Assessment of Drinking Tap Water Quality in Wa Municipality, Ghana

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Abstract

Water quality analysis is an essential component of water supply globally. This study analyzed drinking water quality at the tap in the Wa Municipality of Ghana. Bacteriological, physicochemical, aesthetic, and some chemical parameters of raw, treated and tap water was analyzed. The analysis showed that drinking tap water has a good quality and was satisfactory according to the World Health Organization's (WHO) guidelines for drinking water. However, an assessment of consumers' perception of water consumption profiles revealed that 25 % of the respondents claimed that the water quality was bad and had some taste that may be attributable to the long period of water storage. Therefore, it is recommended that the post chlorination dose should be increased to ensure the disinfection requirements and avoid any post-treatment contamination.

Keywords: consumer perception, drinking water, water quality, Wa Municipality, Ghana

1. Introduction

Water quality is one of the major challenges that societies are facing in the 21st century globally, threatening human health, limiting food production, reducing ecosystem functions, and hindering economic growth. Water quality degradation leads directly to environmental, social and economic problems (Fang *et al.*, 2021; Mohammed, 2021). The availability of the world's scarce water resources is increasingly limited due to the worsening pollution of freshwater resources caused by the disposal of large quantities of poorly treated or untreated wastewater into rivers, lakes, aquifers and coastal waters (du Plessis, 2019). According to WHO and UNICEF (2015), 91% of the world's population used drinking water from improved sources (58% from a piped connection in their dwelling, plot or yard, and 33% from other improved drinking water sources), leaving 663 million people lacking access to an improved source of water.

Therefore, access to potable water is still a major challenge, particularly in many developing countries, as one in nine people worldwide uses drinking water from unimproved and unsafe sources (Ritchie and Roser, 2021). Furthermore, Adelodun *et al.* (2021) observe that about 38% of the population in rural areas and small towns in most developing countries are still without access to potable water. In Ghana, 80% of the population has access to improved water sources (USAID - Ghana, 2019). However, even when water is available in developing countries such as Ghana, there are mostly risks of contamination due to improper maintenance and access to improved sanitation. Water quality testing is rarely undertaken in water supply systems in many developing countries, as more attention is usually paid to water availability and quantity than quality of water (Lee *et al.*, 2017; Ewaid *et al.*, 2020).

The quality of fresh water available on the earth's surface for human consumption is usually affected by natural and anthropogenic activities. This means that except for unusual situations, water must be treated before use. The degree of treatment depends upon the quality of raw water and how it is to be used. Thus, drinking water quality depends on the source from which it is drawn and the treatment it receives. Tap water supplies are considered to be among the safest globally, however, tap water that is not properly treated or flows through an improperly maintained distribution system may be contaminated. So, for public water supply, drinking water at a minimum should be disinfected. Disinfection is most commonly through the use of chlorination or the use of ultraviolet light or any other method that water may need to undergo to ensure treatment, especially in the case of surface water which is infamously known to be polluted (Liew, Linge and Joll, 2016; Wang *et al.*, 2021), mostly due to

anthropogenic activities. The quality of surface water is usually affected by both point and non-point sources of pollution (Nie *et al.*, 2018). These include sewage discharge, discharge from industries, and run-off from agricultural fields and other impervious surfaces.

Nonetheless, drinking water quality is usually determined by the levels of microbiological and physicochemical properties (Pietrucha-Urbanik and Rak, 2020). Therefore, many parameters of water have to be analysed before its quality can be deemed satisfactory. Water quality analysis is an essential component of water supply globally. Water quality is usually analysed in terms of its chemical, physical, and biological constituents. Consequently, different countries and some international organizations have proposed various water quality standards for drinking water. Many developing countries have set their water quality standards based on the World Health Organisation's (WHO's) guidelines for drinking water.

Ghana Water Company Limited (GWCL) is the institution responsible for water supply in urban areas in Ghana. GWCL in the Wa Municipality initially depended on mechanised boreholes to supply water to consumers in the Wa Municipality but since 2017, the company has been supplying water to the Municipality from its newly constructed water treatment plant located at Jambosi in the Wa West District in the Upper West Region. The Jambosi treatment plant has a direct intake from the Black Volta River. Drinking water quality monitoring is a wide-ranging assessment of the quality of water in the distribution system and, importantly, as supplied to the consumer (Bradley *et al.*, 2021). This includes regular sampling and testing to assess whether water quality is meeting the national standards and any regulatory requirements or agreed levels of service. Thus, monitoring and surveillance of a water distribution system are of vital importance to ensure the efficiency of the system. Water quality monitoring provides the evidence for decision-making in managing water quality and water quality surveillance offers the framework to support monitoring and management of the water distribution system quality (Elhag *et al.*, 2019; Bui *et al.*, 2020). This study, therefore, assesses tap water quality and contribute to the objective evidence required for sound decision-making on managing water quality in the water distribution system in the Wa municipality. Although GWCL in the Wa Municipality conducts regular surveillance on its distribution system as a quality monitoring measure but does not publish the results, there no evidence that an independent researcher or institution has assessed the water distribution system in the Wa Municipality. Thus, this study aims to bridge this gap.

