

Physicochemical and Microbiological Quality of Surface Water and Groundwater during Wet and Dry Seasons in the Fétoré Sub-basin, Guinea

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Abstract: Water quality in the Fétoré sub-basin, a tributary of the Konkouré River in Guinea, was assessed during the wet and dry seasons of 2024. Surface water and groundwater samples were analyzed for physicochemical parameters and fecal indicator bacteria. Surface waters were generally weakly mineralized, with mean conductivity of 73.1 $\mu\text{S}/\text{cm}$ in the wet season and 85.6 $\mu\text{S}/\text{cm}$ in the dry season, while dissolved oxygen remained relatively stable at 6.06 and 5.81 mg/L, respectively. Several parameters showed marked spatial and seasonal variability. Mean nitrate concentration increased from 6.45 mg/L in the wet season to 21.71 mg/L in the dry season, with a maximum of 110 mg/L. High local values were also recorded for turbidity (55.5 NTU), TSS (total suspended solids) (62 mg/L), BOD₅ (biochemical oxygen demand over five days) (21 mg/L) and COD (chemical oxygen demand) (45 mg/L). Microbiological contamination was widespread in surface waters. Total coliforms were detected in 100% of wet-season samples and 85.7% of dry-season samples, while fecal coliforms were detected in 93.3% and 71.4%, respectively. Maximum concentrations reached 112 CFU/100 mL for total coliforms, 95 CFU/100 mL for fecal coliforms and 175 CFU/100 mL for fecal streptococci. Groundwater showed lower microbial contamination and generally lower turbidity, but phosphate concentrations remained high, ranging from 5.3 to 14.1 mg/L. Fecal indicators were nevertheless detected in groundwater during the wet season, with positive detections reaching 25% for total and fecal coliforms and 75% for fecal streptococci. These results show strong spatial and seasonal contrasts in water quality across the Fétoré sub-basin and identify localized physicochemical and microbiological contamination. They support the need for regular monitoring of both surface water and groundwater, particularly where these resources are used for domestic purposes.

Key words: Fétoré sub-basin, water quality, hydrochemistry, microbiological contamination, seasonal variability, Fouta Djallon, Guinea.

1. Introduction

In rural West African catchments, surface water and groundwater are used simultaneously for drinking, domestic activities, livestock and small-scale agriculture. These resources are increasingly exposed to pressure from population growth, agricultural expansion, livestock activity and inadequate sanitation, which can transfer nutrients, organic matter and fecal microorganisms into aquatic systems [1-4].

In rural sub-Saharan Africa, catchments frequently face contamination from both diffuse and point sources, as reported by Baguma et al. [5]. Runoff from cultivated areas transports suspended particles, fertilizers and organic residues into streams. Poorly protected wells and springs may also receive contaminated infiltration during the rainy season, particularly where drainage, sanitation and livestock access are poorly controlled. Microbiological contamination is of particular concern

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because many rural populations rely directly on untreated surface water or groundwater for drinking, cooking, washing and irrigation. In such contexts, fecal indicator bacteria serve as a key signal of health risks and sanitation vulnerabilities [6-8].

The Fouta Djallon highlands constitute one of the principal hydrological towers of West Africa, supplying the headwaters of the Niger, Senegal, Gambia and Konkouré river systems [9, 10]. This mountainous region plays a crucial role in sustaining downstream ecosystems, agricultural production and water security across several West African countries [7, 11]. Despite the regional hydrological importance of the Fouta Djallon, published water-quality data remain scarce for small rural headwater catchments in Guinea. In particular, little information is available on differences between wet- and dry-season water quality in the Fétoré sub-basin.

Previous work in tropical and rural catchments has consistently shown that water quality tends to vary significantly between wet and dry seasons [12, 13]. During the wet season, surface runoff generally increases turbidity, suspended solids, nutrient mobilization and fecal contamination, whereas during the dry season reduced flow and evaporation may enhance the concentration of dissolved ions and organic matter [14]. Understanding these seasonal dynamics is therefore a prerequisite for designing effective watershed management and water-quality monitoring strategies.

This study assesses the physicochemical and microbiological quality of surface water and groundwater in the Fétoré sub-basin and examines differences in water quality between the wet and dry sampling campaigns. Specifically, the study aims to: (i) characterize the hydrochemical status of surface water and groundwater; (ii) evaluate wet-season and dry-season differences; (iii) identify sites and parameters indicating anthropogenic pressure; (iv) assess microbiological contamination risks; and (v) provide management recommendations for sustainable protection of water resources in the sub-basin.

2. Materials and Methods

2.1 Study Area

The Fétoré sub-basin is located in the Fouta Djallon highlands of Guinea, within the upper drainage area of the Konkouré River system. The study area is associated with the rural communes of Timbi Madina and Timbi Tounni in the Pita region. The basin is characterized by highland plateaus, dissected valleys and a dense hydrographic network of temporary and permanent streams. Elevations in the wider Fouta Djallon range from approximately 600 to more than 1,500 m, with the Fétoré headwaters emerging in a landscape where agriculture, livestock farming and rural settlements interact closely with surface-water and groundwater resources.

The Fétoré River drains a highland catchment where runoff, erosion and infiltration are strongly controlled by seasonal rainfall. The rainy season promotes rapid transfer of particles and contaminants from hillslopes, cultivated plots and settlements toward streams. Conversely, the dry season is marked by lower flow, reduced dilution capacity and potentially higher concentration of dissolved constituents at some sampling points. These characteristics make the sub-basin suitable for studying seasonal coupling between catchment processes and water quality.

2.2 Sampling Design

Water samples were collected during the wet season in October 2024 and the dry season in March 2024 from surface-water sites distributed across the Fétoré drainage network and from groundwater sources including wells and boreholes. Sampling covered both wet and dry seasons in order to capture seasonal contrasts in runoff, dilution, mineralization and microbiological contamination. The surface-water dataset includes multiple stations coded ES1 to ES15, while the groundwater dataset includes representative boreholes and wells from localities such as TMC (Timbi Madina Centre), TSC (Tokossere Centre), TTC (Timbi Tounni Centre) and DJL (Djimbél) (Table 1).

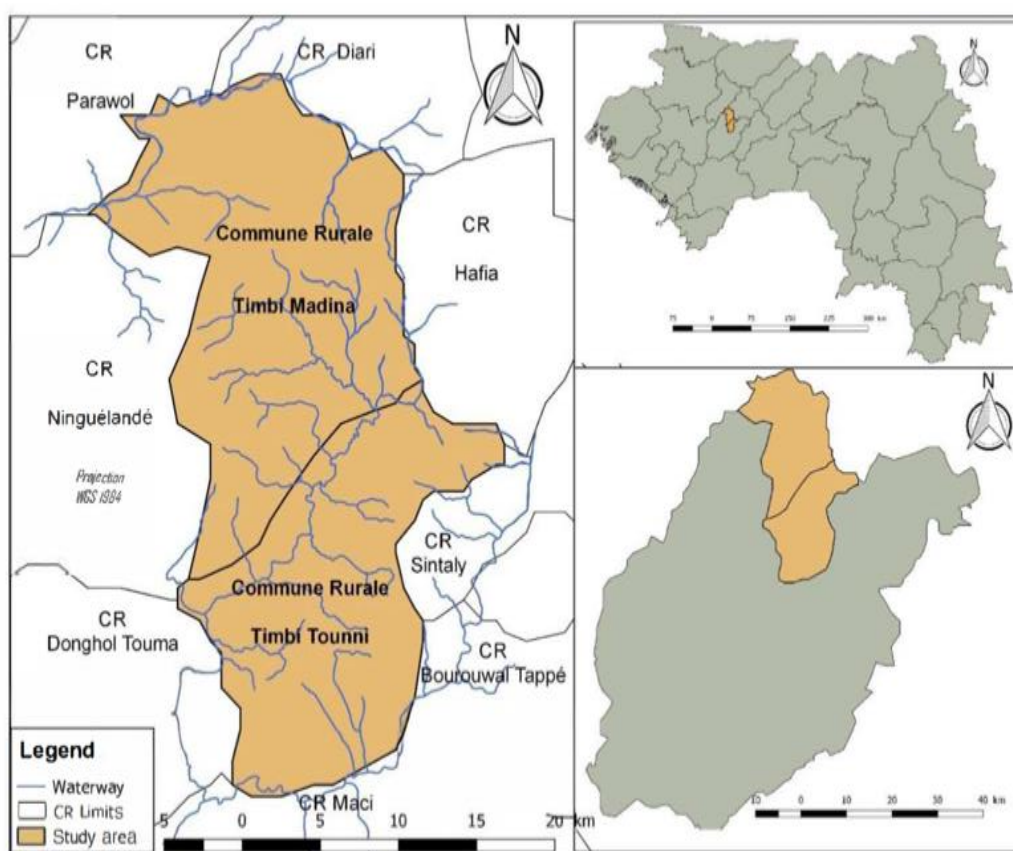


Fig. 1 Location of the Fétoré sub-basin showing the watershed limits, rural communes, drainage network and tributaries.

