Assessment of water supply system from catchment to consumers as framed in WHO water safety plans: A study from Maiduguri water treatment plant, North East Nigeria

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ABSTRACT
Water safety plan (WSP) concept of World Health Organisation based on risk management from catchment to consumers ensures safe drinking water supply by water supply utilities. Water supply system assessment is integral to effective WSP development and implementation. This study reports assessment of Maiduguri water treatment plant from catchment to consumers, toward providing baseline information for effective WSP. A cross-sectional study involving questionnaire, key informant interview, and water analysis was used to collect data on catchment, treatment units, storage, distribution system, and consumers. From the study, concentration of chemical water parameters analyzed within the treatment units was found to be increasing after coagulation, filtration, and disinfection stage, such as (SO₄: 19–26 mg/l at final water); (total alkalinity: 79–102 mg/l after coagulation); and (PO₄: 0.23–0.31 mg/l after filtration), and household storage containers were also infected microbiologically with such as Escherichia Coli. According to the questionnaire, there are low home treatment practices (30%) and low level of water quantity satisfaction (16%) by the consumers; however, some (56.5%) were satisfied with the water quality. The study identified the barriers to effective water services delivery at different stages of the water supply system, which includes heavy sludge and biofilm growth in sedimentation tanks and reservoirs, and manual injection of treatment chemicals within the treatment units; pipeline damages, blockages, leakages, intermittent water supply and illegal connections along the distribution line; and poor water collection and storage practices at consumers point. Therefore, commitment by relevant stakeholders is paramount for effective WSP implementation to protect public health in the study area.

1. INTRODUCTION
Safe drinking water supply is essential for sustaining good public health in urban residents (WHO, 2004). The traditional method of drinking water supply quality control based on end-pipe monitoring, which relies on final water quality and bacterial indicators, is inefficient and uneconomic in protecting public health by water supply systems (Abuzerr et al., 2020; Jose, 2005), as a result, the World Health Organisation (WHO) encouraged and recommended water safety plan (WSP) based on risk assessment and risk management from catchment to consumers, which states that;

“The most effective means of securing the safety of a drinking water supply is through the use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumers (Figure 1), such approaches are known as water safety plan” (Bartram et al., 2009; WHO, 2004, 2011)

WSP is simply a documented plan that identifies hazards; assesses risks from catchment to consumers; Prioritizes risks (with focus on highest risks) and Mitigates risks through control measures. This means moving away from reliance on output monitoring (measuring parameters in final water), and moving into input monitoring (measuring parameters which show that the system is working) (Bartram et al., 2009, Emma and Phillips, 2014). The aim of the WSP is basically to enhance good practices such as preventing or reducing source pollution, reducing pollutants through treatment processes, and preventing its contamination during its storage, distribution, household connection, and handling (Bartram et al., 2009). The plan relies on the fact that there are several factors surrounding safe water
supply and better public health (Pooja et al. 2014) such as catchment activities polluting water sources (Sang & Ji, 2016); improper maintenance and operations in treatment resulting in treatment failures (Jetoo et al., 2015); inadequate management of drinking water distribution system affecting quality water delivery to households (Marroquin et al., 2014; Motasem, 2013) and unhygienic storage and handling of waters causing recontamination at households (Andrea et al., 2013; Bava, 2015).

WSPs are promoted in the third edition of the WHO guidelines of drinking water quality standard in 2004. Since then, WSPs have offered an internationally recognized systematic risk management approach to enhance water quality around the globe, through the implementation of this risk management approach, water systems have seen to be improved in respect of quality, regulatory compliance, communication, asset management, technical operation and performance, and public health outcomes (Baum et al., 2014; Jose, 2015; Kumpel et al., 2018). However, since inception to date, there is practically low level of WSP development and implementation experience in the developing countries (Mahmud et al., 2007), despite the need for enhanced water quality as thousands die yearly due to waterborne and water-related disease. Hence, this WSP research work was intended for Maiduguri water treatment plant, Maiduguri, the capital city of Borno State, Nigeria, where there have been problems of safe water supply systems over the last few years (Hyeladi & Nwangali, 2014, Dammo et al. 2014; Bukar et al., 2015; Aza et al., 2016; Jimme et al., 2016; Zulum et al., 2017; Ibn Abubakar et al., 2018, Mustapha et al. 2019), and currently reported to have high cases of Kidney diseases which perhaps is a result of poor drinking water quality. These observations thus further strengthen the present study calling for sustained water quality to the consumers following a holistic approach from catchment to consumers and development of WSP.

However, the overall processes of WSP development and implementation are primarily a team work that requires huge capital investment, adequate time frame and commitment from different professionals. Therefore, this study aims to provide the baseline information which may serve as a prominent guide in the development and implementation of the WSP in the study area, and followed the Module 2 of the WHO WSP guide known as the system assessment (Bartram et al., 2009). The specific objectives of the research are to: assess the consumers’ level of water supply satisfaction and their water handling practices and attitudes; determine the physical, chemical and microbiological quality of water being treated and supplied, and identify all the hazards and hazardous events that can affect the quality or quantity of water supply at each step of the water supply chain from catchment to consumers.

