

Assessment of the Physicochemical and Bacteriological Quality of Drinking Water from Cemented Wells and Mini Drinking-Water Supply Systems in Awaridi Village, Diffa, Niger.

Abstract:

Water is an essential resource for life, human health, and socio-economic development. The quality of drinking water is a crucial factor in public health. This study aimed to assess the physicochemical and bacteriological quality of drinking water in the Awaridi village (Diffa, Niger) and to evaluate its compliance with WHO and Nigerien drinking water standards. Five water supply systems were sampled: two cemented wells, two boreholes, and one mini-drinking water supply system. Physicochemical parameters were analyzed in situ and in the laboratory following Rodier's (2009) standardized methods and by spectrophotometry, while bacteriological analyses were performed using membrane filtration and incubation techniques. Results indicate satisfactory physicochemical quality (pH 6.65-7.88; EC 316-449 $\mu\text{S}/\text{cm}$; TH 40-192 mg/L CaCO_3) but significant fecal contamination (TC=94 CFU/mL, FC=98 CFU/mL), exceeding the permissible limits. The PCA (72.56% of total variance) distinguishes mineralized borehole waters from contaminated cemented wells, while the dendrogram classifies parameters into three groups reflecting mineralization, hardness, and fecal pollution. Overall, water quality in Awaridi is influenced by both geochemical and anthropogenic factors, emphasizing the necessity of continuous sanitary monitoring and improved protection of drinking water infrastructures.

Keywords: Drinking water quality; Physicochemical quality; Bacteriological contamination; Fecal contamination; Groundwater; Principal component analysis

1. Introduction

Water is fundamental to life, human well-being, food security, and socioeconomic development. Safe drinking water is essential for preventing water-related diseases and supporting resilient communities. Drinking-water quality is therefore a major public-health and environmental concern. International guidelines emphasize a risk-based approach to protecting water safety from the source to consumption (Théophile and Albert, 2023; Talhaoui et al., 2020; WHO, 2022). This need is increasingly important because population

growth, urbanization, rising water demand, and environmental pressures affect both water availability and quality (Vörösmarty et al., 2010; IPCC, 2022).

Globally, access to a water source does not necessarily guarantee access to safe drinking water. In 2022, approximately 2.2 billion people lacked safely managed drinking-water services, while at least 1.7 billion used sources contaminated with faeces (WHO/UNICEF, 2023; WHO, 2023). Unsafe water, sanitation, and hygiene remain important contributors to preventable diseases, particularly diarrhoeal diseases, especially in low- and middle-income countries (WHO, 2023a; Bain et al., 2014a; Bain et al., 2014b). Consequently, regular assessment of drinking-water quality is essential for identifying contamination risks and protecting vulnerable populations.

Groundwater is a major source of domestic water supply, particularly in rural and peri-urban areas. It provides approximately half of the volume of water withdrawn for domestic use globally and is particularly important where centralized water-supply systems are limited (UN-Water, 2023; UNESCO, 2022). In Africa, groundwater provides relatively reliable access to water under variable climatic conditions; however, its quality and vulnerability depend on hydrogeological characteristics, recharge processes, land use, and abstraction practices (MacDonald et al., 2012; MacDonald and Calow, 2009). Increasing water demand and climate change further reinforce the need for groundwater protection and systematic monitoring (IPCC, 2022; Vörösmarty et al., 2010).

Despite natural filtration during infiltration, groundwater is not intrinsically safe. Shallow wells, inadequately protected boreholes, and small water-supply systems may be contaminated by latrines, wastewater, solid waste, agricultural activities, runoff, and poor sanitary management. Evidence from low- and middle-income countries shows that improved water sources may still contain faecal contamination, including protected wells (Bain et al., 2014a). Similar contamination has been reported in African wells and boreholes, particularly where sanitation and source protection are inadequate (Lutterodt et al., 2018). African water-supply systems also face challenges related to infrastructure, treatment capacity, operation and maintenance, governance, and water-quality surveillance (Wang et al., 2014). Household treatment and safe storage can reduce microbial risks, but source protection and regular surveillance remain essential (Sobsey, 2002; WHO, 2022).

These challenges are particularly important in the Sahel, where groundwater is a strategic resource under arid and semi-arid climatic conditions. Studies in Niger have reported

variations in the physicochemical and bacteriological quality of drinking-water sources according to water-source type, hydrogeological conditions, and sanitary environment. In western Niger, Adamou et al. (2020) identified differences in water quality among wells, boreholes, and small drinking-water supply systems, with bacteriological contamination affecting several sources. In Niamey, groundwater contamination has also been associated with inadequate sanitation and infiltration from polluted superficial layers (Chippaux et al., 2002). Recent research in the Komadugu-Yobe Basin highlights the importance of groundwater-quality assessment for sustainable water-resource management in the Sahel (Shuaibu et al., 2024). In northern Niger, contamination by uranium, fluoride, and nitrate further demonstrates the potential for both geogenic and anthropogenic groundwater-quality risks (Alhassane et al., 2026). Similar microbial contamination problems have been reported in other African countries, including Ghana and Nigeria (Lutterodt et al., 2018; Owamah et al., 2021).

