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Original Research Article

Assessment of Water Supply System on Ugbowo Campus of University of Benin, Benin City, Nigeria Using World Health Organization Water Safety Plan Approach

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ABSTRACT

In this study, the water supply system in Ugbowo campus of University of Benin, Benin City, Nigeria was evaluated using WHO water safety plan approach which is from catchment (source) to consumer with the aim of providing baseline information for effective water safety plan (WSP). Data on catchment, treatment units, storage, distribution system, and consumers were collected via key informant interview, questionnaire survey and water quality analysis. Results of water quality analysis indicated that of all parameters examined, pH (which ranges from 4.7 to 5.7) was not within acceptable limits of WHO and Nigerian Standard for Drinking Water Quality (NSDWQ). According to the questionnaire, most of the consumers (50.2%) do not treat their water before use and majority of them (79.9%) were not satisfied with the quantity of water supplied, however, some (43.3%) were satisfied with the quality of water supplied. Barriers to effective water services delivery at different stages of the water supply system were identified and these includes absent of water treatment plant in other units of the water works, pipe leakages (particularly in the areas covered by Hall-one pumping station), intermittent water supply and poor water storage practices at consumers point among others. It was deduced from this study that the water quality is exposed to hazards at various stages of the water supply chain and as such WSP development and implementation is necessary. Hence, it is recommended that all relevant stakeholders' commitment is necessary for effective WSP implementation to protect public health in the study area.

1. INTRODUCTION

Water safety and quality are fundamental to human development and well-being. Despite the overwhelmingly clear evidence that providing access to safe water is one of the most effective instruments in improving health and reducing poverty, millions of people still struggle to access safe drinking water. Globally, 2 billion people lack access to safely managed drinking water services, including 1.2 billion people lacking even a basic level of service (UN Sustainable Development Goals report, 2022). Globally, demand for water is rising owing to rapid population growth, urbanization, and increasing water needs from agriculture, industry, and energy sectors (United Nations Statistical Division, 2022). Thus, efficient water resources management is essential to meet the many competing demand and as such water sources (both surface and ground water) should be developed in such a way that it will be able to provide access to safe water. With this in place, adequate water supply system is necessary to convey water to consumers in the required quality and quantity.

A water supply system deliver water from sources to customers (Wang, 2013). It includes infrastructures for the collection, transmission, treatment, storage and distribution of water to all users (Nathanson, 2023). Lack of access to improved water supply services impose huge costs on society, especially for the poor. Even where access exists, services have been characterized for decades by poor management, inadequate financing and low levels of investment (World Bank, 2022). Poor access to safe drinking water leads to several diseases, mainly diarrhea which result in the deaths of 1.4 million children annually (Climate and Development Knowledge Network, 2013). In 2010, the UN General Assembly explicitly recognized the human right to water, everyone has the right to sufficient, continuous, safe, acceptable, physically accessible and affordable water for personal and domestic use. To reaffirm their commitment to the human right to water, it was ensured that the Sustainable Development Goals (SDGs) has a target (target 6.1) to provide universal and equitable access to safe and affordable drinking water for all by 2030. The target is tracked with the indicator of "safely managed drinking water services" (i.e. drinking water from an improved water source that is located on premises, available when needed, and free from faecal and priority chemical contamination). This goal reflects the growing importance of water as a human right. Although significant progress has been made toward achieving universal access to basic water, however there are huge gaps in the quality of services provided (WHO/UNICEF, 2019a) and mere access is not enough, if the water isn't clean, isn't safe to drink or is far away (WHO/UNICEF, 2019b). Approximately half of all people globally who lack access to safe drinking water live in sub-Saharan Africa (Climate and Development Knowledge Network, 2013). Hence, Africa is a long way from meeting the SDGs target 6.1.

In Nigeria, about 70 million people had no access to basic drinking water services and access to piped water has declined from 36 per cent in 1990 to 11 percent in 2021 (World Bank Report, 2022). Thus, the country has experience low improvement in domestic water supply over the years. The World Health Organization (WHO) recognizes water safety plan (WSP) as the most reliable and effective way to manage drinking water supplies to safeguard public health and as such they recommended that water suppliers develop and implement water safety plans in order to systematically assess and manage risks (WHO, 2004). In this regard, the Nigerian standard for drinking water quality emphasized that all water providers including the State Water Agencies (SWAs) and Community Water Committees (CWCs) shall develop a water safety plan (NSDWQ, 2007) with the intention of ensuring that pollution of water supply from sources is minimized through treatment processes and prevention of contamination during storage, distribution and handling of drinking water (Ezenwaji and Phil-Eze, 2014). A water safety plan is a plan to ensure the safety of drinking water through a comprehensive risk assessment and risk management approach that encompasses all steps in a drinking-water supply chain, from catchment to consumer (IWA, 2023) and water supply assessment is integral to effective WSP development and Implementation (Mustapha et al., 2021). Water supply is shared between three levels of government in Nigeria, namely; federal, state and local governments. The federal government is in charge of water resources management, state governments have the primary responsibility for urban water supply and local government together with communities are responsible for rural water supply (Ezemonye, 2009; Ezenwaji and Phil-Eze, 2014). Unfortunately, the three tiers of government have not done much to improve the quality of drinking water (Ezemonye, 2009; Ezenwaji and Phil-Eze, 2014). Most of the Water Works established some decades ago have undergone little maintenance and as such are dysfunctional resulting in inadequate water supply. The dysfunctional Water Works have so decreased supply that many of them only now produce and distribute about 10% - 15% of the entire demand (Ezenwaji and Phil-Eze, 2014). In addition, full capacity utilization of water supply projects has remained unachieved, thus water supply facilities do not increase with population growth.

Water supply in University of Benin most vividly reflects the above scenario. Also, studies have reported microbial contamination of the drinking water supplied by the central borehole on Ugbowo campus of the University of Benin (Agatemor and Okolo, 2007) and high levels of calcium and magnesium have been reported too (Akpoveta et al., 2011). Inadequate management of the water distribution system (piped water supply system) coupled with the absent of water quality monitoring affect the quality of water delivery to the consumer, thus consumers are at much risk of contracting waterborne diseases by consuming the water (Motasem, 2013; Marroquin et al., 2014; Ezenwaji and Phil-Eze, 2014; Mustapha et al., 2021). Hence, an assessment of the water supply system is required as it will critically revealed where the system is vulnerable to contamination and thus assist in the development and implementation of a WSP. Therefore, this study aimed to assess the water supply system on Ugbowo campus of University of Benin, Benin City using WHO water safety plan approach which is from catchment (source) to consumer. When a new water supply system or an upgrade of the existing system on Ugbowo campus of University of Benin is being planned, developing a WSP is paramount and this study will provide information that will supports subsequent steps in the WSP in which effective strategies for control of hazards are planned and implemented. The WSP will help improve the water supplier's (University of Benin Water Works) knowledge and management of the entire water supply system, thereby enabling them, for example to develop more efficient operating procedures and respond faster to potential incidents.