Table 1 Surface-water and groundwater sampling points in the Fétoré sub-basin.

ID code	Location name	Geographical coordinates		
		X	Y	
ES1	Pallewol	-12.56283	11.12717	Surface-water
ES2	Guessewol	-12.56242	11.11488	
ES3	Boumalolwol	-12.57714	11.07776	
ES4	Fetoréwol toward the outlet	-12.57719	11.06560	
ES5	Wouriwol	-12.54735	11.07740	
ES6	Bâdiwol	-12.51999	11.09689	
ES7	Bappéwol	-12.51233	11.10689	
ES8	Koubiwol	-12.49001	11.16002	
ES9	Tolinwol	-12.52874	11.17236	
ES10	Sonkewol	-12.53871	11.18235	
ES11	Sambiawol	-12.55366	11.17972	
ES12	Foteréwol toward the source	-12.60834	11.19195	
ES13	Galandantawol	-12.59713	11.20800	
ES14	Djollobhéwol	-12.57678	11.21362	
ES15	Barrage Djoungol	-12.56565	11.20819	
TMC	Timbi Madina Centre			Groundwater
TSC	Tokossere Centre			
TTC	Timbi Tounni Centre			
DJL	Djimbel	-12.56796	11.06965	

At each sampling location, observations were conducted to characterize the local environment and identify potential sources of contamination. Particular attention was given to anthropogenic activities, accessibility, proximity to residential areas, agricultural practices, livestock presence and other factors likely to influence water quality. Water samples were collected in sterile 5 L bottles using latex gloves to minimize contamination. After collection, the samples were placed in a refrigerated cooler at approximately 4 °C and transported to the laboratory for analysis within 24 h.

2.3 Physicochemical Analyses

Physicochemical measurements were performed in the field and at the laboratory of Ecology and Environmental Sciences of the IREG (Institute of Research in Environment of Guinea), Gamal Abdel Nasser University of Conakry. The parameters included temperature, pH, electrical conductivity, salinity, total dissolved solids (TDS), turbidity, TSS (total suspended solids), dissolved oxygen (DO), nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), total iron, BOD5 (biochemical oxygen demand over five days) and COD (chemical oxygen demand).

Electrical conductivity was measured using a HANA LF 330 conductivity meter. Temperature and pH were measured using a portable Jenway Model 550 pH meter/thermometer, with pH calibration performed using standard buffer solutions [15]. Dissolved oxygen was determined using a portable oxygen meter, and turbidity was measured using a turbidimeter. TSS was determined gravimetrically after filtration and drying. BOD5 and COD were determined using a BOD meter and a COD meter, respectively. Spectrophotometric measurements were performed using a laboratory spectrophotometer. Temperature, pH, electrical conductivity, salinity, TDS and dissolved oxygen were measured in situ. The remaining physicochemical parameters were analyzed at the laboratory. Nutrient analyses (nitrate, nitrite and phosphate) were performed using a HACH DR/850 portable colorimeter

according to the manufacturer's analytical procedures [16].

2.4 Microbiological Analyses

Microbiological analyses focused on TC (total coliforms), FC (fecal coliforms) and FS (fecal streptococci) as indicators of fecal contamination. A 100 mL aliquot of each water sample was filtered through a sterile 0.45 μm MILLIPORE membrane. TC were cultured on Tergitol 7 medium and incubated at 35 ± 1 °C for 24-48 h. FC were cultured on mFC medium and incubated at 44.5 ± 0.2 °C for 24 h. Fecal streptococci were cultured on Slanetz-Bartley medium and incubated at 37 °C for 48 h. Bacterial counts were expressed as colony-forming units per 100 mL (CFU/100 mL).

2.5 Data Analysis

Data analysis combined descriptive statistics, seasonal comparison, graphical exploration and multivariate interpretation. Wet season and dry season values were compared at site level using seasonal delta plots. In addition, measured values were compared with WHO (World Health Organization) and national guideline values where applicable to assess compliance and identify parameters of concern. Hydrochemical fingerprints were produced using standardized parameter values to identify groups of samples and parameters contributing most strongly to spatial and seasonal differentiation. PCA (principal component analysis) was used to summarize multivariate physicochemical gradients, while Spearman rank correlation was used to evaluate monotonic relationships between parameters. These analyses were interpreted together with field knowledge of land use, hydrology and potential pollution sources.

3. Results

3.1 Surface-Water Mineralization and Nutrient Dynamics

Surface waters of the Fétoré sub-basin were characterized by low to moderate mineralization, with

conductivity ranging from 12 to 220 $\mu\text{S}/\text{cm}$ and TDS from 6 to 110 mg/L across the two campaigns (Table S1, Supplementary Material). Electrical conductivity and TDS remain within the range expected for weakly mineralized highland waters, although some sites show higher values. The highest conductivity and TDS were recorded at ES11 (Sambiawol) during the dry season, reaching 220 $\mu\text{S}/\text{cm}$ and 110 mg/L, respectively (Table S2a, Supplementary Material). This pattern suggests that the natural geochemical background is relatively dilute, but that local concentration effects and anthropogenic inputs may influence specific sampling points.

The seasonal profile of mineralization and nutrient indicators (Fig. 2) shows that conductivity, TDS and salinity tend to increase from wet to dry season at several sites, such as ES3 (Boumalolwol), ES10 (Sonkewol), ES11 (Sambiawol), ES13 (Galandantawol) and ES14 (Djollobhéwol) (Table S2a, Supplementary Material). For example, conductivity at ES11 decreased from 220 $\mu\text{S}/\text{cm}$ in the dry season to 59.3 $\mu\text{S}/\text{cm}$ in the wet season, while TDS decreased from 110 to 29.7 mg/L. At ES3, conductivity decreased from 97.8 to 47.1 $\mu\text{S}/\text{cm}$ and TDS from 49 to 23.6 mg/L between the dry and wet seasons. Salinity also showed higher dry-season values at these sites, including ES3 (152 versus 22 mg/L), ES13 (134 versus 26.3 mg/L) and ES14 (127 versus 29.8 mg/L). This increase can be interpreted as a combined effect of evaporation, reduced water inputs and a progressive concentration of dissolved ions during the dry season.

Sulfate (SO_4^{2-}) concentrations remain low at most sites, although higher dry-season values were recorded at ES2 (48 mg/L) and ES4 (52 mg/L). In contrast, phosphate values show marked site-level increases, particularly at ES2 (Guessewol), ES4 (Fetoréwol toward the outlet) and ES9 (Tolinwol), where dry-season concentrations reached 270, 280 and 310 mg/L, respectively, compared with 23.2, 17.8 and 26.8 mg/L during the wet season. These values indicate localized nutrient enrichment. Agricultural runoff and domestic

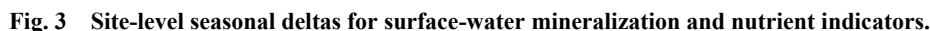
inputs observed in the area are possible sources.

Nitrates (NO_3^-) and nitrites (NO_2^-) display localized peaks rather than uniform basin-wide enrichment, suggesting that nitrogen inputs are spatially heterogeneous and linked to specific land-use or sanitation conditions. The highest nitrate concentrations were recorded during the dry season at ES9 (Tolinwol, 110 mg/L), ES2 (Guessewol, 60 mg/L) and ES14 (Djollobhéwol, 30 mg/L), compared with wet-season values of 8.2, 6.5 and 5.0 mg/L, respectively. Nitrite showed a similar localized pattern, with exceptionally high dry-season values at ES4 (12 mg/L) and ES9 (8 mg/L), whereas concentrations at most other sites remained between 0.01 and 0.06 mg/L. Total iron concentrations remained relatively low at most sites, with limited seasonal variation, although higher values were observed at ES8 (Koubiwol, 1.52 mg/L in the wet season), ES12 (0.86 mg/L in both seasons) and ES1 (1.00 mg/L in the dry season and 0.65 mg/L in the wet season).

Seasonal delta plots for surface-water mineralization and nutrient indicators (Fig. 3) reveal a consistent increase in several parameters from the wet to the dry season, as indicated by the predominance of positive seasonal changes (red dots). Conductivity, TDS, salinity, sulfates, nitrates and nitrites concentrations increased at most sampling sites (more than 60% of the monitoring locations). This again suggests that concentration processes are driven by reduced recharge, lower water levels and diminished dilution capacity. In contrast, phosphate and total iron show more site-specific behavior, indicating an influence of localized factors, including anthropogenic inputs, sediment water interactions and geochemical processes controlling nutrient and metal dynamics in surface-waters.