In Niger, these challenges are compounded by disparities in water infrastructure, limited monitoring capacity, climatic variability, and dependence on groundwater sources. Safe drinking-water management therefore requires an integrated assessment of physicochemical and microbiological quality, together with consideration of sanitary vulnerability and relationships among water-quality parameters (WHO, 2022). Water quantity, accessibility, reliability, and quality are also interconnected determinants of public health and well-being (Howard and Bartram, 2003; Howard et al., 2020). Strengthening water-quality monitoring is consequently important for climate resilience and sustainable development in water-stressed regions such as the Sahel (UNESCO, 2022; IPCC, 2022).

In the urban commune of Diffa, particularly in Awaridi village, drinking water is supplied through groundwater-based facilities, including cemented wells, boreholes, and mini drinking-water supply systems (Mini-AEP). However, localized information on their combined physicochemical and bacteriological quality remains limited. This study therefore aims to assess the physicochemical and bacteriological quality of drinking water from cemented wells, boreholes, and a Mini-AEP in Awaridi village; evaluate its compliance with WHO and Nigerien drinking-water standards; and identify the principal patterns and relationships among the measured water-quality parameters. The findings are intended to support source protection, sanitary monitoring, and sustainable drinking-water management in Diffa.

2. Material and Methods

2.1. Study area

The Urban Commune of Diffa is one of the three communes of the Department of Diffa, Diffa Region. It is located in South-Eastern Niger on National Road No. 1, approximately 1,360 km from Niamey, the capital. The commune borders the Rural Commune of Gueskéroù to the east and north and the Commune of Chétimari to the west. To the south, it borders the Federal Republic of Nigeria (Borno State) along more than 20 km marked by the Komadougou Yobe river (Fig.1).

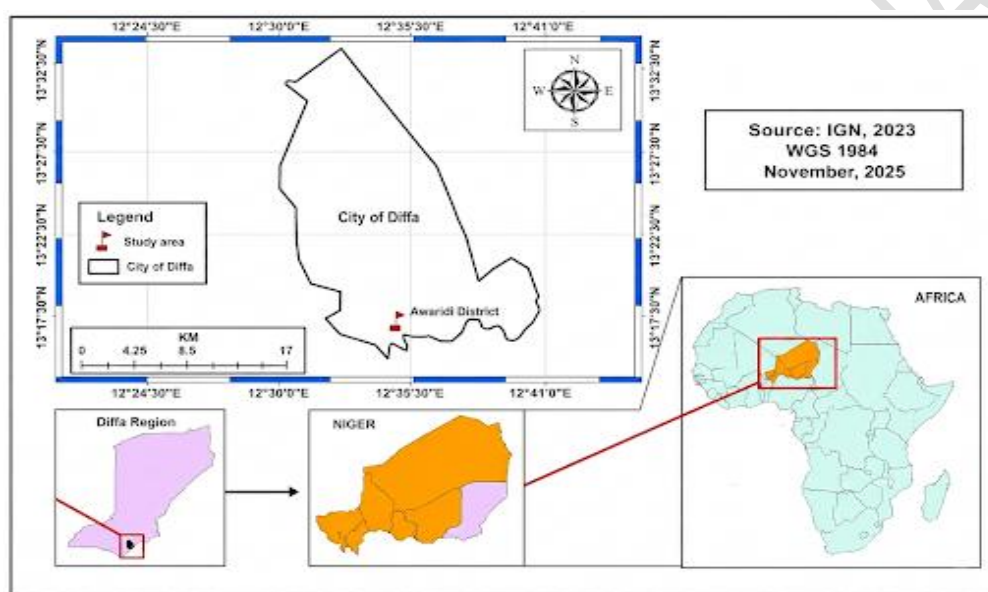


Fig.1: Location of the study area

2.2. Sampling

A total of five drinking water supply facilities in the Awaridi village were sampled. These facilities were selected because they are representative of the main water supply sources used by the population. Samples were collected from two cemented wells, two boreholes, and one mini drinking water supply system (MINI-AEP). These samples were used to assess the physicochemical and bacteriological quality of the water consumed by the population.

2.3. Physicochemical and bacteriological analysis methods and materials used

Table 1 below presents the analytical methods used in situ and in the laboratory, their descriptions and principles, the parameters analyzed, the materials and reagents used, as well as the references and conditions.

Table 1 :Analytical methods and materials for the sampled waters

Analytical method	Principle / Description	Parameters	Material / Reagents used	References / Conditions
Physical measurement	Direct measurement of physical parameters	pH, conductivity, temperature	pH meter, conductivity meter	In situ measurement
Chemical analysis	Determination of major cations and anions according to the standardized Rodier method.	Ca ²⁺ , Mg ²⁺ , K ⁺ , Na ⁺ , NO ₂ ⁻ , NO ₃ ⁻ , Cl ⁻ , SO ₄ ²⁻ , Fe	- Specific chemical reagent for each ion; - Sterilized sampling bottles; - Laboratory glassware	Standard Rodier (2009) methodology
Spectrophotometric method	Quantitative analysis by molecular absorption spectrophotometry	Fe, K ⁺ , SO ₄ ²⁻ , F ⁻ , NO ₃ ⁻ , NO ₂ ⁻	- Spectrophotometer Hach 2010; - Photometer WAGTECH/7100; - Ferrover reagents, Sulfaver4, SPANDS, Nitraver3, potassium reagents 1-2-3 - Sterilized sampling bottles - Laboratory glassware	Wavelengths : Fe (510 nm), K ⁺ (NA), SO ₄ ²⁻ (650 nm), F ⁻ (190 nm), NO ₃ ⁻ (520 nm), NO ₂ ⁻ (507 nm) In laboratory
Ion balance calculation method	Calculation of Sodium from ion balance: sum of cations=sum of anions.	Na ⁺	Formula: [Na ⁺] = ((([Cl ⁻] + [SO ₄ ²⁻] + [NO ₃ ⁻] + [HCO ₃ ⁻]) - ([Ca ²⁺] + [Mg ²⁺] + [K ⁺])) × 23	Rodier (2009) In laboratory
Volumetric methods	Titration to determine ion concentrations.	Ca ²⁺ , Mg ²⁺ , Cl ⁻ , TAC, TH	EDTA, Claver, Na hydroxide, Manver, mercuric nitrate, diphenyl carbazone, sulfuric acid, bromocresol	Calcium hardness: Ca=Dcal × 0,4; TH=EDTA × 4 × 800/20; mg=(TH-Dcal) × 0,243 In laboratory

