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EVALUATION OF GROUNDWATER SUITABILITY FOR IRRIGATION PURPOSE USING GIS AND IRRIGATION WATER QUALITY INDICES

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ABSTRACT

As a major source of water for irrigation, the evaluation and assessment of groundwater to ensure it meets the quality for sustainable agriculture is key. This research presents the findings of the quality of groundwater and its suitability for irrigation purposes. This was carried out using the irrigation water quality indices and the Geographic Information System (GIS). The Inverse Distance Weighted (IDW) method of the GIS was used to study the spatial distribution of these indices. Indices considered include Sodium Absorption Ratio (SAR), Percentage Sodium (%Na), Permeability Index (PI), Kelly Ratio (KR), Magnesium Hazard (MH), Total Hardness (TH), Residual Sodium Bicarbonate (RSBC) and Potential Salinity (PS). The values obtained were SAR (0.00 to 10.99, mean of 3.43), Percentage Sodium (26.00% to 94.42%, mean of 70.33%), Permeability Index (94.14% to 379.47%, mean of 161.45%), Kelly Ratio (0.00 to 8.62, mean of 3.19) and Magnesium Hazard (0.00% to 80.33 %, mean of 39.21%). Total Hardness (12.49 mg/L to 77.50 mg/L, mean of 31.35 mg/L), Residual Sodium Bicarbonate (-0.55 meq/L to 5.46 meq/L, mean of 1.41 meq/L), Potential Salinity (0.88 meq/L to 2.53 meq/L, mean of 1.69 meq/L) and Electrical Conductivity (110*µS/cm* to 910*µS/cm*, mean of 277.14*µS/cm)*. The computed water indices when compared with known standards show that the groundwater from the study area is generally fit and can be applied for irrigation purposes.

Keywords: Geographic Information System, Groundwater Suitability, Irrigation, Irrigation Water Indices, Spatial Distribution

INTRODUCTION

Water is one of the most requested of all urban and rural amenities, the most basic and critical requirement for human survival (Gupta & Gupta, 2021). It is the principal component in the earth that supports the life of all living (Aouiti *et al*., 2021). Water exists substantially either as surface or groundwater. Groundwater is water found in all voids of a geologic stratum (Todd & Mays, 2005). It is considered as the most important source of freshwater especially for the arid and semi-arid regions due to the low precipitation rates in those regions (Kayemah *et al*., 2021).

Groundwater is a valuable natural resource (Hossain & Patra, 2021), according to Mostaza-Colado *et al*., (2018), groundwater is a renewable resource. It is one of the important issues in water resources management, as well as an emerging critical issue for cities and towns around the world (Sutadian *et al*., 2016; Verma *et al*., 2020).

Groundwater is essential to the survival of both plants and animals all over the planet (Bari *et al*., 2021), serving as a major source of water for different purposes (Jamshidzadeh, 2020), including domestic, irrigation and industrial water supply (Oinam *et al*., 2012; Ramakrishnaiah *et al*., 2009). It accounts for 43% of the global irrigation water use as it is considered more suitable for irrigation purpose compared to surface water (Siebert *et al*., 2010).

Water contains some level of dissolved minerals (Mirabbasi *et al*., 2008). These dissolved minerals dissociate into ions-positively and negatively charged ions referred to as cations and anions respectively (Rubini *et al*., 2020). This defines the chemical composition of a water source.

The chemical nature of groundwater is related to products of rock weathering, decomposition and changes with time and space (Raghunath, 2006), as well as anthropogenic sources (Abimbola *et al*., 2002; Drissa *et al*., 2013). The chemical character of any water source determines to some extent its quality (Okunlola & Afolabi, 2015) thereby defining it's suitability for different purposes (Nagaraju *et al*., 2016). Hence, the study of its quality is extremely important (Beg *et al*., 2021).

Irrigation water quality infers water suitable for agricultural purpose (Adegbola *et al*., 2021). Water for irrigation depends on the mineral constituents, as salts exceeding the permissible limit in irrigation water can affect soil permeability, soil structure as well as crop growth and production. (Badmus *et al*., 2020; Murty & Jha, 2011). Based on the foregoing, this study seeks to determine the groundwater irrigation suitability in the study area. This will provide the required knowledge of the water quality so as to apply the necessary irrigation management practices for agricultural sustainability.

Study Area

The study area is part of the Kazaure schist belt, located about 65 km from the Kano metro city in the northwestern part of Kano State. It lies between latitude 12° 30' 00" N to 12° 45' 00" N, and longitude 8° 15' 00" E to 8° 30' 00" E, covering an area of about 770.06 km² (Kankara *et al*., 2021). The area belongs to the Sudan Savanna tropical climatic zone characterized by two distinctive seasons (dry and wet seasons).

The vegetation pattern is predominantly thorny shrubs with grasses of less than 2 m high. Trees found in this area include thorn Acacia, Neem and Baobab which are scattered, and normally shed their leaves completely during the dry seasons. It is denser along river courses due to the presence of moisture which allows the vegetation to flourish (Kankara & Ado, 2020). Figure 1 shows the study area and sampling points.

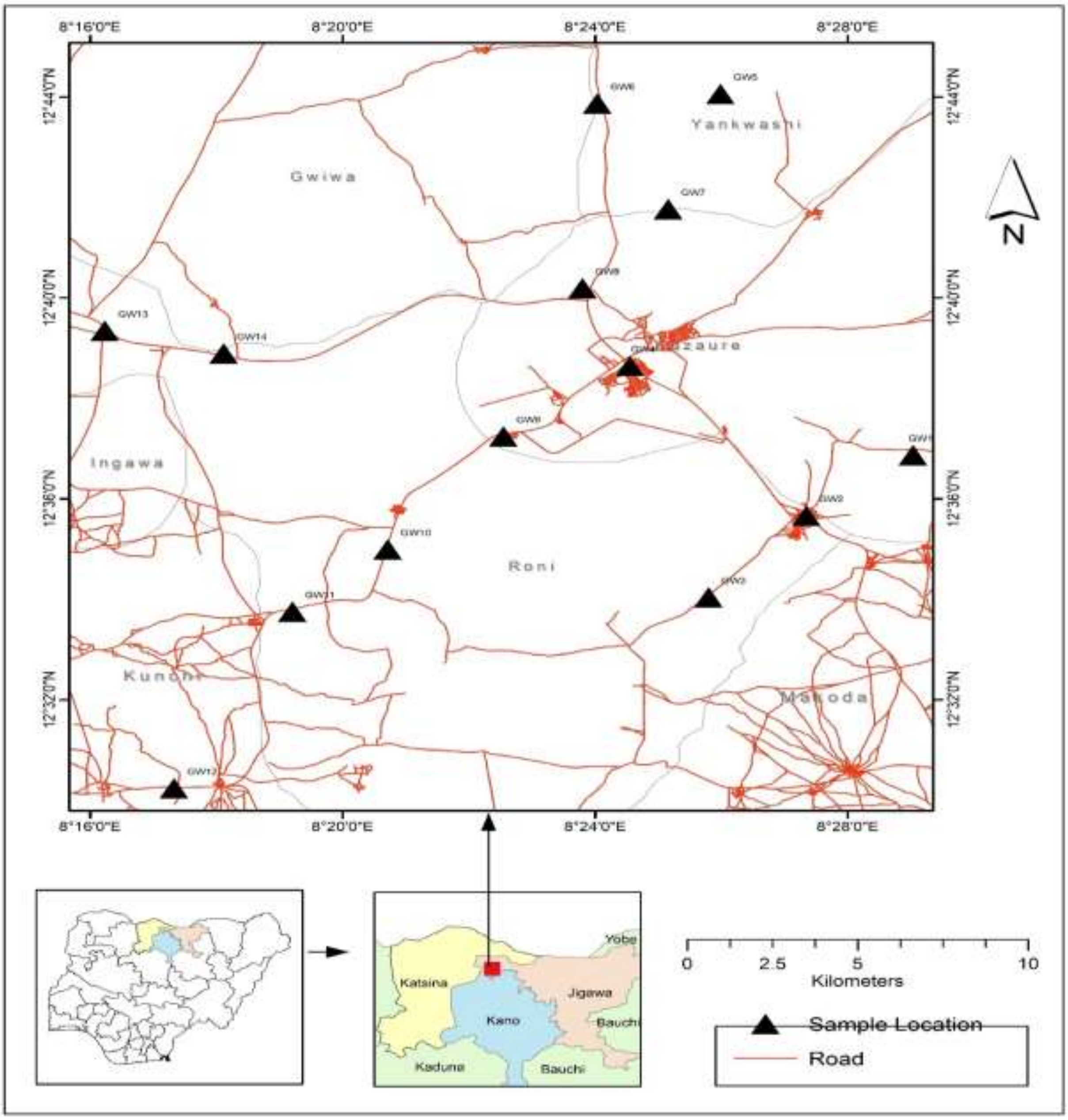

Figure 1: The study area showing the sample locations

Studies have been carried out in this area (Adagba *et al*., 2021; Musa *et al*., 2019). However, there has been no extensive look at the irrigation potentials of water from this area. The main objective of this study is to evaluate the suitability of the groundwater resources for the purpose of irrigation using the Geographic Information System and groundwater irrigational indices from the study area. Irrigation water quality was analysed considering parameters such as the Permeability Index (PI), Percentage Sodium (% Na), Sodium Absorption Ratio (SAR), Kelly Ratio (KR), Magnesium Hazard (MH), Electrical Conductivity (EC), Residual Sodium Bicarbonate (RSBC) and Total Hardness (TH).

