographic, and hydraulic investigations to identify favorable groundwater exploitation zones, estimate future water demand, and evaluate the technical sustainability of the proposed water supply system. The expected outcomes will contribute to improving access to safe drinking water for both refugee and host populations while supporting sustainable groundwater resource management in Sahelian environments.

Materıals and Methods

Study Area: The study was conducted in the Department of Tchintabaraden, located in the Tahoua Region of western Niger. The area lies within the Sahelian climatic zone and is characterized by low and highly variable annual rainfall, high evapotranspiration rates, and recurrent drought conditions. These environmental constraints make groundwater the primary source of water supply for both human and livestock consumption. The geomorphology of the study area is characterized by a succession of lateritic plateaus, limestone outcrops, valleys, and locally developed Quaternary sand dunes. Two sites were investigated: the Tchintabaraden site (15°55'21.32"N;5°48'2.94"E) and the Infagagane site (15°54'15.57"N; 6°00'57.25"E).

The study area hosts significant pastoral and agro-pastoral activities and has experienced increasing demographic pressure due to the settlement of refugee and internally displaced populations. Consequently, the demand for reliable drinking water infrastructure has substantially increased in recent years.

Geological and Hydrogeological Study: The study area belongs to the western sector of the Iullemmeden Basin, one of the largest sedimentary basins in West Africa. The geological formations encountered in the area include Upper Cenomanian deposits, limestone formations, Upper Cretaceous sandstones, Continental Intercalaire (CI), Continental Terminal (CT1), clayey sands, valley alluvium, and locally distributed Quaternary aeolian dunes[17].

These sedimentary formations constitute a heterogeneous geological environment where lithological variations strongly influence groundwater occurrence and aquifer productivity.

Several aquifer systems have been identified within the Tchintabaraden Department.

The Continental Intercalaire aquifer constitutes one of the most important groundwater reservoirs in the region. It occurs mainly in the northern part of the department beneath the Continental Hamadien formations and consists of a multilayered aquifer system composed of clayey sandstones, sandy clays, clayey silts, and silty clays. In the western sector, west of the Tassara–Abalak axis, the aquifer is generally confined.

Borehole depths commonly range from 140 to 750m within the Continental Intercalaire and from 120 to 300m within the Continental Hamadien formations. Static water levels generally remain below 60m but may locally reach depths of up to 215m. Borehole yields can exceed 100m³/h, and groundwater quality is generally suitable for drinking purposes.

The Upper Cretaceous Marine aquifer occurs within Turonian limestone formations and generally exhibits borehole depths ranging from 200 to 300 m. Piezometric levels typically vary between 20 and 60 m below ground level[18].

Marine Paleocene aquifers are confined between impermeable papyraceous shale layers and are generally characterized by poor hydraulic properties and relatively saline groundwater[19].

The Continental Terminal (CT1) forms another important confined aquifer system within the department.

Quaternary aquifers occur within alluvial and colluvial deposits and are generally exploited through shallow wells and auger boreholes because groundwater is usually encountered at depths of less than 10 m[18].

The Tchintabaraden and Infagagane sites are located within the hydrogeological domain of the Upper Cretaceous Marine aquifer, where groundwater exploitation generally requires boreholes deeper than 200 m[19].

Research Methodology, Literature Review and Data Collection: The methodology combined desk studies, hydrogeological investigations, geophysical surveys, socio-economic surveys, topographic surveys, and hydraulic analyses to assess the technical feasibility of a Simplified Drinking Water Supply System (SDWSS).

The first phase consisted of collecting and reviewing available geological, hydrogeological, geophysical, and hydraulic information from previous studies and technical reports. This review provided valuable information regarding geological formations, aquifer characteristics, borehole depths, groundwater yields, and drilling success rates.

The collected information was used to identify potential hydrogeological constraints, evaluate drilling risks, and optimize field survey planning.

Hydrogeological and Geophysical Investigation Methods: A complementary hydrogeological assessment was conducted to evaluate groundwater potential at the selected sites. Particular attention was given to the geological context, aquifer distribution, groundwater occurrence conditions, and existing water supply infrastructures.

Field observations were combined with information obtained from previous boreholes and regional hydrogeological studies.

Electrical Resistivity Tomography (ERT) was employed to characterize subsurface geological structures and identify potential groundwater-bearing formations.

This method is based on measuring the apparent electrical resistivity of subsurface materials. Electrical resistivity (ρ), expressed in Ohm·m, represents the ability of a geological formation to oppose the flow of electrical current[20]. Because geological materials exhibit different resistivity values depending on their lithology, porosity, saturation state, and clay content, resistivity measurements provide valuable information about subsurface hydrogeological conditions.

ERT combines the advantages of Vertical Electrical Sounding (VES), which provides information on vertical resistivity variations, and electrical profiling, which investigates lateral resistivity changes. Consequently, the technique produces two-dimensional images of subsurface resistivity distributions and is particularly suitable for complex geological environments.

Geophysical surveys were performed using the Dipole–Dipole electrode array because of its high sensitivity to lateral resistivity variations and its ability to detect fractured and weathered zones favorable for groundwater accumulation.

Apparent resistivity measurements were collected along survey lines using an electrode spacing of 10 m. Four ERT profiles were completed across the two study sites. Profile orientations were selected according to local geological conditions and site accessibility. Survey lengths varied between 60 and 70 m.

Instrument calibration tests were conducted before data acquisition to ensure data quality and measurement reliability. GPS coordinates of identified anomalies were subsequently recorded in the field for future drilling operations.

Geophysical data were processed using AIDU Prospection 2D software to generate inverted resistivity sections representing the true subsurface resistivity distribution.

Additional spatial analyses and graphical representations were performed using ArcGIS, Surfer, and Map Source software. The interpretation procedure included Data quality control and verification; Importation of field measurements into the processing software; Spatial interpolation using the Kriging method; Generation of 2D resistivity tomograms; Identification of conductive zones potentially associated with aquifers or fractured formations and Selection and validation of favorable drilling locations.

Socio-economic survey and estimation of water demand: The socio-economic survey was conducted using a structured questionnaire administered to a sample of 15 households within the study area. Household heads were interviewed, with particular emphasis placed on the participation of women due to their central role in water management.

The questionnaire covered household socio-economic characteristics, water use practices, sanitation facilities, satisfaction with water services, community expectations regarding water supply, and households' willingness and capacity to contribute to water infrastructure development. Households were selected to ensure adequate representation of the different neighborhoods or groups of compounds.

Future population was projected using an exponential population growth model, assuming an annual growth rate of 3.1% up to the year 2050. The projected population was calculated using the following equation:

$$Pn = P0 \times (1 + a)^n$$

where: Pn: projected population; P0: initial population; a: annual population growth rate; n: projection period (years).

