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Water quality index of selected borehole locations in Jos North LGA of Plateau State, Nigeria

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Abstract
Prevalence of water borne diseases is a public health concern. The study assessed the quality of selected borehole waters in Jos North for their potability. The physicochemical parameters were assessed in addition to chlorides, phosphates, nitrates, and sulphates, total solids, total dissolved solids, total suspended solids, total hardness, using standard methods. Atomic absorption spectrophotometry used for elemental analysis of samples for manganese, lead, cadmium, copper and zinc. microbial analysis was carried out to test for presence of anaerobic bacteria, coliforms, *Escherichia coli, Salmonella typhi*, yeast and mould, *Staphylococcus aureus* using the plate count method. Water Quality Index by Weighted Arithmetic Index Method. Results ranged from 22.19-56.22 mg/L (chlorides), 0.00-0.07 mg/L (phosphates), 0.11-0.19 mS/cm (conductivity), 141.40-169.40 mg/L (alkalinity) and 86.70-160 mg/L (TSS). Kyan Primary school had Mn 0.632 mg/L against 0.500mg/L recommended by WHO. Microbial analysis revealed that Kyan primary school had 1 cfu per 100 mL water for *E. coli*, *Salmonella typhi*, yeast and mould. This indicated faecal contamination. The WQI revealed Village hostel, Kyan Village, Gadabiu had values of 6.54, 19.41, 10.97 are potable, Government College, Angwan Jarawa, Kyan Primary school had 28.90, 61.50, 93.60 are potable, poor, very poor, not potable.

Keywords: Borehole water; Physicochemical; Microbial contamination; Water Quality Index; Jos North

INTRODUCTION

Fresh water is already a limiting resource in many parts of the world. In the next century, it will become even more limiting due to increased population, urbanization and climate change [1]. Water is essential for all forms of life and makes up to 50-95% of all plants and animals, and about 70% of the human body [2]. Being a universal solvent, water is a major source of infectious diseases. According to World Health Organization (WHO) 80% of human diseases are water borne. 3.1% deaths occur due to the unhygienic and poor quality of water [3]. Water supply is one of the fundamental requirements for human life and the quality of water drawn by households is an important aspect of domestic supplies that influences public health [4]. Contamination of water bodies has increasingly become an issue of serious environmental concern [5]. The Federal drinking water regulations define three distinct

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and separate sources of water. Surface water, Ground water, Ground water under the direct influence of surface water (GWUDISW) [6].

However, groundwater is susceptible to contamination if not properly protected from sources of contamination. The chemical, physical as well as microbiological quality of groundwater used for human consumption in developing countries is a significant, but neglected public health issue [7]. Potable water is an essential ingredient for good health and socio-economic development of man [8]. Borehole water become unsuitable for domestic use as a resource due contamination that makes it unfit for many purposes [9]. Most rural areas depend on boreholes or hand-dug wells for the water system. However, there is no guarantee about hygiene condition of this kind of water supply [10]. Many issues of ill health that affects humanity, especially in developing countries can be traced to lack of safe and wholesome water supply [11]. This research is aimed at assessing the quality of selected borehole waters in Jos North Local Government Area of Plateau State, in terms of their physicochemical and microbial properties as well the trace metal concentrations to ascertain, the safety and potability of the waters from these boreholes.

EXPERIMENTAL METHODS

Study area. The study was carried out in Jos North LGA of Plateau State, Nigeria, which lies in the coordinates 9.55^{o}N, 8.54^{o}E / 9.917^{0}N, 8.900^{0}E**.** Its headquarters is located in the city centre of Jos. It has an area of 291 Km^{2} and a population of 429,300 as at 2006 census. The parent rocks in this study area include basaltic, biotite-granites, alluvium, unconsolidated quaternary deposits and granite-gneiss on the Plateau [12]. Borehole points used in this study, at University of Jos Village hostel, Government College Jos, Gada-biu, Kyan Primary school, Angwan Jarawa and Kyan Village, were situated in students' residential areas, public residential areas and family residences respectively. This study was conducted from July 2019 to January 2020.

