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BACTERIOLOGICAL AND PHYSICOCHEMICAL ANALYSIS OF WATER FROM DIFFERENT SOURCES IN A RURAL COMMUNITY OF JOS SOUTH LOCAL GOVERNMENT AREA (LGA), PLATEAU STATE, NIGERIA

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ABSTRACT: *Surface and underground water polluted by microbes and chemicals exacerbates issues of water scarcity, given its importance to all life forms. This study investigated the impact of microbial and chemical pollution from water sources in the K-Vom community in Jos South Local Government Area of Plateau State, Nigeria. Four water samples from various sources underwent bacteriological and physicochemical analyses following the U.S. Environmental Protection Agency standard guidelines to assess their quality. Escherichia coli emerged as the predominant organism, with tap water showing the lowest contamination levels and well water, particularly from Angwan Madugu, displaying the highest bacterial counts. Physicochemical parameters generally met WHO standards, except for Total Suspended Solids (TSS) and Nitrates (Means: 0.14mg/L, 74.9mg/L) which exceeded recommended limits. Statistical analysis revealed non-significant differences for TSS, Nitrates, and Biochemical Oxygen Demand (BOD), suggesting overall compliance with international guidelines. Despite meeting certain standards, local water sources remain unfit for consumption due to bacterial contamination. Consequently, the study recommends the implementation of simple water treatment measures to mitigate health risks associated with waterborne diseases, emphasizing the urgent need for improved water quality management in the region.*

KEYWORDS: Bacteriological, Coliforms, E. coli, Physicochemical parameters, Kaduna Vom, Plateau State.

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INTRODUCTION

Water remains a vital component of the environment, considering the key role it plays in the sustainability and survival of every earthly life. As a necessity, it makes up about 70-90% total mass of living cells (Alberts *et al.*, 2002). Aside from its need by plants, both humans and animals require a lot of its consumption daily for their existence. Access to potable drinking water is a basic human right that is indispensable to well-being and a factor of proper strategy for health fortification (WHO, 2002a). According to recent UNICEF and the World Health Organization's reports, billions of individuals worldwide suffer from continuous dearth of access to water, hygiene and sanitation. Around 2.2, 3 and 4.2 billion individuals do not enjoy safely purified water facilities, suffer a deficiency of handwashing services and lack carefully managed sanitation amenities respectively (WHO/UNICEF, 2014). Sadly, most of these people affected live in communities found in sub-Saharan Africa and Asia. In recent times, water's necessity has been continuously growing due to factors like rising growth in population, modernization and other anthropogenic activities (Adesakin *et al.*, 2020; Aremu *et al.*, 2011). For example, the 2021 World Water Development Report of UNESCO stated that worldwide fresh-water usage, which has been increasing by one percent annually since the 1980s, has grown six-times in the past century (UNESCO, 2021).

Globally, avenues related to obtaining uncontaminated safe water and sanitation remain a public concern especially in Low-Middle income nations like Nigeria, where people continually go through a dearth of means to access potable water from sufficient sanitation amenities alongside improved sources (WHO, 2002b). In 2012, the United Nations, in its move to safe-guard the world and guarantee healthy living, initiated seventeen Sustainable Development Goals (SDGs) in place of the Millennium Development Goals (MDGs), with goal number 6 being "Clean water and Sanitation" (Carlsen & Bruggemann, 2022). It is imperative to observe how Nigeria, a UN member country, is progressing in relation to attaining the goal on access to potable water with respect to amount and quality, eons after the enactment of the universal SDGs. The quality of drinking water in emerging countries is worrisome and the negative health outcomes of water contamination remains the foremost cause of illnesses and deaths from these nations (Lin *et al.*, 2022).

LITERATURE/THEORETICAL UNDERPINNING

The Nigerian citizens, like other underdeveloped countries, are among billions of individuals who are deprived of means to harmless drinking water, as barely just one out of every three Nigerians living in the rural and city areas have means to piped-water source networks in their compounds for consumption, and persons having these can still suffer from undependable and inferior provision (Kumpel *et al.*, 2016). As such, many families fall back to community taps and non-piped water provisions like springs, boreholes, manually burrowed wells, and water sellers (WHO/UNICEF, 2014). Because many rural community residents worldwide obtain their water source primarily from dams, rivers, spring sources and from superficial tunneled wells (Aneck-Hahn *et al.*, 2009; Sun *et al.*, 2010), rising contamination as a result of urbanization, industrialization and agricultural activities is rendering existing water sources impractical and hazardous to well-being (Walker *et al.*, 2019).

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Though a great majority of community drinking-water quality problems are related to faecal contamination from coliforms and bacteria, a substantial amount of these problems can occur as a result of chemical pollution arising from a diversity of artificial and natural causes. To establish whether these hitches exist, chemical investigation must be carried out. However, the determination of a varied series of parameters on a steady basis can be very costly, predominantly in the case of supplies that meet the needs of small numbers of persons. In built-up parts and cities, ground sources of water, like deep wells and boreholes, institute key avenues of drinking water. These sources get contaminated through processes like solid municipal waste leachates from waste yards (Aboyeji & Eigbokhan, 2016) in addition to manufacturing seepage (Bello-Osagie & Omoruyi. 2012) which all constitute a major public health concern.

