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Water Supply System Description and Risk Assessment in Brikama Water Treatment Plant System, West Coast Region, Gambia: WHO Water Safety Plan Based Approach

Amadou Barrow[1], Baboucarr Corr[2], M. Mustapha[3*], Rex A. Kuye[1] and M. K. C. Sridhar[4]

[1]Department of Public and Environmental Health, School of Medicine and Allied Health Sciences, University of The Gambia, Kanifing, The Gambia.
[2]National Water and Electricity Company, Kanifing, The Gambia.
[3]Department of Agricultural and Environmental Resources Engineering, Faculty of Engineering, University of Maiduguri, Maiduguri, Nigeria.
[4]Department of Environmental Health Sciences, Faculty of Public Health, College of Medicine, University of Ibadan, Ibadan, Oyo State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Authors AB, BC and MM designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AB, MM, RAK and MKCS managed the analyses of the study. Authors AB and MM managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Background: Better water quality, improved sanitation and sound water resource management will improve public health and economic development in low-income countries. Water safety plan-based risk assessment and risk management from catchment to consumers are the modern and efficient approaches to safe drinking water supply established by World Health Organization. Thus, this paper aimed to assess risk from catchment level to consumers in the community of Brikama.

**Corresponding author: E-mail: mohammedmusty@unimaid.edu.ng, mohammedmusty88@gmail.com;*

Methods: This study report assessments of risk or hazards from catchment to consumers in Brikama Water Treatment Plant (BWTP), West Coast Region, The Gambia. The various means of data collection used include water quality monitoring, visual field inspection and questionnaire survey to explore data on where the water supply system goes wrong from catchment to consumers, so as to provide an improvement plan.

Results: Overall, the day-to-day administration of services at BWTP was very impressive. The fencing of all the 17 boreholes at catchment sites has drastically reduced the risk of contamination including treatment systems and distribution lines. There are less risks observed and constant monitoring of the system was ensured. However, at the consumer end, there are some risks with poor practices associated with water handling, storage and hygiene measures at the household level. Some still use some unclean 20-liter containers to store water and indiscriminately kept drinking cups on the floor and unclean surfaces, and 50% lacked WASH knowledge related to water treatment, such as boiling and filtration at households. The overall perception of water storage, sanitation and hygiene practices could be rated moderately good.

Conclusion: The overall findings of this study have shown tremendous achievement in the government's commitment to providing potable water to the people in Brikama Local Government Area. WASH education in the study area is recommended to avoid waterborne disease infections.

Keywords: Risk assessment; Brikama water treatment plant; waterborne disease; catchment; consumers.

1. INTRODUCTION

Clean and readily accessible water is vital for public health [1,2], whether used for drinking, domestic use or industrial processes. Better water quality, improved sanitation and sound water resource management will improve economic development in low-income countries and make a major contribution to reducing poverty. In 2010, the United Nations General Assembly expressly recognized water and sanitation as human rights [3]. However, the WHO reported that approximately 10 % of the world's population lack access to improved drinking water supplies [4]. Among other diseases, waterborne infections cause diarrhoea, which kills about one million people per year, mainly children under the age of 5 [5,6]. On the other hand, chemical contamination is an issue and a growing epidemic in low-and middle-income countries. Exposure to drinking water contaminants can lead to a variety of chronic non-communicable diseases e.g. cancer, cardiovascular diseases, adverse reproductive effects, and effects on children's health (e.g., neurodevelopment), among other health effects [7]. While drinking water quality is controlled and monitored in many countries, increasing awareness leads to an almost permanent review of standards and guidelines for both controlled and newly identified contaminants [8].

