__Original Research Article__

Water safety planning and implementation in a Ghanaian small-scale water supply system

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ABSTRACT

Aims: This study looked at the Assin Fosu Small Town Water Supply System to verify whether the operation of the scheme is based on a comprehensive water safety plan and how the practice of water safety planning affects the quality of water delivered to the consumers.

Study design: The study employed document reviews, structured observations, interviews and qualitative assessment of the bacteriological safety and aesthetic quality of water sampled from selected public standpipes.

Place and Duration of Study: This study was conducted in March - July 2014 on the Assin Fosu Small Town Water Supply System in the Central Region of Ghana.

Methodology: System design data files and an Operation and Management Contract document were reviewed. In-depth interviews were conducted with key stakeholders of the water supply system. Structured observations were made to assess the management practices of the system managers. Three water samples were collected at monthly intervals from each of 10 randomly selected public standpipes, 3 boreholes and 2 filtration units. Samples were analysed for physical quality (pH, colour, turbidity) and bacteriological safety. Upon the detection of bacteriological contamination, the adequacy of disinfection was assessed by measure the concentration of residual chlorine in the samples.

Results: Recommended schedule for some key documented water quality control and monitoring activities were not complied with. The quality of water delivered to consumers at several public standpipes failed to meet the WHO guidelines for drinking water. The samples that exceeding the WHO guidelines were 40% for faecal contamination, 60% for turbidity and 50% for colour.

Conclusion: Actual operation and maintenance practices failed to comply with the recommended schedule for some key water quality control and monitoring activities.

Keywords: Ghana; small-scale water systems; water safety planning; water quality

1. INTRODUCTION

The safety of drinking water is an important subject due to the direct impact it has on the health and productivity of the populace [1]. It has been observed that reductions in adverse health effects and healthcare costs yield a net economic benefit on investments in water supply and sanitation [2]. Furthermore, the attainment of the Sustainable Development Goal (SDG) 6, which aims to *“ensure availability and sustainable management of water and sanitation for all”* is recognised as a key prerequisite to the realisation of other SDGs [3].

The global Millennium Development Goal (MDG) target for drinking water was achieved in 2010, with 2.6 billion people gaining access to improved drinking water sources since 1990 [4]. Ghana is classified among the countries that achieved the MDG target for drinking water. Most recent official data collected in 2017 – 2018 revealed that the national water coverage (basic and limited) stood at 86% [5], up from 56% in 1990 [4]. A significant aspect of Ghana's progress in potable water supply is the bridging of the gap that existed between the rural and urban populations in 1990. In 1990, only 39% of Ghana's rural population had access to improved water sources as compared to 84% among the urban population. However, current data estimates the rural and urban water coverage to be 77% and 96% respectively [5]. This progress has been fueled by the development of small-scale water supply systems as part of a National Community Water and Sanitation Programme (NCWSP) that was launched in 1994 [6]. This was followed up with the establishment of a Community Water and Sanitation Agency (CWSA) in 1998 with a mandate to facilitate the provision of safe water and related sanitation and hygiene services in rural communities and small towns [7].

Ghana's example highlights the role small-scale water supply systems played in achieving the MDG target on drinking water and their potential in achieving the SDG 6. Generally, the term *small-scale water supply* is frequently associated or used interchangeably with the terms *community water supplies* [8] *rural water supplies* [9] or *small town water supplies* [10], which are generally distinct from large-scale conventional water supplies by their relatively smaller size and complexity. Nevertheless, they are usually defined by specific legislative criteria such as the population served, quantity of water supplied, number of service connections or the type of technology used [11]. For instance, in Ghana, the CWSA uses the population served as a basis for classification of the systems. Those that serve populations up to 2000 are described as *Small Community* systems whiles those that serve 2000 to 50,000 are described as *Small Town* systems [12].

While the World anticipated the attainment of the MDG target for drinking water, which primarily focused on access to some 'improved sources of water' [13], concerns over the actual safety of water that is consumed around the world began to gain attention. In response to this, the WHO and UNICEF's Joint Monitoring Programme (JMP) piloted the Rapid Assessment of Drinking Water Quality (RADRWQ) survey in five countries (Jordan, Tajikistan, Nicaragua, Nigeria and Ethiopia) between 2006 and 2010 to assess the water safety compliance of selected 'improved water sources'. The results of the RADRWQ showed microbial contamination of supposedly improved water sources in all five countries while chemical contamination with fluoride was recorded in four countries [14]. Concerns over the quality of water supplied from water sources that are considered to be improved have also been raised in Ghana. The CWSA recognises the existence of some naturally occurring water quality challenges such as high salinity in groundwater in the southern part of the country, fluoride in the north and iron in various parts of the country [6]. Beside the chemical contamination, bacteriological contamination has also been reported among some 43% of improved water sources that were sampled in Ghana [4].

