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# Hydrogeochemical analysis and quality evaluation of groundwater from Onicha-Uburu, Southeastern Nigeria for irrigation purposes

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**A total of 20 groundwater samples from boreholes and hand dug wells within Onicha-Uburu and its environs were assessed to determine their suitability for irrigation purposes. Physical and hydrogeochemical parameters were evaluated, while techniques such as sodium absorption ratio (SAR), sodium percent, residual sodium carbonate (RSC) and magnesium adsorption ratio (MAR) were used to assess the suitability of these groundwater samples for the intended purpose. Results indicated that temperature ranges between 20 and 26°C for hand dug wells and 19 and 23°C for borehole samples. The electrical conductivity (EC) varies from 8.4 to 36.4 µs/cm for the hand dug wells and 10.0 to 76.4 µs/cm for the borehole water samples, while pH values range between 7.0 and 9.0 for the entire samples and indicate alkaline water. Statistical analysis shows appreciable concentrations of basic ions (average value of 28.8 mg/l for $Na^+$, 9.1 mg/l for $K^+$, 16.0 mg/l for $Ca^{2+}$, 14.6 mg/l for $Mg^{2+}$, Nil for $C0_3^{2-}$, as well as 45.0 mg/l for $HC0_3^-$, 20.5 for mg/l $Cl^-$ and 8.7 mg/l for $S0_4^{2-}$). While $Na^+$ and $Ca^{2+}$ are the predominant cations, $HC0_3^-$ and $Cl^{-1}$ are the anions that predominate. The chemical analysis revealed that the total hardness (measured in terms of $CaCO_3$) varied from 16 to 140 mg/l for both sets of samples indicating soft to moderately hard water. Based on the values of EC, percent sodium, SAR (which vary from 0.3 to 1.7 meq/l), RSC (from 0.1 to 0.99 meq/l less than the standard value of 1.25 meq/l) and the magnesium hazard (MH) values which range between 0.99 and 89.8%, revealed that water samples from the study area are generally suitable for irrigation purposes except for few locations.**

**Key words:** Groundwater, hydrochemical facies, hydro-geochemical analysis, irrigation purposes, Onicha-Uburu area.

## INTRODUCTION

It is generally recognized that the quality of groundwater is just as important as its quantity. Most groundwater contains dissolved salts in concentrations as to make them unusable for ordinary water supply purposes. Soluble salts in groundwater originate primarily from natural dissolution of common rock minerals such as silicates, clays (for example, kaolinites and montmorillonite), feldspars as well as carbonates (Todd, 1980). Apart from natural processes, other controlling factors on the groundwater quality include pollution, resulting from some uncontrolled affluent discharge from industries, harmful agricultural practices (e.g., excessive application of nitrate-based fertilizers) and acid rain. The quality required of a groundwater supply depends on its purpose,

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examples: drinking (that is, human consumption), industrial use, irrigation, recreation and fish culture purposes (Todd, 1980). Knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity (Brady, 2002).

The suitability of groundwater for irrigation is contingent on the effects of the mineral constituents of the water on the plants and the soils as well as the salt. According to Todd (1980), poor quality irrigation (with high salt concentration) water may affect plant growth physically by limiting the uptake of water through modification of osmotic processes. According to Todd (1980), effects of salts on soils could result in alterations in soil structure, permeability and aeration, which indirectly affect plant growth. Problems of groundwater quality degradation are much difficult to overcome as it often requires long period of time to detect the true extent of degradation. Groundwater chemistry also has a potential use for tracing the origins and the history of water as well as its compositional changes through reactions with the environment. The chemical parameters such as $Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $HCO_3^{-}$, $Cl^{-}$ and $SO_4^{2-}$ play a significant role in classifying and assessing water quality for irrigation.

Considering the individual and paired ionic concentration, certain indices are proposed to find out the alkali hazards. For example, residual sodium carbonate (RSC) can be used as a criterion for ascertaining the suitability of irrigation water (Sadashivaiah et al., 2008). Other methods of representing the chemistry of water, such as Collins bar diagram (Hem, 1970), radiating vectors (Maucha, 1940), and parallel and horizontal histograms (Stiff, 1940), have been successfully used in the past in some parts of the world to study the proportion of ionic concentrations in water samples. Sadashivaiah et al. (2008) followed a series of methods to interpret and classify the chemistry of groundwater in hard rock, including coastal zones in the Southern India. Presentation of chemical analysis in graphical form makes understanding of groundwater system simpler and quicker.

