Spatial and source disparities of groundwater quality in Dawakin-Tofa local government area of Kano State, Nigeria

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Abstract. The research assessed the spatial and source variations in groundwater quality in different locations and wells respectively across Dawakin-Tofa Local Government Area. The study area was divided into 10 by imposing a grid on its map and thereafter 10 hand dug wells and boreholes were selected, one from each location. Physical and chemical parameters like temperature, pH, Total Dissolved Solids (TDS) and heavy metals were tested in the laboratory and figures statistically compared with Nigeria’s national standard using ANOVA. The most notable difference in quality parameters between open wells and boreholes is in TDSs, electrical conductivity and chlorine content. The differences recorded in the other quality parameters ranged from between 0.0026 mg/l (in the case of lead) to 0.7°C (in the case of Temperature). This showed that the physio-chemical properties of open wells and boreholes are not much significantly different in the areas. The mean difference of TDSs between wells and boreholes in Dawakin-Tofa LGA is 35.721 mg/l, meaning that well waters are generally more turbid than that of boreholes which was not unexpected because of structural differences and modes of operation. While some quality parameters in Dawakin Tofa like TDSs, Electrical Conductivity, Temperature, Chlorine and Manganese content generally recorded non-harmful values as compared to the drinking standard; others like lead, chromium, cadmium recorded harmful values. Only Jalli (with above 300) and Tattarawa (with above 400) mg/l recorded TDS levels close to the maximum accepted limit of 500. This study further confirms the increased danger and risk of contaminated groundwater among consumer’s not only urban areas, but also in rural areas as well. Though, the levels of some elements like Sodium, Chlorine, Manganese and Magnesium in groundwater of Dawakin-Tofa LGA are currently within the National Acceptable limits, but the concentration of heavy metals clearly shows there is serious risk. Continuous monitoring, control and necessary policy decisions were recommended.

1. Introduction

Water is one of the most precious gift with which nature has blessed mankind and it is absolutely vital for the sustenance and maintenance of life. The problem of water in many cases has been more of quality than availability [1] and [2]. While it is argued that water availability is the bedrock of human development and monitoring its state of dynamism is critical [3], it is also noted that quality is what determines its usability for different domestic and industrial purposes [4].

Groundwater is the water contained beneath the surface in rocks and soil, and is the water that accumulates underground in aquifers. Groundwater constitutes 97% of global freshwater and is an
important source of drinking-water in many regions of the world [5]. In many parts of the world groundwater sources are the single most important supply for the production of drinking-water, particularly in areas with limited or polluted surface water sources. For many communities it may be the only economically viable option. This is because groundwater is typically of more stable quality and better microbial quality than surface waters. Groundwater often requires little or no treatment to be suitable for drinking whereas surface waters generally need to be treated, often extensively [5]. There are many examples of groundwater being distributed without treatment. It is vital therefore that the quality of groundwater is protected if public health is not to be compromised.

Due to the fact that the available surface water resources are inadequate to the entire water requirements for all purposes, the demand for groundwater has increased over the years [6]. Anthropogenic activities especially in large urban areas and even rural and semi-urban areas have however threatened the safety of groundwater supply sources [6]. It is noted that in the face of scarcity, many people conversely, resorts to self-supply options including; hand-dug wells, ponds, dug-outs, riverbed waterholes, streams, springs and rainwater sources. These sources are usually unprotected and often contaminated as a result of the vast anthropogenic activities that are, in most cases, neither regulated nor properly managed [6].

Dawakin-Tofa local Government area as major semi-urban area is dotted with anthropogenic activities that may alter the quality of groundwater both in the short and in the long run; agricultural activities involving the extensive and intensive use of fertilizers and pesticides in the rural sections of the local government may significantly and adversely affect groundwater quality. This research aims to investigate the problem and offer appropriate recommendations.