MATERIALS AND METHODS

Sample Collection and Analysis

Fourteen (14) water samples were obtained from different sampling points in the study area. The use of a Global Positioning System device was employed to identify the sample locations. Electrical conductivity meter was used to determine the electrical conductivity. The drying process was employed in the determination of total dissolved solids (TDS). Determination of pH Value was done using the pH meter. Calcium, Magnesium, Chlorine and Bicarbonate were determined using titration method, Sulphate was determined using the UV Spectrophotometer while Sodium and Potassium were estimated using the flame photometer. All procedures were done according to prescribed standard (APHA, 1995).

Irrigation Water Quality Indices

To obtain the indices, the physio-chemical parameters were converted form mg/L to meq/L. This was achieved using the equation (1) below:

$$Conc.(meqL^{-1}) = \frac{Conc.(mgL^{-1}) * Valency}{Atomic\ weight} \qquad (1)$$

Sodium Absorption Ratio (SAR)
SAR is classed into four. S1 as low (<10), S2 as medium (10-18), S3 as high (18-26) and S4 as very high (>26). It is expressed in milli-equivalent per Litre (meq/L) and is computed using the equation:

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

Percentage Sodium (% Na)
Percentage Sodium is measured in percentage and is computed using the equation:

$$Na\% = \frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})} * 100 \quad (3)$$

Permeability Index (PI)
The computation of permeability index is expressed in percentage using the equation below.

$$PI = \frac{Na^{+}+\sqrt{HCO_3^{-}}}{(Ca^{2+}+ Mg^{2+}+Na^{+})} * 100 \quad (4)$$

Kelly Ratio (KR)
Kelly ratio is expressed in milli-equivalent per Litre and is computed using the equation:

$$KR = \frac{Na^{+}}{(Ca^{2+}+Mg^{2+})} \quad (5)$$

Magnesium Hazard (%MH)
Mg^{2+} and Ca^{2+} are generally in equilibrium state in water (Hossain & Patra, 2021; Mukiza *et al*., 2021). The increase in value of one of these cations increases the pH thereby reducing the infiltration capacity of the soil hence affecting the crop yield (Singh *et al*., 2020). Magnesium hazard is expressed in percentage and is computed using the equation:

$$MH\% = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} * 100 \quad (6)$$

Total Hardness (TH)
Total hardness was measured in milligram per Litre (mg/L) and computed using the equation:

$$TH = 2.497 * Ca^{2+} + 4.115 * Mg^{2+} \quad (7)$$

Residual Sodium Bicarbonate (RSBC)
Residual sodium bicarbonate (RSBC) was computed using the equation:

$$RSBC = HCO_3^{-} - Ca^{2+} \quad (8)$$

Potential Salinity (PS)
Groundwater Potential Salinity is estimated based on the concentration of Cl^{-} and SO_4^{2-}. It is measured in meq/L. The potential salinity for the present study was computed using the equation below.

$$PS = Cl^{-} + \frac{1}{2}SO_4^{2-} \quad (9)$$

Statistical Analysis and GIS Application
To analyse the acquired data statistically, Microsoft Excel 2016 version was employed. Spatial variability maps of each water indices was generated to provide adequate information about the ground water in the study area. ArcMap of the Environmental and Scientific Research Institute (Esri) GIS 10.7.1 was used to generate the thematic maps using the Inverse Distance Weighted (IDW) method of spatial interpolation.

RESULTS AND DISCUSSION

Table 1: Statistical Summary of the Irrigation Indices

Indices	Unit	Min	Max	Mean	St. Dev
%Na	*%*	26.58	94.42	70.33	24.14
MH%	*%*	0.00	80.33	39.21	21.73
KR	*meq/L*	0.00	8.62	3.19	2.92
SAR	*meq/L*	0.00	11.00	3.43	3.41
RSBC	*meq/L*	-0.55	5.46	1.41	1.42
PI	*%*	94.14	379.47	161.45	69.74
TH	*mg/L*	12.49	77.50	31.35	16.08
EC	*µS/cm*	110.00	910.00	277.14	204.40
PS	*meq/L*	0.88	2.53	1.69	0.44

Sodium Adsorption Ratio (SAR)
SAR or sodium hazard is an expressive term that denotes the degree to which Na^{+} in water is replaced with Ca^{2+} and Mg^{2+}, this replacement results in deflocculation and subsequent loss in soil permeability (Egbueri *et al*., 2021). SAR estimates the accumulation of Na^{+} in the soil at the expense of Ca^{2+} and Mg^{2+} due to the consistent use of sodic water (Rawat *et al*., 2018). Sodium rich water reacts with the soil in a form that leads to the reduction in the soil's permeability which ultimately affects crop production. A high proportion of sodium to calcium and magnesium affects the water available to the crops (Udom *et al*., 2019).
The SAR values in this present study ranged between 0.00 meq/L to 10.99 meq/L with a mean of 3.43 meq/L. This signifies that 93% representing 13 samples of the water samples was excellent for irrigation while 7% representing 1 sample was good based on the Sodium Absorption Ratio posing no sodium hazard. This shows that based on SAR, water in the study area is general suitable for irrigation (Table 2).

Table 2: Classification of Irrigation Water based on SAR

Indices/Reference	Range	Condition	No of Samples	Percent
Sodium Adsorption Ratio	< 10	Excellent	13	93%
(SAR)	10-18	Good	1	7%
(Richards, 1954)	18-26	Doubtful	-	-
	> 26	Unsuitable	-	-

Percentage Sodium (%Na)

High percentage sodium in water causes the inability of the soil to form stable aggregates with a loss of soil structure and tilt (Kumar *et al*., 2017). A base-exchange reaction occurs removing the calcium and magnesium ions in waters with high sodium concentration, thus causing a reduction in the ability of water movement in the soil. This restriction in aeration and infiltration is experienced when the soil is wet but hard when it is dry. The Percentage sodium in the study area was in range of 26 % to 94.42 % with a mean of 70.33 %. The results show that three (3) samples representing 21.5 % had a value range of 20 – 40% showing good quality. One (1) sample corresponding to 7 % was in the range of 40 – 60 % and considered permissible, three (3) samples in the range of 60 – 80 % showed doubtful quality, while seven (7) samples representing 21.5 % had a value greater 80% showing that it is unsafe for irrigation purposes (Table 3).

Table 3: Percentage Sodium (%Na) classification of Irrigation water.

Indices/Reference	Range	Condition	No of Samples	Percent
Percentage Sodium (%Na)	< 20	Excellent	-	-
(Wilcox., 1955)	20-40	Good	3	21.5%
	40– 60	Permissible	1	7%
	60–80	Doubtful	3	21.5%
	> 80	Unsuitable	7	50%

Permeability index (PI)

Permeability Index is directionally proportional to the interconnection of soil grains, as the soil permeability is reduced by using groundwater rich with Mg^{2+}, Ca^{2+}, Na^{+}, and HCO_3^- . (Ayyandurai *et al*., 2022). The permeability of the soil profile is influenced by the concentration of Mg^{2+}, Ca^{2+}, Na^{+}, and HCO_3^- (Singh *et al*., 2015). For the study area, the PI values varied from 94.14 % to 379.47 % with a mean of 161.45 %. High values of PI have also been recorded in previous studies (Amadi *et al*., 2019; Kalpana & Elango, 2012). A high permeability index suggests subsurface structural features that can facilitate groundwater contamination (Singh *et al*., 2020). The high PI values infers a high amount of Na^{+} and HCO_3^- due to the dissolution of carbonate, dolomite and the cation exchange process (Xu *et al*., 2019).

