The Impact of Well Water Use on Human Health in Cotonou, Benin

AIZOUN ZINSOU JACQUES, ZHU HAOCHEN

Tongji University, Shanghai 200092, China

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Abstract:

This paper examines the potential health risks associated with well water use in Cotonou, Benin. Drawing on existing research, environmental data, and community surveys, it analyzes the quality of well water, identifies potential contaminants, and explores their possible health effects on residents. The paper concludes by highlighting the need for improved water infrastructure and sanitation practices to mitigate these risks and promote public health.

1. Introduction

Every individual should have the fundamental right to have uncontaminated and secure water, along with sufficient sanitary amenities. However, the provision of water and sanitation services continues to be a significant obstacle in numerous undeveloped nations. Water is vital for the survival of every plant and animal species, especially for humans. The human body is primarily composed of water. Water is essential for the functioning of living beings since it facilitates important exchanges necessary for the sustenance of life[1]. The freshwater resource comprises groundwater, surface water, and rainwater. Ensuring abundant and top-notch availability of potable water is crucial for all facets of existence and the progress of sustainable development. Groundwater is the favored source for piped water supplies in numerous metropolitan regions in Sub-Saharan Africa, and its expansion is projected to significantly rise in order to enhance the extent of urban water distribution[2]. Groundwater quality is affected by both natural occurrences and human activities. Water is a fundamental necessity for Homo sapiens. Regrettably, as stated in the 2019 World Bank report presented at the United Nations, the global community is currently confronting an overlooked water quality problem[3]. This issue substantially diminishes the economic growth prospects of highly polluted regions by 33% and raises concerns for both human and environmental well-being. Every organism need access to potable water. In order for humans to ensure their continued existence, they need an abundant supply of clean and potable water. The prevalence of waterborne diseases, such as cholera, typhoid, diarrhea, and dysentery, is greatly increased due to the poor quality of drinking water and inadequate sanitation facilities. The inadequate condition of water and sanitation in Africa can be attributed to various issues, such as inadequate strategic planning, a fast-expanding population, lack of accountability, political instability, and insufficient financial resources[4]. The water and sanitation issues in developing countries are more noticeable in rural regions, mostly because of a development planning approach that gives higher importance to urban districts. This strategy can be attributed to the colonial era and regrettably continues to exist throughout Africa after gaining freedom. Impoverished nations encounter substantial limitations in acquiring access to potable water. In Benin, potable water is sourced from several outlets, such as tap water and exposed surface water. The SONEB, a government-owned corporation, provides potable water to urban areas throughout Benin[5]. In areas lacking a centralized water supply, the responsibility for managing water is entrusted to the DGO (Direction Générale de l'Eau), which is a separate governmental entity. The water resources in Benin are characterized by restricted access to potable water and variations in availability based on geography. The Ministry of Economic and Financial Development has estimated that an annual budget of US$80 million and US$22 million, respectively, is required from 2006 to 2015 to achieve the Millennium Development Goals (MDGs) related to water and sanitation[6]. By 2015, the number of individuals without access to improved water sources exceeded 2 million. In terms of sanitation, 20% of the population had access to upgraded sanitation facilities, with 36% and 7% in urban and rural regions, respectively. This study aims to investigate the health implications associated with the utilisation of well water in the city of Cotonou. Approximately 65% of Benin's population has abstained from registering with the National Water Company of Benin (SONEB) due to financial limitations[7]. The population ingests untreated freshwater and is susceptible to a range of diseases. Yetongnon et al.[8] conducted a comprehensive analysis of the physical and chemical properties of well water in the sixth neighborhood of Cotonou, South Benin, along with the detection of metal contaminants. The researchers performed in-situ measurements of various physico-chemical parameters, such as pH, temperature, conductivity, total dissolved salts (TDS), and salinity. Elevated concentrations of ammonium and nitrite ions were identified in the groundwater, indicating potential contamination. The water samples included excessive amounts of aluminum and iron, beyond the guidelines established by the World Health Organization[9]. While the majority of the trace elements fulfilled the toxicity standards, certain atypical levels were detected, suggesting potential sources of contamination. The analysis revealed significant correlations among various chemical elements, indicating a common origin for positively correlated metals and unique origins for negatively correlated metals. In 2022, Avocefohoun et al.[10] conducted a study to examine the physical and chemical properties of well water in the sixth neighborhood of Cotonou, located in South Benin. Furthermore, the study investigated the presence of metallic contaminants in the water. The well water samples undergo analysis to detect the existence of twenty-six metallic elements utilizing the inductively coupled plasma source mass spectrometer (ICP-MS). The study emphasizes the deterioration of the physical and chemical properties of groundwater in the sixth neighborhood, which is characterized by excessive mineral content as indicated by conductivity values that surpass the standard set by the World Health Organization. The groundwater has been discovered to possess elevated levels of ammonium and nitrite ions, beyond the predetermined thresholds. Reports show that the water includes small amounts of aluminium and iron, which in certain cases surpass the standards set by the World Health Organisation[9]. The analysis uncovers substantial relationships among different chemical elements, suggesting both shared and distinct origins for metals that have positive and negative connections. Urban areas, such as Cotonou, may undergo deterioration of shallow underground water sources, such the Quaternary aquifer, as a result of contaminants seeping in, such as seawater, septic tank waste, and sewage. Research conducted in Dakar, Senegal; Douala, Cameroon; and other regions of Ghana has shown that nitrate contamination is a widespread issue in urban shallow groundwater resources[1, 11, 12]. The indiscriminate disposal of waste and insufficient sanitation infrastructure contributes to the contamination of groundwater, leading to the presence of various pollutants. Seasonal variations in aquifers and fluctuations in groundwater quality can impact the amount of pollution in well water. The use of unregulated groundwater for residential purposes, such as drinking water supplies, poses substantial health risks due to water quality issues in many urban areas[13].

