Journal of Water & Health

IWA PUBLISHING

Journal of Water and Health Vol 22 No 2, 414 doi: 10.2166/wh.2024.324

Assessment of current water, sanitation, and hygiene (WASH) practices in the third and ninth districts of N'Djamena, Chad

Daniel Mangueina [a,b,*], Esi Awuah[c], Mathias Fru Fonteh[d], Prince Antwi-Agyei[b] and Emmanuel Tao Nadji[e]

[a] Regional Centre for Energy and Environmental Sustainability (RCEES), School of Engineering, University of Energy and Natural Resources, P.O. Box 214, Sunyani, Ghana
[b] Department of Civil and Environmental Engineering, School of Engineering, University of Energy and Natural Resources (UENR), P.O. Box 214, Sunyani, Ghana
[c] Department of Civil Engineering, Kwame Nkrumah University of Science Technology (KNUST), Kumasi, Ghana
[d] College of Technology, University of Bamenda, P.O. Box 811, Mankon-Bamenda, Mezam Division, North West Region, Bamenda, Cameroon
[e] Sub-Regional Institute of Statistics and Applied Economics, Yaoundé, Cameroon
*Corresponding author. E-mail: daniel.mangueina.stu@uenr.edu.gh

DM, 0009-0003-2857-7338

ABSTRACT

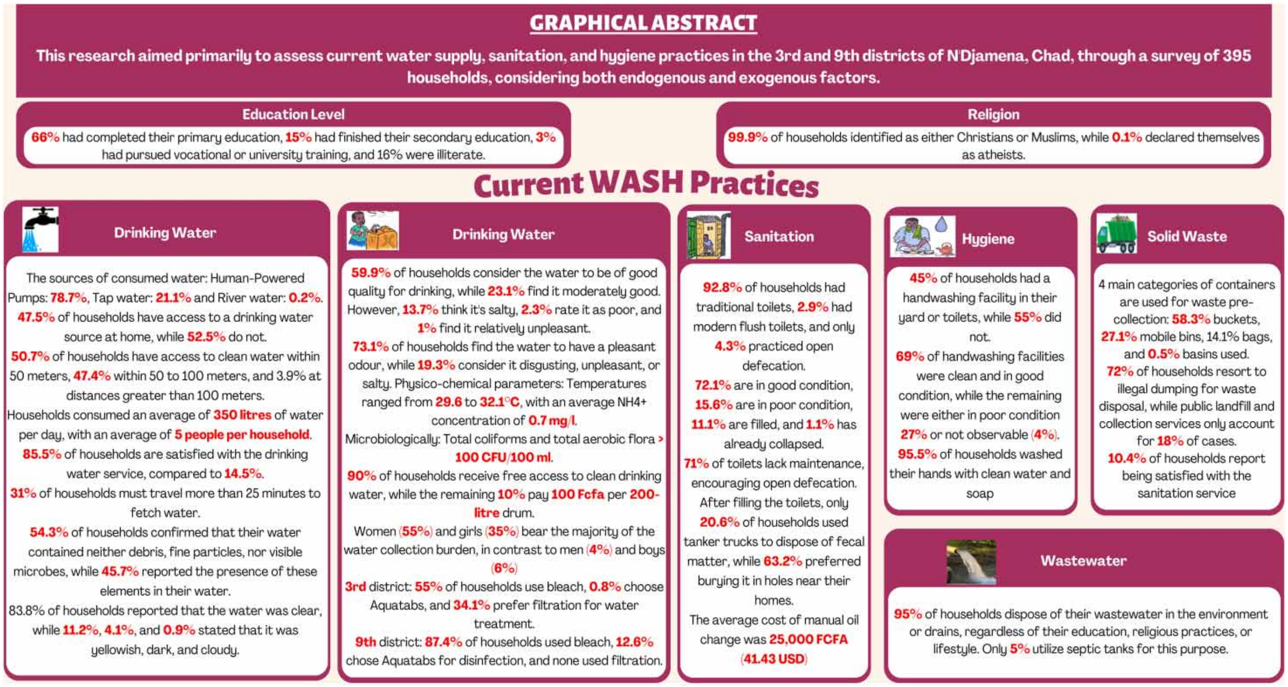
Access to safe drinking water, sanitation, and hygiene in Chad's cities, especially N'Djamena, is a persistent and significant challenge. This study aimed to assess current practices in water, sanitation, and hygiene in N'Djamena's third and ninth districts. We surveyed 395 households, conducted water source identification, and analyzed seven water samples at the National Water Laboratory. Temperature, ammonium, *total coliforms*, and *aerobic flora* values exceeded World Health Organization (WHO) guidelines. Ammonium and temperature averaged 0.7 mg/L and 30.1–31.93 °C, respectively. Bacterial contamination (>100 MPN/100 mL) exceeded the WHO's 0 MPN/100 mL guidelines, rendering the water unfit for consumption. Survey results indicate that 78.7% use hand pumps, 21.1% have tap water access, and 0.2% rely on rivers for water. Regarding toilets, 92.8% have traditional models, 2.9% have modern facilities, and 4.3% practice open defecation. 95% dispose of untreated wastewater into nature, with only 5% using septic tanks. For solid waste, 72% use illegal dumpsites, 18% rely on public services, and 10% burn waste. Finally, 95.5% of households wash their hands with clean water and soap after using the toilet. It is crucial to treat drinking water and implement proper hygiene and sanitation measures to safeguard the population's health in the studied area.

Key words: Chad, districts, hygiene, N'Djamena, potable water, sanitation

HIGHLIGHTS

- Identification of gaps for targeted interventions.
- Enhancement of public health and quality of life.
- Information for more effective WASH policies and programs.
- Foundation for mobilizing resources and partnerships.
- Strengthening resilience in the face of water-related challenges.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Access to safe drinking water, sanitation, and hygiene (WASH) has been recognized as a fundamental right by the United Nations General Assembly and the Human Rights Council in 2010 and 2015, respectively. Consequently, WASH has been at the forefront of development goals. The global targets for drinking water under the Millennium Development Goals (MDGs) were achieved in 2010, 5 years ahead of the 2015 target date, while the sanitation goal was not met. Water is a vital resource for human survival; its unavailability or poor quality can lead to numerous waterborne diseases (Lagnika *et al.* 2014). The source of drinking water and its treatment are crucial in the fight against waterborne diseases, as well as for overall well-being and productivity.

Furthermore, it is anticipated that nearly 3 billion people will lack access to freshwater by 2025, forcing them to live in water-stressed environments (Tran *et al.* 2016). As a result, diseases and deaths resulting from inadequate water and sanitation systems continue to burden the world, affecting both developed and developing nations. Approximately 27% of the global population is estimated to lack access to safe drinking water, with 2.3 billion people lacking adequate sanitation facilities (WHO 2020). Water-related diseases account for approximately 4 billion cases and result in 3.4 million deaths each year. About 88% of these deaths can be attributed to unsafe drinking water and inadequate sanitation (WHO 2020; Yeboah *et al.* 2022).

In some major African cities, there is an alarming proliferation of illegal household waste dumps along public roads, in vacant spaces, watercourses, and near residential areas (Sy *et al.* 2011; Mangoumbou *et al.* 2023). The WHO/UNICEF (2015) reveal that in sub-Saharan Africa, 32% of the population lacks access to clean water, and 70% lacks proper sanitation systems. According to the Unitied Nations (2015), the proportion of people using improved sanitation facilities increased from 24% in 1990 to 30% in 2015. Sanitation remains one of the major public health challenges in Africa. Furthermore, 28% of the population in sub-Saharan Africa practices open defecation, and 23% uses ‘unimproved’ sanitation facilities that do not ensure adequate hygienic separation of human waste and contact (WHO/UNICEF 2015). Due to this lack of sanitation, millions of people in Africa contract fecal–oral diseases, with diarrhea being the most common (Al-Ghamdi *et al.* 2009).

In Chad, according to the report from the Ministry responsible for Water and Sanitation presented on World Water Day 2023, access rates stand at 63% for clean water and 20% for sanitation services for the country’s population. Most of these services are concentrated in urban areas. However, this rate hides disparities in the distribution of infrastructure types and access rates at the provincial level, as well as access inequalities between urban and rural populations. Health statistics from the Ministry of Health and Prevention (MHP) reveal that the lack of clean water and unfavorable hygiene conditions are the leading causes of mortality and morbidity in the population, especially in children aged 0–5 years.

According to the Fourth Household Living Conditions and Poverty Survey in Chad (INSEED 2018), 66.5% of households lacked appropriate sanitation facilities. The absence of toilets is more pronounced in rural areas at 8.3% compared to 17.5% in urban areas. Consequently, bacteriological contamination of water could be attributed to open defecation, one of the primary sources of water contamination by fecal matter, leading to most diarrheal diseases in children aged 0–5 years (WHO 2017). The vast majority, 88% of the population, lacks access to acceptable hygiene and sanitation conditions. As a result, waste disposal methods in urban areas are as follows: 50.4% of households resort to open dumping, 25.2% burn their waste, 10% use public dumps, and 14.4% opt for private waste collection services. Therefore, the primary objective of our study is to examine WASH practices in the third and ninth districts of N'Djamena, Chad.

2. MATERIALS AND METHODS

2.1. Study area description

N'Djamena, situated in the Chari-Baguirmi province, is Chad's political capital and its largest city. Established in April 1900 and designated as a district in 1919, it is located on the eastern bank of the Chari River, bordering Cameroon where the Logone and Chari rivers converge. The terrain is predominantly flat, with slight natural slopes. The city spans 39,500 ha of urbanized areas, divided into ten municipal districts, and boasts a population of 1,390,309 residents, growing at an annual rate of 3.61% as of 2018. N'Djamena experiences distinct seasons, with a dry period from November to April and a rainy season from May to October. The climate registers an average maximum temperature of 44.1 °C and a minimum of 23.8 °C. Recent years have seen an annual rainfall range from 584 to 990 mm. The study primarily focused on the third and ninth districts, positioned between 12°6′0″ and 12°0′0″ North latitude and between15°2′0″ and 15°10′0″ East longitude. These districts are further divided into 13 quarters: Ambassatna, Ardep Djoumal, Djambalbarh, Gardolé1, Kabalaye, Sabangali, Digangali, Gardolé 2, Kabé, Ngoumna, Ngueli, Toukra, and Walia (Figure 1 & Table 1).

2.2. Data collection

The present study offers a comprehensive analysis of data on scientific document consultations from 1977 to 2023, encompassing both qualitative and quantitative data. Qualitative sources include scientific documents, technical reports, and legislation pertaining to water, hygiene, and sanitation. A field survey was conducted using questionnaires aimed at women of reproductive age, utilizing the Kobo Toolbox software on Android smartphones.

The questionnaire targeted adult women, defined as a unit composed solely of women of reproductive age. The women to be interviewed were identified within their respective households, starting with the first surveyed household and skipping three households thereafter. Initially, an exhaustive list of neighborhoods included in the study area, along with the size of their households, was developed based on the 2009–2018 Demographic Projections derived from the Second General Population and Housing Census of 2009 (INSEED 2014). Subsequently, to determine the sample size for this study, the formula developed by Cochran (1977), denoted as 'Equation (1),' was applied.

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

In the study of the third and ninth districts in N'Djamena, 'n' represents the sample size, and 'N' is the number of households. 'e' signifies a 5% margin of error, and '1' represents the probability of an event occurring. Researchers used on-site observations and indirect questioning to assess drinking water and sanitation infrastructure, hygiene practices, and amenities like toilets and faucets. Investigators met specific criteria and were fluent in Arabic and French. They received training in interview techniques and ethics. After the survey, discussions and interviews were held with key informants, including officials from the Water Supply Department, healthcare professionals, and community leaders. Seven samples (four from hand-operated pumps and three from tap water) of drinking water were collected, transported, and analyzed at the National Water Laboratory to assess the quality of water consumed by households, in accordance with the American Public Health Association standards (APHA-AWWA-WPCF 1994).