3.2 Organic Load, Oxygen and Suspended Matter in Surface Water

The organic-load and suspended-matter indicators reveal stronger seasonal sensitivity than the mineralization parameters (Fig. 4). Turbidity and TSS increase at several sites during the wet season. For example,



runoff, soil erosion and transport of fine particles from cultivated slopes, paths and settlement areas. These increases are also important because suspended particles can transport nutrients, organic matter and microorganisms.

The pH ranged from approximately 5.27 to 7.60 across sites and seasons (Table S1, Supplementary material). Several sites show acidic conditions (Table

S2b, Supplementary Material), with the lowest pH recorded at ES10 (Sonkewol) during the wet season (5.27). Other relatively low wet-season values were observed at ES13 (5.48) and ES14 (5.62). These acidic conditions may be influenced by agricultural runoff, organic matter inputs and low buffering capacity.

Dissolved oxygen varied across sites and seasons, with values ranging from approximately 3.8 to 7.8 mg/L. Lower values were observed at some sites, while other sites remained relatively well oxygenated (Table S2b, Supplementary Material). These variations may reflect differences in turbulence, temperature and organic load. Lower oxygen values at some sites may also indicate oxygen consumption associated with microbial degradation of organic matter.

BOD5 and COD patterns indicate the presence of biodegradable and oxidizable organic matter in the sub-basin, with marked differences among sites. BOD5 reached 21 mg/L at ES10 during the wet season, while COD reached 45 mg/L at the same site. Elevated values were also recorded at ES13 and ES14, where wet-season BOD5 reached 18 and 19 mg/L and COD reached 39 and 41 mg/L, respectively (Table S2b,

Supplementary Material). These site-specific differences suggest variations in organic-matter inputs across the sub-basin.

Surface-water seasonal deltas for organic load, oxygen and suspended matter revealed strong inter-site variability (Fig. 5). While pH and some organic load indicators increased during the dry season at several sites, suspended matter, turbidity, dissolved oxygen and temperature show contrasted results. This heterogeneity suggests that seasonal water-quality variation is primarily modulated by local conditions, including organic inputs, runoff, dilution, particle resuspension and site-specific hydrodynamics.

3.3 Spatial and Seasonal Patterns in Surface-Water Chemistry

Fig. 6 shows the standardized values of the measured parameters across sites and seasons. Red colors represent values above the parameter mean, whereas blue colors indicate values below the mean. The heatmap shows that no single parameter controls the entire dataset; instead, the water-quality pattern results from combined mineralization, nutrient, organic and suspended-matter gradients.

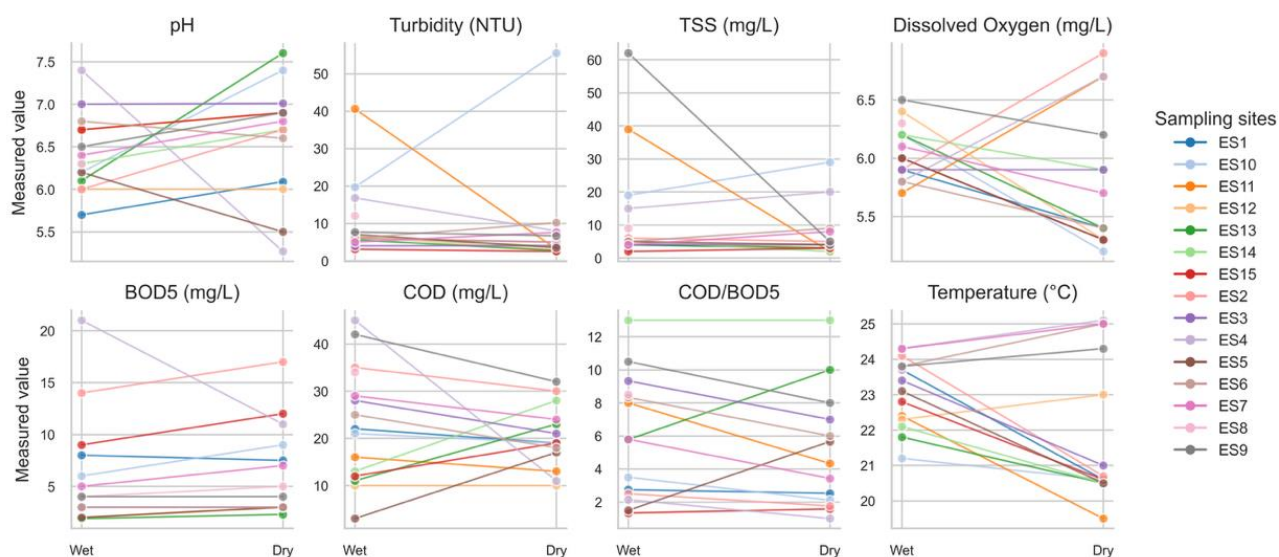


Fig. 4 Seasonal variations in organic load, oxygen and suspended matter in surface-water samples.

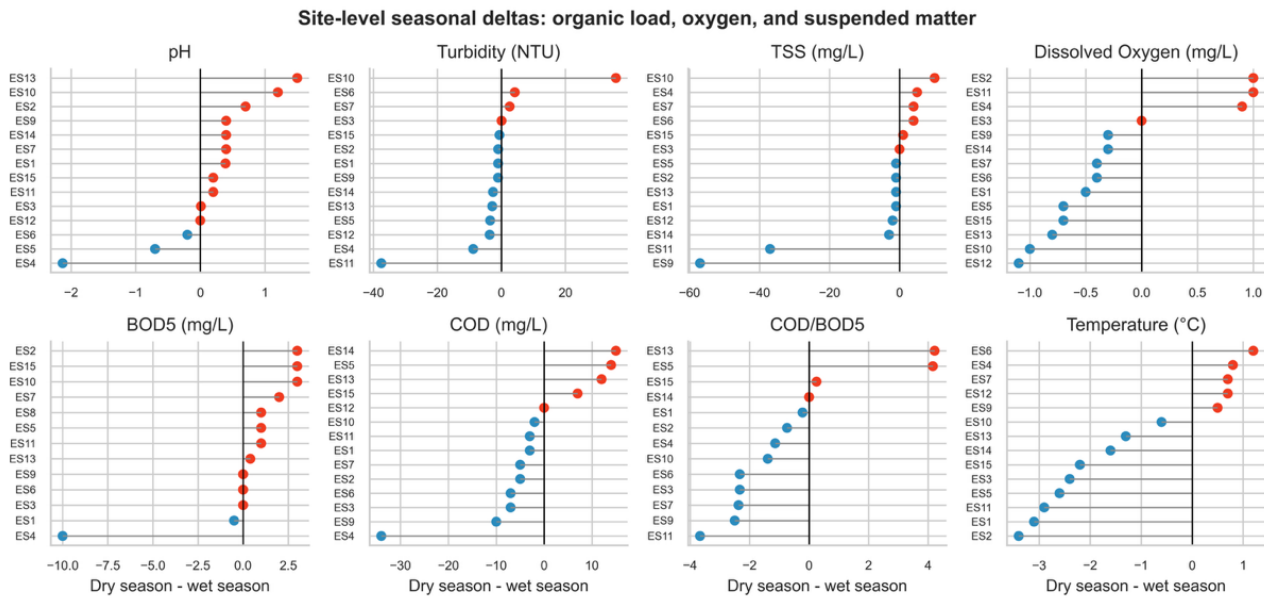


Fig. 5 Site-level seasonal deltas for surface-water organic load, oxygen and suspended matter.