2. MATERIALS AND METHODS

2.1. Study Area

Ugbowo campus of the University of Benin which is usually referred to as the Main campus is situated in Benin City (Figure 1). Benin City is the capital of Edo State, Nigeria and is located in the South-South geopolitical zone of Nigeria. It lies between latitude 6°20'17.3" N and longitude 5°37'32.7"E (Geodatos, 2023). Benin City is approximately 25 miles north of the Benin River and near a number of main highways that connect Lagos to the Eastern State (Braimah, 2020). Benin City is located within the rainforest zone of Nigeria with mean annual rainfall in the range of 1500 mm to 2500 mm and the mean monthly temperature varying from 25°C to 28°C (Rawlings and Ikediashi, 2020). The Benin Region is underlain by sedimentary formation of the South Sedimentary Basin (Ikhile, 2016) and it constitute part of the Benin formation which is made up of over 90% massive, porous, coarse sand with thick clay/shale interbeds having high groundwater retention capacity (Adegbite et al., 2018). The geology is generally marked by top reddish earth, composed of ferruginized or literalized clay sand (Ikhile, 2016). Benin City has two distinct seasons. These are the wet (rainy) season and the dry season. The rainy season occurs between the months of March and October with a short break in August. The dry season on the other hand lasts from November to February with dry harmattan winds between December and February, but with the effect of global warming and climate change, rains have been observed to fall irregularly almost in every month of the year with double peak periods in July and September.

University of Benin is a federal government owned university, funded and managed by the federal government of Nigeria. The university was founded in 1970 (University Compass, 2023). The university is one of the oldest in Nigeria and has a very large student and staff population resulting in a student staff ratio of about 10:1 (University Compass, 2023). The University has a diverse student population with student from different parts of the country and different age brackets. It has a population range of 1,000,000-5,000,000 inhabitants (Campus.Africa, 2023). Uniben community obtained water from her water works (Uniben water works) through piped water supply system. The water works comprises of four units namely: Uniben Water Scheme (Main office), Sub unit, Banquet/Basement unit, Hall-one pumping station. Each of these units have a borehole from which water is supply to students' hostels, staff residential quarters and other University facilities where water is needed (Agatemor and Okolo, 2007). Three of these units (Uniben Water Scheme, Banquet/Basement unit, and Hall-one pumping station) are responsible for water supply on Ugbowo campus.

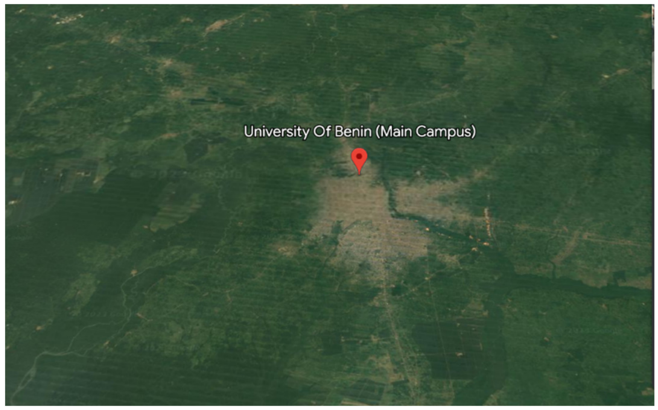

Figure 1: Map Showing the Location of Ugbowo Campus (Main Campus), University of Benin, Benin City (Source: Google Earth, 2023)

2.2. Data Collection and Analysis

The study is cross-sectional and analytical. Data were collected through key informant interviews, questionnaire survey and water quality analysis.

2.2.1. Key informant interviews

Interviews were conducted with staff in the various units of University of Benin Water Works on Ugbowo campus. These units include Uniben water scheme (Main office), Banquet/Basement unit, and Hall-one pumping station. Although the water works comprises of various departments (mechanical, electrical, technical, treatment and administrative departments), but during the interview the supervisor from each unit was interviewed, thus a total number of three staff were interviewed. The interview was carried out along with visual inspection and it was conducted to gain insight into the water supply system (water distribution system) and operating techniques used on Ugbowo campus which will help in predicting hazards and hazardous events (WHO, 2019). The interview covers issues on raw water sources, treatment units and chemicals used, supporting programs available, management procedures, historical records etc.

2.2.2 Questionnaire survey

Cross-sectional structured questionnaires were used to collect data. A stratified random sampling technique was used to constructively administer a total of 410 technically designed, pre-tested, structured questionnaires to the consumers (student and staff residing in the university community). The questions cover social-demographic characteristics of respondents, water quality satisfaction and perception, Knowledge and practice on water treatment, collection and storage, supporting programs and communication gap with the water works. About 10% of the questionnaire was ascertained for validity using Face Validity Method and reliability (using Cronbach's Alpha Statistics). Cronbach's alpha is a measure used to assess the reliability, or internal consistency, of a set of scale or test items and it normally ranges between 0 and 1 (Goforth, 2022). Four Hundred and two (402) completed copies of questionnaires were retrieved (total estimated sample size). Hence, four hundred and two (402) copies of questionnaires were analysed. Data obtained were subjected to statistical analysis using Statistical Package for the Social Sciences (SPSS, version 26.0, 2018) and results were presented using descriptive tables. The sample size for each group of consumers was estimated using equation 1 (Thompson, 2012);

$$n_h = \left(\frac{N_h}{N}\right) \times n \quad (1)$$

Where n_h= Sample size for hth stratum, N_h = Population size for hth stratum, N = Size of entire population and n = Size of entire sample

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2.2.3. Water quality analysis

Water samples were collected from the raw water source in each unit, treatment unit, along the distribution system at selected taps of consumers in at least one area served by each unit (senior staff quarters, NDDC and hall-one hostels) and at household from storage containers of consumers in senior staff quarters, NDDC and hall-one hostels. These samples were collected using 1l plastic bottles in May, 2023 (rainy season). The sample bottles were properly cleaned, sterilized before use and they were rinsed with the water (water to be sampled) before sampling were done. The samples were labelled and transported to Martlet Environmental Research laboratory, Benin City for analysis. The samples were analysed for seventeen physiochemical parameters, namely: pH, Turbidity (Turb.), Temperature (Temp.), Electrical Conductivity (EC), Odour, Total Dissolved Solids (TDS), Total Hardness (TH), Bicarbonate (HCO_3-), Sodium (Na), Calcium (Ca), Magnesium (Mg), Chloride (Cl), Nitrate (NO_3-), Sulfate (SO_4^{2-}), Iron (Fe), Zinc (Zn), Lead (Pb), and a biological parameter (Coliforms count). All laboratory analyses were conducted in accordance with the techniques described by American Public Health (APHA, 1985, 1992 and 2005) and the methods adopted for analysing the samples parameters are shown in Table 1.

