Mapping groundwater suitability for irrigation using GIS: A Case study of Ilorin, Kwara State, Southwestern Nigeria

D A Olasehinde¹, K A Adeniran², D O Olasehinde³, M R Bayeiri⁴ and S O Adewara⁵

¹Department of Agricultural and Biosystems Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria.
²Department of Agricultural and Biosystems Engineering, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria.
³Department of Mineral Exploration, Nigerian Geological Survey Agency, Kaduna.
⁴Department of Agricultural and Bio-environmental Engineering, Institute of Technology, Kwara State Polytechnic Ilorin.
⁵Department of Economics, Landmark University, Omu-Aran

Corresponding E-mail: Olasehinde.david@lmu.edu.ng

Abstract. Agricultural water in the right quantity and desired quality is needed to drive agrarian revolution in Nigeria. Groundwater, among the forms of water in nature is strategic for Nigeria as it is easy to exploit, readily available not affected by seasonality and the largest natural storage of available freshwater on the planet. The study was aimed at evaluating and mapping irrigation water quality of groundwater system within Ilorin metropolis. Forty-four well samples were collected in triplicates over the dry and wet seasons with their locations georeferenced. The water samples were sent to the laboratory and the results were incorporated into a GIS database in the development of a water map. Six indices, Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR), Permeability Index (PI), Residual Sodium Carbonate (RSC), Kelly’s Ratio (KR) and Soluble Sodium Percentage (SSP), were used to evaluate suitability for irrigation. The geo-spatial representation is displayed using Surfer 9 and ARC Map software. The sampling points were concentrated in the southern portion of the study area, with dense settlements and expected anthropogenic activities. The western portion of the study area within the vicinity of Moro river basin reflected general good irrigation water quality and low settlement is prime for irrigated agriculture. The geospatial representations of irrigation water quality developed guides decision makers on the use of various ground water sources within the area. In the same light, it demonstrates high efficiency of GIS in elucidating complex geospatial data through the development of quality maps.

1. Introduction

Nigeria’s over dependence on rainfed agriculture, reduces productivity as result of the unpredictability of rainfall which has become complicated with the incursion of climate change in recent years. Inventory of fresh water on the planet shows that 30 percent of earth’s fresh water are stored as groundwater, while 68 percent are stored as ice-caps and glaciers which are mostly inaccessible for human use [1]. Groundwater as a source of agriculture water presents an exciting solution for Nigeria’s agriculture. It’s exploitation for domestic, agricultural and industrial purposes have yielded positive results over the years. However,
continuous pollution of groundwater sources mainly from anthropogenic activities present a significant concern for sustainable use in agriculture. In a bid to avoid challenges of using poor water quality for agriculture, systematic screening of groundwater for irrigation is imperative.

Irrigation water quality refers to characteristics which will improve crop yield and quality, maintain soil productivity and ensure sustainability of the environment. Irrigation water quality depends mainly on the mineral constituents present in the water. While potability are concerned with physical, chemical and biological properties of water, irrigation water quality emphasizes on the physical and chemical properties. Documented evidences have identified certain water qualities as indicators of quality related problems, such as excessive dissolved salts and trace ions. This water quality challenges are capable of affecting crop yield and soil structure. Important indices for irrigation water include, sodium hazard, salinity hazard, bicarbonates, electrical conductivity and other trace elements [2]. The study is aimed at evaluating and mapping the groundwater system within Ilorin metropolis employing six quality indices in view of delineating zones suitable for agricultural water use.

2. Materials and Methods

Ilorin, the study location is the capital of Kwara state, has a fast-growing population of about a million residents. The study area like most tropics is characterized by two major seasons, the wet and dry seasons [3]. Figure 1. shows the topography of Ilorin metropolis, the concentration in settlement is observed in the southern region of the study area, while the high lands are clustered in the northern parts. Forty-four groundwater samples were systematically selected within Ilorin metropolis, covering a period of nine months. The samples were obtained in triplicates, one sample each during the middle and peak of rainy season and one sample taken during the peak of dry-Season.