Table 4: Classification of irrigation water based on Permeability Index

Indices/Reference	Range	Condition	No of Samples	Percent
Permeability Index (PI)	< 25	Suitable	-	-
(Doneen, 1964)	25 -75	Moderate	-	-
	> 75	Unsuitable	14	100%

Kelly's ratio (KR)

According to Kelly (1963), groundwater having a Kelly Ratio below one (1) is considered fit for irrigation, between 1-2, it is considered moderate while above 2 it is considered to be unsafe. The Kelly's Ratio (KR) for groundwater from the study area was in the range of 0 to 8.62 with a mean value of 3.19. High values of KR have also recorded in previous studies (Iqbal *et al*., 2021; Meena & Bisht, 2020; Raihan & Alam, 2008; Vadiati *et al*., 2019). A high KR suggests a significantly high concentration of Na^{+} or the significantly low concentration of Ca^{2+} and Mg^{2+}. Results from the study are as shown (Table 5).

Table 5: Classification of irrigation water based on Kelly Ratio

Indices/Reference	Range	Condition	No of Samples	Percent
Kelly Ratio (KR)	< 1	Suitable	5	36%
(Kelly, 1963)	1 – 2	Moderate	1	7%
	> 2	Unsuitable	8	57%

Magnesium hazard (MH)

Calcium and magnesium maintains a state of equilibrium in natural waters. The increase in one of these ions can be detrimental to soil as this can increase the soil salinity. Magnesium hazard is therefore a way of estimating this hazard as a magnesium level of more than 50% in water can be unsuitable for use in irrigation. A total number of nine (9) samples representing about 64% of the total samples had Magnesium hazard values below 50% which qualifies for suitable irrigation water see table 6.

Table 6: Classification of Irrigation Water based on Magnesium Hazard

Indices/Reference	Range	Condition	No of Samples	Percent
Magnesium Hazard (MH)	< 50	Suitable	9	64%
(Raghunath, 2006)	> 50	Unsuitable	5	36%

Total hardness (TH)

Divalent metallic cations are the major causes of hardness in water. (Reddy, 2013). The total hardness for the study area ranged from 12.49 mg/L to 77.50 mg/L with a mean value of 31.35 mg/L. Thirteen (13) samples form the study area had values of total hardness below 75 mg/L. Based on the total hardness criteria, the water is suitable for irrigation, see table 7.

Table 7: Total Hardness (TH) classification of irrigation water.

Indices/Reference	Range (mg/L)	Condition	No of Samples	Percent
Total Hardness (TH)	< 75	Soft	13	93.0 %
(Todd & Mays, 2005)	75-150	Moderately Hard	1	7.0 %
	150-300	Hard	-	-
	> 300	Very Hard	-	-

Residual Sodium Bicarbonate (RSBC)

According to Gupta and Gupta (1987) as reported by Mirza *et al*. (2017) water containing RSBC < 5 is considered safe, 5-10 marginal and > 10 meq/L unsatisfactory. The RSBC values ranged from -0.55 to 5.46 meq/L with a mean value of 1.41 meq/L. The results show that 93% of the samples are safe for irrigation with values less than 5 meq/L, see table 8.

Table 8: Residual Sodium Bicarbonate classification of irrigation water

Indices/Reference	Range	Condition	No of Samples	Percent
(RSBC)	< 5	Safe	13	93%
(Gupta & Gupta, 1987)	5 -10	Marginal	1	7%
(Al-Mashakbeh, 2017)	> 10	Unsatisfactory	-	

Electrical Conductivity (EC)

Electrical Conductivity (EC) indicates the amount of dissolved ions in water (Abdalazem *et al*., 2020). It is related to the conduction of electricity through the water and is correlated to the saturation of water with regards to the dissolved solids (Pal *et al*., 2018). High EC decreases significantly the amount of useable water in the soil solution (Reddy, 2013), and the formation of saline soils (Alam, 2013). The electrical conductivity of water in the study area ranged from 110.00 µS/cm to 910 µS/cm with a mean of 277.14 µS/cm. Table 9 shows the classification of all the water samples based on the Electrical Conductivity

Table 9: Classification of irrigation water based on Electrical Conductivity

Indices/Reference	Range	Condition	No of Samples	Percent
EC (µS/cm)	< 250	Excellent	10	71.5%
(Richards, 1954)	250 -750	Good	3	21.5%
	750 – 2000	Permissible	1	7%
	2000 – 3000	Doubtful	-	-
	> 3000	Unsuitable	-	-

Potential Salinity (PS)

According to Rawat *et al*. (2018), PS < 3 meq/l infers water suitable for irrigation. The PS of the study area ranged between 0.88 meq/L to 2.53 meq/L with a mean value of 1.69 meq/L. This therefore indicates that all the water samples are suitable for irrigation based on the Potential Salinity criteria.

Table 10: Summary of Water Samples based on the Irrigation Quality Indices

Indices/Reference	*Range*	*Classification*	*No. of Samples*	*Percentage*
Magnesium Hardness	< 50	Suitable	9	64%
(MH)	> 50	Unsuitable	5	36%
Total Hardness (TH)	< 75	Soft	13	93%
	75 – 150	Moderately Hard	1	7%
	150 – 300	Hard	-	-
	> 300	Very Hard	-	-
Permeability Index (PI)	< 25	Suitable	-	-
	25 -75	Moderate	-	-
	> 75	Unsuitable	14	100%
Percentage Sodium (%Na)	< 20	Excellent	-	-
	20 – 40	Good	3	21.5%
	40 – 60	Permissible	1	7%
	60 – 80	Doubtful	3	21.5%
	> 80	Unsafe	7	50%
EC (µS/cm)	< 250	Excellent	10	71.5%
	250 – 750	Good	3	21.5
	750 – 2000	Permissible	1	7%
	2000 – 3000	Doubtful	-	-
	> 3000	Unsuitable	-	-
Sodium Absorption Ratio (SAR)	< 10	Excellent	13	93%
	10 – 18	Good	1	7%
	18 – 26	Doubtful	-	-
	> 26	Unsuitable	-	-

Kelly Ratio (KR)	< 1	Suitable	5	36%
	1 – 2	Moderate	1	7%
	> 2	Unsuitable	8	57%
Residual Sodium Bicarbonate (RSBC)	< 5.0	Safe	13	93%
	5.0 – 10.0	Marginal	1	7%
	> 10.0	Unsatisfactory	-	-
Potential Salinity	< 3	Satisfactory	14	100%
	> 3	Unsatisfactory	-	-

