SEASONAL VARIATION IN THE BACTERIOLOGICAL AND PHYSICOCHEMICAL PROPERTIES OF WELL WATER IN MINNA TOWN, NIGERIA

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ABSTRACT

Frequent flooding, poorly managed solid waste and other physicochemical contaminants have exacerbated surface and groundwater contamination within Minna town and environs. These have continued to sustain the endemic threat to public health in the town and the State. Bacteriological and physicochemical studies of 72 well water samples were carried out over two successive dry and wet seasons in Minna town. Membrane filtration technique, Cultural and Biochemical tests were used for Bacteriological analysis while the methods of the American Public Health Association (APHA) were used for the physicochemical analysis. One way Analysis of Variance (ANOVA), and Pearson Correlation statistics were used to analyze all data generated. Bacterial counts of well samples tested were all above the limits specified by the Nigerian Standards for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO). Mean total heterotrophic counts (THC) and feacal coliform counts (FCC) for the two successive wet seasons were significantly higher ($P<0.05$) than the values obtained for the dry seasons. All physicochemical parameters recorded significantly higher values($P<0.05$) in the wet seasons compared to the dry seasons, except Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS) and Total Alkalinity- as $CaC0_3$ ($TTA-C0_3$). Mean dry season THC of well samples showed strong negative and positive correlations ($P<0.01$) with respect to only a fraction of the 13 physicochemical parameters tested. The most frequently occurring bacterial isolates for the dry and wet seasons were Streptococcus faecalis (24.6% and 20.9% respectively) and Salmonell aparatyphi (22.1% and 14.7% respectively), while Klebsiell apneumoniae, Shigella dysenteriae and Bacillussubtilis recorded frequencies of 0.7% , 0.9% and 1.5% respectively. Periodic sanitary surveillance and proper siting of wells should help mitigate groundwater contamination in Minna and environs of Niger State.

KEYWORDS: *Physicochemical Parameters, Coliforms, Correlation.*

INTRODUCTION

Water plays a vital role in the life of humans, animals and microorganisms, but water related diseases continue to be one of the major health problems globally. Adetunde, *et al* (2011) report that many water resources in developing countries are unhealthy because they contain harmful physical, chemical and biological agents. The World Health Organization (2004) points out that diseases related to contamination of drinking water constitute a major burden on human health and interventions to improve the quality of drinking water would provide significant benefits to health.

Adelana, *et al* (2002) believes that the assessment of drinking water quality should be an essential element in the evaluation of a country's water resources. This, according to the authors has proven to be a key element in advancing economic and social development, thus eliminating a number of debilitating diseases.

In Africa alone, 54 percent of the 1994 total estimated population of 707million have no access to safe drinking water (Adelana, *et al,* 2002). UNICEF/WHO (2012), puts the number at 2.6 billion worldwide, with Africa alone accounting for 585million. In Nigeria, more than 80% of the population have no access to safe drinking water (Ince, *et al*, 2010).Many of the organisms that cause serious disease, such as typhoid fever, cholera and dysentery are directly traceable to polluted drinking water. These organisms are discharged along with faecal wastes, and are difficult to detect in water supplies (Cabral, 2010).

The microbiological and physicochemical study of the sanitary quality of drinking water has become necessary because of the increasing demand for potable water supply for domestic and commercial purposes nationwide. Shrestha and Kazama (2007) point to the effective, long-term management of groundwaters as requiring a fundamental understanding of hydro-morphological, chemical and biological characteristics.

The weather, always a challenge to predict, has also played a significant historical role in triggering a number of reported waterborne disease events worldwide and is currently undergoing significant alterations from historical patterns due to climate change (Schuster *et al*, 2001). The potential water – related health implications of pronounced climate change is yet to be fully appreciated.

MATERIALS AND METHOD

Location and Description of Study Area

Minna (and itssatellite towns) is situated within Minna Local government Council and located roughly within longitude 6^0 33E and latitude 9^0 37N, and cover an estimated land area of more than 88km^2 with a population of about 202,000 (NPC, 2006)The wells are all located within the basement complex, with a depth range of 3.0 to 7.0 m.Minna has a tropical climate with mean temperature of 30.2^{o}C, relative humidity of 61.0% and mean rainfall of 1334mm. The climate presents two distinct seasons; a rainy season that lasts between April and October and a dry season that lasts between November and March of the following year.