Right from the end of the 19th century, engaging the use of coliforms, precisely *Escherichia coli*, as a pointer of microbiological water quality began from their initial isolation from feaces (Rompre *et al.*, 2002). Coliforms are habitually found in varied natural settings, with some of them being telluric, but their natural abode is not drinking water. Their occurrence in drinking water should at best be looked at as suggestive of or likely threats of bacteriological water quality decline. Total coliform count in treated water samples which should normally be coliform-absent can imply quality failure, treatment ineptitude, disinfectant mishaps (McFeters *et al.*, 1986), intrusion arising from contamination into the potable water stock (Geldreich *et al.*, 1992; Clark *et al.*, 1996) or resurgence glitches (LeChevallier, 1990) from the supply structure, which should not as a consequence be accepted.

Drinking water sources in Nigeria have been discovered to be contaminated with some microbes like *Staphylococcus aureus* and *Pseudomonas species* apart from coliforms (Igbeneghu & Lamikanra, 2014). From the chemical viewpoint, metals such as iron, aluminum, chromium, and calcium have been discovered as surface and packaged sachet-water contaminants (Titilawo *et al.*, 2018; Emenike *et al.*, 2018). Lead, cadmium, nickel and manganese have also been reported above permissible levels from groundwater (Ayedun *et al.*, 2015) with other contaminants such as fluoride. Besides, light Polycyclic Aromatic Hydrocarbons (PAH) are also present in some Nigerian location groundwaters above permissible limits (Emenike *et al.*, 2018; Adekunle *et al.*, 2017). The World Health Organization has stated that 80 percent of diseases are water related and of these 80% illnesses, Lin *et al.* (2022) opined that child deaths account for 50% due to poor-quality water intake, with more than fifty diseases arising from the same cause.

Cancer, neurological disorders, respiratory illnesses, cardiovascular diseases, and diarrhea are among the ailments linked to contaminated water (Arain *et al.*, 2014). Addressing water scarcity in poor nations like Nigeria is crucial and urgent actions are needed to prevent water-borne diseases like cholera and typhoid which are prevalent due to poverty and poor hygiene. Over sixty million Nigerians lack access to clean water, leading to the consumption of contaminated water with severe public health consequences (Coleman *et al.*, 2013; Igbinosa *et al.*, 2017; Ologbosere *et al.*, 2016; Beshiru *et al.*, 2018). This study was therefore aimed at determining the bacteriological and physicochemical parameters of water samples from borehole, tap, well, and rain water in K-Vom community of Jos South Local Government Area.

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MATERIALS AND METHODS

Materials/Equipment: The materials and equipment used for the research analysis were HACH/DR 900 spectrometer, DR 2000 (HACH) spectrophotometer and TDS meters, wagtech pH meter, beakers, and conical flask.

Study Design and Area

This study employed the cross-sectional approach and was conducted within the month of June 2022. The area of the study is known as Kaduna Vom (K-Vom) (Figure 1), a locality in Jos South Local government area (LGA) of Plateau State. K-Vom is located between latitude 7°56 North and longitude 8°53 East and lies at an altitude of about 1,280m above Sea level.

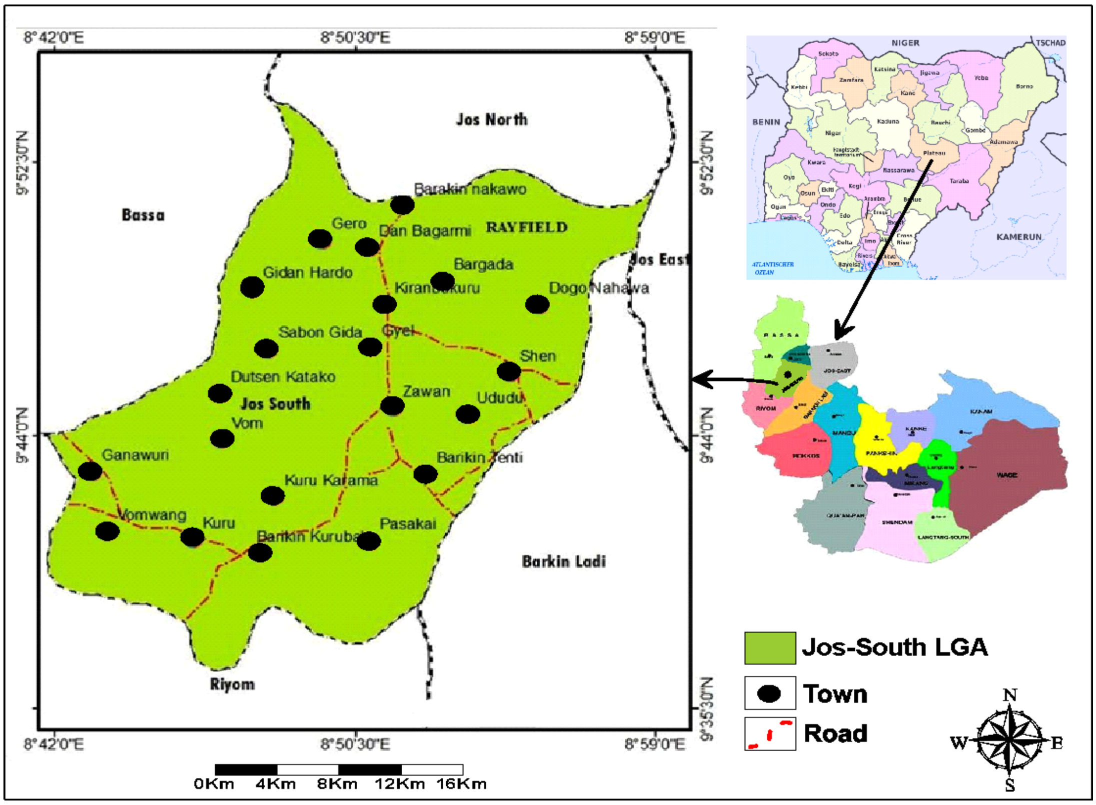

Figure 1: Map of Jos South LGA showing Vom, in Plateau State, Nigeria. **Source:** Anthonia *et al.* (2023).