Collection of samples. The water samples from every borehole point were collected in the morning hours between 8: 00AM and 11: 00AM in sterilized polyethyleneterephthalate bottles and labelled as follows: Village hostel (B_{VH}), Government College Jos (B_{GC}), Kyan Village (B_{KV}), Kyan Primary school (B_{KP}), Angwan Jarawa (B_{AJ}), and Gadabiu (B_{GB}) respectively.

Measurement of temperature. This was done using a mercury-in-glass thermometer which has a temperature range in the scale of 0-100°C. The temperature of the samples was taken using a mercury-in-glass thermometer which has a temperature range in the scale of 0-100°C. After calibration, the thermometer probe was inserted into the water sample and allowed to equilibrate and the reading noted.

Measurement of pH. The pH of the water samples was measured by using a pH meter (digital pH meter Labtech; electrodes). The pH meter was calibrated with a standard solution of pH 7.0.

Measurement of water conductivity. The conductivity of the water samples were measured using a conductivity meter (Model HI86304 HANNA) which measure conductivity in the range of 0.00 to 19.99 mS/cm.

Taste and odour tests. The test was carried out immediately after samples were collected by a team of ten panellists. A clean Neisseleriser glass tube was filled with each water sample to the 50 mL mark. This was placed in the right-side compartment of the Nessleriser. In the left side compartment, which held glass disks at its ends was also placed glass tube filled with distilled water. The colour of the sample was matched with the colour of the tube containing the distilled water plus the calibrated coloured disk when viewed by looking toward a white surface. The

Taste/Odour Threshold Number (T/O TN) of each panellist used in the test procedure was used to calculate a geometric mean T/O TN. The geometric mean T/O TN was converted to a taste/odour dilution number (T/O DN). This conversion was carried out by subtracting 1 from the calculated value.

Colour test. A clean Neisseleriser glass tube was filled with each water sample to the 50 mL mark and placed in a colour comparator and the colours compared with that of distilled water using the calibrated colour disk viewed through a white surface.

Measurement of water chloride content. Determination of chloride ion concentration was carried out using Mohr's method [9]. The titration was done with silver titrate solution added to slowly to the water samples, which gave a white precipitate of silver chloride.

Measurement of water turbidity. Turbidity was determined by nephelometric method using the turbidimeter.

Measurement of water phosphate content. Phosphate content was determined using the Ammonium molybdate-Stannous Chloride method and the absorbance of the samples were read with a UV-VIS spectrophotometer at a wavelength of 650 nm.

Measurement of water alkalinity. To 50 mL of the sample, three drops of bromocresol green indicator was added and titrated with 0.01M sulphuric acid to pH 4.5 where a colour change from blue in base form to yellow in acid form was observed. At pH 4.5, the colour became green which disappears at endpoint to give a colourless solution. [13]

Measurement of water acidity. Water acidity was measured according to the APHA standard methods [14] for the examination of water and wastewater. In the method, Sodium hydroxide 0.02M was prepared by dissolving 0.8 g of sodium hydroxide in 100 mL of distilled water and made up to 1000 mL mark in a volumetric flask. To 50 mL of each water sample in a conical flask. 2-3 drops of methyl orange indicator solution were added. The burette was filled with 0.02M sodium hydroxide and titrated against the water sample until the colour of the solution changes to faint orange. About two drops of phenolphthalein indicator was added to the faint orange colour solution, and titration continued till faint pink colour develops in the solution indicating the end point of the titration.

Measurement of water total hardness. Water hardness was measured by Complexometric titration using EDTA as the chelating agent. In the procedure**,** Eriochrome black T (0.5%) indicator was prepared by dissolving 0.5 g of EBT in 100 mL of 80% ethyl alcohol. EDTA (0.01M) prepared by dissolving 3.72 g disodium salt of EDTA in distilled water and made up to 1000 mL mark. Ammonia buffer solution was prepared by dissolving 13.50 g of ammonium chloride in 114 mL of concentrated ammonium hydroxide and made up to 200 mL with distilled water. Water samples (50 mL) were taken in a conical flask, then added 1 mL of ammonia buffer and three drops of Eriochrome Black T indicator. The water samples turned red-wine in colour and the solution titrated against 0.01M EDTA solution until the red-wine colour turns steel blue indicating the end point of the titration, and titre value noted.