Municipal authorities involved with water supplies are responsible for clean drinking water supply; however, WHO in 2004 introduced a comprehensive systematic risk assessment and risk management framework from catchment to consumers, as the safest way of supplying quality water to the public, known as the *Water safety plan* [1,2], the plan is based on the understanding that the usual monitoring of drinking water at a final product to determine its safety and cleanness is insufficient and uneconomic in public health protection [9] because the analysis can often be too little and too late [1,2,10]; consequently, the detection of risks might be too late or might not happen at all, leading to negative health effects [10]. More so, due to the complexities and uncertainties affecting water supply systems and threatening hazards, for example, catchment protection may reduce the chances of occurrence of chemical pollutants and bacterial outbreaks due to treatment failures [11], lack of proper maintenance, water quality monitoring and increased vigilance within the treatment system may result in contaminated water supplied to consumers [12]; a good quality water supplied to consumers can get deteriorated before arrival at consumers point due to poor water distribution system [13]; also, safe water delivered at households can be made unsafe due to unhygienic storage and handling attitudes of consumers thus causing recontamination at households [14,15]. Hence, a consistent safe water supply is surrounded by factors in catchment, treatment system, distribution, and consumer points. Therefore, the WHO recommended globally to adapt into a proactive and preventative approach through risk assessment and risk management from catchment to consumers (Bartram et al. 2009).

Water Safety Plan (WSP) is currently being implemented successfully in several countries and is expected to become increasingly an important tool for water management in both developed and developing countries [16,17]. WSP facilitates an increase in awareness and understanding of systems vulnerabilities, which serve as a baseline for providing safe drinking water (Rosen et al. 2008). However, before developing and implementing WSP, there is the need for a quantitative understanding of how processes and actions affect water quality, which in turn requires an understanding of environmental risk assessment (Rosen et al. 2008). Therefore, this study aimed to assess potential environmental risks across the various stages of water processes (catchment, storage, treatment, distribution and consumers) at Brikama Water Treatment Plant, Brikama, West Coast Region, The Gambia; using the Water safety plan approach. The risk assessment helps in identifying hazardous events, appraise their implications on the health of the populace [18]. With children especially at risk from water-related diseases, access to improved water supplies can lead to better health and thus better school attendance, with positive long-term effects in the study area [5,6,7,19]. The outcome of the study could be of interest to both managers of the water utilities and decision-makers towards providing an improvement plan for the risks identified. The study also explores the perception and satisfaction level of consumers on water services in the Brikama catchment area.

2. MATERIALS AND METHODS

2.1 Background Information of Brikama, the Gambia

The Gambia is situated in the middle of the western coast of Africa and extends over 400 kilometers inland from west to east on either side of the Gambia River, ranging in width from about 50 km near the mouth of the river to about 24 km upstream. The country is bound north, south and east by the Republic of Senegal and the Atlantic Ocean on the west. The Gambia River, which runs the entire country from the Futa Jallon highlands in the Republic of Guinea to the Atlantic Ocean, divides the country's land area of 10,689 square kilometers almost evenly into two halves: South Bank and North Bank [19]. Gambia's climate is usually Sahelian, with a long dry season from November to May, and a short rainy season from June to October. The Gambia River estuary is essentially a tidal inlet with salt water intrusion, ranging from 180 km upstream during the rainy season to 250 km in the dry season. Irrigable land is scarce and thus agriculture, which is the backbone of the Gambian economy, is largely rain-fed. As a result, agricultural operations are subject to large seasonal variability and production levels are prone to variations in rainfall [20].

Brikama is the largest town within Kombo Central District which is located in West Coast Region with a population of 699,704 people [20]. Brikama is divided into 24 wards (kabilos). Each ward is headed by an Alikalo who is aided by a council of elders. However, all these Alikalos are headed by a supreme Sefo whom all the various Alikalos are answerable to. This study was conducted at Brikama town.

