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Experimental Determination of Drinking Water Quality in Abeokuta Metropolis, South-western Nigeria

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ABSTRACT

In this study, fifty (50) randomly selected drinking water sources in Abeokuta metropolitan city in Ogun state, south-western Nigeria; were experimentally studied to determine their suitability to be designated as "Safe Drinking Water Sources". Thus, water samples collected from each of these fifty(50) drinking water sources [comprising of ten (10) Taps, fifteen(15) Hand-dug wells and twenty(25) Bore-holes] were repeatedly subjected to one(1) microbiological and twenty-five(25) physico-chemical analytical tests, in accordance with the standard test procedures specified by ASTM, APHA and USEPA, under laboratory conditions. This was done, in order to determine whether/not the fifty (50) tested drinking water samples conformed to the global (WHO) and national (NSDWQ, SON) standards' requirements for potable (safe drinking) water. Consequent upon testing, it was observed that, 100% *i.e. all fifty(50) drinking water samples showed conformity to the standards' requirements with respect to Alkalinity, Salinity, Total hardness, Turbidity, Electrical-conductivity, Temperature, Total Dissolved Solids, BOD, Sodium, Potassium, Calcium, Magnesium, Chloride, Sulphate, Nitrate, Zinc, Chromium and Manganese contents. With exception to the Iron content, in which all the water-samples exceeded the standard's limits, [although, no adverse health conditions are associated with this];* 78% *(39 samples),* 12% *(6 samples),* 84% *(42 samples) and* 10% *(5 samples) of the water samples failed to conform to the standard's requirements in terms of pH, Lead, Cadmium and Zero-count of Total coliforms; with values ranging from* $4.33-6.77$, $0.000-0.074 mg/L$, $0.001-0.081 mg/L$ *and* $1.0-4.0\ counts/100mL$ *respectively. The respective health implications of these cases of non-conformity include disequilibrium in the body's alkalinity-acidity balance, cancer, nervous system dysfunction, kidney-related problems and low-risk total-coliforms contamination.*

Keywords: *Water, Potable water, Water sample, Total coliforms, Abeokuta, APHA.*

1. INTRODUCTION

Candidly, the indispensable nature of water, as a critically vital requirement for human existence can never be over-emphasized. This fact which predates these contemporary times, has been repeatedly validated from the evolution of the earliest human species ('homo abalis' and 'homo erectus') and transcends the evolutionary eras of modern man's generic ancestral specie (the 'homo sapiens')—being the times, when human survival basically depended on three critical elements—Fire, Earth and Water. Ranking clearly ahead of 'Concrete', Water is globally adjudged to be man's most used and consumed substance (Ibhadode et al., [1]).

Sadly enough, our current natural reserves/stock of fresh water supply is obviously under the threat of becoming a limited natural resource in many nations of the world—a fact which poses an enormously daunting task/challenge to our present & future leaders, and environmental experts such as Water, Sanitation & Hygiene (WASH) professionals/workers etc; and is further aggravated by a number of factors including rapid urbanization, increased industrialization, explosive population growth, leadership lapses and climate change etc.

Without doubts, the much desired dream of all human beings having easy access to safe and affordable potable (drinking) water is generally considered by many as one of the most basic of all human rights, and should nonetheless assume the status of one of the critical drivers of any effectively planned and properly implemented human health protection and development policy framework—be it local, state, regional, national or global.

According to the World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF), as at the year 2012, as many as 1.758 million Sub-Saharan Africans who reside in rural communities consume /drink surface (exposed & unprotected) water (WHO and UNICEF, [2]). Human consumption of pathogenically contaminated and chemically polluted water adversely affects human health (Howard et al, [3]). Statistical evidence from a WHO 1997 global survey, estimates that as much as eighty percent (80%) of all sicknesses and diseases suffered by humans are the direct consequences of water contamination or potable water unavailability and poor sanitary conditions (Mende and Ayenew, [4]), (WHO, [5]) .

In most developing countries such as Pakistan and Nigeria, it has been proven that the quality of drinking water easily obtained from most affordable sources is low—being oftentimes hazardous and polluted, making then unfit for man's consumption, in view of the rising population and progressive industrial growth indices (Mohson et al., [6]). Some poor Nigerians even harvest and store rainwater which they drink, as seen in Figure 1.2. Thus, conscious efforts aimed at improving water quality are of paramount importance to public health practitioners, when there arises the need to curb/control the spread of epidemics (Howard et al, [3]).

The U. S. Geological Survey (USGS)—a federal non-regulatory science agency saddled with the responsibilities of assessing and monitoring water quality in the USA, through its National Water Quality Laboratory (NWQL), defined water quality as a measure of the physical, chemical, biological, and microbiological characteristics of water (Myers, [7]), (BIS, [8]), (CPCB, [9]), (WHO, [10]).

It is the opinion of the American Water Works Association that, although, the quality of groundwater present within an aquifer remains relatively unchanged, yet it is still subject to some very slowly occurring changes, due to the presence of direct pollutants and contaminants, in addition to the fact that it is not exposed to air. Furthermore, an aquifer's natural filtration action makes its water relatively free of microbiological contamination, thus, it could be said that groundwater contamination in an aquifer is most likely the result of improperly constructed water-wells and/or poorly controlled waste disposal systems. On the other hand, surface water quality—be it a stream, lake, river or any water body is subject to fluctuations, and could, as a matter of fact, be altered based on the catchments area (AWA, [11]).

Whenever the quality of drinking water is considered, its chemical properties (parameters)—[which determine whether or not it is fit for human consumption/use—domestic, industrial and agricultural etc]; must also be duly considered, with respect to protecting the water source from pollution & contamination, efficiency of the water treatment processes/methods and the reliability index (factor) of the water distribution network (Eason and Chatwell, [12]), (WHO, [13]).

From the foregoing, it is obvious that: Water is vital for human existence, on a daily basis, many people experience great difficulties in accessing safe & affordable drinking water—with particular reference to developing countries, and; there exists an undisputable link between human health and drinking water quality. Therefore, there arises the need to continuously embark on drinking water quality assessments and monitoring. In addition, it might be important to state here and now that: "there also seems to be some difficulty in accessing such documented research data on drinking water quality in Abeokuta metropolis—the capital of Ogun state, South-western Nigeria".

Consequently, this study is aimed at conducting a scientific investigation on the drinking water quality in Abeokuta city in Ogun state, Nigeria.

2. MATERIALS AND METHOD

The Study-area is 'Abeokuta' on Latitude: 7° 09' 20.56" N, and Longitude: 3° 20' 42.32" E. Created in 1976, it is the metropolitan capital city of the economically viable south-western Nigerian state called 'Ogun state'—with an average estimated monthly IGR (Internally Generated Revenue) of US$ 16.4 Million (NG₦6 Billion) as at June 2017. It is a rocky savannah forest city situated at the eastern bank of 'river Ogun'. It occupies a comparatively vast land mass (area) of 879Km^2 (339 sq. mi) at an elevation of 66m (217ft). It is bordered on various sides by Lagos, Ibadan, Ilaro, Shagamu, Iseyin and Benin Republic. It is a historically important agrarian city, being home to the famous 'Olumo rock' [which has continued to attract tourists and visitors from within and outside Africa], and is only 77km (48 mi) by rail transport, and 130km (81 mi) by water transport from West Africa's economic nerve-centre—'Lagos megacity'. Originally founded in the year 1830 by a famous hunter named "Sodeke", who also happened to be the

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leader of a group of 'Egba' people, who embarked on an exodus from the gradually disintegrating ancient 'Oyo' empire. It was an important trade route in the past, during the early oil-palm trade era, [prior to Sir. Fredrick Lord Lugard's almagamation of the northern and southern protectorates in 1914 to form the then Nigeria,] which later fell to the British colonial imperialist rule. In Nigeria's year 2006 national census exercise, it recorded a population of 449.088. It is home to a number of tertiary institutions of learning including the 'Federal University of Agriculture, Abeokuta (FUNAAB)'. The dominant tribe is 'Yoruba', and the commonly practised religious faiths are Christianity, Islam and African traditional religion. The city's paramount traditional ruler is known as "The Alake of Abeokuta"—who monarchical supremacy is revered throughout the length and breadth of Ogun state. The city is reputed to have produced a number of notable Nigerian personalities including Nigeria's ex-president—Chief Matthew Aremu Okikiola Olusegun Obasanjo (Retd).

