Evaluation of Irrigation Quality of Groundwater in Wamba Sheet 210, North Central Nigeria

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Authors’ contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

An evaluation of irrigation quality of groundwater from shallow aquifers within Wamba Sheet 210 in Nasarawa State, North Central Nigeria was carried out. The area is located between Latitudes 8°30’N and 9°00’N, and Longitudes 8°30’E and 9°00’E, covering about 3,025 Km². It is underlain by rocks belonging to the Basement Complex, the Younger Granites, and Cretaceous sedimentary rocks. The results of field tests and laboratory analysis were used in assessing the suitability of groundwater found in the area for irrigation. Values obtained for Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR) and Kellys Ratio (KR) were 0.97 - 3.43, 8.18 - 81.76%, 8.03 - 80.22 and 0.04 - 3.43 respectively. These indices are largely within the safe limits for irrigation with very little likelihood that salinity hazards will develop.

Keywords: Wamba sheet 210; irrigation; Sodium Adsorption Ratio (SAR); Soluble Sodium Percentage (SSP); Magnesium Adsorption Ratio (MAR); Kellys Ratio (KR).

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1. INTRODUCTION

Population increase and increase in food demand, as well as a prolonged period of the dry season being experienced in northern parts of Nigeria, have led farmers in many communities to embark on dry season farming through irrigation, utilizing groundwater from shallow aquifers. Irrigation is the application of water to a crop to replace the climatic moisture deficit, especially during the dry season. Until recently, most streams and rivers within Wamba Sheet 210 were perennial, but are now mostly dry from November to April, necessitating the use of groundwater for irrigation as land use in the area is mainly for agriculture.

For water to be suitable for irrigation, indices such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR) and Kellys Ratio (KR) must be within acceptable limits for crops to thrive because accumulation of ions especially sodium causes deterioration in the soil physical properties leading to a decrease in crop yield [1,2,3]. Assessment of water quality indices for irrigation is essential if the good agricultural output is to be achieved. This study intends to investigate the physical and chemical characteristics of groundwater from shallow aquifers within Wamba Sheet 210, to determine their suitability for irrigation.

2. MATERIALS AND METHODS

2.1 The Study Area

The study area (Wamba Sheet 210) is located in North Central Nigeria. The area falls within the Guinea Savannah characterized by short grasses and scattered trees. It is bordered by Latitudes 8°30′N and 9°00′N, and Longitudes 8°30′E and 9°00′E, covering an area of about 3,025 Km². According to Adefolalu [4], rainfall in the area is about 1500 mm and the average temperature is 26°C. Major settlements within Wamba Sheet 210 include Wamba, Nassarawa Eggon, Garko, Adogli, Assakio, Tugan, Panda and Nakere, and the occupation of the people is mainly farming.

The northern part of Wamba Sheet 210 is underlain by rocks of the Basement Complex and the Younger Granites, while the southern part is composed of Cretaceous sedimentary rocks of the Middle Benue Trough Macleod et al. [5]. Recent geological mapping of Wamba Sheet 210 [6] revealed that the Basement rocks in the area consist essentially of migmatites, gneisses and quartzites (Fig. 1). These rocks are associated with pegmatites in some places and structural trends within these pegmatites are generally N-S, NNE-SSW, NE-SW and NNW-SSE [7]. The Younger Granites are made up of microgranites and biotite granites while the sedimentary rocks which constitute the southern part consist of Awgu Shale and Lafia Formation. Awgu Shale is mainly of bluish-grey to black shales, while the Lafia Formation is made up of sandstones and claystones [8].

2.2 Methodology

Seventy-five (75) groundwater samples were collected from shallow wells during the dry season in different locations in the area, and the good coordinates determined using a Garmin Global Positioning System (Table 1). The depths to the static water level in the wells vary from 5-25 metres. The distributions of the wells are shown in Fig. 2. The physical parameters determined in the field included temperature, pH and electrical conductivity. The water samples were later filtered and preserved with 2 ml of nitric acid to avoid adsorption and precipitation of metals. They were then analyzed using Inductively Coupled Plasma - Optical Emission Spectrometry (ICP-OES) at the ACME Laboratory Vancouver, Canada. Details of ICP-OES operation is presented by Xiandeng and Bradley [9].

To assess the quality of groundwater in the area irrigation, the Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), Magnesium Adsorption Ratio (MAR) and Kellys Ratio (KR) were determined based on ionic concentrations (Meq/l) calculated from the results of chemical analysis.

Sodium adsorption ratio (SAR) is a parameter used in the management of sodium in soils. It is an indicator of the suitability of water for use in irrigation, and it is determined from the concentrations of Na⁺, Ca²⁺ and Mg²⁺ present in the water. Irrigation using water with high sodium adsorption ratio may cause long-term damage to the soil [10]. Sodium Adsorption Ratio (SAR) was calculated using Equation 1 according to Richards [11].