2.2 Background Information of Brikama Water Treatment Plant (BWTP)

Brikama Water Treatment Plant (BWTP) was inaugurated by the former Head of State, President Yahya AJJ Jammeh, on Tuesday 28th July 2009. The construction of the site was contracted to Ballast Nedam and was successfully completed as expected. The water treatment plant is among the three treatment plants in the whole of Greater Banjul Area (Serrekunda, Sukuta and Brikama) These are all under the services and supervision of National Electricity & Water Company (NAWEC) which is a parastatal of the Gambia Government. BWTP has a total of 17 captions/catchments as shown in Fig. 1, that supply raw water to the plant from boreholes and are mainly in and around the Brikama forest.

2.3 Study Designs

An analytical cross-sectional study design involving sanitary inspection, interview and questionnaire were used for this research, in accordance with the WHO guidelines [21]. Furthermore, triangulated methods of qualitative and quantitative approaches were used in order to adequately and explicitly describe the study variables as required. The entire data collection phase of the study was conducted from December 21, 2019 to February 13, 2020.

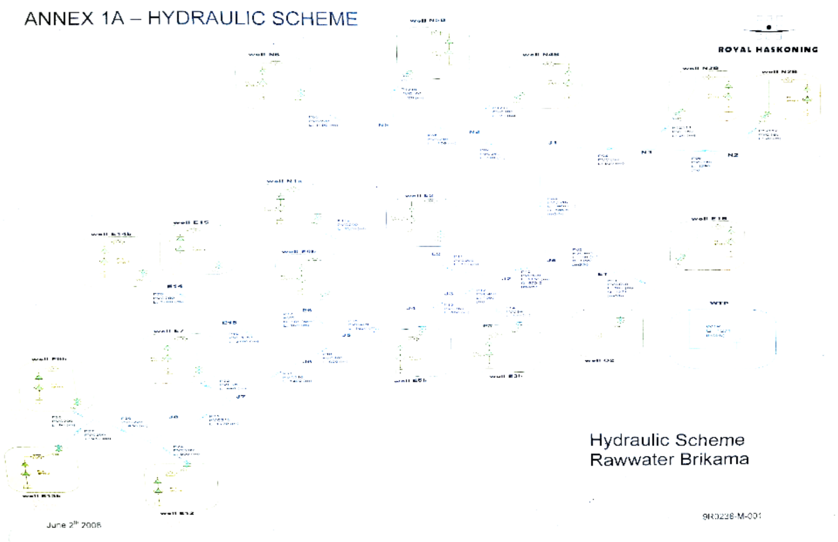

Fig. 1. Distribution of the 17 boreholes supplying BWTP

2.4 Data Collection Tools

2.4.1 Field visits

Sanitary and visual inspection visits were conducted for the catchment, treatment plant, and distribution chain. Other components such as the consumers' points, catchment operations, surrounding areas of water abstraction points, treatment components, structures and facilities of distribution network and household storage systems were also assessed accordingly.

2.4.2 Key Informant Interviews

During the visits, core staff especially the water superintendants, work supervisors, key consumers in both households and selected government institutions were interviewed on the type of water supply system, operating techniques being applied, treatment units/processes, various chemicals used for treatment, storage system, pumps and pumping, distribution system, available documents that describe the system (flow charts, operating techniques, etc.) control measures, challenges and environmental effects. Furthermore, the interviews were conducted along with site visits for visual inspection which subsequently helped in hazard identification.

2.4.3 Households and consumers questionnaire

A total of 60 consumers at household levels were systematically sampled and recruited for the administration of a short consumer questionnaire with the aim of assessing their awareness level on water quality, storage, handling as well as their perceptions and satisfaction level of water services by NAWEC. Furthermore, brief socio-demographic characteristics of the consumer in relation to water quality, storage, handling and perceptions were examined. Hence regularity of water supply to consumers, type of household storage systems used, household treatment methods if any practiced and hygiene measures were also studied.