In order to prevent contamination prior to the testing processes, sterile plastic containers were used to collect fifty (50) Water samples from fifty (50) randomly selected drinking water sources, comprising of: ten (10) taps, fifteen (15) Hand-dug wells and twenty-five (25) Boreholes—all present in fifteen (15) populated residential/business neighbourhoods [i.e. 'GRA', 'Ibara', 'GRA annex/Onikolobo', 'Ojokodo', 'Idiaba', 'Jemo', 'Agbomeji', 'Oluwo', 'Isabo', 'Oke-oko', 'Ago-oko', 'Itoko', 'Olomore', and 'Ikopa'] in Abeokuta city. After which, each of the fifty (50) collected water samples were subjected to a number of physico-chemical, and microbiological analytical tests, as summarily explained below.

For each water sample, alkalinity, salinity, Total hardness [in the form of $CaCO_3(aq)$] and Biochemical Oxygen Demand (BOD) were obtained in accordance with the test methods specified by the American Society for Testing and Materials (ASTM, [14]). While Turbidity was measured with the aid of a Hanna $H198703$ turbidimeter, pH was determined using a Hanna $H199192$ thermometer/pH meter, Electrical conductivity testing was carried out with the aid of the 4510 model of the Jenway conductivity meters, and the temperature was ascertained by means of a model $TM-1$ Hanna HM digital thermometer.

Similarly, adopting the gravimetric test methods specified by the American Public Health Association (APHA), the Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and Total Solids (TS) were carefully obtained (Clesceri et al., [15]). Also, while the analytical methods of Winkler was applied for determination of Dissolved Oxygen (DO) (Ademoroti, [16]); the method of Mohr was adopted to obtain the Chloride [$Cl^-(aq)$]content of each water sample (Clesceri et al., [15]); and then, the concentrations of Sulphate [$SO_4^{2-}(aq)$] and Calcium ions [$Ca^{2+}(aq)$] present within each sample were empirically determined using the calorimetric and EDTA (Ethylene dinitrilo tetraacetic acid) methods respectively. While the Sodium [$Na^+(aq)$], Potassium [$K^+(aq)$], Magnesium [$Mg^{2+}(aq)$] and Nitrate [$NO_3^-(aq)$] contents were measured in accordance with the methods specified by the ASTM i.e. the American Society for Testing and Materials (ASTM, [17]), (Mende and Ayenew, [4]), (ASTM, [18]), (ASTM, [19]).

In addition, the digestion of each water sample using concentrated Trioxonitrate (V) acid [$HNO_3(aq)$] was carried-out prior to testing for the possible presence of heavy metals, so as to significantly decrease the interference of organic matter with the process, and then, ensure a conversion of the heavy metals present into forms that could be analyzed by an Atomic Absorption Spectrophotometer (AAS). This was then followed by measurements of the various concentrations of the following randomly detected heavy metals: Lead (Pb), Zinc (Zn), Iron (Fe), Cadmium (Cd), Chromium (Cr) and Manganese (Mn); with the aid of a Perkin Elmer model 306 AAS, in the chemical testing laboratory of 'FATLAB Nigeria Company', located at 28th Oyo road, near University of Ibadan, Ibadan, Oyo state, Nigeria.

Furthermore, the membrane filtration method for micro-organism analysis of water samples [as specified by USEPA] was adopted, which required the vacuuming of 100mL of each water sample through a sterile cellulose ester membrane filter, by means of a potable hand-operated pump. Consequent upon the filtration process, the sterile filter-paper which retained the yet unidentified bacteria present [in a particular water sample] was then placed inside a Petri-dish with a culture-media [in the form of a nutrient solution].

Incubation of the yet unidentified bacteria present [in the water sample] was carried-out, by placing the Petri-dish inside an incubator at a specifically defined temperature and time duration—both parameters which varied with respect to the particular type of indicator-bacteria and the culture-media used. For instance, while 'Fecal Coliforms' were subjected to an incubation temperature of $44.5°C$ using certain types of culture-media; 'Total Coliforms' on the other hand, were subjected to an incubation temperature of $35.0°C$, for an incubation time of 24 hours. Upon completion, of the incubation process, the colonies of the bacteria present in the water samples were observed with a magnifying glass, even though, they became visible to the human eyes.

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After which, the colour and size of the bacteria colonies were used to identify the particular type of bacteria present and the culture-media used during the microbial analysis (USEPA, [20]).

Finally, all results and data of the physico-chemical, heavy metal(s) identification & quantification and micro-biological analyses of each of the fifty (50) water samples obtained as explained above in the preceding paragraphs, were then collated, tabulated and analytically compared with the maximum [or minimum] values stipulated by three relevant standards, comprising of one (1) global standard [The World Health Organization (WHO)] and two (2) national standards i.e. [The Nigerian Standard for Drinking Water Quality (NSDWQ)], and the [The Standards Organization of Nigeria (SON)]; where the specific standardization value for a particular parameter was provided for comparative analysis (WHO, [21]), (WHO, [22]), (WHO, [23]), (SON, [24]), (NIS [25]).

3. RESULTS AND DISCUSSION

A careful look at Table 1.1 shows that the pH values [which actually measure the concentrations of hydrogen ions present within the water samples] ranged from 4.33 to 6.77, with a mean (average) value of 5.89—this generally suggests a tendency for slight acidity of the water samples. Thirty-nine (39) of all fifty (50) water samples had pH values that were below the World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) stipulated maximum pH range of $6.50-8.50$ for portable water. This deviation is likely due to the presence of organic matter and/or acidic or alkaline substances, such as micro-organism generated excessive levels of $CO_2(g)$ and $SO_2(g)$. Although, some researchers believe that, there are presently no direct health implications attributed to the human consumption of water with pH values deviating from the required standards, it is our candid opinion as the authors of this research paper that, it affects the delicate alkalinity-acidity balance [with the body's preferred bias in favour of slight alkalinity] which the human body strives/attempts to maintain for a healthy functioning of the body's systems. However, it should be noted that, water with pH values below the required standards' values results in the indirect health risk of metallic leaching of plumbing systems, due to the presence of acidic water within domestic and municipal plumbing lines.

From Table 1.1, it could be seen that the alkalinity values [which gives a measure of the acid-neutralizing capacity] of the water samples ranged from $0.00mg/L$ to $35.00mg/L$, with a mean (average) value of $11.34mg/L$. These three values show that, the alkalinity of all fifty (50) water samples were lower than the WHO stipulated maximum alkalinity level of $120.00mg/L$ for potable water consumption and recreational uses such as swimming etc. It is noteworthy to mention that, oftentimes, a mild level of alkalinity is advisable for water, in order to neutralize the acidic effects of water. However, when the alkalinity of water exceeds certain moderate levels, the water is most likely to taste unpleasantly.