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{++} + Mg^{++})}}$$

(1)
Fig. 1. Geological map of Wamba Sheet 210 (After Geology Department, University of Jos [6])

Fig. 2. Groundwater sample points within Wamba Sheet 210
## Table 1. Locations of groundwater sample points

| S/No | Sample Id | Town         | Latitude °N | Longitude °E | S/No | Sample Id | Town        | Latitude °N | Longitude °E |
|------|-----------|--------------|-------------|--------------|------|-----------|-------------|-------------|--------------|
| 1    | AR3       | Nakere       | 8.974983    | 8.526497     | 39   | AR57      | Gid.Buba    | 8.696389    | 8.765        |
| 2    | AR4       | Gudi         | 8.938283    | 8.549533     | 40   | AR58      | Alawagana   | 8.623889    | 8.768056     |
| 3    | AR5       | Kurmi        | 8.937356    | 8.572111     | 41   | AR59      | Asige       | 8.582222    | 8.807222     |
| 4    | AR8       | Wamba Town   | 8.939431    | 8.603794     | 42   | AR61      | FadamaBauna | 8.755083    | 8.756694     |
| 5    | AR10      | Wamba Rd     | 8.952367    | 8.599867     | 43   | AR63      | AdamuAgio   | 8.772333    | 8.794694     |
| 6    | AR11      | Gbombo       | 8.960161    | 8.635453     | 44   | AR65      | Lange       | 8.796975    | 8.675667     |
| 7    | AR13      | Angwan Mango | 8.965447    | 8.613281     | 45   | AR66      | Arugwadu    | 8.757328    | 8.688803     |
| 8    | AR14      | Gwagi        | 8.972906    | 8.602508     | 46   | AR68      | Feferuwa    | 8.702317    | 8.887208     |
| 9    | AR15      | Wude         | 8.918303    | 8.571292     | 47   | AR70      | Ajuhulu     | 8.659878    | 8.680144     |
| 10   | AR16      | Oge          | 8.904489    | 8.566256     | 48   | AR71      | Akura 1     | 8.636444    | 8.678044     |
| 11   | AR17      | Dechu        | 8.888889    | 8.543056     | 49   | AR72      | Chiba       | 8.648103    | 8.712672     |
| 12   | AR19      | Kurize 2     | 8.867578    | 8.533028     | 50   | AR73      | Dungu 1     | 8.612731    | 8.693231     |
| 13   | AR20      | Wadjji       | 8.858667    | 8.528944     | 51   | AR74      | Dungu 2     | 8.601381    | 8.702367     |
| 14   | AR21      | Odrah        | 8.905289    | 8.552386     | 52   | AR75      | Akura 2     | 8.623119    | 8.681167     |
| 15   | AR23      | Ukya         | 8.9175      | 8.613056     | 53   | AR77      | Gako        | 8.789728    | 8.521431     |
| 16   | AR26      | Gwagi        | 8.890556    | 8.639167     | 54   | AR79      | Nass.Eggon  | 8.716161    | 8.538842     |
| 17   | AR27      | Otogu        | 8.882778    | 8.643611     | 55   | AR80      | Azuba       | 8.628122    | 8.555489     |
| 18   | AR28      | Okuso        | 8.868889    | 8.6525       | 56   | AR82      | Shabu       | 8.574769    | 8.557314     |
| 19   | AR29      | Ojule        | 8.868611    | 8.690278     | 57   | AR83      | Akuba       | 8.535342    | 8.569928     |
| 20   | AR30      | Gbanju       | 8.868333    | 8.706111     | 58   | AR84      | Asanya      | 8.554094    | 8.589508     |
| 21   | AR31      | Ukuolo       | 8.868056    | 8.733611     | 59   | AR85      | Agabija     | 8.573469    | 8.614342     |
| 22   | AR32      | Konya        | 8.868889    | 8.665565     | 60   | AR86      | Doka        | 8.591089    | 8.615964     |
| 23   | AR35      | Wugi         | 8.797833    | 8.713917     | 61   | AR87      | Arugba      | 8.594486    | 8.630444     |
| 24   | AR36      | Kompany      | 8.821389    | 8.76575      | 62   | AR88      | Alakio      | 8.595833    | 8.658561     |
| 25   | AR37      | Wayo         | 8.812389    | 8.7575       | 63   | AR89      | Tu.Makeri   | 8.579153    | 8.675444     |
| 26   | AR38      | Arikia       | 8.828944    | 8.67375      | 64   | AR90      | Adogi       | 8.525514    | 8.648555     |
| 27   | AR40      | Kwabe        | 8.873889    | 8.657222     | 65   | AR91      | Koro        | 8.526169    | 8.667886     |
| 28   | AR42      | Ambaka       | 8.939167    | 8.890556     | 66   | AR92      | Sabon-     | 8.531872    | 8.688331     |
| 29   | AR44      | Pashabiyar   | 8.808889    | 8.833056     | 67   | AR94      | Mai-Akuya   | 8.544831    | 8.736111     |
| 30   | AR46      | Zalli        | 8.877778    | 8.766111     | 68   | AR95      | Abu         | 8.534928    | 8.716303     |

*Table 1. Locations of groundwater sample points*
| S/No | Sample Id | Town       | Latitude °N | Longitude °E | S/No | Sample Id | Town       | Latitude °N | Longitude °E |
|------|-----------|------------|-------------|--------------|------|-----------|------------|-------------|--------------|
| 31   | AR49      | Bakyano    | 8.766611    | 8.630575     | 69   | AR96      | Assakio    | 8.593664    | 8.095486     |
| 32   | AR50      | Ashangwa   | 8.568222    | 8.781625     | 70   | AR97      | T sorom    | 8.567639    | 8.912639     |
| 33   | AR51      | Tunga      | 8.663611    | 8.663611     | 71   | AR101     | BakinKogi  | 8.623736    | 8.942456     |
| 34   | AR52      | Gwayaka    | 8.691944    | 8.853333     | 72   | AR103     | Anungo     | 8.634094    | 8.96505      |
| 35   | AR53      | Gallo      | 8.774722    | 8.903611     | 73   | AR105     | Kumme      | 8.627556    | 8.993031     |
| 36   | AR54      | Alingani   | 8.717778    | 8.826667     | 74   | AR107     | Pandam     | 8.645233    | 8.977861     |
| 37   | AR55      | Uga        | 8.695       | 8.803056     | 75   | AR108     | DogonKurmi | 8.651503    | 8.994981     |
| 38   | AR56      | Gid.Agu    | 8.696111    | 8.784167     |      |           |            |             |              |
Soluble Sodium Percentages (SSP) expresses the solubility of Na⁺ in relation to other cations such as Ca²⁺, Mg²⁺ and K⁺. Soluble Sodium Percentage (SSP) was calculated using Equation 2 (After [12]).