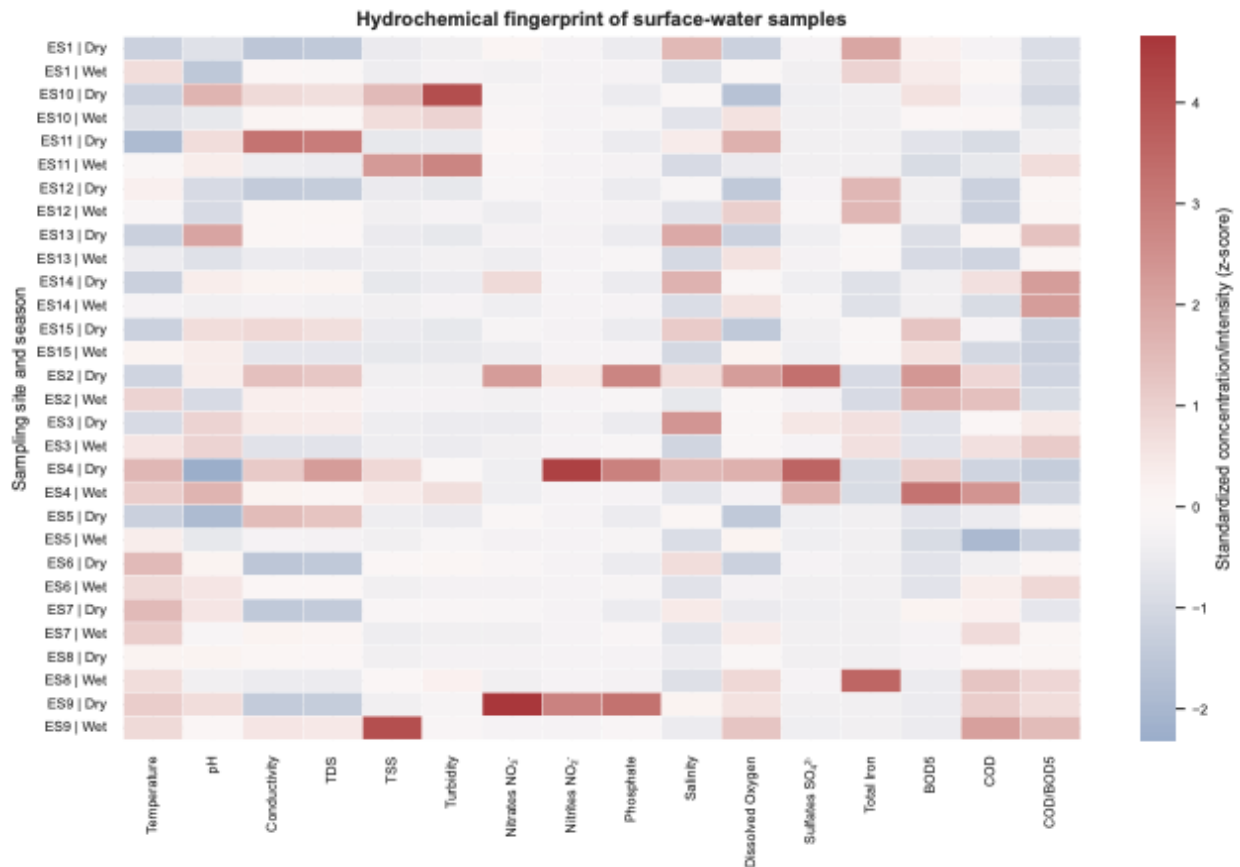


Fig. 6 Standardized hydrochemical fingerprint heatmap of surface-water samples.

Some samples had higher conductivity, TDS, salinity and nutrient concentrations than the others. Other samples are distinguished by turbidity, TSS,

COD or BOD5. The observed differences were associated with both season and sampling site. The contrast between wet and dry samples further indicates

that seasonal hydrology modifies not only the magnitude of individual parameters but also the overall hydrochemical identity of each site.

3.4 Multivariate Structure of Surface-Water Quality

Principal component analysis (PCA) revealed a seasonal pattern in surface-water physico-chemical parameters. The first two axes explain 42.2% of the total variance. PC1 accounted for 26.0% and PC2 for 16.2% (Fig. 7). PC1 mainly represented a mineralization and nutrient enrichment gradient, with positive loadings for conductivity, TDS, salinity, nitrates, nitrites, phosphates, sulfates, dissolved oxygen and, to a lesser extent, BOD5. Dry-season samples from ES2 and ES4 were clearly separated from the main group, suggesting local enrichment associated with low-flow concentration, point inputs or site-specific geochemical conditions.

PC2 primarily contrasts sites associated with conductivity, TDS, salinity in its positive portion with those more closely associated with temperature,

nitrites and nitrites in its negative portion. Sample ES11, in the dry season, with a very high value on PC2, appears as an atypical point dominated by the mineralization gradient. Conversely, ES9, also in the dry season, with a very low value on PC2 and a positive value on PC1, seems more closely associated with the nitrogen and temperature gradients.

Seasonal observation distribution indicates separation between wet and dry season samples. Dry season samples tend to occupy more dispersed positions along the main gradient, indicating strong spatial heterogeneity. This dispersion is probably due to reduced flow, lower dilution capacity, increased solute concentration at some sites, varying local inputs and more pronounced biogeochemical activity during the dry season. Wet-season samples are more clustered for several stations but remain influenced by runoff and erosion processes during periods of increased rainfall. This indicates a more homogeneous physicochemical composition between sites. This homogeneity may reflect a dilution and hydrological mixing effect during the wet period.

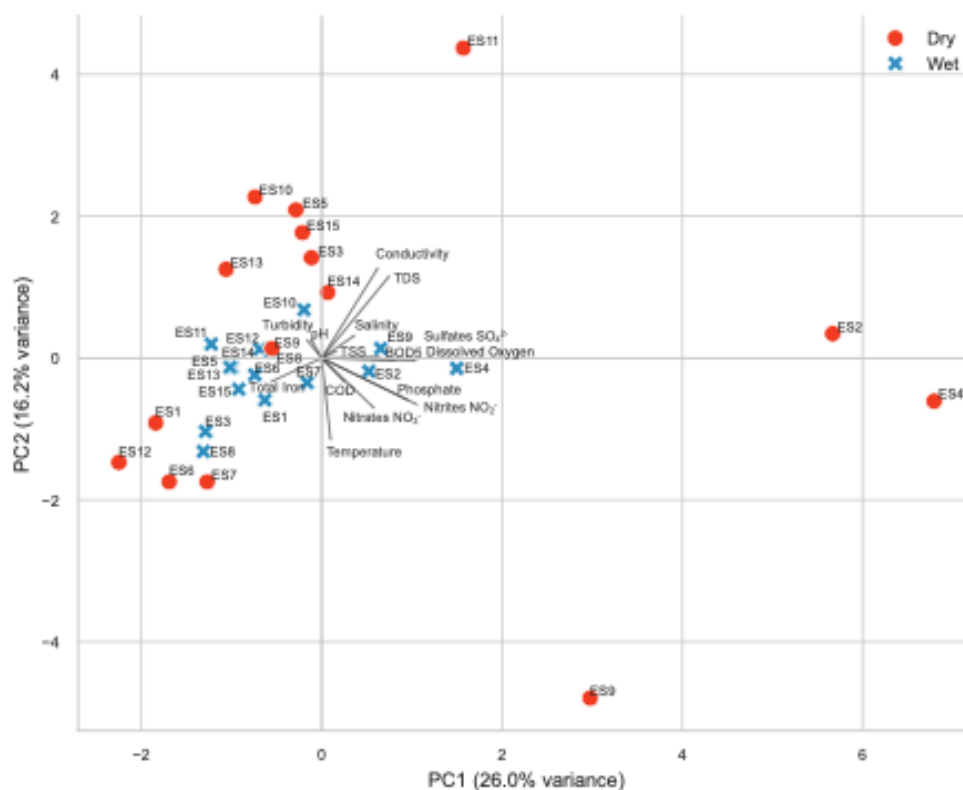


Fig. 7 Principal component analysis biplot of surface-water physicochemical parameters.