Livestock water demand was estimated by converting the different animal species into Tropical Livestock Units (TLU) to standardize livestock numbers. The conversion coefficients adopted were 0.15 TLU for sheep and goats, 0.75 TLU for cattle, 1.0 TLU for camels and horses, and 0.5 TLU for donkeys. An annual livestock growth rate of 2.1% was considered for future projections.

The daily domestic water demand was estimated based on the projected population and a specific water consumption of 20 L/person/day, using the following equation:

$$Bj = (Pn \times d) / 1000$$

where: Bj: daily water demand (m^3/day); Pn: projected population; d: per capita water demand (20L/person/day). For livestock, a fixed daily water demand of 50m^3/day was adopted, following the standard design practice commonly used for rural mini water supply systems.

Water production demand was estimated by considering seasonal variations, daily peak demand, and technical losses within the distribution network. The production demand was calculated using the following equation:

$$Bprod = Bj \times Kps \times Kpj + (Bj \times 0.05)$$

where: Bprod: production water demand (m^3/day); Bj: daily water demand; Kps: seasonal peak coefficient (1.1); Kpj: daily peak coefficient (1.2); 0.05: allowance for technical losses, corresponding to a network efficiency of 95%.

Finally, the flow velocity in the pipelines was determined using the following equation:

$$V = (4 \times Q) / (\pi \times D^2)$$

where: V: flow velocity (m/s); Q: flow rate (m^3/s); D: internal pipe diameter (m); $\pi = 3.1416$.

This methodological approach enabled the estimation of present and future water demands for both the population and livestock while providing the design parameters required for sizing the water supply infrastructure in the study area.

Results and Discussion

Geological, Hydrogeological Characteristics and Groundwater Potential: The geological map of the study area (Figure-1) indicates that the Tchintabaraden region is characterized by a succession of sedimentary formations ranging from the Upper Cretaceous to the Quaternary. The principal lithostratigraphic units include the Upper Cenomanian, Upper Cretaceous marine formations, Continental Intercalaire (CI), Continental Terminal (CT1), sandy-clayey deposits, valley alluvium, and locally developed Quaternary dune sands[9]. This geological succession reflects a complex depositional history controlled by repeated marine transgressions and continental sedimentation within the Iullemmeden Basin, one of the largest intracratonic sedimentary basins in West Africa.

The spatial distribution of these formations has a direct influence on groundwater occurrence because each lithological unit exhibits distinct hydraulic properties. The Upper Cretaceous marine formations are dominated by limestone interbedded with sandstone and marl layers. These carbonate formations frequently develop secondary porosity through dissolution and fracturing, thereby enhancing groundwater storage and transmissivity. In contrast, the Continental Intercalaire is mainly composed of sandstone intercalated with clay and silt horizons, forming a multilayer aquifer system characterized by high storage capacity and relatively good groundwater quality. The Continental Terminal consists predominantly of unconsolidated sandy deposits with localized clay lenses, whereas the Quaternary formations comprise recent alluvial sediments and aeolian dune sands that generally host shallow but highly vulnerable aquifers.

The predominance of consolidated sedimentary rocks beneath both Tchintabaraden and Infagagane constitutes a favorable geological framework for the development of productive deep aquifers. Unlike crystalline basement terrains, where groundwater circulation is mainly restricted to weathered and fractured zones, sedimentary environments provide extensive permeable horizons capable of storing significant groundwater reserves. This characteristic considerably increases the probability of obtaining sustainable borehole yields suitable for rural water supply systems.

An important geological feature of the study area is the alternation of permeable sandstone and limestone units with relatively impermeable clay and marl layers. Such alternations favor the development of confined aquifer systems by limiting vertical groundwater movement while promoting lateral groundwater flow.

Consequently, groundwater is generally protected from direct surface contamination and experiences lower seasonal water-level fluctuations than shallow unconfined aquifers. Similar hydrostratigraphic conditions have been widely reported throughout the Iullemmeden Basin, where confined sedimentary aquifers constitute the principal source of potable water for domestic and pastoral uses.

The geological context also explains the considerable drilling depths required in the study area. The thick sequence of sedimentary deposits overlies the productive aquifer horizons, requiring boreholes to penetrate several hundred meters before reaching sufficiently permeable water-bearing formations. This observation is fully consistent with previous hydrogeological investigations in northern Niger, which reported productive aquifers occurring between approximately 200 and more than 400 m depth, depending on the local stratigraphic configuration[18,19].

Furthermore, the lithological heterogeneity observed within the sedimentary sequence is expected to influence the geophysical response obtained during electrical resistivity tomography (ERT). Massive limestone and consolidated sandstone generally exhibit relatively high electrical resistivity owing to their low primary porosity and limited water content, whereas fractured, weathered, or water-saturated formations display significantly lower resistivity values. Clay-rich layers may also produce low resistivity anomalies due to their high cation exchange capacity. Consequently, the geological interpretation must be integrated with hydrogeological knowledge and geophysical observations to distinguish conductive clay horizons from productive saturated aquifers.

From a hydrogeological exploration perspective, the geological framework strongly supports the implementation of deep boreholes targeting the Upper Cretaceous marine aquifer and, where appropriate, the Continental Intercalaire aquifer. These formations have been recognized as the most promising groundwater reservoirs in the region because of their relatively high transmissivity, favorable water quality, and long-term sustainability under current exploitation conditions.

Overall, the geological setting demonstrates that groundwater occurrence in the Tchintabaraden area is primarily controlled by the regional sedimentary architecture rather than localized weathering processes. The presence of thick permeable sedimentary formations, confined hydrostratigraphic conditions, and structurally controlled permeability provides favorable conditions for groundwater exploration. These geological characteristics establish the foundation for interpreting the geophysical anomalies identified in this study and justify the selection of deep drilling targets designed to ensure reliable water supply for both domestic consumption and livestock production.