In this work, the major ionic chemistry of groundwater samples in Onicha-Uburu and its environs in Southeastern Nigeria are assessed using the methods proposed by Piper (1953) and United States Salinity Laboratory (Wilcox, 1995). Based on the results, their suitability for use for irrigation purposes is highlighted. Salinity, sodicity and toxicity generally need to be considered in the evaluation of the suitability of groundwater for irrigation (Todd, 1980). Parameters such as electrical conductivity (EC), percent sodium, residual sodium carbo-nate (RSC), magnesium hazard (MH) and sodium ad-sorption ratio (SAR) were used to assess the suitability of water for irrigation. Continued use of water with a high SAR value leads to a breakdown in the physical structure of the soil caused by excessive amounts of colloidally absorbed sodium. This breakdown results in the dispersion of soil clay that causes the soil to become hard and compact when dry and increasingly impervious to water penetration due to dispersion and swelling when wet. Fine-textured soils, those high in clay, are especially subject to this action. It is hoped that this study would assist in determining the degree of salinity, sodicity and toxicity thereby removing some of the speculation con-cerning the quality of water used for agricultural purposes in the Onicha-Uburu area, and its impact on crop yield.

## Geology and hydrogeology

Onicha-Uburu lies within the southeastern Nigeria in the southern Benue Trough (Figure 1). The origin of the trough has been associated with the breakup of the Gondwanaland in the early Cretaceous (Wright, 1979). The area is underlain by the Asu River Group. The Asu River Group is believed to be deposited by the first marine transgression in the trough, which started in the mid-Albian period. It is predominately shales and localized development of sandstone, siltstones and limestone (Reyment, 1965). The average thickness is about 2000 m.

Occurrence, movement and storage of groundwater within this area are influence by lithology, thickness and structure of rock formation (predominantly shales of the Asu River Group). Shale is an aquiclude and does not permit reasonable transmission of water, especially when fresh and unweathered. There are, however, intercalations of clays and sand clays which has led to artesian conditions in the study area. Nonetheless, the groundwater in the areas generally exists in zones; fractured zones within the Asu River Group, sandstone and limestone layers or members, weathered zones, and bedrock interfaces with shale group.

The area is largely drained by the Asu River and its tributaries such as River Odii, River Idee and River Ugenoma which is a continuation of Omuiyi River and the tributaries of the Cross River. Asu River takes its origin from Enugu Escarpment. The tributaries are perennial and usually overflow their banks at the peak of the rainy season. They are heavily contaminated as a result of mining activities in Okposi as well as indiscriminate waste disposal in the course of its flow.

## MATERIALS AND METHODS

A total of 20 samples, 10 from hands dug wells and 10 from boreholes, were collected from different locations within the study area for hydrogeochemical analyses whereas; physical tests (pH, temperature and electrical conductivity) were carried out *in situ*. The samples were designated WH A-J for the hand dug well samples and BH A-J for the borehole water samples. All the hydrochemical analyses were carried out in the laboratories of the department of Civil Engineering, University of Nigeria, Nsukka.

Clean 1 L volume plastic containers were used for the sampling. For the pH values of the samples (determined in the field), the HACH portable pH meter was employed. Analyses of ions were