The labelling of the water samples was done appropriately as follows;

Sample 1: Raw water sampled at Uniben water works
Sample 2: Raw water sampled at Banquet unit
Sample 3: Raw water sampled at Hall-one pumping station
Sample 4: Final-treated water at Uniben water works treatment unit
Sample 5: Water sampled at SSQ Household Tap (Water supply is from Uniben water works)
Sample 6: Water sampled at NDDC Hostel Household Tap (Water supply is from Banquet Unit)
Sample 7: Water sampled at Hall-one Hostel household tap (water supply is from Hall-one pumping station)
Sample 8: Water sampled at SSQ household storage system (same house where sample 5 was taken)
Sample 9: Water sampled at NDDC hostel household storage system (same house where sample 6 was taken)

Sample 10: Water sampled at Hall-one hostel household storage system (same house where sample 7 was taken)

Table 1: Analytical methods for water quality parameters

Parameters	Analytical Methods
pH	Flame photometric method
Turbidity	Spectronic 20D+ spectrophotometry method
Temperature	Thermometer method
Electrical conductivity	Flame photometric method
Odour	Human olfaction method
Total dissolved solids	Flame photometric method
Total Hardness	Titrimetric method
Bicarbonate	Titrimetric method
Sodium	Flame photometric method
Calcium	Titrimetric method
Magnesium	Titrimetric method
Chloride	Titrimetric method
Nitrate	Spectrophotometry method (atomic absorption spectrophotometer)
Sulfate	Spectrophotometry method (atomic absorption spectrophotometer)
Iron	Spectrophotometry method (atomic absorption spectrophotometer)
Zinc	Spectrophotometry method (atomic absorption spectrophotometer)
Lead	Spectrophotometry method (atomic absorption spectrophotometer)
Coliforms count	Membrane filtration method

3. RESULTS AND DISCUSSION

3.1. Results of Key Informant Interview and Visual Inspection

The results of key informant interview and visual inspection are presented in the following sub sections.

3.1.1. Catchment

The various socio-economic activities that were observed taking place around the location of the central borehole at the Uniben water scheme unit include inorganic farming and dumping of waste (scrap metals including pipes). It was also observed that the entire area in each unit is literally covered by weed. Similar socio-economic activities have also been reported around a raw water source (Mustapha et al., 2021). Although, the water works authority revealed that that there were catchment regulation policies being implemented to protect the raw water sources, such as no dumping of waste around or close to the location of the boreholes, enforcement of farmers and catchment users to operate at some considerable distance away from the location of the boreholes, but lack of proper monitoring as a result of insecurity has resulted to people defying the rules. The socio-economic activities observed around the location of the raw water source (boreholes) pose threat to the raw water quality. Addition of chemical fertilizers and pesticides has become an essential part of today's agricultural systems in order to increase crop yield. However, excessive application of agrochemicals deteriorates groundwater due to the addition of nitrogen, phosphorous, and persistent pesticides (Prasad, 2020). During rainy season solid waste dumped close to ground water areas can easily release pollutants into the surrounding groundwater and thus contaminates it (Rawlings and Seghosime, 2022a). According to Sang and Ji (2016) pollutants that directly flow into a catchment area are exposed to nature, thus the discharge of wastewater from industrial areas, inflow of chemical fertilizers or animal faces from agricultural and livestock industries, and the inflow of domestic sewage from urban areas are all considered to be hazardous events that can cause chemical, microbial or physical hazards to a water supply system. Adequate water source protection has been recognized as the most suitable and cost-effective method to keep contaminants out of drinking water and as such reduces the cost of water treatment (Conservation Ontario, 2009; GCC, 2011). Therefore, developing and implementing a catchment management plan which includes control measures such as complete abolishment of activities around the catchment (especially around/close to the boreholes) is essential to protect the groundwater source as this will reduce the cost of water treatment and improve the quality of water supply (Mustapha et al., 2021).

3.1.2. Water treatment system

Among the three units of Uniben water works, only the Uniben water scheme unit has a water treatment plant and it operates according to the conventional water treatment processes of filtration and disinfection. Automated system such as pump for chlorine injection was not functioning, thus water treatment chemical injection was achieved manually. The manual dosing of chlorine is a great hazardous event owing to the fact that inappropriate dosages affects the quality of water (Idris et al., 2017; Mustapha et al., 2021). Increased levels of chlorine in drinking water reacts with the organic compounds that are already present in the water to produce disinfection by-products such as trihalomethanes (THMs) which can lead to several serious health complications, such as stillbirths, congenital disabilities, increased risk of kidney and liver cancer, and issues with the central nervous system, heart, kidneys, and liver (Mohsen et al., 2019; Stricklin, 2022). The interview and inspection also found that the water treatment facilities have been in operation for over 52 years (precisely the same time the university was established) without being upgraded, but the water works authority revealed that the filter beds were changed on a yearly basis, and other operational facilities (such as aeration and softening chambers) were observed to be in a dysfunctional state. Although the water works authority revealed that routine maintenance and periodic cleaning of treatment systems, such as aeration chamber, softening chamber and storage reservoirs (surface and overhead) were carried out on a yearly basis, however visual inspection found out that they were heavily polluted with biofilm growth. Filter beds are more effective when they are replaced more often (than once a year) due to their frequency of usage. Thus, non-frequent replacement of filter beds coupled with the storage reservoirs being heavily polluted with biofilm growth may deteriorate the quality of the treated water thereby increasing consumers vulnerability to water-borne diseases (UNICEF, 2023). Treated water from a plant has been reported to contain some parameters that exceed WHO acceptable limits (Hyeladi and Nwagilari, 2014). Hazards may be introduced during treatment or hazardous events may allow contaminants to pass through treatment in significant concentrations (WHO, 2017). Therefore, upgrade of facilities and routine maintenance are crucial within the treatment system for effective WSP development and implementation (Mustapha et al., 2021). Absent of water treatment plant is a hazardous event that can cause hazards to a water supply system since anthropogenic activities in the catchment areas can contaminant raw water source, hence other units of Uniben water works (Banquet/Basement unit, and Hall-one pumping station) requires water treatment plants.