Such reports of contamination of improved water sources have, undoubtedly, informed the definition of the global indicator for the drinking water target of the SDG: the "proportion of population using *safely managed* drinking water services" [3]. The emphasis on *'safely managed'* services underscores the relevance of water safety planning and implementation in water supply systems. The World Health Organisation (WHO) defines a water safety plan (WSP) as a *"comprehensive risk assessment and risk management approach that encompasses all steps in water supply from catchment to consumer"* [2]. Its main objective is to prevent the raw water source from contamination, remove contamination through treatment processes and to prevent the re-contamination of the treated water during storage, distribution and handling at the point of use [15].

Even though a WSP is expected to be developed for all water supply systems, its relevance is more emphasised in small-scale water supply systems which have been found to be at a greater risk of breakdown and contamination [8]. For such systems, the WHO [8] provides a six-step cycle of tasks (shown in Fig. 1) for carrying out the above-mentioned key actions involved in a WSP. Detailed processes and procedures for carrying out each task are also discussed by the WHO [8].

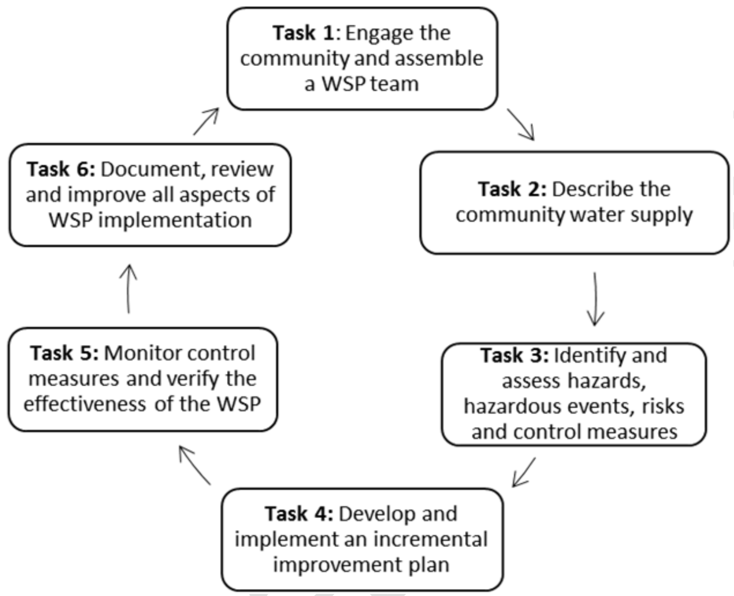

Fig. 1. Water safety plan continuous improvement cycle

Source: WHO [8]

In Ghana's community and small-town water supply systems, the CWSA's approach to water safety planning is similar to that of the WHO [8]. They both emphasise identification of hazards and specific actions to address each hazard from catchment to point of use. Detailed steps and actions to ensure the delivery of safe water in Ghana's small-scale water supply systems have been published by the CWSA in its document *Water Safety Framework* [16]. The Water Safety Framework (WSF) provides general guidelines to aid the development of specific WSPs by managers of individual water systems. However, not much knowledge exists on the actual preparation and implementation of water safety plans by managers of the individual systems to safeguard the quality of water delivered to consumers. In other words, although some success has been achieved in hardware installations to increase the coverage of rural water supply, not much is known about how the quality of the water is being managed, and how water quality management or water safety planning is affecting the final product being consumed by rural and small-town dwellers.

This study was conducted on the Assin Fosu Small Town Water Supply System (AFSTWSS) in the Central Region of Ghana primarily to assess the practice of water safety planning in the system and how it affects the quality of water served to the consumers. However, with a report in 2015 indicating that nearly half (43%) of Ghana's water sources classified as improved were not free from faecal contamination [4], the CWSA has recently intensified its regulatory activities in ensuring that all small-scale water supply systems comply with its WSF. This recent emphasis been laid on WSP has motivated sharing the findings of this study which was conducted in 2014 as part of an unpublished MSc thesis to provide a baseline situation against which the impact of recent intervention may be assessed.

2. METHODOLOGY

2.1 Study Setting

The AFSTWSS serves the 161,341 inhabitants of the Assin Central Municipality with drinking water. The Municipality is one of 22 local authorities in the Central Region of Ghana. It lies within longitudes 1°05' East and 1°25 West and latitudes 6°05' North and 6°40 South and covers a land area of 1,500 sq. km [17]. The Municipal Capital, Assin Fosu, is among a number of otherwise urban centres in Ghana that are served by rural or community water supply systems due to inadequate capacity of the main urban utility, the Ghana Water Company Limited (GWCL), to serve those urbanised townships. With respect to sanitation, data collected in 2009 indicated that only 22% of the Municipality's inhabitants had access to private toilets in their houses. The remaining 78% comprise 71% who patronise public or communal toilets and 7% who practise open defecation [18]. In terms of sanitation technologies, many inhabitants depend on on-site dry sanitation systems such as pit latrines, with only a few using water closets.

The AFSTWSS involves the use of boreholes to extract groundwater, which is given a partial treatment by passing it through a pre-packaged filtration unit. The water is then pumped into two elevated and one ground service reservoirs and distributed under gravity. Fig. 2 shows the process flow diagram for the system. Selected system photographs are presented as Appendix A.