Sample Collection

Two water samples were aseptically collected from each water source in 1 liter sterile containers (i.e., from 2 taps, 4 boreholes, 5 wells and 5 rain water sources) randomly selected from five (5) locations within the study area. These locations were the National Veterinary Research Institute (NVRI) compound, Chaha road area, Angwan Mission, Angwan Madugu, and Angwan Gada. A total of 32 samples having 2 liters of each water sample were obtained from the 5 aforementioned selected sample sites in the locality. Hand gloves were used to collect sterile samples which were placed in cold ice packs before being transported to the various laboratories for analysis less than six hours after collection.

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Statistical Analysis

Data obtained was recorded in Microsoft-Excel spreadsheet and imported to STATA 17 (StataCorp LLC Statistics and Data science USA) package. Descriptive analysis to replicate independent means, comparison using independent sample t-test, standard error of the mean, standard deviation and p-values at 95% confidence level was done.

Bacteriological Analysis

Media Preparation and Bacterial Isolation

Plates of Nutrient agar (NA), Blood Agar (BA), Salmonella Shigella agar (SSA), and MacConkey (MCA) agars were prepared according to the manufacturer's specification and number of dishes needed for bacterial identification. After a 10^{-5} serial dilution of water samples from various sources, dried NA plates were inoculated with 1.5 ml of the samples from the 10^{-3} plate through the spread plate technique, to obtain the various heterotrophic bacteria counts and incubated at 37°C for 24 hrs. Upon macroscopic identification of discrete bacterial colonies, isolates were picked and further sub-cultured on BA, SSA, and MCA agars to obtain pure cultures of enteric and gram-positive organisms. Isolates from these pure culture media were then identified using the standard microbial methods according to Cheesbrough (2005) and tests like Gram's reaction and biochemical tests like Sugar fermentation Methyl Red-Voges Proskauer test, Citrate utilization, Indole, growth in Triple Sugar Iron agar, Catalase, Coagulase, Oxidase, Hydrogen sulfide (H_2S) production, Motility, Urease, sporulation features and Kligler Iron agar tests were employed to identify the bacteria species. Cultural and morphological appearances of isolates from the pure culture were categorized using the conclusive Bergey's bacteriology manual (Holt *et al.*, 1994).

Membrane Filter Technique

From the 1 liter sampled containers, 100 ml of each source's specimen was taken and filtered through 0.45 µm pore size, 47 millimeter diameter membrane filters and incubated aseptically on dried plates of Eosin Methylene Blue (EMB) agars, as described by the American Public Health Association (1926). Before performing the agar plate Coliform count method, as described by Akubuenyi *et al.*, (2013), the plates were incubated at 37ºC for 24-48 hrs for *E. coli* detection through the Most Probable Number (MPN/100ml) of the sample, using the presumptive, confirmative and completed tests.

Physicochemical Analysis

Samples collected from various sources were analyzed using automated laboratory equipment via prescribed standard methods for the analysis of drinking or wastewater, as stipulated by the United States Environmental Protection Agency (Clancy *et al.*, 1999). pH and temperature determination were done at the sample site. For instance, a Wagtech pH meter was dipped inside a buffer solution of 7.0 to calibrate the instrument after which it was dipped into the various samples and reading was taken one after the other from each of the water samples. The temperature was measured by dipping the thermometer about a centimeter into the immediately collected 1 liter water specimen for about three (3) minutes before recording the values.

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The constituent Nitrates, Phosphate and Sulphate ions were assayed using the spectroscopic approach with HACH/DR 900 equipment. The sample's turbidity and total dissolved solids were determined using DR 2000 (HACH) spectrophotometer and TDS meters accordingly.

RESULTS

Total Heterotrophic Bacteria (THB), Total Coliform *(E. coli)* and Faecal Coliform Counts

The result of bacteriological analysis of the water samples obtained from the study location in (Table 1) showed *Escherichia coli* as the predominant bacteria, followed by *Pseudomonas aeruginosa* and *Klebsiella aerogenes*. Others were *Salmonella typhi, Shigella flexneri, Staphylococcus aureus, Enterococcus faecalis* and *Bacillus subtilis*. These bacteria, isolated from the four water sources in the study area, presented a Total Heterotrophic Bacterial (THB) and Total Coliform (TC) counts with well water, especially that from Angwan Madugu having the most contamination (i.e., $8.5x10^4$ CFU/ml) and 800-1500 MPN/100ml), and 13 MPN/100 ml for faecal coliforms. This source was followed by borehole water that recorded 68 MPN/100 ml TC count from Angwan Mission and 35 MPN/100 ml from Angwan Gada's boreholes.