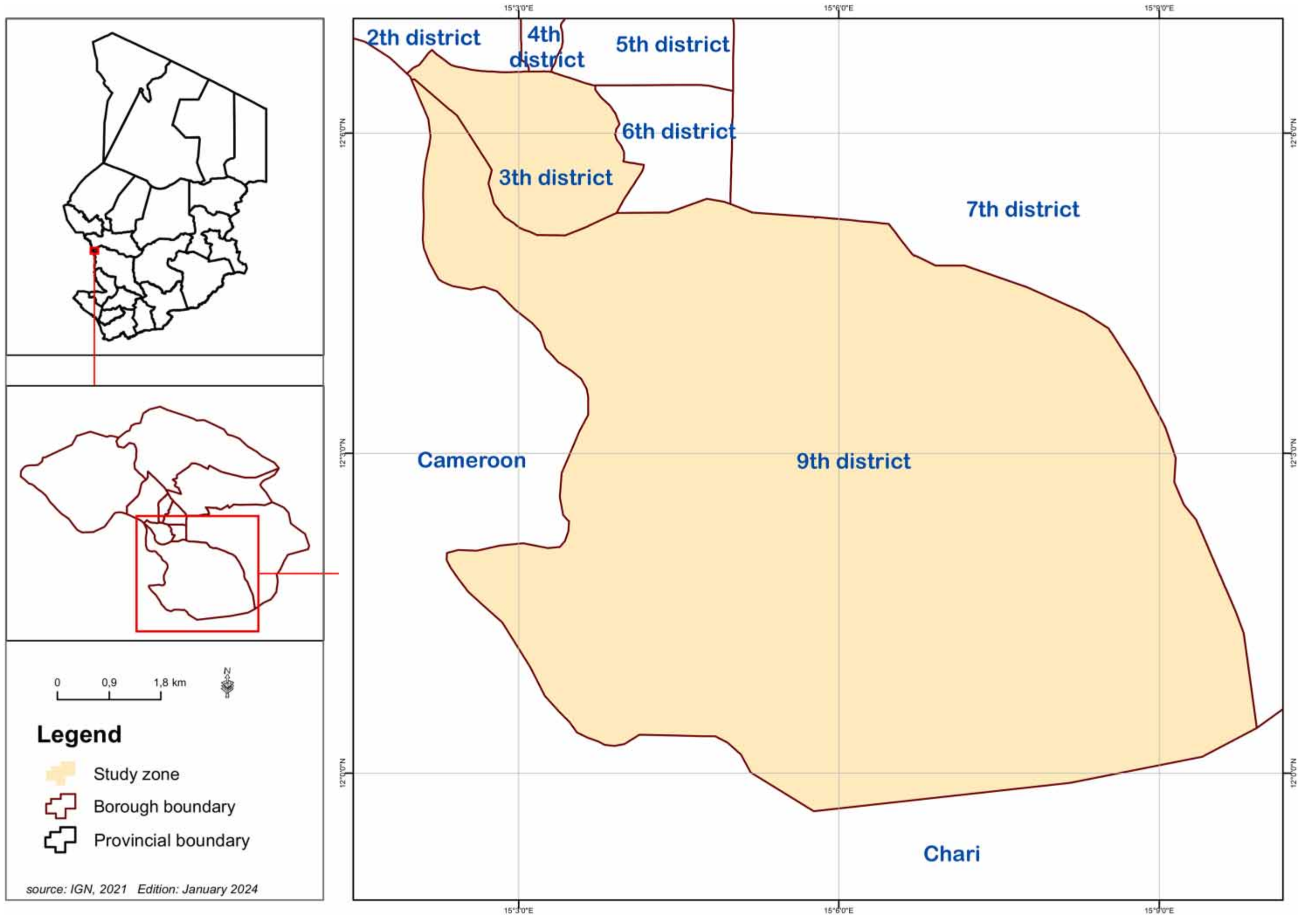


Figure 1 | Geographical location of the third and ninth arrondissements of the city of N'Djamena (Republic of Chad).

Table 1 | Sample of households surveyed by district

Districts	Names of neighborhood	Households in 2018	Households surveyed
Third district	Ambassatna, Ardep Djoumal, Djambalbarh, Gardolé1, Kabalaye, Sabangali	10,691	144
Ninth district	Digangali, Gardolé 2, Kabé, Ngoumna, Ngueli, Toukra, Walia	18,535	251
Total		29,226	395

2.3. Ethical protocol

This research was approved by the National Bioethics Committee of Chad (CNBT) in August 2022. It included a detailed protection protocol outlining potential risks throughout the survey's lifecycle. Verbal consent was obtained from each participating respondent, particularly among women of reproductive age, aged 15–49 years, who were individually interviewed. All respondents were fully informed of the voluntary nature of their participation, as well as the confidentiality and anonymity of the information provided. Furthermore, respondents were informed of their right to refuse to answer any question or terminate the interview at any time, or even decline to participate in the survey entirely.

2.4. Statistical data analysis

The numerical data were analyzed using Microsoft Excel and SPSS software (v21) with the aim of generating graphical representations. Furthermore, the Spatial Analyst module of ArcGIS 10.3 was employed to create a precise map of the study area. It should be noted that all statistical analyses were conducted with a confidence level of 95%.

3. RESULTS AND DISCUSSION

3.1. Institutional framework for the management of basic WASH services

The institutional actors involved in the WASH sector in the two districts are as follows: the Departmental Delegation, the Water Supply Directorate, the Sanitation Directorate (SD), under the Ministry responsible for Water and Sanitation, the delegations from the MHP as well as the Ministry of Environment, Fisheries, and Sustainable Development (MEFSD), the District Delegations, various partners (NGOs, charitable and non-charitable associations, etc.), and the two municipal administrations.

3.2. Characteristics of the surveyed households

Out of the 395 households studied, those with children aged 0–5 years sharing both residence and meals were identified. Among them, 66% had finished primary education, 15% had completed secondary education, 3% had received vocational or university training, and 16% were illiterate. Furthermore, 56% of these households were involved in income-generating activities, 46% were homemakers, and 1% were employed women. Almost all, 99.9%, identified as Christians or Muslims, with a small 0.1% identifying as atheists.

3.3. Determining the size of the sample to be surveyed

A sample of 395 households was determined according to the formula by Cochran (1977) based on a projection from the General Population and Housing Census (RGPH) of 2009 to the year
2018.

Therefore: $n = \frac{N}{1 + N(e)^2}$

$n = (29{,}226)/1 + 29{,}226 \times (0.05)^2$
$n = 29{,}226/74.065$
$n = 394.59$; $\boldsymbol{n} = $ **395 households.**

At the district level, the sample size was allocated as outlined in Table 1.

3.4. Sources of water supply, accessibility, and means of transportation

Understanding the source of safe drinking water is crucial for human health, as contaminated water can lead to illnesses such as diarrhea, dysentery, hepatitis A, cholera, and typhoid, as reported by WHO (2015). This study assessed household drinking water quality, with 78.7% relying on human-powered pumps (HPPs), 21.1% using tap water, and only 0.2% using river water (Figure 2). This diverse water source landscape has implications for infrastructure planning and resource allocation. On average, households consumed 350 L of water daily, meeting the World Health Organization (WHO)'s recommended 20 L per person per day. Unfortunately, water quality analysis revealed contamination in the area, particularly harmful to children due to pathogens, posing a health threat. The study results align with Diawara *et al.* (2021) in Bamako's N'Tabacoro Cité Extension, where 84.3% of households use HPP. Similar results were obtained by Vissin *et al.* (2017) in the Toffo commune, Benin, where 20.77% of surveyed households use tap water. However, they contrast with Traoré (2018) in Bamako, where only 25.6% have improved water access, and Shields *et al.* (2015) in developing countries. In Dakar, Senegal, Diop *et al.* (2021) found that 82.3% use tap water, with 70.5% relying on public water points during interruptions. This differs from Tchouongsi *et al.* (2020) in Yaoundé, Cameroon, where 68.90% use well water.

To address potable water contamination, the Ministry, STE, district authorities, partners, and the community must collaborate on measures like proper chlorination, pipeline maintenance, and regular inspections.

Access to a reliable home water source is essential for daily drinking, cooking, hygiene, and household tasks. A survey found that 47.5% of households have safe water at home, while 52.5% lack it due to limited public water network coverage and costly private connections. This underscores the importance of assessing water quality at the source when implementing community water supply programs (Figure 3).

Access to clean water remains a critical global issue, affecting millions worldwide. Despite some progress, a 2017 report by WHO and UNICEF (WHO/UNICEF 2017) revealed that approximately 785 million people still lack reliable access to clean

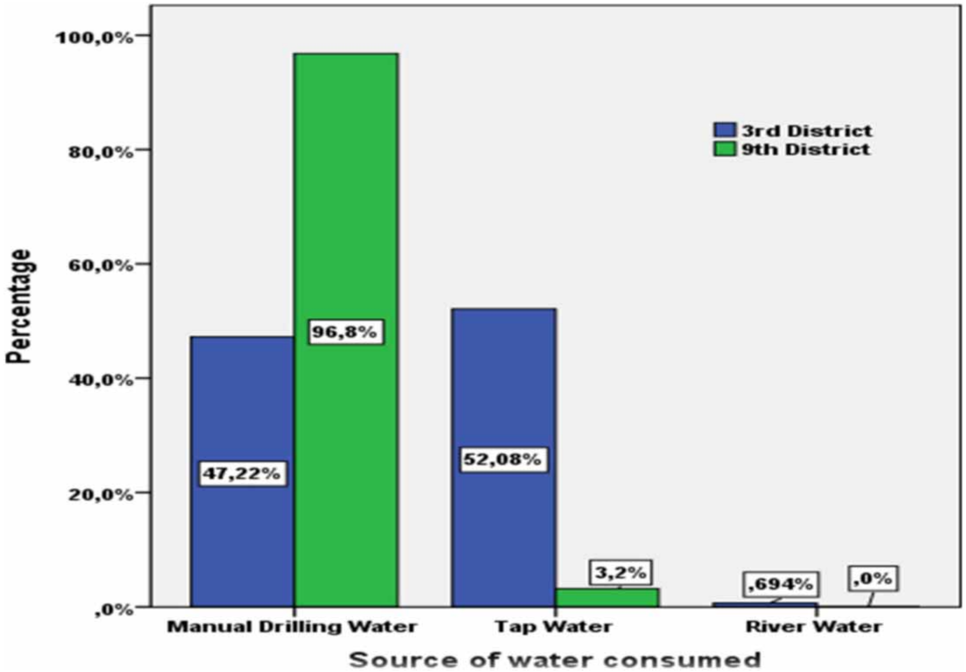


Figure 2 | Sources of drinking water supply in the study area.