3.1.3. Water storage and distribution

The three units of Uniben water works on Ugbowo campus have a total of seven service reservoirs which are made of concrete and steel: two concrete reservoirs (surface and overhead) and five steel tanks (two surface and three overhead). Uniben water scheme unit being the largest has five service reservoirs: surface concrete reservoir with storage capacity of seven hundred thousand liters, overhead concrete reservoir with storage capacity of five hundred thousand liters, two surface steel tanks with storage capacities of two hundred and twenty thousand liters respectively and overhead steel tank with storage capacity of one hundred and fifty thousand liters. This unit covers blocks of flat, senior staff quarters (SSQ), fire services, Uniben health care, professors' quarters, office blocks, administrative office buildings and faculties, however when there is borehole pump failure in other units, the distribution coverage is extended to practically the entire Ugbowo campus. While Banquet/Basement unit and Hall-one pumping station have one overhead steel tank respectively with storage capacity of one hundred thousand liters each. The Banquet/Basement unit covers basement, bursary department, post graduate school, admission office, junior staff quarters, clinical hostel, NDDC hostel, keystone, Hall-four hostel, Hall-five hostel and Hall-six hostel While the Hall-one pumping station covers Hall-one hostel, Hall-two hostel and Hall-three hostel. Different pipe materials used by the units to supply water were combination of asbestos and PVC pipes (main pipes), asbestos (service pipes), PVC pipes (connecting households/hostels) and PVC pipes (individual household/hostel pipe) for Uniben water scheme unit while for Banquet/Basement unit and Hall-one pumping station, PVC pipes were used throughout. The interview found that there were several pipe leakages particularly in the areas covered by Hall-one pumping station which result to a significant percentage of water loss since there are no ball valves connected to the piping system. Also, the three units sometime experience a decrease in pump flow rate. Old pipes increase the risk of water leakage and can cause corrosion due to rust. Wear that affect pump impeller only would result in system flow decrease pump (EMC, 2021) and power fluctuation may cause pressure fluctuation which affects the stable operation of pumps and the life of equipment (Xiao et al., 2021; Ma et al., 2022). Water is distributed intermittently to various consumers in the morning (4am to 10am), afternoon (12.00pm to 2pm) and evening (4pm to 8pm) with maximum hours of distribution per area ranging from 12 to 18 hours/day. Leaky pipes, pressure fluctuations, intermittent water supply among others create public health risk (Marroquin et al., 2014; Mustapha et al., 2021). The use of asbestos as main and service pipes should be considered as hazardous event (Mustapha et al., 2021) as certain levels of asbestos in water supply poses a health risk to the general public, long term exposure could potentially lead to the risk of cancer including mesothelioma (Di Ciaula, and Gennaro, 2016; Luberto et al. 2019; Clemens, 2021). Population growth without corresponding expansion of water supply facilities causes shortfall in terms of supply (Mohammed and Sahabo, 2015). Owing to the population growth of residence coupled with the increase in facilities in the university community, expansion of the water works and increase in the number of water storage reservoirs should be emphasized in the WSP. Maintaining good water quality in the distribution system depends on the design, operation and maintenance of the system. Hence, the WSP should also include replacement of both main and service pipes with PVC pipes, repairs and installations of damaged pipes along distribution and ensuring of constant power within the water works, maintaining constant power within the water works is integral to efficient and consistent water service delivery to the public (Mustapha et al. 2021).

3.2. Results of Questionnaire Survey

3.2.1 Sociodemographic characteristics of consumers

Result of Cronbach's Alpha for reliability of questionnaire is indicated in Table 2 and Table 3 shows the socio-demographic characteristics of respondents. From Table 2, the Cronbach' Alpha value which is more than 70% suggested that the questions in the questionnaire are all similar and relevant to the subject matter of the survey. Hence, it implies a very good questionnaire. Of the 410 questionnaires administered to consumers, 402 were retrieved (estimated sample size) for analysis giving a response rate of 100%. Table 3 revealed that most of the respondents (83.8%) were aged between 18-25 years with females being majority (58.7%). Most of the respondents were students (89.8%) who are studying their subject at undergraduate level (94.5%) with majority of them single (93.3%). Hence, majority of the respondents were residence in the hostel (86.6%) with most room size of between 5 and 8 (63.9%). Length of stay in Ugbowo campus was 2-4 years for most respondents (83.8%).

3.2.2. Water quantity satisfaction by consumers

The water quantity satisfaction by respondents is indicated in Table 4. A large proportion of the respondents (79.9%) were not adequately satisfied with the water quantity supplied by Uniben water works to meet their demand and as such alternative sources of water supply became imperative which led many (49.5%) to obtained water from public and neighbourhood boreholes. Others (32.8%) believed to be staff of the university obtained personal boreholes in their households in the university premises while 16.4%, 0.7%, 0.2% and 0.2% uses water vendors (tankers), river, stream and spring respectively to supplement their demand. These results agree with studies carried out by Mustapha et al. (2021) and Mohammed and Sahabo (2015) where respondents who were not adequately satisfied with the quantity of water supplied by water utilities resorted to use of alternative sources to meet their water demand. Further, 56.7% respondents revealed that the water supply is consistent and 43.0% respondents reported that the water supply is not consistent, often times the supply ceases for one day (30.3%), sometimes more than 3 days (7.7%), 2 days (6.7%) and 3 days (3.0%) respectively leading to water scarcity, according to the study ceased supply was mainly due to constant power failure within the water works. On the other hand, a smaller portion of the respondents (20.1%) reported that they were adequately satisfied with the quantity of water received, this has sometime resulted to water scarcity within the Ugbowo campus of Uniben. Although, the inspection and interview found that of the four units of the water works, three units (Uniben water scheme, Banquet/Basement unit, Hall-one pumping station) were responsible for water supply on Ugbowo campus, however more units should be established to augment supply. Hence, expansion of the water works should be emphasized in the WSP and utilized as part of WSP measures to meet consumers' per capita water demand (Mustapha et al., 2021).

3.2.3. Water quality perception by consumers

The results of water quantity perception by respondents is shown in Table 5. From Table 5, majority of the respondents (53.7%) reported that water appears dirty mostly when water supply is not consistent (78.1%) and an insignificant segment of the respondents (21.9%) claimed that water appears dirty when water supply is consistent. However, some respondents (46.3%) believed that the water is clean for drinking and other domestic purposes. Since water is supplied intermittently as discovered from the interview, the resulting low water pressure will allow the ingress of contaminated water into the system through breaks, cracks, joints and pinholes (WHO, 2017) which in turn result to water appearing dirty in some areas. Contaminated water is strongly linked to transmission of waterborne diseases such as cholera, diarrhoea, dysentery, hepatitis A and typhoid (Inah et al., 2020b; WHO, 2021). Hence, overcoming intermittent supply and replacement of damaged pipes should be considered a priority in the development and implementation of WSP.