The salinity values [which give a measure of the salt content of the water samples] ranged from $10.00mg/L$ to $39.00mg/L$, with a mean (average) value of $20.78mg/L$, implying that they could be used domestically, and are not likely to result in the formation of 'Scum'; as could be seen in Table 1.1. Each of the fifty (50) water samples had a salinity value that was significantly lower than the WHO stipulated maximum salinity level of $200.00mg/L$ for potable water—thus reducing the chances (probability) of hypertension on the part of human consumers.

The total hardness values [which to a large extent gives a measure of the (Ca^{2+} (aq) and Mg^{2+} (aq)) mineral contents in the form of trioxocarbonates (V) i.e. 'CO_3^{2-}' present] of the water samples ranged from $10.23mg/L$ to $38.18mg/L$, with a mean (average) value of $24.82mg/L$, as could be seen in Table 1.1. This is in view of the fact that, the above values indicate that, the total hardness levels of the fifty (50) tested water samples fell below the Standards Organization of Nigeria (SON) stipulated maximum hardness level of $150.00mg/L$ for potable water. Thus, these water samples will not result in skin itching, and would not require so much soap to form lather.

Likewise, the results shown in Table 1.1 reveal that, the turbidity [which is the measure/extent of the clarity or cloudiness] of the water samples ranged from $0.37NTU$ to $2.99NTU$, with a mean (average) value of $1.25NTU$. These three values suggest that all fifty (50) tested water samples had turbidity values which were lesser than the WHO stipulated maximum turbidity value

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Table1.1. Physico-chemical analyses of fifty drinking water sources in Abeokuta city, South-western Nigeria.

S/No.	Water Source	Water Sample Designation	pH	Alkalinity (mg/L)	Salinity (mg/L)	Total Hardness [as 'CaCO$_3$(aq)']	Turbidity (NTU)	Electrical Conductivity (µS/cm)	Temperature (°C)
1	Tap	TW1	5.92	14.00	18.00	23.98	0.64	36.40	29.20
2		TW2	6.55	14.00	20.00	16.53	1.71	32.70	29.90
3		TW3	5.78	18.00	19.00	20.94	1.10	57.60	27.90
4		TW4	6.77	11.00	20.00	19.62	0.86	61.80	30.10
5		TW5	6.60	0.00	20.00	30.73	1.25	44.90	28.60
6		TW6	6.10	22.00	31.00	29.84	0.64	41.30	30.80
7		TW7	4.80	16.00	17.00	29.31	1.69	47.70	28.40
8		TW8	5.93	13.00	12.00	18.86	1.11	53.80	27.40
9		TW9	4.88	1.00	14.00	25.90	2.02	66.90	29.30
10		TW10	6.63	1.00	19.00	24.49	0.48	45.10	27.20
11	Hand-dug Well	HWW1	6.55	3.00	20.00	28.66	2.13	39.10	27.60
12		HWW2	5.75	8.00	20.00	31.68	1.56	55.20	29.30
13		HWW3	6.31	0.00	20.00	22.45	1.55	51.40	28.40
14		HWW4	5.74	10.00	34.00	20.80	1.13	47.00	30.10
15		HWW5	4.96	26.00	23.00	10.23	0.92	60.70	28.10
16		HWW6	5.71	15.00	36.00	17.60	0.78	61.50	30.20
17		HWW7	4.85	0.00	15.00	25.11	0.88	60.90	29.60
18		HWW8	6.39	0.80	10.00	31.65	0.37	60.10	30.90
19		HWW9	5.74	6.00	27.00	15.45	1.93	48.60	27.70
20		HWW10	5.99	13.00	16.00	17.10	2.99	51.10	30.80
21		HWW11	5.29	9.00	10.00	15.36	0.46	54.20	28.30
22		HWW12	6.01	32.00	12.00	28.84	1.53	33.80	28.40
23		HWW13	5.68	0.00	28.00	32.28	2.21	40.60	28.60
24		HWW14	6.32	24.00	11.00	19.55	0.45	35.30	29.40
25		HWW15	6.28	2.00	10.00	20.00	0.87	42.70	30.40
26	Bore-hole	BHW1	5.62	0.00	39.00	24.12	0.88	63.80	29.50
27		BHW2	6.17	35.00	24.00	20.56	0.63	38.60	29.30
28		BHW3	5.59	31.00	31.00	38.18	0.95	44.60	28.80
29		BHW4	5.32	27.00	20.00	30.73	1.24	61.90	30.00
30		BHW5	5.87	16.00	11.00	18.14	2.10	46.70	30.70
31		BHW6	5.48	4.00	18.00	20.88	1.57	46.20	27.60
32		BHW7	6.45	9.00	15.00	20.12	0.99	33.90	27.40
33		BHW8	6.36	2.00	10.00	37.21	1.11	65.70	28.20
34		BHW9	6.36	10.00	22.00	26.56	2.06	58.60	29.40
35		BHW10	6.03	10.00	38.00	19.94	1.53	39.30	29.10
36		BHW11	5.43	10.00	12.00	12.57	1.24	52.70	28.90
37		BHW12	5.25	15.00	13.00	24.03	1.39	36.50	30.60
38		BHW13	4.33	12.00	12.00	25.57	1.00	53.90	27.70
39		BHW14	6.18	1.00	28.00	35.69	0.42	47.40	30.40
40		BHW15	5.59	27.00	25.00	34.56	0.61	48.80	27.70
41		BHW16	6.26	6.00	30.00	30.38	0.94	47.20	28.90
42		BHW17	6.52	30.00	17.00	30.68	1.12	64.00	27.70
43		BHW18	5.79	11.00	24.00	22.64	1.12	35.30	30.60
44		BHW19	6.55	13.00	32.00	31.98	1.86	51.10	28.30
45		BHW20	5.87	0.00	29.00	31.40	2.20	66.50	29.60
46		BHW21	6.21	1.00	13.00	32.18	0.77	64.00	27.80
47		BHW22	5.88	12.00	28.00	21.98	0.81	62.40	30.50
48		BHW23	6.37	14.00	28.00	24.17	1.64	43.70	30.20
49		BHW24	5.84	5.00	22.00	20.65	1.80	47.20	28.60
50		BHW25	5.50	7.00	16.00	28.99	1.13	45.00	30.10
AVERAGE VALUES			***5.89***	***11.34***	***20.78***	***24.84***	***1.25***	***49.91***	***29.08***
WHO Standard			**6.5-8.5**	**120.00**	**200.00**		**5.00**	**400.00**	**40.00**
NDWQS/SON (Nigerian Standards)			**6.5-8.5**			**150.00**			

of $5.00 NTU$ for potable water. More often than not, turbidity is brought about by the presence of colloidal matter and/or suspended particles in water. Although, 'Surface water samples' were not analyzed (studied) in this research work, it may be necessary to mention that, for Surface (exposed) water sources [such as rivers and streams etc.,] , high turbidity levels could be attributed to increase in human activities, as is often times the case.

The electrical conductivity [which is the degree (extent) of electric current transmission, due to the ionic concentration] of water samples ranged from $32.70 \mu S / cm$ to $66.90 \mu S / cm$, with a mean (average) value of $49.91 \mu S / cm$, as could be seen in Table 1.1. Each of the fifty (50) tested water samples had an electrical conductivity which was far lesser than the WHO stipulated

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maximum electrical conductivity value of $400.00\mu S/cm$ for potable water. Now, reiterating the fact that pure water is naturally a poor conductor of electricity [and heat], it must be noted that, higher-than-required electrical conductivity values of water is often the result of an excessive increase in the concentration of dissolved ionic solids within the water samples.