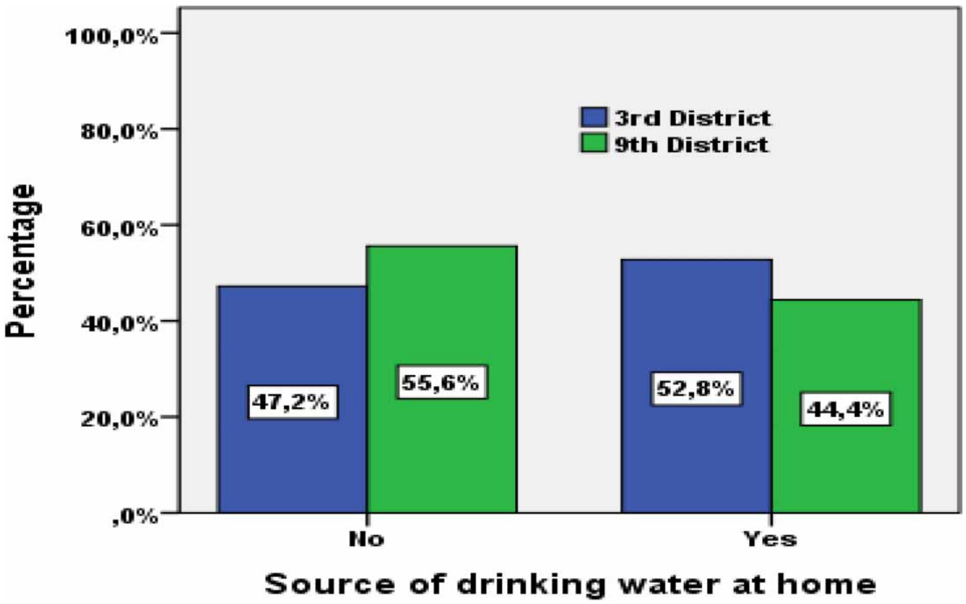


Figure 3 | Availability of a clean water source at home.

water. This means many individuals must travel long distances to find safe drinking water. While 85.5% of households are satisfied with their drinking water service, over 31% of people need to travel more than 25 min to access water. Survey results show that 50.7% of households have clean water within 50 m, 47.4% within 50–100 m, and 3.9% from distances exceeding 100 m, often due to taste preferences or safety concerns. Only a small minority (0.1%) report conflicts over water access points, mainly among the younger population. These findings highlight that most households have access to clean water within the WHO/UNICEF 2010 guidelines of 1,000 m (approximately 1 km) from residential areas. However, a study by

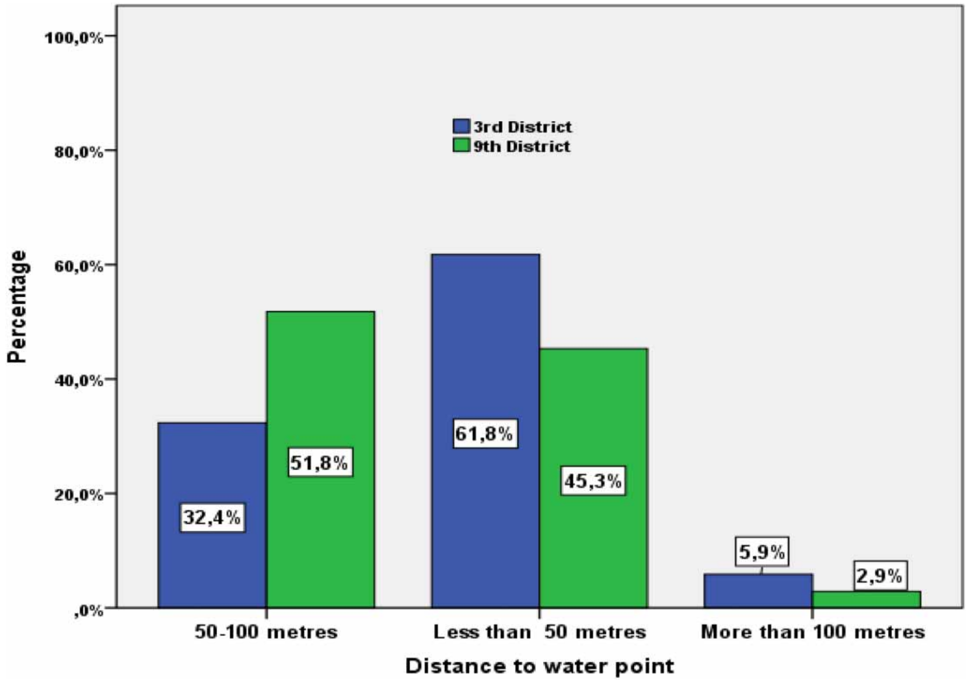


Figure 4 | Distance to water point.

Diawara *et al.* (2021) in Bamako, Mali, found that 55% of households in N'Tabacoro Cité Extension must travel 200–600 m on foot to access water sources due to low population density. Access to clean water not only prevents waterborne diseases but also supports engagement in various socio-economic activities (Figure 4).

Containers for transporting and storing drinking water come in various sizes, from 25-L jerry cans to 200-L plastic drums, clay jars, buckets, basins, and even refrigerators. Households employ different methods, ranging from carrying water on their heads or by hand to using pushcarts, tricycles, wheelbarrows, and sometimes motorcycles or cars. Regarding costs, 90% of households access water freely from charitable and private sources, while 10% pay 100 CFA francs (0.17 USD) for a 200-L drum of tap water. Notably, women (55%) and girls (35%) bear the primary responsibility for water collection, while men (4%) and boys (6%) are less involved. These findings align with a study in Bamako, Mali (Diawara *et al.* 2021), where 57.1% use carts or pushcarts, 35.7% use motorcycles, tricycles, or cars, and 7.2% carry water on their heads. Raising awareness and taking action to ensure equitable access to clean water is crucial for overall well-being and health. Implementing measures to reduce economic and gender disparities is imperative for achieving this goal.

3.5. Local potable water treatment methods

The primary objective of water treatment is to safeguard consumers' health by protecting them against pathogenic microorganisms, as well as unpleasant or potentially hazardous impurities. However, certain inefficient methods lead to the consumption of domestic water harmful to households' health (WHO 2017). Consequently, various water treatment techniques fail to eliminate all pathogenic microorganisms present in drinking water (Hèdible 2007), thereby exposing users to waterborne diseases such as typhoid fever, intestinal parasitic infections, and diarrhea.

In the third and ninth districts, women utilize their own water treatment methods before consumption. These techniques include sedimentation, filtration, as well as disinfection using Aquatabs and hypochlorite tablets (bleach). Figure 5 illustrates the water treatment techniques employed in the study area.

Figure 5 highlights that 87.4 and 12.6% of the surveyed adult women in the ninth district use bleach and Aquatabs tablets, respectively, as their disinfection method, compared to 55 and 0.8% in the third district. Moreover, 34.1 and 7% of households in the third district use filtration, while in the ninth district, no water filtration techniques are employed (0%).

These analyses demonstrate that water treatment techniques such as filtration and sedimentation are not primarily used in the ninth district due to the households' low income, which limits the purchase of equipment like water filters, and a lack of

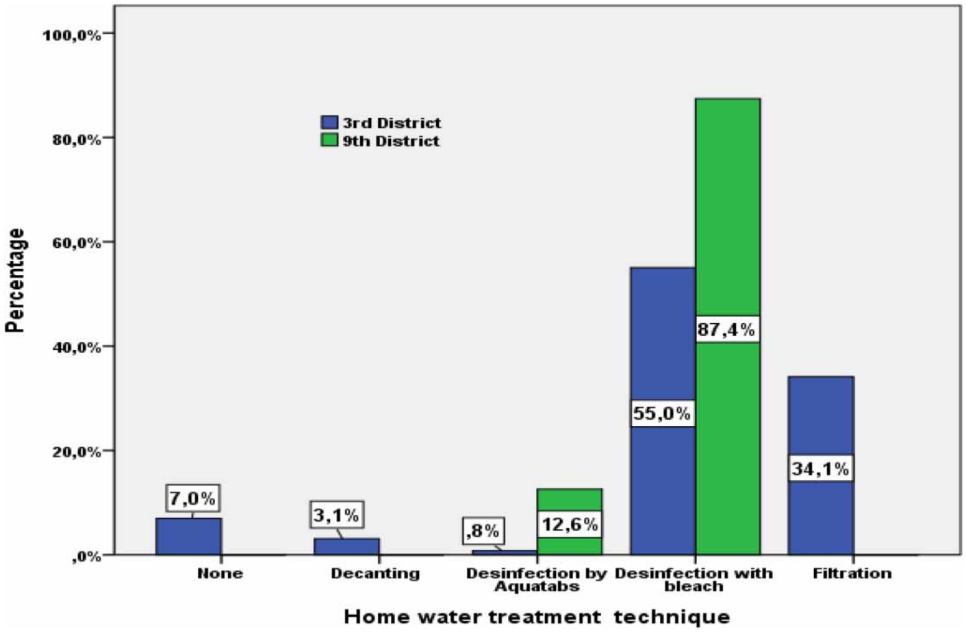


Figure 5 | The different water treatment techniques in the study area.

knowledge about water treatment techniques. However, the majority of the surveyed households consider water treatment before consumption as crucial. As a result, the issue of water quality for household consumption in the third and ninth districts is critical.

Our findings corroborate those obtained by Diop *et al.* (2021) in their study on water supply in the commune of Parcelles Assainies in Dakar, Senegal. Bleach stands out as the primary water treatment method used (66.7%), followed by Aquatabs (32.2%). Filtration and sedimentation are also noteworthy, representing 11.1 and 10.8% of the water treatment methods, respectively. These results contrast with those observed in rural areas, where the predominant water treatment techniques are primarily filtration (30%), sedimentation (17%), and water chlorination (15%), as reported in the study conducted by Diop *et al.* (2019).

Similarly, Biembe (2019) demonstrates that in certain neighborhoods in Yaoundé, Cameroon, 63% of households use multi-stage filters, 13% practice chlorination, and 8% opt for sedimentation. The treatment of drinking water varies depending on the source, contaminants, and available resources. Combinations of methods are employed to ensure safe drinking water.

3.6. Local appraisals of drinking water quality: a criterion for assessing the potability of water

Water is an essential element for the development and sustenance of life for all living beings. That is why people generally consider that drinking water should be free from debris, fine clay particles, and microorganisms visible to the naked eye. The presence of any of these elements in the water renders it unfit for consumption, except for microorganisms visible to the naked eye, which means it is systematically polluted or contaminated. Figures 6 and 7 illustrate the proportions of adult women surveyed who assess drinking water based on its physical appearance.

3.6.1. Taste and smell of the water

Although water is often perceived as tasteless and odorless, several factors can alter our perception of these characteristics (Risso *et al.* 2019). Dissolved ions, contaminants, as well as chemical compounds used in water treatment, and even microbial activity can introduce nuances in the taste and smell of water (Dietrich & Burlingame 2020). Individual sensitivity also plays a significant role in how we perceive these nuances, adding complexity and further interest to the study of the sensory properties of water (Agrawal & Schachner 2023).

The flavors and odors of water generally pose no health risks; however, they can serve as potential indicators of contamination, whether it is of chemical or biological origin (Piccardo *et al.* 2022). An unpleasant taste or odor could signify the need

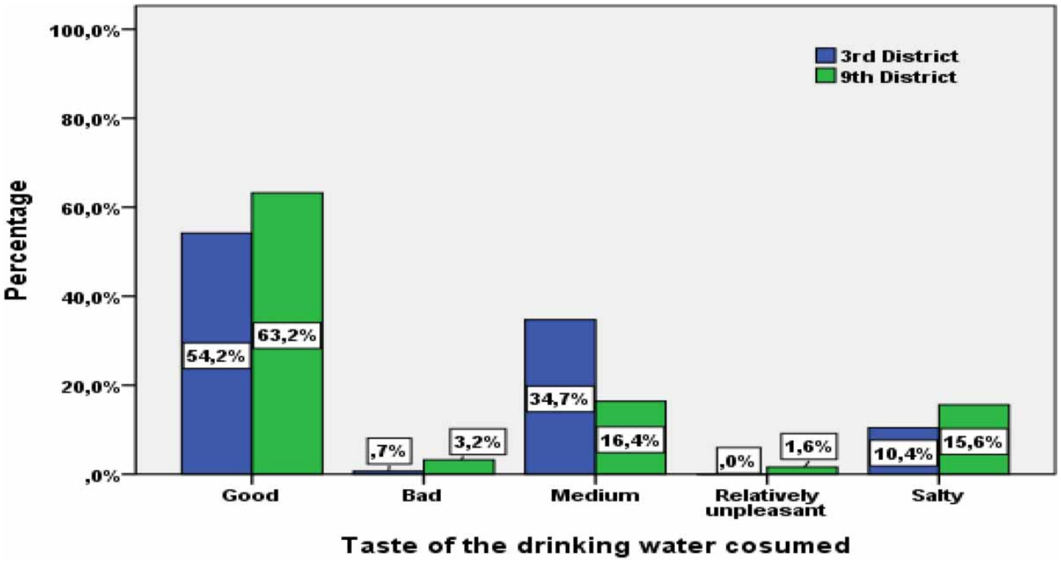


Figure 6 | Appreciation of water quality by taste.