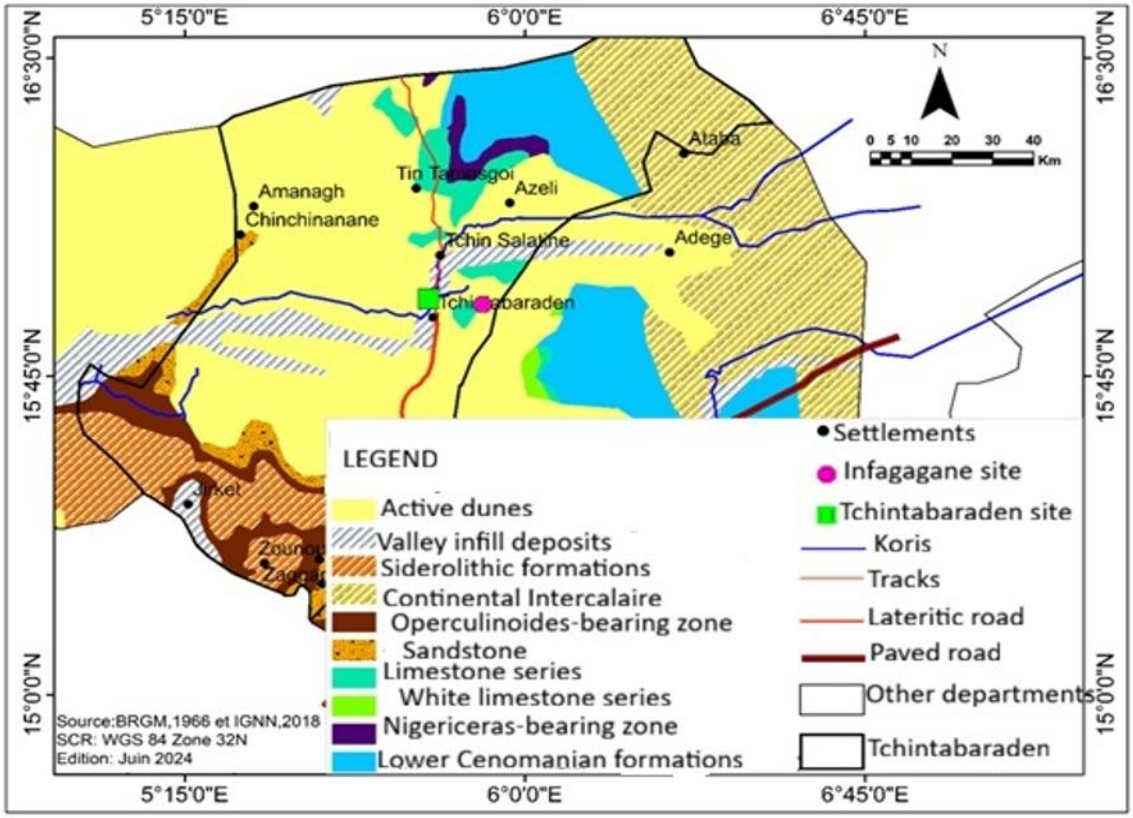


Figure-1: Geological map of the study area.

The hydrogeological investigation of the study area reveals the presence of several aquifer systems associated with the major sedimentary formations of the Iullemmeden Basin. These aquifers include the Continental Intercalaire (CI), Upper Cretaceous marine aquifers, Paleocene marine aquifers, Continental Terminal (CT1), and Quaternary alluvial aquifers. Their distribution, hydraulic characteristics, and groundwater potential are mainly controlled by lithology, stratigraphic organization, and the degree of confinement of the water-bearing formations.

Among these aquifer systems, the Continental Intercalaire (CI) represents one of the most important groundwater reservoirs in the Tchintabaraden Department. It occurs mainly beneath the Continental Hamadien formations and consists of a multilayered aquifer system composed of sandstone, sandy clay, silty sandstone, and clayey silt horizons. The alternation of permeable and impermeable layers gives rise to confine to semi-confined conditions, which favor groundwater storage and protection against direct contamination. In the northern part of the department, borehole depths intercepting the CI aquifer generally range between 140 and 750m, reflecting the significant thickness and depth variability of this formation. The hydraulic productivity of this aquifer is considerable, with reported borehole yields reaching up to 100m³/h, making it one of the most strategic groundwater resources for large-scale water supply. In addition, groundwater quality within the CI aquifer is generally considered suitable for domestic consumption and pastoral activities.

The Upper Cretaceous marine aquifer, which is of particular interest for the present study, constitutes the main hydrogeological target at the Tchintabaraden and Infagagane sites. This aquifer is hosted mainly within Turonian carbonate formations composed of limestone layers with variable degrees of fracturing and secondary permeability. The development of fractures, dissolution channels, and discontinuities within these carbonate units enhances groundwater circulation and storage capacity. Previous studies have shown that boreholes exploiting this aquifer are generally drilled at depths ranging from 200 to more than 300 m, with exploitable yields reaching several cubic meters per hour[18,19]. The groundwater levels are relatively deep, with static water levels commonly ranging between 20 and 60 m, reflecting the confined nature of the system and the regional hydraulic gradient.

The hydrogeological characteristics of this aquifer system are particularly favorable for rural water supply because the confinement of the groundwater limits seasonal fluctuations and provides a more stable resource compared with shallow aquifers (Figure-2). However, the productivity of carbonate aquifers may vary considerably depending on the presence and connectivity of fractures. Therefore, the identification of fractured and water-saturated zones becomes a critical step in borehole siting, which justifies the use of electrical resistivity tomography in the present investigation.

The **Paleocene marine aquifers** identified in the regional hydrogeological framework have comparatively lower groundwater potential. These aquifers occur between impermeable layers of papyraceous shale, generally around twenty meters thick. Their limited permeability and the occurrence of highly mineralized groundwater reduce their suitability for potable water supply. Consequently, these formations were not considered priority targets for future borehole implementation in the study area.

The **Continental Terminal (CT1)** also represents an important aquifer system in the Tchintabaraden region. It is generally composed of sandy formations interbedded with clay layers and occurs as a confined aquifer system. Although it contributes significantly to regional groundwater resources, its exploitation potential depends strongly on local variations in sediment thickness, hydraulic conductivity, and groundwater quality.

The Quaternary aquifers, mainly represented by alluvial and colluvial deposits within valleys, correspond to shallow groundwater systems. These aquifers are generally exploited through traditional wells and shallow boreholes due to their limited depth, often less than 10 m. Despite their accessibility, they remain highly vulnerable to evaporation losses, seasonal drying, and contamination from surface activities. Their limited reliability in arid environments makes them less appropriate for securing long-term water supply compared with deeper confined aquifers.

In the context of the present study, both Tchintabaraden and Infagagane sites are located within the hydrogeological domain of the Upper Cretaceous marine aquifer, where productive boreholes commonly occur between 200 and 300 m depth. This regional hydrogeological information provides a strong basis for interpreting the geophysical results obtained from electrical resistivity tomography. The expected occurrence of fractured limestone horizons saturated with groundwater explains the search for deep conductive anomalies during geophysical investigations.

The groundwater potential of the study area is therefore considered favorable, particularly due to the presence of thick sedimentary aquifer formations capable of storing and transmitting significant groundwater volumes. However, groundwater exploitation requires careful identification of productive zones because of the heterogeneous distribution of permeability within carbonate and sandstone formations. The integration of geological, hydrogeological, and geophysical approaches is consequently essential to optimize borehole positioning and minimize drilling risks.