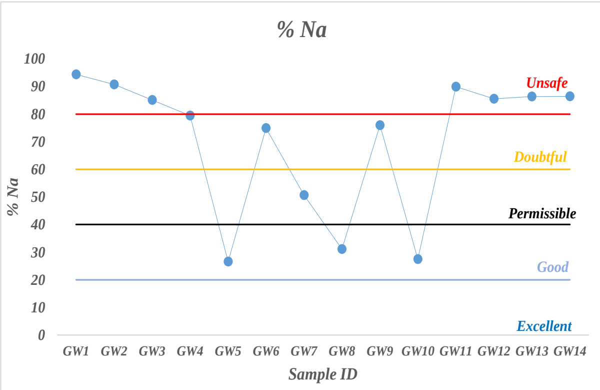

Figure 2: Percentage Sodium

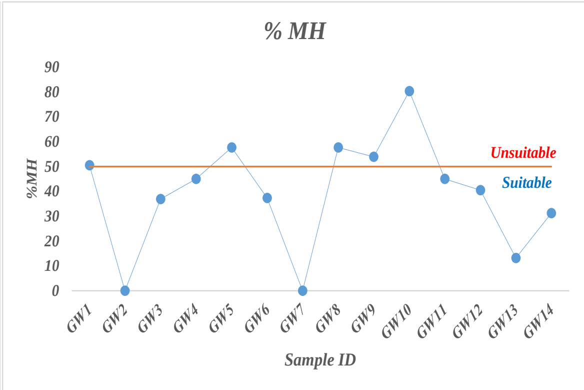

Figure 3: Percentage Magnesium Hazard

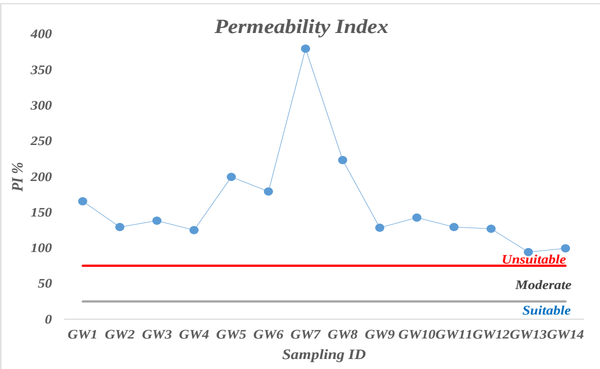

Figure 4: Permeability Index

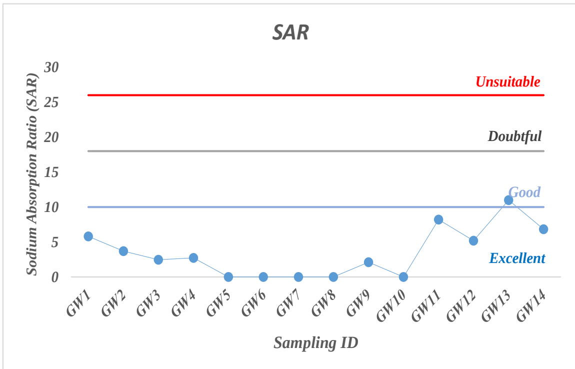

Figure 5: Sodium Adsorption Ratio

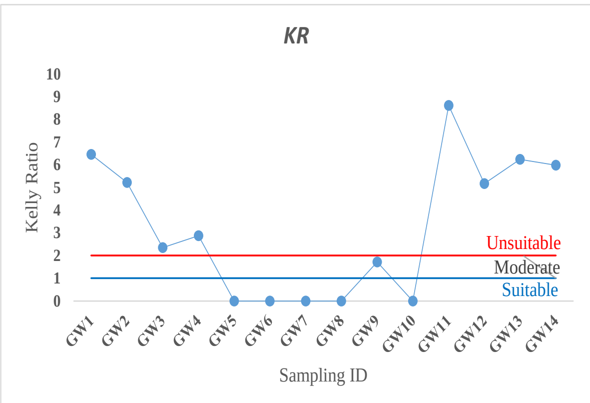

Figure 6: Kelly Ratio

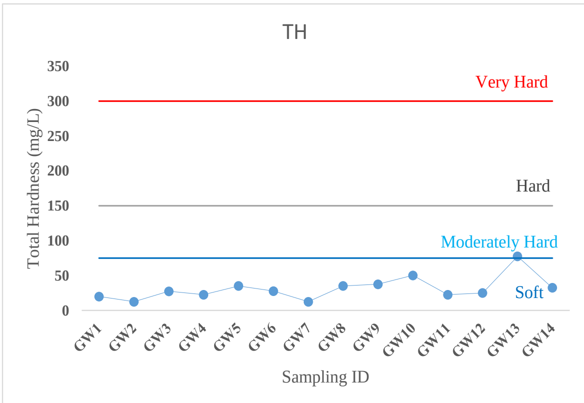

Figure 7: Total Hardness

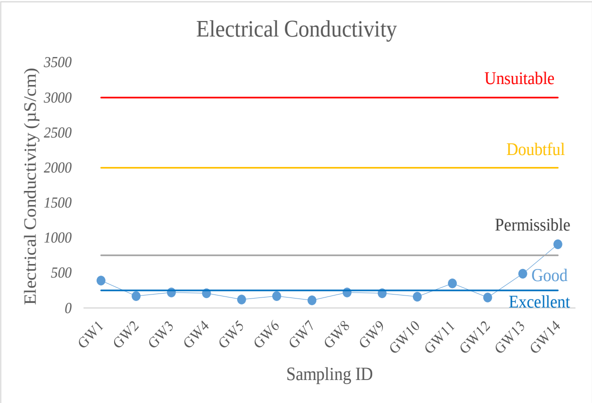

Figure 8: Electrical Conductivity

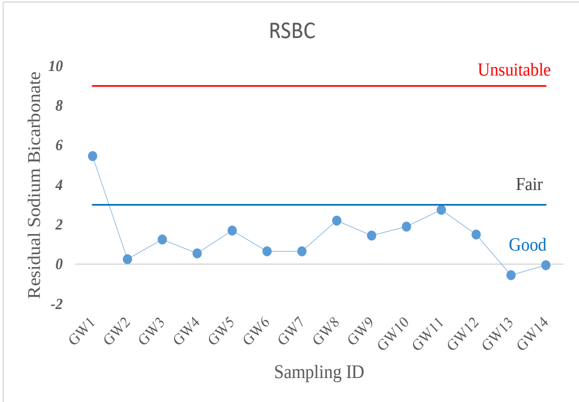

Figure 9: Residual Sodium Bicarbonate

Figs. 2 – 9 shows diagrams for the various irrigation indices and their recommended values.

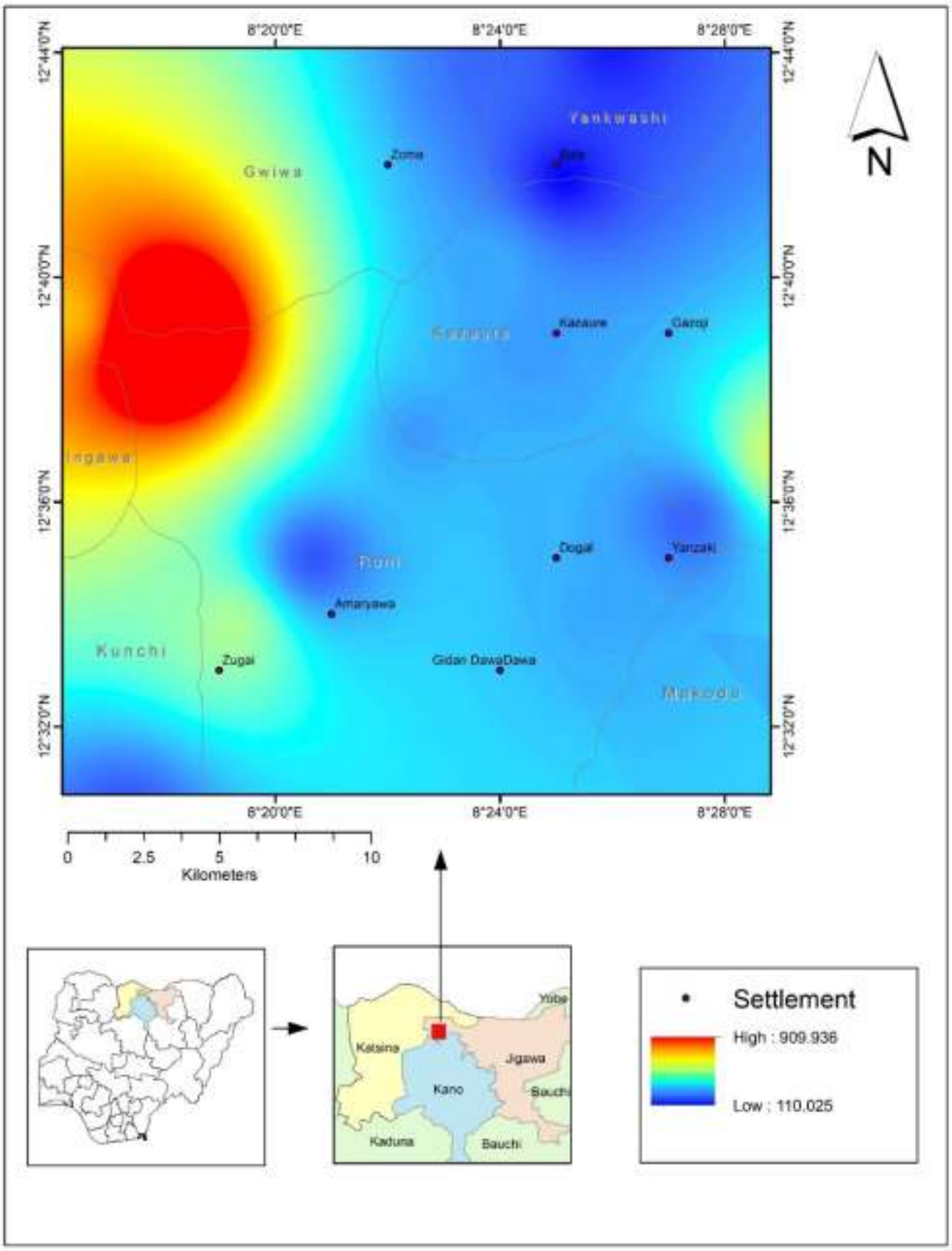

Figure 10: Spatial distribution of Electrical Conductivity (EC) in the Study area

