# GIS-Based Assessment of Irrigation Water Quality Index in Selected Farm Areas, South-Western, Nigeria

*[1]Joseph A. Adeyeye, [2]Toyin Omotoso, [3]Johnson A. Oloruntade and [4]Joseph O. Otugboyega
[1]Department of Water Resources Management and Agro-meteorology, Federal University Oye- Ekiti, Nigeria
[2]Department of Civil Engineering, Ekiti State University, Ado Ekiti, Nigeria
[3]Department of Civil Engineering, Olusegun Agagu University of Science and Technology, Okitipupa, Nigeria
[4]Department of Environmental Management and Toxicology, Federal University Oye- Ekiti, Nigeria
**joseph.adeyeye@fuoye.edu.ng | toyin.omotos@eksu.edu.ng | johntades1@yahoo.com | joseph.otugboyega@fuoye.edu.ng**

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**ORIGINAL RESEARCH**

**Abstract-** Water is the most essential nutrient for plant survival and its quality is vital to soil health and crop yields. This study evaluated, categorized and mapped water quality application condition in selected farm settlements, Ekiti North Senatorial District, Nigeria, using Irrigation Water Quality Index (IWQI). Twelve water samples from surface and groundwater sources across the farm settlements were collected and analyzed with replicates in the laboratory, following standard procedures. IWQI revealed that 61% of the water samples fall within “severe restriction" category covering the northeast and northwest parts while 39 % falls into the “high restriction" category for cropping covering the southern part respectively. The outcomes of the study allow for guided water use in relation to soil factor and provide good quality water database in the face of inadequate rainfall occasioned by climate change for optimum water utilization and crop production.

**Keywords-** Crop production, Irrigation, IWQI, Soil condition, Water management, Water quality.

## 1 INTRODUCTION

The importance of water to life cannot be over emphasized (Ezugwu, 2019) but the threshold quality and quantity to meet the desired need of sustainable-life has constantly been a concern issue for researchers. The global water distribution is conditioned on climate and geological formations (Erler et al. 2019). Anthropogenic activities have greatly impacted water quality all over the world (Abdalla and Khalil, 2018). Factors such as increased global population, intensive farming and climate events have put much pressure on water resources (Missaghi et al. 2017).

Studies have shown that the quality of irrigation water affect not just plant growth but soil conditions and consequently the quality of plant yields (Arvind et al. 2020). Abel and Mooshod, (2011) reported groundwater quality in Ado Ekiti to be characterized with low sodium hazard and few cases of high salinities. Gbolahan et al. (2022) observed challenges of magnesium pollution in few farm settlements in southwest, Nigeria which were attributed to Leachate and other forms of pollutants. He suggested the planting of crops with high magnesium affinity as a means of adaptation or remediation. Consequent upon the numerous factors which have imposed visible stress on agricultural land and water supply, the need for water quality assessment, particularly for the purpose of inventory, ionic characterization and mapping for sustainable use has become inevitable (Jidauna et al. 2017).

*Corresponding Author

**Section E-** CIVIL ENGINEERING & RELATED SCIENCES
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Ruma and Sheikh (2010) reported, that due to growing demand of water for irrigation, increasing reuse of treated and/or untreated wastewater have been witnessed worldwide. The quality of any water sample is a description of its physical, chemical and microbiological characteristics, which are the products of intrinsic and external factors (Naylar, 2019). Relative to agriculture, the chemical characteristics are major determinants because of their possible negative implications on both plants and soil. Their excess or deficiency in irrigation water may cause imbalance in the ionic constituents which normally affect soil and plant nutrients uptake. These ionic constituents are used in calculating irrigation water indices. Water quality indices (WQI) provide useful information upon which sound judgment or decisions could be made with respect to best application. Hence, researchers have applied different WQI (Adeyeye et al. 2021; Adimalla and Qian 2019) to evaluate surface and groundwater quality status for urban water supply. Others have adopted Irrigation water quality index (IWQI) as management tool for water quality classification and management (Rokbani et al. 2011). Besides, for the purposes of making clear spatial inferences and as well as enhancing farming planning, Geographical Information System (GIS) has been incorporated into a few of such studies.