1.1. Water system assessment

System assessment is one of the critical stages in the development of WSP. A good WSP is as good as a reliable system assessment, system assessment will critically reveal where the system is vulnerable to contamination, and hence the extent of WSP needed by the system. It will help WSP team members to be well acquainted with the water supply system from source to the point of consumption, helping to evaluate the type of safety hazards to be anticipated to support the subsequent risk assessment process (NEA, 2008; Bartram et al., 2009; Marroquin et al., 2014). In describing the system according to WHO WSP guide, information such as the following is essential:

Water supply component description
Such as to provide detailed information on sources, treatment works, storage systems, and distribution network (Bartram et al., 2009; WHO, 2012). This can be achieved through field inspection and key informant interview

Water quality description
To provide data on existing water quality from catchment to consumers being treated and supplied by the utility, it helps to analytically predict the presence of hazardous event at any point along the water supply chain (Bartram et al., 2009).

Identification of the users and uses of water
As the traditional practice of assuring drinking water quality only to the point water meter (end pipe monitoring) is now outdated (Bartram et al., 2009) according to the WHO WSP, the focus of the water supply systems includes now also management of household drinking water as consumers unhygienic practices causes recontamination (Andrea et al., 2013, Moatsem, 2013; Bava, 2015). Therefore, identification of the users and uses of water is

Figure 1. The basic elements in water supply system. (Tool 2.2 adopted from Bartram et al., 2009)
necessary to determine tendencies of re-contamination from household collection, storage and handling behavior. Hence, information such as the intended use of water, collection and storage behavior of consumers, hygiene knowledge, and practices of consumers and extent of home water treatment methods and practices is vital information for WSP at the consumers’ point.

2.0 Methodology
2.1. Study area

2.1.1. Maiduguri
Maiduguri, the capital of Borno State is located between latitude 10°00 and 14°00 north of the equator and longitude 11°30 and 14°45 east of the Greenwich Meridian, the state lies some 355 m above sea level and it occupies a total area of 50,778 sq km, lying within the Sudan-Sahalian zone of Nigeria, it is the largest town in the North-Eastern area of Nigeria. The relief of Maiduguri lies on the vast open plains which is relatively flat or gently undulating. The landscape is developed on the young sedimentary rocks of the Chad formation. This formation is overlain by sand drifts which may be up to 90-m thick. The extensive plain contains no prominent hill and attains an elevation of about 350 m above sea level.

The climate is characterized by two distinctive wet and dry seasons, which tend to be controlled by the inter-tropical discontinuity (ITD). The rainy season lasts for about five months (May–October). Available rainfall data reveal that annual rainfall average ranges between 500 mm and 750 mm while the intensity of rainfall ranges from 0.002 mm/h to 112 mm/h. The mean temperature both seasonally and diurnally varies from 25°C to 36°C, the hottest months being March and April with values between 39.80°C and 40.70°C. The corresponding minimum temperatures of 20.60°C and 32°C are in December and January.

2.1.2. Maiduguri water treatment (source water, location and intake facilities)
Maiduguri water treatment plant construction was completed in 1992 (Umara, 2013), it is one of the major sources of water in Maiduguri, it is located along Bama road in Maiduguri, Nigeria. The treatment plant utilizes Lake Alau as the source of raw water. Lake Alau is a reservoir constructed across River Ngadda by the Lake Chad Basin Authority for agricultural purposes, the lake is located between latitude 12°N and 13°N and longitude 1°E and 13°E. Lake Alau has a total surface area of 56 km² and a maximum depth of 10 m with an effective storage capacity of 54,000 ha (CBDA, 1986), the Dam stores water during seasonal floods in undulating low land of the south of Konduga village, Nigeria. Apart from the dam which provides water for agriculture, there are intake works for Raw Water abstraction to the Maiduguri water treatment plant, with pumping Station having three pumps (two on duty and one standby) with flow per pump of 540 l/sec and discharge pressure of 55 m, it has a transmission line for raw water using 800 mm diameter pipe with total length of 14 km to the water treatment plant.

2.2. Study design

The study is cross-sectional and analytical consisting primarily of key informant interviews, questionnaire surveys, and water quality analysis.

2.2.1. Key informant interviews
Discussions were conducted with staff of the water works in various units, such as from the administrators, Stores, Quality assurance/Laboratory, operations, electrical and mechanical unit, for the conduct of the interview, one (1) person to represent each unit making a total of six persons interviewed. The interview was carried out along with visual inspections, was basically to have in-depth information on the type of supply system and operating techniques being deployed, this helps in understanding of the entire water system toward predicting hazards and hazardous events as per the WHO WSP Module 2 guide. Issues discussed in the interviews include: raw water sources, treatment units and chemicals used, storage systems, pumps and pumping, distribution systems, quality assurance, supporting programs available, management procedures, historical records, communication and relations with the concerned authorities (state ministries).

