World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Bacterial contamination of water sources for domestic use in JOS and environs

Delmwa Florence Jurbe [1,*], Emmanuel Isa Bigwan [1], Grace Mebi Ayanbimpe [2], Victoria Kaneng Davou [3], Nanna Luka Abashi [4], Helen Hoomsuk Raplong [5] and Emmanuel John Fyaktu [6]

[1] *Department of Medical Laboratory Science, Faculty of Health Sciences and Technology, University of Jos, Nigeria.*
[2] *Department of Medical Microbiology, Faculty of Clinical Sciences, University of Jos, Nigeria, Nigeria.*
[3] *Department of Microbiology, Faculty of Natural Sciences, University of Jos, Nigeria.*
[4] *Department of Medical Laboratory Science, Health Services, University of Jos, Nigeria.*
[5] *Department of Veterinary Laboratory Technology, School of Science and Information Technology, Federal College of Animal Health and Production Technology, NVRI, Vom, Jos, Plateau State, Nigeria.*
[6] *Department of Medical Microbiology, Faculty of Clinical Sciences, University of Jos, Nigeria.*

World Journal of Advanced Research and Reviews, 2023, 19(01), 375–385

Publication history: Received on 21 April 2023; revised on 01 July 2023; accepted on 04 July 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.19.1.1019

Abstract

Purpose: The purpose of the study was to assess and examine water bodies in Jos, Plateau State for bacterial contamination.

Methods: A total of ninety four (90) water samples were collected aseptically from different sources (stream, well, borehole, tap, dam, storage tanks and water vendors) from different locations and investigated for their bacterial contaminants using the Most Probable Number Technique (MPN). Structured questionnaires were used to obtain information on the location, depth, sanitary condition and closeness of the water sources to septic tanks. The bacterial isolates present in the water samples were identified based on their morphology and biochemical characteristics. Total bacterial count was determined using the pour plate technique and total coliform count was by the Most Probable Number (MPN) method.

Results: From the T-Test result of the mean coliform count of all the seven different water sources investigated, storage tanks (ST) were found to be the least contaminated followed by Tap water (TW) while stream (STR) water had the highest rate of contamination with MPN index of 300/100 ml. However, borehole water 6 (BW6) was the least contaminated among all the samples collected with MPN index of 7/10 ml. The MPN index range from 7/100 ml to 300/100 ml in BH6 and STR7 respectively while the Total viable count ranged from 1.0×10^2 to 3.3×10^3. A total of seven different isolates were characterized and identified as *Pseudomonas aeroginosa, Klebsiella pneumonia, Escherichia coli, Salmonella typhi, Proteus vulgaris, Staphylococcus aureus* and *Proteus mirabilis*. The results obtained were analysed using SPSS Version 21.

Conclusion: This study reveals that all the different water samples collected and investigated were contaminated with bacteria.

Keywords: Bacteria; Contamination; Water; Sources; Domestic purpose

1. Introduction

Water of good drinking quality is basic to human physiology and man's continual existence depends very much on its availability. The provision of portable water to the rural and urban population is necessary to prevent health hazards.

* Corresponding author: Delmwa Florence Jurbe

Before water can be described as potable, it has to comply with certain physical, chemical and microbiological standards which are designed to ensure that the water is palatable and safe for drinking (Arora and Arora, 2020).

With increasing population densities of urban areas and the corresponding increase in demand for social amenities, it has become increasingly difficult to meet all the water requirements in quantity, regularity and quality. The public water supply is generally inadequate and in most cases inaccessible, the supply is intermittent and unreliable thus resulting into difficult to meet all the water requirements (Mile *et al*., 2012).

Safe drinking water is one of the basic necessities for human beings. The quality of drinking water is a powerful environmental determinant of health and continues to be the foundation for the prevention and control of water borne diseases. The quality of drinking water is a powerful environmental determinant of health. Water becomes contaminated due to inadequate protection of the source, unhygienic practices of the community at the source and poor handling practices (Matusala *et al*., 2020).

Drinking water must be free from harmful microorganisms that can cause serious ill health. Supplies of drinking water may be contaminated with sewage being allowed to seep into wells or boreholes, or faecal matter from man and animals being passed into rivers, streams or pools. Such contaminants may cause diseases like typhoid fever, cholera, bacterial dysentery, amoebiasis and helminthiasis. The aim of bacteriological contamination of water is to detect whether contamination with pathogenic bacteria has occurred or not (Ochai and Kolhatkar, 2000).

Water quality monitoring has been carried out to evaluate the portability of a water resource for a particular usage. Water is precious for life. Water supply is an integral part of society for various purposes e.g drinking, agriculture, industry, household etc. much of the health problems in the developing countries are largely due to lack of safe drinking water or unavailability of safe water(Sudip *et al*., 2021).