To achieve the Sustainable Millennium Goals on food production for the increasing population, government, agricultural agencies, including that of Ekiti State, engages in the establishment of integrated and demonstration farm settlement schemes. These schemes incorporated the use of irrigation using water from both surface and groundwater sources. However, there is a dearth of data on the quality of surface and groundwater resources in the settlements. Creating water quality database for the area is imperative to enhance arable crop production and judicious use of the resources. Such would guide farmers on efficient water use in advent of rainfall deficit due to climate change and provide information on ionic constituents essential for soil water relationship and plant growth. Thus, this study evaluated and mapped surface and groundwater quality for ionic characterization using Irrigation Water Quality Index (IWQI) and Geographical Information System (GIS) in the study area.

## 2 STUDY AREA

The study area covered farm settlements of Ekiti State Agricultural Development Project (ESADP) in Ikole (latitude $7.7982^0$N and longitude $5.5144^0$N) and Oye (latitude $7.7979^0$N and longitude $5.3285^0$N) Local Government Areas of Ekiti, North Senatorial District, Ekiti State, Nigeria. This area falls within derived savannah zone of the programme with Ikole Ekiti as the headquarters. The climate is of distinct rainy and dry seasons, usually from April to October (rainy) and November to March (dry), respectively. With an annual rainfall of 1514 mm, the mean temperature ranges from 21 $^0$C to 28 $^o$C and 44 % relative humidity. Agricultural activity remains the major occupation and source of income for many in the area. Main food crops grown include rice, maize, cassava, yam, plantain, citrus, and cashew trees among others (Ekiti State Agricultural Development Province (ESADP), Report 2016). The area is characteristically rain forest type with thick vegetation and evergreen forest (Fig 1).

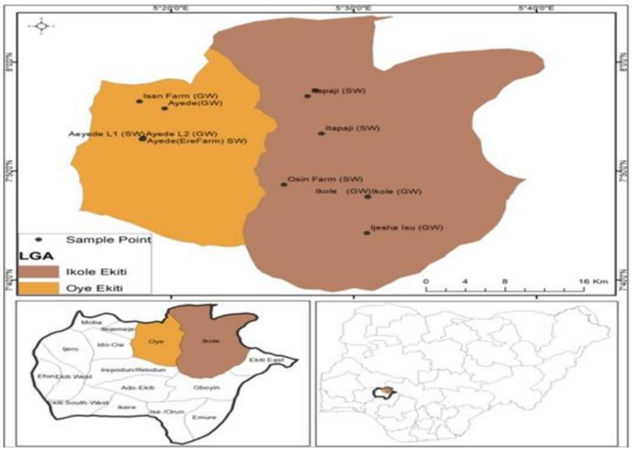


Fig. 1: Map of the study area

### 2.1 THE HYDROGEOLOGY OF THE STUDY AREA

The geology of the area showed typical basement complex where groundwater occurs in joints or weathered and fractured column of the basement, (Bayode et al, 2014). The main lithologic units include the migmatite-gneiss complex, un-migmatised paraschists and the un-metamorphosed granitic rocks. The drainage of the study area is described (Figure 2).

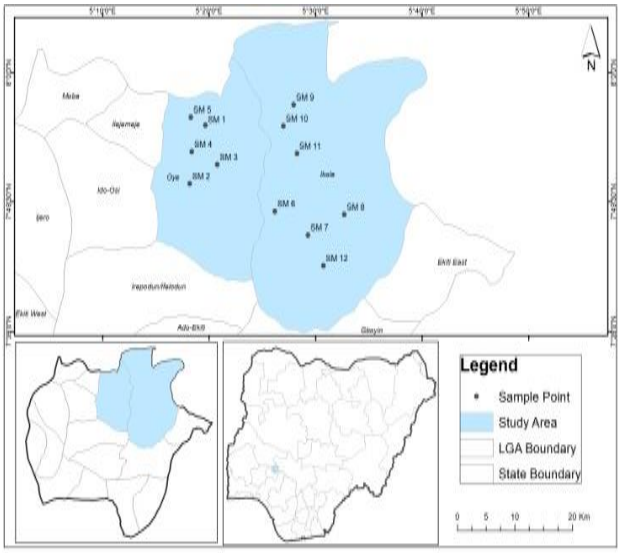


Fig. 2: Map showing the drainage of the study Area

### 2.2 WATER SAMPLING

Water samples were collected from groundwater and surface water sources from Ikole and Oye farm settlements (Table 1) for investigation in a standard clinical method. Samples for cations determination were acidified from the field to prevent ions precipitation in their preparation for laboratory analyses. Analytical quality control was maintained by equipment calibration, duplicate samples and procedural blank measurement. The sampling point coordinates were documented (Table 1).