Collection and Analysis of Samples:

72well samples were collected between 10.00a.m and 3.00 p.m over a period of 24 months (spanning two dry and wet seasons). The samples were divided into 250.0 ml and 500.0ml amounts in glass and plastic bottles for bacteriological and physiochemical analysis respectively. Cluster sampling technique was the method of sampling used, according to the Rapid Assessment of Drinking Water Quality (RADWQ) survey protocol of Howard, *et al*

(2003) and as modified by Ince, *et al* (2010).

Bacteriological Analysis

Bacterial counts were carried out to determine Total Heterotrophic Counts (THC) as well as Total Coliform and Faecal Coliform Counts (TCC and FCC): THC was determined by the Pour Plate method, while TCC and FCC were determined by the Membrane Filtration method, using Membrane Lauryl Sulphate Broth (MLSB) medium (APHA, 2005).

Morphological and biochemical tests were carried out for the identification of bacterial isolates by comparing their characteristics with those of known taxa, according to Cowan and Steel (1974). Biochemical tests included Gram staining, motility, catalase, urease production, methyl red, Voges Proskauer, H_2S production, coagulase, starch hydrolysis, oxidase and indole tests, lactose and citrate utilization, mannitol, sucrose and glucose tests.

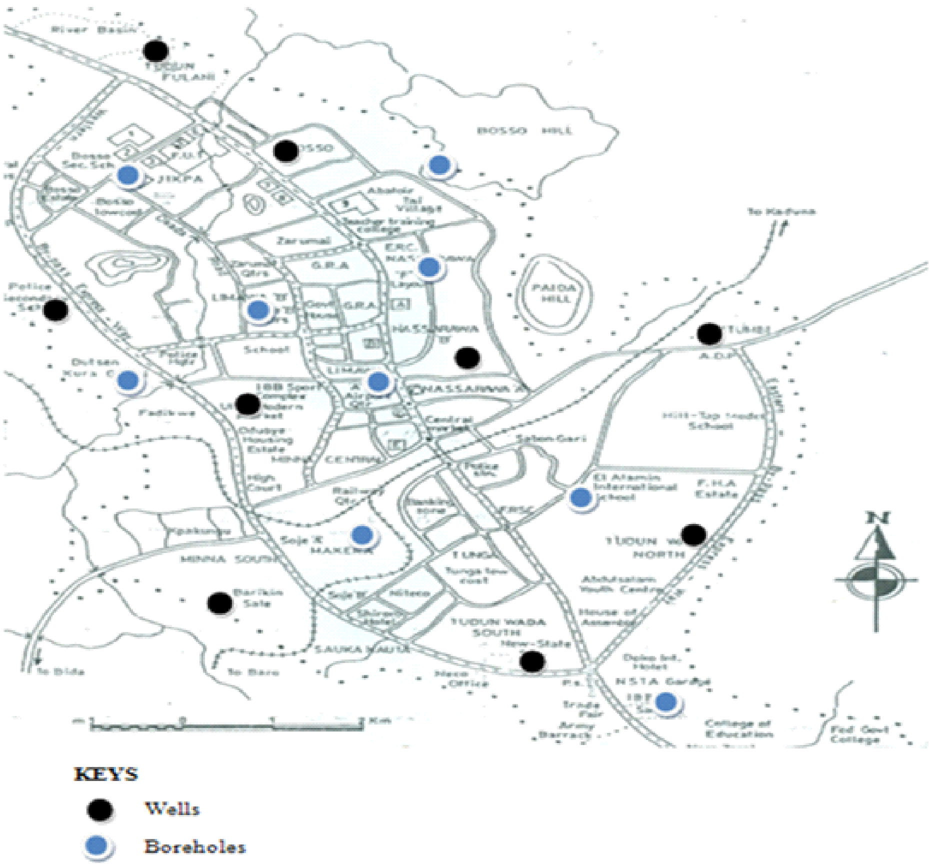

Figure .Minna and the Satellite Towns of Bosso and Maitumbi

Physicochemical Analysis of Water Samples

Physicochemical analyses were carried out on well samples according to the methods of the American Public Health Association (APHA, 2005). Total hardness (mg/l), total alkalinityas well as Magnesium and Calcium hardness (mg/l) were determined by titrimetric method while gravimetric method was used to determine total dissolved and total suspended solids (mg/l). Electrical conductivity (uS/cm) was measured by conductivity meter, while ferrous ironwas determined by atomic absorption spectrophotometry. Dissolved oxygen (mg/l) was determined by the Winkler's test, while Turbidity (mg/l), nitrite and sulphate (mg/l) were determined by UV spectrophotometry.