![Figure 1. Topography Map of Ilorin Metropolis (plotted with remote sensing technique and Surfer 9 software)](image)

The water samples were sent for analysis in the laboratory and the results were aggregated. The water indices were calculated using the following formulas:

i. Sodium Adsorption Ratio (SAR) is given by [4]

\[
SAR = \left( \frac{[Na^+]}{\left(\frac{[Ca^{2+}] + [Mg^{2+}]}{2}\right)} \right)^{1/2}
\]
ii. Soluble Sodium Percentage (SSP) is given by [5]
   \[ SSP = \frac{[(Na + K) \times 100]}{(Ca + Mg + Na + K)} \]

iii. Residual Sodium Carbonate (RSC) is given by [6]
   \[ RSC = HCO_3^- - Ca \]

iv. Permeability Index (PI) was estimated according to [7], [8]
   \[ PI = \frac{[(Na^+ + HCO_3^-)/(Ca^{2+} + Mg^{2+} + Na^+)] \times 100}{(Mg \times 100)/(Ca + Mg)} \]

v. Magnesium Adsorption Ratio (MAR) is given by [9][10]
   \[ MAR = \frac{(Mg \times 100)}{(Ca + Mg)} \]

vi. The Kelly's Ratio (KR) was estimated using the equation described by [11] s:
   \[ KR = \frac{Na}{(Ca + Mg)} \]
   where all the ionic concentrations are expressed in meq/L.

2.1 Geo-Spatial Representation of Irrigation Water Quality in the Study Area

The Geographic Information System (GIS) was used as a tool to illustrate the analyzed result of the irrigation water quality indices within 500 m radius circle area. Kriging method was employed by the ArcGIS software to interpolate the pollutants in the unknown areas. The maps were developed using remote sensing techniques [12].

3. Results and Discussions

The subsurface drainage and permeability of the area are shown on figure 2. The groundwater flows in an east to west and west to east direction with a collection point in the center of the study area. Table 1 shows the sample locations and corresponding irrigation quality indices. The groundwater system is deemed largely suitable for irrigation in tandem with the irrigation water quality indices. The summary of the results is displayed on tables 2 and 3.
Figure 2. Colour-Coded Drainage Contour Map of Groundwater System in Ilorin (Plotted With ARC Map Software)

Table 1. Sampling Points and Corresponding Irrigation Quality Indicators of Groundwater samples