Tap water had the least feacal contamination and presence of other Enterobacteria aside *Enterococcus faecalis*, with Angwan Mission's well having the most contamination with *Pseudomonas aeruginosa* ($2.2x10^3$); Chaha road area's borehole had the most *Klebsiella aerogenes* ($2.5x10^2$) bacteria while Angwan Gada's well recorded the highest *Salmonella typhi* presence ($2.4x10^3$). The highest number of *Enterococcus faecalis* (i.e., $1.6x10^3$) was seen in Angwan Madugu's rain water source, with the same area's well water recording the utmost ($2.2x10^3$) *Shigella flexneri* water. The reason for this bacteria presence may be ascribed to the fact that Angwan Madugu, being a slum with old houses, has a lot of unhygienic areas like toilets, dump sites closer to most of their unsealed wells.

Table 1: Total Heterotrophic Bacteria (THB), Total Coliform (*E. coli*) and Faecal Coliform Counts from Water Samples in Kaduna Vom, Jos South LGA, Plateau State

Sample site	**THB (CFU/ml)**	**Total (*E. coli*) coliform (MPN/100ml)**	**Faecal coliform (MPN/100ml)**	***Pseudomonas aeruginosa* (CFU/ml)**	***Klebsiella aerogenes* (CFU/ml)**	***Salmonella typhi* (CFU/ml)**	***Enterococcus faecalis* (CFU/ml)**	***Shigella flexneri* (CFU/ml)**
Tap 1	$1.2x10^2$	2	0	OND	OND	OND	OND	OND
Tap 2	$1.3x10^2$	3	0	OND	$1.2 x10^2$	OND	OND	OND
Well 1	$2.5x10^3$	38	4	$2.2 x10^2$	$2.4 x10^2$	OND	OND	OND
Well 2	$2.8x10^3$	48	7	$2.5 x10^2$	OND	OND	OND	$2.1 x10^2$
Well 3	$3.5x10^3$	55	5	OND	$1.8x10^3$	$2.2x10^2$	OND	OND
Well 4	$5.3x10^4$	140	9	$2.2x10^3$	$2.5x10^3$	$2.4x10^2$	OND	OND
Well 5	$8.5x10^4$	800-1500	13	OND	$2.3x10^2$	$2.0x10^3$	$1.5x10^2$	$2.2x10^3$
Borehole 1	$1.4x10^3$	8	1	$1.2x10^2$	OND	OND	OND	OND
Borehole 2	$1.8x10^3$	15	1	$1.8x10^2$	$2.5x10^2$	OND	OND	OND
Borehole 3	$2.4x10^3$	35	4	$2.1x10^2$	$1.5x10^3$	OND	OND	OND

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Borehole 4	$3.8x10^3$	68	5	$1.5x10^2$	OND	$1.2x10^2$	OND	$1.3x10^3$
Rain 1	$2.1x10^2$	18	2	$1.4x10^3$	OND	OND	$1.5x10^3$	OND
Rain 2	$1.75x10^2$	15	2	OND	$1.5x10^3$	OND	OND	OND
Rain 3	$2.2x10^2$	20	2	$1.2x10^2$	OND	OND	$1.2x10^2$	OND
Rain 4	$2.3x10^2$	25	3	$1.3x10^2$	OND	$1.5x10^2$	OND	OND
Rain 5	$2.3x10^4$	35	4	OND	$2.1x10^2$	$1.8x10^2$	$1.6x10^3$	OND

KEY: *OND - Organism Not Detected; 1 = NVRI compound, 2 = Chaha road area, 3 = Angwan Gada, 4 = Angwan Mission, 5 = Angwan Madugu.*

Bacteria Isolated from Water Sources in the Study Area and Health-related Conditions

Table 2 shows the various bacteria isolated from water sources within the study area, their health-related conditions and citations. *Escherichia coli*, being the most prominent bacteria isolated from all water sources within the locality, has most strains that are harmless, though some virulent strains cause urinary tract infections, gastroenteritis, and neonatal meningitis, while others have been connected to food poisoning (Pormohammad *et al.*, 2019). Apart from *E. coli*, *Pseudomonas aeruginosa*, which typically infects the pulmonary tract, is most times an opportunistic organism found in immunosuppressed persons and causes urinary tract infections, burns and wounds infections (Thi *et al.*, 2020; Igbeneghu & Lamikanra, 2014). It was the second most abundant bacterial water contaminant present in 10 water sources, followed by *Klebsiella aerogenes* which causes diseases like Pneumonia, septicemia, spondylitis, and ankylosing (Ayandele *et al.*, 2020).

Bacillus subtilis, which is implicated to allergic reactions in individuals on repeated exposure, food poisoning, bacteremia, endocarditis, pneumonia, and septicemia (Edberg, 1991; Logan, 1988), was present in only 2 water sources: wells at Chaha road area and borehole at Angwan Mission. Wells in Angwan Gada, Angwan Mission and Angwan Madugu along with rain water from Angwan Mission and Angwan Madugu were all contaminated with *Salmonella typhi*. *Shigella flexneri* was observed only in well water sources from Chaha road area and Angwan Madugu, while *Enterococcus faecalis* was isolated from Angwan Madugu's well water and rain waters source from NVRI compound, Angwan Gada *and* Angwan Madugu. *Staphylococcus aureus* was found in only 2 water sources: Angwan Madugu well water and Chaha road area's rain water. Results revealed that the water source with the least bacterial contaminants was tap within the NVRI compound, and well water from Angwan Madugu had the most bacterial contaminants.