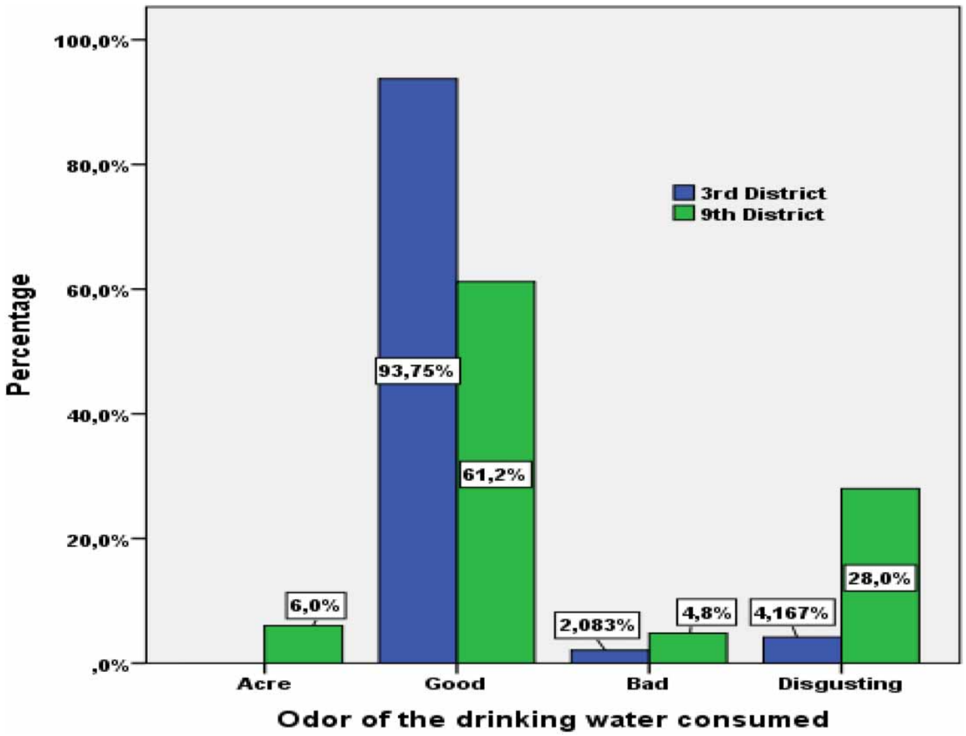


Figure 7 | Assessment of water quality by smell.

for a more thorough analysis (Hawko *et al.* 2021). This feature could be of crucial importance from the user's perspective, particularly concerning the quality of water intended for consumption (Carrard *et al.* 2019).

Figure 6 displays the proportion of adult women surveyed about water quality based on their taste perception. Out of the adult women surveyed, 59.9% reported that the water is good to drink, with 23.1% specifying it as moderately good. Conversely, 13.7, 2.3, and 1% of the women surveyed believed that the water they drink is salty, bad, and relatively unpleasant, respectively.

Figure 7 reveals that a proportion of 73.1% of the adult women surveyed perceived the consumed water to have a good odor. However, 19.3 and 3.8% of the adult women surveyed reported that the consumed water was disgusting, bad, and salty, respectively. This evaluation of drinking water quality is one of the reasons why these adult women must carefully choose their water source.

These study findings corroborate those discovered by Dimitri Miriac *et al.* (2020) in the Lokossa Commune, Southwest Benin, where 68–77% of consumers appreciate water due to its organoleptic quality (taste and odor). However, they differ from the ones found by Diop *et al.* (2021) concerning water supply in the Parcelles Assainies Commune of Dakar, Senegal. In that study, 63–68% of consumers frequently refrain from consuming tap water due to its quality (taste, odor). Contradictory results were also observed in the study conducted by Ballet *et al.* (2018) in the Cocody and Yopougon communes in Ivory Coast, where 90% of the surveyed individuals expressed dissatisfaction with the clarity of the distributed drinking water. Safe drinking water must adhere to strict quality standards to ensure it is fit for consumption and poses no health risks.

3.6.2. Color of the water

Drinking water, a vital element for humans, is witnessing the color of its appearance becoming significantly important in terms of both quality and safety. The color of drinking water can provide valuable clues about potential impurities and pollutants, carrying significant implications for public health (WHO 2017). The ideal characteristic of potable water is to be clear, colorless, and transparent, reflecting its purity without any alteration. However, slight variations in color, ranging from pale yellow to light brown, can result from natural factors such as dissolved minerals or algae. Such minor nuances generally do not raise significant safety concerns. Nonetheless, intense and unusual discolorations can indicate a potential problem. For instance, a yellow, brownish, or reddish coloration might signal the presence of heavy metals like iron, copper, or manganese. These metals could originate from the surrounding soil or ageing infrastructure. In certain situations, the coloration may result from the decomposition of organic matter and highly pigmented industrial waste, with the most common being paper and textile waste (EPA 2012). This not only leads to undesirable coloration but also brings about changes in taste and odor.

In a broader context, water color is an organoleptic parameter measured through visual comparison with a set of standard solutions. Levels exceeding 15 units of true color (UTC) can be detected in a glass of water by most individuals.

Figure 8 highlights the evaluation of water quality based on its color, according to the opinions of surveyed adult women. A proportion of (83.8%) declared that the consumed water was clear, compared to (11.2%), (4.1%), and (0.9%) who asserted that the water was yellowish, dark, and turbid, respectively.

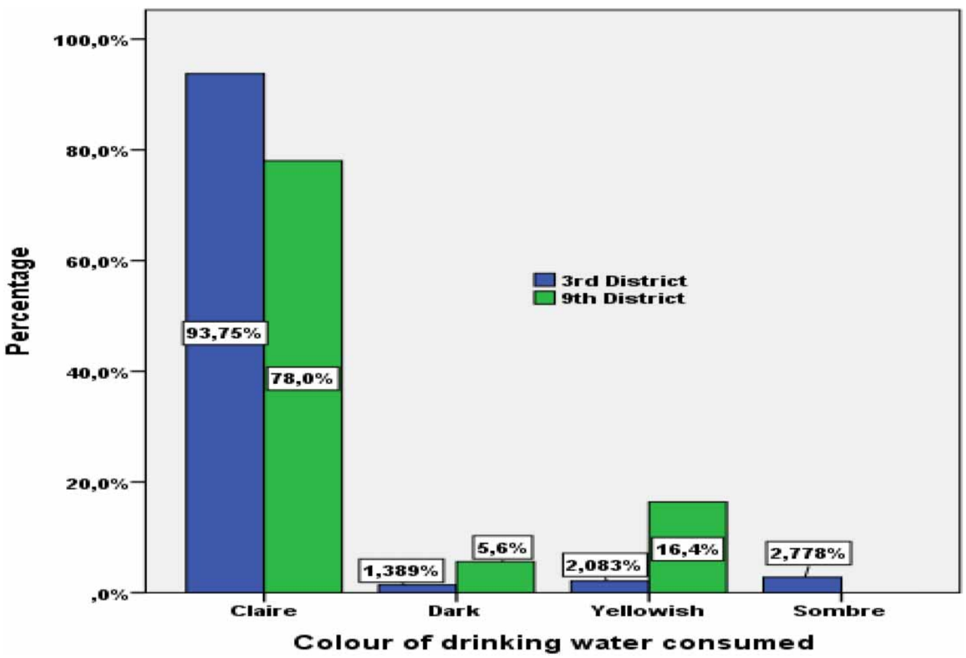


Figure 8 | Appreciation of water quality by color.

The obtained results are similar to the findings of Ochoo *et al.* (2017) in Newfoundland, Canada, where the majority of respondents (>56%) were either completely satisfied or very satisfied with the color of drinking water. However, they contrast with those discovered by Dimitri Miriac *et al.* (2020) in the Lokossa Commune, in the Southwest of Benin, where 62% of consumers appreciate the drinking water due to its color. Monitoring water color is essential, as it can serve as an indicator of its quality and environmental health.

3.6.3. Presence of debris – fine particles and microbes to the naked eye

The presence of debris, fine particles, as well as microorganisms in drinking water constitutes a concerning issue with significant repercussions on human health and the assurance of a safe water supply (WHO 2011). These harmful elements stem from various sources, including pipeline deterioration, soil erosion, and external infiltrations (Kim *et al.* 2021). These particles can be either visible or microscopic, causing turbidity issues and having the ability to absorb toxic substances (Kahle *et al.* 2021). Microorganisms such as bacteria, viruses, and parasites, which act as true pathogens, pose a serious threat that can lead to severe waterborne diseases such as gastroenteritis, typhoid fever, diarrhea, and dysentery (Harwood *et al.* 2014). Contamination of drinking water can originate from multiple sources, including sewage and industrial discharges, resulting in detrimental consequences for the population. This urgent issue requires constant vigilance and rigorous monitoring and prevention measures to ensure the quality and safety of our drinking water supply. Figure 9 illustrates that 54.3% of the surveyed adult women indicated that the water they drink does not contain visible debris, fine particles, or microbes and is of good quality. However, 45.7% of these women noted the presence of these elements in their water.

The results obtained are similar to those found by Ochoo *et al.* (2017) in Newfoundland, Canada, where the majority of respondents (>56%) expressed complete satisfaction regarding the quality of public water in the absence of fine particles and other debris. However, they contrast with those discovered by Dimitri Miriac *et al.* (2020) in the Lokossa Commune, southwest Benin, where 81% of the surveyed populations believe that water containing animal and plant debris is inherently dirty and of poor quality. Polluted water is water overloaded with undesirable elements for living beings. Adequate treatments such as filtration, disinfection, and regular monitoring are essential to ensure safe and healthy drinking water.

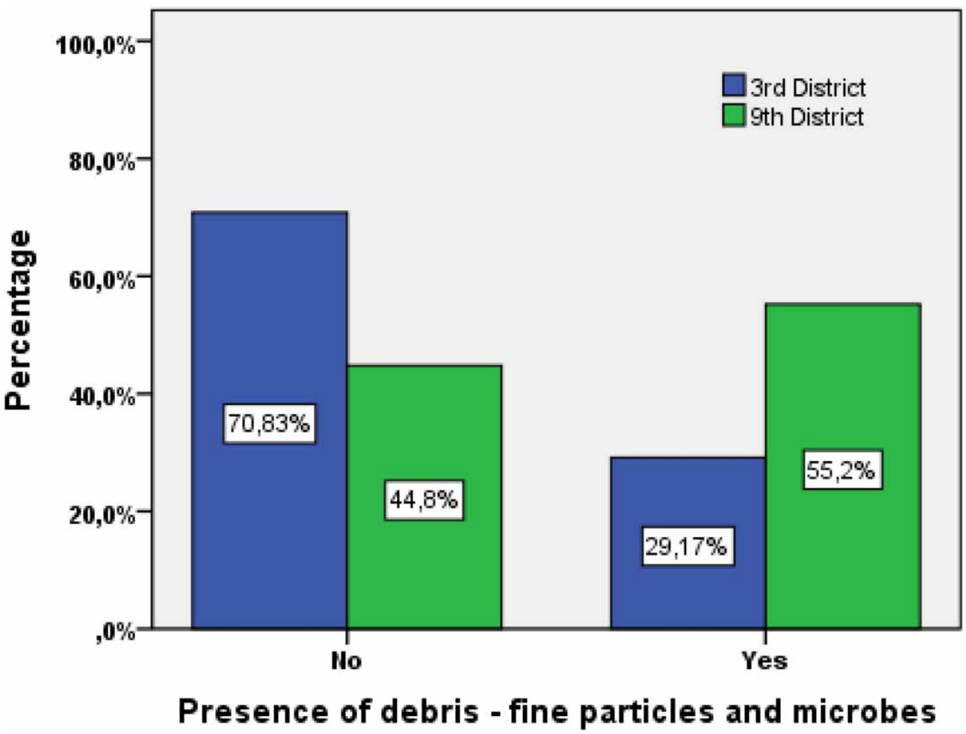


Figure 9 | Assessment of water quality by debris content – fine particles and microbes visible to the naked eye.