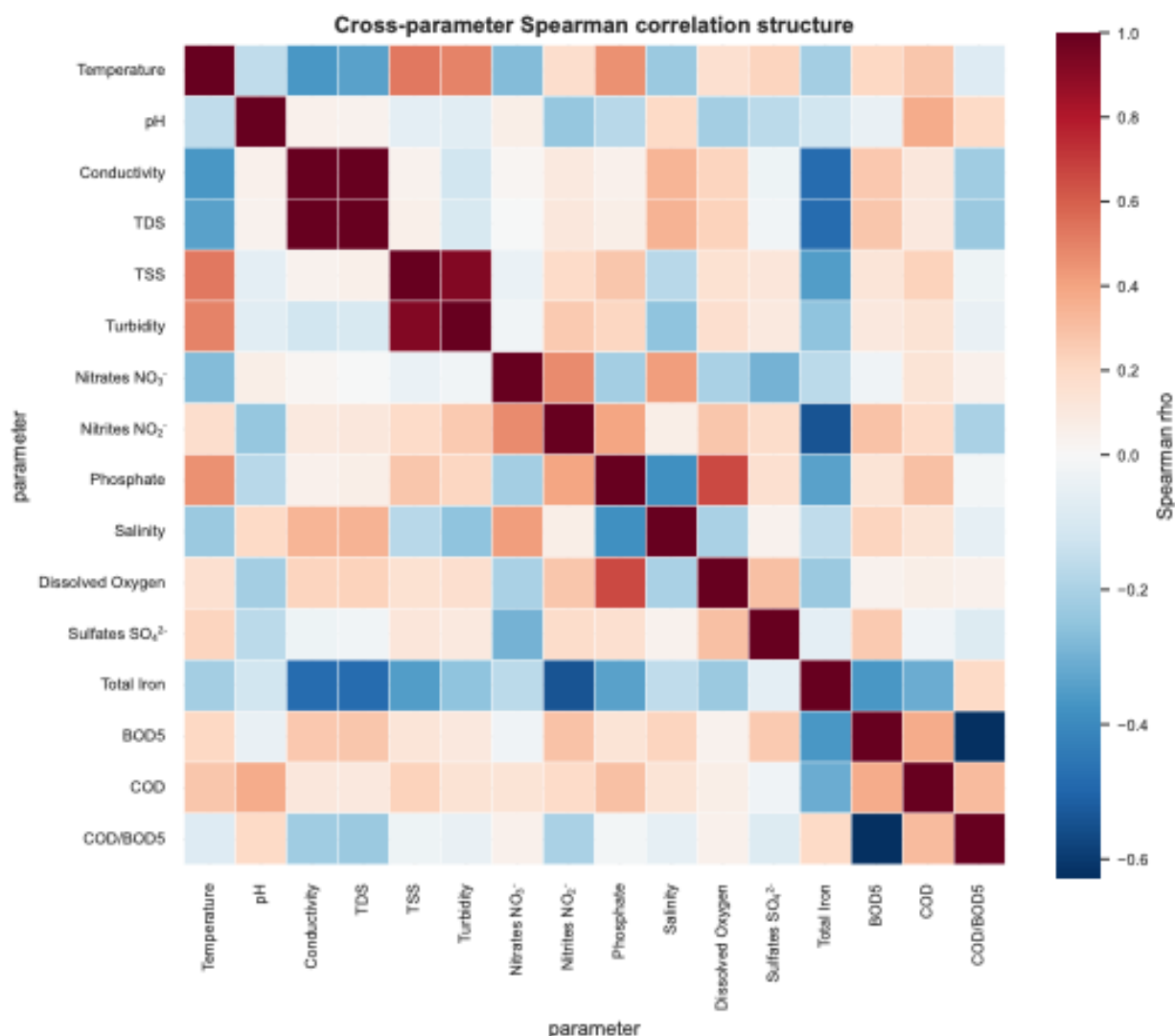


Fig. 8 Spearman correlation heatmap for surface-water parameters.

A few dry-season samples are clearly separated from the central group, suggesting local enrichment or concentration. This PCA shows differences between wet- and dry-season samples, although substantial variability remains among sites.

The Spearman correlation heatmap (Fig. 8) provides additional evidence of strong relationships between hydrochemical parameters. Conductivity was strongly correlated with TDS ($r = 0.85$) and to a lesser extent with salinity ($r = 0.45$), indicating that these variables represent a common dissolved-ion gradient. Associations between turbidity and TSS reflect the particle-transport pathway. Correlations between COD, BOD₅ and some nutrient parameters indicate that these

variables partly covary across the sampled sites. Negative relationships involving dissolved oxygen are consistent with oxygen depletion where organic matter and microbial activity are higher.

3.5 Microbiological Contamination of Surface Water

Fig. 9 and Table S3 (Supplementary Material) summarize microbiological contamination in surface-water samples using log₁₀ (count + 1) values for total coliforms, fecal coliforms and fecal streptococci, with seasonal observations shown as overlaid points. Microbiological indicators confirm that surface waters of the Fétoré sub-basin are vulnerable to fecal contamination. During the wet season, TC (total

coliforms) were detected at all 15 sites (100%), FC (fecal coliforms) at 14 of 15 sites (93.3%), and FS (fecal streptococci) at 13 of 15 sites (86.7%). During the dry season, detection frequencies were 85.7% for TC, 71.4% for FC and 85.7% for FS (Table S3, Supplementary Material).

Results reveal variable fecal contamination across sites, with particularly high levels at ES2 (Guessewol), ES4 (Fetoréwol toward the outlet), ES10 (Sonkewol), ES11 (Sambiawol), and ES15 (Barrage Djoungol). Across all surface-water samples, concentrations reached maximum values of 112 CFU/100 mL for TC, 95 CFU/100 mL for FC and 175 CFU/100 mL for FS. Mean TC concentrations increased from 22.7 CFU/100 mL in the dry season to 45.3 CFU/100 mL in the wet season, while mean FC concentrations increased from 17.1 to 29.3 CFU/100 mL. Mean FS concentrations were also higher during the wet season, increasing from 20.2 to 33.0 CFU/100 mL. The simultaneous detection of FC and FS indicates fecal contamination. Field observations suggest that runoff and nearby human or livestock activities may contribute to this contamination. Conversely, sites such as ES13 (Galandantawol) and ES14 (Djollobhéwol) show the lowest levels of contamination. The observed seasonal variability,

particularly the higher wet-season concentrations and detection frequencies of TC and FC, is consistent with increased transfer of microorganisms to surface waters during the wet season, while contamination detected during the dry season indicates that fecal pollution is not restricted to the rainy period.

3.6 Groundwater Physicochemical Quality

Groundwater samples, including three boreholes and one well, showed more stable physicochemical behavior than surface-water samples, which is expected because subsurface flow and aquifer filtration typically buffer short-term fluctuations. However, groundwater is not completely protected. Fig. 10 compares groundwater parameters with WHO guideline values [17] and shows that most mineralization indicators remain within acceptable limits, while some parameters vary among wells and boreholes.

Among the four groundwater sources, microbiological contamination was highest at TSC, the only sampled well. Variations in turbidity, nutrients or dissolved oxygen may indicate differences in construction, protection, depth and local sanitary conditions. Fig. 10 shows that groundwater quality is generally more favorable than surface-water quality, but still requires protection and

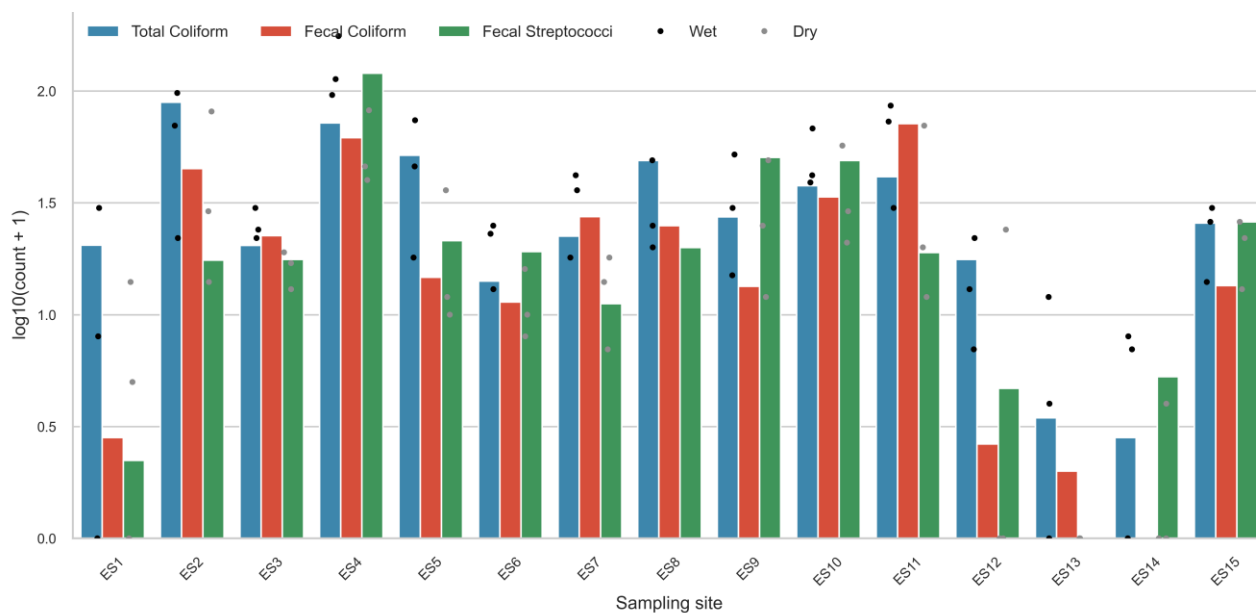


Fig. 9 Microbiological contamination profile of surface-water samples.