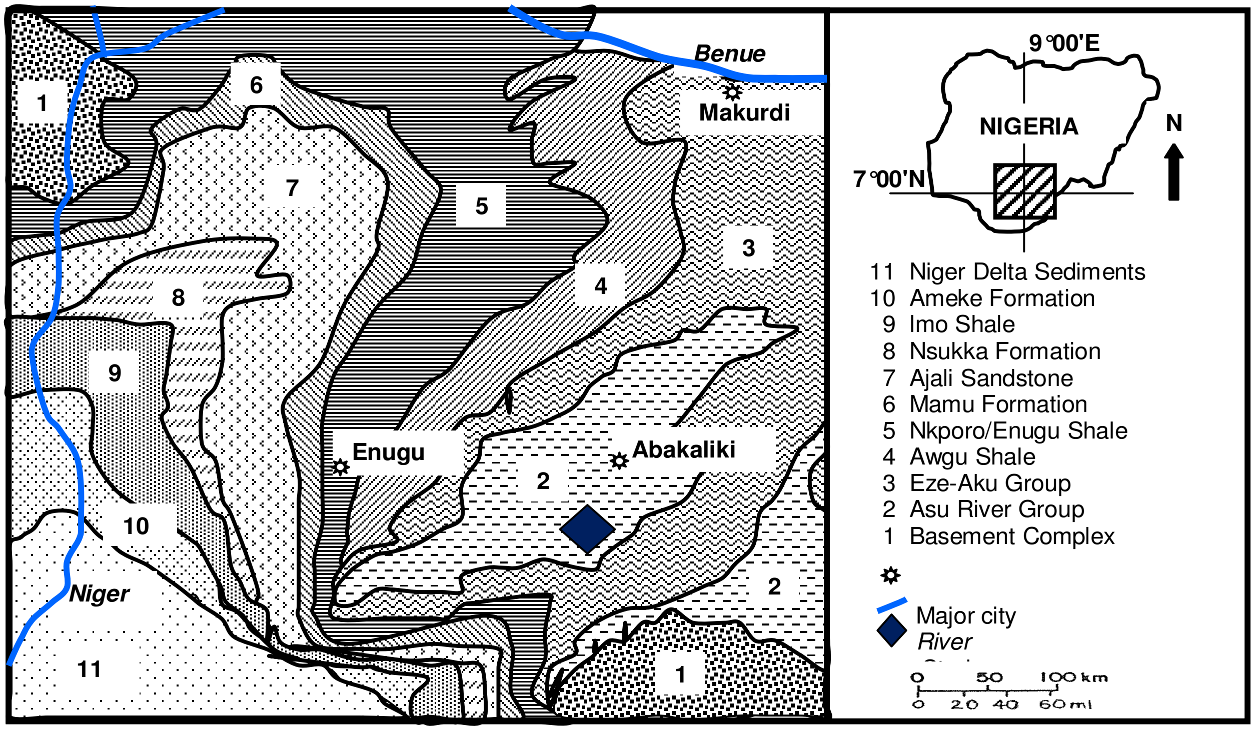


**Figure 1.** Geological map of Southeastern Nigeria showing the study area (Reyment, 1967).

limited to the major elements' ions such as $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, $CO_3^{2-}$, $HCO_3$, $Cl^-$ and $SO_4^{2-}$. These were carried out (in the laboratory) employing standard procedures recommended by American Public Health Association (APHA 1994).

### Statistical analysis

Statistical average and ranges for each of the parameters represent the mean value and the lowest and highest values, respectively, for all the locations considered. The sodium in irrigation water is usually denoted as percent sodium and is determined using Equation 1:

$$Na\ (\%) = \frac{Na^+ \times 100}{Ca^{2+} + Mg^{2+} + Na^+ + k^+} \quad (1)$$

Sodium adsorption ratio (SAR) according to Wilcox (1995) is a better measure of the sodium hazard which is used to express reactions with the soil. It was computed by using the relationship given in Equation 2:

$$SAR = Na^+/\{(Ca^{2+} + Mg^{2+})^{1/2}/2\} \quad (2)$$

The relative proportion of sodium in the water in the form of sodium carbonate was also determined using Equation 3:

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

All the computational formulas given above are possible when ionic concentrations are expressed in meq/l.

Magnesium Hazard (MH) was also calculated in percentage using Equation 4:

$$MH = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \quad (4)$$

This indicator (MH) can be used to specify the magnesium hazard proposed by Szabolcs and Darab (1964) for assessing irrigation water. These analytical data not only can be used for the classification of water for utilitarian purposes but also for ascertaining various factors on which the chemical characteristics of water depend (Sadashivaiah et al., 2008).

## RESULTS AND DISCUSSION

The results of the hydrochemical analyses of the water samples are presented in Table 1. Temperature ranges between 20 and 26°C for the hand dug well and 19 and 23°C for borehole samples. The groundwater temperature tends to remain mildly low and is considered an advantage for industrial uses. The electrical conductivity (EC), as presented in Table 1, varies from 8.4 to 36.4 μs/cm for hand dug well and 10.0 to 76.4 μs/cm for the borehole water samples. The EC values are relatively low except the borehole at Odii market square which has value above 76.4 μs/cm. The pH values range between 7.0 and 9.0 for the entire samples and indicate alkaline water. The pH values generally encountered may be largely due to the influence of the soils and organic