Table 2: Cronbach's Alpha for Reliability of Questionnaire

Cronbach's Alpha	No. of Items
0.703	17

Table 3: Socio-demographic characteristics of the respondents (n=402)

Variables	Number of respondents	Percentage
Age		
18-25	337	83.8
26-34	44	10.9
35 and above	21	5.2
Total	402	100
Sex		
Male	166	41.3
Female	236	58.7
Total	402	100
Status on Ugbowo Campus		
Staff	41	10.2
Student	361	89.8
Total	402	100
Level of Study/Education		
Diploma/ Graduate Diploma	8	2
Undergraduate	380	94.5
Post Graduate (Masters & Doctorate)/Graduate	14	3.5
Total	402	100
Marital Status		
Single	375	93.3
Married	27	6.7
Total	402	100
Name of Residence		
Staff Quarters	54	13.4
Student Hostel	348	86.6
Total	402	100
Quarters' Household Size/ Hostel Room Size		
Less than 2	14	3.5
Between 2 and 4	69	17.2
Between 5 and 8	257	63.9
Above 8	62	15.4
Total	402	100
Length of Stay in Ugbowo Campus		
Less than 2 years	28	7
2-4 years	337	83.8
5-10 years	31	7.7
Above 10 years	6	1.5
Total	402	100

Table 4: Water quantity satisfaction by respondents

Variables	Number of respondents	Percentage
Level of water supply satisfaction		
Satisfied	81	20.1
Moderate	200	49.8
Not satisfied	121	30.1
Total	402	100
Alternative source of water supply		
Borehole(personal)	132	32.8
Borehole (public and neighbour)	199	49.5
River	3	0.7
Stream	1	0.2
Spring	1	0.2
Water vendor(tankers)	66	16.4
Total	402	100
Pattern of water supply		
Consistent	228	56.7
Inconsistent	173	43
Total	402	100
If inconsistent		
Ceased for one day	122	30.3
Ceased for 2 days	27	6.7
Ceased for 3 days	12	3
Ceased for more than 3 days	31	7.7
Total	192	47.8

Table 5: Water quality perception of respondents

Variables	Number of respondents	Percentage
Perception of water quality		
Water is clean	186	46.3
Water is dirty	216	53.7
Total	402	100
When does water appear dirty		
When water supply is consistent	88	21.9
When water supply is inconsistent	314	78.1
Total	402	100

3.2.4. Consumers' Knowledge and Practices on Water Treatment, Water Collection, and Storage

The results of respondents' knowledge and practices on water treatment, water collection and storage are presented in Table 6. Results from Table 6 revealed that although majority of the respondents (50.2%) claimed that they do not treat water before usage, but 34.1% and 15.7% respondents reported that they use boiling and chlorination methods respectively to treat their water domestic purposes (including drinking). In the university premises, quite a large number of people have been suffering currently with typhoid (30.6%), 13.7% with cholera, 10% with other water related diseases, 9.2% with dysentery, 5.7% with diarrhea and 1% with intestinal worms from the water supplied. However, 29.9% reported that they have not encountered any health issues from the water supplied. Regarding respondents not treating water at household before usage, this attitude is consistent with many studies in developing countries and thus it has resulted to the prevalence of water borne diseases (typhoid, cholera, dysentery, diarrhea and intestinal worms) in the campus (Mudau et al., 2017; Venkatashiva et al., 2017; Inah et al., 2020a; Mustapha et al, 2021; Rawlings and Seghosime, 2022b). This respondents' attitude may be attributed to the fact that they may have already considered the source of water to be safe for domestic use. However, the inspection and interview found that among the three units of Uniben water works, only one unit (Uniben water scheme unit) has a water treatment plant which operates according to the conventional water treatment processes of filtration and disinfection only.

Table 6: Respondents' knowledge and practices on water treatment, water collection and storage

Variables	Number of respondents	Percentage
Water treatment method		
Boiling	137	34.1
Chlorination	63	15.7
No treatment	202	50.2
Total	402	100
Health issues encountered from water supplied		
Dysentery	37	9.2
Cholera	55	13.7
Typhoid	123	30.6
Diarrhea	23	5.7
Intestinal worm	4	1
Other water related diseases	40	10
None	120	29.9
Total	402	100
Mode of water collection		
Tap	287	71.4
Concrete made reservoir	10	2.5
Overhead tank (concrete/plastic)	76	18.9
Others	26	7.2
Total	402	100
Water storage method		
Clay	9	2.2
Plastic container (Drum, bowl, bucket, jerry can)	265	65.9
Metal container	8	2
Concrete made reservoir	8	2
Overhead tank (plastic)	112	27.9
Total	402	100
Water storage capacity		
Large (> 100 litres)	128	31.8
Moderate (51 - 100 litres)	71	17.7
Small (25 – 50 litres)	76	18.9
Very small (below 25 litres)	127	31.6
Total	402	100
Frequency of cleaning water storage containers		
Daily	117	29.1
Weekly	71	17.7
Monthly	42	10.4
Semi annually	80	19.9
Annually	92	22.9
Total	402	100

Hence, upgrade and provision of water treatment plants and encouragement of home treatment practices by distribution of water guards, hygiene campaign (Mustapha et al., 2021) as well as trainings to ensure that users understand basic operational monitoring requirements are all paramount as part of WSP measures to protect water quality and prevent diseases at household levels. Due to intermittent system of water supply, consumers collect and store waters, mode of water collection is mainly through tap (71.4%) and Overhead tank (18.9%). In terms of water storage method, majority of the respondents (93.8%) indicated that they store water in plastic containers (drum, bowl, bucket, jerry can, overhead tank) and the water storage capacities reported by respondents were majorly large (31.8%) and very small (31.6%). Although, 29.1% respondents claim that they clean their water storage container every day, but quite a large proportion (70.9%) reported that they clean their water storage container at other times (annually, semi-annually, weekly and monthly). This indicates poor hygiene practice among consumers. Cleaning water storage container more often is vital to avoid water contamination which in turn prevents the transmission of diseases (CDC, 2022a; Rawlings and Seghosime, 2022b). Thus, supporting programs on hygienic storage is necessary and should be incorporated as part of the WSP measures to promote good practices and ensure public health safety within the university premises. Therefore, supporting programs on hygienic storage should be documented in the WSP.