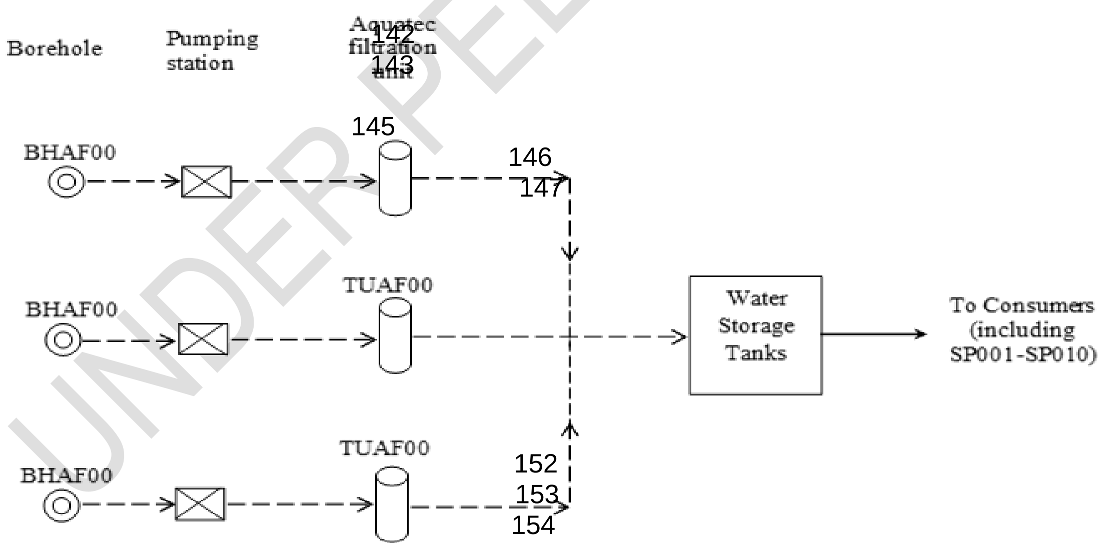

Fig. 2. Process flow diagram for the water system

2.2 Study Design

The study was designed to:

i. qualitatively verify the existence of a WSP for the AFSTWSS and whether any existing plans make adequate or comprehensive provisions for water safety protection
ii. qualitatively assess whether the water system operator complies with any existing WSP
iii. quantitatively and qualitatively establish whether the water supplied to consumers under existing water quality management practices meets relevant quality standards

2.3 Data Collection Methods

The research employed the following qualitative and quantitative methods in the collection of data:

2.3.1 Document review

Document review was done to obtain secondary data on documented, system-specific water safety management practices and procedures. Documents reviewed included system design data files [19] and an Operation and Management Contract (OMC) document [20] signed between the Municipal Assembly and a private limited liability company which operated and managed the water supply system at the time of the study.

2.3.2 Structured observation

Observations were made to assess the management practices of the system managers. An observation guide was developed to verify whether system-specific and generic water safety control measures were adhered to by the system managers. Observations were made on the operation and management of boreholes, treatment units, transmission and distribution lines and public standpipes.

2.3.3 In-depth interviews

In-depth interviews were conducted with representatives of the private operator and Community's Water and Sanitation Management Team (WSMT), an official of the CWSA and the Desk Officer of the Municipal Assembly's Water and Sanitation Development Board. Where relevant, information provided by the system operators were cross-checked through enquiries at the Municipal Water and Sanitation Desk and the Regional Office of the CWSA in Cape Coast.

2.3.4 Water quality testing

2.3.4.1 Sampling

Samples were collected from:

- ten (10) stand-pipes randomly selected from 10 out of 12 suburbs covered by the water supply system
- three (3) boreholes in operation at the time of the study
- the exit of two (2) treatment (filtration) units in operation at the time of the study

Samples were not taken from service reservoirs and the distribution network due to absence of outlets to allow sampling at those points. Table 1 provides a brief description of each water sample.

Table 1. Description of water samples

Sampling points	Location	Sample description
BHAF002—BHAF004	Water source	Raw water directly from boreholes labelled in the OMC document as AF002, AF003 and AF004
TUAF003—TUAF004	Treatment units	Filtered, disinfected water from Aquatec filtration units attached to boreholes AF003 and AF004
SP001—SP010	User installations	Water from public standpipes after storage and distribution

For each sampling point, 3 samples were taken at monthly intervals (i.e. one sample per month for 3 months). The samples were collected with sterile bottles and stored in an ice chest to halt or slow down any microbial activity [21]. They were then transported to the Central Regional laboratory of the GWCL in Cape Coast, where the analyses were performed by competent laboratory personnel of the company. A fourth round of samples was taken from only the standpipes purposefully to obtain an idea of the level of residual chlorine in the distribution network after bacteriological contamination was detected in some of the samples.