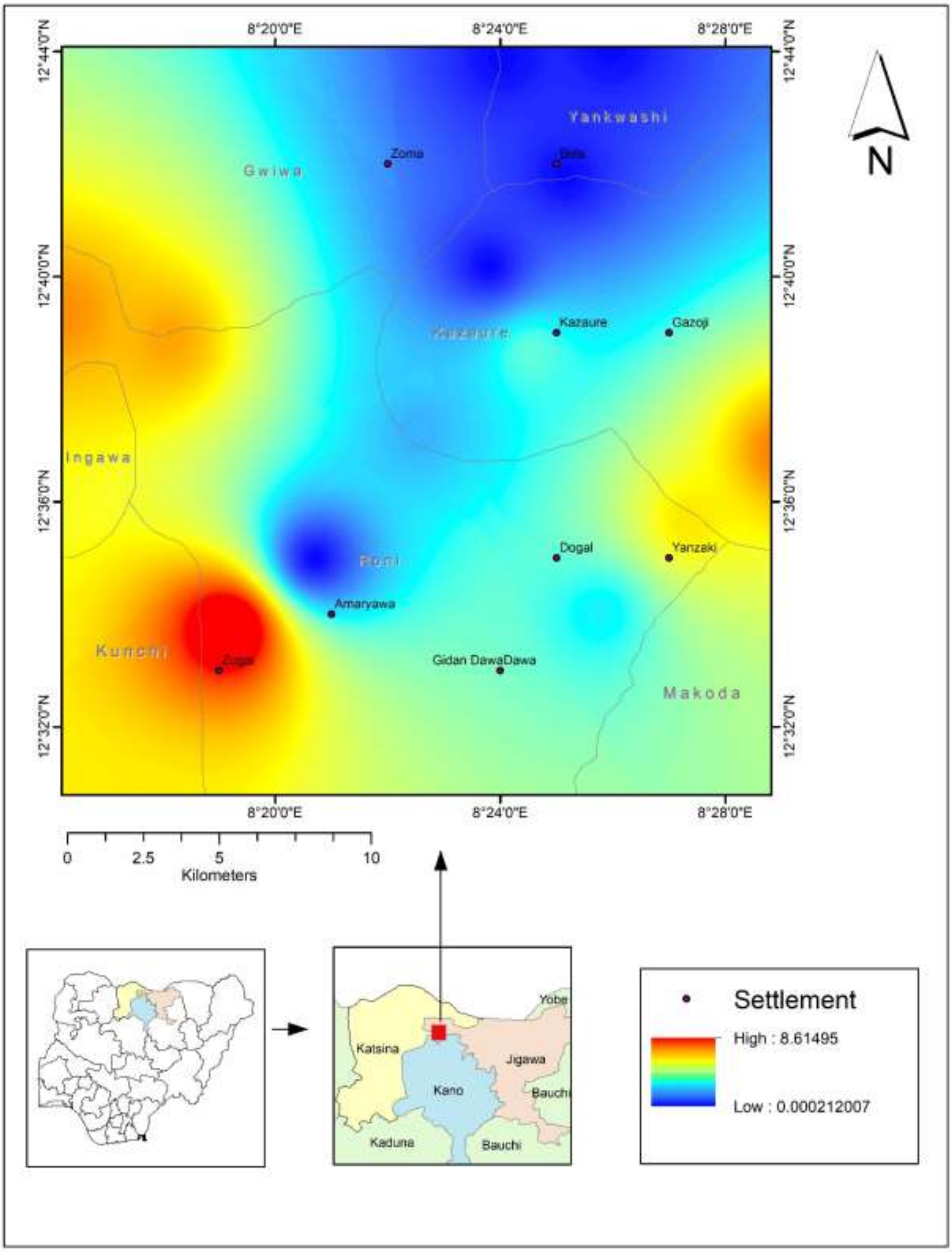

Figure 11: Spatial distribution of Kelly Ratio (KR) in the Study area

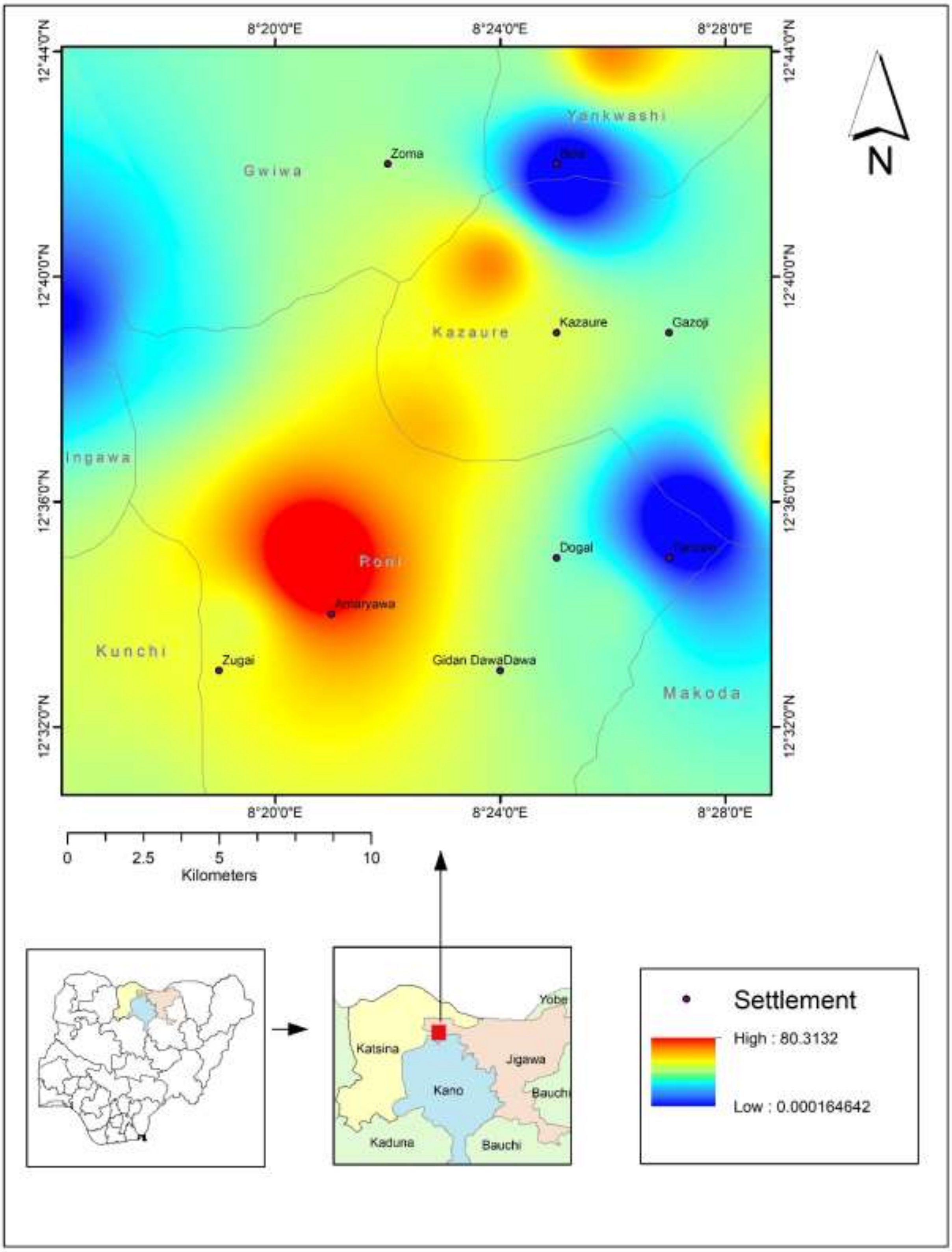

Figure 12: Spatial distribution of Magnesium Hazard (MH) in the Study area