**Table 1.** Summarized results of the hydrogeochemical analysis of the water samples.

| Location | Source | Temperature (°C) | pH mg/l | EC (us/cm) | $Na^+$ (mg/l) | $K^+$ (mg/l) | $Ca^{2+}$ (mg/l) | $Mg^{2+}$ (mg/l) | $C0_3^{2-}$ (mg/l) | $HCO_3^{2-}$ (mg/l) | $Cl^-$ (mg/l) | $S0_4^{2-}$ (mg/l) | Hardness (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amankwo | WH A | 21 | 7.5 | 15.1 | 27.5 | 10.1 | 18.0 | 24.3 | 0 | 24.0 | 38.0 | 17.2 | 40 |
| Afor Enugu | WH B | 20 | 7.4 | 20.0 | 18.9 | 0.4 | 4.0 | 28.9 | 0 | 20.0 | 18.0 | 0.2 | 120 |
| Amanator | WH C | 20 | 7.5 | 16.0 | 9.7 | 0.6 | 28.0 | 9.7 | 0 | 22.0 | 25.0 | 1.6 | 40 |
| Isu | WH D | 26 | 7.7 | 10.4 | 24.3 | 0.3 | 16.0 | 14.3 | 0 | 50.0 | 30.0 | 0.9 | 20 |
| Nkwoagu | WH E | 20 | 7.4 | 8.4 | 24.6 | 0.6 | 18.0 | 14.3 | 0 | 20.0 | 15.0 | 2.6 | 120 |
| Umunko | WH F | 21 | 8.5 | 36.4 | 14.6 | 0.7 | 14.0 | 14.6 | 0 | 10.0 | 13.0 | 13.6 | 110 |
| Umueziuku | WH G | 22 | 7.5 | 28.0 | 9.0 | 0.3 | 30.0 | 0.3 | 0 | 50.0 | 18.0 | 8.6 | 36 |
| Isuachara | WH H | 20 | 9.0 | 36.0 | 45 | 4.6 | 20.0 | 14.3 | 0 | 36.8 | 3.0 | 6.9 | 60 |
| Umubo | WH I | 20 | 7.3 | 48 | 6.7 | 0.2 | 26.5 | 28.6 | 0 | 110 | 13.0 | 6.9 | 40 |
| Onicha Hqt | WH J | 22 | 9.2 | 36 | 44.1 | 0.6 | 8.0 | 9.7 | 0 | 12.0 | 15.0 | 1.2 | 16 |
| Amefi | BH A | 21 | 8.8 | 15.2 | 26.2 | 18.0 | 14.8 | 20.3 | 0 | 20.0 | 22.0 | 12.4 | 120 |
| Isu Hgt | BH B | 20 | 7.4 | 10.0 | 26.2 | 0.4 | 20.0 | 12.4 | 0 | 16.0 | 8.0 | 5.6 | 90 |
| Afor Mkt | BH C | 19 | 8.0 | 47.0 | 26.4 | 4.6 | 18.6 | 16.0 | 0 | 30.0 | 16.0 | 8.2 | 80 |
| Odii Square | BH D | 23 | 7.5 | 76.4 | 16.8 | 0.6 | 12.0 | 19.7 | 0 | 24.0 | 10.2 | 10.0 | 90 |
| Ugenoma | BH E | 20 | 7.0 | 8.0.1 | 44.8 | 0.3 | 20.0 | 13.6 | 0 | 80.0 | 12.2 | 16.1 | 40 |
| Umunko | BH F | 21 | 7.8 | 36 | 36.4 | 10.0 | 16.0 | 18.0 | 0 | 36.0 | 3.0 | 16.8 | 80 |
| Nkwoagu Mkt | BH G | 19 | 7.0 | 46 | 24.6 | 0.8 | 12.1 | 23.6 | 0 | 22.0 | 3.6 | 5.8 | 20 |
| Ata-Nti | BH H | 22 | 8.0 | 20.4 | 16.2 | 8.0 | 4.6 | 10.6 | 0 | 10.0 | 18.0 | 8.0 | 70 |
| Umubo | BH I | 20 | 8.4 | 18.4 | 18.20 | 4.6 | 12.6 | 12.8 | 0 | 16.0 | 10.0 | 10.0 | 40 |
| Isuachara | BH J | 21 | 9.0 | 16.8 | 4.6 | 4.2 | 18.0 | 24.6 | 0 | 28.0 | 12.0 | 6.4 | 140 |

matter present (Orajaka, 1972).