\[ SSP = \frac{(Na^+ + K^+) \times 100}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \]  

Equation 2

Magnesium Adsorption Ratio (MAR) is an index for calculating the magnesium hazard. Magnesium Adsorption Ratio for the water samples was calculated using Equation 3, according to Raghunath [13].

\[ MAR = \frac{Mg^{2+} \times 100}{Ca^{2+} + Mg^{2+}} \]  

Equation 3

Kelly's Ratio (KR) was calculated using Equation 4 as given by Kelly, [14].

\[ KR = \frac{Na^{2+}}{Ca^{2+} + Mg^{2+}} \]  

Equation 4

3. RESULTS AND DISCUSSION

The results of the physicochemical parameters of the groundwater samples from Wamba Sheet 210 are presented in Table 2. It shows that groundwater temperatures here are from 23.2 - 28.4°C with an average of 27.4°C, the pH ranges from 5.4 - 7.0, and the electrical conductivity varies from 9.2 - 210 µS/cm with an average of 125.63 µS/cm. Electrical conductivity is a measure of the water’s capability to pass electrical flow and this is directly dependent on the concentration of ions present in the water.

Generally, all groundwater contains a significant amount of dissolved salts depending on the geology of the area. Most of the salts are left in the soil after the water is lost by evaporation or through transpiration by the irrigated plants. Salts may, therefore, accumulate in sufficient quantities to prevent the effective growth of such crops. According to Ayers, [15], the higher the value of electrical conductivity (EC), the higher the hazards potential to crops. Ayers and Westcot [3] also concluded that for suitability for irrigation, water with electrical conductivity of <117.51 µS/cm is excellent, while 117.51-508.61 µS/cm is good (Table 3). On the basis of EC values of 9.2 to 210 µS/cm therefore, it can be concluded that groundwater found within the shallow aquifers of Wamba Sheet 210 are generally good for irrigation.

The concentrations of Ca²⁺, Mg²⁺, Na⁺ and K⁺ in the water samples are shown in Table 4 and the corresponding milliequivalent values in Table 5. Calcium, magnesium, sodium and potassium concentrations range from 0.89 - 94.15 ppm, 0.13 - 40.47 ppm, 0.51 - 107.9 ppm, and 0.3 - 78.1 ppm respectively. Calcium is a very important mineral in agriculture. Calcium is an important plant nutrient, and calcium-rich soils are friable and easily cultivated, allowing for easy infiltration and good drainage [16,17]. Magnesium equally improves soil fertility and it is an essential constituent of plant chlorophyll [18]. Sodium occurs widely in many igneous and sedimentary rocks but the high concentration of sodium in the soil is generally unfavourable for plant growth as it renders the soils alkaline by replacing calcium and magnesium [19,20]. Potassium is generally found in small concentration in groundwater.

Values obtained for the various irrigation parameters are shown in Table 6. The Sodium Adsorption Ratio (SAR) ranges from 0.07 - 3.42, with a mean value of 0.93 and a standard deviation of 0.726. Only 2 out of the 75 groundwater samples had SAR value of more than 3 indicating therefore that groundwater from more than 97% of the area is good for irrigation in terms of SAR. According to Rollins [23], SAR of less than 3 is generally recommended for irrigation.

The Soluble Sodium Percentage (SSP) ranges from 8.80 - 81.76%. Although SSP values of more than 60% were found in some areas, over 85% of the water samples analyzed have SSP of <60% (Table 6). According to Ayers and Westcot [3], Eaton [21] and Wilcox [22], water with SSP of <60% is generally considered good for irrigation while those >60% are not.

Magnesium Adsorption Ratios (MAR) obtained varies from 8.03 - 80.22. It is generally known that Ca²⁺ and Mg²⁺ maintain a state of equilibrium in groundwater. According to Joshi et al. [2], more Mg²⁺ in groundwater could affect the soil quality by making it alkaline and this, in turn, could result in a decrease in crop yield. Water with MAR values of <50 are considered suitable for irrigation but those >50 are generally considered unsuitable. Although few of the water samples have MAR values greater than 50, the bulk of the samples (94%) have MAR values of less than 50 (Table 6). The water samples can,
The Kelly Ratio (KR) obtained ranges from 0.04 - 3.42 out of which about 84% are less than 1, thus indicating that groundwater from shallow aquifers in many areas within Wamba Sheet 210 is good for irrigation. Generally, waters with KR value of less than 1 are considered suitable for irrigation, while those greater than 1 are unsuitable Kelly [14].