Overall, the hydrogeological context demonstrates that the study area possesses significant groundwater resources suitable for meeting increasing domestic and livestock water demands. The dominance of deep confined aquifers represents a major advantage in terms of resource sustainability, particularly in this

semi-arid environment characterized by low rainfall, high evaporation rates, and increasing pressure on water resources due to population growth and pastoral activities.

Electrical Resistivity Tomography (ERT): Electrical Resistivity Tomography (ERT) surveys were conducted at the two investigated sites (Tchintabaraden and Infagagane) to identify subsurface electrical heterogeneities and locate potential groundwater-bearing formations. The interpretation of resistivity sections was based on the correlation between electrical resistivity values, geological characteristics, and hydrogeological conditions of the study area. In sedimentary environments, low to very low resistivity anomalies may indicate saturated permeable formations, fractured zones, or clay-rich horizons, whereas high resistivity values generally correspond to dry, compact, or poorly conductive formations such as unsaturated sandstone and limestone units. Therefore, the interpretation of ERT profiles was carried out by integrating geophysical responses with the regional geological and hydrogeological framework.

Two electrical tomography profiles (L1 and L2) were performed at the Tchintabaraden site (Figure-3). The results reveal a clear vertical variation of resistivity values, highlighting the presence of distinct geoelectrical units corresponding to different lithological and hydrogeological conditions.

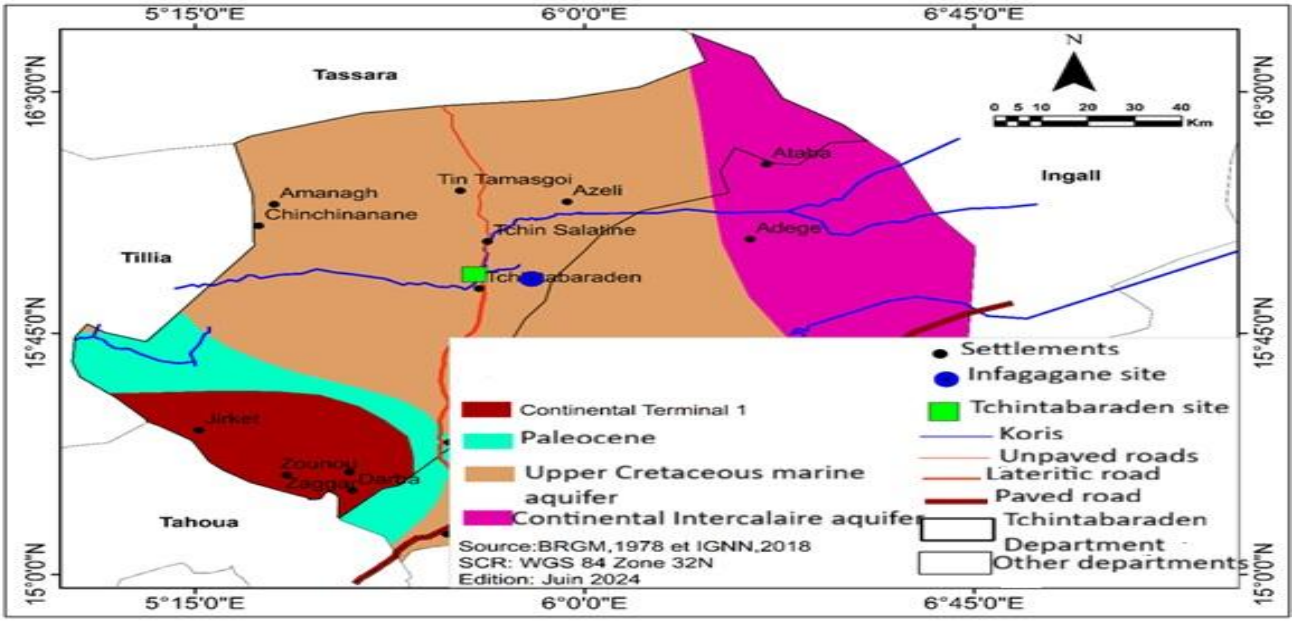


Figure-2: Hydrogeological map of the study area.

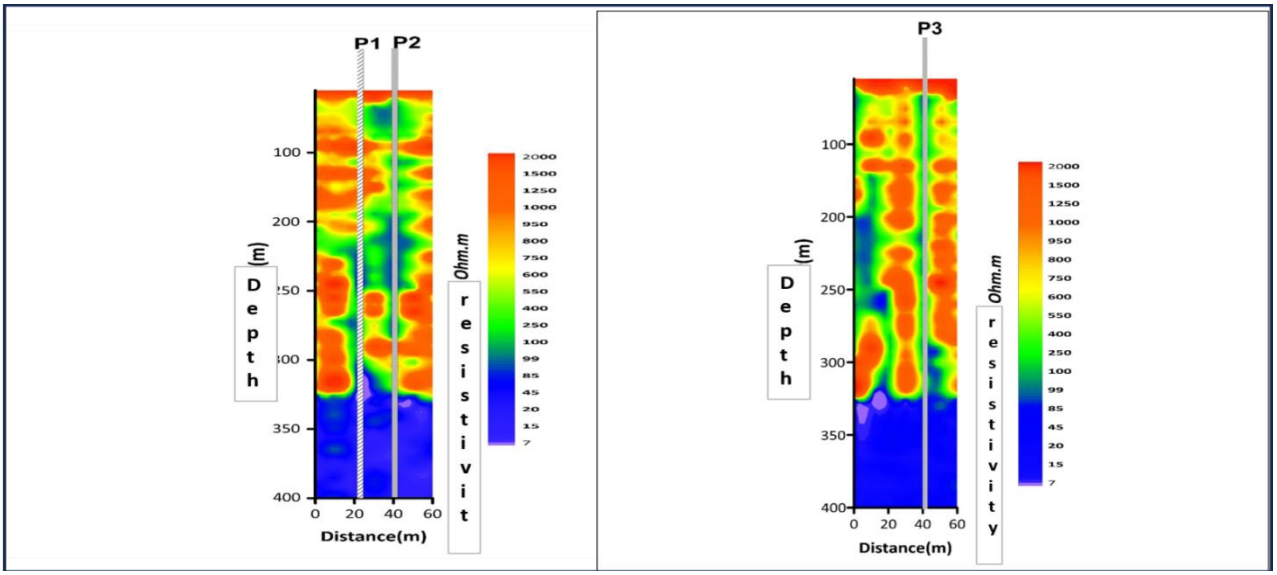


Figure-3: Electrical tomography profiles (L1 and L2) were performed at the Tchintabaraden site.