2. Materials and Methods

The Black Volta River is the main surface water source for GWCL in the Upper West of Ghana, particularly the Wa Municipality, where GWCL only operates in the Region. The Black Volta River has its source in Burkina Faso and flows through Ghana and then between Ghana and Côte d'Ivoire (Figure 1) (Bowan and Tingan, 2020).
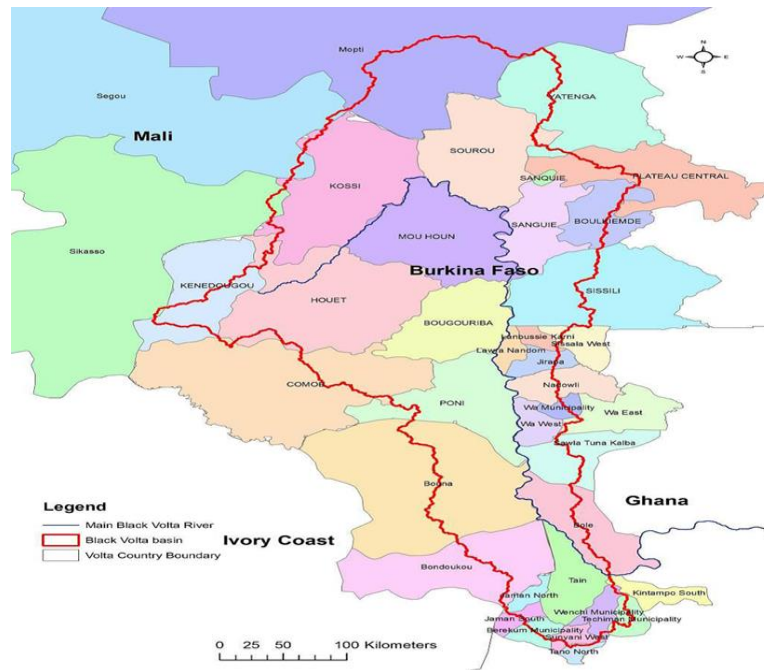

Figure 1. The Black Volta River (Water Resources Commission, 2020)

The Wa Municipality has its capital as Wa (as indicated in Figure 2), which also serves as the regional capital of the Upper West Region (UWR). It has a land area of approximately 579.86 km^2, which is about 6.4% of the region. According to the Ghana Statistical Service (2014), the main sources of water for drinking in the Wa Municipality are bore-hole/pump/tube well (36.1%), pipe-borne outside dwelling (27.8%), pipe-borne inside dwelling (12.0%), public tap/standpipe (8.4%), protected well (7.8%), sachet water (3.5%) and tanker supply/vendor provided (1.5%). The other sources of water for drinking such as unprotected well, protected springs, bottled water and dugouts/ponds/lakes/dams/canals account for small proportions ranging from 0.1 to 0.8 percent in the Municipality.
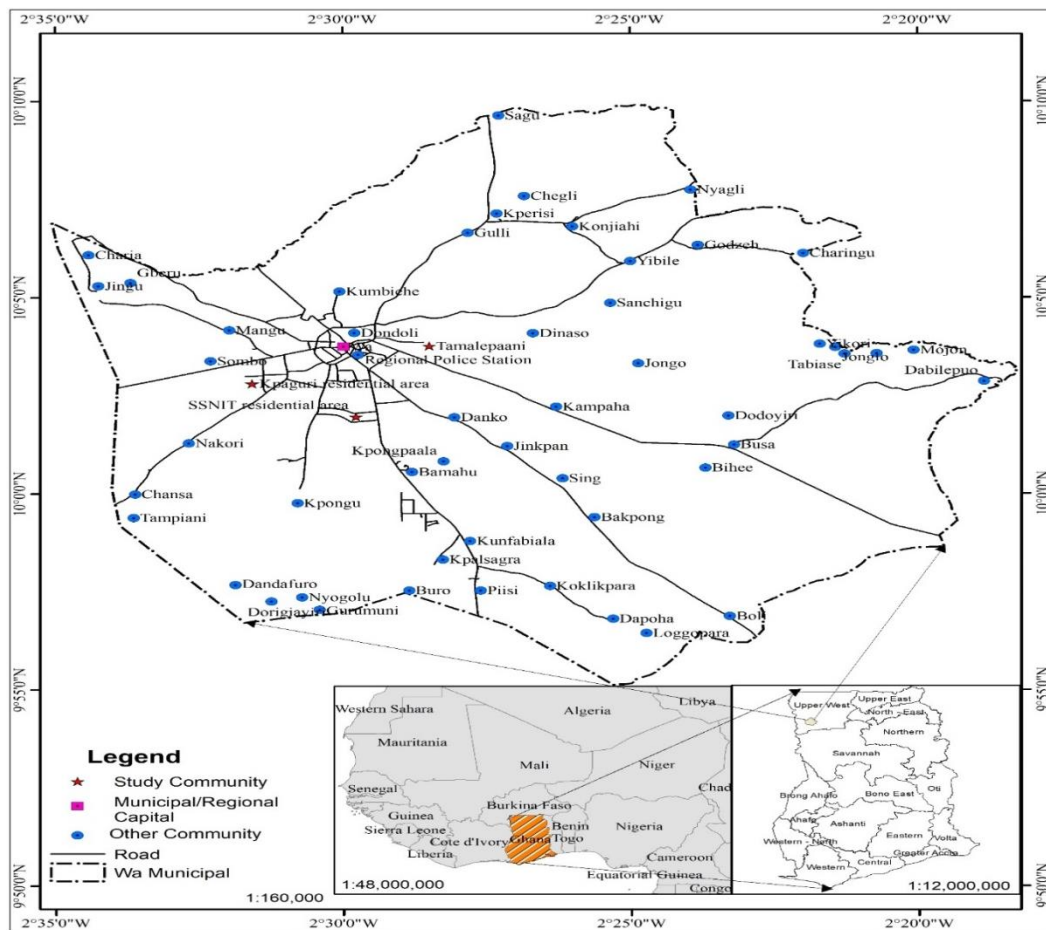

Figure 2. Map of Wa Municipality

The study methods included data collection about water quality in general, questionnaires to obtain information on the consumers' perception of the tap water quality in the Wa Municipality; in addition, the distribution systems together with the treatment process machinery and distribution pipes used for the water supply from the GWCL's treatment plant in Jambusi through to the service reservoirs in Wa were observed. A reconnaissance also enabled the researcher to observe the physical appearance of the tap water supplied to the Municipality as it was freshly fetched and how most tap water pipe connections were directly connected to the storage containers within households due to intermittent supply.