Bacteriological method	Filtration and incubation of 100 mL of samples on membranes to enumerate coliforms.	Total coliforms, fecal coliforms, atypical coliforms	- AquaSafe MSL50; -Membrane filter; - Petri dishes and agar tubes; - Autoclave; - filtration ramp and vacuum flask; - Incubator for bacterial culture; - 0,45 µm filters - distilled water; - sterilized gloves	Incubation: 37 °C (18 hours) for total coliforms; 44 °C (24 hours) for fecal coliforms
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119 2.4. Statistical analyzes and mapping

120 Statistical analyses were performed using several software packages. XLSTAT version 2018
 121 was used to: compute descriptive statistics for the analyzed parameters (minimum, maximum,
 122 mean, and standard deviation); assess the strength of relationships between physicochemical
 123 and bacteriological parameters (Spearman correlation matrix, as the data do not follow a
 124 normal distribution); and perform a principal component analysis (PCA) to identify
 125 relationships and reduce the dimensionality of physicochemical and bacteriological
 126 parameters. Minitab 19 was used to perform hierarchical cluster analysis (dendrogram) to
 127 determine similarities among the different parameters. ArcMap 10.8 was used to produce the
 128 maps.

129 3. Results and Discussion

130 3.1. Physicochemical quality

131 Analysis of the physicochemical parameters of water from the five supply facilities in the
 132 Awaridi village shows an overall satisfactory quality compliant with drinking-water standards
 133 (Table 2). The pH ranges from 6.65 to 7.88 with a mean of 7.53, within the range
 134 recommended by WHO (6.5-8.5) and the Nigerien standard (6.5-8.5). The mean temperature
 135 is 26.8 °C, slightly above the WHO guideline value of 25 °C, which is explained by the hot
 136 climatic conditions of Diffa. The mean electrical conductivity (362.8 µS/cm) remains well
 137 below the guideline limit of 1500 µS/cm, indicating low mineralization. The mean total
 138 hardness (112.8 mg/L CaCO₃) complies with the limit of 500 mg/L, indicating moderately
 139 hard water without scaling risk. Bicarbonates range from 66.37 to 195.20 mg/L, with no
 140 specific limit, but reflect a good buffering capacity. Chlorides (4.30-9.20 mg/L) and sulfates

(11-52 mg/L) are far below the thresholds set by WHO (250 mg/L for Cl^- , 400 mg/L for SO_4^{2-}) and the Nigerien standard (250 mg/L and 200 mg/L, respectively). Nitrates (0.54-1.80 mg/L) and nitrites (0.001-0.002 mg/L) are well below the limits of 50 mg/L (WHO) and 45 mg/L (Nigerien standard) for nitrates, and 0.3 mg/L for nitrites, indicating the absence of domestic or agricultural pollution. Major cations also show very low values: K^+ (3.10-7.40 mg/L), Ca^{2+} (14.40-49.60 mg/L), and Mg^{2+} (0.97-24 mg/L), all well below the Nigerien standard limits (75-200 mg/L for Ca^{2+} and 50-150 mg/L for Mg^{2+}). The mean total iron concentration (0.116 mg/L) also remains below the limit of 0.3 mg/L set by WHO and the national standard. Overall, no parameter exceeds drinkingwater thresholds. These results are consistent with those observed in Niamey by Bachir et al. (2021), where the analyzed waters also showed a stable pH and low to moderate mineralization, confirming the good quality of drinking water in Nigerien urban areas. Similarly, the study conducted in Sô-Ava, Benin, indicates that water from boreholes generally complied with physicochemical standards, with cation and anion concentrations comparable to those observed in the study area (Dan et al., 2018). Despite different geographical and climatic contexts, the physicochemical quality of the water remains stable, reflecting good protection.

Table 2:Physicochemical quality.