2.3.4.2 Water quality parameters and experimental procedures

Laboratory investigations were conducted to establish the bacteriological safety and physical (aesthetic) quality of water (pH, colour, turbidity). The adequacy of disinfection (residual chlorine) was only assessed upon the detection of bacteriological contamination. Available resources did not allow the assessment of the chemical parameters (such as iron) which would have improved the quality of the results. Bacteriological quality was assessed in terms of total coliforms using the multiple tube method (MPN), following procedures described in the *Standard Methods for the Examination of Water and Wastewater* [21]. Samples that tested positive in the initial presumptive test were subjected to further examination to establish whether the contamination was from a faecal origin by confirming the presence of *E. coli*. The Mettler Toledo pH meter was used for pH measurement, the HANNA turbidimeter for turbidity and the Hach DR 2800 spectrophotometer for colour measurement following Standard Methods [21]. Residual chlorine was measured directly in the field using the DPD (N, N-diethylparaphenylenediamene) colorimetric method [21].

2.4 Data Analysis

Comprehensiveness of existing WSP was assessed by analysing how the content of the system-specific documents addressed the key components of a formal WSP as recommended by CWSA [16] and WHO [8], namely:

- water system description
- identification of hazards and risks that the water supply is or may be exposed to
- water safety control measures against hazards and risks
- monitoring mechanisms for control measures

Actual water quality control practices identified through structured observations and in-depth interviews were compared to those required of scheme managers by the OMC document in order to assess the level of compliance. Results on water quality testing were compared to Ghana Standards Authority (GSA) standards and WHO guidelines.

3. RESULTS AND DISCUSSION

3.1 Comprehensiveness of Existing WSPs

Even though the OMC document and system design reports were found to contain some aspects of a WSP, no formal WSP was specifically prepared for the AFSTWSS. The content of these documents were reviewed and summarised below to demonstrate how they address the key components of a formal WSP [8, 16].

3.1.1 Description of water system

Details of the water supply system extracted from system design report and data files as well as the OMC have been summarised in Appendix B. They include type of water source and abstraction infrastructure, water treatment systems, transmission, storage and distribution infrastructure as well as water demand and types of service connections. Although appreciable details have been documented, some information that are highly relevant for understanding the water safety hazards and risks associated with the system were not documented. For instance, no information was provided on the land use pattern and types of human activities within the catchment areas of the boreholes. Similarly, there was no documentation of the types of sanitation facilities and their distances from the boreholes, among other details recommended by WHO [8]. Such details are needed to guide the identification of potential hazards.

3.1.2 Identification of hazards and risks

Available documents do not contain any list of hazards or risks that may be associated with the system. However, the design of the system and the local environment could pose a number of risks and hazards that would be expected in a comprehensive WSP. A notable risk was the presence of dead ends (i.e. stand-alone pipe ends that are not looped to other pipes to allow continuous flow) in the distribution network. Dead ends are noted for high residence times, absence of residual disinfectants and optimum conditions for corrosion, which combine to create a favourable environment for bacterial regrowth [22]. Another technical risk was the possible failure of the filtration and disinfection units that would adversely affect the bacteriological and aesthetic quality of the water. Furthermore, a potential environmental hazard is the use of on-site sanitation systems such as pit latrines in the Assin Fosu Township [20] that could lead to faecal contamination of groundwater resources.

3.1.3 Water safety control measures against hazards and risks

The OMC document specified an operation and maintenance (O&M) schedule to be followed by the system operator. A summary of the schedule is presented in Appendix C. The O&M schedule specifies specific tasks to be performed on the various system components and the frequency (rate) at which they are to be carried out. However, no targeted hazards or risks were specified for the documented O&M activities; they were provided as conventional small-scale water supply O&M practices to protect the quality of water and to keep facilities in good condition. The failure to precede the development of the O&M schedule with identification of system-specific risks led to the omission of some crucial tasks. For instance, the presence of dead ends in the distribution network required the inclusion of tasks such as spot flushing [23] or unidirectional flushing [24, 25] to control biofilm and sediment accumulation at the dead ends. However, no specific tasks were included in the maintenance schedule to manage these risks.

3.1.4 Monitoring mechanisms

Documented monitoring mechanisms were mainly internal operational monitoring activities to be carried out by the system operator. No verification monitoring by an external agent was included in the OMC document. Table 2 summarises the monitoring activities expected to be carried out by the system operator.

Table 2: Water safety monitoring activities

Item	Means of verification	Target/operational limit
Water quality testing	Water quality reports	Ghana Standards Authority requirements
Environmental cleanliness around system components	Annual technical audits	100%

Specific water quality parameters to be monitored were not specified in the OMC document (see Table 2). Similarly, specific indicators to assess the cleanliness of the catchment areas of system components were not specified; no details were provided to clarify the meaning of the ‘100%’ target.

3.1.5 General comments on the comprehensiveness of existing WSPs

The omission of some key components of a formal WSP in the existing documents could be attributed to the fact that they were simply not prepared as WSPs. Even though the mere preparation of a WSP may not necessarily lead to full implementation, it would be a significant step towards protection of water safety by making sure every water supply system has a documented WSP, at least on paper. In this regard, the CWSA should exercise its regulatory powers to demand that the planning and implementation of every rural water supply project in Ghana includes the preparation of a formal WSP just like the legal requirement for the preparation of an environmental impact statement for all major land development projects in the country.