Water samples were collected from intake structure (raw water), water treatment plant (treated water), and tap water in three residential areas namely SSNIT residential area (SRA), Kpaguri residential area (KRA), and Tamalepaani residential area (TRA) (See Figure 2). These residential areas were chosen because not all the residential areas in the Wa Municipality had tap water connections to households. The water samples were collected in sterilized standard 1.5 litres bottles per sample and transported in ice chests with ice packs to ensure that a low temperature (2 to 8 ℃) was maintained at all times and transported to the GWCL laboratory in Wa

within 4 hours. Since the tip of the tap will not be sterilized before the sampling, sample bottles were moved a distance away from the tap outlet to prevent any further contamination.

The laboratory analysis of the sampled water involved purely testing the water samples and comparing the results to strike a balance with WHO's guidelines for drinking water quality; because in drinking water treatment processes, the optimisation of the treatment is always of vital importance. In general, the water treatment process consists of many units including settling, coagulation, flocculation, sedimentation, filtration and disinfection, which successfully produce water of high quality and portability. The tap water quality analysis was focused on the bacteriological (Escherichia coli and total coliforms), physicochemical (temperature, chlorine, pH, turbidity, total dissolved solids (TDS), dissolved oxygen (DO), total hardness, and total alkalinity), aesthetic (color, taste, and odor), and chemical parameters (fluoride, nitrate, nitrites, ammonia, lead, aluminium, mercury, iron, copper, and zinc). Table 1 illustrates the water parameters and their analytical methods.

Table 1. Water quality parameters and analytical methods

Parameter	Unit	Analytical Method
Escherichia coli	CFU/100ml	Most probable number method
Total coliforms	0.00MPN/100ml	Most probable number method
Temperature	°C	Using a thermometer
Chlorine	mg/l	Iodometric method
pH		Electrochemical method using the pH Meter
Turbidity	NTU	Nephelometric meter
Total dissolved solids	mg/L	Total dissolved solids Meter Method
Dissolved oxygen	mg/L	Colorimetry Method
Total hardness	mg/L	Colorimetric titration with an EDTA solution
Total alkalinity	mg/L	Using sulfuric acid with a digital titrator
Color	TCU/Hazen	Spectrophotometric method
Taste		Measurement of specific conductivity
Odor		The threshold odor test
Fluoride	mg/L	Potentiometric method
Nitrate	mg/L	Calorimetric (spectroscopy method)
Nitrites	mg/L	Visible spectrophotometer
Ammonia	mg/L	Spectrophotometric IPB method
Lead	mg/L	Flame atomic absorption spectrometry (FAAS)
Aluminium	mg/L	Deferoxamine infusion test
Mercury	mg/L	Atomic fluorescence spectrophotometer
Iron	mg/L	Color-changing test
Copper	mg/L	Most probable number (MPN) method
Zinc	mg/L	Atomic absorption spectrophotometry

The principal risk associated with water supply in Ghana and other developing countries is infectious diseases related to faecal contamination. Thus, the microbiological examination of the tap water was undertaken to assess the hygienic quality of the supply. Physicochemical parameters were also examined because of their vital importance in water treatment. In addition, aesthetic parameters, which are those detectable by the senses, such as color, taste, and odor were also examined. These are important in monitoring water supplies because they may cause the water supply to be rejected by consumers and alternative (mostly poorer-quality) sources to be adopted (Zhang *et al.*, 2020). Besides, a significant number of serious problems may occur because of chemical

contamination from a variety of natural and man-made sources. Therefore, the study examined the following chemical parameters of tap water: fluoride, nitrate, nitrites, ammonia, lead, aluminium, mercury, iron, copper, and zinc.

Furthermore, simple random sampling, a probability sampling method, was employed to administer 300 questionnaires to households within the three purposively selected residential areas, where the tap water had been sampled in the Wa Municipality to assess the consumers' perception of the tap water quality. Though this household's sample size was small, as the tap water consumers in the selected residential areas were far more than 300, because of a limited budget, it was "big enough" to be of scientific and statistical significance (Altman, 2020). The questionnaire was used to access the perception of consumers on some water consumption profiles, including overall water quality, taste, odor and color.

The use of a questionnaire in this study made the quantification of responses of the respondents possible. Thus, 100 questionnaires were administered to households in each of the three residential areas. The researcher applied systematic sampling in selecting the 100 uniform households in the various residential dwellings, as a systematic sample is obtained by selecting items at uniform intervals (Xiao, Yuan and Zhou, 2020). The data obtained was analyzed using SPSS and the results were presented in percentages and charts. In addition, the distribution system together with the treatment process machinery and distribution pipes used for the water supply from the GWCL's treatment plant in Jambusi through to the service reservoirs in Wa were observed to enable the researcher to gain a deeper and richer understanding of these activities.