3.7. Drinking water quality

The water consumed by households in the study area is exclusively influenced by the contamination of two physico-chemical parameters (temperature and ammonium) and two bacteriological parameters (*total coliforms* and *total aerobic flora*). On the other hand, the 16 other parameters examined, including pH, electrical conductivity, turbidity, total dissolved solids, total hardness, calcium, magnesium, potassium, sodium, bicarbonates, chlorides, sulfates, nitrates, iron, *Escherichia coli* and *Fecal Enterococci* comply with the guidelines established by the WHO as well as with national guidelines governing the quality of water intended for human consumption.

3.7.1. Physico-chemical quality of tap water and HPP water

3.7.1.1. Physico-chemical quality of tap water and HPP water for human consumption. The *in situ* parameters measured were temperature, hydrogen potential, turbidity, and electrical conductivity (Tables 2 and 3).

Case of HPPs

Case of running water taps

Ensuring safe drinking water temperature is vital as it affects microorganism growth and substance dissolution. Warm water can harbor harmful microorganisms, according to WHO (2017)/EPA (2012) which recommend 10–15 °C for human consumption. Our study found 30.1–31.93 °C, exceeding WHO (2017) limit of 25 °C, posing health risks and corrosion potential. Our readings are higher than previous studies: Reyes-Toscano *et al.* (2020) in Mexico (31–37 °C), Dégbey *et al.* (2008) in Benin (28.3–29.9 °C), and Sitotaw *et al.* (2021) in Ethiopia (16.1–24 °C) maintain moderate temperatures to reduce contamination risks.

3.7.1.2. Chemical characteristics of water samples from taps and HPPs. Ammonium (NH_4^+) in drinking water arises from natural and human sources (Rusydi *et al.* 2021). Recent data show an average of 0.7 mg/L, surpassing WHO's limit of

Table 2 | Results of physical parameters of water from HPPs

Physical parameters	Units	*WHO* Guidelines	*National* Standards	Observations	*n*	Minimum	Maximum	Average	Standard deviation
Temperature	°C	25		≤25 >25	0 4	29.6	30.8	30.1	0.3
pH	[H_3O +]	6.5–8.5	6.5 ≤ pH ≤ 9	<6.5 6.5–8.5 >8.5	0 4	7.0	7.7	7.4	0.2
Electrical conductivity	µS/cm	2,000	≤2,500	≤2,000 >2,000	0 4	173.0	244.0	204.5	16.5
Turbidity	NTU		≤5	≤5 >5	0 4	0.8	1.0	0.90	0.10

Table 3 | Results of physical parameters of tap water

Physical parameters	Units	*WHO* Guidelines	*National* Standards	Observations	n	Minimum	Maximum	Average	Standard deviation
Temperature	°C	25		≤25 >25	0 3	31.8	32.1	31.93	0.09
pH	[H_3O +]	6.5–8.5	6.5 ≤ pH ≤ 9	<6.5 6.5–8.5 >8.5	0 3	7.15	7.65	7.35	0.15
Electrical conductivity	µS/cm	2,000	≤2,500	≤2,000 >2,000	0 3	542.0	606.0	582.33	20.27
Turbidity	NTU		≤5	≤5 >5	0 3	0.8	1.0	0.90	0.10

0.5 mg/L. Elevated levels harm ecosystems and lead to groundwater contamination, algae growth, and taste/odor issues. Our measurement is below the EPA's 1.0 mg/L limit but higher than Sitotaw *et al.* (2021) in Ethiopia (0.2 mg/L). Addressing high ammonium levels requires source identification, improved waste management, fertilizer regulation, and enhanced water treatment for efficient removal (Tables 4 and 5).

3.7.2. Bacteriological quality of water from taps and HPPs

According to WHO (WHO 2011) guideline***s*** and Chad's health authority guidelines, drinking water should have no detectable levels of *Escherichia coli*, *total coliforms*, *fecal enterococci*, and *total aerobic flora* in a 100 mL volume. While *Escherichia coli* and *Fecal Enterococci* meet this requirement with 0 MPN/100 mL, the levels of *total coliforms* and *total aerobic flora* in the water sample greatly exceed WHO limits, which is concerning (Table 6).

Case of running water taps

Case of HPPs

Total aerobic flora includes microorganisms (bacteria, yeasts, molds) that thrive in oxygen-rich environments (Zabermawi *et al.* 2022) (Table 7). While it's useful for assessing general contamination, it does not identify specific microorganisms (Behl *et al.* 2023). A recent analysis of a drinking water sample revealed a high presence of both total coliforms and total aerobic flora (Reitter *et al.* 2021). While an abundance of total coliforms alone doesn't confirm the presence of pathogenic bacteria, it suggests issues with chlorination, potentially leading to water contamination by harmful bacteria (Le *et al.* 2023). This contamination is found in both water sources and appears to result from inadequate protection and increased exposure to human, animal, and environmental waste (Dwivedi 2017). This situation could lead to fecal contamination and the emergence of waterborne diseases among residents (Dwivedi 2017). Furthermore, deficiencies in waste and wastewater management infrastructure, shortcomings in drinking water treatment and distribution, limited access to sanitation facilities and toilets, along with low education levels and household incomes, are significant factors contributing to the deterioration of drinking water quality (Licence *et al.* 2013).

The results obtained align with Saïnou *et al.*'s (2019) findings in Toffo, Benin, particularly in the Sèhouè district. Variations in total coliform concentrations ranged from 105 CFU/100 mL for cistern water to 678 CFU/100 mL for traditional well

Table 4 | Chemical characteristics of water samples from HPPs

Chemical Parameters	Units	WHO guidelines	National standards	Observations	*n*	Minimum	Maximum	Average	Standart deviation
Total dissolved solids	mg/L		≤ no mention			84.0	123.0	99.5	9.0
Total hardness ($CaCO_3$)	mg/L	500	≤ no mention	≤500 >500	*4* *0*	32.0	58.0	46.5	6.3
Calcium (Ca_2^+)	mg/L	100	≤200	≤100 >100	*4* *0*	12.6	21.0	15.8	1.8
Magnesium (Mg_2^+)	mg/L	50	≤50	≤50 >50	*4* *0*	0.1	4.4	1.7	0.9
Potassium (K^+)	mg/L		≤12			1.2	2.0	1.6	0.2
Sodium (Na^+)	mg/L		≤200			13.0	23.0	17.8	2.3
Bicarbonates (HCO_3^-)	mg/L		≤no mention			39.0	70.8	56.7	7.7
Chlorides (Cl^-)	mg/L	250	≤250	≤250 >250	*4* *0*	12.0	20.0	16.0	1.8
Sulfates (SO_4^{2-})	mg/L	500	≤250	≤500 >500	*4* *0*	6.0	12.0	8.5	1.3
Nitrates (NO_3^-)	mg/L	50	≤50	≤50 >50	*4* *0*	3.8	9.0	6.0	1.1
Iron (Fe)	(mg/L	0.3	≤0.3	≤0.3 >0.3	*4* *0*	0.0	1.0	0.3	0.2
Ammonium (NH_4^+)	(mg/L)	0.5	≤1.5	≤0.5 >0.5	0 4	0.6	0.8	0.7	0.1

Table 5 | Chemical characteristics of tap water samples

Chemical parameters	Units	WHO guidelines	National standards	Observations	*n*	Minimum	Maximum	Average	Standart deviation
Total dissolved solids	mg/L		≤no mention			84.0	123.0	99.5	9.0
Total hardness ($CaCO_3$)	mg/L	500	≤no mention	≤500 >500	*4* *0*	32.0	58.0	46.5	6.3
Calcium (Ca_2^+)	mg/L	100	≤200	≤100 >100	*4* *0*	12.6	21.0	15.8	1.8
Magnesium (Mg_2^+)	mg/L	50	≤50	≤50 >50	*4* *0*	0.1	4.4	1.7	0.9
Potassium (K^+)	mg/L		≤12			1.2	2.0	1.6	0.2
Sodium (Na^+)	mg/L		≤200			13.0	23.0	17.8	2.3
Bicarbonates (HCO_3^-)	mg/L		≤no mention			39.0	70.8	56.7	7.7
Chlorides (Cl^-)	mg/L	250	≤250	≤250 >250	*4* *0*	12.0	20.0	16.0	1.8
Sulfates (SO_4^{2-})	mg/L	500	≤250	≤500 >500	*4* *0*	6.0	12.0	8.5	1.3
Nitrates (NO_3^-)	mg/L	50	≤50	≤50 >50	*4* *0*	3.8	9.0	6.0	1.1
Iron (Fe)	mg/L	0.3	≤0.3	≤0.3 >0.3	*4* *0*	0.0	1.0	0.3	0.2
Ammonium (NH_4^+)	mg/L	0.5	≤1.5	*≤ 0.5* *> 0.5*	*0* *4*	0.6	0.8	0.7	0.1

Table 6 | Bacteriological characteristics of tap water samples

Bacteriological parameters	Units	WHO Guidelines	National Standards	Observations (*n* = 3)		
Escherichia coli	UFC/100 mL	00	00	0	0	0
Total coliforms	UFC/100 mL	00	00	>100	>100	>100
Fecal Enterococci	UFC/100 mL	00	00	0	0	0
Total aerobic flora	UFC/100 mL	00	–	>100	>100	>100

Table 7 | Bacteriological characteristics of water samples from HPPs

Bacteriological parameters	Units	WHO guidelines	National standards	Observations (*n* = 4)			
Escherichia coli	UFC/100 mL	00	00	0	0	0	0
Total coliforms	UFC/100 mL	00	00	>100	>100	>100	>100
Fecal Enterococci	UFC/100 mL	00	00	0	0	0	0
Total aerobic flora	UFC/100 mL	00	–	>100	>100	>100	>100

water 1. Similarities were also observed in Words (2020) work in Kikwit, Democratic Republic of the Congo, with total coliform concentrations ranging from 117 to 450 CFU/100 mL for water from different sources. Osiemo *et al.*'s (2019) study in Marigat, Kenya, also noted comparable results. Moreover, these findings indicate higher total coliform levels compared to previous studies. Tabor *et al.* (2011) reported a range of 1.01–100 CFU/100 mL for tap water in Bahir Dar, Ethiopia. Jin-song *et al.*'s (2020) research in Taladanda Canal, Paradip region, Odisha, India, showed varying total coliform concentrations throughout the year. Yasin *et al.* (2015) demonstrated 100% total coliform concentration (<100 CFU/100 mL) in all water samples from the water source.

Furthermore, the results differ from Bouba *et al.*'s (2022) study in Garoua Urbain, Cameroon, where total coliforms accounted for 59% of detected microbes (<100 CFU/100 mL) in sachet water sold. These findings highlight a significant exceedance of WHO guidelines for total coliforms and total aerobic flora in N'Djamena's drinking water. This presents a serious public health concern due to ongoing bacterial contamination. Urgent actions such as improved treatment, enhanced protection, and better waste management are imperative to safeguard water quality and mitigate the transmission of water-borne diseases in the community.

3.8. Type of toilets/sanitation facilities, accessibility, and fecal matter disposal methods

To ensure accessibility for all, including individuals with disabilities and reduced mobility, toilets and sanitary facilities must meet accessibility standards. This includes features like wider wheelchair-friendly spaces, handrails, and potential lifting devices. Regular maintenance is crucial for functionality and cleanliness. The survey data reveals that 92.8% of households use traditional toilets as their primary sanitation facility, 2.9% have access to modern flush toilets, and only 4.3% practice open defecation. These latrines are often constructed with various materials, and about 45% have roofing. Modern flush toilets are used by only 2.9% of households due to high material and construction costs, which act as a significant barrier to adoption.