The microbiological quality of water used for human consumption is crucial as it influences human health. It can be contaminated by a wide variety of microorganisms some of which are pathogenic. Contamination of drinking water with human or animal excreta is frequently associated with diseases in man. The occurrence of such diseases can be reduced through efficient water treatment processes but water analysis is essential; particularly in the absence of such processes. The microbiological assessment of a particular water resource provides up to date information on the quality and safety of the water, hence, it is necessary to perform microbial assessment of water sources regularly to ensure continued safety of water supply within communities (Eseoghene *et al*, 2013).

The microbiological quality of drinking water is a concern to consumers, water suppliers, regulators and public health authorities alike. The potential of drinking water to transport microbial pathogens to great numbers of people, causing subsequent illness, is well documented. The number of outbreaks that has been reported throughout the world demonstrates that transmission of pathogens by drinking water remains a significant cause of illness (Medema and Payment, 2003).

Researchers said it was crucial that relevant government agencies provided safe and hygienic potable water, strengthened supervision on water quality and educate people on good hygiene habits because waterborne typhoid fever outbreak was reported in Beijing in China which was caused by extensively drug resistant (XDR) *Salmonella typhi* through polluted water supply (Food Safety News, 2022).

The presence of coliform bacteria specifically *Escherichia coli* (a type of coliform bacteria) in drinking water suggests the water may contain pathogens that can cause diarrhea, vomiting, cramps, nausea, headaches, fever, fatigue and even death sometimes. Bacteria are everywhere in our environment, including Minnesota's surface waters and ground water. Some of these bacteria can be harmful to human health. Drinking water with disease-causing bacteria, viruses or parasites (collectively called pathogens) can make people sick. It is not practical to test drinking water for every type of pathogen but it is simple to test drinking water for coliform bacteria. The presence of coliform bacteria can indicate that there may be harmful pathogens in the water (https://www.health.state.mn.us>water).

Water is considered a vehicle for the propagation and dissemination of human associated bacteria. Safe drinking water is a fundamental human right and if contaminated with opportunistic pathogenic environmental bacteria, it may have health implications for consumers (Mulamattathil *et al*, 2014)

2. Material and methods

2.1. Study area

Plateau State of Nigeria is located in the middle belt area which covers an area of 26,899 square kilometers; the State has an estimated population of 3.2 million people based on the 2006 population censes figures (2006, Census). Plateau State has an average temperature of between 18oC and 22oC. The living conditions of this study area such as unhealthy surroundings, poor sanitation, inadequate built dwellings that are characterized by congestion, poor access to water and improper disposal of waste expose individuals to water borne diseases (Enwerekowe , 2011).

The city of Jos, capital of Plateau State and its environs have for some time, been grappling with scarcity of water occasioned by erratic supply from the State water board coupled with the dry season on whose account a lot of wells within the city have dried up. The people of Jos often face acute scarcity of water throughout the year because of the nature of the terrains which makes it difficult for them to get water. Some of the residents in Jos have been forced to source water from streams and other unhygienic sources and most residents also patronize water vendors due to scarcity of water (The Nigerian Tribune, 2015).

The need for portable water especially in households is continually on the increase due to emergence of new settlements. A great number of people depend on stream water and streams are polluted by refuse dumped in the vicinity of the stream. Similarly, toilets have been built along the streams while households that do not have such facilities have developed a habit of defecating in the open space (Water and Sanitation Media Network, 2012).

2.2. Study population

The study population focused on different water sources comprising of: 14 wells, 7 streams, 5 taps, 10 boreholes, 6 storage tanks, 6 water vendors and 1 dam from different areas and reservoirs. A total of 90 water samples were collected from different water sources. The areas selected for this study include: Angwan Rukuba, Bauchi road, Lamingo area, Tudun Wada, Hwolshe, British American Junction and University of Jos senior Staff Quarters Bauchi road.

2.3. Sample collection and processing

Structured questionnaires were randomly used to obtain some useful data. Water samples were collected from different water sources: comprising of wells, streams, taps, boreholes, storage tanks, water vendors and dam. The samples were aseptically collected in sterile bottles; 20 mls of the water samples were collected. All samples collected were labeled with the sample number, date of collection, sample source and location and then sealed appropriately. The nozzle of the tap and boreholes were also sterilized using cotton wool soaked in 70% ethanol. The samples were carried inside a container containing icebags, the samples were then transported to the laboratory for bacteriological analysis.

Macroscopic examination of the water samples was carried out as well as physical/chemical properties of the different water sources were carried out. Total and faecal coliforms were analysed by multiple tube fermentation test as described by APHA (2005). Coliform count was obtained by using the tube assay of the Most Probable Number (MPN) technique. One hundred milliliters (100mls) of water sample was dispensed in MacConkey broth and incubated for 24 hours at 37°C. The test tubes which showed lactose fermentation with acid and gas production were considered positive and counted by reference to probability tables.