| Sample no. | LAT  | LONG. | SAR  | SSP  | RSC  | PI   | MAR  | KR   |
|------------|------|-------|------|------|------|------|------|------|
| S01        | 8.572| 4.637 | 0.245| 22.48| 1.931| 88.52| 39.46| 0.0650|
| S02        | 8.572| 4.637 | 0.009| 21.11|-2.025| 21.26| 27.07| 0.0032|
| S03        | 8.572| 4.638 | 0.190| 27.53|-1.200| 44.28| 22.85| 0.0747|
| S04        | 8.475| 4.635 | 0.002| 28.52|-0.296| 70.05| 23.96| 0.0007|
| S05        | 8.475| 4.633 | 0.004| 28.86| 0.579| 87.46| 28.42| 0.0014|
| S06        | 8.457| 4.582 | 0.005| 27.92|-2.313| 32.54| 19.58| 0.0017|
| S07        | 8.452| 4.580 | 0.000| 0.00  | 0.751| 0.00 | 13.79| 0.0000|
| S08        | 8.452| 4.630 | 0.000| 0.00  |-1.414| 0.00 | 9.79 | 0.0000|
| S09        | 8.452| 4.633 | 0.000| 0.00  | 0.751| 0.00 | 13.79| 0.0000|
| S10        | 8.493| 4.598 | 0.268| 66.31|-0.987| 43.79| 29.35| 0.1096|
| S11        | 8.494| 4.597 | 0.258| 48.49|-0.619| 33.22| 48.93| 0.1173|
| S12        | 8.490| 4.673 | 0.007| 23.19|-0.713| 64.74| 13.20| 0.0028|
| S13        | 8.535| 4.548 | 0.000| 0.00  |-0.895| 0.00 | 5.47 | 0.0000|
| S14        | 8.550| 4.635 | 0.005| 29.42|-0.641| 65.39| 14.31| 0.0021|
| S15        | 8.496| 4.565 | 0.138| 9.87  |2.474 | 55.17| 23.79| 0.0294|
| S16        | 8.496| 4.565 | 0.137| 13.37|-1.408| 67.25| 20.44| 0.0297|
| S17        | 8.496| 4.566 | 0.005| 18.96|-1.649| 36.73| 16.18| 0.0020|
| S18        | 8.498| 4.562 | 0.211| 57.36| 1.528| 97.27| 27.41| 0.0598|
| S19        | 8.495| 4.561 | 0.224| 53.76|-1.101| 39.35| 45.83| 0.0653|
| S20        | 8.495| 4.561 | 0.240| 60.97|-1.140| 60.27| 16.15| 0.0823|
| S21        | 8.461| 4.562 | 0.006| 29.48|-2.156| 20.52| 17.42| 0.0023|
| S22        | 8.461| 4.562 | 0.002| 48.50|-0.939| 35.90| 24.19| 0.0011|
| S23        | 8.460| 4.550 | 0.001| 29.47|-1.193| 38.70| 21.87| 0.0005|
| S24        | 8.463| 4.553 | 0.000| 0.00  |1.104 | 0.00 | 27.99| 0.0000|
| S25        | 8.462| 4.548 | 0.006| 47.18| 0.017| 74.24| 24.62| 0.0035|
| S26        | 8.463| 4.549 | 0.007| 22.87|-0.383| 74.89| 18.13| 0.0021|
| S27        | 8.493| 4.570 | 0.049| 35.70|-2.718| 28.16| 11.49| 0.0166|
Table 2. Summary Statistics of Irrigation Water indices

|          | SAR  | SSP  | RSC  | PI   | MAR  | KR   |
|----------|------|------|------|------|------|------|
| Average  | 0.061| 31.135| -1.183| 54.914| 19.434| 0.02 |
| Min.     | 0.001| 9.867| -7.667| 11.112| 5.471| 0.0001|
| Max.     | 0.268| 66.313| 1.931| 150.525| 48.932| 0.117|
| Standard Deviation | 0.090787| 14.28704| 1.721313| 30.33056| 9.244006| 0.032103|

Table 3. Percentage distribution Water Quality Indices of Groundwater samples in the study area

| SP (%) | Class | % SAR (meq/l) | class | % RSC (meq/l) | Class | % KR (%) | Class (%) |
|--------|-------|---------------|-------|---------------|-------|----------|-----------|
| <20    | excellent | 30             | <10   | 100           | <1.25 | safe     | 91         | <1        | Safe    | 100     |
| 20-40  | Good | 52             | 10-18 | 1.25-         | marginal | 9       | >1        | unsuitable | 0       |
| 40     |       |                |       |               |       |          |           |           |         |         |      |
3.1 Sodium Adsorption Ratio of groundwater samples within Ilorin metropolis
Sodium Adsorption Ratio represent one most significant index of irrigation water quality. Excess dissolved sodium in irrigation water may produce irreversible damages to the soil structure. In the same light, it also affects soil permeability and its especially undesirable for use in clay soils with inherent low permeability. However, moderate values of SAR values may be employed for salt tolerant crops. Richards (1954) presents a simplified four class yardstick of evaluating SAR values, ranging from excellent to poor. In the study area all the groundwater samples were in the excellent class and hence deemed suitable for use for all crops in view of salt tolerance (Table 3). The spatial distribution of SAR values within the metropolis is displayed on Figure 3. The higher concentrations of SAR values are clustered in the south-central portion of the study area. Anthropogenic activities such as improper disposal of waste is prima facie for this relative increase in concentration. Olasehinde, (2016) also established that the subsurface flow direction in the area discharges into a subsurface basin in this area.