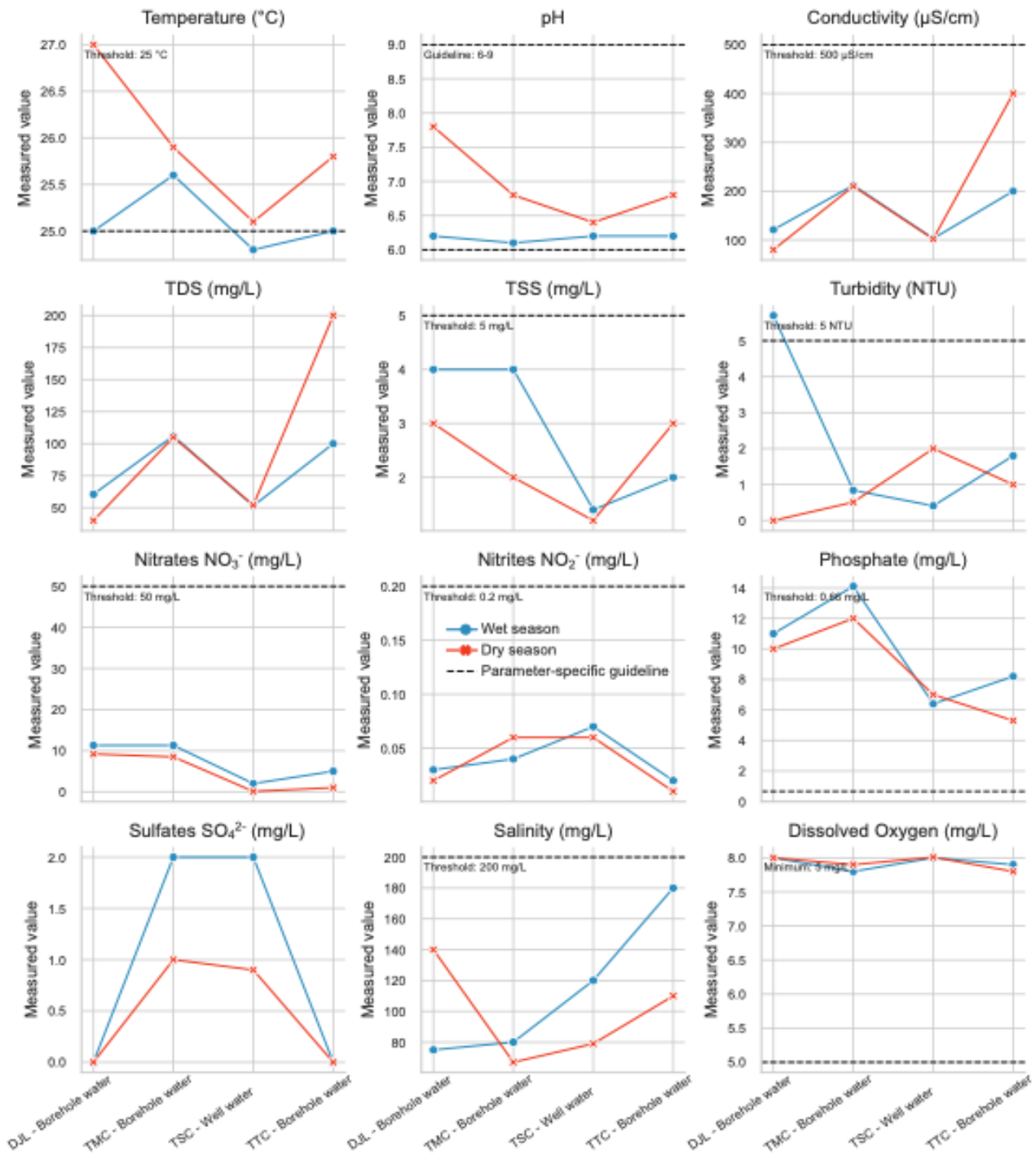


Fig. 10 Groundwater site-season variation relative to parameter-specific guideline values. TMC = Timbi Madina Centre; TSC = Tokossere Centre; TTC = Timbi Tounni Centre; DJL = Djimbel.

monitoring. A study conducted in Boké reported that about 60% of the analyzed borehole samples met the microbiological quality criteria, highlighting the spatial variability of groundwater quality in Guinea [18].

3.7 Microbiological Quality of Groundwater

Groundwater microbiological results (Fig. 11) demonstrate that groundwater is not uniformly protected from fecal contamination. The heatmap highlights a

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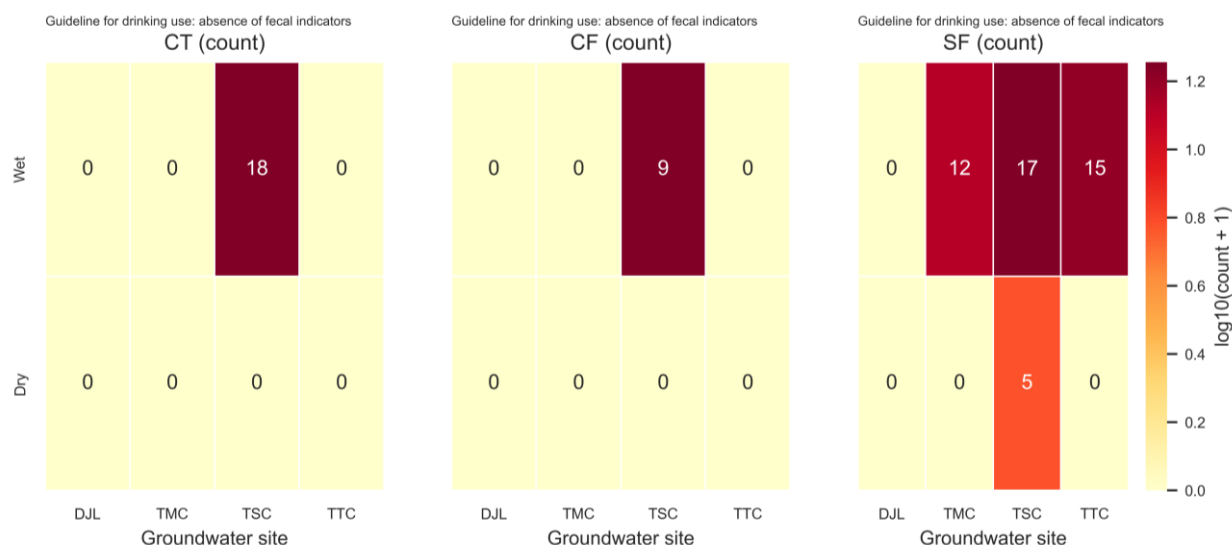


Fig. 11 Groundwater microbiological indicators by site and season in the Fétoré sub-basin. Cell colors represent $\log_{10}(\text{count} + 1)$, while cell labels show the original values in CFU/100 mL. TC = total coliforms; FC = fecal coliforms; FS = fecal streptococci; TMC = Timbi Madina Centre; TSC = Tokossere Centre; TTC = Timbi Tounni Centre; DJL = Djimbel.

mostly low-contamination pattern, interrupted by wet-season detections at specific sites, especially Tokossere Centre, where TC, FC and FS reached 18, 9 and 17 CFU/100 mL, respectively. FSs were also detected during the wet season at Timbi Madina Centre (12 CFU/100 mL) and Timbi Tounni Centre (15 CFU/100 mL), showing that microbiological contamination was not limited to Tokossere Centre. These values exceed the WHO guideline for drinking water, which requires the absence of *E. coli* or thermotolerant coliforms in any 100 mL sample, indicating microbiological concerns for the use of these untreated water sources for drinking.

These results suggest that microbiological contamination of groundwater is episodic and strongly influenced by local protection conditions. Wells are more vulnerable than boreholes because they may be shallower, less sealed and more exposed to runoff. The wet-season pattern indicates infiltration of contaminated water from the surface, possibly related to poor drainage, proximity to latrines, livestock presence or open defecation.

4. Discussion

Water quality differed between sites and between the two sampling campaigns. Surface waters are generally

weakly mineralized, reflecting the dilute hydrochemical background of the basin, but localized increases in conductivity, TDS, salinity and nutrients show that some sites are influenced by anthropogenic inputs or dry-season concentration. The low conductivity and TDS values observed at most sites indicate weakly mineralized waters, consistent with the general relationship between dissolved-ion content and electrical conductivity in freshwater systems [19]. Similar patterns have been also reported in other African agricultural catchments [20].

The wet season is the most critical period for suspended matter and microbiological contamination. Increased turbidity and TSS indicate erosion and runoff from slopes and cultivated areas. These processes can mobilize not only mineral particles but also nutrients, organic matter and fecal microorganisms. The high phosphate signal observed in several samples is particularly relevant because phosphate is commonly associated with fertilizer application, domestic wastewater and particulate transport. Even where nitrate and nitrite remain relatively low, phosphate enrichment can indicate eutrophication pressure and poor nutrient-management practices. This pattern should be interpreted in the broader context of

agricultural nutrient pressure. Although the Fétoré basin remains rural and weakly industrialized, localized nutrient enrichment at specific sites suggests that fertilizer application, domestic wastewater and livestock-related inputs may be sufficient to alter stream chemistry during sensitive hydrological periods.

BOD5 and COD also varied among sites and seasons. Where these indicators increase together with reduced dissolved oxygen, the likely process is microbial degradation of organic inputs. Such conditions may affect aquatic life and reduce the self-purification capacity of streams. The correlation structure supports this interpretation by linking groups of organic-load, mineralization and suspended-matter variables.