Parameters	pH	T°	CE	TH	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻⁻	NO ₃ ⁻	NO ₂ ⁻	K ⁺	Fe	Ca ⁺⁺	Mg ⁺⁺
Unit	-	° C	µs/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
			CaCO ₃										
N	5	5	5	5	5	5	5	5	5	5	5	5	5
Minimum	6.65	25	316	40	66.37	4.30	11	0.540	0.01	3.10	0.020	14.40	0.971
Maximum	7.88	28	449	192	195.20	9.20	52	1.800	0.15	7.40	0.260	49.60	24
Median	7.71	27.80	324	120	136.64	6.80	25	0.800	0.11	4.10	0.100	38.40	3.880
Moyenne	7.53	26.80	362.8	112.8	136.25	6.96	28.4	1.004	0.10	4.72	0.116	35.52	9.462
WHO limit values	6.5 - 8.5	25	-	500	-	250	400	50	3	-	0.3	-	-
Nigerien standard	6.5 - 8.5	-	-	500	-	250	200	45	3	-	0.3	75 - 200	50 - 150
% of non-compliance	0	/	/	0	/	0	0	0	0	/	0	0	0

3.2. Bacteriological quality

Analysis of the bacteriological parameters of the sampled waters reveals overall microbial contamination (Table 3). Total coliforms range from 0 to 200 CFU/mL with a mean of 94 CFU/mL, far exceeding the limit set by WHO and the Nigerien standard (0–10 CFU/mL). The situation is more worrying for fecal coliforms, whose concentrations vary from 50 to 150 CFU/mL with a mean of 98 CFU/mL, far above the standard value of 0 CFU/mL. The non-compliance rate thus reaches 80% for total coliforms and 100% for fecal coliforms. These contamination levels are comparable to those observed in other African contexts, notably in western Cameroon, where Biguioh et al. (2020) reported that 90.9% of water samples contained total coliforms, with concentrations exceeding 10^3 CFU/mL, indicating significant fecal pollution. Similarly, a study conducted in Ghana revealed that all well water samples analyzed in the Atebubu-Amantin district were contaminated with total and fecal coliforms, exceeding the standard value of 0 CFU/100 mL, particularly during the rainy season (Akrong and Banu, 2017). These comparisons confirm that the situation in Awaridi is part of a regional problem of deterioration of the bacteriological quality of groundwater linked to the proximity of latrines, lack of treatment, and poor protection of water points. Thus, despite the satisfactory physicochemical quality observed, the high fecal contamination renders these waters unfit for direct consumption and underlines the need to strengthen protection, treatment, and sanitary monitoring measures for water facilities.

Table 3: Bacteriological quality

Parameters	Total Coliforms	Atypical Coliforms	Fecal Coliforms
Unit	CFU/mL	CFU/mL	CFU/mL
N	5	5	5
Minimum	0	6	50
Maximum	200	70	150
Median	80	20	90
Moyenne	94	27	98
WHO limit values	0-10	200	0
Nigerien standard	0-10	-	0
% of non-compliance	80	/	100

The results in Fig. 2 below indicate high contamination in cemented wells (43% for PC1 and 32% for PC2), moderate in the MINI-AEP (17%), and lower in boreholes (9% for F2 and 0% for F1). This variation reflects better microbiological quality in deep, well-protected facilities, unlike wells that are vulnerable to wastewater infiltration.

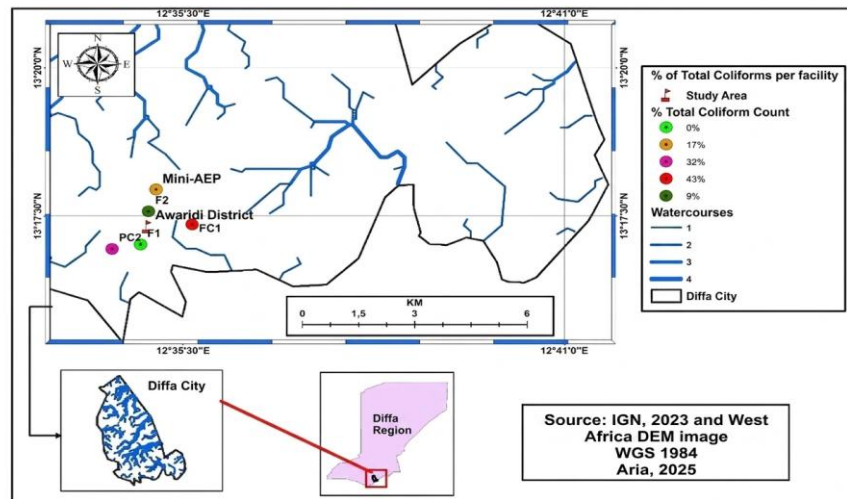


Fig.2: Total coliforms frequency (%) distribution among the sampled facilities

Fig. 3 illustrates the distribution of atypical coliforms in the water facilities of the Awaridi village in Diffa, with rates ranging from 4% to 51%. Borehole F2 shows the highest contamination (51%), indicating a likely technical failure or localized pollution of the aquifer. Cemented wells PC2 (22%) and PC1 (15%) display intermediate levels, linked to their shallow depth and exposure to domestic wastewater infiltration. In contrast, borehole F1 (7%) and the Mini-AEP (4%) show better microbiological quality, reflecting good sanitary protection.