In summary, Figure 10 highlights a troubling situation regarding household sanitation facilities. Approximately 72.1% are in good condition, but 15.6% are in poor condition, 11.1% are full, and 1.1% have already collapsed. Unfortunately, only 1% of households have flush toilets due to inadequate sewage infrastructure. Excessive toilet sharing (71%) leads to poor maintenance and encourages open defecation. Communal toilets also pose health risks, as they are often poorly maintained and facilitate the spread of waterborne diseases (WHO 2017) (Figure 11).

In the study area, there are 55 pay-per-use public toilets, with 35 owned by municipalities and 20 by private entities, all currently operational. Households use various hygiene products for toilet maintenance, but issues like improper lining and infrequent fecal matter removal lead to pit closures and new pit excavation. Only 16.2% of households follow proper procedures, citing cost and design issues. Regarding fecal matter disposal, just 20.6% use septic tank trucks, while 63.2% dig pits around their homes, sealing them after a few days (Figure 12). Despite Article 12 of the sanitation and hygiene code and municipal guidelines explicitly prohibiting manual waste emptying due to concerns about public health, groundwater contamination, and environmental pollution, many households still prefer this option due to its cost-effectiveness,

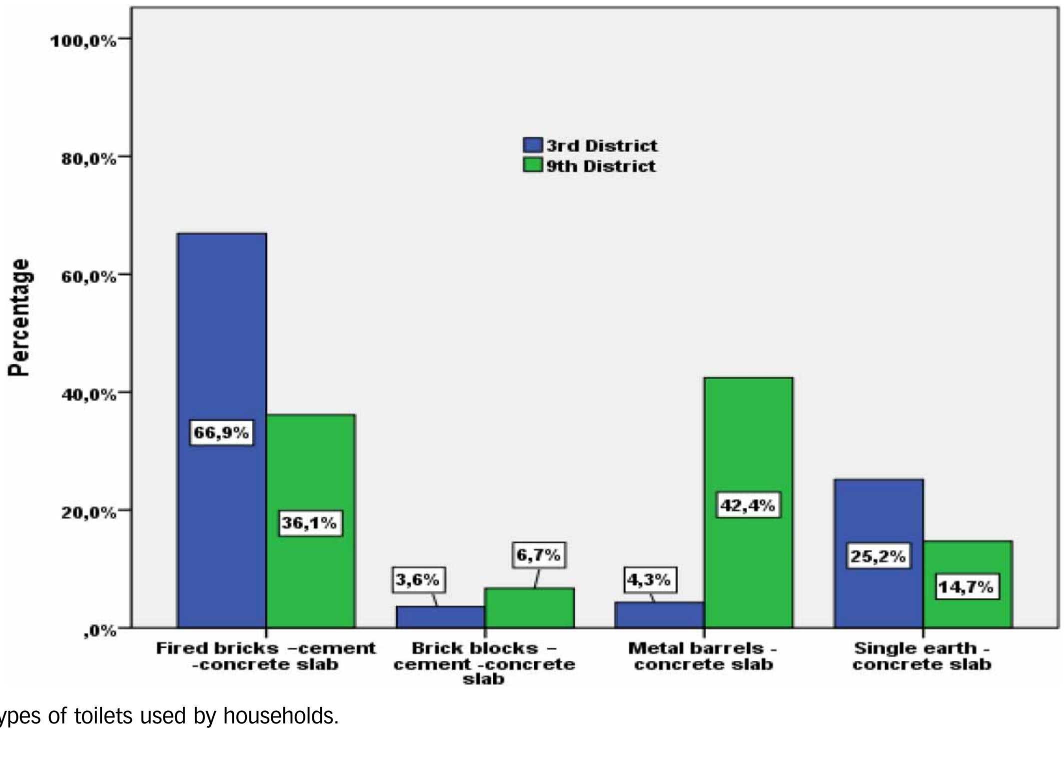


Figure 10 | Types of toilets used by households.

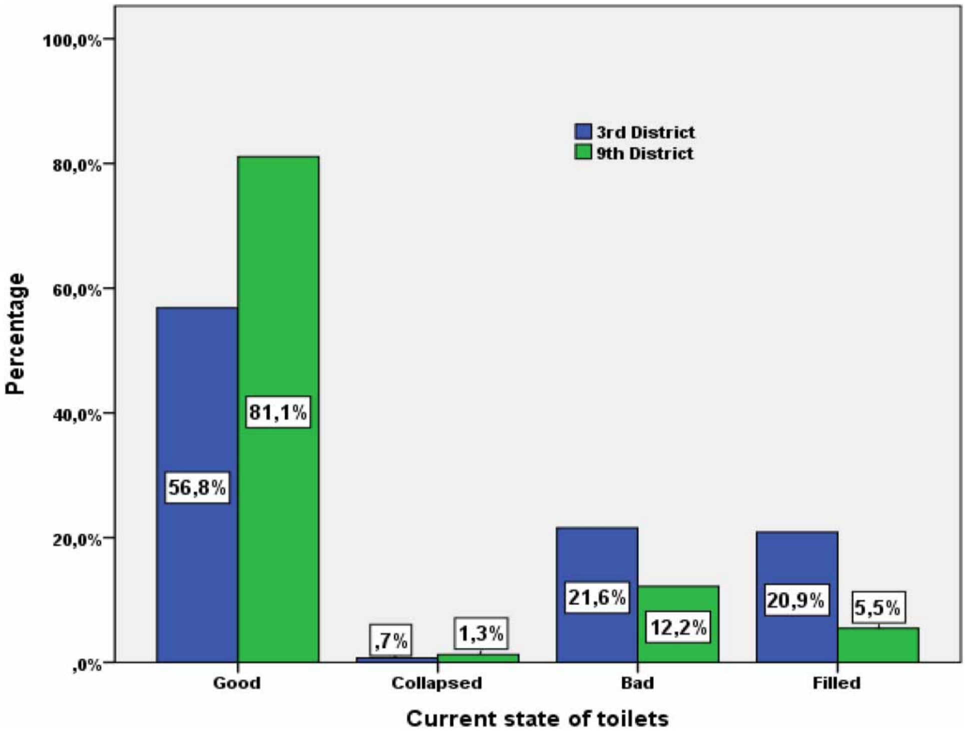


Figure 11 | The functional state of toilets used by households.

Figure 12 | Vacuum sludge collection tanker (a) and disposal of fecal matter into a pit dug around a residential house (b).

convenience, and speed, with an average cost of 25,000 FCFA (41.43 USD). Officials responsible for WASH in two districts have raised concerns about private companies transporting and disposing of sludge, often leading to illegal dumping in the environment, including stagnant ponds, undeveloped land, and residential areas, especially in the ninth district. This, coupled with shallow groundwater tables and the use of shallow wells for drinking water, worsens groundwater contamination, posing significant public health and hygiene risks.

These findings align with a study by Sy *et al.* (2011) in disadvantaged neighborhoods of Nouakchott, Mauritania, where 50.7% of households have in-home toilets, and Blackett *et al.*'s 2014 study in 12 low- and middle-income countries, which found that 98% of households use toilets but only 29% of fecal waste is safely managed. In contrast, a study in central Benin by Dovonou *et al.* (2022) found that 80% of the population practices open defecation. In Dakar, Senegal, data from the National Agency of Statistics and Demography (ANSD 2018) reveals that 45% of households have access to improved unshared toilets, while 32% use unimproved toilets, often traditional latrines. Toilet facility rates also vary in different regions, with 68.6% using improved toilets in Bamendjou households, Cameroon by Bita *et al.* (2017), and 35.80% having precarious toilet facilities in Bouaké, Côte d'Ivoire (Tatongueba Soussou 2017). To protect the environment and ensure universal access to safe sanitation, establishing proper waste disposal practices is crucial. Adequate waste management is essential for maintaining cleanliness and creating a healthy, sustainable living environment for all, aligning with the United Nations Sustainable Development Goal (SDG).

Chad faces a critical open defecation problem affecting people of all backgrounds. The Ministry of Water and Sanitation and N'Djamena's municipalities are working to address this issue, but toilets often lack proper standards, leading to groundwater contamination. The rainy season collapses pit latrines, causing widespread pollution. Public toilets deteriorate, giving rise to paid private ones, mainly in markets and hospitals. Urgent policies are needed to provide sanitation assistance to disadvantaged and middle-income households, safeguarding groundwater and public health.

3.9. Wastewater evacuation method

Efficient wastewater management is vital for safeguarding public health and the urban environment (Oyebode 2018). It includes collecting, transporting, and treating wastewater to reduce health and environmental risks (Khan *et al.* 2021). Surprisingly, a survey reveals that nearly 95% of households, regardless of factors like education, religion, or lifestyle, dispose of wastewater in the environment or streets. Only 5% use septic tanks. This untreated wastewater often ends up in rivers or evaporates, causing pollution and health hazards (Mekonnen & Amsalu 2018). Some health centers even release untreated wastewater directly, worsening living conditions and environmental issues (Tariq & Mushtaq 2023).

Manizan *et al.* (2010) found that untreated domestic wastewater discharge can contaminate surface waters, a finding consistent with Tuo *et al.* (2019) in Abobo Kennedy Clouetcha and Hoteyi *et al.* (2014). Tatongueba Soussou (2017) similarly reported that 75% of households in Bouaké, Côte d'Ivoire, rely on natural methods for wastewater disposal. In contrast, Sy *et al.* (2011) found that only 12.9% of households in three disadvantaged neighborhoods of Nouakchott, Mauritania, have proper domestic wastewater disposal systems (Figure 13).

3.10. Garbage disposal method

Effective waste disposal is crucial for managing waste in communities, preventing disease, safeguarding the environment, and maintaining public health (WHO 2017). In the studied area, household waste is primarily stored in four main containers: 58.3% use bins, 27.1% use mobile garbage bins, 14.1% use bags, and a small 0.5% use basins. Notably, 72% of households favor open dumping as their primary waste disposal method, while public dumping sites and curbside collection account for 18% of cases. Interestingly, the third district shows a higher preference for public dumping sites and curbside collection compared to the ninth district, attributed to municipal collection trucks, daily collectors, and private waste collection companies (Figure 14).

In certain neighborhoods, the absence of public waste disposal facilities leads to improper household waste disposal. People often dump garbage in random locations, including depressions or old quarries. This even involves using household waste as landfill material, leading to groundwater pollution. Managing biomedical waste is complex, and there are no available statistics. Previously, health centers and hospitals had incinerators, but the situation has changed. Only 10.4% of households in the third and ninth districts are satisfied with sanitation services. These findings are consistent with Sy *et al.*'s (2011) study in Nouakchott, Mauritania, where 17.1% of households have access to household waste collection. Similarly, Mbiadjeu Lawou *et al.*'s (2021) study across Cameroonian cities revealed that 57% of households dispose of their waste

Figure 13 | Stagnant wastewater surrounds a small market in the ninth arrondissement.

Figure 14 | N'Djamena Nadif (a) dump truck, pushcart (b), and motorcycle (c) for household waste transportation.

in open dumps. These results differ significantly from prior studies. In Brazzaville, Republic of Congo by Mangoumbou *et al.* (2023), 61.7% of households have trash bins, while 38.3% do not. Conversely, in Zangnanado, Benin by Dovonou *et al.* (2022), 100% of the population disposes of their waste in the environment. Furthermore, in Porto-Novo, Southern Benin by Hoteyi *et al.* (2014), fewer than a quarter of households are subscribed to pre-collection waste services, with 42.73% burying waste and 30.91% burning it in the open air.

Municipalities and local sanitation committees are responsible for launching awareness campaigns to encourage households to use public waste disposal sites and hire private waste collection services, with the aim of enhancing the immediate environment and overall well-being.