Table 2: Water Sources, Bacteria Isolated in the Study Area and Health-related Conditions

Water source	**Bacteria Isolated**	**Health risk/Disease(s) associated**
Tap 1 (pipe)	*E. coli*	*E. coli:* Most strains are harmless but some strains are associated with food poisoning and virulent strains may cause urinary tract infections,
Tap 2 (pipe)	*E. coli, Klebsiella aerogenes*	

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Well 1	*E. coli, Klebsiella aerogenes, P. aeruginosa*	gastroenteritis, and neonatal meningitis. (Pormohammad et al., 2019)
Well 2	*E. coli, Bacillus subtilis, P. aeruginosa, Shigella flexneri*	*P. aeruginosa*: Occurs as an opportunistic organism found in immunosuppressed individuals and classically infects the pulmonary tract and urinary tract infections, burns and wounds infections. (Thi et al., 2020; Igbeneghu & Lamikanra, 2014)
Well 3	*E. coli, Klebsiella aerogenes, Salmonella typhi,*	
Well 4	*E. coli¸ Klebsiella aerogenes, Salmonella typhi, P. aeruginosa*	*Klebsiella aerogenes:* Implicated to diseases such as Pneumonia, septicemia, spondylitis, and ankylosing (Ayandele *et al.*, 2020).
Well 5	*E. coli, Staph. aureus, Klebsiella aerogenes, Salmonella typhi, Enterococcus faecalis, Shigella flexneri*	*Bacillus subtilis:* Causes allergic reactions in persons with repeated exposure, food poisoning, bacteremia, endocarditis, pneumonia, and septicemia (Edberg, 1991; Logan, 1988).
Borehole 1	*E. coli, P. aeruginosa*	*Salmonella typhi:* Causes food-borne acute gastroenteritis, enterocolitis, invasive bacteraemia, typhoid fever (Dekker & Frank, 2015; Sanderson *et al*., 2015)
Borehole 2	*E. coli, Klebsiella aerogenes, P. aeruginosa*	
Borehole 3	*E. coli, Pseudomonas aeruginosa, Klebsiella aerogenes*	
Borehole 4	*E. coli¸ P. aeruginosa, Salmonella typhi, Bacillus subtilis*	*Shigella flexneri:* Shigellosis, dysentery, bacteremia and other extraintestinal infections (Appannanavar *et al.*, 2014; Dekker & Frank, 2015).
Rain 1	*E. coli, Pseudomonas aeruginosa, Enterococcus faecalis*	*Enterococcus faecalis:* Associated with Nosocomial infections like catheter-related urinary tract infections, bacteremia, endocarditis, neonatal sepsis, surgical and burn wound infections, and more rarely meningitis (Dubin & Pamer, 2017; Ramos *et al*., 2020)
Rain 2	*Klebsiella aerogenes, E. coli, Staph. aureus*	
Rain 3	*E. coli, P. aeruginosa, Enterococcus faecalis,*	*Staphycoccus aureus.* It commonly leads to abscess formation and causes skin infections like Scalded skin syndrome, folliculitis, furuncle, carbuncle, impetigo and Toxic shock syndrome. Sometimes cause pneumonia, endocarditis, bacteremia & osteomyelitis. Some elaborate strains produce toxins that cause gastroenteritis, and Staphylococcal food poisoning (Struelens, 1998, Ghalehnoo, 2018)
Rain 4	*Salmonella typhi, E. coli, P. aeruginosa*	
Rain 5	*E. coli, Klebsiella aerogenes, Salmonella typhi, Enterococcus faecalis*	

KEY: E - *Escherichia*, P - *Pseudomonas*, Staph - *Staphylococcus*.

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Physicochemical Characteristics of Water Sources

The mean results for the physicochemical parameters like pH, Turbidity, Total Suspended Solids (TSS), Total Dissolved solids (TDS), Total Hardness, Nitrates, Phosphate, Sulphate, Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) are presented in Table 3 (a, b, c & d). The sum of 2 tap water samples, 3 boreholes, and 4 each of rain and well water sources were tabulated with the various means. The mean values for all the physicochemical parameters assessed from tap water [Table 3(a)] were all within the WHO permissible limits, apart from the TSS (0.09), which was above the WHO standard. Other parameters tested from well water [Table 3(b)] had mean values that were within the WHO standard limits aside TSS (0.25) and BOD (10.5). From the mean values obtained from borehole water sources in Table 3(c), only TSS, Nitrates and Phosphates values (0.02, 150 and 5.7) were above the WHO permissible limits. And finally, mean values, observed from rain water sources in Table 3(d), show most physicochemical measurements falling within the WHO standard limits, apart from those obtained for TSS and Nitrates which were 0.20 and 65.5 respectively.