2. Study Area

2.1. Location and Climate

Cotonou is chosen as the optimal location for this study due to its status as the most densely populated city in Benin. Cotonou is located between the geographical coordinates of 6°20' to 6°23' north latitude and 2°22' to 2°30' east longitude[14]. The municipality is the only administrative subdivision within the Littoral Department. It shares a border with the municipality of Sô-Ava and Lake Nokoué to the north, the Atlantic Ocean to the south, the municipality of Sèmè-Kpodji to the east, and the municipality of Abomey-Calavi to the west. Cotonou is composed of 13 districts, each of which is divided into 143 city districts[15]. The region has two separate periods of rainfall, which take place from April to July and from September to October. The overall amount of rainfall received year ranges from 800 to 1,200 mm (31 to 47 in). Moreover, Cotonou experiences two periods of low precipitation known as dry seasons. The city is affected by harmattan winds from December to January. The temperatures exhibit a similar stability throughout the year, with the average highest temperatures consistently staying around 30°C, and the average lowest temperatures remaining around 25°C[16].

Figure 1: Map of Cotonou

2.2. Sources of water in Cotonou

In Benin, the southern region possesses abundant surface water resources in perennial rivers, while groundwater is extensively utilised throughout the country, both in rural and urban areas, for residential water supply. Cotonou, the capital, relies heavily on groundwater resources. The limited productivity of subterranean aquifers, which are prevalent across Benin, results in challenges with the accessibility of potable water in urban areas of moderate to significant size. In certain areas of the coastal basin, there is a problem with providing an adequate supply of drinkable water due to the limited thickness of the shallow aquifers. When the shallow deposits are incapable of producing enough resources, boreholes are dug to greater depths into the worn basement below. The quality of groundwater in shallow aquifers is frequently compromised as a result of contamination. Coastal aquifers are particularly affected by the issue of saline intrusion. In Cotonou, the capital city, there is a significant extraction of groundwater. However, research has revealed that the groundwater in the urban region above the recommended levels of several pollutants according to the recommendations set by the World Health Organisation. These contaminants include lead, chromium, cadmium, zinc, coliforms, and E.coli[17].

2.3. Sewerage and waste

The study conducted by Totin et al.[17] in Cotonou found that the alteration of groundwater's chemical composition in different climatic conditions is associated with processes such as ion exchange, rock disintegration or weathering, intrusion of seawater, and contamination caused by human pollution.

Figure 2. Water supply sources and their environmental implications in Cotonou: (a) Insufficient waste disposal on Lake Nokoue; (b) Water supply source pollution; and (c) Inadequate separation between pit latrine and well, as per the current WHO guidelines (15 m). **Source:** Totin et al.[17]

Human activities, such as indiscriminate disposal of rubbish and waste, the use of septic tanks, soak-away pits, and similar practices, can produce leachates that pollute the groundwater. The dumping of sanitary wastewater and solid waste in urban areas presents a substantial threat to the quality of shallow groundwater. Wastewater treatment is not regularly conducted in Benin[10]. Usually, wastewater is not properly disposed of. Within Cotonou, 64.9% of families employ latrines that are documented to be impermeable, whereas 13.5% partake in hazardous and unclean behaviours such as utilising stilt latrines or engaging in open defecation. Based on the 2013 data from INSAE, just 20.8% of the population make use of septic tanks, which are commonly emptied through drainage systems[10]. Usually, wastewater is inadequately disposed of. Impoverished persons residing in disadvantaged communities experience more pronounced consequences from the ingestion of contaminated water. Although these water sources are renewable, various global studies have demonstrated that they are contaminated to varying degrees and serve as a fertile environment for numerous diseases. Sanitary facilities and access to clean water significantly influence the health of households. The absence of adequate sanitary infrastructure, leading to water contamination, is a significant issue due to its association with human morbidity and mortality.

2.4. Well water quality and use

The presence of contaminants such as bacteria, viruses, heavy metals, and chemicals in well water in Cotonou is a major concern due to its impact on water quality. However, it remains an essential water source for many people in the area. Every living entity necessitates access to drinkable water in order to survive. For humans to maintain their survival, they require a plentiful provision of uncontaminated and drinkable water. Impoverished communities in disadvantaged neighborhoods of Cotonou are disproportionately affected by the consumption of contaminated water from water wells[12, 14, 17]. These water sources can be refreshed, however multiple global studies have shown that these fluids are contaminated to different extents and act as a breeding ground for various diseases. These pollutants have the potential to induce waterborne illnesses, infections of the skin and eyes, as well as long-term health conditions such as cancer and neurological abnormalities[18, 19]. Groundwater harbours microbiological pollutants, including bacteria, viruses, and parasites, that can constitute a substantial health hazard if consumed[20, 21]. These pollutants are frequently introduced by human faeces, animal dung, and soil. In order to maintain the microbiological purity and safeguard against these contaminants, it is essential to regularly carry out examination, assessment, and resolution.

2.4.1. Water Quality Index

The Water Quality Index (WQI) is a numerical value that represents the overall water quality at a specific location and time, taking into account various criteria that measure water quality[22, 23]. The aim of the Water Quality Index (WQI) is to transform intricate water quality data into comprehensible and practical information for public consumption. Several indices have been created to condense water quality data into a manner that is both simply communicable and easily comprehensible. The Water Quality Index (WQI), initially devised by Horton in the early 1970s, is essentially a statistical method for determining a single numerical value based on several test outcomes[24]. The index result indicates the degree of water quality in a certain water basin, such as a lake, river, or stream. Following Horton's work, numerous workers worldwide have developed Water Quality Index (WQI) are systems that assess water quality based on the evaluation of various parameters. This work aims to evaluate the Water Quality Index (WQI) using data from a study conducted by Vodounon et al.[18] (REF) on a number of sampled wells in Cotonou. The Water Quality Index (WQI) is usually calculated in accordance with the parameters pH, TDS, TH, Ca2+, Mg2+, Na+, K+, Cl−, 2 SO4− , HCO3− and NO3−, which are derived from the studies conducted by Alastal et al.[18] and El Baba et al.[25], as well as the drinking water quality guidelines established by the World Health Organisation (WHO)[9]. This index is used to evaluate the seasonal quality status of water. The correlations among those measures are crucial in determining only the physicochemical quality status of well water.