2.4. Presumptive test

The presumptive test was carried out using MacConkey broth. The test tubes containing MacConkey broth had Durha m tubes before sterilization. The test tubes showing gas production after 24 hours of incubation at 37°C were subcultu red on Macconkey agar, Salmonella Shigella agar, Blood agar, Nutrient agar and Eosin Methylene blue agar and then in cubated at 37°C for 24 hours. The five test tubes had 10 mls double strength broth and another set of 10 test tubes had 5 mls single strength of MacConkey broth.

2.5. Confirmatory test

The confirmatory test was carried out by transferring a loopful of culture from positive tubes in presumptive test into tubes of Brilliant Green Lactose Bile broth with Durham tubes. The tubes were incubated at 37°C for 24hours and obse rved for acid and gas production.

2.6. Ejikman test

After the presumptive test, subcultures were made from all the tubes showing acid and gas to fresh tubes of single stre ngth MacConkey broth warmed to 4°C These tubes were further incubated at 46°C in a thermostatically controlled wa ter bath and examined after 24 hours. The tubes showed gas in Durham tubes indicating the presence of *E.coli*. It was f urther confirmed by testing for indole and citrate utilization

2.7. Pour plate technique

One milliliter (1 ml) of the sample was dispensed in nineteen milliliters (19 mls) of molten Nutrient agar and MacConk ey agar. The plates were allowed to solidify before incubation. The plates were incubated at 37°C for 24 hours and exa mined for growth. Pure colonies were obtained after sub-culturing.

2.8. Identification of isolates

Isolates were identified based on Gram reaction, morphology and biochemical characteristics in accordance to Standar d Microbiological methods. The results obtained were analysed using statistical analysis (T-Test).

3. Results

Ninety four (90) water samples were collected from different water sources from Jos and environs which comprises of three (3) from Lamingo dam (LD), seven (7) from stream (STR), Six (6) from water vendors (WV), five (5) from tap wa ter (TW), six (6) from storage tanks (ST), ten (10) from borehole (BH) and fourteen (14) from well water (WW).

The occurrence of presumptive coliform for stream water revealed that STR7 had the highest mean Most Probable Nu mber (MPN) OF 300/100 ml with a mean Total Viable Count of 1.3×10^3 while STR2 located at Lamingo had the least m ean MPN of 80/100 ml (Table 1). Water vendors (WV) mean MPN ranged from 9/100 ml to 33/100 ml and the mean T otal Viable Count ranged from 1.0×10^2 to 3.0×10^2 (Table 2). Water vendor 6 (WV6) was found to be the least contam inated. The mean total viable count and the mean Most Probable Number (MPN) index for tap water (TW) showed that TW1 located at Lamingo area had the least mean MPN index of 9/100 ml with a total coliform count of 2.0×10^1 CFU/ ml. On the other hand, TW2 and TW5 had the highest MPN index of 27/100 ml with a mean total viable count of 3.0×10^2 and 3.7×10^2 respectively. For storage tank samples, ST1 located at Angwan- Rukuba had the highest mean MPN ind ex of 33/100 ml while ST2, ST3 AND ST5 had the least MPN index of 9/100 ml each (Table 4). Figure 1 shows the resul t of Borehole water (BH) samples which indicated that BH3 located at Lamingo area had the highest rate of contaminat ion with MPN index of 80/100 ml. On the other hand, BH6 located at Government Quarters had the least MPN index of 7/100 ml (Figure1). For Well water (WW) samples, WW2 located at Senior Staff Quarters had the least MPN index of 1.9×10^2 and WW13 located at Tudun-wada had the highest contamination rate with MPN index of 110/100 ml and Tot al Viable Count of 8.0×10^2 (Figure2).

Table 1 Occurrence of Presumptive coliform for stream (STR) WATER

Sample code	Location	Mean Total viable (TVC) count in cfu/ml	Mean Most Probable number
		(MPN)/100ML	
STR2	LAM	2.1×10^2	80
STR5	SSQ	2.5×10^2	90
STR1	AGR	1.1×10^3	110
STR3	AGR	3.2×10^3	110
STR4	TDW	5.3×10^3	170
STR6	BRT	1.2×10^3	220
STR7	BRT	1.3×10^3	300

Key: STR: Stream; AGR-Angwan rukuba, LAM-Lamingo, TDW-Tudun-wada, SSQ-Senior staff quarters, BRT-British America Junction; V-Vendor 1-6; LAM-Lamingo, SSQ-Senior staff quarters, AGR-Angwan rukuba