3. RESULTS

3.1 Catchment Process

The study noted that a total of 17 boreholes were used to supply raw water to the treatment plant. These boreholes were drilled in the early 2009.The average depth of the 15 boreholes was 65m and the highest recorded was 105m while the shortest was 48m in depth. The production capacity of water for these boreholes varies from 40m^3/hr to 104m^3/hr which is inclusive of 75m^3/hr, 85m^3/hr and 95m^3/hr. However, the findings of the physical observations or visual inspection conducted across some randomly selected boreholes at the time of the field visits indicated that the general surroundings of the boreholes were very clean and confined (fenced) with the secured gate of access to only authorized personnel of NAWEC. These made it possible to protect the immediate environment of these boreholes from being accessed by animals. There was no stagnation of water or refuse heaps within 50 meters circumference around the visited boreholes. A fence was constructed at least 20m^2 area around the boreholes with 7 meters of fence height. The borehole structural materials were relatively clean and no corrosion was observed for all the extraction parts for all the five boreholes visited. The extraction materials were made out of painted but galvanized irons that were looking relatively fresh and clean. In terms of determining the depth, capacity and specific water parameters as per boreholes; a dedicated Central Control Panel (CCP) was installed at the administrative block of BWTP that controlled and visualized all process from extraction sites to all other internal processes including storage, water treatment, and distribution. The CCP, also called the distributed controlling system (DCS), centralized plant operations to ensure the flexibility and simplification of individual components and processes by centralizing controlling, monitoring and reporting. A CCP is designed to manage complex processes which may be disseminated geographically using the system-wide distribution of networked control elements.

The CCP as shown in Fig. 2, also shows the entire processes in the treatment plant and could automatically detect problems and troubleshot without manual operations. The functionality and regulation of all the 17 boreholes that supply the treatment plant are all screened and controlled by the panel. The computer screen was found to be dysfunctional at the time of the visit.

3.2 Pre-Treatment Storage

This is the temporal storage of the water prior to the treatment phase with a cumulative capacity of 1500m^3/l from the quantity supplied by the 17 boreholes of the plant. Water is temporarily stored at this stage for a few minutes to hours depending on the amount of water pumped from the boreholes which are also determined by the number of functional ones. It is from this stage that the raw water is pumped to the aeration chamber.

3.3 Water Treatment Processes

At this stage, two major types of water treatment takes place at BWTP namely aeration and chlorination.

3.3.1 Aeration

At this stage, aeration through natural pressure is used for the process. In order to eliminate dissolved gasses (such as carbon dioxide), the aeration promotes water and air in close contact, oxidizing metals that are dissolved such as iron, sulfides of hydrogen and organic volatiles (VOCs). These components are removed or adjusted during aeration until the processes can intervene. Aeration puts water and air in direct contact with the air by exposure of drops or thin sheets of water, or through tiny bubbles of air and causes water to rise. The scrubbing mechanism triggered by the aeration turbulence separates dissolved gasses physically from the solution and allows them to escape to the atmosphere [22].

As shown in Fig. 3, the aeration chamber is the first stage of the water treatment processes at BWTP and there were a lot of colored exudes stained around the filtration micro iron grids at the time of the visits. These show how the majority of volatile organic chemicals and oxidized dissolved metals were extracted from the water which formed stains around the grids and walls of the establishment.

Fig. 2. Central Control Panel (CCP) installed at BWTP

Fig. 3. The Aeration chamber at the water treatment process at BWTP

3.3.2 Chlorination

This is the second stage of the treatment process at the treatment plant. The gaseous form of chlorine was found at the time of the visits. The system use 5mg/litre of chlorine gas at Brikama Water Treatment Plant. There is also an ultimate aim of having a minimum of 0.1mg/litre of residual chlorine at the end-point of the supply.

3.4 Storage of Treated Water

At BWTP, there were only two tanks with a capacity of 1500m^3/l. These tanks are situated at underground level which later pumped to the elevated tank for distribution. These storage systems were made out of cement while the elevated ones are made out of steel iron. The underground storage system are cleanse once per year and the water store in them is continuous on 24 hours basis. They are ash-white or golden black in color. In terms of catchment water composition, they have a chlorine taste, colorless in nature and have good turbidity. Moderate humidity was observed as well as protected lids provided for the two openings of the two storage systems.