The equations used to estimate WQI are:

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} q_i W_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

With,

$$W_i = \frac{K}{S_i} \tag{2}$$

Where, W_i = unit weight for n^{th} parameter, S_i= standard permissible value for n^{th} parameter, and K = proportionality constant.

$$K = \frac{1}{\sum_{i=1}^{n} \left(\frac{1}{S_i}\right)} \tag{3}$$

q_i is a quality rating for n^{th} water quality parameter is given by the equation:

$$q_i = 100 \bullet \frac{V_i - V_0}{S_i - V_0} \tag{4}$$

The following table displays the appropriateness of WQI values for human eating. The WQI is divided into five categories to represent different water quality statuses[12, 24]: The quality is categorised as follows: excellent (0 - 25), good (26 - 50), bad (51 - 75), very poor (76 - 100), and inappropriate for drinking (>100).

Table 1. Water quality index and water quality status

WQI Level	Water quality status
0-25	Excellent water quality
25-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
>100	Unsuitable for drinking

2.5 Methods

Various districts within the city of Cotonou are chosen at random for the purpose of sampling. The study employed several data collection techniques, including document analysis for existing reports and surveys, in-depth interviews, and group discussions. Surveys have also been conducted to collect quantitative data on health impacts and water usage trends in the district. The researchers initiated their investigation by doing a comprehensive analysis of the existing data on water quality in Cotonou, Benin, as well as pertinent articles on health. The reviewed reports contain information about the analysed chemical and microbiological constituents of the well water in the study area. Health surveys can provide insights into the prevalence of waterborne diseases and other issues related to the use of well water. Furthermore, the researchers conducted interviews with the locals who rely on well water in the study area to get comprehensive information about the environment under investigation. In addition, interviews were conducted with both community members and the individuals in question to gather information regarding the community's perspectives, including their worries and previous experiences related to the utilisation of well water and any associated health effects. Group talks likely served to promote interactive and collaborative exploration of perspectives and experiences about the utilisation of well water. The group members expressed their viewpoints regarding the flavour, aroma, visual characteristics, and potential health concerns associated with well water. These talks enhanced the research by incorporating a qualitative dimension that encompasses a wide range of perspectives from the entire spectrum of human experiences. The interviews and focus groups likely underwent qualitative data analysis, such as theme analysis or another method of qualitative data analysis. The researchers likely employed coding techniques to discern reoccurring themes and patterns about the utilisation of well water and its effects on human health. Statistical analysis may have been used to establish correlations between the water quality characteristics and health outcomes in the quantitative data. To summarise, this study employs a non-experimental design, utilising secondary data analysis along with interviews and focus group discussions to thoroughly investigate the correlation between the use of well water and the well-being of individuals in Cotonou, Benin.

3. Results and Discussion

3.1. Sources and uses of water in Cotonou

The primary sources of water provision in Cotonou consist of privately-owned home wells and the urban infrastructure operated by the SONEB national water corporation. A significant portion of the population utilises well water for the purposes of laundering, dishwashing, bathing, and cleaning. Occasionally, this water source is also used for drinking due to the insufficient presence of reliable water networks, unfavourable socioeconomic circumstances, and the limited availability of shallow groundwater (0.5 to 2m). There are various sources of water supply in Cotonou. Based on the study's findings the sources of water for the inhabitants are depicted in Figure 3.

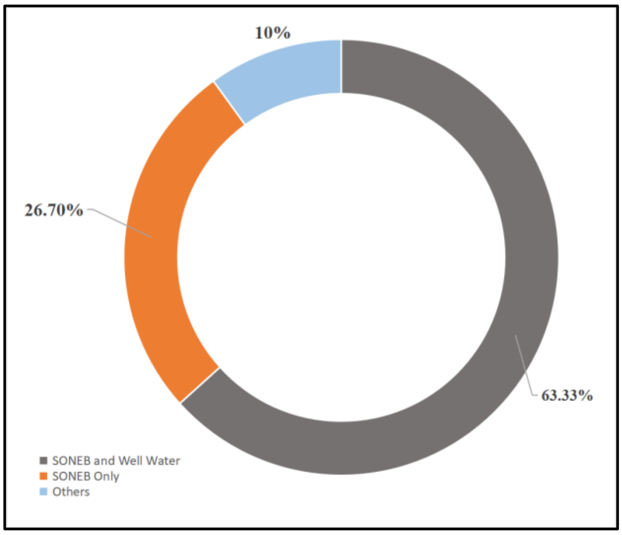

Figure 3. Access to drinking water in Cotonou adapted from survey results (Source: Authors)

Cotonou has multiple water supply sources. Figure 3 illustrates the water sources available to the residents. The populace utilizes multiple water sources. Therefore, a total of 19.9% or 95 individuals out of the examined population of 150 exclusively rely on SONEB water for all their household needs. Out of the total population, a mere 26.7%, equivalent to 40 individuals, rely on well water to meet their additional water requirements. Additionally, 10%, or 15 individuals, utilize alternative sources such as bottled water and rainfall, following the usage of SONEB and well water. The insufficient availability of safe water has caused many residents to rely on wells as a supplement to the SONEB water. However, a significant proportion of the population uses this method, which may result in health problems due to the use of well water in response to the existing water scarcity, leading to a higher prevalence of diseases. This scenario can heighten the susceptibility to waterborne illnesses, particularly when the well water is not subjected to treatment before to its consumption, bathing, and culinary purposes[26]. Water treatment is crucial in mitigating the health hazards associated with its domestic usage, as it is a vital component of life. The study conducted by Hounkpe et al.[27] collected the following data on the utilization of well water, as presented below:

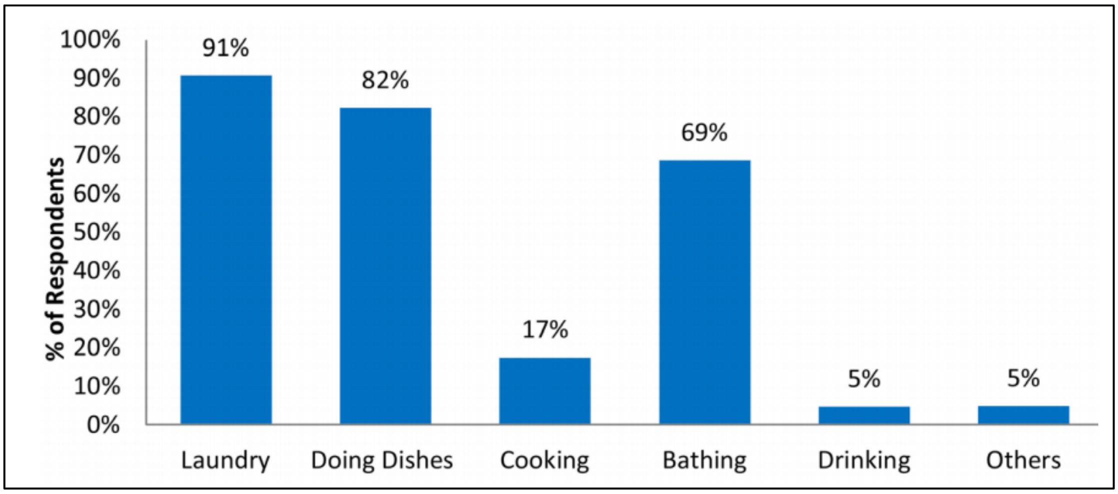

Figure 4. Uses of water from wells (Source: Survey data, Hounkpe et. al[27])

The findings revealed that well water is the predominant supply for non-potable purposes in Cotonou, with a majority utilising it for laundry (91%), dishes (82%), and bathing (69%). Cooking is dependent on well water to a lesser extent, accounting for only 17% of its usage. This indicates the need to explore other sources for this essential activity. Merely a minor fraction (5%) of individuals utilise well water for consumption, emphasising the inherent health hazards and the imperative for secure substitutes. Drinking well water carries a substantial health hazard as it may be contaminated with faecal bacteria, pesticides, and various contaminants.

3.2. Status of sanitation and hygiene in Cotonou

The contamination of well water by bacteria in coastal cities of West Africa has been studied by Yapo et al.[28], Soncy et al.[29], and Totin Vodounon[17]. The lack of adequate sanitation facilities in vulnerable communities, including faulty septic tanks, improper waste disposal, and the close proximity of toilets and pit latrines (within 5 to 10 metres) to water wells, is a contributing factor.

Figure 5. Toilets and temporary ponds close to the wells in Cotonou (Source: Totin et al.[17], Houéménou, et al.[21])

The close proximity of urban homes hinders adherence to the standard 15m distance requirement between wells and latrines, which is necessary to prevent contamination of the aquifer[30]. Furthermore, a prominent feature of sanitation facilities in residences in both cities is the absence of septic tanks, which, if they do exist, are predominantly non-waterproof. During such occurrences, microbial pollutants originating from inadequate sanitation and hygiene practices can easily contaminate groundwater through the development of internal fissures in wells over a period of time. The present urban growth in cities like Cotonou is accompanied by inadequate infrastructure, neglect of gutter maintenance, poor hygiene and sanitation practices, construction of faulty septic tanks within households, and disregard for the recommended distance between wells and latrines[31]. As a result, neighbourhoods situated near lagoons, lakes and the ocean face a dire situation. The correlation between water system contamination and the high level of environmental degradation highlights the improper allocation and use of urban land by individuals in West African towns. Stakeholders assert that urban pollution in complex coastal towns with wet sandy soils is caused by solid and liquid waste, excreta, and floods[32]. Our analysis reveals that approximately 65.7% of the urban population have an unfavourable connection to poor sanitation practices (55.5%), home solid waste (45.5%), and wastewater management (33%). The strategies employed for solid waste treatment include burial, discharge into gutters, bridging the swamp, and burning[18]. These methods have adverse effects on both the environment and human health. Wastewater is primarily released into sumps and dumped onto the streets, gutters, and courtyards of residences, while pit latrines and septic tanks are the predominant methods of disposing of excreta. The irregular collection of municipal waste in coastal areas of West Africa poses a significant difficulty, resulting in unpleasant odours, environmental damage (such as water contamination), and potential health issues[28]. Sanitation and hygiene systems, for which individuals are responsible, are frequently obsolete, inadequately built, unsuitable, or not maintained. Plumbing systems are generally subpar. The absence of latrines and proper upkeep of garbage receptacles, coupled with the indiscriminate disposal of waste in swamps, streets, gutters, and lagoons without previous treatment, serves as an indication of the inadequate understanding of hygiene and sanitation in coastal cities, particularly in the impoverished areas. According to Banerjee and Morella[33] a significant number of sub-Saharan African countries have a sewer infrastructure that serves just approximately 10% of their people. Approximately 85% to 90% of wastewater worldwide is released into metropolitan areas without undergoing any form of treatment[33]. The rise of informal settlements (slums) in developing nations such as Benin and Togo, along with their respective large towns, presents a significant challenge in terms of wastewater generation[12]. West African coastal cities have the challenge of insufficient and flexible infrastructure that promotes sustainable sanitation and hygiene. Another factor contributing to poor sanitation practices is poverty and a lack of awareness regarding the consequences of inadequate sanitation on the quality of water sourced from wells. Insufficient or unsuitable water supply, sanitation, and hygiene in complex metropolitan settings such as coastal cities can have negative impacts on human health, mostly through the spread of water-borne infections, and on the environment, particularly through the release of untreated wastewater[31].