2.2.2. Consumers’ questionnaire and sample size
A structured questionnaire was developed and administered on the consumers. The questionnaire was drafted in English language and included information are personal profile of the respondent, drinking water sources at households, alternative domestic water supply sources, level of water supply satisfaction (both in quality and quantity), health issues encountered from the water supply, either in the past or present, pattern of water supply received, type of household storage systems used, household treatment methods practiced, hygiene awareness and practice level and consumers’ communication gap with the plant were captured in the
survey. The Questionnaires were administered to 200 consumers in 20 areas (Table 1), capturing the entire water distribution areas and wards which includes: Lamisla Jabarmari Ward comprising Millionaire Quartres, State Locust and Galadima, Wuladi, Hausari, Mafoni, Shehuri North, Shehuri South, Limanti, Bulabulin, Fizzan, Gamboru, University of Maiduguri, 202/303 housing estate, Dalori Estate, New G.R.A., Gwange, Old G.R.A., University Teaching Hospital, London Ciki, Shokari, and Damboa Road. Ten households in each area were randomly selected, while one person in the household had the questionnaire administered on, any household member he or she could not read or write, questions were administered in the language that he/she understood and the respond is recorded.

### 2.2.3. Water quality analysis

Water samples were collected from raw water source; through the treatment processes at each treatment process unit; along the distribution system at selected taps of consumers and at household from storage containers. The samples collected were then subjected to physical, chemical and microbiological analysis in a standard laboratory.

#### 2.2.3.1. Parameters analyzed.

(a) Physical: turbidity, Temp, EC  
(b) Chemical: pH, hardness, alkalinity, iron, zinc, lead, calcium, potassium, sodium, total dissolved solids, fluoride, chloride, sulfate, residual chlorine, nitrate, phosphate,  
(c) Microbiological: fecal coliforms and total coliforms.

#### 2.2.3.2. Procedures of sample collection.

Clean Plastic (PET) bottles were used to collect samples for analysis, in that have been cleansed and rinsed carefully, the water sample was collected using best practicable technique of sampling. For microbiological sampling, sterile glass bottles were used. In addition, for accurate identification, a descriptive data were written on each sampling container, includes the date of collection, collection point, sample number, and parameters to be measured.

#### 2.2.3.3. Number of samples and sample locations. (a)

**Microbiological analysis:** Six samples were taken for total coliforms and fecal coliforms count (E. coli), sampling location and labels are:

- **Sample 1:** final-treated water at treatment plant,  
- **Sample 2:** water sampled 3.5 km away from the treatment plant at Gwange area household tap,  
- **Sample 3:** water sampled at Gwange area household storage system (same house where sample 2 was taken),  
- **Sample 4:** water sampled 8.5 km away from Gwange area at London ciki household tap (end users),  
- **Sample 5:** water sampled at London Ciki area household storage (Sample house as sample 4),  
- **Sample 6:** water sampled at London Ciki household tap (same point as sample 4).

**Note:** Samples 4 and 6 were taken at the same location, but the samples were of different time and circumstances; sample 6 was taken after 2 days of ceased supply in which pipes were empty for 2 days thus expecting ingress of

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| Areas                          | Frequency | Percent | Valid% |
|-------------------------------|-----------|---------|--------|
| University of Maiduguri       | 10        | 5       | 5      |
| Teaching hospital             | 10        | 5       | 5      |
| 202/303                       | 10        | 5       | 5      |
| Dalori estate                 | 10        | 5       | 5      |
| New G.R.A.                    | 10        | 5       | 5      |
| Old G.R.A.                    | 10        | 5       | 5      |
| Mairi                         | 10        | 5       | 5      |
| Gwange                        | 10        | 5       | 5      |
| London ciki                   | 10        | 5       | 5      |
| Shokari                       | 10        | 5       | 5      |
| Damboa road                   | 10        | 5       | 5      |
| Lamisla jabarmari ward        | 10        | 5       | 5      |
| Wuladi                        | 10        | 5       | 5      |
| Hausari                       | 10        | 5       | 5      |
| Mafoni                        | 10        | 5       | 5      |
| Shehuri north                 | 10        | 5       | 5      |
| Shehuri south                 | 10        | 5       | 5      |
| Fizzan                        | 10        | 5       | 5      |
| Limanti                       | 10        | 5       | 5      |
| Gamboru                       | 10        | 5       | 5      |
| Total                         | 200       | 100     | 100    |
contamination through perforations as most pipes are passing through polluted drainages.

(b) Chemical parameters: a total of five samples were taken for analysis, sampling position, and their appropriate labeling were

- Sample A: Raw water sample;
- Sample B: Aerated water sample;
- Sample C: Coagulated water sample;
- Sample D: Filtered water sample; and
- Sample E: Final treated water sample.