Table 3 Occurrence of Presumptive coliform for Tap Water (TW)

Sample code	Location	Mean Total viable count (TVC) Cfu/ml	Mean Most Probable number (MPN)/100ml
TW1	LAM	2.0×10^{1}	9
TW3	SSQ	2.6×10^{1}	14
TW4	AGR	2.5×10^{2}	17
TW2	LAM	3.0×10^{2}	27
TW5	TDW	3.7×10^{2}	27

Key: TW-Tap water; LAM-Lamingo, SSQ-Senior staff quarters, AGR-Angwan rukuba, TDW-Tudun wada

Table 4 Occurrence of Presumptive coliform for storage tank (ST)

Sample code	Location	Mean Total Viable count (TVC)	Mean Most Probable number (MPN)/100ml
ST2	LAM	1.5×10^{2}	9
ST3	SSQ	2.0×10^{2}	9
ST5	AGR	3.0×10^{2}	9
ST6	LAM	3.3×10^{2}	12
ST4	SSQ	3.5×10^{2}	14
ST1	AGR	4.0×10^{2}	33

Key: ST-Stream; AGR-Angwan rukuba, LAM-Lamingo, SSQ-Senior staff quarters

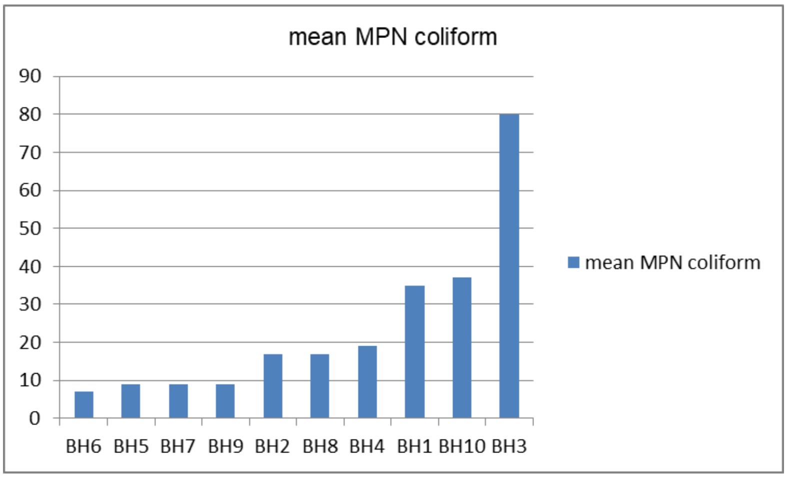

Figure 1 Occurrence of presumptive coliform for boreholes (BH) **Key:** Y axis=Mean MPN coliform number, X axis= Borehole number

The result of the statistical analysis showed that stream water (STR) was found to be the most contaminated water source among all the water sources investigated with mean difference of 154.28 (Table 8). The contamination of water sources according to location showed that samples collected from Tudun-Wada had the highest contamination of 81% followed by Angwan-Rukuba with 78% (Table 9). The frequency of occurrence for the bacterial isolates from various water sources indicated that a total of seven (7) different bacteria isolates were characterized and identified as *Staphylococcus aureus*, *Proteus mirabilis*, *Proteus vulgaris, Escherichia coli, Klebsiella pneumonia, Salmonella typhi* and *Pseudomonas aeroginosa* with frequency of occurrence of 20.5%, 25%, 13%, 11.4%, 9.1%, 11.4% and 9% respectively. Stream (S

TR) water had the highest total number of bacterial isolates with 11 isolates followed by borehole (BH) and well wate r (WW) having a total bacterial isolates of 8 (Table9). Samples collected from Lamingo dam from different locations a nd at different time indicated that sample 3 collected early mornings had the least MPN index of 17/100 ml while the s ample collected at afternoon time had the highest MPN of 33/100 ml. The sample collected in the rainy season in the m orning had 27/100 ml.

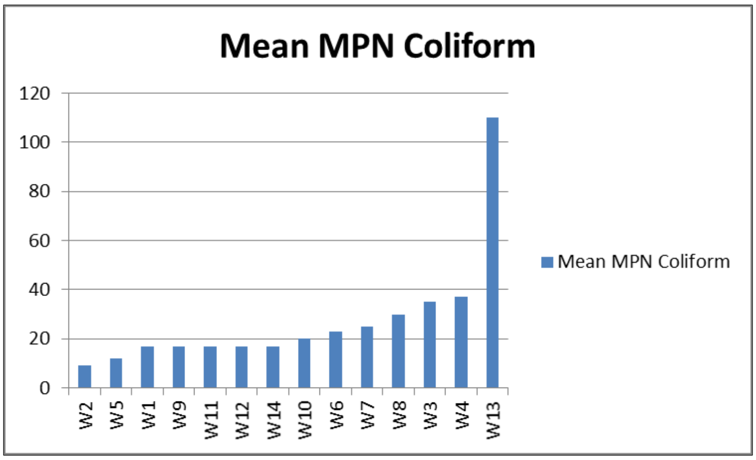

Figure 2 Occurrence of presumptive coliform for well water (WW). Y axis: Mean MPN coliform number; X axis: Well number