3.3. Well water physicochemical and bacteriological quality status

The authors' examination of the literature on water quality found the presence of both physicochemical and bacteriological contaminants in home wells that are frequently neglected and lacking protection. The analysis of physicochemical characteristics primarily considers factors that allow for the evaluation of water quality or the extent of organic pollution.

3.1.1 Physicochemical state of well water

The fluctuating chemical composition of groundwater in various climatic situations is attributed to alterations in ion exchange, weathering or rock disintegration, seawater intrusion, human-induced pollution, and other contributing factors. The main factors contributing to the presence of nitrate in the local drinking water were determined to be agricultural pollution during the wet season, which was subsequently carried by wastewater during the dry season[17]. The study conducted by Sintondji et al.[14] examined the physicochemical condition of well water in six districts of Cotonou. The results of their analysis are outlined below.

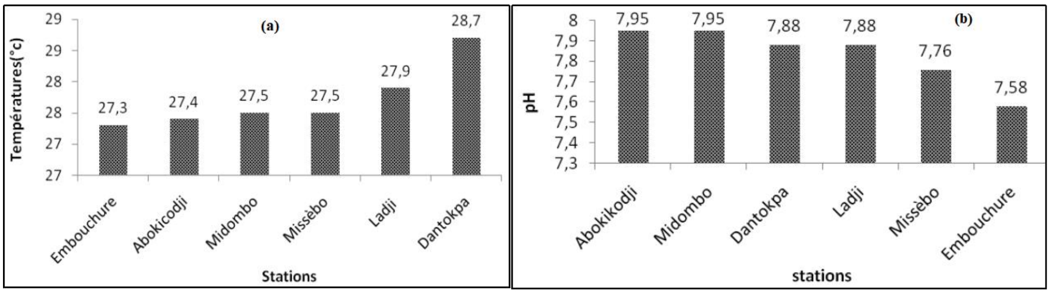

Figure 5. Variations in (a) water temperature (b) hydrogen potential (pH) at the different stations. Modified from Sintondji et al.[14]

All locations have recorded temperatures between 27.3 and 28.7°C, which is within the recommended range of 25 to 30°C for hot water-dwelling aquatic creatures. Specifically, the temperature of the channel's waters is conducive to the existence of many species, notably tilapia guineensis, which thrives within a temperature range of 14 to 33°C[34]. The pH scale, which spans from 0 to 14, is used to measure the acidity or alkalinity of water. It offers a measure of the H+ ion concentration in water. Figure 5 illustrates the pH fluctuations in the water at several sites. The obtained pH values vary from 7.58 to 7.95, with a mean of 7.83. The optimal pH range for promoting the growth of aquatic species is between 6.5 to 8.5, which is considered the accepted norm for water quality.

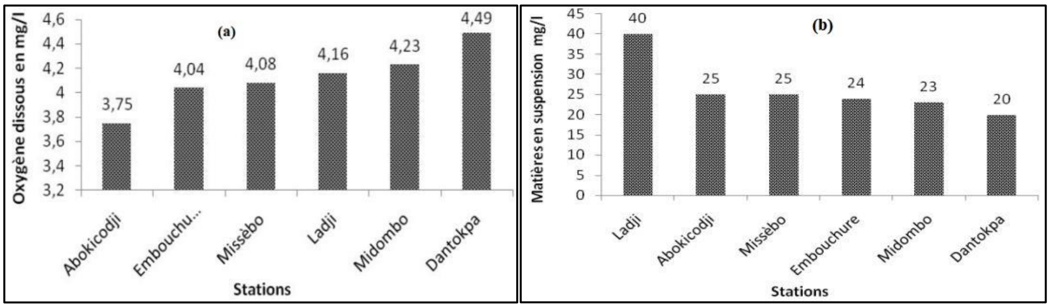

Figure 6. (a) Dissolved Oxygen Concentrations (b) Suspended matter in well water samples. Modified from Sintondji et al.[14]

Adequate levels of dissolved oxygen are crucial for the survival of aquatic organisms. The process of self-purification of watercourses is enhanced through the utilisation of micro-organisms[35]. In their study, Sintondji et al. reported that dissolved oxygen readings recorded at all locations are consistently below the acceptable quality limit of 7 mg/L, ranging from 3.75 to 4.49 mg/L. This can be attributed to a significant abundance of organic matter in this particular environment. Aerobic bacteria, often known as oxygen-consuming bacteria, utilise the oxygen present in water to break down organic substances[36]. The water appears hazy due to the significant concentration of suspended particles. Turbidity fluctuates based on the presence of suspended particles, which can be attributed to the inflow of run-off and the movement of plant waste, animals, and other similar substances. The measured amounts of suspended solids range from 20 to 40 mg / l. Among all the stations, the Ladji station has the highest level of strength, surpassing the acceptable quality requirement of 30 mg/L. This demonstrates the contamination of the lagoon at this location due to anthropogenic activity. The presence of suspended solids at all stations indicates the substandard quality of the channel water, as high-quality water should be devoid of suspended solids. Biodegradable suspended particles have a substantial impact on oxygen demand and lead to a reduction in the concentration of dissolved oxygen in the aquatic environment[37].