Researches in groundwater quality and vulnerability to contamination in Dawakin-Tofa and many parts of rural Kano State in general are largely inadequate. Two general factors are responsible for this; our general assumption that groundwater is virtually safe as compared to surface water [7] and our subconscious belief that groundwater sources in rural and semi-urban areas are not susceptible to pollution as against their urban and metropolitan counterparts. It is noted that the challenge for the future development of groundwater of the Kano Region has to do with the rising demand of water by an ever increasing population and per capita demand for water by the urban and rural dwellers [8].

Assessing physical and chemical groundwater quality in general and making quality comparisons between groundwater from hand dug wells and boreholes on one hand and with national and international standards on the other which many researches like [9-14] among others didn’t adequately address, is a primary aim of this research. The transformation of the study area from a typically rural setting to a semi-urban and in some sections, fully urban setting over the last fifteen years has been rapid. One of the resources that have been significantly affected by such transformation is water in terms of both quantity and quality. It is against this backdrop that this research aims to conduct research in order to proffer valuable solutions and recommendations.

2. Materials and methods

2.1. Description of study area

Dawakin-Tofa Local Government area lies between latitude 11° 57′ N to 12° 09′ N and longitudes 8° 08′ E to 8° 09′ E, with an area size of 479km² [8,15]. The study area is bordered to the East by Minjibir and Ungogo Local Governments, to the South by Tofa Local Government, to the West by Bagwai Local Government and to the South by Bichi and Makoda Local Governments. The sampled villages and towns among the 38 major districts in the study area are Tattarawa, Ganduje, Jemomi, Marke, Dungurawa, Jalli, Dawakin-Tofa, Tumfafi, Danguguwa and Dawanau as shown in figure 1.
2.2. Materials
Materials used in this research include plastic bottles for collecting and storing water samples; masking tape was used to label the samples. Garmin 72 Geo-Positioning System (GPS) was used to take coordinates of sampling points. Data collected include water samples from boreholes and hand dug wells.

2.3. Reconnaissance survey and sampling
A reconnaissance survey was carried out for the familiarization with the study area as well as observation of some major sources of groundwater and water related problems in the area and to compare on the field, different groundwater sources as well as to examine the kind of water sources and needs of people in the study area. This helped in ascertaining and consolidating the suitability of the sampling methods adopted.

The research had identified a total of 20 areas (5 outside the grid, making only 15 functional, from which 10 were chosen) across the local government. Twenty (20) points that are well spatially distributed were sampled from a grid drawn on a geo-referenced map of the study area (figure 2). The study selected one available borehole and one available open well within the grid from each sampled area for a thorough laboratory study so as to determine the groundwater quality.
2.4. Laboratory and statistical analyses

| SN | Parameter                                                                 | Equipment                      | Procedure                                                                                     |
|----|---------------------------------------------------------------------------|--------------------------------|----------------------------------------------------------------------------------------------|
| 1  | pH                                                                        | pH Meter                       | 50-mL water sample were measured and transferred in 100-mL flask, the combined electrode was inserted in the water sample (about 3-cm deep). The reading was taken after 30 seconds. The combined electrode were removed from the sample, and rinsed thoroughly with DI water in a separate beaker, and carefully dry excess water with a tissue. |
| 2  | Total Dissolved Solids (TDS) and Electrical Conductivity                   | Conductivity Bridge Meter.     | 75-mL of water sample was transferred in a 100-mL glass beaker, and the clean and dried conductivity cell were inserted in the glass beaker. The reading was taken and the display will also need some time to stabilize before the reading. The conductivity cell was removed from the glass beaker, rinsed thoroughly with DI water, and carefully dry excess water with a tissue. |
| 3  | Chloride                                                                 | Titration                      | In the case of chloride concentration, it was determined by titration with a standard solution of silver nitrate using an indicator of 8% potassium chromate solution, the appearances of red precipitate signifies the titration end point. |
| 4  | Sodium                                                                   | Flame photometer               | The portion of water sample was filtered through Whatman filter paper No. 42. For operating the Flame Photometer, follow the maker’s instructions. Flame Photometer was calibrated with a series of suitable Na standards with DI water as blank sample. The water samples were measured, take the emission reading on the Flame Photometer at 589-nm wavelength, and record the readings. The flame photometer was Switch off according to the maker’s instructions. |
Heavy Metals

Various

- 100 ml of water sample were transferred into a large beaker (750 ml capacity); 5 ml of concentrated HNO₃ were added and evaporated on a steam bath to approximately 25 ml; 50 ml acid-washed was transferred in to volumetric flask; The deionized water volume was brought up; Chromium, Lead, Cadmium, Manganese and Magnesium were analyzed using atomic absorption spectrometer (AAS), while Sodium was analyzed using plane photometer (ppm).