3.2 Compliance to existing water quality control and monitoring schedules

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Table 3 summarises findings on actual practice of documented water safety control measures and monitoring activities.

Table 3. **Summary of actual water quality control and monitoring practices**

System component	Specific task	Specified schedule in OMC	Actual reported schedule	Time elapsed since task was last performed	Remarks on status of task and observation made
Water source	Borehole blowing	Once in 5 years	Never done before	Not applicable	Not due to be performed
	Repair of pump leakages	Annually	When leakages occur	8 months	No leakages were observed but surroundings were bushy
Treatment	Backwashing of filtration units	Daily	Daily	Less than 12 hours	Not overdue
	Checking of leakages at filtration unit joints/valves	Daily	Daily	Less than 12 hours	Not overdue No leakages were observed
	Regeneration of filtration units	Monthly	1—2 times every 2 months	7 weeks	Overdue: OMC not strictly followed
	Cleaning of chlorine dosing chamber and filter	Monthly	Once in 8 weeks	6 weeks	Overdue: OMC not strictly followed
	Fixing of leakages and cracks in chlorine dosing system	Monthly	When leakages occur	Not applicable	No leakages or cracks were observed
Transmission, storage and distribution	Repairs of structural defects and leakages in storage tanks	Monthly	When defects or leakages occur	6 days	No structural defects or leakages were observed
	Cleaning and disinfection of tank	Biannually	Quarterly	2 months	Not overdue
	Repair of transmission and	Quarterly	When faults occur	1 week	No installations requiring

	distribution pipe installations				repairs were observed
User installations	Cleaning of standpipe platform area	Weekly	Weekly	Less than 1 week for all stand pipes	Not overdue but there was sand/dirt on 6 out of 10 observed
	Repair of structural defects on standpipe platform and drains system	Monthly	When defects occur	Two weeks	No structural defects or blocked drains were observed
Monitoring of water quality	Internal monitoring of water quality	Quarterly	Every 2 months or after receiving complaints	5 weeks	Not overdue
	Water quality testing by a recognised laboratory	Biannually	Biannually	13 months	Overdue

The results on actual water safety control and monitoring activities show that the system operator failed to comply with the schedule for some operation and maintenance tasks that are key to the protection of water safety in the system. For instance, the regeneration of the Aquatec filtration unit was found to be done 1–2 times in 8 weeks instead of once every month. At the time of enquiry, it had been in operation for 7 weeks without regeneration. Although the composition of the packaged filter medium and any special pollutant it could remove were not documented, it was revealed by a staff of the system operator that it had been packaged to remove iron from the groundwater. Thus, failure to regenerate it within the recommended period of time could lead to high levels of iron and, consequently, impartation of colour and taste to the water [26]. Deterioration in these aesthetic quality parameters could negatively affect consumer confidence and compel some of them to resort to other unimproved sources of water. Besides this, failure to clean the chlorine dosing chamber and filter according to schedule could affect the efficiency of the chlorination process which is the system's main protection against bacteriological contamination [27]. Although the operator undertook regular internal monitoring of the level of iron, it was found that a more comprehensive water quality testing by a recognised laboratory had not been undertaken biannually as stipulated by the OMC and generally required by the CWSA [16].

The lapses observed in the performance of operation and maintenance tasks could be attributed to inadequate supervision by the Community's WSMT, the Municipal Assembly's Water and Sanitation Development Board and the CWSA as a regulatory body. It is also an indication of potential challenges in implementing a more comprehensive WSP in the future. This underscores the need for effective participation by the Community's WSMT or other community representatives in system monitoring activities as recommended by WHO [8]. As the closest and the most affected stakeholder, members of the community should be oriented to demand accountability from the system operator. The CWSA should therefore sensitise beneficiaries of small-scale water supply systems in Ghana on the advantages of the water safety planning approach as part of a national effort to introduce this approach into the rural water sub-sector in Ghana.

3.3 Quality of Water Supplied

Table 4 presents the quality of water sampled from various points within the water supply system. The results indicate that water delivered to consumers at some points in the distribution system fails in some of the water quality parameters that were examined.

3.3.1 pH

The pH of all borehole and standpipe samples fell within the GSA required range of 6.5—8.5 [16] with the exception of one standpipe where a pH of 9.2 was recorded. Although the pH of another standpipe (8.4) exceeded the WHO guideline value of 8.0 [2], it fell within the range of the GSA. No scientific explanation could be deduced for the high pH of 9.2 recorded at one of the standpipes. Studies conducted in other rural water supply systems in Ghana reported lower pH levels. At Obuasi in the neighbouring Ashanti Region which is located 81 km from Assin Fosu, Ewusi [28] reported average pH levels of 5.01—5.33 while Rossiter [29], in a nationwide survey, reported pH levels as low as 3.69 in some boreholes in Ghana though the overall average was 6.32. Similarly, a mean pH of 6.34 has been measured in ten districts/municipalities/metropolitan areas (including Assin Fosu) in the Central Region [30]. Generally, the pH of groundwater is influenced by the nature of the geology of the area [31] which is reported to be granitoids in Assin Fosu with an average groundwater pH of 6.04 [32].