The results obtained in this study are similar to those obtained from shallow aquifers in Awe and Kyekwura areas of same Nasarawa State where SAR, SSP, MAR, and KR values were found to vary from 0.02 - 1.63, 2.18 - 52.72%, 24.43 - 73.44 and 0.00 – 0.98 respectively [24]. They are also comparable to those obtained from shallow groundwater in Pindiga, Gombe, and Yola areas to the NE of the Benue Trough [25] where SAR of 0 - 0.035, SSP of 2.60 - 38.40, and KR of 0.0004 - 0.029 were reported.

| S/No | Sample ID | PH  | Cond. (mS/cm) | Temp (°C) | S/No | Sample ID | PH  | Cond. (mS/cm) | Temp (°C) |
|------|-----------|-----|---------------|-----------|------|-----------|-----|---------------|-----------|
| 1    | AR 3      | 6.6 | 181.7         | 27.4      | 39   | AR 57     | 6.3 | 69.8          | 23.3      |
| 2    | AR 4      | 6.4 | 78.7          | 28.4      | 40   | AR 58     | 6.1 | 206           | 23.23     |
| 3    | AR 5      | 6.3 | 49.8          | 27.5      | 41   | AR 59     | 6.2 | 26.4          | 27.9      |
| 4    | AR 8      | 6.3 | 160.9         | 27.7      | 42   | AR 61     | 6.5 | 194.9         | 27.7      |
| 5    | AR 10     | 6.6 | 9.2           | 27.3      | 43   | AR 63     | 6.2 | 183.4         | 27.7      |
| 6    | AR 11     | 6.5 | 96.7          | 27.6      | 44   | AR 65     | 7.0 | 198.6         | 27.4      |
| 7    | AR 13     | 6.9 | 77.6          | 27.8      | 45   | AR 66     | 6.3 | 160.9         | 27.8      |
| 8    | AR 14     | 6.8 | 11            | 27.3      | 46   | AR 68     | 6.6 | 9.2           | 27.3      |
| 9    | AR 15     | 6.7 | 210           | 27.3      | 47   | AR 70     | 5.4 | 96.7          | 27.7      |
| 10   | AR 16     | 6.5 | 100.8         | 27.4      | 48   | AR 71     | 6.4 | 77.6          | 27.8      |
| 11   | AR 17     | 6.2 | 158.1         | 27.7      | 49   | AR 72     | 6.8 | 11            | 28.4      |
| 12   | AR 19     | 6.1 | 69.8          | 27.3      | 50   | AR 73     | 6.6 | 187           | 27.8      |
| 13   | AR 20     | 6.1 | 205.2         | 23.3      | 51   | AR 74     | 6.7 | 210           | 27.5      |
| 14   | AR 21     | 6.3 | 106           | 23.2      | 52   | AR 75     | 6.1 | 100.8         | 27.7      |
| 15   | AR 23     | 6.8 | 55.9          | 27.9      | 53   | AR 77     | 6.7 | 158.1         | 27.7      |
| 16   | AR 26     | 6.9 | 82.7          | 27.7      | 54   | AR 79     | 6.2 | 181.7         | 27.3      |
| 17   | AR 27     | 6.6 | 206           | 27.7      | 55   | AR 80     | 6.0 | 78.7          | 27.6      |
| 18   | AR 28     | 6.3 | 26.4          | 27.4      | 56   | AR 82     | 6.5 | 198.6         | 27.8      |
| 19   | AR 29     | 6.3 | 194.9         | 27.8      | 57   | AR 83     | 6.4 | 160.9         | 27.3      |
| 20   | AR 30     | 6.4 | 183.4         | 27.3      | 58   | AR 84     | 6.3 | 9.2           | 27.3      |
| 21   | AR 31     | 6.6 | 11            | 27.7      | 59   | AR 85     | 6.9 | 96.7          | 27.4      |
| 22   | AR 32     | 6.6 | 210           | 27.8      | 60   | AR 86     | 6.2 | 77.6          | 27.7      |
| 23   | AR 35     | 6.9 | 100.8         | 28.4      | 61   | AR 87     | 6.1 | 11            | 27.3      |
| 24   | AR 36     | 7.0 | 158.1         | 27.5      | 62   | AR 88     | 6.3 | 210           | 27.8      |
| 25   | AR 37     | 6.8 | 181.7         | 27.7      | 63   | AR 89     | 6.2 | 160.4         | 27.5      |
| 26   | AR 38     | 6.8 | 78.7          | 27.3      | 64   | AR 90     | 6.5 | 100.8         | 27.3      |
| 27   | AR 40     | 6.5 | 198.6         | 27.6      | 65   | AR 91     | 6.7 | 194.9         | 27.7      |
| 28   | AR 42     | 6.5 | 160.9         | 27.8      | 66   | AR 92     | 6.2 | 183.4         | 27.3      |
| 29   | AR 44     | 6.3 | 9.2           | 27.3      | 67   | AR 94     | 6.1 | 198.6         | 27.6      |
| 30   | AR 46     | 6.5 | 111.2         | 27.2      | 68   | AR 95     | 6.3 | 160.9         | 27.4      |
| 31   | AR 49     | 6.2 | 198.6         | 27.7      | 69   | AR 96     | 6.4 | 9.2           | 28.4      |
| 32   | AR 50     | 6.4 | 160.9         | 27.3      | 70   | AR 97     | 6.6 | 198.6         | 27.5      |
| 33   | AR 51     | 6.4 | 200.6         | 27.6      | 71   | AR 101    | 6.4 | 160.9         | 27.7      |
| 34   | AR 52     | 6.2 | 100.8         | 27.4      | 72   | AR 103    | 6.1 | 9.2           | 27.4      |
| 35   | AR 53     | 6.0 | 181.7         | 28.4      | 73   | AR 105    | 6.3 | 96.7          | 27.8      |
| 36   | AR 54     | 5.7 | 210           | 27.5      | 74   | AR 107    | 6.7 | 77.6          | 27.3      |
| 37   | AR 55     | 5.7 | 100.8         | 27.7      | 75   | AR 108    | 6.2 | 11            | 27.7      |
| 38   | AR 56     | 6.0 | 158.1         | 27.3      |      |           |     |               |           |
Table 3. Some parameter indices for rating the sustainability of groundwater quality for irrigation [3, 21,22]

| Class | EC (μS/cm) | RSC | SAR | SSP | Suitability for irrigation |
|-------|------------|-----|-----|-----|----------------------------|
| I     | <117.51    | <1.25 | <10 | <20 | Excellent                  |
| II    | 117.51-508.61 | 1.25-2.5 | 10-18 | 20-40 | Good                       |
| III   | >508.61    | >2.5  | 18-26| 40-80| Fair                       |
| IV    | -          | -     | >26 | >80 | Poor                       |