2.2.3.4. Laboratory analyses. Laboratory analyses were carried out at four different laboratories for different parameters, namely:

(a) Geochemistry lab at geology Department (University of Maiduguri)

Elemental analysis of some of the major Cations (Na, K, Ca, and Mg) were analyzed using LAQUAtwin meter (Horiba Scientific), and Chloride and Hardness (C0₃ and HC0₃ determination) using titration, the reagents used for the titration of C0₃ and HC0₃ determination are Phenolphthalein 1% (1 g of Phenolphthalein in 100 ml alcohol), methyl-orange, and 0.1 N of H₂SO₄, and for chloride determination are 250 ml conical flask, K2CrO4 (Potassium Chromate) as indicator and 0.02 N Silver Nitrate (Ag₂NO₃).

(b) NAFDAC laboratory in Maiduguri

here total alkalinity was analyzed using titrimetry and iron, manganese, zinc, lead, fluoride, sulfate, and phosphate analyzed using Atomic Absorption Spectrophotometer (AAS, Model AA-6800 SHIM).

(c) Veterinary microbiology laboratory (University of Maiduguri)

The analysis of microbiological parameters of total coliforms and fecal coliform counts were carried out using total coliform count test method and most probable number method, respectively. Materials used are EMB (Eosine Methylene Blue B agar) culture media, MacConkey broth, eAger count plate, test tubes, and 0.85% normal saline solution.

(d) Maiduguri water treatment laboratory

parameters analyzed were nitrate, total dissolved solids, temperature, electrical conductivity, pH, and turbidity using HI 9829 multi-parameter and measurement of residual chlorine using a DPD (Diethyl phenylene diamine) tablet method.

3. Results

3.1. Results of key informant interview/visual inspection

3.1.1. Catchment (details of land use in the catchment and pollution)

The various social and economic activities taking place around the lake observed were inorganic farming, animal grazing, dumping of refuse, fishing and open defecation practices, which may endanger water quality and health. However, the plant’s authority revealed that there were catchment regulation policies being implemented to protect the raw water source, such as enforcement of farmers and catchment users to operate at some considerable distance away from the lake water, especially around the raw water intake side, but lack of proper monitoring due to insecurity has resulted to people defying the rules.

3.1.2. Water treatment system

Maiduguri water treatment plant operates according to the conventional water treatment processes of aeration, coagulation, filtration, and disinfection. Field inspections within the treatment plant found that most automated systems were not functioning, such as pumps for chlorine, alum and lime injection, thus water treatment chemical injection were achieved manually. The interview and inspection also found that the water treatment facilities have been in operation for over 30 years without being upgraded, such as filter beds life has exceeded, and many important operational facilities were in a state of dysfunctional. In addition, routine maintenance and periodic cleaning of treatment systems, such as aeration chambers, sedimentation tank, and underground reservoirs, were not carried out as they were observed to be heavily polluted with biofilm growth and sludges.

3.1.3. Water storage and distribution (storage capacity and population coverage, distribution pipe materials, distribution pattern)

The plant has two service reservoirs which are overhead, named System 1 and System 2. The System 1 is cited behind
Imam Malik school, Wulari Ward, Maiduguri. It has storage capacity of one million gallon and covers the main center of the metropolis, which includes: Lamisla Jabarmari Ward (comprising of Millionaire Quatres, State Locust, and Galadima), Wulari, Hausari, Mafoni, Shehuri North, Shehuri South, Limanti, Bulabulin, and Fizzan ward. While the System 2, having same storage capacity as System 1, was rightly located within the treatment plant, distribution coverage includes: University of Maiduguri, 202/303 Housing Estate, Dalori Estate, New G.R.A., Gwange, Old G.R.A., Teaching hospital, London Ciki, Shokari and Damboa Road. Different pipe materials used to supply water were ductile pipes (main pipe), asbestos (service pipes), stainless-steel pipes (connecting households), and PVC (individual household pipe). Water is distributed intermittently to various consumers from 7 am to 5 pm (total distribution time frame), with maximum hours of distribution per ward ranging from 1 to 5 h/day varying among areas with slightly seasonal differences. There were shifting valves at various strategic locations, which were timely adjusted to divert water flow from one area to another.