The interpretation of profile L1 shows that the shallow subsurface, between 0 and approximately 320 m depth, is characterized by relatively high resistivity values ranging from 200 to 1500 Ω.m. These values correspond to a resistant geological unit, likely associated with relatively compact and poorly saturated formations such as limestone, sandstone, or unsaturated sedimentary layers. Within this resistant zone, localized conductive anomalies are observed between approximately 30-80 m and 200-250 m depth. These isolated low-resistivity zones may reflect the presence of discontinuities, clay intercalations, or localized water accumulation along fractures.

Below approximately 320 m depth, the resistivity decreases significantly, reaching values between 7 and 120 Ω.m. This conductive horizon extends downward to about 400 m depth and is interpreted as a probable saturated aquifer zone. The low resistivity values observed at these depths are consistent with the presence of groundwater-filled porous or fractured formations. Considering the regional hydrogeological context dominated by Upper Cretaceous carbonate formations, this conductive anomaly may correspond to a fractured limestone aquifer where groundwater circulation is enhanced by secondary permeability.

Based on the persistence and thickness of this conductive anomaly, the depth of investigation for the proposed boreholes P1 and P2 was estimated at approximately 400 m. This depth is consistent with the regional occurrence of deep aquifers in the Tchintabaraden area, where productive groundwater horizons are commonly encountered between 200 and more than 400 m depth.

The interpretation of profile L2 confirms the observations obtained from L1. The upper section, between 0 and 320 m depth, presents resistivity values ranging from 200 to 1500Ω.m, indicating a predominantly resistant geological sequence. However, a significant vertical conductive anomaly is identified between approximately 38 and 42 m along the profile, extending from shallow depths to nearly 320 m. This anomaly is characterized by resistivity values ranging from 7 to 150Ω.m and is interpreted as a probable fractured zone. Such a feature may represent a preferential pathway for groundwater flow and therefore constitutes an important hydrogeological target.

At depths greater than 320 m, profile L2 also reveals a conductive layer with resistivity values between 7 and 110 Ω.m, corresponding to a probable saturated aquifer horizon. The correlation between L1 and L2 demonstrates the lateral continuity of this conductive unit, confirming the presence of a significant groundwater-bearing formation beneath the site.

Consequently, the proposed borehole P3 along profile L2 was positioned at a predicted depth of approximately 400 m, targeting the identified conductive aquifer horizon and associated fractured zones.

The agreement between the two profiles highlights the reliability of the ERT interpretation. The consistent occurrence of low-resistivity anomalies at similar depths indicates that the identified conductive layer is not a local anomaly but rather represents a regional hydrogeological structure. This reinforces the suitability of the selected drilling points for groundwater exploitation.

ERT interpretation at Infagagane site: At Infagagane, two electrical tomography profiles (L1 and L2) were also conducted to investigate subsurface conditions and identify potential groundwater-bearing formations (Figure-4).

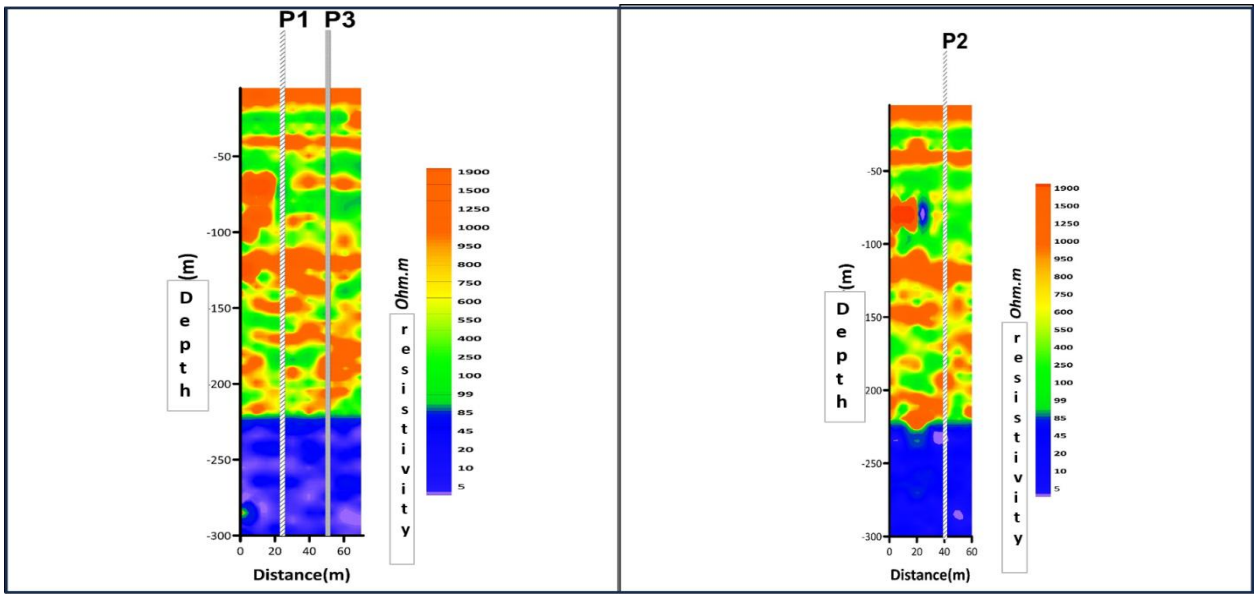


Figure-4: Electrical tomography profiles (L1 and L2) of the Infagagane site.

The interpretation of profile L1 indicates that the subsurface between 0 and approximately 225 m depth is characterized by resistivity values ranging from 95 to 1900 Ω.m. This interval corresponds to a heterogeneous resistant unit, reflecting variations in lithology, including compact sedimentary formations and locally less resistant layers. The relatively high resistivity values suggest limited groundwater saturation in the upper part of the profile[21].

Below approximately 225 m depth, a significant decrease in resistivity is observed, with values ranging from 5 to 100 Ω.m. This conductive anomaly extends over a thickness of nearly 75 m, suggesting the presence of a saturated permeable formation. Considering the regional geology, this conductive layer is interpreted as a probable aquifer horizon associated with fractured carbonate formations or water-bearing sedimentary units.

The thickness and continuity of this conductive zone justify the selection of borehole locations P1 and P3 with a predicted drilling depth of approximately 300 m.

The interpretation of profile L2 provides similar results. The upper section, from the surface to approximately 220 m depth, displays resistivity values between 110 and 1900 Ω.m, corresponding to resistant geological formations. A localized low-resistivity anomaly is observed between 60 and 110 m depth, but its limited lateral extension suggests that it does not represent a major aquifer target. This anomaly may correspond to a localized clay layer, weathered zone, or minor water accumulation[22-23].