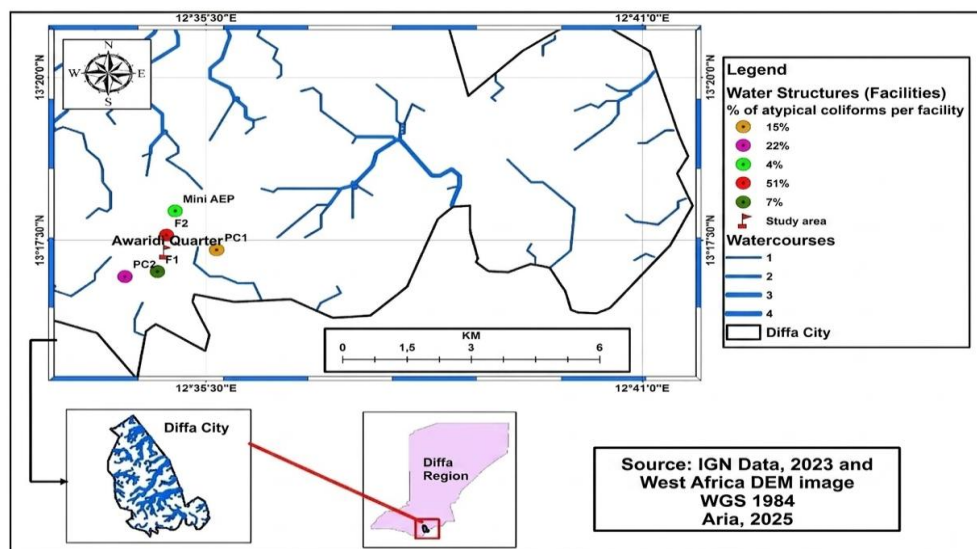


Fig.3: Atypical coliforms frequency (%) distribution among the sampled facilities

Fig. 4 below shows the spatial distribution of fecal coliforms in the sampled facilities. Contamination rates vary from 10% to 31%, indicating pollution of variable intensity

depending on the type of facility and its location. Cemented wells (PC1 and PC2) record the highest rates, 31% each, indicating strong fecal contamination. Borehole F1 presents an intermediate contamination level (18%), suggesting localized pollutant infiltration. In contrast, borehole F2 and the Mini-AEP show lower rates (10% each). This distribution illustrates the vulnerability of groundwater to domestic pollution and underscores the importance of better sanitary management of water facilities in the Awaridi village

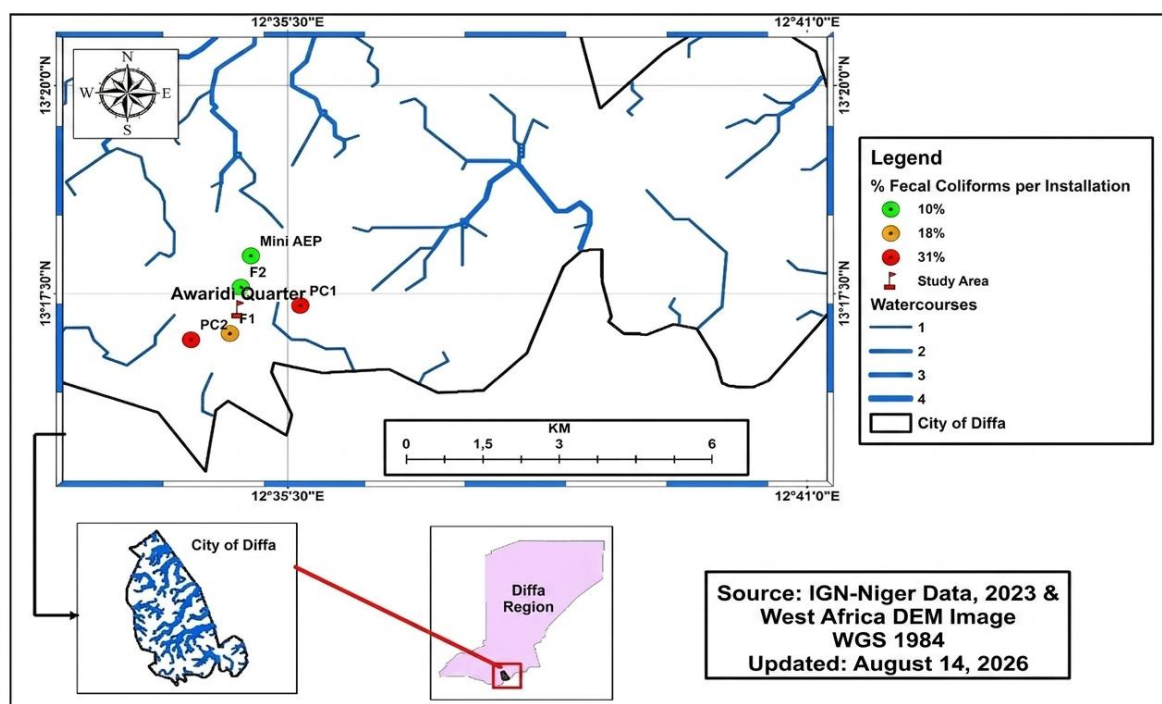


Fig. 4: Fecal coliforms frequency (%) distribution among sampled facilities.

3.3. Principal component analysis of physicochemical and bacteriological parameters

Analysis of the Spearman correlation matrix of physicochemical and bacteriological parameters, as shown on Table 4, reveals several significant relationships, reflecting interactions between mineral quality and microbiological contamination of the water. The results first show strong interdependence among physicochemical parameters. Total hardness (TH) is very highly positively correlated with bicarbonate ions (HCO_3^- , $\rho=0.900$) and calcium (Ca^{2+} , $\rho=1.000$), indicating that water hardness is essentially of carbonate origin. Similarly, electrical conductivity (EC) is positively correlated with bicarbonate concentration ($\rho=0.800$). Sulfate (SO_4^{2-}) and chloride (Cl^-) ions also show a strong correlation ($\rho=0.900$). Conversely, some negative correlations indicate opposing behaviors between parameters. Hardness (TH) is inversely correlated with sulfates (SO_4^{2-} , $\rho=-0.900$) and potassium (K^+ , $\rho=-0.900$). Likewise,

total iron (Fe) shows a strong negative correlation with electrical conductivity ($\rho=-0.900$). Regarding environmental parameters, temperature (T°) and pH show a moderate positive correlation ($\rho=0.564$).