3. Results and Discussion

The importance of treating drinking water before use cannot be overemphasized, as there are public health associated requirements with drinking water quality that must be met. Thus, drinking water quality monitoring is a wide-ranging assessment of the quality of water in the distribution system and, importantly, as supplied to the consumer (Bradley *et al.*, 2021). This includes regular sampling and testing to assess whether water quality is meeting the national standards and any regulatory requirements or agreed levels of service.

3.1 Tap Water Quality Evaluation

3.1.1 Bacteriological Analysis

In most developing countries, water-associated diseases still have an impact on public health. Bacteria, viruses, protozoa, and parasites in poorly treated or untreated water can cause water-borne diseases, which can result in morbidity and mortality (Wolde *et al.*, 2020). Thus, the microbiological examination of drinking water emphasizes the assessment of the hygienic quality of the supply. Therefore, Escherichia coli (*E. coli*) and total coliforms were the bacteriological indicators of the tap water that were analyzed. The analysis of raw water showed 0.96 CFU/100 ml and 16.00 MPN/100 ml, *E. coli* and total coliform, respectively. However, the analysis of the tap water samples from the three residential areas produced 0.00 CFU/100ml, which indicates that the sampled water from the three residential areas was free of *E. coli*. *E. coli* is abundant in human and animal faecal; in fresh faecal, it may attain concentrations of 10^9 per gram (Holcomb *et al.*, 2020). Furthermore, Kim and Cha (2021) observe that *E. coli* is found in sewage, treated effluents, and all-natural waters and soils subject to recent faecal contamination, whether from humans, wild animals, or agricultural activity. However, the distribution system for the Wa municipality is fairly new (less than 5 years) and may not have leakages, hence the absence of *E. coli* in the tap water sampled.

Equally, the analysis for total coliforms of the water sampled from the three residential areas also produced 0.00MPN/100ml. Coliform organisms have long been recognized as a suitable microbial indicator of drinking-water quality, largely because they are easy to detect and enumerate in water (Osmani *et al.*, 2019). Additionally, Niyoyitungiye et al (2020), observe that coliform organisms are also oxidase-negative and non-spore-forming and display β-galactosidase activity. Coliform bacteria should not be detectable in treated water supplies and, if found, suggest inadequate treatment, post-treatment contamination, or excessive nutrients (Daud *et al.*, 2017; Isingoma and Stephen, 2021). Thus, the 0.00 MPN/100ml result obtained from the water sample for the three residential areas indicates that the GWCL's water treatment was efficient and that the distribution system was of high integrity.

3.1.2 Physicochemical Analysis

The analysis of physicochemical parameters is very important in drinking water quality analysis, as they determine the acceptability of water by consumers. Various disinfectants abound for the disinfection of drinking water; however, chlorine in one form or another is the most commonly used disinfectant in many developing countries because of its relative cheapness, efficacy, and ease of measurement, both in laboratories and in the

field (Kamal *et al.*, 2019; Gallandat *et al.*, 2021). Additionally, Hurst (2019) posits that an important advantage over some other disinfectants is that chlorine leaves a disinfectant residual that assists in preventing recontamination during distribution, transport, and household storage of water. The analysis for chlorine in the sampled treated and tap water from the three residential areas is indicated in Table 2. The free chlorine content in the treated water was 1.5 mg/l, and its content in tap water in the three residential areas was lower than the acceptable limits of the WHO's guidelines (0.50 to 1.00 mg/l). The absence of sufficient chlorine residue in the distribution system may indicate the possibility of post-treatment contamination (Matsa, Mavugara and Dzawanda, 2021). So, there is a need to increase the post chlorine dose for the treated water to achieve the disinfection requirements during the distribution and storage of the water.

The pH values for raw and treated water were 6.9 and 6.8, respectively. Meanwhile, the pH analyzed for the tap water sampled from the three residential areas was satisfactory according to the WHO guidelines for drinking water of 6.5 to 8.5, as shown in Table 2. Wang *et al.* (2021) observe that it is important to measure pH at the same time as chlorine residue since the efficacy of disinfection with chlorine is highly pH-dependent: where the pH exceeds 8.0, disinfection is less effective.

Furthermore, turbidity is important because it affects both the acceptability of water to consumers, and the selection and efficiency of treatment processes, particularly the efficiency of disinfection with chlorine since it exerts a chlorine demand and protects microorganisms and may also stimulate the growth of bacteria (Linden, Hull and Speight, 2019; Nyakundi *et al.*, 2020). The analysis of turbidity of the water sampled from the three residential areas produced a turbidity of 0.00 for all three samples. This supports the low pH and low chlorine residue in the sampled water, as in all processes in which disinfection is used, the turbidity must always be low (Maciel *et al.*, 2021). In addition, analysis of TDSs and TSSs for the water samples from the three residential areas produced results which were within the WHO's guidelines for drinking water, as indicated in Table 2. Also, the temperature of all water samples was moderate and ranged between 22.7 and 26.30 ◦C, as compared to the WHO's standard of 25 ◦C.

3.1.3 Aesthetic Parameters

Aesthetic parameters are those detectable by the senses, namely turbidity, color, taste, and odor. They are important in monitoring water supplies because they may cause the water supply to be rejected. Drinking water should be colorless and color in drinking water may be due to the presence of colored organic matter, e.g. humic substances, metals such as iron and manganese, or highly colored industrial wastes (Ghernaout, 2020). The raw water sample showed 23 TCU/Hazen. Meanwhile, the results on the color of the tap water sampled from the three residential areas were within the WHO guideline (15 TCU/Hazen), as indicated in Table 2.