The temperature [which is a measure of the degree of hotness or coldness] of the water samples ranged from $27.20°C$ to $30.90°C$, with a mean (average) value of $29.08°C$ as could be seen in Table 1.1. All fifty (50) water samples recorded temperature values which were lower than the WHO stipulated maximum temperature level of $40.00°C$ for potable water. Actually, no ill-health effect is necessarily associated with water samples having temperatures that exceed $40.00°C$. This is simply because, all things being equal, the water samples may just be allowed to cool down to room temperature within a matter of minutes, prior to human consumption (drinking) and/or other domestic/industrial uses (application) etc., as deemed appropriate.

Table 1.2 shows the respective quantities of two alkali metals (group 1 elements) [i.e. 'Na' & 'K'] and two alkali-earth metal (group 2 elements) [i.e. 'Ca' & 'Mg'] possibly present in each of the fifty (50) tested water samples. Thus, while Sodium (Na) ranged from $0.00mg/L$ to $2.68mg/L$, with a mean (average) value of $0.96mg/L$—all three values which were considerably lower than the 'WHO' and 'NSDWQ' stipulated maximum Sodium level of $200.00mg/L$ for potable water; and Potassium (K) ranged from $0.00mg/L$ to $2.74mg/L$, with a mean (average) value of $1.42mg/L$—all three values which were also lesser than the 'WHO' and 'NSDWQ' stipulated maximum Potassium level of $12.00mg/L$ for potable water.

Similarly, from Table 1.2, while Calcium (Ca) ranged from $47.02mg/L$ to $71.94mg/L$, with a mean (average) value of $59.62mg/L$—each of these values were observed to be lower than the 'WHO' and 'NSDWQ' stipulated maximum Calcium level of $75.00mg/L$ for potable water; and Magnesium (Mg) ranged from $0.00mg/L$ to $32.87mg/L$, with a mean (average) value of $28.85mg/L$—all of which were also lower than the 'WHO' and 'NSDWQ' stipulated maximum Magnesium level of $150.00mg/L$ for potable water.

Again, from Table 1.2, it could be seen that, the Chloride [Cl^-(aq)] content [which is the sum total of both the combined forms of chlorine and the free chlorine dissolved in water]of all fifty (50) water samples, ranged from $2.26mg/L$ to $6.11mg/L$, with a mean (average) value of $4.31mg/L$. These values were clearly lower than the WHO and NSDWQ stipulated maximum chloride levels of $250.00mg/L$ for potable water. Now, it may be necessary to mention that, although, chlorine is an active agent in most commonly used drinking water disinfectants, yet it is advisable that its usage/application [even at very low concentrations] must be closely monitored.

On the other hand, the Sulphate [SO_4^{2-}(aq)] content of all fifty (50) tested water samples ranged from $0.21mg/L$ to $0.98mg/L$, with a mean (average) value of $0.61mg/L$, as is shown in Table 1.2. These values do not pose any health risk, since the $250.00mg/L$ WHO stipulated maximum Sulphate concentration for potable water is higher than them—i.e. all three above values. Then, the Nitrate [NO_3^-(aq)] contents of each of the fifty (50) water samples ranged from $0.05mg/L$ to $0.53mg/L$, with a mean (average) value of $0.22mg/L$, as is also shown in Table 1.2. Similarly, the $50.00mg/L$ WHO stipulated maximum Nitrate concentration for potable water is higher than the above minimum, average and maximum values.

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Table1.2. Mineral content analyses of fifty drinking water samples in Abeokuta city, South-western Nigeria

S/No.	Water Source	Water Sample Designation	Sodium [Na] (mg/L)	Potassium [K] (mg/L)	Calcium [Ca] (mg/L)	Magnesium [Mg] (mg/L)	Chloride [Cl^-(aq)] (mg/L)	Sulphate [SO_4^{2-}(aq)] (mg/L)	Nitrate [NO_3^-(aq)] (mg/L)
1	Tap	TW1	0.00	0.70	71.20	31.26	4.28	0.75	0.16
2		TW2	0.00	2.16	70.16	31.08	2.26	0.91	0.18
3		TW3	0.00	1.90	58.60	32.44	3.43	0.27	0.05
4		TW4	2.67	2.40	71.60	0.00	3.51	0.33	0.53
5		TW5	1.84	2.73	66.58	31.19	4.44	0.61	0.15
6		TW6	2.05	1.65	59.74	0.00	3.07	0.34	0.43
7		TW7	0.93	1.90	63.91	31.65	6.00	0.36	0.33
8		TW8	0.28	1.90	64.15	32.57	5.25	0.94	0.13
9		TW9	0.00	1.30	63.50	31.66	5.18	0.56	0.05
10		TW10	1.44	2.10	70.15	32.08	3.66	0.68	0.14
11	Hand-dug Well	HWW1	1.26	1.59	54.50	32.60	4.97	0.52	0.15
12		HWW2	1.10	2.63	71.94	32.55	3.82	0.27	0.20
13		HWW3	0.00	0.88	71.80	32.13	3.50	0.93	0.31
14		HWW4	2.49	1.30	55.60	0.00	4.15	0.53	0.21
15		HWW5	1.87	1.30	43.40	31.61	4.24	0.98	0.31
16		HWW6	0.65	1.70	70.16	32.87	4.83	0.69	0.37
17		HWW7	1.33	2.20	47.30	31.60	6.02	0.61	0.15
18		HWW8	1.32	2.74	69.24	32.14	5.11	0.31	0.36
19		HWW9	1.33	2.19	53.12	31.59	3.28	0.64	0.14
20		HWW10	1.27	0.89	46.50	32.63	3.33	0.62	0.22
21		HWW11	0.46	1.26	45.50	32.05	3.61	0.23	0.08
22		HWW12	1.50	0.43	44.30	32.12	3.79	0.82	0.11
23		HWW13	2.68	1.26	46.06	0.00	4.25	0.59	0.07
24		HWW14	0.00	2.37	71.18	32.59	4.01	0.26	0.39
25		HWW15	2.10	0.90	55.00	30.99	5.63	0.93	0.37
26	Bore-hole	BHW1	0.96	1.81	62.72	31.68	6.10	0.80	0.21
27		BHW2	0.45	0.00	48.43	32.14	3.88	0.35	0.47
28		BHW3	0.62	2.61	71.15	32.62	3.54	0.68	0.10
29		BHW4	1.09	1.74	44.42	32.57	5.25	0.68	0.12
30		BHW5	0.05	0.69	67.00	32.15	5.17	0.51	0.22
31		BHW6	0.00	0.00	52.50	31.63	5.39	0.57	0.35
32		BHW7	0.10	0.96	70.80	32.64	6.00	0.84	0.19
33		BHW8	2.24	2.45	49.50	31.62	4.32	0.22	0.30
34		BHW9	1.74	1.39	63.00	32.16	2.99	0.87	0.20
35		BHW10	0.58	0.00	65.85	31.61	4.28	0.74	0.11
36		BHW11	0.00	2.63	65.30	0.00	4.33	0.75	0.10
37		BHW12	2.40	1.30	63.40	32.65	2.84	0.69	0.07
38		BHW13	1.99	1.30	58.22	32.07	5.26	0.50	0.13
39		BHW14	0.65	2.20	71.16	32.14	5.07	0.65	0.31
40		BHW15	1.29	1.28	42.02	31.66	3.31	0.85	0.47
41		BHW16	0.00	0.66	51.25	32.62	4.18	0.21	0.19
42		BHW17	1.01	0.87	62.93	31.65	2.95	0.86	0.51
43		BHW18	1.83	0.89	48.21	32.15	2.95	0.62	0.05
44		BHW19	0.07	2.56	56.08	32.60	2.95	0.33	0.20
45		BHW20	0.07	0.00	70.24	32.64	2.95	0.59	0.12
46		BHW21	0.00	0.05	67.96	32.10	5.14	0.71	0.37
47		BHW22	0.12	1.93	43.58	31.70	3.89	0.98	0.14
48		BHW23	0.06	1.25	71.37	32.57	6.11	0.55	0.36
49		BHW24	0.34	0.00	54.47	31.71	6.10	0.91	0.13
50		BHW25	1.59	0.00	54.34	32.09	4.85	0.29	0.21
AVERAGE VALUES			***0.96***	***1.42***	***59.62***	***28.85***	***4.31***	***0.61***	***0.22***
WHO Standard			**200.00**	**12.00**	**75.00**	**150.00**	**250.00**	**250.00**	**50.00**
NDWQS/SON (Nigerian Standards)			**200.00**	**12.00**	**75.00**	**150.00**	**250.00**		