3.5 Distribution

At this stage, transmission pumps are used to pump to elevated tanks at a higher pressure for 24 hours services as per storage capacity of the treated water. At the treatment plant, a total of 6 transmission pumps were installed and were all functional at the time of the study. A total of 4 elevated tanks are installed in the Brikama region. Out of these, water gets distributed to the rest of the neighborhood settlements and streets to the consumers. During this process, it was revealed that the pipe size connecting caption to the treatment plant was 300mm while those connecting the treatment plant to the elevated storage tanks were 250mm. The lateral pipes were 100 to 150 mm, connecting the elevated storage tanks to the neighborhood streets.

At the consumer level of the distribution, smaller-sized pipes such as 1-inch (2,4cm) quarter pipes are used for 150m distance while 1-inch pipes are used for a distance less than 100m. It was further revealed that breakage or bursting of pipes in the distribution phase at the community levels were not automated and could only be noticed by reports from the community members or NAWEC field workers. As a result of their constant monitoring of the system, it was reported that unapproved connection of pipes are not major problems at the time of the visit. There were more public tapes before than now and they are standpipes made out of galvanized steels.

3.6 Household and Consumer Awareness and Perceptions on Quality and Storage of Drinking Water

The mean age of household consumers in this study was 44.3 years old, with a standard deviation of ±14.4. More than one-third of the consumers were 26-39 years of age, as shown in Table 1. Slightly more than half of the respondents were male, while about 88.3% reported being married, 48.3% were found to have Madarasa (Arabic) education. The majority of the consumers were Muslims and housewife was reported as the main occupation of the participants. The mean monthly income was D2341.7 (dalasis) with a standard deviation of 1822.3, while the family size was 16 with a standard deviation of 5.

The study revealed that all consumers get their drinking water supply from NAWEC and are stored at the household level. The two most popular materials used to store water for drinking at household levels were plastic containers and refrigerators. Of these, almost 9 of every 10 consumers have their water collection points at homes. More than half of the consumers use plastic containers to collect and transport water for household consumption, as shown in Table 2. As shown in Table 3, half of the consumers checked for the wholesomeness of the water before drinking. Out of which, 100% of them reported looking at the taste and smell, dissolved chemicals, and appearance to determine how safe the water is. The majority of consumers (84.3%) reported filtration of water as domestic household water treatment methods. In terms of knowing the reasons for boiling drinking water at household levels, 50% reported that they do not know why the practice is done as well as the effectiveness of filtration of water for drinking purposes. Almost two-thirds of the consumers believed that poor water quality is detrimental to human health. About 78.3% reported that poor water quality causes diarrhoea and other gastrointestinal diseases.

About 50% of the consumers perceived that boreholes are the major source of NAWEC water supply to their households and about 72% reported paying their monthly water bills regularly. However, 7 out of every 10 consumers reported that the water supplied by NAWEC is enough for their needs. At the same time, only 65% perceived that NAWEC is doing enough to protect their drinking water quality. About 55% of the consumers were satisfied with the quality of tap water in their homes/neighbourhoods, as shown in Table 4.

4. DISCUSSION

4.1 Catchment

Catchment protection is imperative for the delivery of safe drinking water. Safeguarding source water helps prevent the system's source of water pollution, and ultimately the risks of exposure to the served population if efficient treatment barriers were not implemented. There are better water sources which mean less expenditure on health, as people are less likely to fall ill and incur medical costs; and are better able to remain economically productive [23,24]. However, the quality of water can be affected by socio-economic activities around source water, inflow from the sewage system and agricultural activities [25,26,27]. In the study area, the surrounding area of the 17 boreholes used as the source of water supply to the treatment plant were well protected, cleaned, and distant from any source of pollution, which has drastically reduced the risk of contamination, primarily chemical and biological elements. This is evidenced by the indicative parameter composition of the water quality described as balanced within the tolerable range of WHO standards.