Additionally, the analysis of the treated and tap water sampled from the three residential areas for odor proved to be odorless for all three samples. Odors in water are caused mainly by the presence of organic substances (Rawdkuen *et al.*, 2020). However, Singh and Chandra (2019) observe that some odours are indicative of increased biological activity; others may result from industrial pollution. Taste is one of the problems that usually account for the largest single category of consumer complaints on drinking water quality (Burlingame, Doty and Dietrich, 2017; Mix, George and Haas, 2020), The analysis of the taste of the treated and tap water samples showed that all samples were tasteless, and therefore, the drinking water should be satisfactory for consumers.

3.1.4 Chemical Parameters Analysis

A significant number of serious problems of drinking water quality may occur as a result of chemical contamination from a variety of natural and man-made sources (Borah, Kumar and Devi, 2020; Saravanan *et al.*, 2021). To establish whether such problems existed at the tap in the Wa Municipality, analysis for fluoride, nitrate, nitrite, ammonia, lead, aluminium, mercury, iron, copper, and zinc was undertaken. Table 2 illustrates the values obtained for these chemicals from the water sampled from the three residential areas. The examination of these chemicals of health significance for the water sampled from the three residential areas resulted in values that were within the WHO guideline values. These acceptable values could be attributed to the newness (five years old) of the GWCL's treatment plant and distribution system, which supplies water to the Wa Municipality, and therefore, indicates that the treatment plant and distribution system were efficient. In addition, analysis of total hardness and total alkalinity for all the sampled water produced values which were within the WHO's recommended values of 500.00 and 400.00 mg/l respectively.

Notwithstanding that all the parameters measured for the water sampled from the three residential areas were within WHO's recommendation for drinking water, there were variations in the values of some of the parameters. This could be attributed to the period of the storage of the treated water in service reservoirs before distribution,

as the three chosen residential areas depended on different service reservoirs.

Table 2. Values of chemical parameters from the water sampled from raw, treated, and tap water from the three residential areas

Parameter	WHO Guidelines (Cotruvo, 2017)	Raw Water	Treated Water	SRA	KRA	TRA
Odor	Odorless	Inoffensive	Odorless	Odorless	Odorless	Odorless
Taste	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless	Tasteless
Temperature (C^0)	≤ 25 ∘C	23.20	22.70	24.10	26.30	25.20
pH	6.50 – 8.50	6.90	6.80	6.20	6.60	6.30
Colorless (TCU/Hazen)	15	23.00	5.00	10.00	8.00	5.00
Turbidity (NTU)	0.00 – 1.00	562.30	0.00	0.00	0.00	0.00
Total Dissolved Solids (mg/l)	< 600.00	655.00	5.00	140.00	122.00	96.00
Dissolved Oxygen (mg/l)	6.5 - 8	5.00	3.20	3.60	3.00	3.40
Total Hardness (mg/l)	500.00	85.00	69.00	72.00	76.00	78.00
Total Alkalinity (mg/l)	30 - 400	55.00	24.00	45.00	38.00	40.00
Nitrate (mg/l)	50.00	2.10	0.20	0.30	0.30	0.20
Nitrite (mg/l)	3.00	0.002	0.00	0.00	0.00	0.00
Ammonia (mg/l)	Odor concentration of approximately 1.5	BDL	BDL	BDL	BDL	BDL
Iron	≤ 0.30	1.50	0.02	0.05	0.03	0.01
Copper (mg/l)	2.00	0.20	0.13	0.14	0.02	0.00
Mercury (mg/l)	0.006	0.018	0.00	0.00	0.00	0.00
Aluminium (mg/l)	0.10 – 0.20	0.01	0.02	0.02	0.01	0.00
Zinc (mg/l)	$5.00 - \leq 3.00$	0.05	0.01	0.02	0.02	0.01
Lead (mg/l)	0.01	BDL	BDL	BDL	BDL	BDL
Fluoride (mg/l)	1.50	BDL	BDL	BDL	BDL	BDL
Free Chlorine (mg/l)	0.50 – 1.00	-	1.50	0.21	0.25	0.10
E.coli $(CFU/100ml)$	0.00	0.96	0.00	0.00	0.00	0.00
Total Coliforms $(MPN/100ml)$	0.00	16.00	0.00	0.00	0.00	0.00

BDL = Below Detectable Limit, SRA = Samples collected from SNNIT Residential Area, KRA = Samples collected from Kpaguri Residential Area, and TRA = Samples collected from Tamalepaani Residential Area

3.2 Consumers' Perception of Tap Water Quality

The perception of tap water is subject to a wide range of factors and interactions (Javidi and Pierce, 2018; Delpla *et al.*, 2020). Monitoring of consumer comments and complaints can provide valuable information on potential problems that may not have been identified by performance monitoring of the water supply system (Monks *et al.*, 2019). Consumer satisfaction with drinking water quality is largely based on a judgment that the aesthetic quality of tap water is 'good', which usually means that it is colorless, free from suspended solids and has no unpleasant taste or odor. Thus, a questionnaire survey was conducted among 300 consumers in households in the three sampled residential areas to assess the factors that influence and determine consumers' behaviour concerning drinking water.

The consumers in the sampled residential areas elaborated the following water consumption profiles: overall water quality, taste, odor and color. Figure 3 below shows the consumers' perception of the overall tap water quality in the study area. About 74 % of respondents said that the overall water quality was good and very good.