Statistical Analysis of Data

Data generated were subjected to statistical analysis, using one wayanalysis of Variance

(ANOVA) for the treatments.Probability level was maintained at 0.05 (i.e 95% confidence limits) and used for the test of significance of variations between the study areas and the months of each study year. Percentage data was transformed by arc sin transformation according to Zar (1984). Relatedness established were thereafter correlated using Pearson correlation (at 99% and 95% confidence limits) to determine the effect of the physicochemical parameters on the THC, using computer packages SPSS version 11.0 and Minitab Release 14.

RESULTS AND DISCUSSION

The twenty four month assessment of well water in Minna revealed that the groundwater source harbour diverse bacterial contaminants. The bacterial load recorded counts well above the levels recommended by the Nigerian Standards for Drinking Water Quality (NSDWQ, 2010) and the World Health Organization (WHO, 2012). Mean THC for both dry and wet seasons were much higher than the mean FCC and TCC (Table 1). The generally high bacterial counts could be attributed to the open nature of most of the wells and the improper communal and individual hygiene of the residents in the study area. These results are supported by the findings of Muhammad (2012) who reported high bacterial load in well water in the low-income high density areas of Kaduna metropolis.

However, mean THC and FCC for the wet seasons was significantly higher ($p < 0.05$) than the values recorded for the dry seasons. The differences observed in the mean TCC for both seasons were however not significant. The variations observed in the THC and FCC could be attributed to the fact that groundwater resource is subject to large seasonal variations in physical and biological characteristics. The observation is supported by the findings of Shridha (2009) as well as Adekunle, *et al* (2007) who reported significant changes in total heterotrophic bacterial counts between the dry and wet seasons in Nigeria. The higher wet season coliform counts could also be attributed to the higher temperatures and effluent discharges which characterizes the season as well as stormwater runoffs that could have gained entry into the water body through cracks or crevices. This assertion is supported by the findings of Abdo, *et al* (2010) who reported higher coliform counts in the Ismailia canal of the River Nile in Egypt during the wet season which witnessed a reduction towards the period preceding the dry season.

Table 1. Mean Variation of Bacterial Count of Well Water for two successive Dry and Wet Seasons.

Bacterial Count	Season	
	Dry	Wet
THC (cfu/ml)	$2001.43^{ab} \pm 348.06$	$2892.50^{a} \pm 409.49$
TCC (cfu/100ml	$38.53^{a} \pm 4.32$	$49.28^{a} \pm 4.00$
FCC (cfu/100ml	$6.36^{ab} \pm 0.73$	$14.33^{a} \pm 1.48$

Data on the same row carrying the same superscript do not differ significantly (P<0.05) from each other.
Values are ± Standard Error of Mean.

With the exception of Turbidity, all physicochemical parameters tested recorded higher concentrations for the wet seasons. However, only the differences between EC, Calcium Hardness, Magnesium Hardness,Ferrousiron, Dissolved Oxygen, Nitrite, Magnesium and Sulphate ions were significant ($p < 0.05$). With the exception of Turbidity, Total Hardness, nitrite and pH, all the parameters were either within the limits specified by NSDWQ (2007) or have no specified limits (Table 2). Correlations of THC with physicochemical parameters recorded werein most cases negatively highly significant ($P < 0.01$), particularly for the dry seasons, while others were either significant($P < 0.05$) or non-significant at both confidence limits (Table3).

Turbidity values obtained from the current study corroborates those of Abdo *etal*. (2010), Mahananda, *et al* (2010) as well as Adekunle, *et al* (2007) who reported similar observations. Although the NSDWQ (2007) attributes no direct health impact to consumption of turbid water, Abdo, *et al* (2010) point to the level of turbidity of a groundwater source as an indication of its degree of pollution. The higher turbidity observed during the dry season could be attributed to concentration build-up of suspended organic matter, soluble coloured organic compounds, planktons and other microscopic organisms. It could also be due to reduction in transparency due to the presence of particulate matter, which are observations supported by Efe, *et al* (2005) in a previous assessment of groundwater in the Niger Delta Region of Nigeria.