The term 'Total Solids (TS)' could be defined as the total mass of material residue that remains in a vessel, after a sample has been allowed to evaporate, followed by another process of oven-drying at a predefined temperature. It is usually present in water in two forms, which are Total Dissolved Solids (TDS) and Total Suspended Solids (TSS). It was carefully observed that, TS was the sum of TDS and TSS. TDS is that portion of the TS that passed through a filter, while TSS is that portion of the TS that was retained on the filter. These three (3) parameters (TDS, TSS and TS) ranged as follows: $13.59-49.40 mg/L$, $1.04-13.11 mg/L$, and $18.88-59.19 mg/L$ respectively; while the respective average values were $29.89 mg/L$, $7.03 mg/L$ and $36.92 mg/L$, as shown in Table 1.3. Besides, it was noted that, all the recorded values [including the highest, lowest and average] of TDS, were lower than the WHO stipulated maximum TDS level of $600.00 mg/L$ for potable water.

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Table1.3. Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Solids (TS), Dissolved Oxygen (DO) and Biochemical Oxygen Demand (BOD) of fifty drinking water samples in Abeokuta city, south-western Nigeria

S/No.	Water Source	Water Sample Designation	Total Dissolved Solids [TDS] (mg/L)	Total Suspended Solids [TSS] (mg/L)	Total Solids [TS] (mg/L)	Dissolved Oxygen [DO] (mg/L)	Biochemical Oxygen Demand [BOD] (mg/L)
1	Tap	TW1	14.45	6.43	20.88	9.62	1.99
2		TW2	20.12	3.45	23.57	8.05	0.75
3		TW3	33.70	9.12	42.82	8.93	2.84
4		TW4	23.32	2.58	25.90	8.86	1.14
5		TW5	24.24	1.04	25.28	8.99	3.32
6		TW6	47.77	11.42	59.19	7.82	1.28
7		TW7	23.01	8.95	31.96	8.48	3.51
8		TW8	28.71	4.56	33.27	7.44	2.03
9		TW9	40.21	5.72	45.93	8.18	2.27
10		TW10	28.78	7.15	35.93	6.43	1.29
11	Hand-dug Well	HWW1	39.12	13.11	52.23	9.09	1.73
12		HWW2	19.64	6.42	26.06	5.83	3.85
13		HWW3	31.90	9.07	40.97	4.81	3.01
14		HWW4	43.07	12.55	55.62	8.91	2.03
15		HWW5	19.74	10.90	30.64	6.06	2.91
16		HWW6	36.86	4.70	41.56	7.65	1.62
17		HWW7	35.71	4.11	39.82	5.25	2.18
18		HWW8	17.08	7.11	24.19	7.76	2.03
19		HWW9	41.56	6.31	47.87	5.47	3.06
20		HWW10	33.06	8.23	41.29	10.84	0.95
21		HWW11	34.84	9.71	44.55	6.28	3.86
22		HWW12	39.08	7.48	46.56	11.42	1.59
23		HWW13	13.59	5.29	18.88	5.03	3.12
24		HWW14	48.07	3.32	51.39	8.33	1.51
25		HWW15	25.90	8.14	34.04	6.82	3.08
26	Bore-hole	BHW1	43.44	2.43	45.87	8.13	0.95
27		BHW2	29.18	10.85	40.03	8.08	1.65
28		BHW3	49.40	5.36	54.76	8.12	1.59
29		BHW4	33.62	8.65	42.27	9.19	1.86
30		BHW5	23.61	6.12	29.73	5.15	2.19
31		BHW6	34.59	4.53	39.12	7.85	2.25
32		BHW7	25.65	5.15	30.80	8.67	2.03
33		BHW8	17.55	7.33	24.88	8.49	1.85
34		BHW9	34.79	8.52	43.31	6.34	2.01
35		BHW10	25.44	8.30	33.74	7.98	1.61
36		BHW11	34.39	8.91	43.30	8.41	2.60
37		BHW12	27.98	9.26	37.24	6.29	0.98
38		BHW13	42.45	9.45	51.90	8.64	1.52
39		BHW14	14.57	13.05	27.62	8.12	1.13
40		BHW15	29.12	5.37	34.49	8.36	0.97
41		BHW16	20.87	7.10	27.97	8.46	0.53
42		BHW17	23.01	1.36	24.37	9.05	0.87
43		BHW18	31.12	6.17	37.29	6.65	0.34
44		BHW19	18.40	9.52	27.92	9.13	0.39
45		BHW20	34.51	4.83	39.34	9.02	0.67
46		BHW21	24.34	8.72	33.06	9.00	0.82
47		BHW22	25.39	2.58	27.97	9.25	0.61
48		BHW23	23.54	1.97	25.51	9.00	0.94
49		BHW24	28.00	12.28	40.28	9.27	0.78
50		BHW25	35.85	7.01	42.86	7.93	2.72
AVERAGE VALUES			***29.89***	***7.03***	***36.92***	***7.94***	***1.82***
WHO Standard			**600.00**				**≥6.00**
NDWQS/SON (Nigerian Standards)							

In addition, two closely related parameters i.e. 'Dissolved Oxygen (DO)' and 'Biochemical Oxygen Demand (BOD)' ranged from $4.81mg/L$ -$11.42mg/L$ and $0.34mg/L$ -$3.86mg/L$ respectively; while the average values were $7.94mg/L$ and $1.82mg/L$ respectively, as is also shown in Table 1.3. All the recoded values of BOD were lesser than the WHO stipulated maximum BOD level of $\geq 6.00mg/L$ for potable water—a condition which implied that each of the fifty (50) tested water samples had less organic pollution, and that the tested water samples constituted aquatic habitats that could support the existence of marine organism(s).

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Based on the results of the heavy metal qualitative and quantitative analyses of the water samples, shown in Table 1.4, six (6) heavy metals [i.e. 'Pb', 'Zn', 'Fe', 'Cd', 'Cr' and 'Mn'] were randomly detected in some of the water samples. After subjecting each of the fifty (50) water samples to a series of chemical analytical tests: Lead (Pb) was detected in only six (6) samples, in quantities ranging from $0.000 mg/L$ - $0.074 mg/L$ and averaged at $0.005 mg/L$; while Zinc (Zn) was detected in only ten (10) samples, in quantities ranging from $0.000 mg/L$ - $0.005 mg/L$ and averaged at $0.001 mg/L$; then, Iron (Fe) was detected in all fifty (50) samples, in quantities ranging from $0.220 mg/L$ - $1.620 mg/L$ and averaged at $0.691 mg/L$.