The bacteriological parameters (TC, AC, and FC) are closely linked to certain environmental and chemical parameters. Indeed, atypical coliforms (AC) show a very strong correlation with temperature ($\rho=0.872$), showing that heat favors their development. Fecal coliforms (FC) are also positively correlated with pH ($\rho=0.791$), indicating that slightly alkaline conditions are conducive to their survival. In contrast, the presence of total iron (Fe) appears to limit bacterial proliferation, as shown by the negative correlations with AC ($\rho=-0.700$) and FC ($\rho=-0.158$), probably due to the oxidizing power of iron in certain forms.

Table 4: Spearman correlation matrix of physicochemical and bacteriological parameters

Variables	pH	T°	CE	TH	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻⁻	NO ₃ ⁻	NO ₂ ⁻	K ⁺	Fe	Ca ⁺⁺	Mg ⁺⁺	TC*	AC*	FC*
pH	1															
T°	0.564	1														
CE	0.200	0.359	1													
TH	0.100	0.564	0.500	1												
HCO ₃ ⁻	0.000	0.462	0.800	0.900	1											
Cl ⁻	0.100	-0.051	-0.100	-0.800	-0.600	1										
SO ₄ ⁻⁻	-0.300	-0.410	-0.300	-0.900	-0.700	0.900	1									
NO ₃ ⁻	-0.500	0.308	-0.300	0.100	0.000	0.100	0.200	1								
NO ₂ ⁻	-0.564	0.000	0.564	0.667	0.821	-0.564	-0.410	0.205	1							
K ⁺	-0.300	-0.821	-0.300	-0.900	-0.700	0.600	0.800	-0.300	-0.359	1						
Fe	-0.100	-0.205	-0.900	-0.700	-0.900	0.500	0.600	0.400	-0.718	0.400	1					
Ca ⁺⁺	0.100	0.564	0.500	1.000	0.900	-0.800	-0.900	0.100	0.667	-0.900	-0.700	1				
Mg ⁺⁺	0.100	0.205	0.900	0.700	0.900	-0.500	-0.600	-0.400	0.718	-0.400	-1.000	0.700	1			
TC*	0.100	-0.205	0.500	-0.500	-0.100	0.700	0.600	-0.400	-0.103	0.600	-0.200	-0.500	0.200	1		
AC*	0.300	0.872	0.700	0.600	0.700	0.000	-0.300	0.300	0.359	-0.700	-0.500	0.600	0.500	0.100	1	
FC*	0.791	0.162	0.474	-0.158	0.000	0.316	0.000	-0.791	-0.406	0.158	-0.316	-0.158	0.316	0.632	0.158	1

FC*: Fecal Coliforms; **AC*:** Atypical Coliforms; **TC*:** Total Coliforms

The analysis of the Spearman correlation matrix made it possible to highlight significant relationships between the physicochemical and bacteriological parameters of the five drinking water supply facilities. However, these bilateral correlations do not allow visualization of the overall relationships and groupings among all variables. Therefore, a Principal Component Analysis (PCA) was conducted to summarize these interactions and better distinguish groups of variables responsible for the main variations in water quality in the studied facilities. The first two factorial axes explain 72.56% of the total variance, with 49.80% for axis F1 and 22.76% for axis F2, indicating good representativeness of the information contained in the data. On the first axis (F1), the variables TH, Ca^{2+} , HCO_3^- , EC, Mg^{2+} , T° , and AC are strongly positively correlated with each other. The second axis (F2) contrasts, on one hand, fecal coliforms (FC) and total coliforms (TC), which are positively correlated with pH, and, on the other hand, nitrates (NO_3^-) and total iron (Fe) located on the opposite side. This opposition highlights two distinct behaviors: slightly alkaline waters favor bacterial survival and proliferation, while elevated iron and nitrate concentrations appear to be associated with lower bacterial load, probably due to iron oxidation and precipitation processes or a dilution effect. Compared with the study by Amadou et al. (2014) in the Tillabery region, factor F1 (44.42%) was strongly correlated with electrical conductivity (0.95), also with Na^+ (0.89), F^- (0.74), Cl^- (0.79), HCO_3^- (0.76), and hardness (0.82). Factor F2 represented 20.35% and was correlated with chemical parameters such as pH, SO_4^{2-} , NO_2^- , and NO_3^- . The results of the characterization of public water supply by Principal Component Analysis (PCA) in Boguédia, Ivory Coast, revealed a correlation between the physicochemical and microbiological parameters of the studied waters. Factor F1 in the F1–F2 factorial plane represented 22.38% of total variance and was determined by turbidity, pH, nitrate, ammonium, magnesium, temperature, *E. coli*, and total coliforms. Axis 2 represented 16.19% of total variance in the F1–F2 plane and was defined by conductivity, fluoride, and chloride ions. This factor expressed mineralization and inorganic pollution of the waters (Ab & Tg, 2018).