Source: Soil and Water Lab, Bayero University Kano.

The statistical tools employed in this study are both descriptive and inferential. Tools like measures of central tendencies (mean, median and mode), Analysis of Variation (ANOVA), frequency calculation, percentages, pie charts and bar charts were used in this research for data analysis and presentation. Other statistical methods used included totals, mean deviations and standard deviations.

3. Results and discussions

3.1. Physiochemical properties of groundwater

Some of the physiochemical properties of groundwater were analysed and presented according to their source of exploration (hand dug wells and borehole), variation and comparison between hand dug wells and borehole water samples was also carried out.

3.1.1. Quality of hand-dug wells water. The laboratory results for hand dug wells water collected from 10 wells across Dawakin-Tofa Local-Government revealed the analysis of some important physical and chemical quality parameters (table 1). The mean pH is 6.66 with a range of 6.0 in Jemomi to as much as 7.2 in Dawakin-Tofa town. This variation is observed to be caused by urbanization and complexity of activities (Dawanau) because, with the exception of Jemomi, all the remaining towns and villages level of water acidity was a reflection of the complexity of activities in the areas. Concentration of heavy metals was high across all towns due to excessive use of fertilizers in farms. Total Dissolved Solids and Chlorine content are the most variable among the towns as they had the highest standard deviation from the others. Lead and Chromium concentration are almost uniform with low standard deviation (table 1).

| Parameter | pH | EC | Pb (ppm) | TDS (mg/l) | Cr (mg/l) | Cd (mg/l) |
|-----------|----|----|----------|-----------|----------|----------|
| Mean Dug Well | 6.66 | 221.62 | 0.088695652 | 132.895 | 0.0740741 | 0.16 |
| Mean Borehole | 6.36 | 159.99 | 0.091304348 | 97.174 | 0.062963 | 0.12 |
| Nigerian Standard | 6.5-8.5 | 1000 | 0.01 | 500 | 0.05 | 0.003 |

Source: Laboratory and Statistical Analysis, 2017

| Parameter | T (°C) | Cl (mg/l) | S (mg/l) | Pb (ppm) | Mn (mg/l) | Mg (gm/l) |
|-----------|--------|-----------|----------|----------|-----------|-----------|
| Mean Dug Well | 22.76 | 74.195 | 0.005 | 0.088695652 | 0.09 | 0.56 |
| Mean Borehole | 22.6 | 61.415 | 0.001813 | 0.091304348 | 0.1 | 0.64 |
| Nigerian Standard | Ambient | 250 | 0.05 | 0.01 | 0.2 | 0.2 |

Source: Laboratory and Statistical Analysis, 2017
3.1.2. Quality of boreholes wells water. The laboratory results for boreholes water collected from 10 towns across Dawakin-Tofa Local-Government analysed some important physical and chemical quality parameters (table 2). The mean pH is 6.36 with a range of 5.8 in Jemomi to as much as 7.2 in Tattarawa town. Total Dissolved Solids and electrical conductivity are the most variable among the towns as they had the highest standard deviation from the others. Lead, Cadmium and Chromium concentration are almost uniform with low standard deviation (table 2).