Table 1. Geographical coordinates of the sampling points

| Sample Code | Longitude | Latitude | Location | Altitude(Z) |
|---|---|---|---|---|
| SM 1 | 5.32 | 7.9289 | Ayede(GW) | 574.7 |
| SM 2 | 5.30 | 7.8816 | AeyedeL1 (SW) | 553.4 |
| SM 3 | 5.30 | 7.8841 | Ayede(EreFarm) SW) | 551.6 |
| SM 4 | 5.30 | 7.8816 | Ayede L2 (GW) | 552.5 |
| SM 5 | 5.30 | 7.9397 | Isan Farm (GW) | 545.1 |
| SM 6 | 5.43 | 7.8122 | Osin Farm (SW) | 506.1 |
| SM 7 | 5.51 | 7.7936 | Ikole (GW) | 556.2 |
| SM 8 | 5.51 | 7.7941 | Ikole (GW) | 551.5 |
| SM 9 | 5.46 | 7.9565 | Itapaji (SW) | 505.1 |
| SM 10 | 5.45 | 7.9477 | Itapaji (SW) | 506.7 |
| SM 11 | 5.47 | 7.8905 | Itapaji (SW) | 515.4 |
| SM 12 | 5.51 | 7.7383 | Ijesha Isu (GW) | 557.3 |

GW: Groundwater, SW: Surface water

### 2.3 WATER ANALYSIS

The pH and electrical conductivity (EC) were measured in-situ, using portable water quality meter (HI9813-61). Total dissolved solids (TDS), suspended solids (TS), total hardness (TH) and main cations like magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$), sodium ($Na^+$), potassium ($K^+$), and anions such as carbonate (CO3-), bicarbonate (HCO3-), nitrate ($NO_3$-), sulphate ($SO_4^{2-}$), chloride ($Cl^-$) and alkalinity were analyzed in the laboratory following standard procedure as outlined by American Public Health Association (APHA, 1995). Total hardness and bicarbonate were determined by volumetric analysis while sulphate and

 

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nitrate were obtained by spectrophotometer and ion chromatography respectively. Calcium and magnesium were estimated using Atomic Absorption while sodium and potassium were determined using Flame Photometer. Chloride was obtained by volumetric analysis using silver nitrate solution (AgNO3 and K2Cr). Titration method was employed to estimate bicarbonate using hydrochloric acid, phenolphthalein and methyl orange indicator titration. Heavy metals were determined in acidified water samples using Atomic Absorption Spectrometer (AAS-bulk scientific model VGP211). For the metals, adjustment wavelengths of determination were recorded (Table 2).

Table 2. Metals and wavelength determination of the elements of interest

| Metals | Wavelength |
|---|---|
| Sodium (Na) | 589.0 nm |
| Manganese (Mn) | 279.5 nm |
| Potassium (K) | 766.5 nm |
| Zinc (Zn) | 213.9 nm |
| Calcium (Ca) | 422.7 nm |
| Magnesium (Mg) | 285.2 nm |
| Iron (Fe) | 248.3 nm |

## 3 Data Analysis

The data obtained were subjected to simple descriptive statistics to measure mean, mode and median of the distributions as empirical parameters for the determination of the irrigation water quality index (IWQI) following Grmay, (2016). Parameters of interest and significance used in computing the IWQI include Electrical conductivity (EC), Sodium Absorption Ratio (SAR), sodium ion (Na+), Chloride ion (Cl-) and Bicarbonate ion (HCO3-) which dominantly influenced water quality for irrigation. Sodium Adsorption Ratio was calculated using equation (1)

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

where:

*SAR:* Sodium Adsorption Ratio $(meq/l)^{1/2}$

Concentrations of ions ($Na^{2+}$, $Ca^{2+}$, and $Mg^{2+}$) are expressed in milli-equivalents per litre (meq/l)

### 3.1 Irrigation Water Quality Index (IWQI) Application Stages

The study adopted IWQI model developed by Meireles et al. (2010). The model at the first stage identified water quality parameters considered more relevant to irrigation. Following this, the definition of quality measurement values (*qi*) and aggregation weights *(wi)* were established. Values of qi were estimated based a proposal by the University of California Committee Consultants - UCCC and by the criteria established by Ayers and Westcot (1999) (Table 3). Each water quality parameter was assigned numerical value based on its significance; the higher the value the better the quality of the water sample.