Table 4. Results of chemical analysis of the groundwater samples (ppm)

| S/No | Sample ID | Ca²⁺ (ppm) | K⁺ (ppm) | Mg²⁺ (ppm) | Na⁺ (ppm) | S/No | Sample ID | Ca²⁺ (ppm) | K⁺ (ppm) | Mg²⁺ (ppm) | Na⁺ (ppm) |
|------|-----------|------------|----------|------------|-----------|------|-----------|------------|----------|------------|-----------|
| 1    | AR3       | 21.94      | 3.34     | 4.78       | 15.11     | 39   | AR57      | 1.29       | 1.52     | 0.13       | 0.51      |
| 2    | AR4       | 31.54      | 2.62     | 9.1        | 19.22     | 40   | AR58      | 3.88       | 4.9      | 1.09       | 3.92      |
| 3    | AR5       | 20.21      | 3.23     | 1.91       | 7.1       | 41   | AR59      | 37.51      | 5.5      | 9.38       | 10.2      |
| 4    | AR8       | 69.54      | 8.69     | 16.39      | 51.3      | 42   | AR61      | 72.06      | 7.74     | 34.23      | 39.84     |
| 5    | AR10      | 30.82      | 6.08     | 2.14       | 54.19     | 43   | AR63      | 32.95      | 4.73     | 14.55      | 80.81     |
| 6    | AR11      | 21.72      | 2        | 5.85       | 18.07     | 44   | AR65      | 49.8       | 26.03    | 11.29      | 36.03     |
| 7    | AR13      | 89.44      | 38.15    | 7.13       | 6.58      | 45   | AR66      | 72.7       | 44.84    | 15.91      | 38.64     |
| 8    | AR14      | 29.73      | 3.06     | 9.54       | 11.89     | 46   | AR68      | 25.47      | 13.58    | 4.35       | 13.68     |
| 9    | AR15      | 28.64      | 3.55     | 3.37       | 6.64      | 47   | AR70      | 19.36      | 3.84     | 4.87       | 13.77     |
| 10   | AR16      | 17.22      | 2.6      | 2.72       | 8.19      | 48   | AR71      | 33.32      | 13.77    | 12.08      | 49.68     |
| 11   | AR17      | 34.42      | 2.54     | 15.28      | 25.68     | 49   | AR72      | 4.12       | 3.27     | 0.69       | 4.8       |
| 12   | AR19      | 58.3       | 1.32     | 13.81      | 14.98     | 50   | AR73      | 3.06       | 1.09     | 0.65       | 1.52      |
| 13   | AR20      | 66.56      | 3.61     | 36.2       | 36.95     | 51   | AR74      | 1.23       | 0.47     | 0.2        | 0.61      |
| 14   | AR21      | 20.22      | 1.82     | 6.79       | 16.94     | 52   | AR75      | 0.95       | 0.46     | 0.15       | 2.39      |
| 15   | AR23      | 22.37      | 3.67     | 10.94      | 18.28     | 53   | AR77      | 45.93      | 36.31    | 15.72      | 11.8      |
| 16   | AR26      | 20.54      | 4.63     | 15.3       | 29.28     | 54   | AR79      | 76.77      | 1.66     | 34.84      | 69.37     |
| 17   | AR27      | 18.62      | 5.57     | 3.33       | 28.87     | 55   | AR80      | 25.88      | 5.47     | 2.52       | 8.76      |
| 18   | AR28      | 31.91      | 8.11     | 9.29       | 32.76     | 56   | AR82      | 1.96       | 1.92     | 0.41       | 1.67      |
| 19   | AR29      | 34.57      | 4.54     | 7.05       | 25.64     | 57   | AR83      | 25.63      | 37.15    | 11.2       | 56.54     |
| 20   | AR30      | 1.43       | 5.83     | 3.5        | 6.15      | 58   | AR84      | 16.45      | 10.35    | 1.77       | 25.78     |
| 21   | AR31      | 45.67      | 3.8      | 18.5       | 36.77     | 59   | AR85      | 2.49       | 1.97     | 0.5        | 1.4       |
| 22   | AR32      | 23.66      | 7.52     | 8.24       | 19.46     | 60   | AR86      | 8.28       | 4.77     | 4.76       | 11.06     |
| 23   | AR35      | 25.95      | 12.38    | 7.33       | 32.31     | 61   | AR87      | 1.02       | 0.3      | 0.31       | 0.82      |
| 24   | AR36      | 32.29      | 6.08     | 9.33       | 18.88     | 62   | AR88      | 3.49       | 0.72     | 0.57       | 1.93      |
| S/No | Sample ID | Ca$^{2+}$ (ppm) | K$^+$ (ppm) | Mg$^{2+}$ (ppm) | Na$^+$ (ppm) | S/No | Sample ID | Ca$^{2+}$ (ppm) | K$^+$ (ppm) | Mg$^{2+}$ (ppm) | Na$^+$ (ppm) |
|------|-----------|-----------------|-------------|----------------|-------------|------|-----------|-----------------|-------------|----------------|-------------|
| 25   | AR37      | 29.65           | 10.17       | 5.47           | 22.69       | 63   | AR89      | 0.89           | 0.73        | 0.15           | 4.56        |
| 26   | AR38      | 77.99           | 78.1        | 20.26          | 53.56       | 64   | AR90      | 1.6            | 0.81        | 0.57           | 0.93        |
| 27   | AR40      | 16.64           | 2.8         | 4.63           | 15.73       | 65   | AR91      | 2.45           | 2.44        | 1.1            | 4.22        |
| 28   | AR42      | 3.32            | 1.58        | 0.73           | 11.71       | 66   | AR92      | 17.43          | 4.12        | 11.29          | 1.59        |
| 29   | AR44      | 37.1            | 12.39       | 7.33           | 23.55       | 67   | AR94      | 3.97           | 2.21        | 2.76           | 6.82        |
| 30   | AR46      | 79.81           | 8.07        | 23.47          | 66.78       | 68   | AR95      | 1.48           | 0.84        | 0.51           | 0.94        |
| 31   | AR49      | 88.8            | 1.88        | 40.47          | 32.57       | 69   | AR96      | 2.12           | 2.5         | 0.55           | 3.29        |
| 32   | AR50      | 2.39            | 1.72        | 1.02           | 1.21        | 70   | AR97      | 3.76           | 2.82        | 1.09           | 5.28        |
| 33   | AR51      | 2.15            | 7.32        | 1.12           | 2.79        | 71   | AR101     | 36.17          | 27.93       | 7.69           | 77.96       |
| 34   | AR52      | 32.86           | 24.22       | 8.65           | 49.14       | 72   | AR103     | 8.48           | 8           | 1.17           | 11.18       |
| 35   | AR53      | 94.15           | 5.27        | 28.73          | 107.9       | 73   | AR105     | 2.94           | 4.48        | 0.79           | 2.43        |
| 36   | AR54      | 66              | 19.56       | 19.13          | 42.43       | 74   | AR107     | 3.42           | 9.66        | 0.71           | 12.46       |
| 37   | AR55      | 3.38            | 9.18        | 0.63           | 17.48       | 75   | AR108     | 0.97           | 4.42        | 0.2            | 2.11        |
| 38   | AR56      | 4.56            | 14.11       | 1.71           | 5.46        |      |           |                |             |                |             |