Correlation of mean turbidities with THC of well samples were highly significant ($P < 0.01$) which highlights the key role played by turbidity in the heavy bacterial pollution observed in the study area. Storm-water runoffs poor well maintenance and the sustained anthropogenic activities observed around the wells could cause entry of contaminant-laden debris, thereby resulting into the very high bacterial load encountered. Poor coverage of the wells or leaching of contaminants into the well water sources may be additional reasons responsible for the results obtained. The results largely agree with those of Muhammad (2012) and Adakole, *et al* (2010). The investigation by Yisa, *et al* (2012) also encountered high levels of turbidity in some well water sources in Doko Community of Suleja in Niger State. The dangers associated with high turbidity in ground water sources is related to the shielding capacity afforded bacteria by turbid particles, in addition to their ability to grow in anaerobic zones or soil micropores (Ishii and Sadowsky, 2008).Values for TSS were generally lower than the values obtained for water samples during the wet seasons. High TSS concentrations in ground waters could be attributed to turbidity due to silt and organic matter. It could also be an indication of the wide variations in the carbonates, bicarbonates, organic matter, and the different salts that TSS comprises. Elevated TSS concentrations recorded could also be attributed to heavy rainfall which according to Gimba (2011) may reach as high as 1335mm during the peak of the rainy season, an observation supported by Hong *etal*.(2010) as well as Liang, *et al* (2008) in their investigations of groundwater sources in the Pearl River Delta Region of China. However, the correlation of TSS with all bacterial parameters tested for both seasons were not significant ($p > 0.01$; $p > 0.05$).

High mean EC values obtained for well samples for both seasons from the study area, though within recommended limits, suggests the potential impact of contamination from external sources which could be due to location close to refuse dumps and defeacation sites. Both observations corroborate results from the investigations of Muhammad (2012) as well as Adekunle, *et al* (2007) on the groundwaters of Kaduna Metropolis in Kaduna State and Ogbomosho Township of Oyo State respectively. Higher wet season EC values could also be due to leaching of mineral salts from the bedrock surface run-offs, or resuspension of precipitated solids. However, high dry season mean EC values could be attributed to the low volume of water during the perioddue to increased evaporation that could cause an elevation in the concentration of ions originating from inorganic compounds. These assertions support the observations of Ojituku and Kolo (2011) in their assessment of River Chanchaga in Minna, Niger State.

Dry season THC of well samples appear to be strongly influenced by the electrical conductivities of the groundwater sources as shown by the significant positive ($P < 0.01$) correlations with the bacterial counts. The positive correlations of EC with the well samples may be indirect indications of the influence of other physicochemical parameters (such as turbidity, TSS and TDS) whose presence in groundwater are usually revealed by the levels of EC observed in the water sources. The report by Abdo, *et al* (2010) of the presence of high levels of inorganic contaminants in well waters (indicated by a high abundance of ions) supports findings from the current study.

The relatively high TDS values obtained could be attributed to the higher seasonally-influenced concentrations of metal ions during the dry season and the dilution effect associated with precipitation of the wet season. The high TDS concentration in the groundwaters may also be an indication of pollution. Although high TDS concentration in groundwater usually indicates pollution, groundwaters overlying calcite-rich bedrock could cause the release of carbonate and bicarbonate ions, which in solution could increase TDS in the groundwater source. Although high TDS concentrations in groundwater used for drinking have not been linked directly to any negative health effect (WHO, 2012) high TDS has been observed by Kouame, *et al*. (2012) to be a cause of decrease palatability of such groundwater sources and has been linked to gastro intestinal irritation, laxative effect and development of kidney stones in consumers Highly significant ($P < 0.01$) positive correlation of TDS with the THC of well water samples from Kontagora during the dry season suggests the strong influence of the TDS in the bacterial load recorded for well samples from the study area.

The higher wet season values ofTotal, magnesium and calcium hardnesss could be attributed to increased chemical dissolution (occasioned by high precipitation) and the lower values obtained, due to the strong dilution effect of rainfall. The results corroborates findings of Pritchard, *et al* (2006) from their assessment of groundwaters in several districts of Malawi but is at variance with the results recorded by Efe, *et al* (2005) in a study of well and borehole water sources in the Western Niger Delta Region of Nigeria.