3.11. Hygiene facilities and practices

Maintaining proper hygiene across various settings such as workplaces, homes, schools, healthcare facilities, and public spaces is vital for disease prevention and overall well-being (WHO 2020). A survey revealed that 45% of households have handwashing facilities, but 55% lack consistent access. Among these facilities, 69% are clean, 27% are in poor condition, and 4% are not visible. Some households bring their own hygiene containers. Communal handwashing facilities often lack maintenance, with soap frequently absent or stolen. Curtis and Cairncross propose that promoting soap as a desirable household item may be more effective than hygiene campaigns. Surprisingly, 95.5% of households prioritize handwashing with soap and clean water, irrespective of education, religion, or lifestyle. Globally, one in four people lacks access to soap and water for handwashing, with only 26% practicing handwashing after potential fecal contact by Wolf *et al.*(2019). Rates are even lower in sub-Saharan Africa (14%) and Southeast Asia (17%). Poor hygiene can result in waterborne diseases, particularly in children aged 0–5 years, leading to stunted growth and delayed development (Al-Ghamdi *et al.* 2009; Humphrey 2009). These findings contrast with studies in other regions, such as Benin (70.41% lacking handwashing after defecation), Senegal (14.3% limited hand hygiene to water), and Vietnam (poor hygiene due to lack of knowledge and ingrained habits) (Martin *et al.* 2019; Diop *et al.* 2021). The WHO recommends handwashing with soap and water, particularly when hands are visibly soiled (WHO 2017).

4. CONCLUSION

The study conducted in the third and ninth districts of N'Djamena has shed light on major challenges related to water supply, sanitation, and hygiene. Despite the presence of institutional actors, deficiencies in financial, material, and technical resources were observed. Water quality analyses from two sources revealed contamination by temperature, ammonium, total coliforms, and total aerobic flora, rendering it unsuitable for consumption according to WHO guidelines. The inadequacy of sanitation and hygiene services is evident. While overall access to water is satisfactory, sanitation facilities do not meet recommended standards. Traditional communal latrines are widely used, underscoring the absence of a wastewater and fecal matter treatment system. In conclusion, hygiene promotion is crucial to prevent household contamination by fecal matter. The importance of accessible handwashing facilities, soap, and proper treatment to improve water quality is emphasized. Additionally, the collection and safe disposal of household waste pose a major challenge in Ndjamena, particularly in the study area.

RECOMMENDATIONS

To effectively ensure the population's health preservation in these two districts, the study recommends providing interest-free microloans to households to help them build modern toilets, thus ensuring safe waste disposal. It is also essential to guarantee access to safe drinking water and promote good hygiene practices. This includes subsidizing handwashing soaps, providing hygiene education within the community, and continuing awareness campaigns to encourage behavioral change. Finally, rational waste management and the promotion of a circular economy are crucial elements for ensuring sustainable development in the study area.

ACKNOWLEDGEMENTS

The authors express their profound gratitude to the World Bank, through the Regional Center for Energy and Environmental Sustainability, for their financial support of this study. They also extend their warm appreciation to the ten investigators from the third and ninth districts of the city of N'Djamena, as well as the local authorities for their unwavering support throughout the survey.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Agrawal, T. & Schachner, A. 2023 Hearing water temperature: Characterizing the development of nuanced perception of sound sources. *Developmental Science* **26** (3), 1–16. https://doi.org/10.1111/desc.13321.

Al-Ghamdi, M. A., Bentham, G. & Hunter, P. R. 2009 Environmental risk factors for diarrhoea among male schoolchildren in Jeddah City, Saudi Arabia. *Journal of Water and Health* **7**, 380–391. https://doi.org/10.2166/wh.2009.058.

ANSD Agence Nationale de la Statistique et de la Démographie 2018 *La population du Sénégal en 2017*. https://www.ansd.sn/sites/default/files/2022-12/Rapport_population_2017_05042018.pdf.

APHA 1994 *Standard Methods for the Examination of Water and Wastewater, 15th Eds.* APHA-AWWA-WPCF, Washington DC.

Ballet, T. G. N., Gnagne, A. E. J. E. Y., Fofana, V. & Yapo, B. O. 2018 Évaluation de la perception des ménages de la qualité de l'eau du robinet de deux communes, Cocody et Yopougon de la ville d'Abidjan, Côte d'Ivoire. *Afrique Science* **14** (6), 48–57.

Behl, M., Thakar, S., Ghai, H., Sakhuja, D. & Bhatt, A. K. 2023 Fundamentals of fermentation technology. In: *Basic Biotechniques for Bioprocess and Bioentrepreneurship*. https://doi.org/10.1016/B978-0-12-816109-8.00021-0.

Biembe, Y. J. 2019 Risques sanitaires liés à la potabilisation domestique de l'eau dans les quartiers à habitats spontanés de Yaoundé: cas du bassin versant de l'Abiergue, Mémoire de Master, 82 p, Université de Liège, Belgique.

Bita, A., Nkamedjie Pete, P., Chukuwchindun Azik, B., Fotsing, M., Atouba, B., Sanou Sobze, M. & Sieleunou, I. 2017 Accès à l'assainissement, eau et maladies diarrhéiques des enfants dans les ménages de Bamendjou, Cameroun.Médecine d'Afrique Noire 1ère Revue Médicale Internationale Panafricaine, (July).

Blackett, I., Hawkins, P. & Heymans, C. 2014 'The Missing Link in Sanitation Service Delivery: A Review of Fecal Sludge Management in 12 Cities.' Water and Sanitation Program Research Brief, World Bank, Washington, DC.

Bouba, G., Djaouda, M., Hermine, A. A., Martin, M. F., Hamadama, O. G., Poullo, A. O., Lilian, A. & Valerie, M. 2022 Bacteriological Analysis of Sachet Water Sold in Some Municipalities Markets of Garoua Urbain City, Cameroon.August. https://doi.org/10.12691/jephh-10-1-2.

Carrard, N., Foster, T. & Willetts, J. 2019 Groundwater as a source of drinking water in Southeast Asia and the Pacific: A multi-country review of current reliance and resource concerns. *Water (Switzerland)* **11** (8). https://doi.org/10.3390/w11081605.

Cochran, W. G. 1977 *Sampling techniques (3rd ed.)*. John Wiley & Sons, New York.

Dégbey, C., Makoutodé, M., Ouendo, E. M., Fayomi, B. & de Brouwer, C. 2008 La qualité de l'eau de puits dans la Commune d'AbomeyCalavi au Bénin. *Environnement Risque Santé* **2008** (7), 279–283. doi:10.1684/ ers.0158.

Diawara, H., Ahimir, S., Berthé, T. & Guindo, A. 2021 Etude De La Contribution Des Forages Dans L'amélioration De L'accès À L'eau Potable Dans Le Quartier De N'Tabacoro Cité Extension À Bamako. *European Scientific Journal ESJ* **17** (40), 106–120. https://doi.org/10.19044/esj.2021.v17n40p106.

Dietrich, A. M. & Burlingame, G. A. 2020 A review: The challenge, consensus, and confusion of describing odors and tastes in drinking water. *Science of the Total Environment* **713**, 135061. https://doi.org/10.1016/j.scitotenv.2019.135061.

Dimitri Miriac, A. S., Noukpo, A. & Christophe, H. S. 2020 Eau De Consommation Et Maladies Hydriques Dans La Commune De Lokossa Au Sud-Ouest De La Republique Du Benin (Afrique De L'ouest). *European Scientific Journal ESJ* **16** (15), 393–417. https://doi.org/10.19044/esj.2020.v16n15p393.

Diop, C., Toure, A., Cabral, M., Thiandoum, M. & Fall, M. 2019 Évaluation des pratiques de potabilisation des eaux de boisson en zone rurale: Cas de Sindia au Sénégal. *Afrique Science* **15** (3), 253–260.

Diop, C., Toure, A., Bah, F., Lam, A., Cabral, M., Fedior, S. & Fall, M. 2021 Approvisionnement en eau dans la commune des Parcelles Assainies de Dakar (Sénégal): Perception de la qualité et pratiques des populations. *European Scientific Journal ESJ* **17** (7). https://doi.org/10.19044/esj.2021.v17n7p256.

Dovonou, F., Aïna, M., Boukari, M. & Alassane, A. 2022 Pollution physico-chimique et bactériologique d'un écosystème aquatique et ses risques écotoxicologiques: Cas du lac Nokoue au Sud Bénin. *International Journal of Biological and Chemical Sciences* **5** (4), 1590–1602. http://dx.doi.org/10.4314/IJBCS.v5i4.23.

Dwivedi, A. K. 2017 © Associated Asia Research Foundation (AARF) researches in water pollution : A review. *International Research Journal of Natural and Applied Sciences* **4** (January), 118–142. https://doi.org/10.13140/RG.2.2.12094.08002.

EPA 2012 Recreational Water Quality Criteria. U.S.Environnement.Protection Agency.1-69p.

Harwood, V. J., Staley, C., Badgley, B. D., Borges, K. & Korajkic, A. 2014 Microbial source tracking markers for detection of fecal contamination in environmental waters: Relationships between pathogens and human health outcomes. *FEMS Microbiology Reviews* **38** (1), 1–40.

Hawko, C., Verriele, M., Hucher, N., Crunaire, S., Leger, C., Locoge, N. & Savary, G. 2021 A review of environmental odor quantification and qualification methods: The question of objectivity in sensory analysis. *Science of the Total Environment* **795**. https://doi.org/10.1016/j.scitotenv.2021.148862.

Hèdible, S. C. 2007 *Perceptions et stratégies d'adaptation des communautés rurales du département de l'atlantique face à la dégradation de la qualité de l'eau de consommation*. *Doctoral dissertation*, Thèse de doctorat de l'Ecole Doctorale Pluridisciplinaire (EDP) de l'Université d'Abomey-Calavi (UAC).

Hoteyi, S. M. I., Gnimadi, C. C., Adjadji, G. V. & Igue, A. M. 2014 Analyse des risques de consommation des eaux en sachet pour les populations dans la ville de Porto-Novo au SudBénin Risk analysis of water in nylon bag consumption for the populations in Porto-Novo city in Southern Benin Abstract. Bulletin de La Recherche Agronomique Du Bénin (BRAB), 1–8.

Humphrey, J. 2009 Child undernutrition, tropical enteropathy, toilets, and handwashing. *The Lancet* **374** (9694), 1032–1035. [PubMed].

INSEED 2014 Deuxième Recensement Général de la Population et de l'Habitat de 2009, rapport d'analyse, thème 18, Projections démographiques 2009-2050, N'Djaména, Juillet 2014, 90 p.

INSEED. 2018 *Profil de Pauvrete au Tchad en 2 0 1 8. Quatrième Enquête sur les Conditions de vie des Ménages et la Pauvreté au Tchad (ECOSIT4)*.

Jin-song, Y. A. N. G., Zhe, L. I. U., Xiang-dong, W. A. N. G., Hua, Z. H. A. O., Lei, S. O. N. G., Tai-bei, L. I. U., Mangueina, D., Awuah, E., Fonteh, M. F., Antwi-Agyei, P., Nadji, E. T. & Peng, Z. 2020 Features and values of geological heritage resources in Shunping County, Hebei Province. *Journal of Groundwater Science and Engineering* **8** (4), 349–357. https://doi.org/10.19637/j.cnki.2305-7068.2020.04.004.

Kahle, E. M., Zarnkow, M. & Jacob, F. 2021 Beer turbidity part 1: A review of factors and solutions. *Journal of the American Society of Brewing Chemists* **79** (2), 99–114. https://doi.org/10.1080/03610470.2020.1803468.

Khan, M. T., Shah, I. A., Ihsanullah, I., Naushad, M., Ali, S., Shah, S. H. A. & Mohammad, A. W. 2021 Hospital wastewater as a source of environmental contamination: An overview of management practices, environmental risks, and treatment processes. *Journal of Water Process Engineering* **41** (March), 101990. https://doi.org/10.1016/j.jwpe.2021.101990.