Table 5 Mean and Standard Deviation of Occurrence of presumptive coliform

Source	Number of Samples	Minimum	Maximum	Mean	Standard Deviation
Stream	7	80.00	300.00	154.2857	81.00558
Vendor	6	9.00	33.00	20.1667	8.65833
Tap water	5	9.00	27.00	18.8000	8.01249
Storage Tank	6	9.00	33.00	14.3333	9.37372
Borehole	10	7.00	80.00	22.6000	22.38650
Well	14	9.00	110.00	25.9286	25.59587
Lamingo Dam	3	17.00	33.00	25.6667	8.08290

Table 6 T-Test of occurrence of presumptive coliform for the different sources of water

Source Test Value =0				**95% Confidence interval of the difference**		
T		**df**	**Sigma (2-tailed)**	**Mean Difference**	**Lower**	**Upper**
Stream	5.039	6	0.002	154.28571	79.3680	229.2034
Vendor	5.705	5	0.002	20.16667	11.0803	29.2530
Tap water	5.247	4	0.006	18.80000	8.8512	28.7488
Storage Tank	3.746	5	0.013	14.33333	4.4962	24.1705
Borehole	3.192	9	0.011	22.60000	6.5857	38.6143
Well	3.790	13	0.002	25.92857	11.1500	40.7072
Lamingo	5.500	2	0.032	25.66667	5.5876	45.7457
Dam						

Table 7 Contamination of water sources according to location

Location	No of water sources	No contaminated	Percentage (%)
LAM	17	11	64
SSQ	20	13	65
HOW	18	13	72
BRT	4	3	74
AGR	19	15	78
TDW	16	13	81

Key: AGR-Angwan rukuba, SSQ- Senior staff quarters, LAM-Lamingo, HOW-Hwolshe, TDW- Tudun wada, BRT- British America Junction

Table 8 Frequency of occurrence of Bacteria isolates from various water sources

Bacteria	Tap	Borehole	Well	Stream	Storage tank	Dam	Water vendor	% of occurrence
Pseudomonas aeroginosa		1	1	1			1	9.0
Klebsiella pneumonia	1			1	1	1		9.1
Escherichia coli		1	2	1		1		11.4
Salmonella typhi		3	1	1				11.4
Proteus vulgaris		1		2	1		2	13.6
Staphylococcus aureus	2		2	2	2		1	20.5
Proteus mirabilis	1	2	2	3	1	1	1	25.0
Total	4	8	8	11	5	3	5	100

Table 9 Physical/chemical Characteristics of the Different water sources

Parameters	Tap	Borehole	Well	Stream	Storage tank	Dam	Water vendor
Temperature	20	21	24	20	23	20	22
(in ^{o}C)							
pH	6.3	7.2	6.5	5.9	7.4	6.9	7.6
Odour	NO	NO	NO	YES	NO	NO	NO
Depth (in meters)	5.2 to 11.3						
Distance from	10 to 30 8 to 25						
Septic tank							
Sanitary Survey	Prese Presence Presence Human						
	ence of refuse of faeces/						
	Of waste dump/gutter animal waste						

	In BH14	dropping/	disposal
	human faeces		

4. Discussion

From the results for stream (STR) water samples, the most probable number (MPN)/100 ml for all the samples showed that STR7 located at British American Junction was found to be the most contaminated with mean MPN of 300/ml and mean Total viable count of $1.3 \times 10^{3.}$ This could be due to open defecation, indiscriminate disposal of waste, and other human activities such as bathing and washing of cars/clothes; while STR2 located at Lamingo was the least contaminated with mean MPN of 80/100 ml, this could be due to low human activities, less population and lack of open defecation. Streams are used by large population of individuals for different activities which include bathing, washing, irrigation, building and construction works may have greatly affected the quality of stream water.