Measurement of water total dissolved solids (TDS). Water samples (50 mL) were stirred and filtered through Whatman filter paper (Whatman No 2). The filtrates were poured into a pre-weighed evaporating dish and evaporated to dryness at 105°C.

Measurement of water total suspended solids (TSS). To determine the TSS**,** Labelled filter papers were placed in a pyrex dish and dried in an oven at maintained 105°C, they were then transferred to a desiccator for cooling at room temperature and weighed. Pre-weighed filter papers were used to filter 50 **mL** of each sample. After filtration, the filter

papers plus the residues were placed in an oven set to 105°C and allowed to dry. The filter papers plus the residues were removed from the oven and placed in a desiccator to cool. On cooling, the filter paper plus residue were weighed.

Measurement of water total solids (TS). Water total solids was measured by weighing evaporating dishes and were placed in the oven maintained at 105°C to attain a constant weight, transferred into a desiccator for cooling before reweighing. The samples (50 mL) were pipetted into the evaporating dishes and evaporated to dryness in the oven maintained at 105°C, cooled and weighed.

Measurement of water sulphate content. Sulphate was determined by gravimetric method. Water samples 200 mL were taken in different beakers. Two drops of methyl red indicator and concentrated hydrochloric acid were added drop by drop to the beakers till the colour changes to pink. Two drops of concentrated hydrochloric acid was added in excess. The solution was heated till the volume reduced to 50 mL. Hot, 10% Barium Chloride solution was added to them with stirring until the formation of precipitate was complete. Two drops of Barium Chloride were added in excess. The precipitate (Barium tetraoxosulphate VI) was digested for about two hours. The resulting solution was filtered using ashless filter paper. The precipitate was washed several times with distilled water until the washings were free of chloride ions. After filtering, precipitate was transferred into a previously weighed crucibles and ignited at 800-900°C till all traces of filter paper were burnt. The crucibles were transferred into a desiccator, cooled and reweighed.

Measurement of water nitrate content. The nitrate content in the water samples were measured by the spectrophotometric method. Sodium salicylate (0.5%) was prepared by dissolving 0.5 g of the salt in 100 mL of distilled water. 1.0 M sodium hydroxide was prepared by dissolving 40g of the salt in 1000 mL of distilled water. 100 mg/L stock solution of potassium nitrate was prepared by dissolving 0.16 g potassium trioxonitrate (V) dried at a temperature of 105°C and dissolved in 1000 mL distilled water in volumetric flask. To determine nitrate, 10 mL of each water samples was mixed with 1 mL sodium salicylate and were evaporated in an evaporating dish and cooled. Concentrated tetraoxosulphate (VI) acid (1 mL) was added to dehumidify the residue and allowed to stand for 10 minutes then transferred to a 50 mL volumetric flask. Sodium hydroxide (7 mL) was added and after cooling at room temperature, the volume was made to 50 mL with distilled water. After 10 minutes, the absorbances of the solutions were measured at 520 nm against a blank prepared in the same way. Colorimeter was used to take absorbance of the solutions to give the concentration which were used to plot a calibration curve of absorbance against nitrate concentrations in the range of 0-15 mg/L.

Elemental analysis of water samples. The samples were acidified at the time of collection with 5 mL/L concentrated nitric acid. After being acidified, 100 mL of each sample was transferred into beakers to which 2 mL of concentrated nitric acid and 5 mL of concentrated hydrochloric acid were added. The samples were placed on a hot plate maintained at 95°C until the volumes were reduced to 15 mL. The beakers were removed, allowed to cool and walls washed down with deionized water. The solutions were filtered to remove silicates and other insoluble materials that could clog the nebulizer. The filtrate was adjusted to 100 mL with deionized water prior to Atomic Absorption Spectroscopy (AAS) analysis.

Microbial analysis of the water samples. The water samples were aseptically collected in 75 **mL** pre-sterilized and labelled polyethyleneterephthalate (PET) bottles which had been washed in hot water and detergent.