Beyond 220 m depth, the profile reveals a continuous conductive zone characterized by resistivity values ranging from 5 to 105 Ω.m over an estimated thickness of approximately 80 m. This anomaly is interpreted as a potential aquifer horizon containing groundwater within permeable or fractured formations.

The correlation between profiles L1 and L2 confirms the presence of a deep conductive structure between 220 and 300 m depth, suggesting a laterally continuous aquifer system. Consequently, borehole P2 was proposed at a predicted depth of approximately 300 m to intercept this groundwater-bearing formation.

Hydrogeological significance of ERT and Selection of Drilling Sites: The ERT investigations conducted at both sites reveal comparable geoelectrical patterns characterized by resistant shallow formations overlying deeper conductive horizons. This vertical organization is consistent with the regional hydrogeological model of the area, where deep confined aquifers occur beneath relatively impermeable or poorly saturated sedimentary layers.

At Tchintabaraden, the conductive aquifer horizon is identified between approximately 320 and 400 m depth, whereas at Infagagane it occurs between 220 and 300 m depth. The difference in target depths reflects local variations in sedimentary thickness, structural configuration, and aquifer geometry.

The presence of conductive anomalies alone cannot distinguish between water-saturated formations and clay-rich layers; however, the integration of ERT results with geological and hydrogeological data confirms that these anomalies are likely related to productive aquifer formations rather than only clay deposits[24]. The location of the study sites within the Upper Cretaceous marine aquifer domain, combined with the expected presence of fractured carbonate formations, supports this interpretation.

Overall, the ERT results significantly improved the understanding of subsurface conditions and allowed the identification of favorable drilling targets. The selected borehole locations represent zones where geological structure, electrical response, and hydrogeological potential converge, thereby reducing exploration uncertainty and increasing the probability of successful groundwater exploitation for domestic and pastoral water supply.

The selection of drilling sites was carried out based on an integrated interpretation of geological, hydrogeological, and geophysical investigations. The objective was to identify locations where the probability of intercepting productive aquifer formations is maximized while reducing the risks associated with deep groundwater exploration. The final borehole locations were selected by combining the results of Electrical Resistivity Tomography (ERT), regional hydrogeological knowledge, and the expected geometry of the groundwater-bearing formations.

The integration of the different datasets revealed that the groundwater potential of the study area is mainly controlled by the presence of deep sedimentary aquifers associated with the Upper Cretaceous marine formations. The geophysical surveys allowed the identification of conductive anomalies interpreted as saturated zones, while the geological and hydrogeological analyses confirmed the suitability of these zones for groundwater exploitation.

Borehole site selection at Tchintabaraden: At the Tchintabaraden site, three potential drilling points were identified from the interpretation of the two ERT profiles (L1 and L2). The proposed points include one priority location and two alternative locations.

The first priority point (P1) was selected along profile L1 because it corresponds to the most favorable combination of geophysical and hydrogeological characteristics.

The ERT section indicates the presence of a significant conductive anomaly between approximately 320 and 400 m depth, characterized by resistivity values ranging from 7 to 120 Ω.m. This low-resistivity zone is interpreted as a water-saturated permeable formation, probably corresponding to a fractured or porous aquifer horizon within the Upper Cretaceous sedimentary sequence[25].

The second proposed point (P2) located along the same profile was considered as the first alternative drilling location. Its selection is justified by the lateral continuity of the conductive anomaly observed on L1, suggesting that the aquifer body extends beyond the primary target area. The presence of similar resistivity characteristics indicates a comparable probability of intercepting the productive aquifer horizon.

The third point (P3) was identified on profile L2 as a second alternative location. This point benefits from the presence of both a deep conductive horizon and a probable vertical fracture zone. The vertical anomaly observed between approximately 38 and 42 m along the profile, characterized by resistivity values between 7 and 150 Ω.m, suggests a structural discontinuity that may enhance groundwater circulation. The combination of fracture permeability and deep aquifer saturation makes this location a favorable hydrogeological target[26].

Considering the depth of the identified aquifer horizon, the predicted drilling depth for all three points at Tchintabaraden was estimated at approximately 400 m. This depth is consistent with the regional characteristics of the Upper Cretaceous and Continental Intercalaire aquifer systems in northern Niger.

The coordinates and characteristics of the selected points are summarized as follows: i. P1 (priority point): productive borehole, predicted depth = 400 m; ii. P2 (alternative point 1): productive borehole, predicted depth = 400 m; iii. P3 (alternative point 2): productive borehole, predicted depth = 400 m.

Borehole site selection at Infagagane: At Infagagane, three drilling locations were also proposed based on the interpretation of ERT profiles L1 and L2. The identified targets are located within a deep conductive horizon occurring between approximately 220 and 300 m depth.

The priority point (P1) was selected on profile L1 due to the presence of a continuous conductive anomaly with resistivity values ranging from 5 to 100 Ω.m. This anomaly extends over an estimated thickness of approximately 75 m, indicating favorable conditions for groundwater storage and circulation[27]. The thickness and continuity of this conductive unit suggest a significant aquifer potential.

The first alternative point (P2) was positioned along profile L2. The selection of this location is supported by the presence of a similar conductive anomaly between 220 and 300 m depth, characterized by resistivity values between 5 and 105 Ω.m. The close similarity between the L1 and L2 responses confirms the lateral continuity of the aquifer horizon and increases confidence in the drilling recommendations.

The second alternative point (P3) was also identified along profile L1 based on the continuity of the conductive structure. Although localized shallow conductive anomalies were observed between 60 and 110 m depth, they were considered less significant because of their limited extension. The main drilling target remains the deeper conductive formation interpreted as the productive aquifer.

The predicted drilling depth for all selected points at Infagagane was estimated at approximately 300 m, which corresponds to the expected depth of the Upper Cretaceous marine aquifer in this area.

The selected points are summarized as follows: i. P1 (priority point): productive borehole, predicted depth = 300 m; ii. P2 (alternative point 1): productive borehole, predicted depth = 300 m; iii. P3 (alternative point 2): productive borehole, predicted depth = 300 m.

Drilling strategy and groundwater exploration: The drilling recommendations obtained from this study demonstrate the effectiveness of integrating geophysical investigations with geological and hydrogeological information. In sedimentary basins such as the Iullemmeden Basin, groundwater occurrence is strongly influenced by the thickness, continuity, and hydraulic properties of sedimentary formations. Therefore, the identification of conductive zones through ERT provides valuable information for targeting saturated formations but requires geological validation to avoid confusing aquifers with clay-rich horizons.