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

The result of water safety plan development supported by respondents and communication gaps is shown in Table 7. Consumers' participation is a desirable component in the development of strategies for incremental improvement of the quality of drinking-water supply service (WHO 2017). Results from Table 7 shows that most respondents (68.9%) are willing to support any program which may enhance water quality. This is an indication that the consumers recognize the importance of good quality drinking water and as such their involvement in decision-making should be documented in the WSP for effective implementation. Regarding communication, majority of the respondents (80.3%) reported that there is absence of effective communication between them and the water works, thus should be documented as a priority in the WSP. Information on the safety of the water supplied to consumers for domestic purposes is fundamental to protection of human health. Also, the consumers represent a resource that can be drawn upon for local knowledge and experience, they are the people who are likely to first notice problems in the drinking-water supply and therefore can provide an indication of when immediate remedial action is required. Therefore, effective communication between water service providers and users is critical in the delivery of safe water supply.

Table 7: Water safety plan development supported by respondents and communication gaps

Variables	Number of respondents	Percentage
Willingness to support any program which may enhance water quality		
Yes	227	68.9
No	125	31.1
Total	402	100
Effective communication with water works		
Present	79	19.7
Absent	323	80.3
Total	402	100

3.3. Results of Water Quality Analysis

The Physio-chemical properties of water samples compared with standards is presented in Table 8. Result from Table 8 shows that all parameters analyzed were within WHO and NSDWQ acceptable limits for drinking water quality standards except for pH. The pH of water samples ranged from 4.7 to 5.7 which is below the acceptable 6.5-8.5 limits of WHO (2011, 2017) and NSDWQ (2015) and is indicating strongly acidic waters. Lower pH values were observed in the water samples from the raw water sources in the three units of Uniben water works (sample 1, Uniben water scheme = 4.9; sample 2, Basement/Banquet unit = 4.7; Hall-one pumping station = 5.1) than water samples from the areas served by these units (sample 5= 5.7;

sample 6=4.8; sample 7=5.4). Hence, the low pH values recorded for all water samples may be attributed to the socio-economic activities within and around the catchment, such as inorganic farming, dumping of waste etc. Excess nitrogen and phosphates (from fertilizers) together with acidic waste materials (from indiscriminate disposal of acidic waste materials) through surface runoff and leaching may have given rise to the strongly acidic nature of the waters (FAO, 2017; Egbueri et al., 2021). Though pH has no direct effect on human (WHO, 2011 and 2017), however low pH increases the dissolution of heavy metals and minerals in water (Rawlings and Ikediashi, 2020; Egbueri et al., 2021) which results in contamination of drinking water and thus affect human health. This might account for the high levels of HCO_3^- (146.4mg/l; 128.1mg/l; 91,5; 109.8mg and /l;73.2mg/l) and Cl^- (88.6mg/l; 77.3mg/l; 59.5mg/l; 70.9mg/l and 59.5mg/l) observed in samples 4, 5, 6, 8, 9, and Fe (0.251mg/l; 0.324mg/l and 0.280mg/l) in samples 3, 7 and 10, however these values were below the WHO and NSDWQ acceptable limits. This result is implying that there might be potential minerals and heavy metals contamination of the raw water sources. Hence, it is important that the WSP team considers catchment regulation policies such as complete abolishment of activities around the catchment (especially around/close to the boreholes) to protect the raw water sources. Also, upgrade of the existing water treatment plant in Uniben water scheme unit and provision of water treatment plants in Basement/Banquet unit and Hall-one pumping station with treatment process involving pH adjustment after disinfection should be a priority in the WSP. Adjusting pH improves taste, reduces corrosion (breakdown) of pipes and ensures chemical disinfectants continue killing germs as the water travels through pipes (CDC, 2022b).

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Table 8: Physio-chemical properties of water samples compared with standards

Parameters	Raw water			Final treated water	Household tap water			Household storage water			Standards	
	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	WHO (2011)	NSDWQ (2015)
pH	4.9	4.7	5.1	4.8	5.7	4.8	5.4	5.3	5.0	5.3	6.5-8.5	6.5-8.5
Turb. (NTU)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5	5
Temp. (^{o}C)	24.9	25.3	25.5	24.5	24.8	24.5	25.3	24.7	24.8	25.4	Ambient	Ambient
EC(µS/cm)	52	54	32	72	66	60	30	64	56	30	1500	1000
Odour	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Odourless	Unobjectionable	Unobjectionable
TDS (mg/l)	26	27	18	35	32	30	15	32	28	15	1000	500
TH (mg/l)	2.81	3.50	2.48	6.63	5.66	3.95	1.52	4.34	3.42	1.98	200	150
HCO_3^- (mg/l)	67.1	67.1	61.0	46.4	128.1	91.5	24.1	109.8	73.2	54.9	500	500
Na (mg/l)	0.11	0.10	0.09	0.31	0.28	0.20	0.07	0.21	0.17	0.09	200	200
Ca (mg/l)	0.58	0.61	0.55	1.40	1.21	0.74	0.33	0.88	0.66	0.43	200	N/A
Mg (mg/l)	0.33	0.48	0.27	0.76	0.64	0.51	0.17	0.52	0.43	0.22	50	20
Cl (mg/l)	30.4	40.4	24.1	88.6	77.3	59.5	18.4	70.9	59.5	22.4	250	250
NO_3^- (mg/l)	0.104	0.154	0.071	0.533	0.380	0.164	0.017	0.214	0.154	0.031	50	50
SO_4^{2-} (mg/l)	0.008	0.023	0.005	0.048	0.041	0.031	0.003	0.033	0.045	0.005	<250	100
Fe (mg/l)	0.201	0.188	0.251	0.133	0.155	0.183	0.324	0.183	0.184	0.280	0.3	0.3
Zn (mg/l)	0.103	0.051	0.108	0.062	0.070	0.098	0.181	0.074	0.077	0.141	3-5	3
Pb (mg/l)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01	0.01
Col. (Pt. Co)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.00	0.00

4. CONCLUSION

In this study, the water supply system on Ugbowo Campus of the University of Benin was assessed from catchment (source) to consumers (WHO water safety plan approach). Data were collected via interviews, questionnaire survey and water quality analysis with the aim of providing vital information toward supporting hazard identification and risk assessment for effective WSP development and implementation. Results from the study revealed that the water quality is being exposed to hazards at various stages of the water supply chain as pointed out in the findings from the study:

- Various socio-economic activities (inorganic farming, dumping of waste etc.) take place within and around the catchment (particularly Uniben water scheme unit). Though catchment activities do not impede effective water treatment, however catchment activities such as inorganic farming and dumping of waste presents potential source of raw water contamination.
- Water treatment plants are absent in other units (Basement/Banquet unit and Hall-one pumping station) of the water works in Ugbowo campus and the raw water from the three units of the water works (Uniben water scheme unit, Basement/Banquet unit and Hall-one pumping station) are strongly acidic in nature (pH values range from 4.7 to 5.7). Water treatment plant make water safe, hence absent of water treatment can hinder the provision of portable water.
- The integrity of water distribution (particularly in the areas covered by Hall-one pumping station) is poor. Leakages in the distribution network allows potential harmful contaminants into the water.
- Consumers hygiene practice towards water storage is poor. This attitude (behavior) alters the quality of water and may spread illness.