Table 3. Comparism of groundwater quality parameters for hand dug wells and boreholes.

| Parameters | pH    | EC   | T (°C) | TDS (mg/l) | Cl (mg/l) | S (mg/l) |
|------------|-------|------|--------|------------|-----------|----------|
| Wells Mean | 6.66  | 221.62 | 22.76 | 132.90     | 74.19     | 0.005    |
| Boreholes Mean | 6.36  | 159.99 | 22.6  | 97.17      | 61.42     | 0.0018   |
| Difference  | 0.30  | 61.63 | 0.7    | 35.721     | 12.78     | 0.0032   |

Parameters | Pb (ppm) | Cr (mg/l) | Cd (mg/l) | Mn (mg/l) | Mg (gm/l) | Na (mg/l) |
|------------|----------|-----------|-----------|-----------|-----------|-----------|
| Wells Mean | 0.089    | 0.074     | 0.16      | 0.09      | 0.56      | 9.867     |
| Boreholes Mean | 0.091  | 0.063     | 0.12      | 0.1       | 0.64      | 10.333    |
| Difference  | 0.0026   | 0.068     | 0.04      | 0.01      | 0.08      | 0.47      |

Source: Laboratory analysis, 2017

3.1.3. Comparism of hand-dug wells and boreholes water quality parameters. The most notable difference in groundwater quality parameters between hand dug wells and boreholes is in total dissolved solids, electrical conductivity and chlorine content (table 3). The differences recorded in the other quality parameters ranged from between 0.0026 mg/l (in the case of lead) to 0.7°C (in the case of Temperature). This shows that the physio-chemical properties of hand dug wells and boreholes are not much significantly different in the areas. The reason behind this is that both of them have roughly the same average depth with their aquifers having same recharge sources as well as being vulnerable to similar if not the same pollutants.

Figure 3. Variation in physiochemical properties of hand-dug wells and boreholes.

The mean difference of total Dissolved solids between hand dug wells and boreholes in Dawakin-Tofa Local government area is 35.721 mg/l, meaning that hand well waters are generally more turbid than that of boreholes which was not unexpected because of structural differences and modes of
operation. However, with the exception of Jalli and Tattarawa, the difference between the individual Total Dissolved Solids levels of boreholes and hand dug wells in the other 8 towns and villages was not significant (figure 3). There was also a wide difference in electrical conductivity values in the two villages (figure 3). Significant differences in chlorine levels between hand dug wells and boreholes were also sharply observed in Ganduje, Danguguwa and Dawakin-Tofa towns (figure 4). The main reason behind this is that apart from been open; wells are shallower than boreholes and therefore more vulnerable natural and anthropogenic chlorination activities.

Parameters like pH, temperature, Sulphur, Cromium, Cadmium, Magnesium and Sodium levels showed insignificant or negligible differences between boreholes and hand dug wells across the towns (figure 4).

With the general level of Total dissolved solids recorded at below 450 mg/l, the electrical conductivity was not expected to be high. The variation of heavy metals in general and Lead levels in particular between boreholes and hand dug wells was not significant, but with the element being a parameter with serious negative health implications, it was analysed only some wells in Dawanau and Jemomi recorded relatively lower values as shown in figure 4 above.

3.2. Groundwater quality against national standard

Quality wise, there was little to separate between boreholes and hand dug wells across Dawakin-Tofa local government. However, there was significant difference when compared to the drinking standard. The 2007 Nigerian Standard for Drinking Water Quality, prepared by the Standards Organization of Nigeria and approved by its governing council was used to compare the mean recorded values of quality parameters in both wells and boreholes.

3.2.1. General groundwater water quality standard against national standard. While some quality parameters in Dawakin Tofa like Total dissolved Solids, Electrical Conductivity, Temperature, Chlorine and Manganese content generally recorded non-harmful values as compared to the drinking standard; others like lead, chromium, cadmium recorded harmful values (figures 3-9).

Only Jalli (with above 300) and Tattarawa (with above 400) mg/l recorded total dissolved solid levels close to the maximum accepted limit of 500 (figure 5). This partly explains why the two villages also recorded a relatively higher electrical conductivity (figure 6), but none of which was quite close.
to the 1000 uS/cm maximum accepted levels for usage.