3.2. Results consumers questionnaire

3.2.1. Respondents category

Of the consumers that had the questionnaire administered on, 100% response were recorded as shown in Table 1. Most (38.5%) respondents were in the age range of (26–35) years with males being majority (88.5%). The educational level showed 39.5% hold higher education certificate while 50.5% hold elementary education. Household occupancy rate was 10 years and above for most (50.5%) respondents. Most of the respondents have stayed in the area for more than 2 years. Detailed results of the age, sex categories, family members, and educational level are given in a Table 2–5

3.2.2. Water quantity satisfaction

Concerning the water quantity satisfaction, quiet a large proportion (84%) were not adequately satisfied with the water quantity supplied to meet their demand, as shown in Figure 2, thus use of alternative sources of water supply became necessary and led many (24.34%) who were financially capable obtained personal boreholes in

Table 2. Respondents’ age

| Age range | Frequency | Percent | Valid% |
|-----------|-----------|---------|--------|
| 18–25     | 25        | 12.5    | 12.5   |
| 26–35     | 77        | 38.5    | 38.5   |
| 36–45     | 54        | 27      | 27     |
| 45–55     | 31        | 15.5    | 15.5   |
| 55 and above | 13 | 6.5     | 6.5    |
| Total     | 200       | 100.00  | 100.00 |

Table 3. Respondents’ sex

| Sex       | Frequency | Percent | Valid% |
|-----------|-----------|---------|--------|
| Male      | 177       | 88.5    | 88.5   |
| Female    | 23        | 11.5    | 11.5   |
| Total     | 200       | 100     | 100    |

Table 4. Number of occupants in the House

| Family members | Frequency | Percent | Valid% |
|----------------|-----------|---------|--------|
| 1–3 persons    | 5         | 2.5     | 2.5    |
| 4–6 persons    | 35        | 17.5    | 17.5   |
| 6–9            | 59        | 29.5    | 29.5   |
| 10 and above   | 101       | 50.5    | 50.5   |
| Total          | 200       | 100     | 100    |

Table 5. Educational status of respondents’

| Educational level | Frequency | Percent | Valid% |
|-------------------|-----------|---------|--------|
| No formal education | 5         | 2.5     | 2.5    |
| Primary           | 28        | 14      | 14     |
| Secondary         | 73        | 36.5    | 36.5   |
| Higher education  | 79        | 39.5    | 39.5   |
| Islamic studies   | 15        | 7.5     | 7.5    |
| Total             | 200       | 100     | 100    |
their households. Others use alternative sources of public boreholes or neighborhood (41.27%) and water vendors (31.75%) to supplement their demand, this was more dominant in the low income and highly populated areas, such as the areas of London Ciki and Gwange areas. In addition, the water supply is not consistent, often times the supply ceases for 2–3 days, sometimes even for a week, leading to water crisis and hardships especially in the low-income zones lacking private boreholes or finance to buy from vendors, according to the study ceased supply was mainly due to constant power failure within the plant. However, there were no records of use of water from spring, stream, or rivers either for drinking or other activities. On the other hand, 16% responded to be adequately satisfied with the water quantity received, the study found that these were consumers with few household members but with large household water storage system where stored water last for several days. Some consumers closed to the plant also experienced satisfaction due to pressure advantage. Meanwhile consumers in the areas of State Locust, Damboa Road, and some part of 202/303 estate, the new G.R.A., Gamboru, and Mairi reported to be completely seized from water supply, it is found that this was generally due to gravity problems, urbanization effect, low water distribution pressure, and problems of pipelines blockages and destruction from civil works, such as road construction.

3.2.3. Water-quality perception/satisfaction
People in the areas of 202/303, Teaching hospital, University of Maiduguri and Mairi, raised serious concern over high residual chlorine in the drinking water, and many revealed water appears dirty sometimes, particularly when seized supply were experienced as residents of Fizzan area and London ciki responded. Nevertheless, quiet a large number of respondents (56.5%) believed that the water is clean for drinking

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**Figure 2.** Graph showing the level of water quantity satisfaction by consumers.

**Figure 3.** A graph showing level of water quality satisfaction by consumers. A graph showing home water treatment practices by consumers.
and other domestic activities. Figures 3–4 below shows the level of water satisfaction by consumers in terms of quality.

3.2.4. Knowledge and practices on household water treatment, water collection, and storage
From the study, majority (70%) of the consumers drink water both from the treatment plant and other sources directly without treatment (Figure 3). However, (15.5%) claimed to sometimes boil the water and few others (11%) and (3.5%) use cloth filter and chlorine, respectively, to disinfect waters, use of chlorine were majorly reported in the areas of Gamboru and kofa Biyu. In millionaire Quarters area people have been suffering currently with intestinal worms, diarrhea, and typhoid, consumers in Gamboru area have suffered from typhoid and diarrhea in the last 6 months, and the issue of waterborne disease outbreak had also been experienced in the past by areas of millionaire quarters, Gamboru, London Ciki, and Fizzan in which many became ill. However, waterborne disease prevalence was generally low in the study area. Due to intermittent system of water supply, consumers collect and store waters, mode of water collection is mainly through taps and reservoirs, Storage containers capacity and type varied greatly among households classified mainly by material and economic status; clay and plastic containers ranging from 25 to 50 l in capacity were mostly used among low-income households, while some high-income groups use large concrete-made reservoir with pumps and overhead tank for collection and storage. However, Children were mainly involved in water collection and storage and many unhygienic attitudes were observed, such as dipping hands and droppings foreign objects into collected water.