Table 4. **Results of water quality analyses**

Sampling points	pH			Colour (Pt-Co)			Turbidity (NTU)			Total coliforms/ E. coli (per 100 ml)			Residual chlorine (mg/l)
	S1	S2	S3	S1	S2	S3	S1	S2	S3	S1	S2	S3	
Raw water from boreholes													
BHAF002	6.5	7.2	7.4	9	0	0	2.5	4.3	1.4	N	N	N	Not applicable
BHAF003	6.6	7.7	8.0	102	142	71	15.0	27.5	12.7	N	N	N	
BHAF004	6.6	7.7	8.0	282	221	123	37.0	35.2	20.7	N	N	N	
Average	6.6	7.5	7.8	131.0	121	64.7	18.2	22.3	11.6	-	-	-	
Filtered water from Aquatec filtration units													
TUAF03	6.5	7.3	7.7	94	110	103	15.0	20.6	19.9	N	N	N	Not applicable
TUAF04	6.7	7.3	8.0	101	110	108	17.0	18.0	17.7	N	N	N	
Average	6.6	7.3	7.9	97.5	110	105.5	16.0	19.3	18.8	-	-	-	
Final water from public standpipes													
SP001	6.5	7.1	7.3	11	0	0	2.9	8.7*	4.2	N	N	N	0.1
SP002	6.5	7.0	9.2*	7	21*	38*	4.8	6.2*	10.3*	N	N	N	0.1
SP003	6.6	7.2	7.2	2	60*	97*	4.0	7.0*	20.9*	N	PP*	N	0.1
SP004	7.1	6.6	7.8	28*	1	10	4.2	2.3	6.5*	N	N	N	0.1
SP005	6.6	7.3	7.6	2	0	79*	4.2	8.7*	12.1*	N	P*	N	0.1
SP006	6.5	7.3	7.9	22*	0	256*	3.5	5.9*	19.9*	P*	PP*	PP*	0.3
SP007	6.6	7.0	7.4	2	22*	91*	4.0	6.2*	19.9*	N	N	N	0.1
SP008	6.9	7.0	7.6	1	11	21*	1.4	2.4	5.3*	PP*	PP*	N	0.1
SP009	6.5	6.9	7.7	2	76*	30*	4.0	10.3*	8.1*	P*	P*	N	0.2
SP010	6.6	7.0	8.4*	1	22*	0	3.1	4.1	2.7	PP*	N	N	0.1
Average	6.6	7.0	7.8	7.8	21.3*	62.2*	3.6	6.2*	11.0*	-	-	-	0.13

GSA standard	6.5-8.5	15	5	0.00 (not detected)	0.2 (minimum)
WHO guideline	6.5-8.0	15	5	0.00 (not detected)	0.2—0.5

*S1, S2, S3 = Sampling days 1, 2 and 3; N = Negative (total coliform not detected); P = Positive (total coliform detected); PP = Positive confirmatory test (E. coli detected); *= Results of final water from standpipes which do not meet GSA/WHO guidelines*

3.3.2 Colour and turbidity

Colour and turbidity are among the parameters that define the aesthetic quality of water [33]. High levels of colour were observed in the raw water. The average colour level for the boreholes for the 3 sampling dates ranged between 64.4 and 131 Pt-Co, as compared to a guideline value of 15 Pt-Co [16], and an average of 7.7 Pt-Co reported for boreholes in the Densu basin of Ghana [34]. Similarly, the levels of turbidity were high, with averages ranging between 11.6 and 22.3 NTU and a maximum of 35.2 NTU being recorded. These exceed the guideline value of 5 NTU [2, 16] and an average of 2.6 NTU reported by Amoako, Karikari [34] for the Densu basin. Nevertheless, Schafer [35] and Rossiter [29] reported much higher turbidity levels in boreholes studied throughout Ghana, with their respective maximum turbidity levels reaching as high as 266 and 629.7 NTU. High levels of colour and turbidity could be indicative of ageing boreholes or the presence of iron. Even though the concentration of iron was not measured in this study due to resource constraints, the more likely cause of high colour and turbidity levels could be the presence of iron since the boreholes were less than five years old. Moreover, Asante-Annor [32] reported high level of colour, turbidity and iron in groundwater from Assin Fosu and attributed the results to the geological formation of the area. The high iron levels in the groundwater may have necessitated the installation of the Aquatec filtration units.

It was expected that the high colour and turbidity of the raw water would be reduced to the recommended levels after undergoing treatment in the filtration units but the reduction observed was marginal and inconsistent as seen in Table 4. This could be attributed to inefficient filtration which could primarily result from poor management of the filtration units. The management of the filtration units was one of the areas where the stipulated operational (regeneration) schedule was not strictly followed.