It is important to note that, the minimum, maximum and average values of Lead in the six(6) affected water samples, were higher than the WHO stipulated maximum Lead level of $0.010 mg/L$ for potable water—a condition which could result in growth of cancerous cells within the human body, and adversely affect the nervous system. The lowest, highest and mean Zinc levels in the ten (10) affected water samples were below the WHO stipulated maximum Zinc level of $5.000 mg/L$ and the NSDWQ stipulated maximum Zinc level of $3.000 mg/L$ for potable water; even though at the moment, no negative health implication has been clearly linked to excessive levels of Zinc in drinking (potable) water. Also, the minimum, maximum and average Iron levels in all fifty (50) tested water samples were higher than the WHO stipulated maximum Iron level of $0.100 mg/L$ and the NSDWQ stipulated maximum Iron level of $0.300 mg/L$ for potable water; while realizing that, presently, any clearly defined ill-health condition is yet to be directly associated with excessively high levels of Iron in potable (drinking) water.

Similarly, from Table 1.4, it could be seen that, for all fifty (50) water samples, the measured Cadmium (Cd) levels ranged from $0.001 mg/L$ to $0.081 mg/L$, and averaged at $0.041 mg/L$. Then, forty two (42) out of the fifty (50) water samples had Cadmium levels which were higher than the WHO and NSDWQ stipulated maximum Cadmium level of $0.003 mg/L$ for potable water—a condition which may increase the chances (probability) of kidney-related problems in humans. Likewise, as is shown in Table 1.4, only seven (7) out of the fifty (50) tested water samples were observed to contain Chromium (Cr) which ranged from $0.000 mg/L$ to $0.040 mg/L$, and averaged at $0.003 mg/L$. All three (3) values were lower than the WHO and NSDWQ stipulated maximum Chromium level of $0.050 mg/L$ for potable water; thus, reducing the chances (probability) cancerous cells growth in the human consumers. Moreover, based on the results displayed in Table 1.4, for all fifty (50) water samples, the measured Manganese (Mn) levels ranged from $0.000 mg/L$ to $0.031 mg/L$, and averaged at $0.015 mg/L$. In addition, all the samples had Manganese levels which were considerably lower than the WHO stipulated maximum Manganese level of $0.100 mg/L$, and the NSDWQ stipulated maximum Manganese level of $0.200 mg/L$ for potable water—a positive condition which will most likely prevent cases of neurological disorders when consumed by man.

Furthermore, it must be noted that, the absence of bacterial contaminants from a water source is actually one of the major determinants for designating it a "safe source of drinking (potable) water". During the course of this study, it was agreed that, 'total coliform bacteria group' was the basic pathogen that may be found present in any drinking water sample. Thus, by inference, the higher the number of coliforms observed to be present in any particular water sample, higher the probable chances (possible risks) of pathogenic bacterial contamination in that water sample.

Now, according to the WHO standard requirements for potable (safe drinking) water, "a potable water source must be absolutely free of the presence of total coliform. However, from Figure 1.1, it could be seen that, the total coliform bacteria was found to be present in only five (5) of the water samples, and that, the bacteria count ranged from 1.0 to 4.0 with an average value of $0.26 colony/100mL$. At this juncture, it is pertinent to state that, even the slightest trace amount of total coliform, most likely confirms the dreaded reality of fecal contamination of the five (5) affected water samples; even though, the WHO designates a Total Coliforms count range of $1-10 counts/100mL$ as a "low risk contamination".

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Table1.4. Heavy metal content analyses of fifty drinking water samples in Abeokuta city, South-western Nigeria

S/No.	Water Source	Water Sample Designation	Lead [Pb] (mg/L)	Zinc [Zn] (mg/L)	Iron [Fe] (mg/L)	Cadmium [Cd] (mg/L)	Chromium [Cr] (mg/L)	Manganese [Mn] (mg/L)
1	Tap	TW1	ND	0.004	0.670	0.040	ND	0.000
2		TW2	0.025	ND	0.670	0.044	ND	0.000
3		TW3	ND	ND	1.250	0.034	ND	0.013
4		TW4	ND	0.002	0.360	0.002	ND	0.022
5		TW5	ND	ND	0.460	0.001	ND	0.015
6		TW6	0.037	ND	0.220	0.041	ND	0.029
7		TW7	ND	ND	0.900	0.050	0.010	0.018
8		TW8	ND	ND	0.690	0.041	0.010	0.012
9		TW9	0.074	ND	1.000	0.070	ND	0.000
10		TW10	ND	ND	0.260	0.039	ND	0.026
11	Hand-dug Well	HWW1	ND	ND	0.700	0.076	ND	0.016
12		HWW2	ND	ND	1.020	0.003	ND	0.018
13		HWW3	ND	ND	1.010	0.043	0.020	0.019
14		HWW4	ND	ND	1.020	0.042	ND	0.024
15		HWW5	ND	0.005	0.680	0.002	ND	0.017
16		HWW6	ND	ND	1.000	0.045	ND	0.019
17		HWW7	ND	ND	1.350	0.040	ND	0.021
18		HWW8	ND	ND	1.010	0.048	ND	0.013
19		HWW9	0.032	ND	1.030	0.035	ND	0.015
20		HWW10	ND	ND	1.620	0.037	ND	0.011
21		HWW11	ND	ND	0.840	0.081	0.040	0.012
22		HWW12	ND	0.002	0.720	0.001	ND	0.000
23		HWW13	ND	ND	0.910	0.047	ND	0.013
24		HWW14	ND	ND	0.730	0.038	ND	0.016
25		HWW15	ND	ND	1.010	0.003	ND	0.000
26	Bore-hole	BHW1	ND	ND	0.360	0.042	0.010	0.031
27		BHW2	ND	ND	1.030	0.041	ND	0.028
28		BHW3	ND	ND	0.380	0.050	ND	0.024
29		BHW4	ND	ND	0.710	0.003	ND	0.012
30		BHW5	ND	ND	0.920	0.040	ND	0.000
31		BHW6	ND	0.003	0.320	0.031	ND	0.023
32		BHW7	ND	ND	1.010	0.072	ND	0.015
33		BHW8	ND	ND	0.420	0.037	ND	0.018
34		BHW9	ND	0.001	0.500	0.053	0.030	0.013
35		BHW10	ND	ND	0.370	0.039	ND	0.016
36		BHW11	ND	ND	0.660	0.038	ND	0.021
37		BHW12	ND	ND	0.310	0.051	ND	0.017
38		BHW13	0.018	ND	0.350	0.043	ND	0.000
39		BHW14	ND	ND	1.060	0.065	ND	0.019
40		BHW15	ND	ND	0.530	0.042	ND	0.019
41		BHW16	ND	ND	0.490	0.036	ND	0.020
42		BHW17	ND	ND	0.250	0.044	ND	0.018
43		BHW18	ND	0.003	0.310	0.003	ND	0.011
44		BHW19	ND	ND	0.280	0.052	ND	0.026
45		BHW20	ND	ND	0.950	0.067	0.020	0.000
46		BHW21	ND	ND	0.330	0.077	ND	0.011
47		BHW22	0.059	ND	0.470	0.063	ND	0.010
48		BHW23	ND	ND	0.610	0.058	ND	0.015
49		BHW24	ND	0.004	0.270	0.049	ND	0.010
50		BHW25	ND	ND	0.540	0.060	ND	0.014
AVERAGE VALUES			***0.005***	***0.001***	***0.691***	***0.041***	***0.003***	***0.015***
WHO Standard			**0.010**	**5.000**	**0.100**	**0.003**	**0.050**	**0.100**
NDWQS/SON (Nigerian Standards)				**3.000**	**0.300**	**0.003**	**0.050**	**0.200**

NOTE: Where 'ND' denotes "None Detected"