Table 5. Results of chemical analysis of the groundwater samples (meq/l)

| S/No | Sample ID | Ca$^{2+}$ (meq/l) | K$^+$ (meq/l) | Mg$^{2+}$ (meq/l) | Na$^+$ (meq/l) | S/No | Sample ID | Ca$^{2+}$ (meq/l) | K$^+$ (meq/l) | Mg$^{2+}$ (meq/l) | Na$^+$ (meq/l) |
|------|-----------|-------------------|-------------|-----------------|-------------|------|-----------|-----------------|-------------|-----------------|-------------|
| 1    | AR3       | 1.097             | 0.086       | 0.398           | 0.657       | 39   | AR57      | 0.065           | 0.039       | 0.011           | 0.022       |
| 2    | AR4       | 1.577             | 0.067       | 0.758           | 0.836       | 40   | AR58      | 0.194           | 0.126       | 0.091           | 0.17        |
| 3    | AR5       | 1.011             | 0.083       | 0.159           | 0.309       | 41   | AR59      | 1.876           | 0.141       | 0.782           | 0.443       |
| 4    | AR8       | 3.477             | 0.223       | 1.336           | 2.23        | 42   | AR61      | 3.603           | 0.198       | 2.853           | 1.732       |
| 5    | AR10      | 1.541             | 0.156       | 0.178           | 2.356       | 43   | AR63      | 1.648           | 0.121       | 1.213           | 3.513       |
| 6    | AR11      | 1.086             | 0.051       | 0.488           | 0.786       | 44   | AR65      | 2.49            | 0.667       | 0.941           | 1.567       |
| 7    | AR13      | 4.472             | 0.978       | 0.594           | 0.286       | 45   | AR66      | 3.635           | 1.15        | 1.326           | 1.68        |
| 8    | AR14      | 1.487             | 0.078       | 0.795           | 0.517       | 46   | AR68      | 1.274           | 0.348       | 0.363           | 0.595       |
| 9    | AR15      | 1.432             | 0.091       | 0.281           | 0.289       | 47   | AR70      | 0.968           | 0.098       | 0.406           | 0.599       |
| 10   | AR16      | 0.861             | 0.067       | 0.227           | 0.356       | 48   | AR71      | 1.666           | 0.353       | 1.007           | 2.16        |
| 11   | AR17      | 1.721             | 0.065       | 1.273           | 1.117       | 49   | AR72      | 0.206           | 0.084       | 0.058           | 0.207       |
| 12   | AR19      | 2.915             | 0.034       | 1.151           | 0.651       | 50   | AR73      | 0.153           | 0.028       | 0.054           | 0.067       |
| 13   | AR20      | 3.328             | 0.093       | 3.017           | 1.607       | 51   | AR74      | 0.062           | 0.012       | 0.017           | 0.027       |
| 14   | AR21      | 1.011             | 0.047       | 0.566           | 0.737       | 52   | AR75      | 0.048           | 0.012       | 0.016           | 0.104       |
| 15   | AR23      | 1.119             | 0.094       | 0.912           | 0.795       | 53   | AR77      | 2.297           | 0.931       | 1.31            | 0.513       |
| S/No | Sample ID | $\text{Ca}^{2+}$ (meq/l) | $\text{K}^+$ (meq/l) | $\text{Mg}^{2+}$ (meq/l) | $\text{Na}^+$ (meq/l) | S/No | $\text{Ca}^{2+}$ (meq/l) | $\text{K}^+$ (meq/l) | $\text{Mg}^{2+}$ (meq/l) | $\text{Na}^+$ (meq/l) |
|------|-----------|--------------------------|---------------------|--------------------------|----------------------|------|--------------------------|---------------------|--------------------------|----------------------|
| 16   | AR26      | 1.027                    | 0.119               | 1.275                    | 1.273                | 54   | AR79                     | 3.839               | 0.043                    | 2.903                |
| 17   | AR27      | 0.931                    | 0.143               | 0.278                    | 1.255                | 55   | AR80                     | 1.294               | 0.14                     | 0.21                 |
| 18   | AR28      | 1.6                      | 0.208               | 0.774                    | 1.424                | 56   | AR82                     | 0.098               | 0.049                    | 0.034                |
| 19   | AR29      | 1.735                    | 0.116               | 0.588                    | 1.115                | 57   | AR83                     | 1.282               | 0.953                    | 0.933                |