Fecal contamination was the main water-quality concern observed in this study. The presence of total coliforms, fecal coliforms and fecal streptococci in surface water confirms that human and animal fecal inputs reach the aquatic environment. The wet-season intensification of contamination is consistent with runoff from settlements, livestock areas and poorly managed sanitation systems. Recent work in West African rural watersheds shows that water-resource contamination is often linked to spatially clustered pollution sources rather than uniform basin-wide pressure. Kondo et al. [21] emphasized the value of diagnosing and mapping potential anthropogenic sources in rural watershed heads in Benin. A similar approach would strengthen future monitoring in the Fétoré sub-basin by linking high-risk sites to land use, settlement proximity, livestock corridors, latrines and drainage pathways. The health relevance of this microbiological signal is reinforced by recent studies linking fecal pollution to agricultural, environmental and public-health risks in rural African settings. Amaefule et al. [22] showed that fecal pollution can represent a direct pathway of exposure for populations relying on untreated water. In the Fétoré sub-basin, the detection of fecal coliforms and fecal streptococci therefore represents not only an environmental-quality issue but also a practical domestic-water safety concern.

Because many rural communities may use untreated water for domestic purposes, these findings support improved protection of water points, household water treatment where untreated sources are used for drinking, and better sanitation.

Groundwater is comparatively less variable and generally shows better physicochemical quality than surface water. This reflects natural attenuation during infiltration and subsurface flow. However, the presence of fecal indicators in selected groundwater samples shows that aquifer protection is incomplete. Wet-season fecal indicators were detected at the TSC well and at two boreholes, showing that contamination was not restricted to the well. The detection of fecal streptococci and coliforms in wet-season samples suggests rapid infiltration pathways or direct entry of contaminated runoff. Therefore, groundwater cannot be assumed to be safe without regular monitoring and sanitary inspection. The groundwater results align with recent West African evidence showing that groundwater quality can vary strongly across short distances depending on well construction, aquifer vulnerability and nearby pollution sources. Millogo et al. [23] reported spatial variability in groundwater quality in a watershed draining Manga, Burkina Faso, emphasizing the need for local-scale assessment rather than broad assumptions of groundwater safety. In the Fétoré sub-basin, the wet-season detection of fecal indicators supports the need for sanitary inspection of wells and boreholes.

The PCA differentiates samples along gradients of mineralization, organic load and nutrient enrichment, while the hydrochemical fingerprint reveals that contamination is spatially heterogeneous. These spatial differences support site-specific monitoring and management. Instead, priority should be given to sites showing repeated signals of fecal contamination, high turbidity, phosphate enrichment or organic load. The Spearman correlations further indicate that parameters can be grouped into process-based families: dissolved-ion mineralization, particle transport, nutrient enrichment and organic contamination.

Overall, the study indicates moderate physicochemical pressure but clear microbiological contamination. While most dissolved chemical parameters may remain within acceptable ranges, fecal contamination can still make water unsafe for domestic use. Therefore, a monitoring program focused only on physicochemical parameters would underestimate public-health risks in the Fétoré sub-basin. This finding also supports the need for regular microbiological monitoring of rural water sources. Such monitoring remains insufficient in many parts of sub-Saharan Africa, particularly for small and rural water supplies [24].

5. Conclusion

This study assessed the physicochemical and microbiological quality of surface water and groundwater in the Fétoré sub-basin, a tributary of the Konkouré River in the Fouta Djallon highlands of Guinea, during wet- and dry-season campaigns. Surface waters were generally weakly mineralized, but marked spatial variations were observed in conductivity, TDS, salinity, turbidity, suspended solids and organic-load indicators. Localized nutrient enrichment was particularly pronounced, with nitrate and phosphate concentrations reaching 110 and 310 mg/L, respectively. Field observations indicate agriculture, livestock and domestic activities as possible contributing sources. Wet-season conditions were associated with greater suspended-matter transport and fecal contamination, whereas higher dissolved-ion concentrations occurred at several stations during the dry season.

Groundwater showed more stable physicochemical characteristics than surface water, but it was not uniformly protected from microbiological contamination. During the wet-season campaign, TC, FC and FS reached 18, 9 and 17 CFU/100 mL, respectively, at Tokossere Centre. Fecal streptococci were also detected at Timbi Madina Centre (12 CFU/100 mL) and Timbi Tounni Centre (15 CFU/100 mL), showing that groundwater contamination was not restricted to a single site. These results indicate the vulnerability of

some groundwater sources to focal contamination during the wet season. Multivariate analyses highlighted several gradients associated with water-quality variability across the basin, including mineralization, nutrient enrichment, organic load and microbiological contamination.

This study has some limitations. Water quality was assessed during one wet-season campaign and one dry-season campaign in 2024. The observed differences therefore represent contrasts between the two sampling periods rather than the full range of seasonal variability. Repeated sampling over several months and years would help confirm these patterns. In addition, potential pollution sources were identified from field observations but were not quantified directly.

Overall, the main environmental and public-health concern in the Fétoré sub-basin is microbiological contamination, especially during the wet season. Sustainable water-resource management should therefore combine regular monitoring, protection of wells and springs, improved sanitation, erosion control and community awareness. These measures are needed to reduce risks for local communities and to preserve the hydrological role of the Fouta Djallon highlands.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships

that could have appeared to influence the work reported in this paper.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Author Contributions

A.O.D. designed the study and coordinated sampling and laboratory analysis; A.O.D., E.T.D., M.D. and F.K. contributed to data analysis and interpretation; A.O.D., B.S.D. and E.T.D. contributed to manuscript preparation and revision. All authors read and approved the final manuscript.

Supplementary Material

Table S1 Descriptive statistics for surface-water physicochemical parameters by season.

Parameter	Unit	Season	n	mean	SD	median	min	Q25	Q75	max	CV (%)
Temperature	°C	Dry	14	21.92	2.06	20.65	19.5	20.52	23.98	25.1	9.42
		Wet	15	23.12	0.97	23.4	21.2	22.35	23.8	24.3	4.20
pH		Dry	14	6.60	0.66	6.75	5.27	6.217	6.9	7.6	10.07
		Wet	15	6.42	0.44	6.3	5.7	6.15	6.7	7.4	6.85
Conductivity	µS/cm	Dry	14	85.63	63.61	92.6	12	18	125.63	220	74.29
		Wet	15	73.07	16.34	76.4	47.1	59.15	85.05	102.1	22.36
TDS	mg/L	Dry	14	44.68	33.99	46.5	6	9	65.75	110	76.08
		Wet	15	36.58	8.17	38.4	23.6	29.6	42.55	51.1	22.33
TSS	mg/L	Dry	14	7.14	7.83	4	2	3	7.25	29	109.67
		Wet	15	12.53	16.65	5	2	4	12	62	132.82
Turbidity	NTU	Dry	14	8.61	13.69	4.53	2.51	3.2	7.368	55.5	158.99
		Wet	15	10.16	9.62	6.4	3.1	5.8	9.85	40.6	94.69
Nitrates NO ₃ ⁻	mg/L	Dry	14	21.71	29.21	10.25	4.1	8.975	15	110	134.52
		Wet	15	6.45	1.96	6.2	4.2	5	7.3	10.4	30.30
Nitrites NO ₂ ⁻	mg/L	Dry	14	1.59	3.69	0.03	0.01	0.02	0.06	12	231.44
		Wet	15	0.03	0.01	0.03	0.02	0.02	0.04	0.05	35.21
Phosphate	mg/L	Dry	14	62.56	121.73	1.55	1	1.2	2.075	310	194.59
		Wet	15	20.47	4.21	20.8	14.1	17.3	22.9	28.6	20.58
Salinity	mg/L	Dry	14	96.21	30.65	89	56	72	122.5	152	31.86
		Wet	15	33.25	6.59	34.4	22	28.5	37.8	45	19.83
Dissolved Oxygen	mg/L	Dry	14	5.81	0.60	5.55	5.2	5.33	6.13	6.9	10.25
		Wet	15	6.06	0.24	6	5.7	5.9	6.2	6.5	3.89
Sulfates SO ₄ ²⁻	mg/L	Dry	14	8.64	17.81	1	0	0	2	52	206.01
		Wet	15	2.97	6.99	1	0	0.5	2	28	235.48
Total Iron	mg/L	Dry	11	0.34	0.33	0.2	0.01	0.14	0.43	1	97.67
		Wet	12	0.41	0.44	0.25	0.01	0.17	0.58	1.52	106.95
BOD5	mg/L	Dry	13	6.68	4.50	5	2.3	3	9	17	67.39
		Wet	13	6.38	5.60	4	1.9	3	8	21	87.78
COD	mg/L	Dry	14	20.29	6.67	19	10	17.25	23.75	32	32.89
		Wet	15	23.07	12.43	22	3	12.5	31.5	45	53.89
COD/BOD5		Dry	13	5.11	3.64	4.33	1	2.111	7	13	71.22
		Wet	14	5.93	3.74	5.79	1.33	2.56	8.46	13	63.14

**Physicochemical and Microbiological Quality of Surface Water and Groundwater
during Wet and Dry Seasons in the Fétoré Sub-basin, Guinea**

Table S2a Surface-water site-season matrix for mineralization and nutrient indicators.