Table 3. Parameter Limiting Values for Quality Measurement (qi) Calculation

| *qi* | EC (µs/cm) | SAR $(Mg/l)^{1/2}$ | $Na^{+}$ | $Cl^{-}$ | $HCO^{3-}$ |
|---|---|---|---|---|---|
| | | | Mg/l | | |
| 85-100 | $200 \leq EC < 750$ | SAR<3 | $2 \leq Na < 3$ | Cl<4 | $1 \leq HCO_3 < 1.5$ |
| 60-85 | $750 \leq EC < 1500$ | $3 \leq SAR < 6$ | $3 \leq Na < 6$ | $4 \leq Cl < 7$ | $1.5 \leq HCO_3 < 4.5$ |
| 35-60 | $1500 \leq EC < 3000$ | $6 \leq SAR < 12$ | $6 \leq Na < 9$ | $7 \leq Cl < 10$ | $4.5 \leq HCO_3 < 8.5$ |
| 0-35 | $200 > EC \geq 3000$ | $SAR \geq 12$ | $2 > Na \leq 9$ | $Cl \geq 10$ | $1 > HCO_3 \geq 8.5$ |

Source: Ayers and Westcot (1999)

Values of qi were calculated using equation (2), based on the tolerance limits shown in Table (3) and the observed water quality:

$$q_{i} = q_{imax} - \frac{\{[(x_{ij}-x_{inf})*q_{iamp}]\}}{x_{amp}} \quad \text{..................... (2)}$$

where:

*q_imax* = the highest value of qi for the class
*x_ij*= the experimental value for the parameter
*x_inf*= the resultant value to the lower limit of the class to which the parameter belongs
*q_iamp* = class amplitude
*x_amp* = class amplitude to which the parameter belongs.

In order to calculate $x_{amp}$ of the last class of each parameter, the upper limit was considered to be the highest value determined in the physicochemical analysis of the water samples from which the corresponding IWQI weight ($w_i$) Table 4, was determined.

Table 4. Weights for the Irrigation Water Quality Index Parameters

| Parameter | Weight *(Wi)* |
|---|---|
| EC | 0.211 |
| Na | 0.204 |
| $HCO_3$ | 0.202 |
| Cl | 0.194 |
| SAR | 0.189 |
| Total | 1.0 |

The values were normalized such that their sum equals 1. The irrigation water quality index (IWQI) was calculated using equation (3):

$$IWQI = \sum_{i=0}^{n} q_i w_i IWQI = \sum_{i=0}^{n} q_i w_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

IWQI is dimensionless parameter ranging from 0 to 100. The *qi* is the quality of the *ith* parameter as a function of its measured concentration while *wi* is the normalized weight of the *ith* parameter as a function of its relative importance to groundwater quality. Class division based on the projected water quality index was based on present water quality indices and, classes were defined considering soil water infiltration reduction, salinity risk and toxicity to plants in the classifications (Holanda and

 

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Amorim 1997). Restrictions to water use classes were characterized based on the information in Table 5.

Table 5. Water Quality Index Characteristics (Meireles et al. 2010).

| IWQI | Water Use Restrictions | Recommendation | |
|---|---|---|---|
| | | Soil | Plant |
| 85-100 | No restriction (NR) | May be used for the majority of soils with low probability of causing salinity and sodicity problems, being recommended leaching within irrigation practices, except for in soils with extremely low permeability. | No toxicity risk for most plants |
| 70-85 | Low restriction (LR) | Recommended for use in irrigated soils with light texture or moderate permeability, being recommended salt leaching. Soil sodicity in heavy texture soils may occur, being recommended to avoid its use in soils with high clay | Avoid salt sensitive plants |
| 55-70 | Moderate restriction (MR) | May be used in soils with moderate to high permeability values, being suggested moderate leaching of salts. | Plants with moderate tolerance to salts may be grown |
| 40-55 | High restriction (HR) | May be used in soils with high permeability without compact layers. High frequency irrigation schedule should be adopted for water with EC above 2000 µS cm-1 and SAR above 7.0. | Should be used for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl and $HCO_3$ values |
| 0-40 | Severe restriction (SR) | Should be avoided its use for irrigation under normal conditions. In special cases, may be used occasionally. Water with low salt levels and high SAR require gypsum application. In high saline content water soils must have high permeability, and excess water should be applied to avoid salt accumulation. | Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl and $HCO_3$. |

## 3.2 Thematic Maps

Using Geographical Information System (GIS), the map for irrigation water quality of the study area was created using the Inverse Interpolation Technique, IDW based on data obtained from sampled waters. The description of IWQI for the delineated area was accomplished using ArcGIS map (Spatial Analyst extension 10.7.1) which revealed the overall quality assessment of the water sources for irrigation purposes.