Around 25 % of the respondents claimed that the overall water quality was bad and very bad, whereas the sampled water quality analysis indicated that the overall water quality was within the acceptable limits prescribed by the WHO. The claim of taste in the water by some consumers could be attributed to the storage of water in various receptacles due to intermittent water supply, as water stored for a long period can be contaminated and lead to some sort of taste. Nevertheless, all the respondents indicated that their water was tasteless, odorless and colorless, which supports the good water quality analysis results.
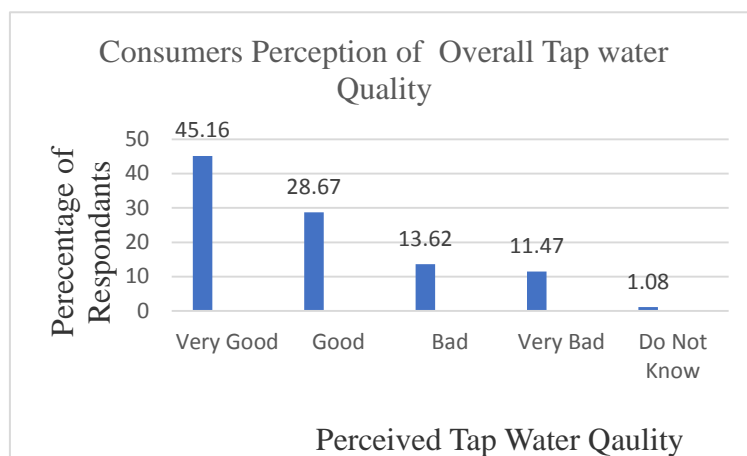

Figure 3. Perception of overall tap water quality

4. Conclusion

The study examined bacteriological, physicochemical, chemical and aesthetic parameters of raw, treated and tap water. In addition, consumers' perception of tap water quality in the Wa Municipality was also assessed. The results showed that all the examined parameters of the tap water were within the acceptable limits per the WHO's guidelines for drinking water. GWCL, the sole supplier of drinking water in the Wa Municipality is encouraged to put in place proper monitoring and evaluation measures to maintain the continuous efficiency of the water treatment and distribution systems. However, an assessment of consumers' perception of the overall tap water quality through a questionnaire survey indicated that 74 % of respondents said that the overall water quality was good and very good. Nonetheless, 25 % of the respondents claimed that, the water quality was bad and very bad, and had some taste, which could be attributable to the long period of water storage. So, further analysis for water stored for a long period of time is recommended in future studies. Additionally, the chlorine dose in the post-treatment should be increased to ensure the disinfection requirements are met. The researcher admits that the limitation of the paper is that one water sample was collected in each of the chosen residential areas but the results were analysed and generalized to represent the entire residential areas.

Competing Interests

The authors declare no competing financial interests.

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References

Adelodun, B., Ajibade, F. O., Ighalo, J. O., Odey, G., Ibrahim, R. G., Kareem, K. Y., … Adeniran, K. A. (2021). Assessment of socioeconomic inequality based on virus-contaminated water usage in developing countries: A review. *Environmental Research*, *192*, 110309. https://doi.org/10.1016/j.envres.2020.110309

Altman, M. (2020). A more scientific approach to applied economics: Reconstructing statistical, analytical significance, and correlation analysis. *Economic Analysis and Policy*, *66,* 315-324. https://doi.org/10.1016/j.eap.2020.05.006

Borah, P., Kumar, M., & Devi, P. (2020). Types of inorganic pollutants: metals/metalloids, acids, and organic forms. *Inorganic Pollutants in Water*, 17-31. https://doi.org/10.1016/b978-0-12-818965-8.00002-0

Bowan, P. A., & Tingan, E. M. (2020). Influence of Illegal Small-Scale Gold Mining on the Black Volta Water Quality. *Communications in Applied Sciences*, 0-18. Retrieved from infinitypress.info/index.php/cas/article/view/2023

Bradley, P. M., LeBlanc, D. R., Romanok, K. M., Smalling, K. L., Focazio, M. J., Cardon, M. C., … Gray, J. L. (2021). Public and private tapwater: Comparative analysis of contaminant exposure and potential risk, Cape Cod, Massachusetts, USA. *Environment International*, *152,* 106487. https://doi.org/10.1016/j.envint.2021.106487

Bui, D. T., Khosravi, K., Tiefenbacher, J., Nguyen, H., & Kazakis, N. (2020). Improving prediction of water quality indices using novel hybrid machine-learning algorithms. *Science of the Total Environment*, *721*, 137612. https://doi.org/10.1016/j.scitotenv.2020.137612

Burlingame, G. A., Doty, R. L., & Dietrich, A. M. (2017). Humans as Sensors to Evaluate Drinking Water Taste and Odor: A Review. *Journal - American Water Works Association*, *109*(11), 13-24. https://doi.org/10.5942/jawwa.2017.109.0118

Cotruvo, J. A. (2017). Who guidelines for drinking water quality: first addendum to the fourth edition. *Journal - American Water Works Association*, *109*(7), 44-51. https://doi.org/10.5942/jawwa.2017.109.0087

Daud, M. K., Nafees, M., Ali, S., Rizwan, M., Bajwa, R. A., Shakoor, M. B., … Malook, I. (2017). Drinking Water Quality Status and Contamination in Pakistan. *BioMed Research International*. https://doi.org/10.1155/2017/7908183