**Figure 5.** Comparison of TDS levels in Dawakin-Tofa groundwater with Nigerian Standard.

**Figure 6.** Comparison of electrical conductivity in Dawakin-Tofa groundwater with Nigerian Standard.

In terms of chlorine content, none of the recorded values across the wells and boreholes of the 10 towns in Dawakin-Tofa Local government that are half as much the acceptable limit of 250 mg/l except hand dug wells Tattarawa that were observed to be mostly uncovered and vulnerable (figure 7). The high amount of manganese in Jemomi, Tumfafi and Marke (figure 8) is believed to be due to the nature of weathered rocks and aquifers in those areas. The areas are dominated by laterites which
contains high amount of manganese and iron.

![Chlorine (mg/L)](chart1.png)

Source: Statistical Analysis, 2017

**Figure 7.** Comparism of Chlorine levels in Dawakin-Tofa groundwater with Nigerian Standard.

![Manganese (Mg/L)](chart2.png)

Source: Statistical Analysis, 2017

**Figure 8.** Comparism of manganese levels in Dawakin-Tofa groundwater with Nigerian Standard.

Heavy metals are very high in all the areas as compared to the national standard (figures 9-11). The worst case was that of Cadmium with Dungurawa and Dawakin-Tofa towns recording values 100 times higher than the acceptable limit of 0.003 mg/l. all other areas have values from 33 to above times higher than the permissible limits. The case of lead was also alarming particularly in areas like Tattarawa, jemomi and Dawanau. Chromium concentration, despite being relatively lower when
compared to lead and chromium was still high compared to the permissible limits. It was observed that towns and villages in the study area that were located close to major roads had higher concentration of heavy metals.

**Figure 9.** Comparison of lead levels in Dawakin-Tofa groundwater with Nigerian Standard.

**Figure 10.** Comparism of chromium levels in Dawakin-Tofa groundwater with Nigerian Standard.
Figure 11. Comparism of cadmium levels in Dawakin-Tofa groundwater with Nigerian Standard.

3.2.2. Analysis of variance of quality parameters with National Standard. The Analysis of Variation (ANOVA) was conducted using Microsoft excel and the results and interpretations are shown in tables 4 and 5 below.

Table 4. Analysis of variation for groundwater quality parameters.

| Parameter | pH | EC | Pb (ppm) | TDS (mg/l) | Cr (mg/l) | Cd (mg/l) |
|-----------|----|----|----------|------------|-----------|-----------|
| Source    | Well | Borehole | Well | Borehole | Well | Borehole | Well | Borehole | Well | Borehole | Well | Borehole |
| Mean      | 6.66 | 6.36 | 221. 159. | 0.0886 | 0.0913 | 132.8 | 97.17 | 0.074 | 0.062 | 0.16 | 0.12 |
| Limits    | 6.5-8.5 | 0.01 | 500 | 0.05 | 140.9 | 74.71 | 0.024 | 0.030 | 0.09 | 0.04 |
| Standard  | 0.34 | 0.40 | 234. 123. | 0.0470 | 0.0380 | 10213 | 7174 | 6914 | 4916 | 6609 | 2164 |
| Variation | 0.007163539 | 0.001808251 | 0.21560262 | 0.011377478 | 0.076643847 | 0.126048376 |

Source: Laboratory and Statistical Analysis, 2017

Table 5. Interpretation of ANOVA results.

| Parameter           | Anova Interpretation                                                                 |
|---------------------|---------------------------------------------------------------------------------------|
| pH                  | No significant difference between means which are all within acceptable drinking range. |
| Electrical Conductivity | No significant difference between means which are all far below the minimum acceptable standards. |
| Lead                | High significant difference between means. This means despite the averages being high above acceptable drinking standards, many samples are at extreme risk compared to others. |
| Total Dissolved Solids | No significant difference between means which suggests that the turbidity levels are more or less the same. |
| Chromium            | High significant difference between means. This means despite the averages being high above acceptable drinking standards, many samples are at extreme |
risk compared to others.

Cadmium

High significant difference between means. This means despite the averages being high above acceptable drinking standards, many samples are at extreme risk compared to others.