For water vendors, (Table 2); V6 located at Angwan-Rukuba had the least bacterial contamination with mean MPN of 9/100 ml and Total viable count of $1.0 \times 10^{2.}$ This may be as a result of proper cleaning of Jerri cans before fetching water while V4 also located at Angwan-Rukuba had the highest mean MPN of 33/100ml with mean TVC of 3.0×10^{2} , this may be as a result of poor sanitary area. Contamination may also be as a result of lack of proper hygiene in washing the galloons used in fetching water and unsanitary way of dumping refuse around the areas where they fetch water. For Tap water (TW) samples, TW5 and TW2 located at Tudun-Wada and Lamingo respectively had the highest mean MPN. This could be as a result of rusting of pipes, pipe burst or lack of proper treatment of water before distribution. On the other hand, TW1 also located in Lamingo area had the least mean MPN this could be due to the fact that metal pipes had been replaced with plastic pipes. Storage tank (ST) samples showed that ST1 located at Angwan-Rukuba had the highest mean MPN of 33/100 ml with mean TVC of 4.0×10^{2} , this might be due to lack of proper washing of the tank before storage of water or the water stored inside the tank had stayed for long which might have encouraged the growth of microorganisms; while ST2, ST3 and ST5 located at Lamingo, Senior Staff Quarters and Angwan-Rukuba had the least MPN this may be due to proper washing and cleaning of storage tanks before storing the water.

Borehole (BH) water samples (Figure1) indicated that BH3 located at Lamingo had the highest mean Most Probable Number (MPN) of 80/100 ml with mean Total Viable Count (TVC) of 7.0×10^{2}. This could be attributed to poor sanitary conditions, lack of proper construction and closeness of the borehole to septic tanks which might have increased the rate of contamination. On the other hand, BH6 located at Government Quarters had the least mean MPN of 7/100 ml, this could be due to proper construction, proper location and must have been located far away from the septic tanks. Also BH5, BH7 and BH9 located at Tudun-Wada, Bauchi road and Bauchi road respectively also had low MPN of 9/100 ml. Sanitary survey of the borehole, dam, revealed the proximity of some of the water sources to solid waste dump site and animal droppings being littered around them. Well water (WW) samples (Figure ii) showed that WW2 located at Senior Staff Quarters had the least mean MPN of 9/100 ml with mean TVC of 1.9×10^{2}, this could be as a result of proper siting of the well which might be located far away from the septic tanks, proper construction of the well, use of one drawer to fetch the water and the depth of the well because the deeper the well the less contaminated it will be while WW13 located at Tudun-Wada had the highest mean MPN of 110/100 ml, this might be as a result of over use and over dependence on the water, location of the well close to septic tank or gutter, lack of proper construction and protection of the well, use of different drawer to fetch the water and also the depth of the well which may not be deeper. Depth of the well ranges from 15ft to 23ft deep.

Water samples taken from storage tanks (ST) were the least contaminated followed by tap water (TW), water vendors (V), borehole (BH), Lamingo dam (LD), well water (WW) and lastly stream (STR). This could be attributed to the fact that wells, streams and dam were exposed to contamination in that most of them were not so deep, not well covered and some were very close to soakaway and refuse dumps. Samples collected from Lamingo dam from different locations and at different time showed that early morning sample had the least mean MPN of 17/100 ml, this could be as a result of less activities in the morning hours while the afternoon sample had the highest mean MPN of 33/100 ml, this might be due to high rate of human activity such as irrigation, washing of cars and clothes, bathing and construction work being carried out.

The study showed that stream water was found to be the most contaminated with a mean difference of 79.36 which could be as a result of open defection, indiscriminate waste disposal, irrigation, washing, bathing, animal droppings and other industrial and agricultural waste that have been carried into the stream during rainy season (Table 6). This conforms to the study of Antony and Renuga (2012) who reported that contamination of stream water is as a result of surface runoff, pasture and animal waste. This study also conforms to the study of Taura and Hassan(2013) who reported that tap water were less contaminated than well water and this may be attributed to the fact that most of the wells were exposed to contamination; not so deep; not covered and some very close to toilets. Also Bello *et al* (2013) in their studies on the bacteriological and physicochemical analyses of borehole water reported that borehole waters are safe for consumption while well waters were of poorer bacteriological qualities. On the other hand, this study does not conform to the study of Oluyege, Koko and Aregbesola (2011) that reported that all the household drinking water in Ado-Ekiti, met the WHO standard for drinking water. This study does not agree with the study of Badiyya (2013) who reported from their results that borehole water was found to be the best source of water for drinking and domestic purposes.