The PET bottles were thoroughly rinsed with hot water, followed by distilled water to make sure that detergent has been removed. The sample containers were then autoclaved at 100^{o}C for five minutes. Sodium thiosulfate was then placed in each of the sample bottles to neutralize chlorine present in the samples. These analyses were carried out within the first 24 hours upon collection of samples.

Determination of Total Plate Count (TPC). To determine the TPC, Water samples (1 mL) were pipetted into their respective petri dishes. 10 mL of melted and cooled plate count agar and nutrient agar were poured into each dish. The inoculums were mixed by swirling the plate three times clockwise; three times anticlockwise; and three times back and forth. They were then allowed to set in piles. The petri dishes were incubated in the incubator for 24 hours and 48 hours at 30^{o}C in an inverted position. They were removed, and the TPC were enumerated with the aid of a colony counter.

Determination of Coliforms. Water samples (1 mL) were added into the respective MacConkey broth with inverted Durham tube. These were incubated at 37°C for 24 hours. The presence of gas (in the Durham tube) and colour change indicated positive test for coliforms. To determine coliforms, 1 mL of each water sample was added into different sterile petri dishes. Molten MacConkey agar (10 mL) was poured into the different petri dishes. The plates were swirled to ensure samples were well mixed. The mixtures were allowed to solidify before incubating them at 37°C for 24 hours, after which the petri dishes were placed in the colony counter for coliform enumeration. Dark red ovoid shaped colonies and pink colonies were counted.

Determination of *Escherichia coli.* Water samples (1 mL) were added into one of the MacConkey broth inverted Durham tube and the Plate Count Enumeration Method was used as described in published source [14].

Determination of *Staphylococcus aureus.* About 150 g of Staphylococcus Medium No. 110 was suspended in 1000 mL of distilled water and brought to boil on a Bunsen burner to dissolve completely. The mixtures were then sterilized in an autoclave at 121°C for 15 minutes. One millitre of each of the water samples were pipetted into sterilized and labelled petri dishes in duplicates. 10 mL of the Staphylococcus Medium No. 110 was dispensed into each petri dish. The mixture was swirled for uniform distribution and then incubated at 37°C for 24 and 48 hours.

Determination of *Salmonella typhi.* The mixture of prepared S*almonella typhi* were heated gently with frequent agitation until the medium just begins to boil and simmer for 30 seconds to dissolve the agar. The mixture was cooled to 55°C and well mixed to disperse suspension. 1 mL of each water sample was pipetted into labelled and sterilized petri dishes in duplicates. 25 mL of bismuth agar medium was poured into each petri dish. The plates were inverted and placed in incubators at 37°C for 24 and 48 hours. Black 'rabbit eye' colonies of *Salmonella typhi* was observed with a colony counter.

Determination of yeast and mould. Malt extract agar (30 g) and 15 g of agar were dissolved in 1000 mL of distilled water and brought to boil. The mixture was dispensed into flasks and autoclaved for 15 minutes at 121°C. The water samples (1 mL) were pipetted into labelled sterile petri dish. The resulting mixtures were swirled for uniformity and then allowed to solidify. The petri dishes were inverted and placed in the incubator at 27°C for 24 and 48 hours. Smooth white yeast and fluffy cotton-like mould colonies were enumerated with the aid of a colony counter.

Determination of Water Quality Index (WQI). The Water Quality Index (WQI) was computed using Weighted Arithmetic Water Quality Index Method [15, 16]. This method classifies the water quality according to the

degree of purity by using the variables (pH, conductivity, turbidity, taste/odour, chlorides, phosphates, nitrates, sulphates, alkalinity, total hardness, TSS, TDS, TS) determined in the methods.

RESULTS AND DISCUSSION

The data in Table 1 showed that temperature of the water samples ranged from 23.00°C to 26.30°C compared to 28.49°C obtained by [1]. These are within the World Health Organization (WHO) permissible limit of 30^{o}C. Temperature affects both chemical and biological reactions in water. High temperature reduces the solubility of gases and amplifies taste and odour. High temperature increases metabolic activity of organisms which requires more oxygen and also decreases the solubility of oxygen thus increasing stress. Change in temperature occurs due to sunlight intensity, climate, industrial and domestic wastes [17].