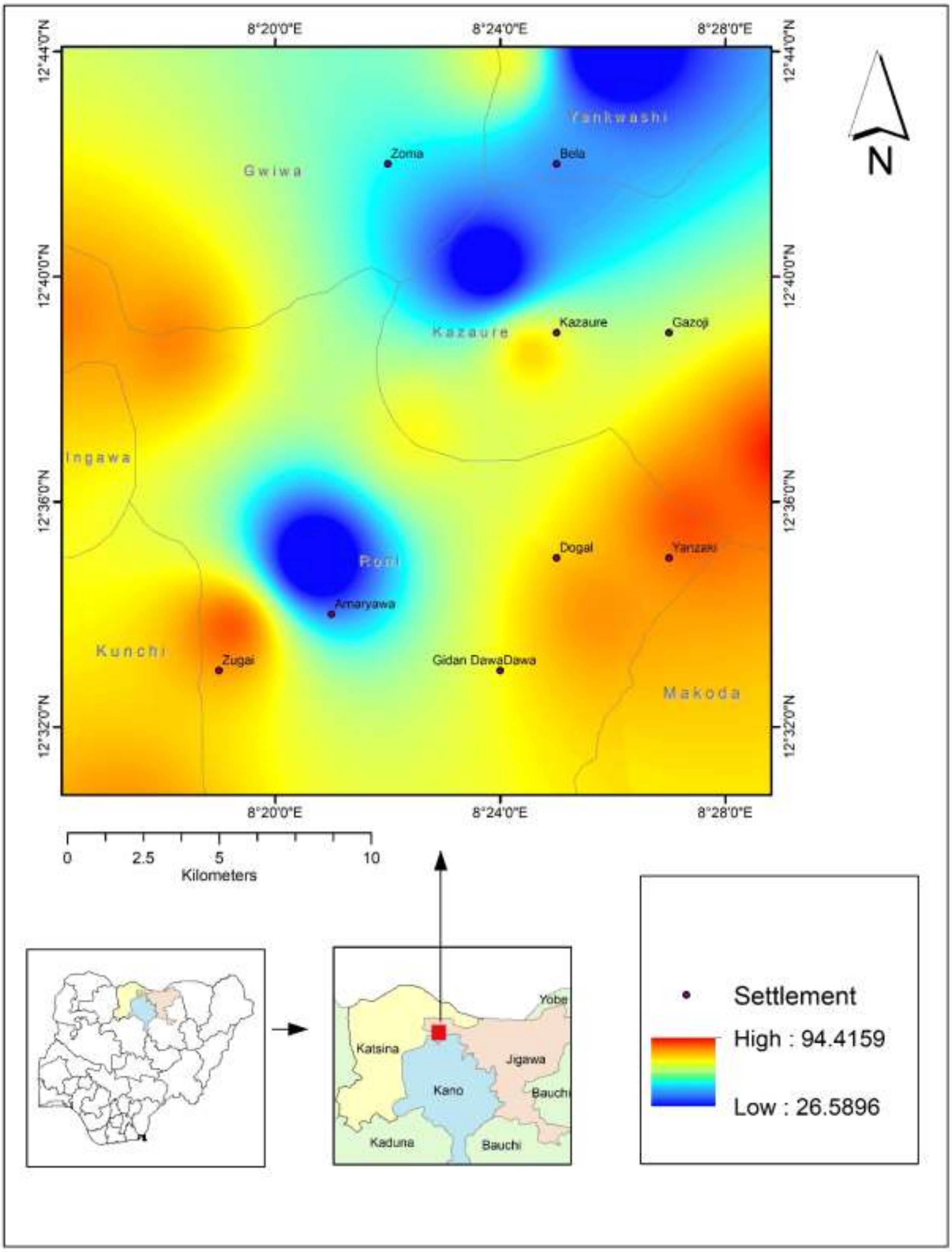

Figure 13: Spatial distribution of Sodium Percentage (% Na) in the Study area

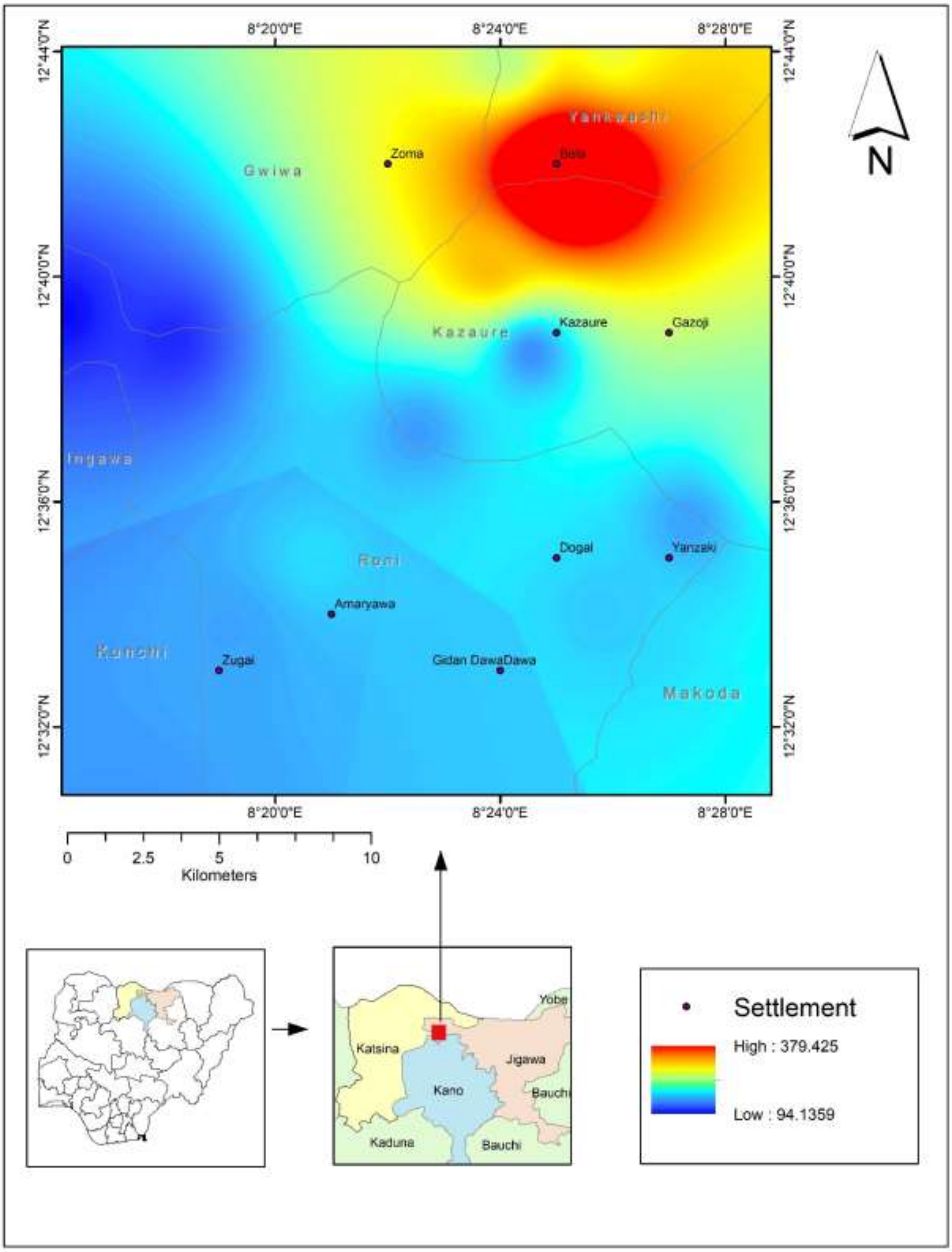

Figure 14: Spatial distribution of Permeability Index (PI) in the Study area