The level of THC in the well samples appear to have been influenced by the TTH-CO_3 concentrations during the dry and wet seasons as shown by the significant correlations ($P < 0.01$) of TTH-CO_3 with THC.

The generally low concentrations of ferrous iron corroborates the results of Adetunde, *et al*. (2011) who recorded ferrous iron concentrations well below the limits recommended for drinking water quality from groundwater sources in Ogbomosho Township of Oyo State, Nigeria. The results also agree with the findings of Yisa, *et al*. (2012) who investigated groundwaters in Doko Community of Suleja in Niger State, Nigeria. The results are however at variance from those reported by Aremu, *et al*. (2011) from their assessment of well water sources in Kubwa, Bwari Area Council of the Federal Capital Territory, Abuja. The low ferrous iron concentrations could also be attributed to the probable absence of any build-up of dissolved iron under anaerobic conditions of the aquifer recharging the groundwater sources in the study areas (Idoko, 2010).The correlation of ferrous iron with the THC were however not significant ($P > 0.01$) ($P > 0.05$). The results indicate the probable presence of iron oxidizing bacteria in significant numbers among the bacterial population encountered in the samples during the wet and dry seasons.

The low levels of DO maybe due to increased levels of nutrients in the water sources or the concentration of dissolved and suspended solids present in the water. This assertion is supported by the findings of Muhammad (2012) on the studies of ground water sources in the densely populated parts of Kaduna metropolis. It could also have been due to the fact that most of the well water sources investigated were exposed to multiple sources of physical, biological and chemical contaminants of human and other animal origins. Ololade and Ajayi (2009) whose findings support the results from the current study attribute low DO content of groundwater to biological degradation of organic matter. Kumar, *et al* (2011) however attributes DO deficit in groundwater to higher deoxygenation rate during the period to biological decomposition compared to reoxygenation from the atmosphere or from the oxygen-demanding chemical and organic wastes in the groundwater source.

The significant negative correlation ($P < 0.01$) of DO with the THC of well samples during the dry seasons reflects the high bacterial load encountered in the well samples during the period. This highlights the probable role of high organic matter biodegradation (Ololade and Ajayi, 2009) or the increased nutrient levels of the water (Muhammad, 2012) during the dry seasons.

The higher concentrations of nitrite encountered during the wet seasons could be attributed to the disposal of municipal effluents by sludge and stormwater run-offs during and after rainfall episodes in addition to the location of well water sources close to pit latrines or soakaways. This assertion is supported by Eni, *et al*. (2013) who recorded higher nitrite concentrations in their investigation of groundwater sources in different parts of Calabar, Cross River State of Nigeria. High nitrite concentration could also be due to variation in phytoplankton excretion, oxidation of ammonia and reduction of nitrate to nitrites and by the recycling of nitrogen and bacterial decomposition of planktonic detritus in the environment.Excess nitrite in water above 10mg/l is a known cause of cyanosis and asphyxia (or blue-baby syndrome) in infants under 3 months (Gimba, 2011). Low concentrations of nitrite could be attributed to its relative instability and rapid conversion to nitrate. The results are corroborated by Adekunle, *et al* (2007) who recorded low nitrite concentrations of 0.06 mg/l from the groundwaters of some rural settlements inSouth Western Nigeria.

The highly significant positive correlation ($P < 0.01$) of nitrites with THC of well samples maybe an indication of high nitrite levels, possibly due to the effects of runoffs and deposition of nitrogenous wastes into the well sources. These observations are supported by the findings of Yisa, *et al*. (2012) on their studies of different groundwater sources in Doko Village of Suleja town, Niger State.

Levels of alkalinity observed in the well samples showed no significant variation between the wet and dry. However values obtained were similar to those recorded by Adetunde, *et al* (2011) and Yusuf (2007). The results are a probable indication of the relative presence of different levels of carbonates (CO_3^{2-}), bicarbonates (HCO_3^-) and hydroxyls (OH^-) in the water according to the reports of Faparusi, *et al* (2011).

Table 2. Mean Variation of Physicochemical Properties of Well Water for two successive Dry and Wet Seasons.