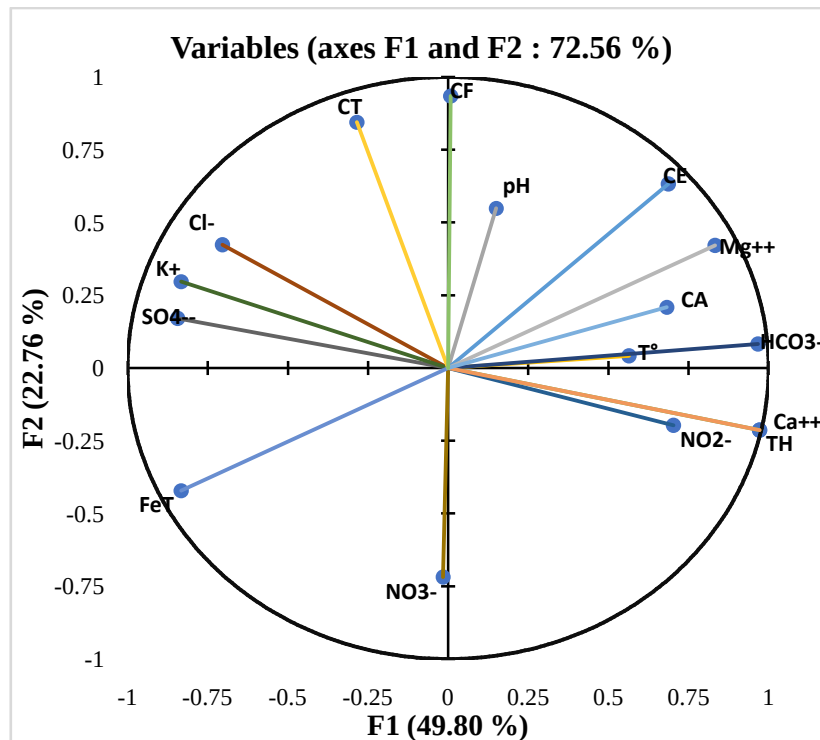


Fig.4 :Correlation circle of physicochemical and bacteriological parameters of the samples

The projection of the facilities onto the factorial plane (Fig. 6) shows a clear differentiation according to their quality characteristics. Facilities F1 and F2, located on the positive side of axis F1, are associated with mineralization parameters (EC, TH, Mg²⁺, Ca²⁺, HCO₃⁻), indicating hard and mineralized water, which may be explained by the influence of the geological nature of the soil or the dissolution of carbonate rocks. Facilities PC1 and PC2 are positioned on the positive side of axis F2, closely linked to bacteriological parameters (TC and FC), revealing marked microbiological contamination related to domestic wastewater infiltration or poor maintenance of water points. In contrast, the Mini-AEP, located on the negative side of axis F1, opposes the majority of variables. This position reflects low mineralization and low ionic and bacteriological concentrations, suggesting better physicochemical and bacteriological quality of the water from this facility.

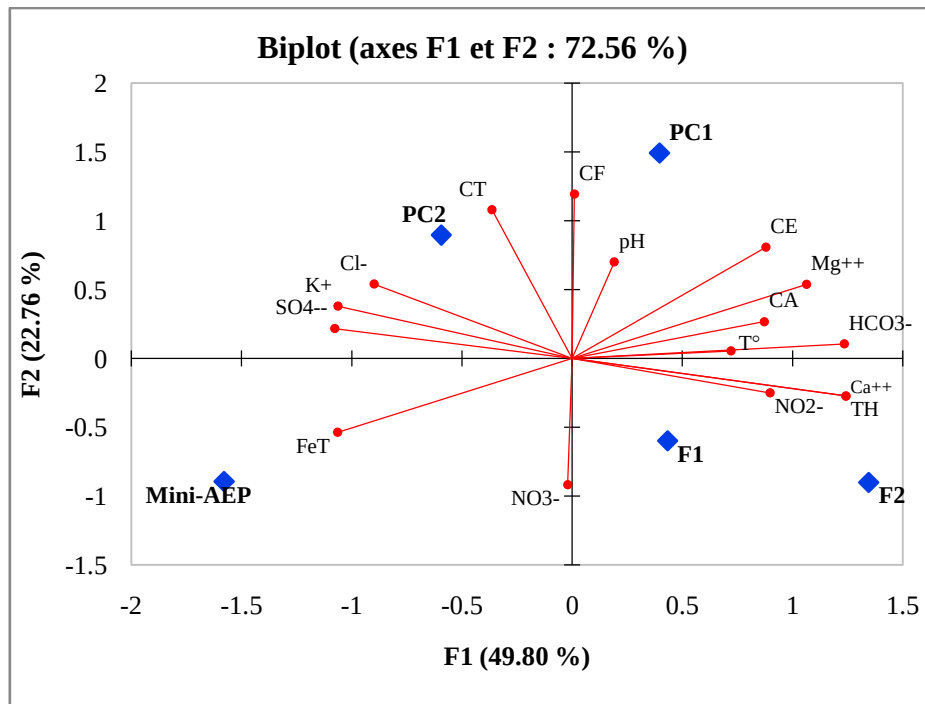


Fig.5 : Correlation circle of physicochemical and bacteriological parameters according to the sampled facilities.