# 4 Results

## 4.1 Physicochemical Characteristics of the Sampled Water

The mean, maximum, minimum and standard deviations of physicochemical characteristics of the water samples across the farm settlement are illustrated (Table 6).

## 4.2 Irrigation Water Quality Index

The Irrigation Water Quality Index (IWQI) concept was applied by adopting the model to determine the suitability of the water samples for irrigation purposes. Accordingly, the five parameters (EC, SAR, Na+, Cl-, and $HCO_3$) with dominant influence on water quality for irrigation were considered for computing IWQI (Table 7) for sample 1, ditto to others for which summary is presented in Table 8.

Table 6. Statistical measures of the parameters of interest in the study area

| Sample Code | Mean Values | Maximum | Minimum | SD |
|---|---|---|---|---|
| Ph | 6.67 | 7.11 | 6.28 | 0.22 |
| EC(µS/cm) | 255.8 | 1087 | 81.3 | 298.98 |
| TDS (mg/L) | 184.17 | 798 | 46.1 | 219.01 |
| SS (mg/L) | 3.55 | 10.68 | 0.18 | 3.49 |
| TS (mg/L) | 186.38 | 799.32 | 46.64 | 218.67 |
| $Cl^-$ (mg/L) | 22.35 | 42.6 | 6.12 | 10.55 |
| $NO_3$ (mg/L) | 1.11 | 2.24 | 0.2 | 0.62 |
| $Fe^{2+}$ (mg/L) | 30.83 | 74.84 | 0.74 | 30.74 |
| $SO_4^{2-}$ (mg/L) | 61.58 | 118.04 | 5.43 | 43.00 |
| $Ca^{2+}$ (mg/L) | 61.08 | 241.08 | 7.84 | 68.12 |
| $Mg^{2+}$(mg/L) | 38.31 | 74.84 | 7.29 | 23.54 |
| $Na^+$ (mg/L) | 36.08 | 86 | 17 | 21.41 |
| $K^+$ (mg/L) | 71.75 | 208 | 0 | 70.51 |
| $Mn^{2+}$(mg/L) | 0.55 | 2.19 | 0.04 | 0.73 |
| $Zn^{2+}$ (mg/L) | 0.11 | 0.21 | 0.02 | 0.06 |
| $HCO_3$(mg/L) | 227.56 | 406.50 | 21.52 | 151.77 |
| SAR | 5.48 | 7.93 | 2.16 | 2.28 |

Table 7. Irrigation water quality index calculation for sample 1 as obtained from the equation

| Parameter | $X_{ij}$ | Class | $Q_{imax}$ | $Q_{iamp}$ | $X_{inf}$ | X amp | $Q_i$ | $W_i$ | IWQI |
|---|---|---|---|---|---|---|---|---|---|
| EC | 307 | 1 | 100 | 15 | 200 | 550 | 97.08 | 0.21 | 20.48 |
| Na+ | 18 | 4 | 35 | 35 | 2 | 84 | 28.33 | 0.20 | 5.78 |
| $HCO_3^-$ | 406.50 | 4 | 35 | 35 | 1 | 405.50 | 0 | 0.20 | 0 |
| $CL^-$ | 32.4 | 4 | 35 | 35 | 1 | 41.6 | 8.58 | 0.19 | 1.66 |
| SAR | 2.16 | 1 | 100 | 15 | 2 | 1 | 97.57 | 0.19 | 18.44 |
| | | | | | | | | 1 | 46.37 |

Table 8: IWQI summary for the water samples across the farm settlements as obtained from the IWQI equation