| 20   | AR30      | 0.072                    | 0.149               | 0.292                    | 0.267                | 58   | AR84                     | 0.823               | 0.263                    | 0.148                |
| 21   | AR31      | 2.284                    | 0.097               | 1.542                    | 1.599                | 59   | AR85                     | 0.125               | 0.051                    | 0.042                |
| 22   | AR32      | 1.183                    | 0.193               | 0.687                    | 0.846                | 60   | AR86                     | 0.414               | 0.122                    | 0.397                |
| 23   | AR35      | 1.3                      | 0.317               | 0.612                    | 1.405                | 61   | AR87                     | 0.051               | 0.008                    | 0.026                |
| 24   | AR36      | 1.615                    | 0.156               | 0.778                    | 0.821                | 62   | AR88                     | 0.175               | 0.018                    | 0.048                |
| 25   | AR37      | 1.483                    | 0.261               | 0.456                    | 0.987                | 63   | AR89                     | 0.045               | 0.019                    | 0.013                |
| 26   | AR38      | 3.9                      | 2.003               | 1.688                    | 2.329                | 64   | AR90                     | 0.08                | 0.021                    | 0.05                 |
| 27   | AR40      | 0.832                    | 0.072               | 0.386                    | 0.684                | 65   | AR91                     | 0.123               | 0.063                    | 0.092                |
| 28   | AR42      | 0.166                    | 0.041               | 0.061                    | 0.509                | 66   | AR92                     | 0.872               | 0.106                    | 0.941                |
| 29   | AR44      | 1.855                    | 0.318               | 0.611                    | 1.024                | 67   | AR94                     | 0.199               | 0.057                    | 0.23                 |
| 30   | AR46      | 3.991                    | 0.207               | 1.956                    | 2.903                | 68   | AR95                     | 0.074               | 0.022                    | 0.043                |
| 31   | AR49      | 4.44                     | 0.048               | 3.373                    | 1.416                | 69   | AR96                     | 0.106               | 0.064                    | 0.046                |
| 32   | AR50      | 0.12                     | 0.044               | 0.085                    | 0.053                | 70   | AR97                     | 0.188               | 0.072                    | 0.091                |
| 33   | AR51      | 0.108                    | 0.188               | 0.093                    | 0.121                | 71   | AR101                    | 1.809               | 0.716                    | 0.641                |
| 34   | AR52      | 1.643                    | 0.621               | 0.721                    | 2.137                | 72   | AR103                    | 0.423               | 0.205                    | 0.098                |
| 35   | AR53      | 4.708                    | 0.135               | 2.394                    | 4.691                | 73   | AR105                    | 0.147               | 0.115                    | 0.066                |
| 36   | AR54      | 3.3                      | 0.501               | 1.594                    | 1.845                | 74   | AR107                    | 0.171               | 0.248                    | 0.059                |
| 37   | AR55      | 0.169                    | 0.235               | 0.053                    | 0.76                 | 75   | AR108                    | 0.049               | 0.113                    | 0.017                |
| 38   | AR56      | 0.228                    | 0.362               | 0.143                    | 0.237               |      |                          |                     |                          |                     |

Table 6. Calculated irrigation parameter indices for groundwater in Wamba Sheet 210