3.2 Residual Sodium Carbonate of groundwater samples within Ilorin metropolis
Eaton, 1950 evaluated the combination of carbonate and bicarbonate in excess of alkaline earth for measurement of the high carbonate in water as it affects suitability for use for irrigation. High RSC values in irrigation water may increase alkalinity of soil beyond tolerable levels for crops especially in fine textured soils. Continuous usage of high RSC irrigation water may lead to burning of plants leaves. Similarly, to SAR values RSC classification was done by Richards, 1954 as safe, moderate and unsuitable. In the study area 91 percent of the water samples fell to the safe category while the remaining 9 percent fall to the moderate category. The Spatial distribution of RSC values in the area are displayed on Fig 4. Carbonate concentrations in ground water are mainly a result of geogenic rather than anthropogenic factors.
3.3 Soluble Sodium Percentage of groundwater samples within Ilorin metropolis

Generally, calcium and magnesium maintain a state of equilibrium in groundwater. More magnesium present in waters affects the soil quality converting it to alkaline and decreases crop yield [2]. Spatial spread of SSP in the study area follows a Bimodal pattern with point source concentration in the south-central portion of the study area (figure 5). The average values of SSP on the study area is 31.1 meq/L. Wilcox, 1955 stated that SSP value below 60% is suitable for irrigation. In the study area, 93 percent of the water samples fell to the excellent to permissible categories.
3.4 Permeability Index of groundwater samples within Ilorin metropolis
Permeability index evaluates sodium, calcium, bicarbonate and magnesium contents of the soil as it is influenced by the long-term usage of irrigation water. Doneen, 1964 classified observed permeability to three classes, which are class I (P.I above 75%), Class II (P.I between 25-75%) and Class III (<25%), Class I & II are considered good for irrigation [7]. 84 percent of the water samples fell to the Class I & II are suitable for irrigation, therefore will not give any permeability or infiltration problem. The Geospatial representation of the Permeability index on Figure 6. shows that the few high permeability values continue to coincide with the southern part of the study area with high settlements.

3.5 Magnesium Adsorption Ratio of groundwater samples within Ilorin metropolis
MAR elucidates the state of equilibrium of magnesium and calcium in irrigation water. Similar to RSC, MAR affects soil alkalinity and may decrease crop yield at high concentration. The geospatial representations of MAR are shown on Figure 7. The central western portion of the study area reflects very low MAR values. MAR values above 50 meq/L may cause damages to the soil. Table 2 shows that the average value of MAR in the water samples analyzed was 19.434 meq/L with a maximum value of 48.9 which are all satisfactory values of MAR.

3.6 Kelly’s Ratio of groundwater samples within Ilorin metropolis
All the groundwater samples in the study area had Kelly’s ratio less than one, ranging form 0.0001 to 0.117%. A KR more than 1 indicates an excess level of sodium in water; hence, KR values less than 1 are deemed suitable for irrigation. The geospatial representations are displayed on Figure 8.
Figure 6. PI Map of groundwater samples within Ilorin

Figure 7. MAR Map of groundwater samples within Ilorin
6. Six water quality indices were employed to evaluate the criteria for irrigation quality in the study area. The study findings revealed that groundwater poses a veritable solution for irrigation as several samples analysed displayed good irrigation quality index. The geospatial representations of underground water and its corresponding quality provides a platform for relevant policy makers, and other users of groundwater on the state of groundwater within the area. In the same light, it demonstrates high efficiency of GIS in elucidating complex geospatial data through the development of quality maps.

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