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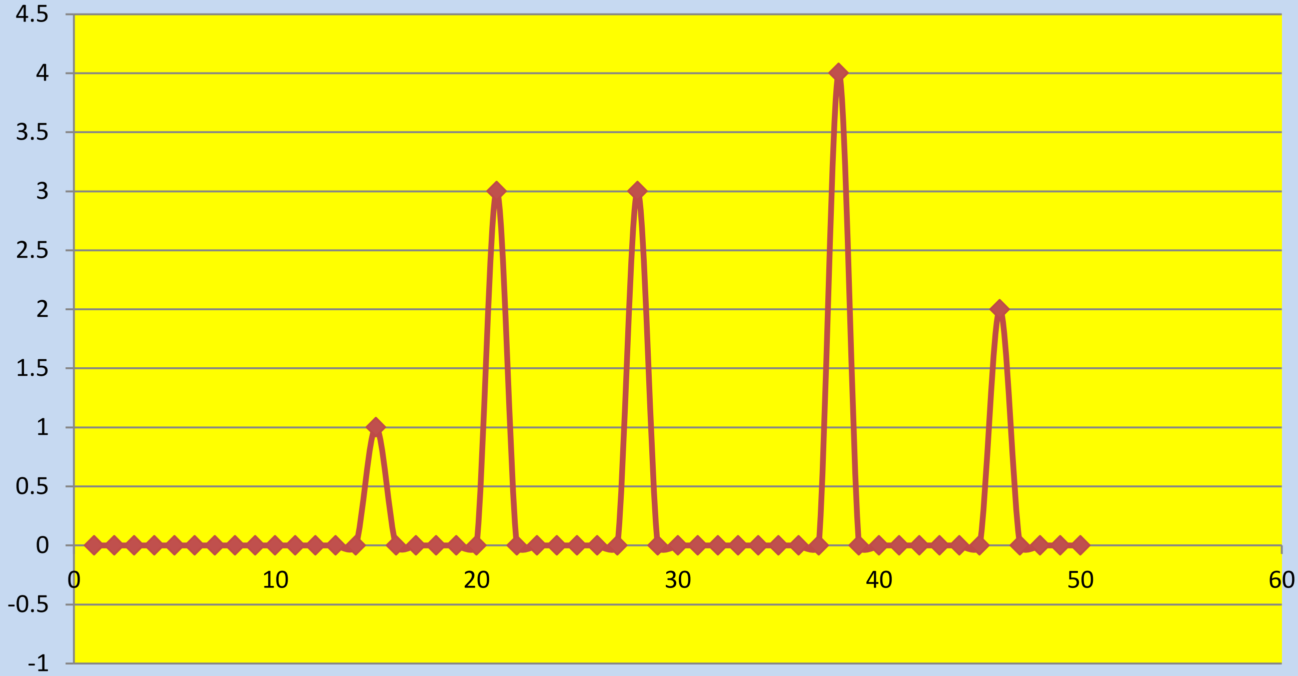

Figure1.1: Mean Values of Total Coliform Bacteria count in fifty (50) drinking Water samples in Abeokuta city, South-western Nigeria

4. CONCLUSION

Conclusively, the physico-chemical characterization of a total of fifty (50) differently sourced water samples obtained from fifty (50) drinking water sources [comprising of ten (10) taps, fifteen (15) Hand-dug wells and Twenty-five (25) Bore-holes] in Abeokuta metropolis –the capital city of Ogun state in South-western Nigeria; were carefully carried-out under laboratory conditions to determine whether or not they [i.e. the Water samples] are suitable to be consumed by humans as potable (safe drinking) water; by comparative analysis of the measured value of each of the twenty-six (26) tested parameter per sample with the maximum [or minimum] standard values stipulated by three relevant standardizing bodies/organizations i.e. the World Health Organization (WHO), the Nigerian Standard for Drinking Water Quality (NSDWQ), and the Standards Organization of Nigeria (SON); where applicable.

Now, based on the experimentally obtained results and data, it is evident that, 100% [I.e. all fifty (50)] tested representative drinking water samples conformed to the standards' required limits with respect to eighteen (18) out of the twenty-two (22) analytically comparable parameters [based on provided specific standard limit, which were: Alkalinity, Salinity, Total hardness, Turbidity, Electrical-conductivity, Temperature, Sodium, Potassium, Calcium, Magnesium, Chloride, Sulphate, Nitrate, Total Dissolved Solids, Biochemical Oxygen Demand, Zinc, Chromium and Manganese].

The only exceptions were the isolated cases of the 78% [i.e. 39 out of the 50] water samples that did not conform to the standard water pH safe limits, the 12% [i.e. 6 out of 50] water samples with non-conformity to the standard water Lead safe limits, the 100% [i.e. 50 out of the 50] water samples that did not conform to the standard water Iron safe limits, and the 84% [i.e. 42 out of 50] water samples with non-conformity to the standard water Cadmium safe limits. It is noteworthy to mention that, apart from the non-conformity case of excessive iron content in water, all other aforementioned cases of non-conformity [i.e. instances of excessive pH, Lead and Cadmium in water] could result in one or more combinations of the following adverse health conditions: disequilibrium in the delicate alkalinity-acidity balance maintained by the human body, cancer, nervous system dysfunction and kidney-related problems. Finally, only 10% [i.e. 5 out of 50] water samples had a low risk total coliforms contamination.

RECOMMENDATIONS

Based on the above fore-goings, we hereby make the following recommendations:

i. The government should put in place a system that ensures the efficient management and safe use of water resources by public/business organizations and private individuals.

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ii. The government should ensure that, an effective sanitation and waste management system be put in place to eliminate/mitigate the commonly occurring cases of ground water contamination.

iii. Private home owners and real estate developers should adhere to the standardized practice of allowing a minimum spacing of $15m$ (approximately 50 *feet*) between septic tanks and bore-holes/hand-dug wells, as is illustrated in Figure 1.3

iv. Private home-owners should not site their Septic tanks or Soak-away pits near the perimeter fence demarcating their premises/ apartments from those of their proximal [parallel] neighbours. This is to prevent more of the rampant cases of underground movement of biodegraded liquid-like fecal wastes from their septic tank, and contaminated waste water from their soak-away pits to their neighbours' borehole water source (aquifer, triggered by the unprofessional alignment of both the Borehole/Hand-dug well and the septic tank/Soak-away pit, in a common (the same) plane of the underground fluid flow direction and gradient; as is illustrated in Figure 1.4

v. Private home-owners and small business entrepreneurs should not utilize more than forty percent (40%) of their land (premises) for structural development.

vi. Architects should be consulted by intending private home-owners and real estate developers for proper space planning and management of their premises prior to, and during the infrastructural developments of their landed properties.

vii. Government should organize sensitization workshops and public awareness programmes on the dangers of consuming (drinking) contaminated water.

viii. Government should fund and support further research in this and other technically related subject matters.