Table 3(a): Physicochemical Characteristics of Tap (Pipe-borne) Water Sources

Water source	pH	T^0C	Turbidity (NTU)	TSS (mg/L)	TDS	TH	Nitrate (mg/L)	Phosphate	Sulphate	COD	BOD
Tap 1.	6.1	25.8	2.4	0.15	135	190	28.8	2.2	1.7	0.16	6.6
Tap 2.	6.3	27.2	2.6	0.03	261	150	48.4	2.8	2.3	0.14	5.8
Mean	**6.2**	**26.5**	**2.5**	**0.09**	**198**	**170**	**38.6**	**2.5**	**2.0**	**0.15**	**6.2**
Permissible limit	**6.5-8.5**	**25-30**	**5.0**	**0.01**	**<300**	**100-500**	**<50**	**1 - <5.0**	**250**	**30-350**	**6-10**

Table 3(b): Physicochemical Characteristics of Well Water Sources

Water source	pH	T^0C	Turbidity (NTU)	TSS (mg/L)	TDS	TH	Nitrate (mg/L)	Phosp-hate	Sulphate	COD	BOD
Well 1.	6.40	23.5	3.6	0.31	260	220	42.5	3.7	2.8	0,21	9.5
Well 2.	6.20	21.5	3.5	0.15	310	210	55.0	3.9	3.1	0.18	8.5
Well 3.	6.00	22.0	3.9	0.09	280	185	38.2	2.5	3.3	0.30	12.6
Well 4.	6.15	24.0	2.8	0.50	240	260	37.3	4.1	2.8	0.28	10.9
Well 5.	6.50	23.0	4.2	0.2	260	275	53.5	4.8	3.0	0.23	11.0
Mean	**6.25**	**22.8**	**3.6**	**0.25**	**270**	**230**	**45.3**	**3.8**	**3.0**	**0.24**	**10.5**
Permissible limit	**6.5-8.5**	**25-30**	**5.0**	**0.01**	**<300**	**100-500**	**<50**	**1 - <5.0**	**250**	**30-350**	**6-10**

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Table 3(c): Physicochemical Characteristics of Borehole Water Sources

Water source	pH	T^0C	Turbidity (NTU)	TSS (mg/L)	TDS	TH	Nitrate (mg/L)	Phosp-hate	Sulphate	COD	BOD
Borehole 1.	6.3	28.5	3.5	0.02	130	270	155	6.5	2.5	0.20	8.9
Borehole 2.	6.5	27.5	3.0	0.01	115	275	150	5.6	3.0	0.19	8.3
Borehole 3.	6.4	27.0	2.5	0.02	110	285	135	4.9	2.3	0.23	8.6
Borehole 4.	6.2	29	3.8	0.03	125	290	160	5.8	2.2	0.26	8.2
Mean	**6.35**	**28**	**3.2**	**0.02**	**120**	**280**	**150**	**5.7**	**2.5**	**0.22**	**8.5**
Permissible limit	**6.5-8.5**	**25-30**	**5.0**	**0.01**	**<300**	**100-500**	**<50**	**1 - <5.0**	**250**	**30-350**	**6-10**

Table 3(d): Physicochemical Characteristics of Rain Water Sources

Water source	pH	T^0C	Turbidity (NTU)	TSS (mg/L)	TDS	TH	Nitrate (mg/L)	Phosphate	Sulphate	COD	BOD
Rain 1.	6.3	24.9	4.0	0.10	200	175	65.0	4.2	4.95	0.20	7.2
Rain 2.	6.1	24.4	3.9	0.30	240	186	64.6	5.2	4.05	0.10	7.9
Rain 3.	6.5	25.0	3.6	0.20	225	195	66.2	4.3	5.50	0.16	7.0
Rain 4.	6.7	26.7	4.2	0.09	235	196	62.8	4.1	4.60	0.25	7.4
Rain 5.	6.8	26.5	4.3	0.31	250	198	68.9	4.7	4.90	0.29	8.0
Mean	**6.5**	**25.5**	**4.0**	**0.20**	**230**	**190**	**65.5**	**4.5**	**4.80**	**0.20**	**7.5**
Permissible limit	**6.5-8.5**	**25-30**	**5.0**	**0.01**	**<300**	**100-500**	**<50**	**1 - <5.0**	**250**	**30-350**	**6-10**

Statistical Analysis for the Physicochemical Parameters of Water Samples from Four Water Sources in Kaduna Vom, Jos South LGA, Plateau State

The summarized physicochemical parameters and statistical analysis of water samples from the four water sources in the locality (Table 4) showed rain water to have the highest pH of 6.50, Mean of 6.33±0.07 Standard error, 0.132 Standard Deviation, with the highest t-Test score value of 95.63, and a very significant p-value of 0.001 falling between a 95% close range Confidence Interval of 6.11-6.54. Borehole water source recorded the highest temperature of 28^0C with Mean of 26.95±0.59 Standard error, Standard Deviation of 1.173, a high t-Test score of 45.94, and a very significant p-value of 0.001 falling between a 95% close range confidence interval of 25.08-28.82. Various other parameters like Turbidity, TDS, Total Hardness, Phosphate, Sulphate and COD had high t-Test scores with a significant p-value at 95% close

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range confidence intervals, while well water had the highest TSS of 0.25 mg/L, with Mean value 0.14±0.05, SD 0.104, low t-Test score of 2.69 and a non-significant p-value of 0.075 (95% CI of -0.03-0.31). Other parameter like Nitrates and BOD also recorded low t-Test score values of 2.91 for Nitrates and 2.94. Nitrates had a Mean of 74.9±25.7 SE, SD 51.39, and non-significant p-value of 0.062 (95% CI wide range of -6.92-156.62), while BOD had a Mean of 6.13± 2.08 SE, a Standard deviation of 4.17 with a non-significant p-value of 0.060 (95% CI wide range of 0.50 to12.75) accordingly.