Furthermore, the borehole areas were fenced to restrict access by animals which otherwise may result in vandalization and animal fecal matter pollution of the water supply system [28]. This finding is contrary to some similar risk assessment studies in developing countries where water sources were unprotected, presenting serious hazards to the supply system [26,27]. Nonetheless, the Central Control Panel (CCP), which is crucial for detecting and troubleshooting faults with the water supply and treatment systems and operations, was observed to have a damaged screen. The CCP helps determine the depth, capacity, and specific water parameters as per boreholes and through which faulty components were displayed. Hence, a dysfunctional CCP screen can affect early and efficient detection and timely repairs of faulty facilities; for example, as reported by Malika et al. [26], WSP risk assessment studies were burst, leaking, and broken pipes last for days and weeks without due attention, could be detrimental to the smooth running of the system and overall health of consumers.

4.2 Treatment and Storage

Effective treatment processes and operations are key to a sustainable quality of water distribution to consumers; proper maintenance and optimized operations are vital risks associated with the treatment system [28]. In the study area, water aeration and chlorination were the treatment methods being deployed to make water clean, and the systems were well maintained except for few stains observed.

Although this has not affected the water quality, However,there is a need to regularly clean in order to sustain sanitation around the aeration system. At storage, systems were also cleaned regularly, and protected lids were provided. Moreover, stored water quality was found with good physical characteristics [29].

4.3 Distribution

Management of risks along with the distribution system also ensures safe drinking water delivery to public health. Inadequate drinking water distribution may lead to disease outbreaks and contaminations. Cross connections, pressure drops leakages in pipes, disinfectants by-product formation, illegal connections are common risks of effective water distribution [28,27,30]. At the Brikama water supply system, there are no many risks observed and constant monitoring of the system were ensured; nevertheless, a minor repairs/upgrade are necessary where breakage or bursting of pipes were not automated and were only noticed through reporting by consumers, this corresponds to the findings Malika et al. [26], which may not be quite efficient.

Table 1. Socio-demographic characteristics of water consumers

Variables	Frequency (n)	Percentage (%)
Age of consumers		
≤25 years	3	5.0
26 – 39	24	40.0
40 – 52	13	21.7
53 – 66	13	21.7
67 – 79	7	11.7
Mean (SD)	44.3 (±14.4)	
Sex of consumers		
Male	34	56.7
Female	26	43.3
Marital status		
Single	7	11.7
Married	53	88.3
Educational level		
Never been to school	6	10.0
Madarasa	29	48.3
Primary	14	23.3
Secondary	7	11.7
Tertiary	4	6.7
Religion		
Muslim	56	93.3
Christian	4	6.7
Occupation		
Farmer	14	23.3
Housewife	26	43.3
Civil servant	4	6.7
Business	9	15.0
No occupation	7	11.7
Monthly income in Dalasis		
50 and below	1	1.7
51 – 2038	34	56.7
2039 – 4025	19	31.7
4026 – 6013	4	6.7
≥6014	2	3.3
Mean (SD)	2341.7 (±1822.3)	
Family size		
≤8	2	3.3
9 – 14	22	36.7
15 – 21	24	40.0
22 – 27	10	16.7
≥28	2	3.3
Mean (SD)	16 (±5)	

Table 2. Consumers water collection points, handling and storage

Variables	Frequency (n)	Percentage (%)
Do you get your drinking water from NAWEC?		
Yes	60	100.0
No	0	0.0
Current water collection point		
Home	52	86.7
Street	8	13.3
Materials used to collect and transport water for household consumption		
Gallon	32	53.3
Uncovered bucket	15	25.0
Covered bucket	13	21.7
Do you store your drinking water at household level?		
Yes	60	100.0
No	0	0.0
Materials used to store drinking water at household level *		
Gallon	60	100.0
Covered bucket	9	15.0
Refrigerator	52	86.7
Traditional clay jar	21	35.0