Code	Site	Season	Conductivity	TDS	Salinity	Sulfates SO ₄ ²⁻	Nitrates NO ₃ ⁻	Nitrites NO ₂ ⁻	Phosphate	Total iron
ES1	Pallewol	Dry	12	6	121	2	15.8	0.04	1.2	1
		Wet	76.4	38.4	34.4	1	6.5	0.04	19.5	0.65
ES10	Sonkewol	Dry	113	56	59	0	9.2	0.02	1.4	-
		Wet	83.7	41.9	37.4	0.5	10.4	0.04	21	-
ES11	Sambiwol	Dry	220	110	78	1	12.6	0.04	1.7	0.2
		Wet	59.3	29.7	27.2	1	10.2	0.04	14.1	0.2
ES12	Fetoréwol toward the source	Dry	18	9	56	2	9.7	0.02	2	0.86
		Wet	82.6	41.3	36.9	3	4.5	0.02	15.5	0.86
ES13	Galandantawol	Dry	80	40	134	0	7.1	0.01	2.1	0.3
		Wet	56.9	28.5	26.3	1.5	4.3	0.02	22.6	0.3
ES14	Djollobhéwol	Dry	87.4	44	127	0	30	0.06	1.9	0.08
		Wet	65.3	32.8	29.8	2.5	5	0.02	16.8	0.08
ES15	Barrage Djoungol	Dry	114	56	104	1	8.9	0.01	1	0.3
		Wet	51.9	25.9	24.2	0	4.2	0.02	19	0.3
ES2	Guessewol	Dry	138.1	69	89	48	60	2	270	0.01
		Wet	93.2	46.6	41.3	1.5	6.5	0.05	23.2	0.01
ES3	Boumalolwol	Dry	97.8	49	152	12	4.1	0.01	1.2	0.55
		Wet	47.1	23.6	22	2	6.2	0.03	24.7	0.55
ES4	Fetoréwol toward the outlet	Dry	129.5	92.5	123	52	5	12	280	0.02
		Wet	86.4	43.2	38.2	28	5	0.04	17.8	0.02
ES5	Wouriwol	Dry	143	71	66	0	11.2	0.03	1.1	-
		Wet	66.5	33.3	30.2	0	7.5	0.03	20.8	-
ES6	Bâdiwol	Dry	12	6	89	2	10.8	0.03	1	0.2
		Wet	78.9	39.5	35.3	0.5	7.1	0.03	20.9	0.2
ES7	Bappéwol	Dry	16	8	79	0	9.6	0.02	1.2	0.2
		Wet	86.8	43.4	38.6	1	5.4	0.02	28.6	0.2
ES8	Koubiwol	Dry	-	-	-	-	-	-	-	-
		Wet	59	29.5	31.9	2	5.8	0.02	15.7	1.52
ES9	Tolinwol	Dry	18	9	70	1	110	8	310	-
		Wet	102.1	51.1	45	0	8.2	0.02	26.8	-

Table S2b Surface-water site-season matrix for organic load, oxygen and suspended-matter indicators.

Code	Site	Season	Temperature	pH	TSS	Turbidity	Dissolved oxygen	BOD5	COD	COD/BOD5
ES1	Pallewol	Dry	20.6	6.09	3	5	5.4	7.5	19	2.53
		Wet	23.7	5.7	4	6	5.9	8	22	2.75
ES10	Sonkewol	Dry	20.6	7.4	29	55.5	5.2	9	19	2.111
		Wet	21.2	6.2	19	19.7	6.2	6	21	3.5
ES11	Sambiwol	Dry	19.5	6.9	2	3.1	6.7	3	13	4.333
		Wet	22.4	6.7	39	40.6	5.7	2	16	8
ES12	Fetoréwol toward the source	Dry	23	6	3	2.85	5.3	-	10	-
		Wet	22.3	6	5	6.5	6.4	-	10	-
ES13	Galandantawol	Dry	20.5	7.6	3	2.75	5.4	2.3	23	10
		Wet	21.8	6.1	4	5.6	6.2	1.9	11	5.78
ES14	Djollobhéwol	Dry	20.5	6.7	2	3.81	5.9	-	28	13
		Wet	22.1	6.3	5	6.4	6.2	-	13	13
ES15	Barrage Djoungol	Dry	20.6	6.9	3	2.51	5.3	12	19	1.583
		Wet	22.8	6.7	2	3.1	6	9	12	1.333

ES2	Guessewol	Dry	20.7	6.7	5	5.02	6.9	17	30	1.76
		Wet	24.1	6	6	6	5.9	14	35	2.5
ES3	Boumalolwol	Dry	21	7.01	4	4.06	5.9	3	21	7
		Wet	23.4	7	4	4	5.9	3	28	9.33
ES4	Fetoréwol toward the outlet	Dry	25.1	5.27	20	8	6.7	11	11	1
		Wet	24.3	7.4	15	16.8	5.8	21	45	2.14
ES5	Wouriwol	Dry	20.5	5.5	4	3.5	5.3	3	17	5.66
		Wet	23.1	6.2	5	7	6	2	3	1.5
ES6	Bâdiwol	Dry	25	6.6	9	10.2	5.4	3	18	6
		Wet	23.8	6.8	5	6	5.8	3	25	8.33
ES7	Bappéwol	Dry	25	6.8	8	7.6	5.7	7	24	3.429
		Wet	24.3	6.4	4	5	6.1	5	29	5.8
ES8	Koubi wol	Dry	-	-	-	-	-	5	-	-
		Wet	23.7	6.3	9	12	6.3	4	34	8.5
ES9	Tolinwol	Dry	24.3	6.9	5	6.67	6.2	4	32	8
		Wet	23.8	6.5	62	7.7	6.5	4	42	10.5

Table S3 Descriptive and detection statistics for surface-water microbiological indicators.

Parameter	Unit	Season	n	Positive n	Positive (%)	mean	median	min	max
TC	CFU/100 mL	Dry	14	12	85.714	22.714	19.5	0	80
		Wet	15	15	100	45.267	29	7	112
FC	CFU/100 mL	Dry	14	10	71.429	17.143	11.5	0	69
		Wet	15	14	93.333	29.333	17	0	95
FS	CFU/100 mL	Dry	14	12	85.714	20.214	11.5	0	81
		Wet	15	13	86.667	33	22	0	175

Note: Positive detection corresponds to values greater than zero CFU/100 mL.

Table S4a Groundwater site-season matrix for mineralization and nutrient indicators.

Code	Site	Season	Conductivity	TDS	Salinity	Sulfates SO ₄ ²⁻	Nitrates NO ₃ ⁻	Nitrites NO ₂ ⁻	Phosphate	Total iron
DJL-Bore water	Djimbel	Dry	400	200	110	0	1	0.01	5.3	0.08
		Wet	200	100	180	0	5	0.02	8.2	0.07
TMC-Bore water	Timbi Madina Centre	Dry	80	40	140	0	9.2	0.02	10	0.05
		Wet	121	60.5	75	0	11.3	0.03	11	0.05
TSC-Rainwater	Tokossere Centre	Dry	210	105	67	1	8.5	0.06	12	0.08
		Wet	212	106	80	2	11.3	0.04	14.1	0.29
TTC-Bore water	Timbi Tounni Centre	Dry	102	52	79	0.9	0.1	0.06	7	0.01
		Wet	103	51.5	120	2	2	0.07	6.4	0.02

Table S4b Groundwater site-season matrix for organic load, oxygen and suspended-matter indicators.

Code	Site	Season	Temperature	pH	TSS	Turbidity	Dissolved oxygen
DJL-Bore water	Djimbel	Dry	25.8	6.8	3	1	7.8
		Wet	25	6.2	2	1.8	7.9
TMC-Bore water	Timbi Madina Centre	Dry	27	7.8	3	0	8
		Wet	25	6.2	4	5.7	8
TSC-Rainwater	Tokossere Centre	Dry	25.9	6.8	2	0.51	7.9
		Wet	25.6	6.1	4	0.84	7.8
TTC-Bore water	Timbi Tounni Centre	Dry	25.1	6.4	1.2	2	8.01
		Wet	24.8	6.2	1.4	0.41	8

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