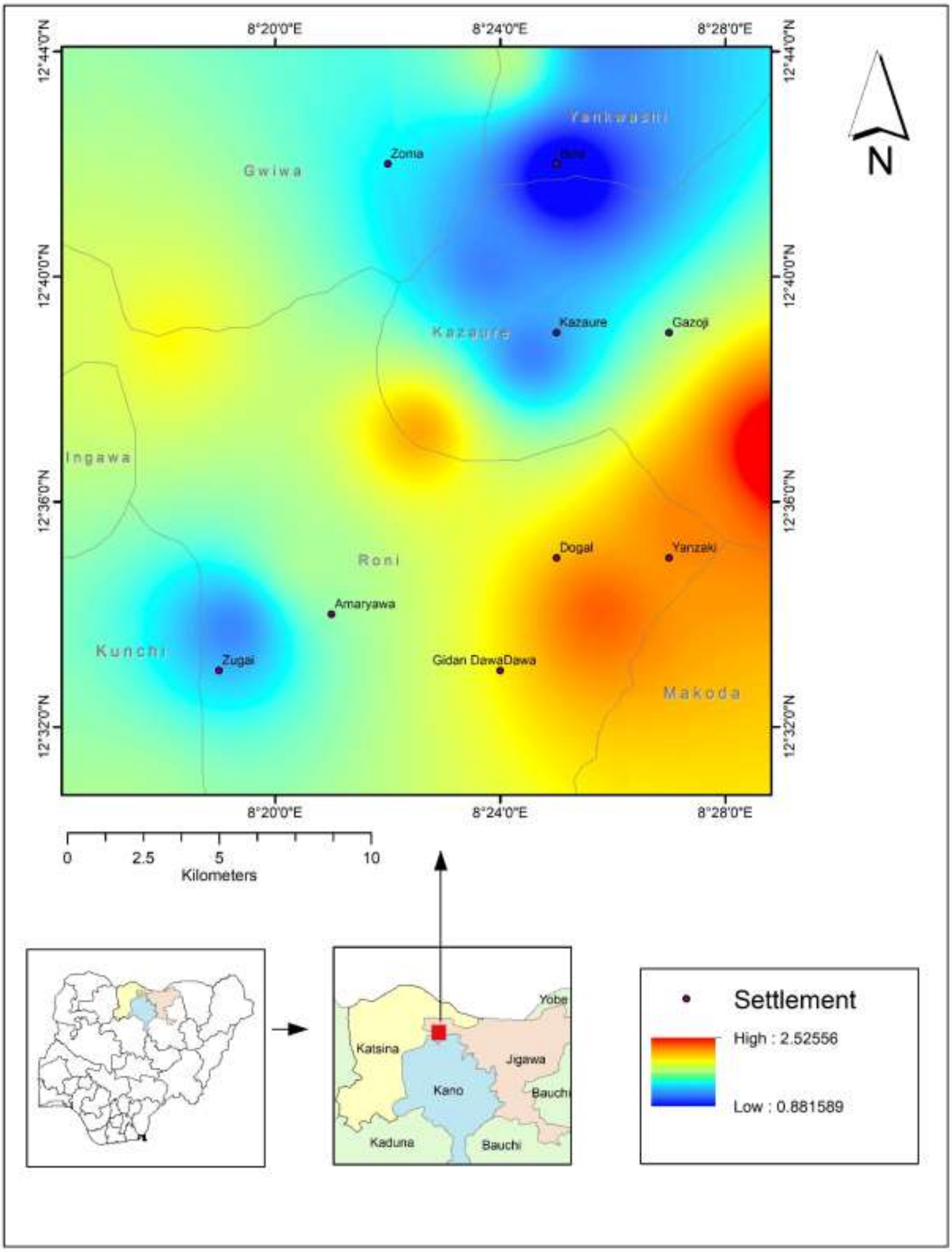

Figure 15: Spatial distribution of Potential Salinity (PS) in the Study area

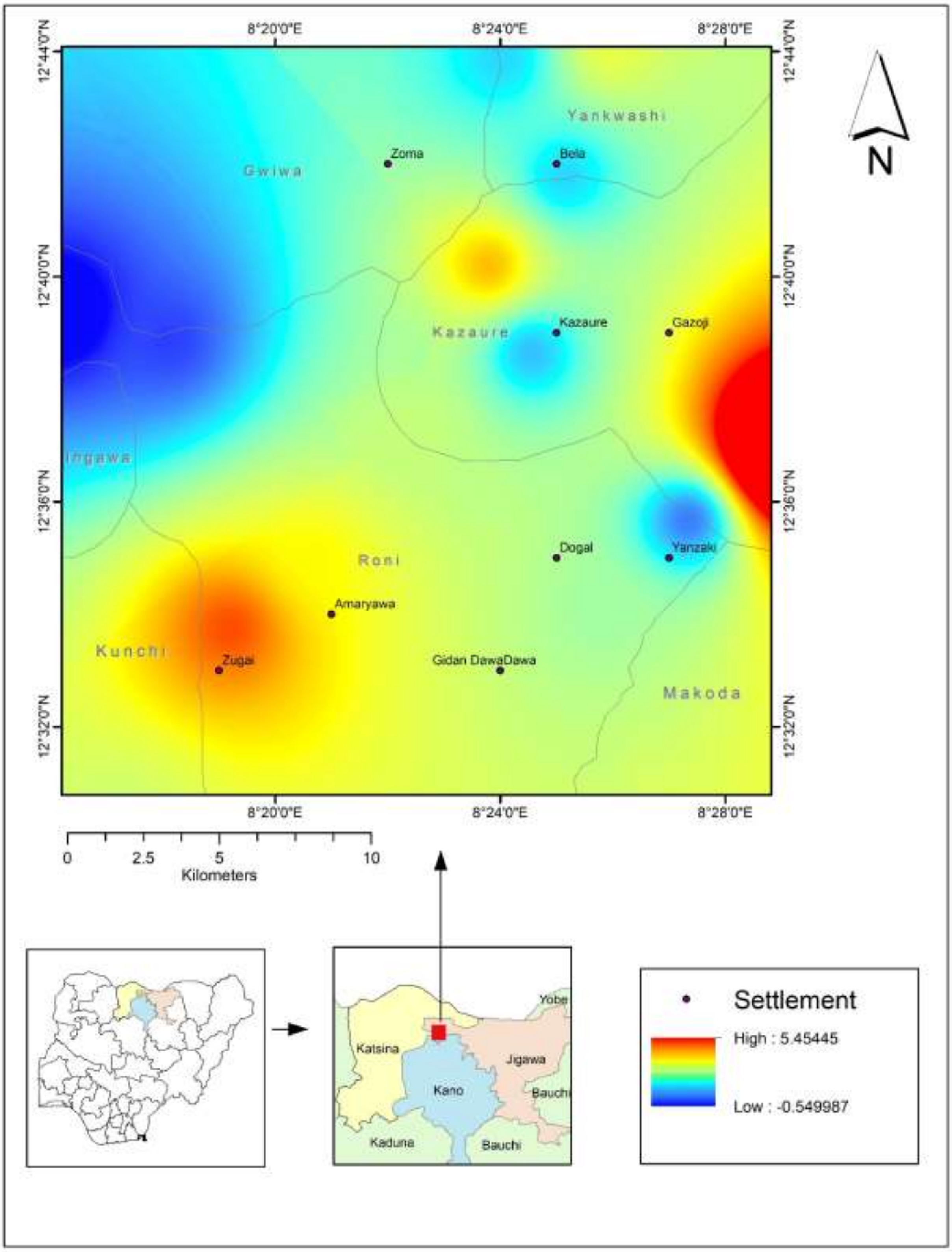

Figure 16: Spatial distribution of Residual Sodium Bicarbonate (RSBC) in the Study area