Hence, the water supply system on Ugbowo campus is not supportive for public health protection and as such WSP development and implementation is the way forward. Therefore, participation and commitment by all WSP stakeholders (including environmental or public health or hygiene professionals, operational staff (water works) and representatives of consumers etc.) is essential to ensure consistent and reliable water supply on the campus by the water work.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

REFERENCES

Agatemor, C., Okolo, P.O. (2007). University of Benin Water Supply System: Microbiological and Physico-chemical Assessments. Environmentalist 27, 227–239.

Akpoveta, O. V., Okoh, B. E. and Osakwe, S. A. (2011). Quality Assessment of Borehole Water Used in the Vicinities of Benin, Edo State and Agbor, Delta State of Nigeria. *Current Research in Chemistry,* 3(1), pp. 62-69.

American Public Health, APHA (1985). Standard methods for the examination of water and waste water, 16th edition. American Public Health Association (APHA)/American Water Works Association/Water Environment Federation, Washington DC, USA.

American Public Health, APHA (1992). Standard methods for the examination of water and waste water, 18th edition. American Public Health Association (APHA)/American Water Works Association/Water Environment Federation, Washington DC, USA.

American Public Health, APHA (2005). Standard methods for the examination of water and waste water, 21st edition, American Public Health Association (APHA)/American Water Works Association/Water Environment Federation, Washington DC, USA.

Braimah, A. (2020). Benin City, Nigeria (10th Century). Available online from: www.BlackPast.org [Accessed 25th February, 2023].

Campus. Africa, (2023). University of Benin, Benin City, Nigeria. Available online from: https://www.campus.africa/university/university-of-benin [Accessed 27th February, 2023].

Centers for Disease Control and Prevention (CDC), (2022a). Safe Water Storage. Available online from: https://www.cdc.gov [Assessed on April 28th, 2022].

Centers for Disease Control and Prevention (CDC), (2020b). Water Disinfection with Chlorine and Chloramine, National Center for Emerging and Zoonotic Infection Diseases (NCEZID), Division of Foodborne, Waterborne and Environmental Diseases (DFWED). Available online from: https://www.cdc.gov/healthywater/drinking/public/water_disinfection.html

Clemens, E., (2021). Asbestos in Drinking Water: The Danger of Old Asbestos Pipes and Natural Disasters. Available online from: https://www.mesothelioma.com/blog/asbestos-in.-drinking-water-the-danger-of-old-asbestos-pipes-and-natural-disaster/

Climate and Development Knowledge Network, (2013). Securing Safe Water in Sub-Saharan African. Available online from: https://cdkn.org/story/securing-safe-water-in-sub-saharan-africa

Conservation Ontario (2009): Wellhead Protection Areas. Newmarket: Conservation Ontario. Available online from: https://sswm.infro/node/3602 [Accessed 01 May, 2023]

Di Ciaula, A. and Gennaro, V. (2016). Possible Health Risks from Asbestos in Drinking Water. Epidemiologia e Prevenzione, 40(6): 472-475.

Egbueri, J. C., Unigwe, C. O., Omeka, M. E. and Ayejoto, D. A. (2021): Urban Groundwater Quality Assessment Using Pollution Indicators and Multivariate Statistical Tools: A Case Study in Southeast Nigeria. *International Journal of Environmental Analytical Chemistry,*103(14), pp 3324-3350.

Equipment Maintenance and Construction (EMC), (2021). 4 Reasons for Low Flows in Pumps. Available online: https://www.equipmac.com/contact

Ezemonye, M.N. (2009) Surface and Groundwater Quality of Enugu Urban Area. Unpublished Ph.D. Thesis, University of Nigeria, Nsukka.

Ezenwaji, E. E. and Phil-Eze, P. O. (2014). Water Safety Plan as a Tool for Improved Quality of Municipal Drinking Water in Nigeria. *Journal of Environmental Protection,* 5, pp. 997-1002.

Food and Agricultural Organization (FAO), (2017). Water Pollution from Agriculture: A Global Review. Available online from: htpp://www.fao.org/3/i7754e/i7754e.pdg

Green Communities Canada (GCC), (2011): Well Aware. A Guide for Well Owners. Peterborough: Green Communities Canada (GCC). Available online from: https://greencommunitiescanada.org/programs/well-aware [Accessed 01 May, 2023]

Geodatos, (2023). Benin City Geographic Coordinates-Latitude and Longitude. Available online from: https://latitude.to/map/ng/nigeria/cities/benin-city [Accessed 27th February, 2023].

Goforth, C. (2022). Using and Interpreting Cronbach's Alpha. Available online from: https://www.virginia.edu [Assessed on April 28, 2022].

Google Earth, (2023). Explore Google Earth. Available online from: https://earth.google.com [Accessed 9th March, 2023].

Hyeladi, A. and Nwagilari, J. E. (2014). Assessment of Drinking Water Quality of Alau Dam, Maiduguri, Borno State, Nigeria. *International Journal of Science and Research Publications,* 4(10), pp1-6.

Idris, M. N., Ali, W. M. and Suleiman, E. (2017). Evaluation of Water Treatment Problems: Case Study of Maiduguri Water Treatment Plant (MWTP) and Maiduguri Environs. *Arid Zone Journal of Engineering, Technology and Environment,* 13(5), pp. 630–642.

Ikhile, C. I. (2016). Geomorphology and hydrology of the Benin region, Edo State, Nigeria. *International Journal of Geosciences,* 7, pp.144-157.

Inah, S. A., Eko, J. E., John, E. A., Ochei, K. C., Obot, N., Iniam, D. E. and, Elemi, L. A. (2020a). Assessment of Water Supply, Sanitation and Hygiene Practices among Households in Southern Nigeria. *International Journal of Environment and Pollution Research,* 8(2), pp 42-53.

Inah, S. A., Ntekim, V. E., Nji, E. L., Egbonyi, D. E. and, Mboto, F. E. (2020b). Assessment of Water Supply and Sanitation Facilities in Public Primary Schools in Calabar South Local Government Area, Cross River State, Nigeria. *New York Science Journal,* 13(7), pp 43-51.

IWA, (2023). Water Safety Planning. International Water Association. Available online from: https://www.iwa-network.org/project/water-safety-planning/ [Accessed 26th March, 2023].