The selected drilling points at both sites correspond to zones where three favorable conditions are simultaneously present a suitable geological framework, characterized by sedimentary formations capable of storing groundwater; a favorable hydrogeological environment, corresponding to deep confined aquifer systems with regional continuity and geophysical signature, marked by persistent low-resistivity anomalies interpreted as saturated formations.

The difference in drilling depth between Tchintabaraden (400 m) and Infagagane (300 m) reflects variations in the depth of the aquifer roof and local sedimentary architecture. The deeper target at Tchintabaraden may indicate either a greater thickness of overlying formations or a deeper position of the productive horizon, whereas the shallower target at Infagagane suggests a more accessible aquifer zone.

The proposed boreholes are therefore considered technically suitable for the development of a sustainable water supply system. Their implementation should nevertheless be

accompanied by hydrogeological monitoring, pumping tests, and water quality analyses after drilling in order to confirm aquifer productivity, hydraulic parameters, and suitability of groundwater for domestic and livestock consumption.

Overall, the selected drilling sites represent the most favorable locations identified during the investigation campaign and provide a reliable basis for future groundwater development in the Tchintabaraden and Infagagane areas.

Population Projection, Livestock Assessment and Water Demand Evaluation: Population projection and livestock assessment: The socio-economic survey and demographic analysis indicate that the locality of Tchinta Nord is experiencing significant demographic growth. The Table-1 present the population projection and living asseesment in Tchinta North.

The current population was estimated at 2695 inhabitants in 2025. Considering an annual population growth rate of 3.1%, the population is expected to reach approximately 5,781 inhabitants by 2050. This substantial increase highlights the need for long-term planning of water supply infrastructure to ensure adequate availability of drinking water in the future.

The study area is also characterized by a strong pastoral activity, with livestock representing an essential component of the local economy and livelihoods. The livestock inventory revealed a diversified herd composed mainly of goats, sheep, cattle, camels, horses, and donkeys. The total livestock population converted into Tropical Livestock Units (TLU) indicates a significant animal pressure on available water resources.

The dominance of small ruminants, particularly goats and sheep, reflects the adaptation of pastoral activities to the arid and semi-arid conditions of the region. However, the high livestock density increases competition for water resources, especially during dry periods when surface water availability becomes limited. Therefore, the consideration of livestock water requirements is essential for the design of a sustainable water supply system capable of meeting both domestic and pastoral needs.

The estimation of water requirements was carried out by considering both domestic consumption and livestock needs. Domestic water demand was calculated based on the projected population and a specific consumption rate of 20 L/person/day. The Table-2 presents the population's water demand.

The results show that the domestic water demand will increase from approximately 54 m³/day in 2025 to 116 m³/day by 2050. This increase reflects the direct impact of demographic growth on future water requirements.

Livestock water demand was also considered due to the pastoral character of the study area. Given the uncertainties associated with livestock mobility and seasonal variations in herd numbers, a conservative approach based on a fixed livestock consumption was adopted. The integration of domestic and livestock requirements indicates that the total daily water demand will increase from approximately 104 m³/day in 2025 to 166 m³/day in 2050.

The progressive increase in total water demand demonstrates the necessity of designing hydraulic infrastructure according to future requirements rather than current needs only. In pastoral regions such as Tchinta Nord, livestock represents a significant proportion of water consumption and must be integrated into water resource planning to avoid conflicts between human and animal needs.

The production requirements, including peak demand variations and technical losses of the distribution system, were estimated at approximately 131 m³/day in 2025 and 209 m³/day in 2050. These values represent the minimum production capacities required to ensure reliable service delivery under future operating conditions.

The results emphasize that the planned water supply system must be designed with sufficient capacity to accommodate both population growth and increasing livestock demand. In addition, considering the semi-arid climate of the region, characterized by low rainfall and high evaporation rates, the development of a reliable groundwater-based supply system represents a strategic solution for ensuring long-term water security.

Table-1: Population projection and livestock assessment in Tchinta North (2025–2050).

Locality	Annual growth rate (%)	Population 2025 (inhabitants)	Population 2050 (inhabitants)	Main livestock species	Total livestock (TLU)
Tchinta Nord	3.1	2695	5781	Goats, sheep, cattle, camels, horses, donkeys	83312

Table-2: Population water demand (2025-2050).

Locality	Year	Population water demand (m³/day)	Total water demand including livestock (m³/day)	Required production capacity (m³/day)
Tchinta Nord	2025	54	104	131
Tchinta Nord	2050	116	166	209

Overall, the demographic projections, livestock assessment, and water demand analysis confirm the necessity of implementing a sustainable borehole-based water supply system. The identified groundwater potential from geological, hydrogeological, and geophysical investigations provides an appropriate foundation for meeting the projected water requirements of the local population and livestock up to the 2050 planning horizon.

Conclusion

This study aimed to assess the groundwater potential and define suitable borehole locations for the development of a sustainable water supply system in the Tchintabaraden and Infagagane areas, northern Niger. The approach combined geological, hydrogeological, geophysical, socio-economic, and water demand assessments in order to provide an integrated understanding of groundwater availability and future water requirements.

The geological investigation showed that the study area is located within the sedimentary domain of the Iullemmeden Basin, characterized by Upper Cretaceous marine formations, Continental Intercalaire, Continental Terminal, and Quaternary deposits. The predominance of sedimentary formations, particularly sandstone and limestone units, provides favorable conditions for groundwater storage. The alternation between permeable and impermeable layers contributes to the development of confined aquifer systems, which represent the main groundwater resources in this semi-arid region.

The hydrogeological analysis highlighted the importance of the Upper Cretaceous marine aquifer and the Continental Intercalaire as strategic groundwater reservoirs. The Tchintabaraden and Infagagane sites are located within the domain of the Upper Cretaceous aquifer, where productive boreholes are generally encountered at depths ranging from approximately 200 to more than 300 m. These aquifers present favorable characteristics in terms of groundwater availability and regional continuity, making them suitable targets for rural water supply development.

The Electrical Resistivity Tomography (ERT) investigations successfully identified deep conductive anomalies interpreted as potential groundwater-bearing formations. At Tchintabaraden, the main aquifer target was identified between 320 and 400 m depth, with resistivity values ranging from 7 to 120 Ω.m, leading to the recommendation of three drilling points with an estimated depth of approximately 400 m. At Infagagane, conductive zones were identified between 220 and 300 m depth, characterized by resistivity values ranging from 5 to 105 Ω.m, resulting in the selection of three potential drilling points with an estimated depth of approximately 300 m. The consistency between the different geophysical profiles confirms the reliability of the proposed drilling locations.