Source: Statistical Analysis, 2017

3.3. Groundwater quality implication for the area

3.3.1. Parameters showing serious health implications.

Table 6. Observed parameters with serious health implications.

| Parameter       | Permitted levels | Observed levels | Health impact                          | Areas at risk                                      |
|-----------------|------------------|-----------------|----------------------------------------|-----------------------------------------------------|
| Cadmium (Cd)    | 0.003 mg/L       | 0.16 and 0.12   | Toxic to kidney                        | All areas with the exception of Tumfafi              |
| Chromium (Cr 6+) | 0.05 mg/L        | 0.074 and 0.063 | Cancer                                 | Ganduje, Dungurawa and Dawakin-Tofa looks safer; all other areas at serious risk. |
| Lead (Pb)       | 0.01 mg/L        | 0.089 and 0.091 | Cancer, interference with vitamin D, Metabolism, affects mental development in infants, toxic to the central and the peripheral nervous system. | All areas                                           |
| Manganese (Mn +2) | 0.2 mg/L       | 0.09 and 0.1    | Neurological disorder                  | Jemomi and Marke                                    |

Source: Modified after SON, 2007

3.3.2. Parameters showing minimal health implications.

Table 7. Observed parameters with minimal or no health implications.

| Parameter            | Permitted levels | Observed levels | Health impact                      | Areas at risk                  |
|----------------------|------------------|-----------------|------------------------------------|--------------------------------|
| Temperature          | Ambient          | 22.76 and 22.6  | None                               | None                           |
| Total Dissolved Solids | 500mg/L        | 132.895 and 97.174 | None                              | None                           |
| Chloride (Cl)        | 250 mg/L         | 74.195 and 61.415 | None                              | None                           |
| Conductivity         | 1000 µS/cm       | 221.62 and 159.99 | None                              | None                           |
| Magnesium (Mg+2)     | 0.2 mg/L         | 0.56 and 0.64   | Consumer acceptability             | Safe                           |

Source: Modified after SON, 2007

4. Conclusion

This study further confirms the increased danger and risk of contaminated groundwater (as shown in tables 6 and 7) among consumer’s not only urban areas, but also in rural areas as well. However, the levels of some elements like Sodium, Chlorine, Manganese and Magnesium in groundwater of Dawakin-Tofa Local Government Area the metals are currently within the National Acceptable safe limits, but the concentration of heavy metals clearly shows there is serious risk. Furthermore, the discrepancies between groundwater quality of boreholes and that of wells in many areas suggests that only high quality and properly maintained and standardized groundwater extraction facilities can bridge this gap between the two.

If the practice of consuming groundwater without treatment continues in the area, it may lead to health hazard (tables 6 and 7) on the part of consumers both in the short and long term. Therefore, there is a need to continually monitor, control and take necessary policy decisions so as to limit and ultimately prevent these avoidable problems. Groundwater quality monitoring adequate to assess the
achievement of water quality objectives set for designated Beneficial Uses need to be put into place in priority areas. Regular reporting should be at the groundwater management unit scale and capable of being collated at National and State levels and be publicly available.

Since the supply of treated pipe borne water to all villages and settlements in Dawakin-Tofa is not beyond the capacity of local and state authorities, it is advisable that such should be done as soon as possible. Alternatively, this can be jointly done by local and state governments especially in providing pipe-borne water. This will minimize the level of consumption of some heavy metals in the water, since it will undergo some treatment before sending it to various villages and towns.

5. Appendix: quality standards
The latest available Nigerian national drinking water standard (table 8) as prepared by the National Administration for Foods Drugs Administration and Control (NAFDAC) and certifies by the Nigerian National Standard (Nigerian Industrial Standard, 2007) was reviewed.