Luberto, F., Ferrante, D., & SIlvestri, S. (2019). Cumulative asbestos related diseases in a pooled analysis of 21 asbestos cement cohorts in Italy. Environmental Health, 18(1), p.71.

Ma, X., Zheng, L., Qu, J. and Wang, M. (2022). Numerical Study of Unsteady Pressure Fluctuation at Impeller Outlet of a Centrifugal Pump. *Science and Technology of Nuclear Installations,*2022, Article ID 1758382, pp. 1-12

Marroquin, A. C., Perez-Vidal, A. and Torres-Lozada, P. (2014). Risk Assessment in Water Distribution Systems: Framed in Water Saftey Plan. *Revista EIA*, 11, pp.155-166.

Mohammed, A. B. and Sahabo, A. A. (2015). Water Supply and Distribution Problems in Developing Countries: A Case Study of Jimeta-Yola, Nigeria. *International Journal of Scientific Engineering and Applied Science (IJSEAS),* 1(4), pp. 473-483.

Mohsen, I. H., Mohsen, A. H. and Zaidan, H. K. (2019). Health Effects of Chlorinated Water: A Review Article. *Pakistan Journal of Biotechnology,* 16(3), pp. 163-167

Motasem, Y. A. (2013). Development of Safety Plan for Desalinated Water use in Gaza Strip: Middle Governorate Case Study. Msc Thesis, Department of Civil Engineering, Water Resources Engineering, Islamic University of Gaza.

Mudau, L. S., Mukhola, M. S. and Hunter, P. R. (2017). Cholera and Household Water Treatment Why Communities Do Not Treat Water After a Cholera Outbreak: A Case Study in Limpopo Province. *Southern African Journal of Infectious Disease,* 32(1), pp. 5–8.

Mustapha, M., Sridhar. M. and & Coker, A. O. (2021). 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. *Sustainable Environment,* 7(1), pp.1-14.

Nathanson, J. A. (2023). Water Supply System. Available online from: https://www.britannica.com [Accessed 21st February, 2023].

NSDWQ, (2007). Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard, NIS 554, Standard Organization of Nigeria, Lagos.

Prasad, M. N. V., (2020). Agrochemicals Detection, Treatment and Remediation. Elsevier Science & Technology, Chapter 6, pp. 143-159.

Rawlings, A. and Ikediashi, A. I. (2020). Impact of Urbanizing Ovia-North East on the Quality of Groundwater using Water Quality Index. *Nigerian Journal of Environmental Sciences and Technology (NIJEST),* 4 (1), pp. 87 – 96.

Rawlings, A. and Seghosime, S. (2022a). Effect of Open Dumping of Municipal Solid Waste on Groundwater Quality in Ekurede Itsekiri, Warri South LGA, Delta State, Nigeria. *Journal of Engineering Research,* 27 (1), pp. 11-25

Rawlings, A. and Seghosime, S. (2022b). Evaluation of Water Supply, Sanitation and Hygiene Facilities in Ekosodin Community of Ovia North-East LGA, Benin City, Edo State, Nigeria. *Nigerian Journal of Technology (NIJOTECH),* 41 (4), pp. 632-643

Sang-II, L. and H. W., Ji (2016). Identification of Hazardous Events for Drinking Water Production Process Using Managed Aquifer Recharge in the NAKDONG River Delta, Korea. *Malaysian Journal of Analytical Sciences,* 20(2), pp. 365–372.

Stricklin, T. (2022). Chlorine in Drinking Water: The Good, the Bad and the Ugly. Springwell Water Filter System, 2381 Mason Ave. Ste. 140, Daytona Beach, FL 32117. Available online from: https://www.springwellwater.com/chlorine-drinking-water-good-bad-ugly

Thompson, S. K. (2012). Sampling, 3rd edition, John Wiley & Sons, Hoboken.

UN Sustainable Development Goals, (2022). Goal 6: Ensure Access to Water and Sanitation for all. Available online from: https://www.un.org/sustainabledevelopment/water-an [Accessed 21st February, 2023].

United Nations Statistics Division, (2022). SDG 6: Clean Water and Sanitation (ensure availability and sustainable management of water and sanitation for all). Development Data and Outreach Branch, New York, NY 10017. Available online from: https://unstats.un.org/sdgs/report/2022/Goal-06

UNICEF, (2023). Water borne Diseases. Available online from: https://www.unicef.org/topics/water-borne-diseases

University Compass, (2023). University of Benin, Uniben- School Fees, Courses and Admission Info. Available online from: https://www.universitycompass.com/africa/Nigeria/... [Accessed 27th February, 2023].

Venkatashiva, R. B., Kusuma, Y.S., Pandav, C. S., Goswami, A. K. and Krishnan, A. (2017). Water and Sanitation Hygiene Practices for Under-Five Children among Households of Sugali Tribe of Chittoor District, Andhra Pradesh, India. *Journal of Environmental and Public Health,*2017, Article ID 7517414, pp 1- 7.

Wang, Y. (2013). Handbook of Seismic Risk Analysis and Management of Civil Infrastructure System, Woodhead Publishing Series in Civil and Structural Engineering, pp. 659-681.

World Health Organization (WHO), (2004). Guidelines for Drinking Water Quality: Recommendations (Vol. 1). World Health Organization.

World Health Organization (WHO), (2021). Drinking Water. Available online from: https://www.who.int [Accessed on October 5, 2021].

World Health Organization (WHO), (2022). Drinking Water Services. Available online from: https://www.who.int/news-room/fact-sheets/detail/drinking-water#SnippetTab

World Health Organization (WHO), (2017). Guidelines for Drinking Water Quality, 4th Edition Incorporating the First Addendum.

World Health Organization (WHO), (2009). Water safety plan manual (WSP manual) (Module 2). https://www.who.int/publications-detail-redirect/9789241562638

WHO/UNICEF, (2019a). Progress on Drinking Water, Sanitation and Hygiene: 2000-2017: Special Focus on Inequalities. The Joint Monitoring Programme report. Available online from: https://www.unicef.org/reports/progress-on-drinking-water-sanitation-and-hygiene-2019

WHO/UNICEF, (2019b). 1 in 3 People Globally Do Not Have Access to Safe Drinking Water. News release, New York, Geneva. Available online from: https://www.who.int/news/item/18-06-2019-1-in-3... [Accessed 25th February, 2023].

World Bank, (2022). Water Supply Overview. Available online from: https://www.worldbank.org/en/topic/watersupply [Accessed 21st February, 2023].

Xiao, W. Y. and L. Tan, (2021). Design Method of Controllable Velocity Moment and Optimization of Pressure Fluctuation Suppression for a Multiphase Pump. *Ocean Engineering*, 220, pp. 108-402.