Kim, C., Chen, L., Wang, H. & Castaneda, H. 2021 Global and local parameters for characterizing and modeling external corrosion in underground coated steel pipelines: A review of critical factors. *Journal of Pipeline Science and Engineering* **1** (1), 17–35. https://doi.org/10.1016/j.jpse.2021.01.010.

Lagnika, M., Ibikounle, M., Montcho, J. C., Wotto, V. D. & Sakiti, N. G. 2014 Caractéristiques physico-chimiques de l'eau des puits dans la commune de Pobè (Bénin, Afrique de l'ouest). *Journal of Applied Biosciences* **79** (1), 6887. https://doi.org/10.4314/jab.v79i1.13.

Le, N. D., Hoang, T. T. H., Nguyen, T. M. H., Rochelle-Newall, E., Pham, T. M. H., Phung, T. X. B., Duong, T. T., Nguyen, T. A. H., Dinh, L. M., Duong, T. N., Nguyen, T. D. & Le, T. P. Q. 2023 Microbial contamination in the coastal aquaculture zone of the Ba Lat river mouth, Vietnam. *Marine Pollution Bulletin* **192** (March), 115078. https://doi.org/10.1016/j.marpolbul.2023.115078.

Licence, M. D. E., En, P., Social, T., La, C. A. S. D. E. & Sabotsy, C. D. E. 2013 *USAGE DE L 'EAU DANS LE CADRE DU DEVELOPPEMENT SOCIAL EN MILIEU*.

Mangoumbou, G., Bekabeka, A. & Ngouma, D. 2023 Gestion des déchets et impacts sanitaires dans les campus de Brazzaville en République du Congo. *Revue Espace Géographique et Société Marocaine* **67**, 105–122.

Manizan, N. P., Ouattara, A., Gourene, G. & Dosso, M. 2010 Influence Hes MaraMtérTstTques pCysTMo-chimiques sur la distribution spatiotemporelle Hes HensTtés ЛaMtérTennes Hans le système fluvTo-lacustre de la Bia, Sud-Est de la côte H'TvoTre. *Rev. Ivoir. Sci. Technol.* **15**, 201–210.

Martin, H., Rodrigue, L. C., Thierry, A. & Christophe, H. S. 2019 Facteurs Associes a la Qualite des Eaux Consommees dans la Commune d'Abomey-Calavi au Sud du Benin en Afrique de L'Ouest. *European Scientific Journal ESJ* **15** (30). https://doi.org/10.19044/esj.2019.v15n30p56.

Mbiadjeu-lawou, S. P., Djellouli, Y. & Tchindjang, M. 2021 *Les pratiques locales de gestion des déchets solides ménagers en lien fort avec l ' économie circulaire de Bangangté*. pp. 417–436.

Mekonnen, M. T. & Amsalu, Z. 2018 Causes and impacts of shankila river water pollution in Addis Ababa, Ethiopia. *Environ Risk Assess Remediat* **2** (4), 21–30. Available form: http://www.alliedacademies.org/environmental-risk-assessment-and-remediation/

Ochoo, B., Valcour, J. & Sarkar, A. 2017 Association between perceptions of public drinking water quality and actual drinking water quality: A community-based exploratory study in Newfoundland (Canada). *Environmental Research* **159**, 435–443.

Osiemo, M. M., Ogendi, G. M. & M'Erimba, C. 2019 Microbial quality of drinking water and prevalence of water-related diseases in marigat urban centre, Kenya. *Environmental Health Insights* **13**. https://doi.org/10.1177/1178630219836988.

Oyebode, O. J. 2018 Evaluation of municipal solid waste management for improved public health and environment in Nigeria. *European Journal of Advances in Engineering and Technology* **5** (8), 525–534.

Piccardo, M. T., Geretto, M., Pulliero, A. & Izzotti, A. 2022 Odor emissions: A public health concern for health risk perception. *Environmental Research* **204** (PB), 112121. https://doi.org/10.1016/j.envres.2021.112121.

Reitter, C., Petzoldt, H., Korth, A., Schwab, F., Stange, C., Hambsch, B., Tiehm, A., Lagkouvardos, I., Gescher, J. & Hügler, M. 2021 Seasonal dynamics in the number and composition of coliform bacteria in drinking water reservoirs. *Science of the Total Environment* **787**, 147539. https://doi.org/10.1016/j.scitotenv.2021.147539.

Reyes-Toscano, C. A., Alfaro-Cuevas-Villanueva, R., Cortés-Martínez, R., Morton-Bermea, O., Hernández-Álvarez, E., Buenrostro-Delgado, O. & Ávila-Olivera, J. A. 2020 Hydrogeochemical characteristics and assessment of drinkingwater quality in the Urban Area of Zamora, Mexico. *Water (Switzerland)* **12** (2). https://doi.org/10.3390/w12020556.

Risso, P., Maggioni, E., Etzi, R. & Gallace, A. 2019 The effect of the tactile attributes of a container on mineral water perception. *Beverages* **5** (1), 6–13. https://doi.org/10.3390/beverages5010023.

Rusydi, A. F., Onodera, S. I., Saito, M., Hyodo, F., Maeda, M., Sugianti, K. & Wibawa, S. 2021 Potential sources of ammonium-nitrogen in the coastal groundwater determined from a combined analysis of nitrogen isotope, biological and geological parameters, and land use. *Water (Switzerland)* **13** (1). https://doi.org/10.3390/w13010025.

Saïnou, J. E., Behanzin, P., Mariano, S. & Johnson, F. I. 2019 Etude de la qualité physicochimique et bactériologique des eaux de consommation dans la commune de Toffo au Bénin: Cas de l'arrondissement de Sèhouè (Study of the physico-chemical and bacteriological quality of drinking water in the municipality of Toffo. *Journal of Applied Science and Environmental Studies JASES* **2** (3), 126–138. Available from: http://revues.imist.ma/index.php?journal=jases

Shields, K. F., Bain, R. E., Cronk, R., Wright, J. A. & Bartram, J. 2015 *Association of Supply Type with Fecal Contamination of Source Water and Household Stored Drinking Water in Developing*.

Sitotaw, B., Melkie, E. & Temesgen, D. 2021 Bacteriological and physicochemical quality of drinking water in Wegeda Town, Northwest Ethiopia. *Journal of Environmental and Public Health* **2021**. https://doi.org/10.1155/2021/6646269.

Sy, I., Koita, M., Traoré, D., Keita, M., Lô, B., Tanner, M. & Cissé, G. 2011 Vulnérabilité sanitaire et environnementale dans les quartiers défavorisés de Nouakchott (Mauritanie) : analyse des conditions d'émergence et de développement de maladies en milieu urbain sahélien. http://vertigo.revues.org/11174; doi:10.4000/vertigo.11174.

Tabor, M., Kibret, M. & Abera, B. 2011 Bacteriological and physicochemical quality of drinking water and hygiene- sanitation practices of the consumers in Bahir Dar City, Ethiopia. *Ethiopian Journal of Health Sciences* **21** (1), 19–26. https://doi.org/10.4314/ejhs.v21i1.69040.

Tariq, A. & Mushtaq, A. 2023 Untreated wastewater reasons and causes: A review of most affected areas and cities. *International Journal of Chemical and Biochemical Sciences* **23** (1), 121–143.

Tatongueba Soussou, A. A. (2017). Revue Ivoirienne de Géographie des Savanes, Numéro 1 Janvier 2017, ISSN 2521-2125, (1), 66–77.

Tchouongsi, E. K., Mougoue, B., Tagne, C. T., Touoyem, F. M. & Bonganjum, N. S. 2020 Approvisionnement en eau et risques sanitaires dans le bassin versant amont de l'Abiergué à Yaoundé (Cameroun). *European Scientific Journal ESJ* **16** (8), 102–123. https://doi.org/10.19044/esj.2020.v16n8p102.

Tran, M., Koncagul, E. & Connor, R. 2016 *Water and Jobs: Facts and Figures*. United Nations World Water Development Report, United Nations, New York, pp. 1–12.

Traoré, H. (2018). Accès à l'eau potable et aux infrastructures d'assainissement à Bamako, Editions universitaires européennes, 340.

Tuo, P., Coulibaly, M. & Ake-Awomon, D. F. 2019 Gestion des eaux usées et nuisances sanitaires dans les cadres de vie des populations d'Abobo -Kennedy- Clouetcha (Abidjan, Côte d'Ivoire). *Revue Africaine Des Sciences Sociales et de La Sante Publique* **1** (1), 74–90. Available from: https://www.revuegeo-univdaloa.net/fr/publication/gestion-des-eauxusees-et-risques-sanitaires-abobo-sud-3eme-tranche-abidjan-cote (Last visit 24/1/2021).

Unitied Nations 2015 *The Millennium Development Goals Report*. Available from: http://www.un.org/millenniumgoals/2015_MDG_Report/pdf/MDG%202015%20rev%20 (Ju ly%201).

Vissin, E. W., Aimade, H. S. S., Dougnon, L. D., Sohounou, M., Atiye, E. Y. & Atchade, G. A. A. 2017 Qualité de l'eau et maladies hydriques dans la commune de Toffo (Bénin, Afrique de l'ouest). *Journal of Applied Biosciences* **106** (1), 10300. https://doi.org/10.4314/jab.v106i1.10.

WHO 2017 Guidelines for Drinking Water Quality: First Addendum to the Fourth Edition First published: 01 July 2017. https://doi.org/10.5942/jawwa.2017.109.0087.

WHO 2020 Water Supply and Sanitation: Progress on Sanitation and Drinking Water (2020). WHO Library Cataloguing

WHO/UNICEF 2017 Progress on drinking water, sanitation and hygiene, ISBN 978-92-4- 151289-3, 108 p

WHO/UNICEF 2010 *Joint Monitoring Programme for Water Supply and Sanitation, Progress on Sanitation and Drinking-Water: 2010 Update*. World Health Organization: Geneva, Switzerland.

WHO (World Health Organization) and UNICEF (United Nations Children's Fund) 2015 Progress on Drinking Water and Sanitation: 2015 Update and MDG Assessment. Geneva: WHO and UNICEF.countries: a bivariate meta-analysis. Environ. Health Perspect. 123, 1222–1231.

Wolf, J., Johnston, R., Freeman, M. C., Ram, P. K., Slaymaker, T., Laurenz, E. & Prüss-Ustün, A. 2019 Handwashing with soap after potential faecal contact: Global, regional and country estimates. *International Journal of Epidemiology* **48** (4), 1204–1218. https://doi.org/10.1093/ije/dyy253.

Words, K. E. Y. 2020 Assessment of the phyico-chemical and microbiological quality of spring waters in the city of Kikwit (Democratic Republic of Congo) Évaluation de la qualité physico- chimique et microbiologique de l ' eau des. **4** (3), 451–459.

World Health Organization (WHO) 2011 *Guidelines for Drinking-Water Quality*, 4th edn.. Available form: https://www.who.int/publications/i/item/9789241548151.

Yasin, M., Tsige, K. & Ketema, B. 2015 Physicochemical andbacteriological quality of drinking water of different sources. Jimma zone, Southwest Ethiopia. 7–13p.

Yeboah, S. I. I. K., Antwi-Agyei, P. & Domfeh, M. K. 2022 Drinking water quality and health risk assessment of intake and point-of-use water sources in Tano North Municipality, Ghana. *Journal of Water Sanitation and Hygiene for Development* **12** (2), 157–167. https://doi.org/10.2166/washdev.2022.15.

Zabermawi, N. M., Alsulaimany, F. A. S., El-Saadony, M. T. & El-Tarabily, K. A. 2022 New eco-friendly trends to produce biofuel and bioenergy from microorganisms: An updated review. *Saudi Journal of Biological Sciences*. https://doi.org/10.1016/j.sjbs.2022.02.024

First received 31 October 2023; accepted in revised form 22 December 2023. Available online 10 January 2024