3.3. Results of water quality analysis
Table 6 below shows the result of physical and chemical water quality analysis, it is found that source water quality is within limit and final-treated water is meeting standard (WHO standard) except for hardness. However, within the treatment unit operations, concentration of most parameters was found to be increasing as the treatment process is progressing at the stages of coagulation, filtration, and after disinfection. The microbiological water quality for total coliforms (Table 7) and fecal coliforms (Table 8) showed negative for all the samples except sample 5 with total coliforms (6x10³) and fecal coliforms (43MPN/100 ml value), However, contaminants of Corynebacterial species and Staphylococcus albus were found in sample 2, 3, 5 and 6, Pseudomonas aeruginosa in sample 2, 3, 4 and Bacillus species in sample 5 and 6. While sample 1; the final treated water from the treatment plant is free from any form of microorganisms.

4.0 Discussion
4.1. Catchment
Catchment protection is one of the crucial factors toward ensuring effective water supply, it reduces treatment cost and helps to reduce incidence of waterborne diseases during treatment failures. In the study area, various socioeconomic activities observed around the raw water source were potential threat to the quality of raw water to the plant (Barbosa et al., 2018). This observation supports the findings by Damo et al. (2014), in which the lake water was found to be polluted with high concentration of nitrate (260–230 mg-N\textsubscript{O}/l), phosphate
| S/No | Parameters measured | Sample A | Sample B | Sample C | Sample D | Sample E | Maximum permitted levels (NDWQS) |
|------|---------------------|----------|----------|----------|----------|----------|--------------------------------|
|      | Temperature °C      | 30.4     | 29.9     | 30.0     | 30.2     | 30.0     | Ambient                        |
|      | E C µS/cm           | 156      | 155      | 180      | 175      | 180      | 1000                           |
|      | Turbidity (NTU)     | 22.0     | 22.6     | 4.5      | 6.3      | 2.5      | 5                              |
|      | pH                  | 8.35     | 8.11     | 7.83     | 7.75     | 7.64     | 6.5–8.5                        |
|      | Nitrate (mg/l)      | 0.66     | 0.25     | 0.12     | 0.14     | 0.20     | 50                             |
|      | TDS (mg/l)          | 78       | 79       | 81       | 90       | 90       | 500                            |
|      | Hardness (mg/l)     | 219.67   | 286.79   | 176.96   | 158.65   | 195.26   | 150                            |
|      | Alkalinity (mg/l)   | 79.0     | 69.0     | 102.0    | 82.0     | 88.0     | -                              |
|      | Iron (mg/l)         | 0.14     | 0.14     | 0.11     | 0.13     | 0.13     | 0.3                            |
|      | Manganese (mg/l)    | 0.035    | 0.021    | 0.031    | 0.025    | 0.024    | 0.20                           |
|      | Zinc (mg/l)         | 0.79     | 0.56     | 0.40     | 0.65     | 0.22     | 3                              |
|      | Lead (mg/l)         | ND       | ND       | ND       | ND       | ND       | -                              |
|      | Sodium (mg/l)       | 25.0     | 25.0     | 29.0     | 26.0     | 23.0     | 200                            |
|      | Potassium (mg/l)    | 19.0     | 18.0     | 20.0     | 20.0     | 19.0     | -                              |
|      | Calcium (mg/l)      | 24.0     | 25.0     | 26.0     | 26.0     | 28.0     | -                              |
|      | Fluoride (mg/l)     | 0.23     | 0.11     | 0.10     | 0.13     | 0.10     | 1.5                            |
|      | Chloride (mg/l)     | 2.2      | 3.4      | 3.8      | 2.8      | 3.4      | 250                            |
|      | Sulphate (mg/l)     | 19.0     | 23.0     | 17.0     | 13.0     | 26.0     | 100                            |
|      | Phosphorous (mg/l)  | 0.023    | 0.020    | 0.011    | 0.031    | 0.034    | -                              |

NTU: Nephelometric Turbidity Units  
ND: Not detected  
NDWQS: Nigerian Drinking Water Quality Standard
(22–28 mg/l), and *Escherichia coli* (24 MPN/100 ml), mainly due to the inorganic agricultural practices and other socioeconomic activities taking place around the lake. Similarly, Andrea et al. (2016) and Sang and Ji, 2016 on WSPs assessment of water supply also reported that water quality incidents were majorly associated with different types of land use of the water sheds, which causes diffuse pollution and point source pollution such as discharge of waste water from industrial areas, inflow of chemical fertilizers or animal feces from agricultural and livestock industries and the inflow of domestic sewage from urban areas. Hence, catchment regulation such as complete abolishment of activities around the catchment became necessary especially around the intake side, thus reducing raw water source pollution, and water treatment cost, leading to quality water supply meeting health-based targets.