All the water samples were within a pH of 6.5 to 7.0 except for borehole at B_{KP} and B_{GB} with pH of 7.02 and 7.09 respectively. These results are less acidic than the results (6.0-6.3) obtained by Musa et al at Maigatari town in Jigawa State [18]. This shows that the groundwater in the study area is generally neutral to slightly alkaline. The pH of drinking water has no immediate direct effects on human health but has some indirect health effects by bringing changes in other water quality parameters such as solubility of metals and survival of pathogens [18]. WHO recommends a 6.5-8.5 pH value for drinking water.

The measured conductivity values for all drinking water are shown in Table 1. The results showed that the measured conductivity of all water samples ranged from 0.11mS/cm to 0.19 mS/cm, with the highest recorded at B_{VH} and lowest at B_{KV}. Musa et al, [18] obtained higher values of 0.4 - 1.0 mS/cm The electrical conductivity is the ability of any medium, in this case water, to carry an electric current [19]. WHO stipulates a conductivity level of 0.4 mS/cm for drinking water.

All the water samples showed a taste/odour number of 1,0 indicating less contamination by foreign matters. Environmental Protection Agency [20] permissible taste/odour threshold number is 0.1mg/l. According to WHO [21], the permissible value of chlorides in drinking water is 250 mg/L.

The current analysis revealed that all the samples of water from the various boreholes have chloride ranging from 22.19 mg/L to 56.22 mg/L which are within WHO permissible range for chlorides in drinking water. WHO recommended value for colour in drinking water is five Hazen units (Hz). In the present study, B_{KP} had the highest colour with a value of 3Hazen units, although all the measured samples were within the WHO stipulated value for colour in drinking water.

In this study, turbidity was highest in borehole points B_{KV} (1.08) and B_{KP} (1.08). The turbidity of all the sampled waters falls within the WHO recommended value of 5 Nephelometric Turbidity Units. The turbidity in water refers to loss of transparency caused by the presence of clay, organic matter, microscopic organisms and other particulate matters [22]. There is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of disinfectants [23].

The phosphate levels for the water samples B_{VH}, $B_{GC,}$ B_{KV}, B_{KP}, B_{AJ}, and B_{GB} were 0.00, 0.07, 0.03, 0.03, 0.07 and 0.03 mg/L respectively, with B_{VH} having the least value while B_{GC} and B_{AJ} having the highest values. The phosphate levels in the water samples are similar to the range 0.018 and 0.5878 mg/L as reported by Behailu et al [24].

In this study alkalinity with phenolphthalein indicator and alkalinity with bromocresol indicator (total alkalinity) were determined and the results showed that the total alkalinity of the water samples ranged

from 141.40 to 169.40 mg/L. In this study alkalinity with phenolphthalein indicator and alkalinity with bromocresol indicator (total alkalinity) were determined and the results showed that the total alkalinity of the water samples ranged from 141.40 to 169.40mg/L. Alkalinity of water is its acid neutralizing capacity. The alkalinity of groundwater is mainly due to carbonates and bicarbonates [25]. The acceptable limit of alkalinity is 200 mg/L and in the absence of alternate water source, alkalinity up to 600 mg/L is acceptable for drinking. The total alkalinity content in all samples were found to be within WHO permissible alkalinity level. Acidity is the measure of acids in a solution. The acidity of water is its quantitative capacity to neutralize a strong base to a selected pH level.

Acids can influence many processes such as corrosion, chemical reactions and biological activities. Carbon dioxide from the atmosphere or from the respiration of aquatic organisms causes acidity when dissolved in water by forming carbonic acid [26]. In this study, borehole point B_{GC} show the highest level of acidity with a value of 199.40 while borehole point B_{KV} had the minimum value of 164.60mg/L

Hardness is one of the very important properties of ground water from a utility point of view for different purposes. In groundwater, hardness is mainly contributed by bicarbonates, carbonates, sulphates and chlorides of calcium and magnesium. Principally, hardness is caused by calcium and magnesium ions [15]. WHO standard given for hardness in drinking water is 500 mg/L. The samples total hardness in the ranged from 80mg/L to 122 mg/L. All the measured samples were in the recommended range of WHO.