Table 4: Summarized Physicochemical Parameters and Statistical Analysis of Water from Four Sources in Kaduna Vom, Jos South LGA, Plateau State

Test Parameter (Unit)	Water source				WHO Limits	Total Mean ± SE	Standard Dev.	t-Test	p-value	95% Confidence Interval
	Borehole	***Tap***	***Rain***	***Well***						
pH	6.35	6.20	6.50	6.25	6.5-8.5	6.33±0.07	0.132	95.63	**0.001****	6.11- 6.54
Temperature (^{o}C)	28.0	26.5	25.5	27.80	25-30	26.95±0.59	1.173	45.94	**0.001****	25.08-28.82
Turbidity (NTU)	3.2	2.5	4.0	3.6	5.0	3.33±0.32	0.640	10.40	**0.002***	2.31-4.34
Total Suspended Solid (mg/L)	0.02	0.09	0.20	0.25	0.01	0.14±0.05	0.104	2.69	0.075	-0.03-0.31
Total Dissolved Solid (mg/L)	120	198	230	270	<300	204.5± 31.78	63.568	6.43	**0.008***	103.35-305.65
Total hardness (mg/L)	280	170	190	230	100-500	217.5±24.28	48.563	8.96	**0.003***	140.23-294.77
Nitrate (mg/L)	120.0	38.6	65.5	45.3	<50	74.9± 25.7	51.39	2.91	0.062	-6.92-156.62
Phosphate (mg/L)	5.70.	2.50	4.50	3.80	1 - <5.0	4.13±0.67	1.338	6.17	**0.009***	2.00-6.25
Sulphate (mg/L)	2.50	2.00	4.80	3.00	250	3.08± 0.61	1.220	5.04	**0.015***	1.13-5.02
Chemical Oxygen Demand (mg/L)	0.22	0.15	0.20	0.24	30-350	0.20±0.02	0.039	10.49	**0.002***	0.14-0 .26
Biological Oxygen Demand (mg/L)	4.80	2.20	5.50	12.00	6-10	6.13± 2.08	4.17	2.94	0.060	-0.50-12.75

***** *=Significant p-value*, *******Very significant p-value*

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DISCUSSION

The THB count obtained from water samples analyzed (Table 1) revealed the presence of various heterotrophic bacteria in all the water sources. According to the World Health Organization (WHO, 2002a), the heterotrophic bacterial limit in clean water should not exceed 100 CFU/mL. But as regards this study, the heterotrophic bacteria counts exceeded the WHO limits signifying that the water sources had high bacterial contamination, hence certified unfit for direct consumption. These THB count results ranged from $1.2x10^2$ in NVRI Tap water to $8.5x10^4$ CFU/ml in Anguwan Madugu Well. This outcome was in-tune with several research findings like the one from Plateau State's neighboring state of Kaduna, conducted by Adesakin *et al.* (2020) in Samaru, Zaria, others from within the state by Junaid and Agina (2014), Miner *et al.* (2015) and the most recent outcome in Jos South LGA in particular from the findings of Anthonia *et al.* (2023). This rampant water contamination can be attributed to poor dumping and unsanitary conditions that most times persist in rural Nigerian communities. Bacterial contamination can arise due to seepage and runoffs from waste and faecal materials, which happens mostly during the rainy season (Adesakin *et al.,* 2020) and this study was conducted at such a time. Contaminated water sources are mostly implicated in causing diseases like typhoid, diarrhoea, cholera, gastroenteritis, dysentery, urinary tract contagions etc. (Orji *et al.,* 2008; Nwidu *et al.,* 2008). Tap water recorded the least microbial contamination from the study location compared to other water sources, perhaps due to the prior treatment which such sources receive most times before distribution. This was closely related to the study by Jurbe *et al.* (2023) who reported such water as being the second least polluted water source for domestic use in Jos and environs. The presence of *Escherichia coli* being the most common faecal indicator of water sample contamination, as seen in the research findings, is a sign of the occurrence of other enteric agents (Petridis, 1998).

Well water sources, followed by rain water, had the most microbial contamination, possibly because hand dug wells serve as main water sources in rural areas and are more susceptible to pollution from dirty surroundings, as opined by Adesakin *et al.* (2020), or lack of proper well sanitary seals, use of unclean drawer containers and ropes, or non-hygienic practices done by people while fetching water from wells, as explained by the same outcome of Iduh's (2022) thesis work across the state, with the study location inclusive. Rain water was second to well water, probably as a result of the dirt that sometimes resides on housing roofs which can seep into the water when rain falls, or using unclean containers for water collection/storage, an activity employed by many rural dwellers most frequently to ameliorate water scarcity.