Parameter	Season		(mg/l)	
	Dry	Wet	NSDWQ Standard	WHO Standard
Turbidity (ftu)	30.63[a] ± 0.88	26.10[a] ± 1.24	5.00	NS
Total Suspended Solids (mg/l)	23.14[b] ± 1.42	25.30[b] ± 2.90	NS	NS
Electrical Conductivity (us/cm)	1262.28[a] ± 46.87	808.56[b] ± 53.47	1000	NS
Total dissolved Solids (mg/l)	455.33[c] ± 5.60	466.56[c] ± 6.49	500	NS
Total Hardness – as $CaCO_3$ (mg/l)	99.19[c] ± 5.18	205.79[b] ± 10.86	150	300
Calcium Hardness – as $CaCO_3$ (mg/l)	59.78[bc] ± 4.76	123.37[b] ± 9.05	NS	NS
Magnesium Hardness – as $CaCO_3$ (mg/l)	41.40[c] ± 2.74	83.02[b] ± 7.62	NS	NS
Ferrous Iron (mg/l)	0.20[a] ± 0.07	0.13[b] ± 0.01	0.3	0.3
Dissolved Oxygen (mg/ml)	1.82[d] ± 0.16	2.45[cd] ± 0.17	NS	NS
Nitrite (mg/l)	0.03[b] ± 0.00	23.87[a] ± 13.37	0.2	NS
Total Alkalinity – as $CaCO_3$ (mg/l)	256.27[a] ± 4.07	257.73[a] ± 13.53	NS	300
pH	7.31[a] ± 0.05	9.29[a] ± 0.96	6.5-8.5	6.5-8.5
Sulphate (mg/l)	7.16[a] ± 0.53	10.26[ab] ± 0.98	100	200

Data on the same row carrying the same superscript do not differ significantly ($P<0.05$) from each other. Values are ± Standard Error of Mean.

NS: Not Specified.

Table 3. Mean Correlation of Physicochemical Properties with THC of Well water for two successive Dry and Wet Seasons.

Parameter	Season	
	Dry	Wet
Turbidity (ftu)	0.504**	-0.446**
Total Suspended Solids (mg/l)	0.107	0.231
Electrical Conductivity (us/cm)	0.441**	-0.280
Total dissolved Solids (mg/l)	-0.017	-0.395*
Total Hardness – as $CaCO_3$ (mg/l)	-0.645**	-0.692**
Calcium Hardness – as $CaCO_3$ (mg/l)	-0.481**	-0.645**
Magnesium Hardness – as $CaCO_3$ (mg/l)	-0.506**	-0.241
Ferrous Iron (mg/l)	-0.586**	-0.260
Dissolved Oxygen (mg/l)	-0.597**	-0.052
Nitrite (mg/l)	0.545**	-0.267
Total Alkalinity – as $CaCO_3$ (mg/l)	0.643**	0.178
pH	-0.377*	-0.313
Calcium – as Ca^{2+} (mg/l)	0.153	0.069
Magnesium – as Mg^{2+} (mg/l)	-0.220	-0.399*
Sulphate (mg/l)	-0.214	-0.278

Data on the same row carrying the same superscript do not differ significantly (P<0.05).
** = Pearson Correlation (2-tailed) is Significant at 99.0% (P<0.01).
*= Pearson Correlation (2-tailed) is Significant at 95.0% (P<0.05).

The strong positive correlation of TTA-CO_3 recorded with the THC of well samples during the dry seasons could be attributed to the low water table and lower temperature, which according to Mahananda, *et al* (2010) tend to slow down the rate of decomposition of the salts in groundwater. The investigators also point to the possible effects of the increase in decomposition of organic matter and seasonal fluctuations in the pollution load of the water bodies.

WHO (2004) reported sulphates as occurring naturally as barite (barium sulphate), epsomite (magnesium sulphate heptahydrate) and gypsum (calcium sulphate dehydrate). These minerals when present in the subsoil have been observed by Jordana and Batista (2004) to contribute to the mineral content of groundwaters. WHO (2012) also reported that groundwater flowing through rocks such as gypsum can incorporate big amounts of sulphur as sulphate and that sodium, potassium and magnesium sulphates are all highly soluble in water, while calcium and barium sulphates and many heavy metal sulphates are less soluble.