From the filters to the user installations (standpipes) the colour and turbidity of the water generally improved but the averages for the 2nd and 3rd batches of samples taken from the standpipes failed to meet the GSA and WHO guidelines [2]. The reduction could be attributed to settling in the reservoirs and the pipelines, a phenomenon which explains the sharp deterioration in colour and turbidity whenever operation is restarted after a shut down. High levels of colour and turbidity may not in itself be harmful to human health but could provide shelter for microorganisms and consequently affect the efficiency of the disinfection process. In addition, high levels of colour and turbidity negatively affect consumer confidence and perception of the actual quality of the water [16, 33] and may also provide shelter for microorganisms affecting t. It should therefore be well managed to ensure that the customers do not resort to unprotected sources of water that may be aesthetically appealing but bacteriologically unsafe.

3.3.3 Bacteriological safety

The raw water from the boreholes was found to be free from bacteriological contamination as generally expected of groundwater [36]. However, samples from 6 out of 10 standpipes tested positive in the presumptive (total coliform) test on, at least, one of the 3 sampling dates. Of these, 4 tested positive in the confirmatory (*E. coli*) test, which is an indication of faecal contamination, on one or more sampling dates. The proportion of samples contaminated with *E. coli* (40%) is fairly consistent with earlier reports that 43% of improved water sources in Ghana are not free from *E. coli* [4]. However, investigations conducted on borehole water samples from other small-scale water supplies in Ghana have reported varied results. Adetunde and Glover [37] reported the presence of total and faecal coliforms in some water samples collected from both boreholes and standpipes on the Navrongo Campus of the University of Development Studies in northern Ghana. In another study, Arnold, VanDerslice [38] reported the presence of total coliform in 1 out of 10 borehole samples in rural Ashanti Region but no faecal contamination (*E. coli*) was detected. However, that same study reported the presence of total coliform in all 18 samples taken from public standpipes, with *E. coli* being detected in 11 of the samples. The poor bacteriological quality of water samples recorded in this study is also consistent with results of high bacteriological contamination (43%) of similar water sources reported in Ghana by UNICEF/WHO [4].

Generally, bacterial regrowth in water results from biological processes such as biofilm development on pipe walls [39], bio-corrosion of pipe material [40], nitrification [41] as well as physical factors such as pipe breaks, permeation of contaminated water through porous pipe joints, absence of effective backflow devices and cross-connection with wastewater or other fluids [42, 43, 44]. As noted earlier, biological processes that lead to bacterial growth are notably favoured by the presence of dead ends in the distribution system [22]. This could be a major contributory factor in this study since 3 of the 4 standpipes where confirmatory tests proved positive were located close to dead ends.

Another major cause of bacterial growth in drinking water is inadequate disinfection [27]. Following the detection of bacteriological pollution, a single round of sampling from the 10 standpipes was done to assess the level of residual chlorine in the distribution system. The results showed that samples from only 2 standpipes met the minimum (0.2 mg/l) of residual chlorine required [2, 16]. It is recalled that, the management of the chlorine dosing system is among the maintenance tasks which were found not to be executed according to the schedule provided in the OMC.

Beside the low levels of residual chlorine, the high turbidity and colour could interfere with the efficiency of the disinfection process [45]. It is therefore important for the filtration units to be well managed to improve upon the levels of turbidity since its impact on the water quality goes beyond aesthetics to affect disinfection efficiency. It is also important for the dead ends in the distribution systems to be flushed regularly in order to minimise the conditions which favour bacterial growth.

4. CONCLUSION

The AFSTWSS does not have a comprehensive water safety plan prepared according to the general framework provided by Ghana's Community Water and Sanitation Agency or the model recommended by the WHO. Existing documents do not provide some details of the system components that are relevant for water safety planning and also fail to identify potential sources of hazards and risks in the system. Furthermore, documented water safety control measures are not linked to system-specific risks and hazards, as expected in the conventional practice of water safety planning. Even though a general operation and maintenance schedule was developed, it does not include control measures that would address some system-specific risks such as the management of dead ends in the distribution system. Actual operation and maintenance practices failed to comply with the recommended schedule for some key water quality control and monitoring activities. Such activities include regeneration of filtration units, maintenance of a chlorine dosing system as well as water quality testing by a recognised laboratory. Under the existing water safety management regime, the quality of water delivered to the consumers at some points in the distribution system failed to meet the GSA and WHO limits for some parameters. Colour and turbidity were found to be high. Final drinking water from fifty per cent of samples taken from public standpipes had levels of colour exceeding the GSA/WHO threshold of 15 Pt-Co to as high as 60 Pt-Co and above on at least one of three sampling dates. For turbidity, 60%

of the water samples from public standpipes exceeded the GSA/WHO threshold of 5 NTU on at least two of the three sampling dates, with same proportion of samples recording levels above 10 NTU on at least one sampling date. In terms of bacteriological quality, faecal contamination was detected at 40% of public standpipes on at least 1 of 3 sampling dates.