Water hardness is primarily caused by the presence of cations such calcium and magnesium as well as anions such as carbonate and bicarbonate. According to Sawyer and McCarty (1967) classification for hardness (Table 3), ten samples fall under soft while the remaining ten samples fall under moderately hard. The chemical analysis revealed that the total hardness as in $CaCO_3$ varied from 16 to 140 mg/l for both samples indicating soft to moderately hard water. The moderate hard water noticed in most of the samples especially the Isuachara borehole (140 mg/l) could be attributed to calcareous soil and limestone unit found in the Asu River Group that contain calcareous soil and limestone unit. The $Ca^{2+}$ salt in most of the groundwater samples suggests calcareous aquifer. The normal ranges of concentration of the ion analyzed are presented in Table 2. The predominant cations are $Na^+$ and $Ca^{2+}$, whereas the predominant anions are $HC0_3^-$ and $Cl^-$. The $CO_3^{2-}$ values for all the samples are low.

## Criteria for irrigation purposes

The suitability of groundwater for irrigation purposes depend on its mineral constituent (Sadashiviah et al., 2008). Total salt concentration as measured by electrical conductivity (EC), relative proportion of sodium to other principal cation as expressed by SAR, sodium percent and residual sodium carbonate (RSC) are some of the techniques adopted by the US Salinity Laboratory of the Department of Agriculture (Wilcox, 1995) in evaluating the suitability of water for irrigation purposes. The total concentration of soluble salts in irrigation water in all the samples expressed in terms of specific conductance according to salinity hazard classes (Table 4) were found to be excellent and hence suitable for irrigation purposes.

The classification of groundwater samples with respect to percent sodium are shown in Table 5. Four samples have percent sodium values 6 to 20% which indicates values largely less than or

**Table 2.** Normal ranges of concentrations.

| Ion (mg/l) | Range | Average | Well sample mean | Borehole mean |
|---|---|---|---|---|
| $Na^+$ | 4.6- 45.0 | 24.8 | 22.40 | 24.00 |
| $K^+$ | 0.2- 18.0 | 9.1 | 1.80 | 5.2 |
| $Ca^{2+}$ | 4.0 - 28.0 | 16.0 | 6.0 | 10.0 |
| $Mg^{2+}$ | 0.3 - 28.9 | 14.6 | 15.9 | 17.2 |
| $CO_3^{2-}$ | Nil | Nil | Nil | Nil |
| $HCO_3^-$ | 100 - 80.0 | 45.0 | 32.5 | 28.2 |
| $Cl^-$ | 3.0 - 38.0 | 20.5 | 18.8 | 11.5 |
| $SO_4^{2+}$ | 0.2 - 17.2 | 8.7 | 6.0 | 9.9 |

**Table 3.** Classification of water based on hardness after Sawyer and McCarthy (1967).

| Hardness as $CaCO_3$ | Water class | Hand dug well | Borehole |
|---|---|---|---|
| 0-75 | Soft | 7 samples | 4 samples |
| 75-150 | Moderate Hard | 3 samples | 6 samples |
| 150 - 300 | Hard | - | - |
| >300 | Very hard | - | - |

-Not available.

**Table 4.** Salinity hazard class after Wilcox (1995).

| Class | EC (µmoh/cm) | Remarks on quality |
|---|---|---|
| $C_1$ | 100-250 | Excellent |
| $C_2$ | 250 -750 | Good |
| $C_3$ | 750 -2250 | Doubtful |
| $C_4$ & $C_5$ | >2250 | Unsuitable |
| Study samples | 8.4 - 76.4 | Excellent* |

*All values fall below 100 µmoh/cm.