3.4. Hierarchical cluster analysis of physicochemical and bacteriological parameters

The hierarchical analysis presented by the dendrogram (Ward's method, distance based on absolute correlation coefficient) reveals three distinct groups of physicochemical and bacteriological parameters from the five drinking-water supply (Fig. 7). The first group includes pH, Fe, T°, K⁺, Cl⁻, SO₄²⁻, and Ca²⁺, which mainly reflect the natural mineralization of the water. These variables show strong similarity, indicating that they evolve concomitantly according to the geochemical characteristics of the environment. The second group comprises electrical conductivity (EC), magnesium (Mg²⁺), total hardness (TH), bicarbonates (HCO₃⁻), and atypical coliforms (AC). This association reflects a relationship between mineralization and non-fecal environmental contamination. Indeed, EC and TH depend on the total concentration of dissolved salts, particularly Mg²⁺ and HCO₃⁻ ions. Finally, the third group includes nitrates (NO₃⁻), nitrites (NO₂⁻), fecal coliforms (FC), and total coliforms (TC). Their grouping points to a common contamination source, probably anthropogenic, related to the proximity of facilities to latrines, soak away pits, or contaminated runoff zones. By contrast, the study by Amadou et al. (2014) identified two groups: the first consisted of Na⁺, EC, hardness, HCO₃⁻, SO₄²⁻, Cl⁻, and F⁻, reflecting mineralization-residence time or the hydrolysis of bicarbonate and silicate minerals; the

second group, comprising Fe^{2+} , turbidity, pH, NO_3^- , and NO_2^- , indicated the contribution of organic matter degradation to groundwater mineralization in the region. This classification confirms that water quality in the Awaridi village results from both geological factors and local human activities, requiring increased surveillance of the facilities most exposed to fecal contamination.

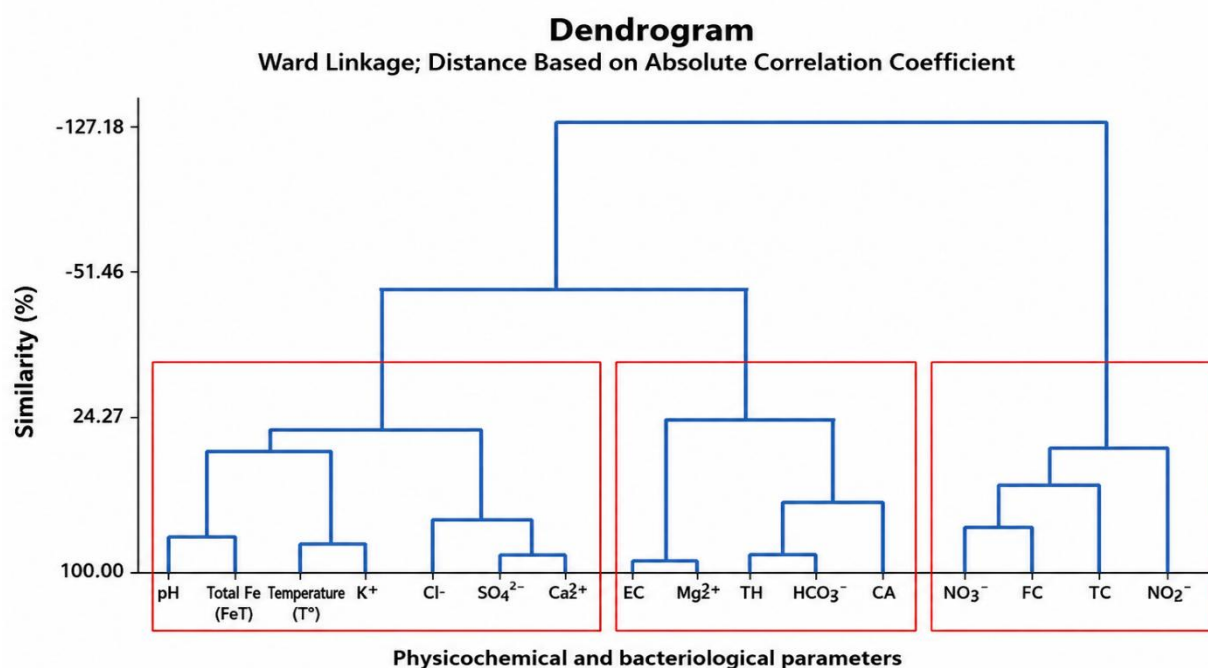


Fig.6 : Hierarchical classification of physicochemical and bacteriological parameters.

4. Conclusion

The assessment of the physicochemical and bacteriological quality of drinking water in the Awaridi village (Diffa City, Niger) provided an overall diagnosis of the quality of the main water supply sources. The analyses revealed that, from a physicochemical standpoint, the waters are generally of satisfactory quality, with neutral to slightly alkaline pH, low mineralization, and major ion concentrations compliant with WHO and Nigerien standards. These results reflect a good chemical balance, probably influenced by the geological nature of the substrate and the depth of certain facilities, particularly boreholes and the Mini-AEP. However, bacteriological quality is of concern. The high levels of total and fecal coliforms observed in the majority of samples indicate fecal contamination of anthropogenic origin, linked to the proximity of latrines, domestic wastewater infiltration, and the absence of sanitary protection devices at water points. The Mini-AEP, for its part, stands apart from the

other facilities due to its low mineralization and better sanitary quality. Thus, this study highlights the need for integrated and sustainable management of water resources in Diffa City, combining surveillance, community awareness, and technical improvement of facilities, to guarantee sustainable access to drinking water that meets sanitary and environmental requirements

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Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

Ethical approval

Ethical approval was not required for this study, as the research involved a non-interventional field survey and did not involve clinical or experimental procedures.

Informed consent

We obtained informed consent from all participating traders before data collection. Participation was voluntary, and we used the information collected solely for research purposes.

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