### 4.2. Water treatment system

Lack of proper management of treatment systems and operations most often have let to treatment failures and resulted in waterborne disease outbreak (Jetoo et al., 2015), systems automation, routine maintenance, and effective monitoring of treatment operations helps to consistently maintain quality water distribution to consumers. In this study, the manual dosing of treatment chemicals of alum, lime and chlorine are great hazardous event within the treatment plant which may lead to desired water quality being affected from inappropriate dosages. This finding is supported by Idris et al., a 2017 study analysis which showed that treated water from the plant contained excess chlorine and aluminum with 1.10 mg/l and 0.68 mg/l, respectively, presumably arising from treatment chemical overdosing due to manual operation. Furthermore, the use of wound out facilities such as life span exceeded filter beds can result in inefficient water filtration as evidenced, besides, sedimentation tank, and storage reservoirs being heavily polluted from sludge accumulation and biofilm growth which may also alter quality of treated water, thus putting consumers at greater risk of diseases. This corresponds to Hyeladi and Nwangiari, 2014 report; in which the treated water from the plant were found to be highly turbid showing 39NTU/L and color showing 40 Hazen scale units/l, of which these values were above the WHO specified standards. Hence, this assessment hinted that upgrade of facilities and routine maintenance is key emphasis within the treatment system for effective WSP development and implementation.

### 4.3. Distribution system

Adequate management of distribution system may enhance greatly the integrity of water distribution (Marroquin et al., 2014; Motasem, 2013), leakages, ingress of contamination, pipe burst, improper materials, cross-connections, back siphonages, intermittent water supply, damage to pipelines, pressure fluctuations, internal and external corrosion in the elements (Marroquin et al., 2014) are some of most associated faults which may endanger health of consumers. In this study, several illegal pipe connections and pipe leakages were observed resulting to drop in distribution pressure

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Table 7. Microbiological analysis results (Total coliforms count results)

| Sample no | Cfu     | Bacteria              | Max. permissible limit |
|-----------|---------|-----------------------|------------------------|
| 1         | 0*10³   | -                     | 10                     |
| 2         | 0*10³   | -                     | 10                     |
| 3         | 0*10³   | -                     | 10                     |
| 4         | 6*10³   | *Escherichia coli     | 10                     |
| 5         | 0*10³   | -                     | 10                     |
| 6         | 0*10³   | -                     | 10                     |

*Cfu = colony forming unit
10 = number of test tubes
3 = third tube

Table 8. Microbiological analysis results (Fecal coliform test; *Escherichia coli*)

| Sample No | MPN/100 value | Max. Permissible limit | Residual chlorine (mg/l) |
|-----------|---------------|------------------------|--------------------------|
| 1         | <1            | 0                      | 0.2                      |
| 2         | <1            | 0                      | 0.2                      |
| 3         | <1            | 0                      | 0.1                      |
| 4         | <1            | 0                      | 0.2                      |
| 5         | 43            | 0                      | 0.1                      |
| 6         | <1            | 0                      | 0.2                      |

Key

MPN = most probable number
in alternative locations, in addition most water pipes were passing through drains which carry communities’ grey water and other wastes, hence high possibility of contamination through pipe perforations, observation by Aza et al., 2016 could be linked to these scenarios, where higher microbial load count at the point of household delivery compared to the source were noticed, affecting the integrity of water distribution. The use of asbestos as service pipes should be noted as hazardous event as there are number of public health concern from the use of asbestos pipe in drinking water supply, long-term exposure may lead to cancer (Luberta et al. 2019).

On the other hand, considering the population growth and urban development experienced over the last decade, the distribution coverage needs to be extended as many areas within the metropolis were not captured and hence increase in the number of storage reservoirs should, therefore, be an utmost priority to the WSP stakeholders. WSP should also include repairs and installations of damaged pipes along distribution and ensure constant power within the treatment plant, maintaining constant power within the plant is integral to efficient and consistent water service delivery to the public.

4.4. Consumers satisfaction (in terms of quantity and quality)

With respect to the quantity, only few (16%) consumers were adequately satisfied with their water demand, this has occasionally resulted in water supply hardships in many areas particularly in low-income zones. However, the inspection and interview found that the plant was earlier cited with a provision for expansion known as the Phase two; thus should be utilized as part of WSP measures to meet consumers per capita water demand. Regarding quality, high residual chlorine was reported to be objectionable in many areas, this could be primarily due to nonfunctioning of the chlorine dosing pump observed during field inspection, leading to erroneous dosing from manual chlorination; thus, a serious public health concern, high residual chlorine can result in the formation many carcinogenic substances known as disinfectant by products (DBPs) (Nsiak et al., 2017), such as trihalomethanes (THMs), and haloacetic acids (HAAs) (Mohsen et al., 2014). Regarding consumers report on water appearing dirty sometimes in some areas, finding showed these were due to ingress of contamination resulting from the combined effect of leakages and intermittent water supply system. Hence, the WSP team should focus on improving such locations as a priority in the WSP development and implementation process.