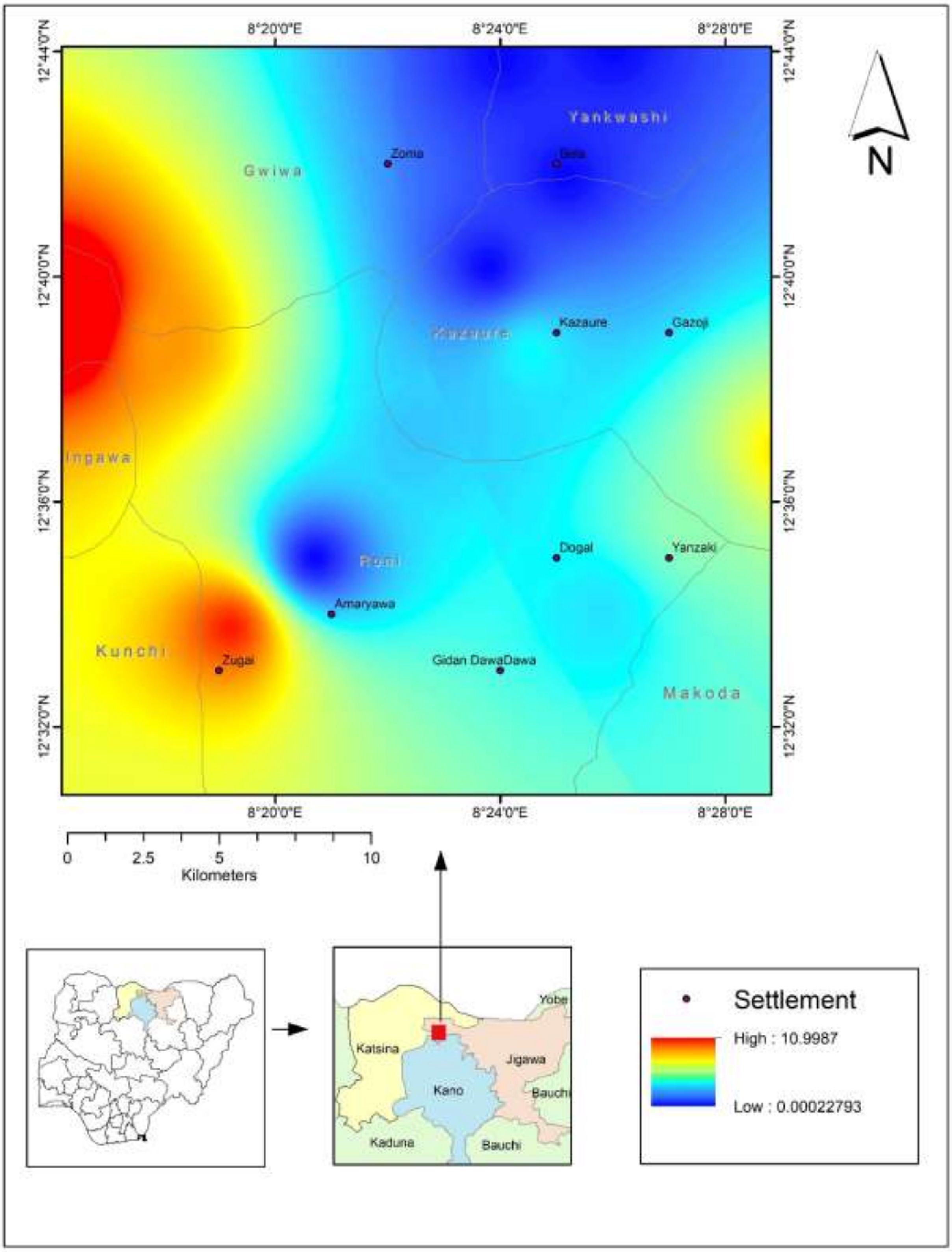

Figure 17: Spatial distribution of Sodium Adsorption Ratio (SAR) in the Study area

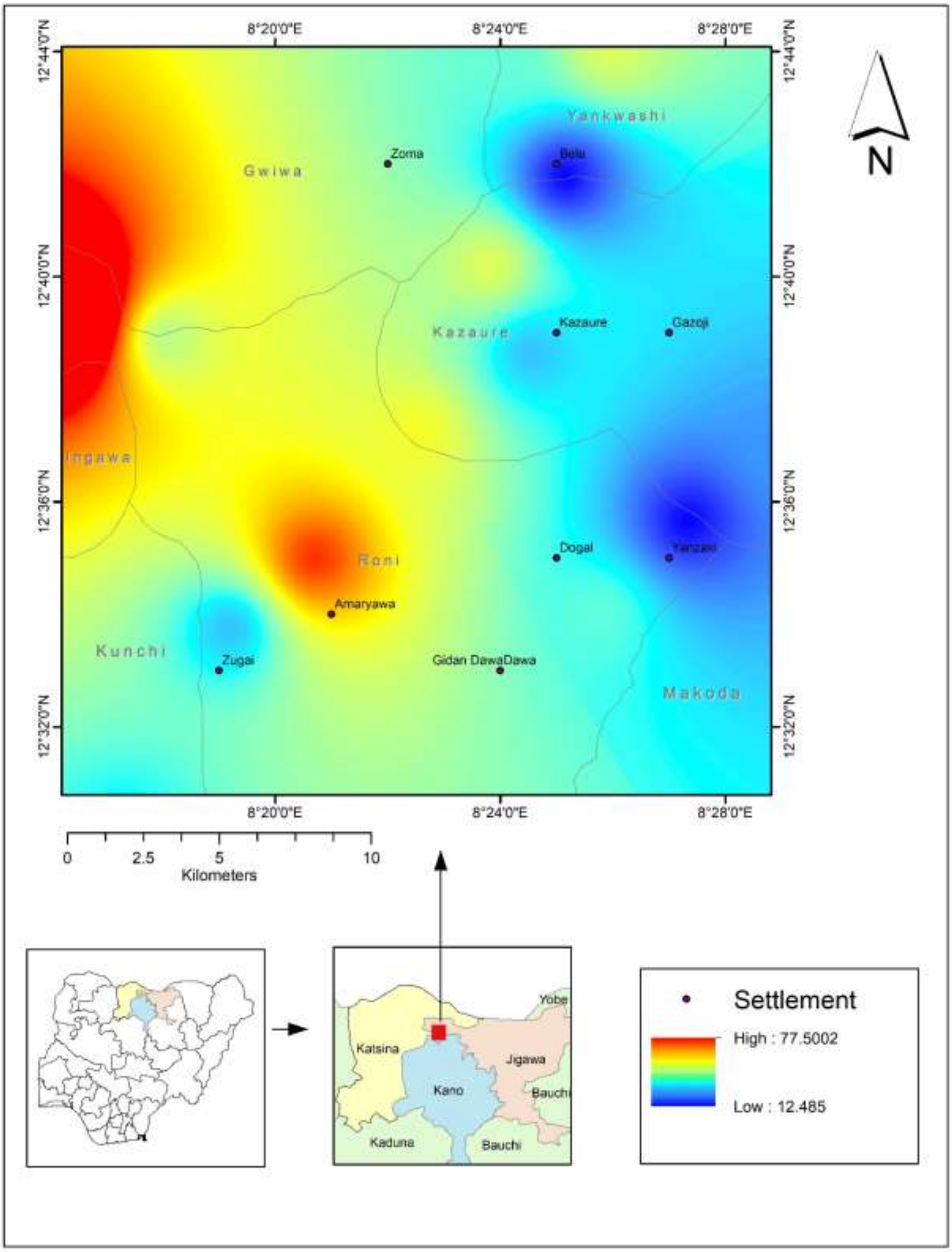

Figure 18: Spatial distribution of Total Hardness (TH) in the Study area

Spatial interpolation using the IDW method was employed in the study of the groundwater irrigational suitability. The GIS is an effective tool which aids in the determination of values at unknown locations from known values by creating a continuous surface thereby providing the required information which can assist in decision making for a particular area under consideration.

Figures above shows the thematic map of groundwater irrigation indices. It shows the locations of the study area with indices that are suitable and unsuitable for irrigation purposes. The cool colours indicate low values of considered parameters while the hot colours show high values of the parameters considered.

CONCLUSION

The groundwater suitability for irrigation purposes was evaluated in this present study using the Geographic Information System (GIS) and Groundwater Irrigation Quality Indices. The study shows that the GIS and Irrigation indices can be effectively employed in understanding the quality of groundwater. Several irrigation indices such as Sodium Adsorption Ratio (SAR), Percentage Sodium (%Na), Permeability Index (PI), Kelly Ratio (KR), Magnesium Hazard (MH), Total Hardness (TH), Residual Sodium Bicarbonate (RSBC) and Potential Salinity (PS). The values of the indices obtained were compared against known standards in order to categorize the samples based on these standards. It was observed that almost all the indices had most of the values within the recommended range suggesting that the condition of water from the study area is generally satisfactory and can be considered fit for irrigation purposes. High Permeability and Kelly Ratio were however recorded in some of the samples analysed. It is therefore recommended that irrigation management practices be employed if these water samples are to be used for irrigation over a long period of time.

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