Table 8. Nigerian Water Quality Standard (2017).

| Parameter                   | Unit    | Max. permitted levels | Health impact                                           | Note       |
|-----------------------------|---------|-----------------------|---------------------------------------------------------|------------|
| Physical/organoleptic       |         |                       |                                                         |            |
| Colour                      | TCU     | 15                    | None                                                    |            |
| Odour                       |         |                       | Unobjectionable                                         |            |
| Taste                       |         |                       | Unobjectionable                                         |            |
| Temperature                 | ° Celsius | Ambient                | None                                                    |            |
| Turbidity                   | NTU     | 5                     | None                                                    |            |
| Chemical/inorganic          |         |                       |                                                         |            |
| Aluminium (Al)              | mg/L    | 0.2                   | Potential neuro-degenerative disorder                   | Note 1     |
| Arsenic (As)                | mg/L    | 0.01                  | Cancer                                                  |            |
| Barium                      | mg/L    | 0.7                   | Hypertension                                            |            |
| Cadmium (Cd)                | mg/L    | 0.003                 | Toxic to kidney                                          |            |
| Chloride (Cl)               | mg/L    | 250                   | None                                                    |            |
| Chromium (Cr 6+)            | mg/L    | 0.05                  | Cancer                                                  |            |
| Conductivity                | µ S/cm  | 1000                  | None                                                    |            |
| Copper (Cu +2)              | mg/L    | 1.0                   | Gastro-intestinal disorder                              |            |
| Cyanide (CN-)               | mg/L    | 0.01                  | Very toxic to the thyroid and nervous system             |            |
| Fluoride (F−)               | mg/L    | 1.5                   | Fluorosis, skeletal tissue (bones and teeth) morbidity   |            |
| Hardness (CaCO3)            | mg/L    | 150                   | None                                                    |            |
| Hydrogen Sulphide (H2S)     | mg/L    | 0.05                  | None                                                    |            |
| Iron (Fe +2)                | mg/L    | 0.3                   | None                                                    |            |
| Lead (Pb)                   | mg/L    | 0.01                  | Cancer, interference with vitamin D, Metabolism, affects mental development in infants, toxic to the central and the peripheral nervous system. |            |
| Magnesium (Mg +2)           | mg/L    | 0.2                   | Consumer acceptability                                  |            |
| Manganese (Mn +2)           | mg/L    | 0.2                   | Neurological disorder                                   |            |
| Chemical/organic            |         |                       |                                                         |            |
| Detergents                  | mg/L    | 0.01                  | Possibly carcinogenic                                   |            |
| Mineral oil                 | mg/L    | 0.003                 | Possibly carcinogenic                                   |            |
| Pesticides                  | mg/L    | 0.01                  | Possibly carcinogenic                                   |            |
| Phenols                     | mg/L    | 0.001                 | Possibly carcinogenic                                   |            |
| Parameter                                      | Unit     | Value  | Limitation                                      |
|-----------------------------------------------|----------|--------|------------------------------------------------|
| Polyaromatic hydrocarbons                     | mg/L     | 0.007  | Possibly carcinogenic                           |
| Total organic carbon or oxidisability         | mg/L     | 5      | Cancer                                          |
| **Disinfectants and their by-products**       |          |        |                                                 |
| Free residual chlorine                        | mg/L     | 0.2-0.25| None                                            |
| Trihalom-ethanes                              | mg/L     | 0.001  | Cancer                                          |
| Total 2,4,6-trichlorophenol                   | mg/L     | 0.02   | Cancer                                          |
| Radioactive limits                            |          |        |                                                 |
| Radionuclides                                 | Bq/L     | 0.1    | Cancer                                          |
| **Microbiological limits**                    |          |        |                                                 |
| Total coliform count                          | cfu/mL   | 10     | Indication of faecal contamination              |
| Thermo-tolerant coliform or E.coli            | cfu/100mL| 0      | Urinary tract infection, bacteraemia, meningitis, diarrhea (one of the main causes of morbidity and mortality among children), acute renal failure and haemolytic anaemia. |
| Faecal streptococcus                          | cfu/100mL| 0      | Indication of recent faecal contamination       |
| Clostridium perfringens spore                 | cfu/100mL| 0      | Index of intermittent faecal contamination      |

Source: Standard Organization of Nigeria, 2007

Note 1: Parameters subject to monitoring water treated using aluminium compound
Note 2: Parameters subject to monitoring water treated using chlorine compound
Note 3: 95% compliance over a one-year period

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