3.3.2. Water quality index

The estimated Water Quality Index (WQI) and the current status of water quality reported by Vodounon et al.[18] are displayed in Table 2. The Water Quality Index (WQI) for well water in Cotonou varies between 37.3 and 144.3 during the great rainy season (GRS), between 35.9 and 169.6 during the small dry season (SDS), and between 47.6 and 161.0 between the small rainy season (SRS) and the great dry season (GDS). The WQI values also suggest that, on average, 91% of well water samples in Cotonou fall into the categories of poor to unsuitable for drinking, particularly during the dry seasons. The representation of good water quality in Cotonou is rather low, with 21% during the great dry season, 7% during the little dry season, and in the small wet season.

Table 2. The Water Quality Index (WQI) assesses the condition of water quality and the distribution of seasonal well water samples in Cotonou.

WQI	Water Status	Cotonou			
		GRS	SDS	SRS	GDS
0-25	Excellent water quality	0%	0%	0%	0%
26-50	Good water quality	21%	7%	7%	0%
51-75	Poor water quality	36%	29%	29%	14%
76-100	Very poor water quality	29%	29%	43%	64%
>100	Unsuitable for drinking	14%	36%	21%	21%

Sadhana et al.[38] have shown that the microbiological quality of shallow groundwater decreases dramatically during the wet season compared to the dry season, based on statistical analysis. This pertains to a significant volume of water movement and the spread of contamination resulting from the disposal of waste. The bacterial concentration above the drinking water criteria set by the World Health Organisation (WHO)[9], indicating a significant level of faecal contamination in the groundwater. The contamination of well water by bacteria is linked to the presence of waste deposits, toilets, and pit latrines located within a distance of 5 - 10 metres from the well. It is also related with faulty septic tanks and the infiltration of wastewater into shallow aquifers at depths ranging from 0.5 to 2 metres. Azzellino et al.[39] verified that the quality of groundwater in heavily urbanised regions is significantly impacted by human activities, specifically through the spread of pollution from various sources. The anthropogenic sources of waste in Cotonou include residences, agriculture processing facilities, industries, and construction companies[40]. These sources contribute chemical and bacteriological pollutants to the groundwater system. Therefore, within the framework of climate change, the yearly flooding in Cotonou worsens the decline of urban groundwater quality due to the spread of pollution from improper and unofficial methods of disposing of waste, including as pit latrines, sumps, gutters, residential sewage, and landfills. Sadhana et al.[38] hypothesised that the seasonal variation may be attributed to two hydrological phenomena: the intrusion of pollutants and fluctuations in the water table. The prevailing sandy soils in Cotonou, together with the relatively low amount of groundwater, appear to corroborate the theory that environmental variables are contributing to the deterioration of groundwater quality.

3.3.3. Bacteriological state of well water

The quality of well water in Cotonou is a significant concern due to variables such as ion exchange, rock disintegration, seawater intrusion, and human pollution. The primary contributors to nitrate levels in the local drinking water are agricultural pollution during the rainy season and the subsequent transfer of this pollution through the replenishment of groundwater by wastewater during the dry period[41]. Anthropogenic activities, such as the application of inorganic fertilisers and animal manure, as well as the installation of pit latrines, are responsible for the deterioration of groundwater quality. Bacterial analysis has repeatedly detected bacterial contaminants such as total coliforms, Escherichia coli, and faecal streptococcus that are beyond the drinking water criteria set by the World Health Organisation (WHO)[9]. The degradation of groundwater quality in Cotonou is exacerbated by inadequate sanitation and unsanitary behaviours[42]. The shallow nature of the quaternary sandy aquifer enhances susceptibility to contamination and infiltration of micro-pollutants. Azzellino et al.[39] substantiated the human-induced impact of dispersed pollution on the quality of groundwater in densely urbanised regions. Inadequate sanitation and hygiene facilities significantly contribute to the degradation of the bacteriological quality of well water. The presence of pathogens in well water may be attributed to the infiltration of sewage. Nevertheless, the presence of these substances in surface water is linked to the faeces deposited by humans and animals[42]. Adandé, 2021 reports the detection of faecal coliforms in the collected water. The presence of E. Coli in food and drink not only indicates recent faecal contamination, but also indicates the probable presence of pathogenic bacteria and protozoa. Therefore, this is a reliable indicator of faecal contamination. Figure below depicts the concentration of E. Coli in the sampled waters.

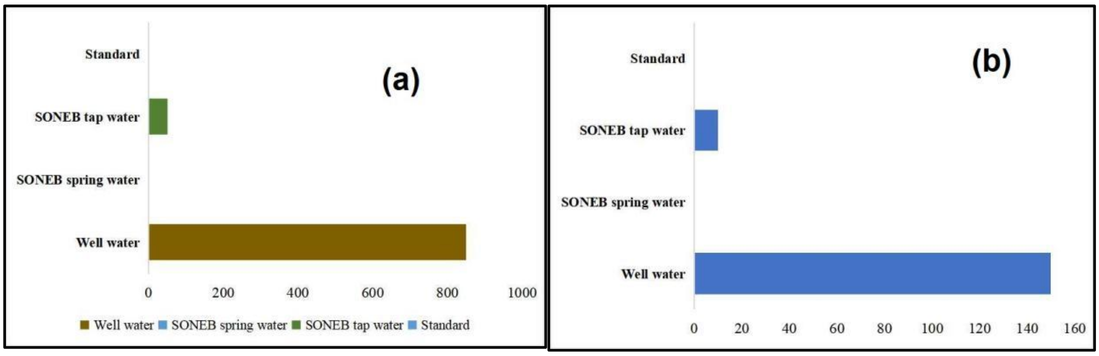

Figure 5 (a) Quantification of faecal coliform levels in the water samples; (Source: Field data, Cotonou, Adandé, 2021) (b) Water and vegetable in E. Coli samples; (Source: Field data, Cotonou, Adandé, 2021)