Delpla, I., Legay, C., Proulx, F., & Rodriguez, M. J. (2020). Perception of tap water quality: Assessment of the factors modifying the links between satisfaction and water consumption behavior. *Science of the Total Environment*, *722,* 137786. https://doi.org/10.1016/j.scitotenv.2020.137786

Elhag, M., Gitas, I., Othman, A., Bahrawi, J., & Gikas, P. (2019). Assessment of water quality parameters using temporal remote sensing spectral reflectance in arid environments, Saudi Arabia. *Water (Switzerland)*, *11*(3), 556. https://doi.org/10.3390/w11030556

Ewaid, S. H., Abed, S. A., Al-Ansari, N., & Salih, R. M. (2020). Development and evaluation of a water quality index for the Iraqi rivers. *Hydrology*, *7*(3), 67. https://doi.org/10.3390/HYDROLOGY7030067

Fang, X., Li, X., Zhang, Y., Zhao, Y., Qian, J., Hao, C., … Wu, Y. (2021). Random forest-based understanding and predicting of the impacts of anthropogenic nutrient inputs on the water quality of a tropical lagoon. *Environmental Research Letters*, *16*(5), 055003. https://doi.org/10.1088/1748-9326/abf395

Gallandat, K., Kolus, R. C., Julian, T. R., & Lantagne, D. S. (2021). A systematic review of chlorine-based surface disinfection efficacy to inform recommendations for low-resource outbreak settings. *American Journal of Infection Control*, 90-103. https://doi.org/10.1016/j.ajic.2020.05.014

Ghana Statistical Service. (2014). *2010 Population & Housing Census: District Analytical Report, Wa Municipality*. Accra, Ghana.

Ghernaout, D. (2020). Natural Organic Matter Removal in the Context of the Performance of Drinking Water Treatment Processes—Technical Notes. *OALib*, *7*(9), 1-40. https://doi.org/10.4236/oalib.1106751

Holcomb, D. A., Knee, J., Sumner, T., Adriano, Z., de Bruijn, E., Nalá, R., … Stewart, J. R. (2020). Human fecal contamination of water, soil, and surfaces in households sharing poor-quality sanitation facilities in Maputo, Mozambique. *International Journal of Hygiene and Environmental Health*, *226*, 113496. https://doi.org/10.1016/j.ijheh.2020.113496

Hurst, C. J. (2019). Options for Providing Microbiologically Safe Drinking Water. *Cham,* 185-260. https://doi.org/10.1007/978-3-030-16775-2_8

Isingoma, B. E., & Stephen, K. (2021). Microbiological analysis of domestic water sources in Banda slum of Kampala, Uganda. *Journal of Water, Sanitation and Hygiene for Development*, *11*(4), 676-686. https://doi.org/10.2166/washdev.2021.236

Javidi, A., & Pierce, G. (2018). U.S. Households' Perception of Drinking Water as Unsafe and its Consequences: Examining Alternative Choices to the Tap. *Water Resources Research*, *54*(9), 6100-6113. https://doi.org/10.1029/2017WR022186

Kamal, M. A., Khalaf, M. A., Ahmed, Z. A. M., & El Jakee, J. (2019). Evaluation of the efficacy of commonly used disinfectants against isolated chlorine-resistant strains from drinking water used in Egyptian cattle farms. *Veterinary World*, *12*(12), 2025-2035. https://doi.org/10.14202/vetworld.2019.2025-2035

Kim, D. W., & Cha, C. J. (2021). Antibiotic resistome from the One-Health perspective: understanding and controlling antimicrobial resistance transmission. *Experimental and Molecular Medicine*, 301-309. https://doi.org/10.1038/s12276-021-00569-z

Lee, M., Kim, M., Kim, Y., & Han, M. (2017). Consideration of rainwater quality parameters for drinking purposes: A case study in rural Vietnam. *Journal of Environmental Management*, *200*, 400-406. https://doi.org/10.1016/j.jenvman.2017.05.072

Liew, D., Linge, K. L., & Joll, C. A. (2016). Formation of nitrogenous disinfection by-products in 10 chlorinated and chloraminated drinking water supply systems. *Environmental Monitoring and Assessment*, *188*(9), 1-16. https://doi.org/10.1007/s10661-016-5529-3

Linden, K. G., Hull, N., & Speight, V. (2019). Thinking outside the treatment plant: UV for water distribution system disinfection: Published as part of the Accounts of Chemical Research special issue "water for Two Worlds: Urban and Rural Communities". *Accounts of Chemical Research*. https://doi.org/10.1021/acs.accounts.9b00060

Maciel, P. M. F., Fava, N. D. M. N., Lamon, A. W., Fernandez-Ibañez, P., Byrne, J. A., & Sabogal-Paz, L. P. (2021). Household water purification system comprising cartridge filtration, UVC disinfection and chlorination to treat turbid raw water. *Journal of Water Process Engineering*, *43*, 102203. https://doi.org/10.1016/j.jwpe.2021.102203

Matsa, M., Mavugara, R., & Dzawanda, B. (2021). Urban domestic water supply crisis in the city of Gweru, Zimbabwe. *GeoJournal*. Springer, *86*(3), 1173-1192. https://doi.org/10.1007/s10708-019-10118-x

McKenna, A. (2020). *Black Volta River*. Retrieved 10 April 2020, from https://www.britannica.com/place/Black-Volta-River

Mix, N., George, A., & Haas, A. (2020). Social Media Monitoring for Water Quality Surveillance and Response Systems. *Journal - American Water Works Association*, 44-55. https://doi.org/10.1002/awwa.1555