The socio-economic analysis revealed significant future pressure on water resources due to population growth and pastoral activities. The population of Tchinta Nord is expected to increase from 2,695 inhabitants in 2025 to about 5,781 inhabitants by 2050, while livestock remains a major component of local livelihoods. The estimated total water demand, including domestic and livestock requirements, is projected to increase from 104 m^3/day in 2025 to 166 m^3/day in 2050. Considering peak demand coefficients and technical losses, the required production capacity is estimated at 131 m^3/day in 2025 and 209 m^3/day in 2050.

Overall, the results demonstrate that the study area has significant groundwater potential capable of supporting long-term domestic and pastoral water supply. The integration of geological, hydrogeological, and geophysical approaches proved essential for reducing drilling uncertainty and improving the success rate of groundwater exploration in this semi-arid environment. The recommended borehole sites provide a reliable basis for future water infrastructure development.

However, before final implementation, it is recommended that exploratory drilling be followed by pumping tests to determine aquifer hydraulic parameters (transmissivity, hydraulic conductivity, and sustainable yield), as well as comprehensive groundwater quality analyses to confirm suitability for human consumption and livestock use. Continuous monitoring of groundwater levels is also recommended to ensure sustainable exploitation of this strategic resource under increasing demographic and climatic pressures.

Acknowledgements

The authors would like to express their sincere gratitude to the CERISES-CSF Consulting Firm for facilitating the collection of the data used in this study and for providing practical training opportunities to our students. The authors particularly appreciate the support and cooperation of the CERISE-CSF team throughout the fieldwork and the practical training activities. The authors also gratefully acknowledge the École des Mines, de l'Industrie et de la Géologie (EMIG) for providing the institutional framework and support necessary for this study. Special thanks are extended to the CEA Project of EMIG for its valuable support and contribution to the successful completion of this work.

References

1. WHO & UNICEF Joint Monitoring Programme (JMP). (2023). *Progress on household drinking water, sanitation and hygiene 2000–2022: Special focus on gender*. New York and Geneva.

2. WHO. (2023). *Water, sanitation and hygiene monitoring report*. World Health Organization.

3. UNICEF. (2024). *Access to drinking water*.

4. UNICEF. (2023). *A triple threat of water-related crises is endangering the lives of 190 million children*.

5. Mahamana, R. A., Nazoumou, Y. & Favreau, G. (2025). Hydrogeological dynamics of a large alluvial aquifer in the dryland Iullemmeden Basin of Niger. *Hydrological Sciences Journal*, 70(14), 2465–2478.

6. Favreau, G., Cappelaere, B., Massuel, S., Leblanc, M., Boucher, M., Boulain, N. & Leduc, C. (2009). Land clearing, climate variability and water resources increase in semiarid southwest Niger. *Water Resources Research, 45*,

7. UNHCR (2023). *Niger Situation Operational Update*. Geneva, Switzerland.

8. Adams, E. A., Boateng, G. O. & Amoyaw, J. A. (2022). Socioeconomic and demographic predictors of access to water and sanitation in Sub-Saharan Africa. *Journal of Water, Sanitation and Hygiene for Development*, 12(4), 291–304.

9. Greigert, J. & Pougnet, R. (1967). *Essai de description des formations géologiques de la République du Niger*. BRGM.

10. Leduc, C., Favreau, G. & Schroeter, P. (2017). Long-term rise in a Sahelian water-table: The Continental Terminal in south-west Niger. *Journal of Hydrology,* 243(1–2), 43–54.

11. Torou, B. M., Favreau, G., Barbier, B., Pavelic, P., Illou, M., & Sidibé, F. (2013). Constraints and opportunities for groundwater irrigation arising from hydrologic shifts in the Iullemmeden Basin, south-western Niger. *Water International*, *38*(4), 465–479.

12. Dahlin, T. & Zhou, B. (2022). A numerical comparison of 2D resistivity imaging with ten electrode arrays. *Geophysical Prospecting*.

13. Aizebeokhai, A. P. (2010). Geoelectrical resistivity imaging: Theory and applications in environmental geophysics. *African Journal of Environmental Science and Technology*, *4*(6), 295–305.

14. Balasco, M., Lapenna, V., Rizzo, E., & Telesca, L. (2022). Deep electrical resistivity tomography for geophysical investigations: the state of the art and future directions. *Geosciences*, *12*(12), 438.

15. Ezeh, C. C., Agu, C. P. & Okonkwo, A. (2022). Combined application of vertical electrical sounding and 2D electrical resistivity tomography for groundwater exploration in southeastern Nigeria. *International Journal of Physical Sciences,* 17(3), 67–83.

16. Rossman, L. A. (2020). *EPANET 2.2 User Manual*. U.S. Environmental Protection Agency.

17. Greigert, J. & Pougnet, R. (1967). *Essai de description des formations géologiques de la République du Niger*. BRGM, Paris.

18. Abdel Kader, M. (2019). *Contribution à l'étude hydrogéologique du bassin des Iullemmeden au Niger: caractérisation des aquifères et gestion des ressources en eau souterraine*. Université / Rapport scientifique.

19. BRGM (1978). *Étude hydrogéologique du bassin des Iullemmeden (Niger)*. Bureau de Recherches Géologiques et Minières, France.

20. Loke, M. H. (2004). *Tutorial: 2-D and 3-D Electrical Imaging Surveys*. Geotomo Software, Malaysia.

21. Telford, W. M., Geldart, L. P. & Sheriff, R. E. (1990). *Applied Geophysics*. Cambridge University Press.

22. Kirsch, R. (2009). *Groundwater Geophysics: A Tool for Hydrogeology*. Springer-Verlag, Berlin.

23. Freeze, R. A., & Cherry, J. A. (1979). *Groundwater*. Prentice-Hall, Englewood Cliffs, New Jersey.

24. Ouedraogo, I., Soro, N. & Kouamé, K. J. (2021). Hydrogeological characterization of sedimentary aquifers in semi-arid West Africa using geophysical methods. *Arabian Journal of Geosciences,* 14(8), 674.

25. Barbosa, S. A., Jones, N. L., Williams, G. P., Mamane, B., Begou, J., Nelson, E. J., & Ames, D. P. (2023). Exploiting Earth observations to enable groundwater modeling in the data-sparse region of Goulbi Maradi, Niger. *Remote Sensing*, *15*(21), 5199.

26. Adeyemo, I. A., Omosuyi, G. O. & Ako, B. D. (2023). Application of electrical resistivity tomography for groundwater exploration in semi-arid environments. *Journal of African Earth Sciences,* 198, 104812.

27. Kpegli, K. A., Kouassi, A. M. & Yao, T. K. (2022). Groundwater exploration using electrical resistivity tomography in fractured basement terrains of West Africa. *Hydro Research*, *5*, 100061.