** Multiple responses*

Table 3. Consumers awareness of potable water and household treatment methods

Variables	Frequency (n)	Percentage (%)
Do you check for wholesomeness of water before drinking?		
Yes	30	50.0
No	30	50.0
How do you know if the water is safe to drink *		
Looking at taste and smell	30	100.0
Environment around the water source	21	70.0
Features considered in determining drinkable water *		
Chemicals dissolved in water	39	100.0
Appearance of water	39	100.0
Things you do when you suspect the portability of the water		
Treat it at home	51	85.0
I do nothing	9	15.0
Household water treatment methods practice at homes *		
Filtering only	43	84.3
Filtering and boiling	8	15.7
Adding chlorine	8	15.7
Reasons for boiling drinking water at households		
To kill germs only	10	16.7
To render harmful chemicals harmless only	20	33.3
Do not know	30	50.0
Is filtering using piece of clothes effective to improve water quality?		
Yes	51	85.0
No	9	15.0
How effective is filtering of water for drinking purposes?		
It removes germs only	10	16.7
It removes harmful chemicals only	20	33.3
Do not know	30	50.0
Preferred household water treatment methods *		
Boiling methods that kills all the germs	8	15.7
Filter that removes most of the dissolved chemicals	51	100.0
Do you believe poor water quality could impact human health?		
Yes	38	63.3
No	22	36.7
Do poor water quality cause(s) diarrhea and other related diseases?		
Yes	47	78.3
No	13	21.7

** Multiple responses*

Table 4. Perception of consumers on NAWEC water supply

Variables	Frequency (n)	Percentage (%)
What is the source of NAWEC water supply to your household		
Groundwater (well)	17	28.3
Surface water (river)	13	21.7
Boreholes	30	50.0
Does your household pays the monthly bills regularly		
Yes	43	71.7
No	17	28.3
Does NAWEC supply the water enough for your needs		
Yes	29	48.3
No	31	51.7
Do you think NAWEC is doing enough to protect the water quality for drinking?		
Yes	39	65.0
No	21	35.0
Are you satisfied with the quality of tap water in your home/neighborhood		
Yes	33	55.0
No	27	45.0

4.4 Consumers

Safe drinking water quality also depends on proper water collection, storage, and handling at consumers' end [14,15]. The lack of awareness and low perception of health risks may lead to unhygienic practices greatly affecting the quality of household water [14]. In this study area, there were some risks with poor practices associated with water handling, storage, and hygienic measures at the household level. The overall perception of water storage, sanitation, and hygiene practices could be rated moderately good. Some consumers still use some unclean 20 litre plastic containers to store water and indiscriminately kept drinking cups on the floor or on unclean surfaces [31]. Moreover, the economic levels of the consumers were good, and the majority could afford to pay water bills, which is often an obstacle to the quality of drinking water among communities in developing countries [32,33,34]. However, 50% of the consumers in this study lack WASH knowledge related to water treatment of boiling and filtration at household level, similar to the risk assessment findings by Shyari et al. (2019). Thus education is crucial in ensuring quality drinking water at household levels.

5. CONCLUSION

The overall findings of this study have shown tremendous achievement in the government's commitment to providing potable water to the people in Brikama Local Government Area. The treatment plant and services were relatively impressive in managing and controlling risks and potential hazards from the catchment sites to the treatment plant. All captions/ catchment sites were adequately controlled and free from animal-related toxicity and minimal risk scores were observed, however, there is a need for proper monitoring systems for chemical parameters, including residual chlorine. More advocacy and sensitization regarding water management at the household level are needed to reduce morbidities and mortalities.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather, it was funded by personal efforts of the authors.

CONSENT

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

ETHICAL APPROVAL

It is not applicable.

DATA AVAILABILITY

Data used in this study are included in the article, and some can be made available upon request.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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