Mohammed, N. A. L. (2021). The development trap: militarism, environmental degradation and poverty in the South. *A world divided*, 44-66. https://doi.org/10.4324/9781003111825-3

Monks, I., Stewart, R. A., Sahin, O., & Keller, R. (2019). Revealing unreported benefits of digital water metering: Literature review and expert opinions. *Water (Switzerland)*, 838. https://doi.org/10.3390/w11040838

Nie, J., Feng, H., Witherell, B. B., Alebus, M., Mahajan, M. D., Zhang, W., & Yu, L. (2018). Causes, Assessment, and Treatment of Nutrient (N and P) Pollution in Rivers, Estuaries, and Coastal Waters. *Current Pollution Reports*, 154-161. https://doi.org/10.1007/s40726-018-0083-y

Niyoyitungiye, L., Giri, A., & Ndayisenga, M. (2020). Assessment of Coliforms Bacteria Contamination in Lake Tanganyika as Bioindicators of Recreational and Drinking Water Quality. *South Asian Journal of Research in Microbiology*, *6*(3), 9-16. https://doi.org/10.9734/sajrm/2020/v6i330150

Nyakundi, V., Munala, G., Makworo, M., Shikuku, J., Ali, M., & Song'oro, E. (2020). Assessment of Drinking Water Quality in Umoja Innercore Estate, Nairobi. *Journal of Water Resource and Protection*, *12*(1), 36-49. https://doi.org/10.4236/jwarp.2020.121002

Osmani, M., Mali, S., Hoxha, B., Bekteshi, L., Karamelo, P., & Gega, N. (2019). Drinking water quality determination through the water pollution indicators, Elbasan district. *Thalassia Salentina*, *41*(0), 3-10. https://doi.org/10.1285/i15910725v41p3

Papenfus, M., Schaeffer, B., Pollard, A. I., & Loftin, K. (2020). Exploring the potential value of satellite remote sensing to monitor chlorophyll-a for US lakes and reservoirs. *Environmental Monitoring and Assessment*, *192*(12), 1-22. https://doi.org/10.1007/s10661-020-08631-5

Pietrucha-Urbanik, K., & Rak, J. R. (2020). Consumers' perceptions of the supply of tap water in crisis situations. *Energies*, *13*(14), 3617. https://doi.org/10.3390/en13143617

du Plessis, A. (2019). Primary Water Quality Challenges, Contaminants and the World's Dirtiest Places. *Springer Water*, 79-114. https://doi.org/10.1007/978-3-030-03186-2_5

Rawdkuen, S., Faseha, A., Benjakul, S., & Kaewprachu, P. (2020). Application of anthocyanin as a color indicator in gelatin films. *Food Bioscience*, *36*, 100603. https://doi.org/10.1016/j.fbio.2020.100603

Ritchie, H., & Roser, M. (2021). *Clean Water and Sanitation*, *Our World in Data*. Retrieved 21 January 2022,

from https://ourworldindata.org/clean-water-sanitation

Saravanan, A., Kumar, P. S., Jeevanantham, S., Karishma, S., Tajsabreen, B., Yaashikaa, P. R., & Reshma, B. (2021). Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable development. *Chemosphere*, *280*, 130595. https://doi.org/10.1016/j.chemosphere.2021.130595

Singh, A. K., & Chandra, R. (2019). Pollutants released from the pulp paper industry: Aquatic toxicity and their health hazards. *Aquatic Toxicology*, 202-216. https://doi.org/10.1016/j.aquatox.2019.04.007

USAID - Ghana. (2019). *Water*, *Where we work*. Retrieved 21 January 2022, from https://www.usaid.gov/ghana/water

Wang, C., Moore, N., Bircher, K., Andrews, S., & Hofmann, R. (2019). Full-scale comparison of UV/H2O2 and UV/Cl2 advanced oxidation: The degradation of micropollutant surrogates and the formation of disinfection byproducts. *Water Research*, *161*, 448-458. https://doi.org/10.1016/j.watres.2019.06.033

Wang, Z., Li, L., Ariss, R. W., Coburn, K. M., Behbahani, M., Xue, Z., & Seo, Y. (2021). The role of biofilms on the formation and decay of disinfection by-products in chlor(am)inated water distribution systems. *Science of the Total Environment*, *753*, 141606. https://doi.org/10.1016/j.scitotenv.2020.141606

Water Resources Commission. (2020). *BASINS*, *Black Volta*. Retrieved 10 April 2020, from http://www.wrc-gh.org/basins/black-volta/

WHO and UNICEF. (2015). *2015 Update and MDG Assessment*. Retrieved 22 February 22, from www.wssinfo.org

Wolde, A. M., Jemal, K., Woldearegay, G. M., & Tullu, K. D. (2020). Quality and safety of municipal drinking water in Addis Ababa City, Ethiopia. *Environmental Health and Preventive Medicine*, *25*(1), 1-6. https://doi.org/10.1186/s12199-020-00847-8

Xiao, N. C., Yuan, K., & Zhou, C. (2020). Adaptive kriging-based efficient reliability method for structural systems with multiple failure modes and mixed variables. *Computer Methods in Applied Mechanics and Engineering*, *359,* 112649. https://doi.org/10.1016/j.cma.2019.112649.

Zhang, T., Tao, Y. Z., Yang, H. W., Chen, Z., Wang, X. M., & Xie, Y. F. (2020). Study on the removal of aesthetic indicators by ozone during advanced treatment of water reuse. *Journal of Water Process Engineering*. Elsevier, *36*, 101381. https://doi.org/10.1016/j.jwpe.2020.101381