Based on location, water samples collected from Tudun-Wada (TDW) were found to be more contaminated with 81% than from other sites, this could be due to high population density which can increase the rate of sewage disposal, indiscriminate defecation, over dependence and frequent use of the water available (Table 7). This means that individuals in the area might be prone to waterborne disease (Taura and Hassan, 2013). Coliforms in general and *E.coli* in particular are conventionally referred to as indicators of faecal contamination. *E.coli* and *Klebsiella pneumonia* reflect the human origin of the contaminants. The presence of *Salmonella* points to the risk of exposure to enteropathogen thereby leading to typhoid (Nkere *et al*, 2011). The physical and chemical properties of the different water sources are represented in Table 9, the temperature range from 19 for tap water to 24 for well water. The temperature of the water samples fall within the WHO and SON standard that is 20 to 26 while the pH also fall within the WHO standard and SON standard with the pH standard of 6.5 to 8.5. The temperature of the samples is suitable for the growth and metabolic activities of the bacterial organisms. Increase in temperature increases the rate of metabolic activities and chemical reaction. The pH is close to neutrality which will allow the growth of most bacterial pathogens. Exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes. The presence of odour in stream water signifies high rate of waste materials in the water. The depth of the well water range from 5.2 to 11.2 meters, shallow wells (5.2 meters) were more contaminated than deep wells (11.2 meters). Distance from septic tanks showed that wells and boreholes located far way (25 to 30 meters) from septic systems/soakaway were found to be less contaminated than those located close to septic systems (7 to 10 meters). The sanitary survey of the water sources such as waste disposal, presence of gutters, animal droppings and open defecation have contributed a lot to the contamination of water sources which has affected the quality of the water and has led to the occurrence of bacterial pathogens.

Water suitable for drinking and domestic purposes should be free from disease causing organisms. The World Health Organization (WHO) defines acceptable water as that in which no thermotolerant bacteria are detected in any 100ml sample. In this study, most samples of water investigated did not comply with the Microbiological standard of drinking water which states that no sample water should contain more than 3 coliforms/100ml. Okonko *et al* (2008) recorded MPN of 9.3 to 44 MPN/100ml in different water samples used for domestic purposes in Abeokuta and Ojota. Shittu, *et al* (2008) in Abeokuta recorded Total coliform count of 1600 t0 1800 MPN/100ml and total viable counts ranging from 6.3×10^6 to 2.01×10^7cfu/ml. Olajubu and Ogunika (2014) in their studies on borehole water samples recorded total coliform count of 1.6×10^5cfu/ml.

The temperature range is 23 to 28 °C which are suitable for the growth of bacterial species in the water samples while the pH range is 6.45 to 7.78 which is neutral and can allow the growth of most bacterial species. Stream and well water samples had the highest contamination rates since large population of residents depend on these sources. The routes of contamination may have been due to poor planning, design and construction of wells; closeness of the well to soakaway or latrines, closeness of the wells to gutters; lack of proper covering, overdependence, unsanitary way of using containers to fetch water, improper disposal of waste. Rain water must have washed and carried waste materials into the wells and streams (Egwari and Aboaba, 2002).

5. Conclusion

This study reveals that water sources for domestic use in Jos and environs were contaminated. This finding is attributed to the fact that all the water samples from different water sources contain microorganisms. The microorganisms that were isolated in the study include; *E.coli, Klebsiella pneumonia, Pseudomonas aeroginosa, Proteus vulgaris, Proteus mirabilis, Staphylococcus aureus* and *Salmonella typhi*. This study also showed that tap water, borehole water and storage tanks were the least contaminated while stream water is the most contaminated source of water. Based on the findings of this study, there should be proper enlightenment campaign to the public on the dangers of using contaminated water which is a leading cause of water borne diseases. The public should be enlightened on proper disposal of waste, proper siting, construction and protection of wells and boreholes. Open defecation should be discouraged. There should be proper treatment of water before drinking and proper treatment of water for domestic use. There should be prompt reporting of leaking water pipes by communities to the government and the government should also in turn respond promptly.

Compliance with ethical standards

Acknowledgments

Acknowledgments must be inserted here. We thank the Department of Medical Microbiology, Faculty of Clinical Sciences, University of Jos for granting the permission to carry out the work in their Laboratory and we also thank all the staff of Medical Microbiology Department (academic, non-academic and Laboratory Staff) for their support and encouragement throughout the period of the research work.

Disclosure of conflict of interest

If two or more authors have contributed in the manuscript, the conflict of interest statement must be inserted here. There are no conflicts of interest associated with this work to the best of our knowledge.

Statement of informed consent

If studies involve information about any individual e.g. case studies, survey, interview etc., author must write statement of informed consent as "Informed consent was obtained from all individual participants included in the study."Informed consent was obtained from all authors who participated in the study.