According to the bacteriological requirements of the Beninese standard, which states that there should be no E. Coli bacteria present in 1 millilitre of water, the well water and SONEB water at the household level have a significantly higher quantity of E. Coli bacteria than the norm allows[43]. The studies conducted by Totin et al.[17] and Soncy et al. in 2015 revealed that there are significant levels of Escherichia coli in the wells of Cotonou[44]. This is attributed to the transfer of organic pollutants during the period when groundwater is being replenished. The temperature rise causes a significant growth of bacteria, resulting in the excessive generation of carbon dioxide[45]. Unsecured wells frequently experience flooding during the rainy season, leading to the contamination of water with waste and excrement from insufficient latrines. In order to address the susceptibility of groundwater in Cotonou's dynamic environment, it is necessary to develop policies that ensure the provision of clean water in the face of population expansion. In addition, a study conducted by Y. Georges[31] offered significant findings to demonstrate the abundance of bacteria in well water. Laboratory examination was conducted on water samples from five wells in different areas of a district in Cotonou to assess the bacteriological quality of the well water. The results of the analysis are shown in Table 1.

Table 1: Bacteriological results of Cotonou well water samples (Georges, 2022)

	Hinde 1	Djidje 1	Ahouansori	Ladji	Toweta 1	Standard
Common germs	8000	46000	520	40000	512000	50
Coliforms totals	10000	30000	7000	44000	20000	0
Coliforms fecal	9000	1000	440	10000	2000	0
E. Coli	1000	1000	80	2000	1000	0
Stretococci fecal	1000	31000	0	4000	2000	0

Hindé 1: The significant prevalence of total, faecal coliforms, and common pathogens indicates that the well water has low hygiene standards, making it unsuitable for direct use as a beverage. Furthermore, it is contaminated with animal faeces. Djidjè 1: The elevated prevalence of typical pathogens, such as faecal streptococci and total coliforms, indicates that this well also exhibits substandard hygiene conditions. The water from this well contains human faeces and is unfit for consumption. Ahouansori: The concentration of total coliforms exceeds that of other microorganisms. The significant quantity of total coliforms indicates that the water is not suitable for consumption, so the absence of faecal streptococci does not indicate acceptable water quality. The water in Ladji honto is of poor quality and is not suitable for consumption due to its high concentration of total coliforms and common pathogens. Test 1 reveals a significant presence of common germs and total coliforms, rendering this water of low quality and unsuitable for consumption. The bacteriological investigations reveal that all the wells examined contain organic contamination. Indeed, the levels of common bacteria, total coliforms, faecal coliforms, Escherichia coli, and faecal streptococci in them exceed the acceptable threshold for drinking water by ten to ten thousand times. The Ahouansori well is the only well that is free of faecal streptococci. These results are consistent with the data obtained from health centres. Health experts can detect the presence of bacteria such as faecal streptococci, Escherichia coli, total coliforms, and faecal coliforms by conducting bacteriological studies on well water. Based on the aforementioned findings, the majority of individuals who rely on well water for their household requirements are subject to a significant hazard by utilising this water source. The danger is elevated due to the utilisation of untreated well water and the lack of adherence to proper sanitation practices, resulting in a range of health ailments, as indicated by the study.

3.4. Health issues linked to well water in Cotonou

Several studies have established a correlation between the consumption of well water in Cotonou, Benin, and a heightened susceptibility to diarrheal illnesses such as typhoid fever, hepatitis A, amoebiasis, and diarrhoea[46]. These studies indicate that the occurrence of faecal coliforms, E. coli, total coliforms, Giardia lamblia, and Cryptosporidium parvum in well water heightens the likelihood of specific health issues. Several natural and human factors, such as differences in land elevation, changes in water and climate patterns, and geological influences, affect both water supply systems and environmental well-being[47]. These factors encompass population density and uncontrolled land utilisation. As to the research conducted by the World Bank and submitted to the United Nations in 2019, there is a hidden issue concerning water quality worldwide[48]. This problem has the ability to decrease the economic growth of consistently contaminated areas by one-third and put human and environmental health at risk. The substandard hygiene and sanitation conditions in Benin have a detrimental impact on the quality of the country's potable water. Unsanitary living conditions contaminate sources of drinking water, facilitate the transmission of diseases associated with the oral-fecal route, and enable the transfer of these pathogens between individuals. Diarrhoea and stomach infections pose significant risks to one's health. In a study conducted in 2015 by Yongabi et al.[46], it was discovered that children who consumed water from wells containing elevated levels of faecal coliform were five times more prone to experiencing diarrhoea compared to children who used water from wells with lower levels. Consuming well water in the 6th district of Cotonou has been linked to several health issues, such as cholera, diarrhoea, vaginal infections, skin disorders, and gastroenteritis[31]. An analysis of the well water samples in the district indicated elevated levels of coliforms, faecal coliforms, Escherichia coli, and faecal streptococci, beyond the permissible limits set by the United Nations for drinking water. Individuals are compelled to utilise well water of dubious quality as a result of harsh local circumstances and a scarcity of hydraulic equipment, so endangering their well-being. Although certain households in the area employ boiling or chlorination methods to eliminate germs and other pathogens from their well water, these approaches may prove ineffectual if not executed correctly. Bacterial analysis revealed elevated concentrations of common germs, total coliforms, faecal coliforms, Escherichia coli, and faecal streptococci in well water samples, surpassing the permissible limits set by the UN for drinking water. The district's well water is of substandard quality due to poverty and inadequate hydraulic equipment, posing a threat to human health. The well water supply in Cotonou is a cause for worry due to its inadequate physicochemical and bacteriological quality, as well as the high incidence of waterborne diseases such as malaria, gastroenteritis, and diarrheal disorders. The well water in Cotonou has been discovered to contain significantly elevated levels of total coliforms, Escherichia coli, and faecal enterococci/streptococcus[18]. These findings indicate that the water is of extremely low quality and should not be consumed. The health problems are linked to the district's use of well water for drinking purposes, underscoring the necessity for additional initiatives to raise awareness about cleanliness and hygiene, as well as improve the availability of potable water. In order to safeguard the health of the population, it is imperative for the government to endorse adequate sanitation practices and enhance the affordability of potable water. The findings indicate a significant threat to public health due to the presence of contaminated well water in Cotonou. In order to enhance access to piped water and raise public knowledge regarding the significance of safe drinking water, it is imperative for the government and public health agencies to implement measures aimed at enhancing the quality of Cotonou's drinking water. A significant obstacle for the movement to ensure access to and sustain the availability of these resources is the absence of definitive proof about the consequences of system failure on the advantages of enhanced drinking water supplies for public health[49]. It is crucial to examine the reliability of these systems and evaluate their effect on public health goals regarding the potential enhancements in public health that can be attained through interventions aimed at providing safe drinking water to communities[50]. Reports indicate that choleraic vibrios and typhoid bacteria have the potential to pollute well water, hence endangering the riparian community[18, 28, 46]. In addition, the significant mineral content, abnormal levels of ammonium and nitrite ions, and the existence of trace elements such as iron and aluminium suggest a deterioration in the physicochemical characteristics of the groundwater in Cotonou. The need of enhancing the quality of well-water and sanitation systems in Cotonou is underscored by these health concerns, since it is crucial for protecting the health of all people.