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Figure1.2. Typical illustration of Rainwater harvesting and storage for use as drinking water source in some poor Nigerian homes

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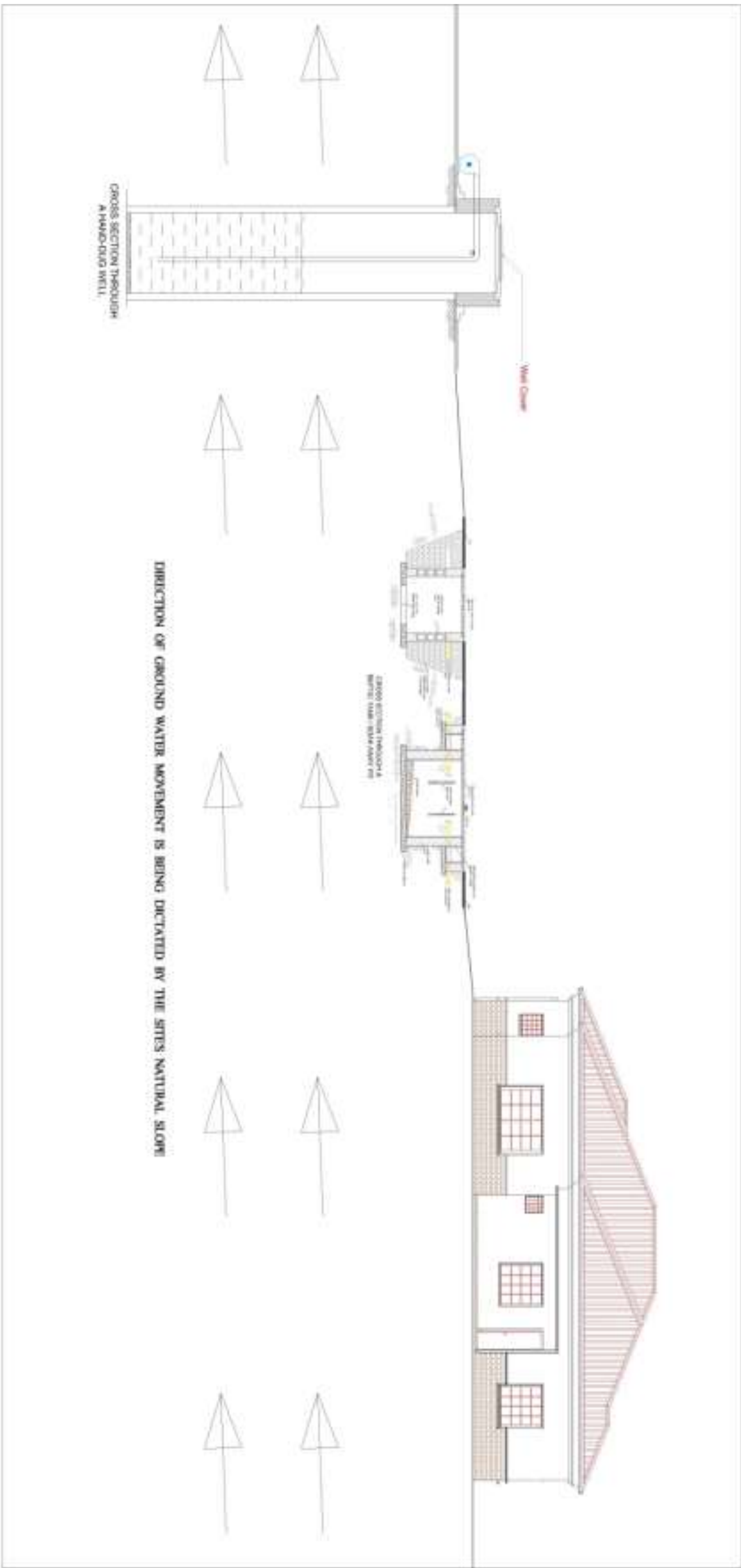

Figure1.3. **Hand-dug well/Borehole sunk (dug) at a distance (spacing) which is less than 15m from the Septic tank/Soak-away pit, resulting in the underground movement of biodegraded fecal wastes and contaminated waste water, from the 'Septic tank/Soak-away pit' to the 'Hand-dug well/Borehole'.**

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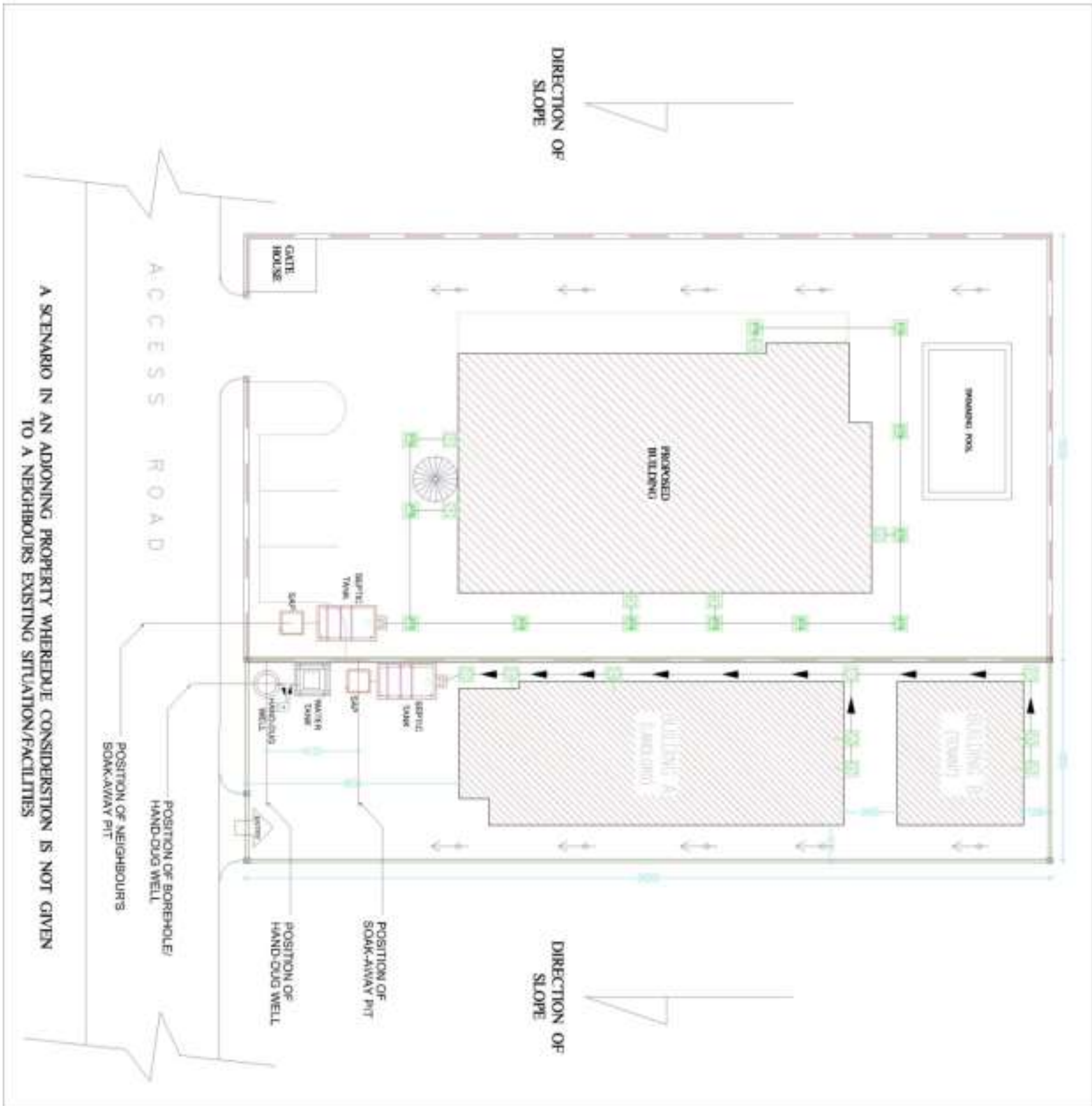

Figure1.4. **Septic tank/Soak-away pit of Neighbour 'A' near (very close to) the perimeter fence demarcating his premises from the nearby parallel premises of his Neighbour 'B'. This could result in the underground movement of biodegraded fecal wastes and contaminated waste water, from the Septic tank/Soak-away pit of Neighbour 'A' to the Hand-dug well/Borehole of Neighbour 'B'.**

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