4.5. Hygiene knowledge, attitudes and practices on water treatment, storage, and collection

As part of WSP, home treatment practices are encouraged to overcome issues of recontamination and preventing diseases at households (UNICEF, 2012; Lantane and Yates, 2018). In the study area, quiet a large respondents (70%) do not treat water at households, this attitude is consistent with many studies in developing countries (Bitew et al., 2017; Genet & Desta, 2017; Muda et al., 2017) particularly in the rural areas (Rosa et al., 2016), the situation thus has resulted to infections of diarrhea, cholera, and worms in some areas. Hence, distribution of water guards and hygiene campaign is critical as part of WSP measures to protect water quality and prevent diseases at household levels. Furthermore, water storage and collection vessels used were accessible to children which may also cause contamination; many children were observed dipping hands and dropping foreign objects into collected and stored waters, this coincides with the results of microbiological analysis indicating Escherichia Coli in household water storage container (Table 7), supporting programs on hygienic water collection and storage is necessary in a view to promoting good practices and ensuring public health in the study location (Kurui et al., 2019).

4.6. Water quality analysis

The progressive deterioration of water quality within the treatment at the stages of especially coagulation, filtration, and disinfection was undoubtedly a result of improper maintenance of sedimentation tank, use of life span exceeded filter beds, and excessive sludge in reservoirs (Idris et al., 2017). However, the lower level of pollution in the raw water source as contrary to the previous studies of Hyeladi and Nwagilari, 2014 and Dammo et al. 2014, was due to the relative low socio-economic activities around the catchment during the period of the study, such as low agricultural activities, it is, therefore, important that WSP team considers future season seasonal changes during risk assessment and possible improvement plan for hazards within the treatment plant system and operations. However, the presence of fecal bacteria, total coliforms in sample 5 (Household water storage container) was a serious public health concern, similar to McGuiness et al. 2020 findings, mainly resulting from unhygienic practices at households level and low integrity in water distribution associated with ingress of contamination through pipe perforations, this corresponds to WSP study findings by Motasem, 2013, Andrea et al., 2013 and Bava, 2015; where common risk of recontamination comes from
the water handling and storage practices of the users, with home tanks, storage systems, and plumbing systems infected with microorganisms basically due to lack of hygiene awareness regarding water handling at households. These findings indicate that relying on indicator bacteria and end-pipe monitoring is not a guaranty to reliable water supply (WHO, 2004, 2011) and that household’s behavior can cause recontamination.

4.7. Water safety plan development support by consumers and communication gaps

As framed by WHO, consumers are also part of the WSP team, their consent, and support need to be assessed for effective implementation of WSP for their community, from the questionnaire, it is deduced that consumers recognize the importance of good quality drinking water and supports any program, which may enhance water quality. Hence, involving local communities as part of WSP team will yield positive results. In terms of communication, the questionnaire study found that there is absence of effective communication between treatment plant and consumers hence should be prioritized as part of WSP. Effective communication between water service providers and users is critical in the delivery of safe water supply, such as for prompt notification of outbreaks, failures, and leakages.

5. Conclusion and recommendation

This study presents Maiduguri water supply system assessment from source to final consumers using WHO WSP approach, using different means of data collection (water analysis, consumers survey, and interviews), the aim is to provide crucial information toward supporting the hazard identification and risk assessment as part of WSP focus. It is found that water quality is being exposed to hazards at different stages of the water supply chain. However, at present, catchment activities those not hinder effective water treatment by the water supply system, but cattle rearing, inorganic farming, and open defecation in and around the water lake water, presents potential source of water contamination. Upgrade of treatment facilities is necessary as most automated things were non-functional which may result in treatment failures. The integrity of water distribution is poor as leakages allow ingress of contamination through pipe perforations. And consumers unhygienic behavior toward water collection and handling alters water quality and may spread illness. Hence, the end-product testing is not supportive for public health protection and WSP development and implementation is the way forward. Therefore, participation and commitment by all WSP stakeholders (water service providers, health, agriculture, water resources and environment entities, consumers, administrators, and catchment community and consumers representative) is a fundamental requisite to ensure consistent and reliable water supply by Maiduguri water treatment plant.

PUBLIC INTEREST STATEMENT

The concept of water safety plan (WSP) was promoted by WHO in 2004 as the most effective means of consistent quality water service delivery to the public. WSP basis on the fact that safety of drinking water supply depends on several factors including quality of source water, effectiveness of treatment, integrity of the water distribution to consumers, and proper handling of the waters at the consumers end. Hence, all risk of poor water services delivery must be identified, mitigated, and monitored at all stages of the water supply system. However, the WSP development and implementation exercise have 11 steps; one of the most critical steps is the second step known as water supply system assessment, for which the overall success of WSP implementation relies on, and this article focuses on that aspect, the assessment provides thorough data on where the system goes wrong, thus paving way for action plan.

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Data Availability

Data used to support the findings of this study are included within the article, and some can be made available upon request.

Disclosure statement

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