According to WHO [27], the palatability of water with a TDS level of less than 600 mg/L is generally considered to be good. TDS is an indicator for the general water quality because it directly affects the aesthetic value of the water by increasing turbidity. High concentrations of TDS limit the suitability of water for drinking source and irrigation supply. The measured TDS values were found to be in the ranged of 60.00 mg/L and 140.00 mg/L. The results are within the WHO recommended guidelines for drinking water. This indicates that no palatability problem is associated with the TDS of the studied water samples.

The measured values for TSS in the water samples were in the range of 13.30 mg/L to 23.30 mg/L, which are all within the permissible limits ($\leq$ 30 mg/L) of WHO. The sum of total suspended solids (TSS) and total dissolved solids (TDS) gives a measure of the total solids in drinking water [27]. In this study, total solid was highest at borehole point B_{GB} and lowest at borehole point B_{VH} with values of 160.00 mg/L and 86.70 mg/L respectively. Due to high value of sulphate in drinking water, people can come down with diarrhoea and dehydration. Infants are found to be more sensitive to sulphates than adults. Cathartic effects have been reported to be severe with people consuming drinking water containing sulphates in concentrations exceeding 600 mg/L [28]. The WHO permissible level of phosphates in drinking water is 200 mg/L. In this study the level of sulphate ranged from 3.00 mg/L to 6.50 mg/L, and falls within the stipulated value by WHO. Nitrate anions are found in natural water as the result of bacteriological oxidation of nitrogenous materials in soil. That is why the concentration of these anions rapidly increases in summer when the process of the nitrification takes place very intensely [29]. In the present study, concentration of nitrate was highest in borehole point B_{VH} (2.79 mg/L) and lowest in borehole point B_{AJ} (1.02 mg/L). However, all the water samples show nitrate concentration falling within WHO recommended value.

Results in Table 2 revealed that Borehole point at Kyan Primary school (B_{KP}) had the highest concentration of Manganese as indicated by its peak on the table. Mn was

below the detectable limit of the instrument at Borehole point at Government College Jos (B_{GC}), Angwan Jarawa (B_{AJ}), and Gada-Biu (B_{GB}). High lead content in drinking water causes skin damage, circulatory system problems and increased risk of cancer [22]. Table 2 showed that B_{KP} had the highest lead content followed by B_{GC} and B_{GB} respectively. Lead was not detected at B_{KV} and B_{AJ}. Cadmium and Zinc were not detected in all the water samples, possibly because their values were below detectable limit of the instrument used. Table 2 showed that all the borehole points had Copper. B_{KV} had the least Copper content while B_{AJ} and B_{VH} had the highest. Although all the measured values indicated that all samples had their Copper content falling within WHO permissible limit. Results have indicated that the concentrations of trace metals examined were not higher than permissible values by WHO except for borehole point at Kyan Primary school (B_{KP}). This result indicates that the borehole water at these locations are potable and fit for human consumption because they have significantly less inputs from anthropogenic sources.

The microbial pathogens determined in the water samples B_{VH}, B_{GC}, B_{KV}, B_{KP}, B_{AJ}, and B_{GB} are Coliform, *E. coli, Staphylococcus aureus, Salmonella typhi,* yeast and moulds. WHO stipulated standard values for Coliform, *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella typhi* as 0cfu/100 mL water. Accordingly, as seen in Table 3, all the bacteriological parameters analysed in the water samples were within this value except for Borehole point Kyan Primary school (B_{KP}) whose value was 1cfu/100 mL water.

Table 1: Physico-chemical parameters in borehole water samples at study locations