3.5. Recommendations for improved water quality and sanitation

Sanitation and the availability of potable water are crucial for preserving human health and overall welfare. Nevertheless, encountering these essential requirements poses significant challenges in Cotonou. Yetongnon et al.[31] found a correlation between the district's utilisation of well water and an increased susceptibility to waterborne diseases such as amoebiasis, typhoid fever, diarrhoea, and hepatitis A. This study presents a range of recommendations to improve sanitation and water quality in Cotonou, aiming to address these problems effectively. Sanitation and the availability of potable water are essential for human well-being and prosperity. However, some developing nations, such as Cotonou, continue to have challenges in ensuring that their populations have access to uncontaminated water and adequate sanitation facilities[27]. Multiple factors, including urbanisation, exponential population growth, and insufficient infrastructure, contribute to this issue. Poor sanitation and water quality in Cotonou exert a significant impact on the health of its residents. These difficulties can lead to a variety of waterborne diseases, including cholera, typhoid fever, hepatitis A, and diarrhoea. These diseases have the capacity to be life-threatening or cause significant impairment in children. Currently, there is an insufficient supply of potable water in Cotonou to meet the demands of the entire population[51]. Expanding the number of households connected to piped water systems is crucial for enhancing the availability of potable water. Furthermore, it is imperative to educate well operators and owners on appropriate well maintenance and disinfection methods. This will reduce the likelihood of contamination from alternative sources, such as fecal matter. The growing population of Cotonou is putting strain on the city's water resources. In order to ensure an adequate water supply for all individuals, it is imperative to promote responsible water consumption. One way to achieve this is by implementing water conservation measures, such as leak detection and repair programs, and by educating the public about the importance of water conservation. Cotonou lacks enough infrastructure for the treatment and disposal of wastewater. Consequently, both groundwater and surface water are being polluted. In order to mitigate the risk of waterborne diseases, it is imperative to allocate resources towards the development of wastewater treatment infrastructure. It is crucial to educate the public about the need of proper wastewater disposal. In Cotonou, the existing rules and processes for ensuring cleanliness and water quality are now inadequate. This leads to a violation of water quality rules. In order to ensure that water providers are meeting the necessary standards for providing safe drinking water, it is imperative to strengthen the regulation and enforcement measures. The issues of sanitation and water quality in Cotonou necessitate a solution that involves multiple stakeholders. For the development and implementation of solutions, it is essential to involve the government, water providers, community organizations, and the business sector. Enhancing the water and sanitation quality in Cotonou is a challenging yet crucial undertaking for the overall health and well-being of the community. Cotonou should take action by implementing the recommendations outlined in this report. Improving the water quality and sanitation in Cotonou is essential for promoting the city's economy and safeguarding public health.

4. Conclusion

The findings underscore the presence of organic, chemical, and microbial contamination in the tap water commonly utilised in houses in Cotonou. This serves as a cautionary message to the local community. Disposing of garbage into the environment causes harm to both soil and water resources. The study's strategy centres on the origins of water supply, the well water's quality, and its detrimental impact on human health in the specified district. According to the survey results, the population's drinking water supply is distributed among three sources: SONEB (26.7%), SONEB and wells (63.33%), and other sources (10%). Nevertheless, the limited percentage of individuals exclusively utilising SONEB water indicates that various factors impact the exclusive use of drinking water in households. These factors include the socioeconomic status of the populations, the geographical positioning of these communities, inadequate management of solid and liquid waste, and prevalent poor hygiene in these areas. These factors are all contributing factors that rationalize the use of dubious sources, such as groundwater. Although the study has provided information about the current condition of wells in various areas of Cotonou, the challenge of promoting knowledge about the dangers of using untreated well water, which might result in the diseases mentioned in this study, still persists. In order to mitigate these health hazards, the populace resorts to therapeutic techniques such as boiling and employing lemon juice due to the absence of affordable measures to effectively address this issue. The health consequences of utilising well water are expected to escalate in the future, particularly in peri-urban regions like those examined in this study. This is due to the observed lack of adherence to hygiene and sanitation regulations, rapid population expansion, and challenges associated with providing clean water in these settings. The enhancement of well water quality in Cotonou will be achieved through the establishment of flexible socio-ecological systems for sanitation and the promotion of healthy hygiene practices. In addition, implementing strategies such as deepening well drilling, relocating landfills away from wells, and installing protective fences around wells can contribute to the maintenance of a secure and reliable well water supply.

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