The most prominent bacteria isolated from the study's water sources *(E. coli)* implied a faecal contamination of all the water sources sampled in the research, possibly given the poor sanitary and hygienic conditions seen in the study area. The second bacteria to *E. coli* in the study being *Pseudomonas aeruginosa* was consistent with findings from the work of Igbeneghu and Lamikanra (2014) who also explained how the bacteria has been associated with resistance to most antimicrobial agents making infections difficult to treat. *Pseudomonas aeruginosa* has been found from studies to be dogged as a water establishment pollutant (Morais *et al.,* 1997). This organism, being an opportunistic pathogen, when ingested, can cause illness in immunosuppressed individuals, according to findings from the UK Environment Agency (2002). Other gram-negative bacteria like *Klebsiella aerogenes, Salmonella typhi* and *Shigella flexneri,* apart from gram positive *Enterococcus faecalis,* were all indicative of serious faecal contamination of water sources. These organisms are implicated in causing several diseases

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like Pneumonia, septicemia, salmonellosis, gastroenteritis, endocarditis, neonatal sepsis, surgical and burn wound infections, shigellosis, dysentery, etc. Many studies consistent with this research have revealed similar findings that reinforced the presence of all these organisms in various water sources in many parts of the state, alongside some related consequences, to cite a few (Miner *et al.,* 2015; Jurbe *et al.,* 2023; Anthonia *et al.,* 2023).

From the physicochemical viewpoint, the studies established that most of the parameters assessed were within the WHO stipulated limits aside from TSS and Nitrates which exceeded the normal range, though the TSS values recorded from this study were inconsistent with findings from the research conducted by Anthonia *et al.* (2023) in the same Jos South of Plateau State. This outcome on Nitrates, which is implicated in causing methemoglobinemia in under six months old infants, adverse pregnancy conditions like unprompted abortion, low birth weight, fetal losses, intrauterine growth impedance, congenital deformities, etc., as opined by Ward & Brender (2019), was consistent with the high levels they recorded which were higher than the WHO acceptable limits. They opined that the higher nitrate levels discovered from their research could be a result of nitrate leaching into the water table that could have occurred from factors related to the soil type, geology, rate of Nitrogen utilization by crops in the study location, style employed during fertilizer application, and rate of nitrate conversion by microbes in the area. Considering that more than 85% of the locality's residents engage in one type of farming or the other, especially crop farming, livestock rearing and lots of poultry farming, it is most probable that such Nitrates come from artificial fertilizers and manures (Ward & Brender, 2019) used by individuals staying in the locality. Another possible factor could come from the fact that the NVRI site in this locality where the study was conducted has many farms; hence, it makes the residents get lots of natural fertilizers for their farms, leading to high nitrates seeping into the water table. Although Anthonia *et al.* (2023) presumed that the relatively high nitrate figures could have been associated with sewage leaching from pit latrines, a rampant sanitary system that is in practice within the K/Vom locality and also due to the close proximity of wells and other water sources to waste dumps sites observed in the area. Study findings showed a relatively high TSS from some water sources in Calabar metropolis (Akubuenyi *et al.*, 2013). This was similar to that recorded in the study area and could be implicated to poor hygienic practices by residents in the area when fetching water, because of unclean fetching containers especially from hand dug wells and since most of them, as confirmed by Petridis (1998), lacked concrete linings and proper covering seals, hence the high TSS.

IMPLICATION TO RESEARCH AND PRACTICE

This study holds significant implications for research and practice in that it provides valuable insights into the water quality challenges faced by rural communities, particularly in developing countries like Nigeria. It highlights the prevalence of bacterial contamination, with *Escherichia coli* being a dominant organism, and identifies key physicochemical parameters that exceed recommended limits, such as Total Suspended Solids (TSS) and Nitrates. Researchers can use these findings as a basis for further investigation into the sources and causes of water pollution in similar settings, as well as exploring potential solutions to address these issues.

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In practice, the study underscores the urgent need for improved water management strategies and infrastructure in rural areas. The high levels of bacterial contamination observed in local water sources indicate a significant health risk for community members. Therefore, practical interventions such as implementing simple water treatment practices, promoting hygiene education, and upgrading water supply systems are essential to ensure access to safe and clean drinking water. By translating research findings into actionable measures, policymakers, public health officials, and community leaders can work together to safeguard the health and well-being of residents in rural communities.

CONCLUSION

The study reveals elevated Total Heterotrophic Bacteria (THB) counts in water sources, surpassing WHO limits, indicating high bacterial contamination and making the water unfit for direct consumption. *Escherichia coli* was the most prominent enterobacteria present in the five water sources, pointing to widespread faecal contamination. *Pseudomonas aeruginosa*, an antimicrobial-resistant bacterium, coexists, emphasizing an incidence of water pollution challenges. Other gram-negative bacteria like *Klebsiella aerogenes*, *Salmonella typhi* and *Shigella flexneri,* apart from gram positive bacteria like *Enterococcus faecalis*, further indicate severe faecal contamination, aligning with previous findings in the region. Most physicochemical parameters were generally within the WHO limits, except for Total Suspended Solids (TSS) and Nitrates, which surpass acceptable levels. Nitrate sources may stem from farming practices, non-sanitary activities regarding waste management and dump sites, and proximity to a veterinary institute, contributing to adverse health implications. The study underscores urgent intervention measures to address water quality issues in the area.

FUTURE RESEARCH

This research was carried out in a small locality within one of the five districts of Jos South LGA. Given the size of Vwang district, where the study site is situated, future research works, involving a broader sampling range within and possibly across the districts and the entire LGA, will be encouraged to provide more comprehensive data on the bacteriological and physicochemical parameters investigated in the study area. Also, performing future studies should involve determining additional physicochemical parameters like Conductivity, Odour, Colour, Dissolve Oxygen, and the presence of heavy metals like Iron, Lead, Zinc, Chromium, Cadmium and Arsenic, which were not assessed in this study due to financial constraints.

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