Parameters	Locations					
	B_{VH}	B_{GC}	B_{KV}	B_{KP}	B_{AJ}	B_{GB}
Temp (°C)	24.30±0.58	23.00±0.03	24.00±.02	25.30±0.58	26.30±0.58	25.00±0.01
pH	6.91±0.01	6.95±0.01	6.81 ± 0.01	7.02±0.01	6.73±0.01	7.09 ± 0.01
Conductivity (mS/cm)	0.19 ± 0.01	0.13± 0.01	0.11 ± 0.01	0.17 ± 0.01	0.12 ± 0.01	0.14 ± 0.01
Taste and odour	1.0±0.00	1.0±0.00	1.0±0.00	1.0±0.00	1.0±0.00	1.0±0.00
Colour (Hz)	1.00±0.00	1.00±0.00	2.00±0.00	3.00±0.00	2.00±0.00	1.00±0.00
Turbidity (NTU)	1.07±0.03	0.86±0.03	1.08±0.01	1.08±0.02	1.04±0.01	1.00±0.01
Alkalinity (mg/L)	141.40±0.25	151.40±0.13	156.00±0.00	164.60±0.01	169.40±0.25	194.60±0.00
Mineral Acidity (mg/L)	190.60±0.01	199.40±0.02	164.60±0.01	171.40±0.03	196.60±0.02	178.60±0.05
Total Hardness (mg/L)	122.60±0.00	80.60±0.02	100.60±0.02	110.60±0.03	92.60±0.04	116.60±0.02
TDS (mg/L)	60.00±20.00	80.00±20.00	100.00±20.00	113.00±11.55	100.00±0.00	140.00±20.00
TSS (mg/L)	23.30 ± 5.77	13.30 ± 5.77	23.30 ± 11.55	16.70 ± 5.77	20.00±0.00	16.70±11.55
TS (mg/L)	86.70±11.55	80.60±0.40	100.60±0.25	133.30±11.55	113.30±24.48	160.00±20.00

Table 1 continued

Parameters	Comparable standards		
	WHO 2011	Indian Standard 2012	EPA 2018
Temp (°C)	30.00	-	-
pH	6.50-8.50	6.50-8.50	6.50-8.50
Conductivity (mS/cm)	0.4	-	-
Taste and odour	-	-	3
Colour (Hz)	5	5 – 15	15
Turbidity (NTU)	5	1	5
Alkalinity (mg/L)	200	200	
Mineral Acidity (mg/L)	-	-	-
Total Hardness (mg/L)	500	200	-
TDS (mg/L)	300		500
TSS (mg/L)	-	100	-
TS (mg/L)	-	-	-

B_{VH} = University of Jos Students Village, B_{GC} = Government College, B_{KV} = Kyan village, BDL = Below Detectable Limit, B_{KP} = Kyan Primary school, B_{AJ} = Angwan Jarawa, B_{GB} = Gadabiu

Table 2: Anions and elemental content of borehole water samples in study locations

Parameters	Locations					
	B_{VH}	B_{GC}	B_{KV}	B_{KP}	B_{AJ}	B_{GB}
Chlorides	42.04±0.01	28.10±0.00	22.19±0.11	43.04±0.02	25.03±0.01	56.22±0.02
Phosphates	0.00±0.00	0.07±0.01	0.03±0.01	0.03±0.02	0.07±0.01	0.03±0.00
Sulphates	5.00±0.25	4.50±0.35	6.00±0.20	3.00±0.01	6.50±0.02	6.50±0.03
Nitrates	2.79±0.02	1.43±0.01	1.70±0.03	1.53±0.05	1.02±0.02	2.04±0.01
Mn	0.014±0.005	BDL	0.023±0.041	0.632± .008	BDL	BDL
Pb	0.003± 0.001	0.041±0.001	BDL	0.073±0.019	BDL	0.037±0.007
Cd	BDL	BDL	BDL	BDL	BDL	BDL
Cu	0.040±0.016	0.026±0.021	0.003±0.001	0.037±0.003	0.041±0.026	0.018 ± 0.010
Zn	BDL	BDL	BDL	BDL	BDL	BDL

Table 2 continued

Parameters	Comparable standards		
	WHO 2011	Indian Standard 2012	EPA 2018
Chlorides	250	250 - 1000	250
Phosphates	-	-	-
Sulphates	200	250	250
Nitrates	50	45	10
Mn	0.500	-	-
Pb	0.100	-	-
Cd	0.030	-	-
Cu	2.000	-	-
Zn	3.000	-	-

B_{VH} = University of Jos Students Village, B_{GC} = Government College, B_{KV} = Kyan village, BDL = Below Detectable Limit, B_{KP} = Kyan Primary school, B_{AJ} = Angwan Jarawa, B_{GB} = Gadabi