References

[1] Antony R. and Renuga F.B (2012): Microbiological Analysis of Drinking Water Quality of Ananthanar channel of Kanyakumiri district, Tamil Nadu, India. An Interdisciplinary Journal of Applied Sciences 7 (2) 42-48

[2] Arora D.R and Arora B. (2008), Textbook of Microbiology, 3rd Edition. CBS Publishers and Distributors,New-Delhi, Banglore India. 737-740

[3] Badiyya H.M (2013): Comparative Bacteriological Analysis of Drinking Water Samples in Katsina State. www.ajol.info/journals/jorina

[4] Bello O.O, Osho A., Bankole S.A and Bello T.K (2013): Bacteriological and physicochemical analysis of borehole water and well water sources in Ijebu-Ode, SouthWestern Nigeria. Journal of Pharmacy and Biological Science, 8 (2):18-25

[5] Enwerekowe E. O.(2011): An Appraisal of waste management systems for informal settlements within Jos and Urban areas in Nigeria. Journal of Sciences and Multidisciplinary Research.3: 43-50

[6] Edet E.J., E.E.Etim and Titus O.M (2012): Bacteriological and Physico-Chemical Analysis of streams water in Nduetong Oku Community, Uyo, Akwa Ibom State, Nigeria. International Journal of Modern Chemistry 3(10):65-73.

[7] Egwari L., Aboaba O.O (2002): Environmental Impact on the Bacteriological Quality of Domestic water supplies in Lagos, Nigeria. Publication 36 (4) 513-520

[8] Eseoghene O.E, John D.M, and Oluwafemi A.O (2013): Microbiological Quality of water in Fulani settlements in Gidan Kwano, Minna, Niger State, Nigeria. Journal of Microbiology Research 3(2):67-70

[9] Food Safety News (2022): China records Salmonella outbreak from contaminated water. Retrieved from Google 16th May, 2022 https://www.health,state.mn.us>water 26/05/2023

[10] Matusala G, Amha A, Chala W and Etagegnehu A (2020): Bactteriological contamination of Drinking Water Supply from Protected Water Sources to point of use and water Handling Practices among Beneficiary Households of Booso, Sore Woreda, Wolaita Zone, Ethiopia. International Journal of Microbiology. http://doi.org/10.1155/2020/5340202 26/05/2023

[11] Mile I.I, Jande J.A and Dagba B.I (2012): Bacteriological Contamination of well water in Makurdi Town, Benue State, Nigeria. Pakistan Journal of Biological Sciences, 15:1048-1051

[12] Medema G. J.,Payment P. (2003): Safe Drinking Water: An ongoing challenge. In W. OECD, Assessing microbial safety of drinking water improving approaches and methods. London: IWA publishing 11-46.

[13] Mulamattathil S.G, Bezuuideenhout C., Mbewe M. and Ateba C.N (2014): Isolation of Environmental Bacteria from Surface and Drinking Water in Mafikeng, South Africa, and Characterization using their Antibiotic Resistance Profiles. Journal of Pathogens 1-11. http//dx.doi.org/10.1155/2014/371208

[14] Nkere K.C, Ibe N.I and Iroegbu C.U (2011): Bacteriological Quality of Foods and Water sold by Vendors and Restaurants in Nsukka, Enugu State, Nigeria. A Comparative Study of three Microbiological methods. Journal of Health Population and Nutrition, 29(6):560-566

[15] Ochei J. and Kolhatkar A.(2007). Medical Laboratory Science: Theory and Practice. McGraw-Hill Publishing Company Limited, New Delhi, 818-820

[16] Okonko I.O.,Adejoye O.D., Fajobi A.E and Shittu O. (2008): Microbiological and Physicochemical Analysis of different water samples used for domestic purposes in Abeokuta and Ojota, Lagos state, Nigeria. African Journal of Biotechnology 7 (5) 617-621.

[17] Olajubu F. A. and Ogunika, F. (2014): Assessment of the physico-chemical and microbiological properties of borehole water samples from Akungba-Akoko, Ondo State, Nigeria. International Journal of pharma sciences and Research 5 (7):367-373.

[18] Shittu, O.B, Olaitan J.O and Amusa T.S (2008): Physico-chemical and Bacteriological Analyses of water used for drinking and swimming purposes in Abeokuta, Nigeria. African Journal of Biomedical Research, 2:285-290.

[19] Sudip S, Rittick M, Debasis M, Divya J, Devvret V and Semanwita D (2021): Microbial Pollution of Water with Special Reference to Coliform Bacteria and their Nexus with Environment. http://doi.org/10.1016/j.nexus.2021.100008 26/05/2023

[20] Taura D.W and Hassan A. (2013): Bacteriological Examination of Households Drinking Water in Some Local Government Areas of Kano State, Nigeria. International Research Journal of Pharmacy and Pharmacology, 3(6):91-96.

[21] The Nigerian Tribune Newspaper (2015): Acute Water Scarcity hits Jos and Environs. 08/05/2015.

[22] Water and Sanitation Media Network Nigeria (2012): Water aid and water supply and sanitation collaborative council, Jos, New Nigeria, West Africa wash media Network, 2ndNov, 2012.

[23] WHO (2008): Guidelines for Drinking-Water Quality, Third Edition 1-5.

[24] World Health Organization (2004): Regional office for Africa, country Health Systems Profiles Nigeria.1- 24.