Low sulphate concentrations recorded from the study could be attributed to the ease with which sulphate precipitates and settles an observation supported by the findings of Kumar, *et al* (2011) in their assessment of the seasonal variations of the Sabarmati River and Kharicut Canal at Ahmedabad, Gujarat, India. The results also corroborate those by Adetunde, *et al*. (2011) who investigated groundwaters of Ogbomosho Township of Oyo State and those of Ewekoro and Sagamu in Ogun State, Nigeria respectively. However, the results obtained by other investigators such as Ololade and Ajayi (2009) as well as Abdo *et al.* (2010) showed relatively higher sulphate concentrations during the dry seasons. The significantly higher concentration ($p<0.05$) recorded for wet seasons should be a cause for further investigation. This is because of the report by WHO (2004) which linked the occurrence of catharsis in adult males to ingestion of drinking water containing small amounts of sodium and magnesium sulphate.

Streptococcus faecalis and *Salmonella typhi occurred* most frequently, compared to the other bacterial isolates, while *Klebsiellapneumoniae* and *Shigella dysenteriae* and *Bacillussubtilis* recorded the least frequencies of occurrence. Other isolates varied in their frequencies of occurrence (Table 4).Variations in the percentage occurrence of bacterial isolates could be attributed to the uneven distribution of groundwater resource and its liability to large seasonal variations in physical and biological characteristics. Results obtained are supported by the findings of Shridha (2009) as well as Adekunle, *et al* (2007) who reported significant changes in heterotrophic bacterial counts between the dry and wet seasons in Nigeria.

Table 4.Mean Frequency of Occurrence (%) of Bacterial Isolates in Well Water for two successive Dry and Wet Seasons.

Organism		**Frequency (%)**	
		Dry	**Wet**
1.	*Escherichia coli*	3.1	3.8
2.	*Klebsiella pneumoniae.*	0.7	0.8
3.	*Pseudomonas aueroginosa.*	6.4	10.5
4.	*Salmonella typhi*	13.0	2.1
5.	*Salmonella paratyphi.*	22.1	14.7
6.	*Proteus mirabilis.*	4.6	5.7
7.	*Citrobacter freundii.*	2.5	2.9
8.	*Enterobacter aerogenes*	3.2	5.8
9.	*Staphylococcus aureus*	4.2	10.8
10	*Serratiamarcecens.*	4.0	5.3
11	*Streptococcus*	24.6	20.9
12	*Micrococcus luteus*	7.5	13.3
13	*Bacillus cereus*	1.6	1.8
14	*Bacillus subtilis*	1.5	1.5
15	*Shigellla dysenteriae*	0.9	

The presence of the bacterial isolates (particularly *E. coli*) is an indication that the well water sources investigated are faecally contaminated and reflects the unsanitary practices prevalent in the study areas. These practices usually include location of wells to toilets, soakaways, septic tanks or refuse dump sites as well as poor well construction. Chronic unhygienic practices of the inhabitants of the areas investigated in addition to the abilities of some of the isolates (such as *E. coli* and *Streptococcus* sp.) to survive for long periods in water may also have contributed to the presence of the organisms in the well water sources. These results are

corroborated by Muhammad (2012) and Ibiene, *et al* (2012). Similar observations were made in previous studies by Marissa, *et al*. (2005) and Cabral (2010). Okonko, *et al* (2009) identified most of the isolates encountered in the current study in their investigations of groundwater sources in different parts of Nigeria.

CONCLUSIONS AND RECOMMENDATIONS

The assessment of well water sources in Minna metropolis over the dry and wet seasons revealed bacterial counts well above the limits specified by the NSDWQ and the World Health Organization.

Most physicochemical parameters tested recorded higher concentrations in the wet seasons,with some values well above the limits specified by the guidelines for drinking water quality. Correlations of physicochemical properties with the THCof well samples were heterogeneous for both seasons (in terms of positive and negative correlations).

Recommendations

Periodic sanitary risk surveillance of the bacteriological and physicochemical properties of wells should be carried out to help address the prevailing dearth of information on their level of contamination and potability.

Siting of wells or boreholes should be done from potential point sources of pollution such as refuse dumps, sewage channels or areas where effluent discharges are common.

Coverings should be provided for wells in order to minimize contamination from anthropogenic and airborne sources.

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