Table 3: Microbial analysis of borehole water samples from study locations

Parameters	Locations						Comparable standard
	B_{VH}	B_{GC}	B_{KV}	B_{KP}	B_{AJ}	B_{GB}	WHO
TPC (Cfu/ml)	12	10	5	13	8	6	-
Coliform (Cfu/ml)	0	0	0	0	0	0	0Cfu/100ml
Escherichia coli (Cfu/ml)	0	0	0	1	0	0	0Cfu/100ml
*Staphylococcus. aureu*s (Cfu/ml)	0	1	0	0	0	0	0Cfu/100ml
Salmonella typhi (Cfu/ml)	1	0	0	1	0	0	0Cfu/100ml
Yeast and Mould (Cfu/ml)	1	1	0	1	0	0	-

B_{VH} = University of Jos Students Village, B_{GC} = Government College, B_{KV} = Kyan village, B_{KP} = Kyan Primary school, B_{AJ} = Angwan Jarawa, B_{GB} = Gadabiu

Table 4: Water Quality Index rating borehole water samples at study locations

Borehole location	Numerical Value	Rating	WQI [30]	Rating of Water Quality
B_{VH}	6.54	Excellent	0-25	Excellent
B_{GC}	28.90	Good	26-50	Good
B_{KV}	19.41	Excellent	51-75	Poor
B_{KP}	93.60	Very Poor	76-100	Very poor
B_{AJ}	61.50	Poor	Above 100	Unsuitable for Drinking
B_{GB}	10.97	Excellent	-	-

B_{VH} = University of Jos Students Village, B_{GC} = Government College, B_{KV} = Kyan village, B_{KP} = Kyan Primary school, B_{AJ} = Angwan Jarawa, B_{GB} = Gadabiu

This is less than the results in a published report [30] from Tube well's water samples collected from Peshawar city, (India) which were analysed for Coliform, Faecal coliform and *Escherichia coli*, tube well's water samples contained coliform population in the range of 2.2-16 MPN/100 mL. A positive test for *Escherichia coli* in hand pump water supply from water vendors has also been reported [31]. The most likely cause of this

should be a close proximity of the soak away system to the borehole point. This water therefore is not suitable for drinking and will need treatment or boiling before usage to avoid diseases like cholera, typhoid as well as other water borne diseases.

Results in Table 4 show that borehole water at Village Hostel; B_{VH}, Kyan Village, B_{KV}, and Gada-Biu; B_{GB}, (WQI < 25) were considered excellent in quality and are considered potable and safe for drinking. Borehole point at Government College Jos, B_{GC}, have good quality (WQI, 28.90) and considered good and potable drinking water. B_{AJ} and B_{KP} had the rating in WQI as poor and very poor respectively and are considered not potable and not safe for drinking. Table 4 showed that of all the water sampled in the different boreholes, B_{VH} (WQI, 6.54) had the best water quality and hence the most potable and suitable for drinking. While B_{KP} had the largest WQI value, and is most unsuitable and not potable for consumption without treatment or boiling.

The high value of WQI have been attributed mainly to higher value of *Escherichia coli, Salmonella typhi* and manganese in the water samples. This could be linked to improper disposal of wastes, cottage activities, large quantity of agricultural and urban run-off, sewage, over application of inorganic fertilizer, improper operation and maintenance of septic system [32].

This research has provided useful information on the potability and suitability of borehole waters in Jos North which used the Weighted Arithmetic Water Quality Index a friendly guide in determining the quality of drinking water of any origin or source. The weighted arithmetic water quality index method is a modified form of Horton's formula [33], created by Brown et al [34]. This method has been used to assess or classify the quality of water type, and it is effective for determining the regional and physical variance in groundwater conditions and providing knowledge on water quality to concerned locals and policymakers [35]. According to the WQI values (see Table 4), the borehole sites at Village hostel (B_{VH}), Kyan village (B_{KV}), Gadabiu (B_{GB}) have excellent water quality, followed by Government college (B_{GC}) with good quality water, Angwan Jarawa (B_{AJ}) have poor quality water and Kyan Primary school (B_{KP}) have very poor-quality water. Borehole water at four locations are potable while the other two are not potable and will therefore need treatment before drinking.

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