equal to 20%, whereas 12 samples have values ranging between 23 and 38%, with most values generally less than 40%, indicating that they are all safe for irrigation purpose. Three samples are within permissible water class of (46 and 47%). Water sample from Uburu hand-dug has value as high as 61%, suggesting that its suitability is doubtful if used for irrigation purpose. Orajaka (1972) have noted occurrences of salt ponds (with salinity of 4.5% and pH 8 at 25°C) within Uburu and its environs. Total dissolved solids are measured at 4.55% and NaCl at 4.32%. These confirmed the high concentrations of sodium in most of the studied samples. The Salinity Laboratory of the U.S Department of Agriculture established the sodium adsorption ratio as a direct method of assessing the suitability of water for irrigation. The classification of the groundwater samples from the study, with respect to SAR as presented in Table 6 indicate that the SAR values of all the samples were found to vary from 0.3 to 1.7 meq/l, revealing excellent irrigation water. The classifications of the groundwater samples based on residual sodium carbonate are presented in Table 7. The values which vary from 0.1 to 0.99 meq/l are generally less than 1.25 meq/l also revealing good irrigation water. According to USSL Department of Agriculture, water having more than 2.5 meq/l of RSC is not suitable for irrigation purposes. Based on RSC values obtained, all the 20 samples are generally less than 1.25 meq/l and therefore safe for irrigation purposes. Another indicator can be used to specify the magnesium hazard (MH) as proposed by Szabolcs and Darab (1964) for irrigation water. They proposed that if this percentage hazard was greater than 50, then the water will not be safe and will be unsuitable for irrigation purposes. From the calculated value, the magnesium hazard values range between 0.99 and 89.8% (Table 8), and can be classified as suitable for irrigation use for those that ranged from 0.99 to 50% while those that ranged from 51.9 to 89.8% are unsuitable. These were noted mostly in the water samples listed as follows: 66.1 (BH-G), 69.7 (BH-H) and 89.8% (WH-B).

The chemical analyses revealed that samples (from boreholes and hand dug wells) of groundwater from Onicha-Uburu are classified as soft water. The classification of the groundwater samples from the study, with respect to SAR indicate that the SAR values of all the samples were found to vary from 0.3 to 1.7 meq/l and classified as excellent for irrigation purposes as no sodium toxicity will arise by using the groundwater for surface irrigation. The classifications of the groundwater samples based on residual sodium carbonate vary from 0.1 to 0.99 meq/l indicating that the samples are safe as values generally less than 1.25 meq/l are good for irrigation purposes. The magnesium hazard (MH) values

**Table 5.** Sodium percent water class after Wilcox (1995).

| Sodium (%) | Water class | Study samples (%) | Remarks |
|---|---|---|---|
| < 20 | Excellent | 6, 7, 16, 20, | 4 samples |
| 20-40 | Good | 23-38 | 12 samples |
| 40- 60 | Permissible | 46- 47 | 3 samples |
| 60-80 | Doubtful | 61 | 1 sample |
| >80 | Unsuitable | - | - |

-Not available.

**Table 6.** Sodium hazard classes based on sodium adsorption ratio after Wilcox (1995).

| Sodium hazard class | SAR | Remark on quality | Study samples | Remarks |
|---|---|---|---|---|
| $S_1$ | 10 | Excellent | 0.3-1.7 | All the 20 samples |
| $S_2$ | 10-18 | Good | - | |
| $S_3$ | 18-26 | Doubtful | - | |
| $S_4$ and $S_5$ | >26 | Unsuitable | - | |

-Not available.

**Table 7.** Water quality based on residual sodium carbonate after Wicox (1995).

| RSC (meq/l) | Remark in quality | Study sample | Remark |
|---|---|---|---|
| < 1. 25 | Good | < 0.99 | All the 20 samples |
| 1. 25 -2.5 | Doubtful | - | |
| > 2.5 | Unsuitable | - | |

-Not available.

**Table 8.** Water quality based on magnesium hazard after Szabolcs and Darab (1964).

| MH (%) | Remark in quality | Study sample |
|---|---|---|
| < 50 | Suitable | 0.99% (WH-G), 25.7%, WH-C), 38.4% (BH-B), 40.5% (BH-E), 42% (WH-H), 44.2% (WH-E), 47.1% (BH-C), 47.19% (WH-D), 48% (BH-I), 50% (WH-F) |
| >50 | Unsuitable | 51.9% (WH-I), 52.9% (BH-F), 54.8% (WH-), 57.1% (BH- J) 57.4% (WH-A),57.8% (BH- A), 62.1% (BH-D.14), 66.1% (BH-G), 69.7% (BH-H), 89.8% (WH-B) |

range between 0.99 and 89.8% (Table 8). However, water samples from the following locations: Nkwoagu Mkt borehole, BH-G (66.1%), Ata Nti borehole, BH-H (69.7%) and Afor Enugwu well, WH-B (89.8%) may not be unsuitable for irrigation purpose using the proposed parameter (MH).

Generally, the analyzed water samples are suitable for irrigation purposes except for few samples from Nkwoagu Mkt borehole, Ata Nti borehole and Afor Enugwu well. To maximize the benefits for irrigation purpose, it is suggested that groundwater utilization and management policies should be formulated and implemented to overcome future conflict in utilization of the groundwater in the area and also to maintain the sustainability of the irrigation scheme.

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