| S. No | Sample ID | SAR (%) | MAR (%) | SSP (%) | KR | S/No | Sample ID | SAR (%) | MAR (%) | SSP (%) | KR |
|-------|-----------|---------|---------|---------|----|------|-----------|---------|---------|---------|----|
| 1     | AR 3      | 0.76    | 27.45   | 33.2    | 0.44 | 39   | AR57      | 0.11    | 14.47   | 45.53   | 0.1 |
| 2     | AR4       | 0.77    | 32.46   | 27.89   | 0.36 | 40   | AR58      | 0.6     | 31.93   | 50.95   | 0.6 |
| 3     | AR5       | 0.4     | 13.59   | 25.1    | 0.26 | 41   | AR59      | 0.38    | 29.42   | 18.01   | 0.17 |
| 4     | AR8       | 1.44    | 28.38   | 33.76   | 0.46 | 42   | AR61      | 0.96    | 44.19   | 23.01   | 0.27 |
| 5     | AR10      | 2.54    | 10.35   | 59.37   | 1.46 | 43   | AR63      | 2.94    | 42.4    | 55.95   | 1.23 |
| 6     | AR11      | 0.89    | 31      | 34.72   | 0.5  | 44   | AR65      | 1.2     | 27.43   | 39.44   | 0.46 |
| S. No | Sample ID | SAR  | MAR (%) | SSP (%) | KR  | SNo | Sample ID | SAR  | MAR (%)  | SSP (%) | KR  |
|-------|-----------|------|---------|---------|-----|-----|-----------|------|-----------|---------|-----|
| 7     | AR13      | 0.18 | 11.73   | 19.97   | 0.06| 45  | AR66      | 1.07 | 26.73     | 36.32   | 0.34|
| 8     | AR14      | 0.48 | 34.83   | 20.68   | 0.23| 46  | AR68      | 0.66 | 22.17     | 36.43   | 0.36|
| 9     | AR15      | 0.31 | 18.12   | 18.78   | 0.17| 47  | AR70      | 0.72 | 29.55     | 33.66   | 0.44|
| 10    | AR16      | 0.3  | 8.03    | 13.02   | 0.13| 48  | AR71      | 1.87 | 36.67     | 48.46   | 0.81|
| 11    | AR17      | 0.91 | 42.52   | 28.3    | 0.37| 49  | AR72      | 0.57 | 21.97     | 52.43   | 0.78|
| 12    | AR19      | 0.46 | 28.31   | 14.42   | 0.16| 50  | AR73      | 0.21 | 26.09     | 31.46   | 0.32|
| 13    | AR20      | 0.9  | 47.55   | 21.13   | 0.25| 51  | AR74      | 0.14 | 21.52     | 33.05   | 0.34|
| 14    | AR21      | 0.83 | 35.9    | 33.21   | 0.47| 52  | AR75      | 0.58 | 25        | 64.44   | 1.6 |
| 15    | AR23      | 0.78 | 44.9    | 30.44   | 0.39| 53  | AR77      | 0.38 | 36.32     | 28.59   | 0.14|
| 16    | AR26      | 1.19 | 55.39   | 37.68   | 0.55| 54  | AR79      | 1.64 | 43.06     | 31.21   | 0.45|
| 17    | AR27      | 1.62 | 23      | 53.62   | 1.04| 55  | AR80      | 0.44 | 13.96     | 25.73   | 0.25|
| 18    | AR28      | 1.31 | 32.6    | 40.74   | 0.6 | 56  | AR82      | 0.28 | 25.76     | 47.83   | 0.55|
| 19    | AR29      | 1.03 | 25.31   | 34.64   | 0.48| 57  | AR83      | 2.34 | 42.12     | 60.63   | 1.11|
| 20    | AR30      | 0.63 | 80.22   | 53.33   | 0.73| 58  | AR84      | 1.61 | 15.24     | 58.77   | 1.15|
| 21    | AR31      | 1.16 | 40.3    | 30.71   | 0.42| 59  | AR85      | 0.21 | 25.15     | 40.14   | 0.37|
| 22    | AR32      | 0.87 | 36.74   | 35.72   | 0.45| 60  | AR86      | 0.76 | 48.95     | 42.64   | 0.59|
| 23    | AR35      | 1.44 | 32.01   | 47.39   | 0.73| 61  | AR87      | 0.18 | 33.75     | 31.43   | 0.47|
| 24    | AR36      | 0.75 | 32.51   | 29      | 0.34| 62  | AR88      | 0.24 | 21.33     | 31.19   | 0.37|
| 25    | AR37      | 1    | 23.52   | 39.16   | 0.51| 63  | AR89      | 1.16 | 22.41     | 78.91   | 3.41|
| 26    | AR38      | 1.39 | 30.21   | 77.52   | 0.42| 64  | AR90      | 0.16 | 38.46     | 31.94   | 0.31|
| 27    | AR40      | 0.88 | 31.69   | 38.3    | 0.56| 65  | AR91      | 0.56 | 42.79     | 53.31   | 0.85|
| 28    | AR42      | 0.51 | 26.87   | 70.79   | 2.24| 66  | AR92      | 0.07 | 51.9      | 8.8     | 0.04|
| 29    | AR44      | 0.92 | 24.78   | 35.24   | 0.42| 67  | AR94      | 0.64 | 53.61     | 47.01   | 0.69|
| 30    | AR46      | 1.68 | 32.89   | 34.34   | 0.49| 68  | AR95      | 0.17 | 36.75     | 35      | 0.35|
| 31    | AR49      | 0.72 | 43.17   | 15.78   | 0.18| 69  | AR96      | 0.52 | 30.26     | 57.66   | 0.94|
| 32    | AR50      | 0.17 | 41.46   | 32.12   | 0.26| 70  | AR97      | 0.62 | 32.62     | 51.98   | 0.82|
| 33    | AR51      | 0.38 | 46.27   | 60.59   | 0.6 | 71  | AR101     | 3.06 | 26.16     | 62.63   | 1.38|
| 34    | AR52      | 1.97 | 30.5    | 53.85   | 0.9 | 72  | AR103     | 0.95 | 18.81     | 57.01   | 0.93|
| 35    | AR53      | 2.49 | 33.71   | 40.46   | 0.66| 73  | AR105     | 0.33 | 30.99     | 50.92   | 0.5 |
| 36    | AR54      | 1.18 | 35.57   | 32.4    | 0.38| 74  | AR107     | 1.6  | 25.65     | 77.45   | 2.36|
| 37    | AR55      | 3.42 | 23.87   | 81.76   | 3.42| 75  | AR108     | 0.51 | 25.76     | 75.64   | 1.39|
| 38    | AR56      | 0.55 | 38.54   | 61.75   | 0.64|     |           |     |           |        |     |
4. CONCLUSION

The qualities of groundwater from shallow aquifers in Wamba Sheet 210 in North Central Nigeria have been assessed for the purpose of irrigation. The study revealed that the electrical conductivities (EC) are within the recommended range suitable for irrigation. Other major indices such as Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP) Magnesium Adsorption Ratio (MAR) and Kellys Ratio (KR) are also largely within the safe limits. It can be concluded therefore that groundwater from virtually all parts of the study area is suitable for irrigation purposes.

DISCLAIMER

The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by the personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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