| SAMPLE CODE | Longitude (XDD) | Latitude (YDD) | $W_i$*QI of EC | $W_i$*QI of Na | $W_i$*QI of HCO3 | $W_i$*QI of Cl | $W_i$*QI of SAR | IWQI |
|---|---|---|---|---|---|---|---|---|
| SM 1 | 5.327500 | 7.928888 | 20.48 | 5.78 | 0 | 1.66 | 18.44 | 46.37 |
| SM 2 | 5.308055 | 7.881666 | 8.37 | 4.25 | 1.83 | 4.21 | 10.43 | 29.10 |
| SM 3 | 5.308055 | 7.884166 | 8.05 | 5.61 | 1.67 | 2.91 | 16.01 | 34.24 |
| SM 4 | 5.306944 | 7.881666 | 8.28 | 5.865 | 1.50 | 3.95 | 16.94 | 36.54 |
| SM 5 | 5.304722 | 7.939722 | 8.12 | 5.61 | 0.75 | 3.26 | 17.19 | 34.94 |
| SM 6 | 5.436388 | 7.812222 | 21.04 | 3.995 | 0.08 | 2.29 | 12.20 | 39.60 |
| SM 7 | 5.513132 | 7.793658 | 18.86 | 1.275 | 3.92 | 1.60 | 10.02 | 35.68 |
| SM 8 | 5.512912 | 7.794198 | 15.56 | 0 | 1.96 | 0 | 10.16 | 27.68 |
| SM 9 | 5.465848 | 7.956536 | 7.83 | 4.335 | 6.34 | 4.24 | 10.49 | 33.23 |
| SM 10 | 5.458055 | 7.947777 | 7.79 | 4.505 | 6.59 | 3.98 | 10.22 | 33.09 |
| SM 11 | 5.470833 | 7.890555 | 8.32 | 4.93 | 6.71 | 9.64 | 9.82 | 39.42 |
| SM 12 | 5.512222 | 7.738333 | 8.35 | 4.76 | 6.09 | 13.06 | 12.74 | 45.00 |

The summary of the IWQI calculations for all the water samples across the farm settlement is illustrated (Figure 3). IWQI calculated for each sample across the farm settlements showed that the values varied from 27.68 to 46.37 using equation (2) and (3). This shows that all the samples fell within the severe restriction (SR) (0 - 40) and High restriction category (40 - 55) as indicated by water quality index calculation (Meireles et al. 2010).

 

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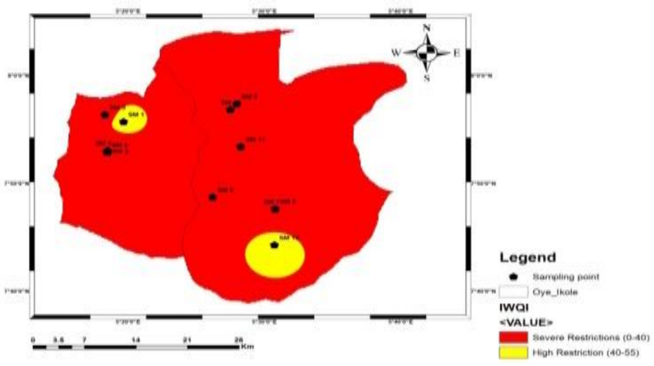


Fig. 3: Spatial distribution of Irrigation Water Quality Index across the study location

## 5 Discussion

IWQI showed variations from severe restriction (SR) to high restriction (HR) across the farm settlement as indicated by spatial distribution map (Fig. 4) and as interpreted with Table (5). This is similar to Khalars and Hassan, (2013) report on water quality for irrigation. On a vast area to the northeast and northwest of the study area, there was a severe restriction (SR) water quality. About 61 % of the study area was covered by severe restriction (SR) water quality characteristics while the remaining 39 % was classified as high restriction (HR). Evaluation according to Meireles et al. (2010) revealed that water with a severe restriction (SR) should only be used in soil with high permeability, and excess water should be applied to avoid salt accumulation. In this situation, such water could be used for irrigation with some restrictions on the type of plant with salt tolerance. While high restriction (HR) water could be used in soils with high permeability without compact layers, and should be used for irrigation of plants with moderate to high salt tolerance. The integrated map displays the IWQ index's spatial distribution within the farm settlement and can be adopted as a general suitability map for required water quality information for irrigation in the area under study. This allowed for order of water used demonstrated by others studies (El Behairy and Baroudy, 2021; Al Habithi et al. 2019). The map shows the spatial distribution of water quality simply as index values, which made it much easier for a decision making on water quality management for irrigation purposes.

## 6 Conclusion

The application of analytical method, Irrigation Water Quality Index (IWQI) and GIS mapping provide a very effective and efficient tool for summarizing agro-meteorological data. This allowed for better understanding of water quality and for effective and efficient water plan use on the farm. IWQI map showed that the northeast and northwest parts of the study area were characterized with ''severe restriction" water category while the southern part falls into the ''high restriction" water-use division for irrigation application. The severe and high restriction water classes obtained in the study area could only be used on soil with high permeability index, with critical attention on crop salt tolerance.

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