5. RECOMMENDED POLICY DIRECTION

Development and implementation of WSPs is key in ensuring that water of acceptable quality is supplied to consumers at all times. The Assemblies' in collaboration with CWSA should build the capacity of technical staff at the District/Municipal Assemblies in the performance of this activity. The CWSA may also consider making it a legal requirement for every rural water supply project in Ghana to include the preparation of a WSP so that consultants assigned to such projects would assist the respective District Assemblies in this exercise.

To ensure that operators of rural water supply schemes in Ghana commit themselves to any WSP to be prepared for their systems, the CWSA should sensitise beneficiary communities of rural water supply projects on the importance of the water safety planning approach and the role they can play to support the system operator in following a WSP. Also, the various District Water and Sanitation Teams and the Regional Offices of the CWSA should ensure effective supervision of the activities of system operators.

There is also the need to repeat this study in other rural water supply systems in Ghana to obtain a broader understanding of the opportunities and challenges for implementing the water safety planning approach to water quality management in Ghana's rural water sub-sector.

COMPETING INTERESTS

Authors have declared that no competing interests exist

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APPENDICES

Appendix A – Selected System Photographs

Plate 2 Water source – borehole and pumping station – at Assin Fosu (*Credit: Authors*)

Plate 3 An Aquatec filtration unit installed in the AFSTWSS (Source: ANMA [20])

Plate 4. Service reservoirs of the AFSTWSS (a) Elevated aluminium reservoir; (b) Ground-level concrete reservoir (Source: ANMA [20])

Appendix B – Summary of Description of the Water Supply System

System component	Description	Other details provided
Water source	**Type of resource**: Groundwater **Abstraction infrastructure**: 4 mechanised boreholes Average depth: 74.3m Average test yield: 48.3 m^3/h	Location of boreholes Depth and test yield of individual boreholes Casing diameter of each borehole
	Pumping system: 4 pumps of unspecified type Total discharge: 112.5 m^3/h for 16 hours per day Average head: 129.5 m **Power source:** National grid	Discharge and head of each pump
Treatment	**Type of treatment system:** 3 Aquatec filtration units* (See Plate 2 in Appendix A)	No further details provided
Transmission, storage and distribution	**Transmission mains**: Dedicated transmission with no draw-off into distribution Number of different pipe sizes: 5 Average outer diameter: 122 mm Total length: 9.1 km Pipe material: High density polyethylene Pipe class: Pressure number (PN) 16	Diameter and length of each transmission main
	Storage tanks: 2 aluminium (elevated) and 1 concrete (ground) tanks (See Plate 3 in Appendix A) Total service capacity: 480 m^3 Height of elevated tanks: 12m	Location of each storage tank Service capacity of each storage tank
	Distribution network: Number of different pipe sizes: 7 Average diameter: 116 mm Total length: 52.3 km Pipe material: High density polyethylene Pipe class: Pressure number (PN) 10	Length and diameter of each distribution line
User installations	**Water demand**: Design horizon: 10 years (2006—2016) Design population: 47,200 (2016) Daily peak water demand: 1800 m^3	No further details provided
	Types of service connections: Public standpipes: 46 Large institutions with bulk connection: 11 Private household connections: 127 Fire hydrants: 2	

*The Aquatec filtration unit is pre-packaged for the removal of iron from the groundwater. Water from the boreholes passes through the unit before transmission into the storage reservoirs.

Appendix C - Documented Operation and Maintenance tasks to be performed by the System Operator

System component	Specified tasks	Expected Frequency
Water source	**Abstraction infrastructure (borehole)**:	
	• Borehole blowing	Every 5 years
	Pumping system:	
	• Pump testing	Every 5 years
	• Servicing of pumps by accredited pump agent	Annually
	• Inspect pump house and repair cracks	Annually
	• Repair leakages and other damages	Annually
	• Carry out painting	Annually
	• Inspect electrical installations and replace defective ones	Monthly
	•	
Treatment	**Aquatec filtration units**:	
	• Backwashing	Daily
	• Check for leakage at joints and valves	Daily
	• Regeneration	Monthly
	Disinfectant dosing system:	
	• Clean filter and dosing chamber	Monthly
	• Check for leakage and cracks	Monthly
Transmission, storage and distribution	**Service reservoirs**:	
	• Inspect structure and repair structural defects and leakages	Monthly
	• Remove rusts and paint structure	Annually
	• Drain, clean and disinfect inside of tank	Twice a year
	Transmission and distribution pipelines:	
	• Inspect transmission and distribution pipe routes	Quarterly for all tasks
	• Repair pipe installations	
	• Refill earth depressions	
	• Remove trees and roots	
	Surge vessels:	
	• Check and correct pressures if necessary	Monthly
User installations	**Standpipes**:	
	• Cleaning the platform area	Weekly
	• Check for small erosion and protect if necessary	Weekly
	• Check and repair structural defects	Monthly
	• Check and repair cracks in drains	Monthly
	Meters:	
	• Check operations and if necessary repair	Monthly
	Valves and taps:	
	• Keep access free	Annually
	• Check operations and if necessary repair	Annually