

# GIS-based identification of potential irrigable areas in Ejiba, Nigeria

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**Abstract:** This study aims to identify suitable sites for irrigation along the river's bank using geographic information systems (GIS) and the analytical hierarchy process (AHP). Rivers are vital natural resources for transportation, recreation, irrigation, fishing, water, and electricity. GIS technology is crucial in analysing large datasets in agricultural land management to determine land suitability for irrigation purposes. In Nigeria, the implementation of irrigation systems has been slow and limited to specific regions, primarily in the northern part. GIS in agricultural planning is significant, especially in regions with high agricultural potential but limited access to water resources. This study identified 10 existing irrigation sites along the River Kampe in 2023 using GIS. The built-up area covered 1.43 km<sup>2</sup>, while bare land and water bodies covered 81.69 km<sup>2</sup> and 1.22 km<sup>2</sup>, respectively. The vegetation cover class recorded the highest area at 122.76 km<sup>2</sup>, while agriculture land covered 24.91 km<sup>2</sup>. The most suitable, more suitable, suitable, less suitable, and unsuitable land uses accounted for 24.67%, 22.62%, 19.30%, 13.74%, and 19.68% of the area, respectively. The map created using this platform can guide the selection of appropriate sites for surface irrigation in the area.

**Keywords:** Geo-spatial analysis, Geographical Information System, land suitability, natural resources, River Kampe

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## 1 Introduction

Agriculture is crucial for human life, providing food, raw materials, and economic resources (Loizou et al., 2019; Ayinde et al., 2020). In Nigeria, the agricultural sector is the backbone of the economy, accounting for a significant portion of Gross Domestic Product (GDP) and employment (Oluwole et al., 2021). However, unreliable rainfall and poor

water management systems often hinder agricultural productivity (Golla, 2021). This research explores the potential of geographic information systems (GIS) technology in improving the process of identifying suitable land for irrigation, a significant step towards enhancing agricultural productivity (Bwambale et al., 2022).

GIS technology allows users to capture, store, manipulate, analyse, and display spatial and geographic data (Zhu et al., 2021). It is widely adopted across various sectors, including agriculture, where it manages resources, optimises land use, and enhances decision-making processes. GIS is pivotal

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in analysing large datasets in agricultural land management to determine land suitability for various purposes, including irrigation (Paul et al., 2020).

The GIS-based approach to identifying potential irrigable areas involves combining topography, soil type, climate, hydrology, and land use data (Hussien et al., 2019). These data layers are then analysed spatially to produce maps showing the most suitable irrigation areas. This method offers several advantages over traditional methods, including faster processing time, higher accuracy, and the ability to visualise data for better decision-making.

By utilising GIS, stakeholders in the agricultural sector can more efficiently allocate resources, plan irrigation schemes, and develop strategies to enhance agricultural productivity (Ara et al., 2021; Ashour et al., 2021). GIS also helps identify areas suitable for irrigation and those at risk of erosion, flooding, or other environmental challenges, facilitating more sustainable land use (Chikabvumbwa et al., 2021; Sun et al., 2022).

The implementation of irrigation systems in Nigeria has been slow and limited to specific regions, primarily in the northern part of the country (Bjornlund et al., 2020; Chikabvumbwa et al., 2021). Many areas with high agricultural potential, such as Ejiba in Kogi State, remain underutilised due to the lack of irrigation infrastructure and limited knowledge of land suitability. This highlights the need for a systematic approach to identifying potential irrigable areas and prioritising investments in irrigation infrastructure.

The GIS-based approach to identifying potentially irrigable areas involves several steps, including data collection from various sources such as topography, soil type, climate, hydrology, and land use. Topographic data provides information on the slope and elevation of the land. In contrast, soil data helps understand the soil's water-holding capacity, permeability, and fertility, influencing crop cultivation and irrigation methods. Climate data, including rainfall and temperature patterns, helps

determine crop water requirements and natural water resources for irrigation.

The use of GIS in agricultural planning is significant, particularly in regions with high agricultural potential but limited access to water resources. By leveraging the power of GIS, stakeholders in Nigeria's agricultural sector can make more informed decisions that promote sustainable land use, improve food security, and enhance farmers' livelihoods. This study explores how GIS can identify potential irrigable areas in Ejiba, Kogi State, Nigeria.

## 2 Methodology

### 2.1 Study area

Ejiba, a town in Nigeria's Middle Belt, is known for its agricultural activities, including yam, maize, cassava, rice, and vegetables. However, the town's agricultural productivity relies heavily on unreliable rainfall, making it insufficient for year-round farming. Ejiba is located on latitude 8°18'N and longitude 5°39'E in the Southern Guinea Savannah Agro-Ecological Zone of Nigeria, having dry and wet seasons with ultisol soil. It is bounded in the north by Niger State, Yagba East, south by Odo Ara Omi Ogga, and in the east by Odo Eri Okoto and Isaulu Esa. The major river within the study area is the Kampe river, which flows from north to south. In Ejiba, rainfall is monomodal and spans from April to November. It peaks in June, while the dry season extends from December to March. The mean annual rainfall is 1570 mm per annum, with an annual temperature range of 18°C – 32°C and a mean relative humidity (RH) of 60% (NiMET, 2022).

### 2.2 Data type and source

#### 2.2.1 Primary Source

**Reconnaissance survey:** This is an extensive personal observation of the study area to determine the existing pattern of land use and land cover.

**Field data collection:** The latitude and longitude of the existing irrigation site were collected using a mobile GPS device.

### 2.2.2 Secondary Source

This consists of information from existing literature, including published and unpublished materials. Landsat 9 OLI Imagery of the study area was obtained from the USGS (i.e., the United States Geographical Survey (<https://earthexplorer.usgs.gov/>), and aerial photographs were obtained from Google Earth Pro.

The factors considered to determine the irritable areas of the study location include soil type, topographic wetness index, RH, slope, elevation, distance from the water body, land use pattern, and rainfall. The selected factors were processed using Satty’s pair-wise comparison scale and the analytical hierarchy process (AHP), a structured and hierarchical decision-making process used in solving complex decisions.

### 2.3 Mapping existing irrigation site

The existing irrigation site’s collected coordinate (latitude and longitude) was saved in a C.S.V format and exported to ArcGIS 10.8 for further spatial analysis and representation.

#### 2.3.1 Image Pre-processing

The image pre-processing includes mosaicking the raster bands, atmospheric correction, band composition, and image enhancement. The atmospheric correction will be done using Equation 1.

$$\frac{(Band\ Specific\ Reflectance\ Mult\ Band \times DN\ Value + Reflectance\ Add\ band)}{\sin(\text{sun elevation})} \tag{1}$$

The band composition was done to visually interpret features on the Landsat imageries (De Alban et al., 2018). The Red, Blue, and Green bands were used for band composition, i.e., bands 4–3–2 for Landsat-9 OLI (Ousmanou et al., 2024). The imageries were enhanced using the Pan sharpening tool of ArcMap 10.8.

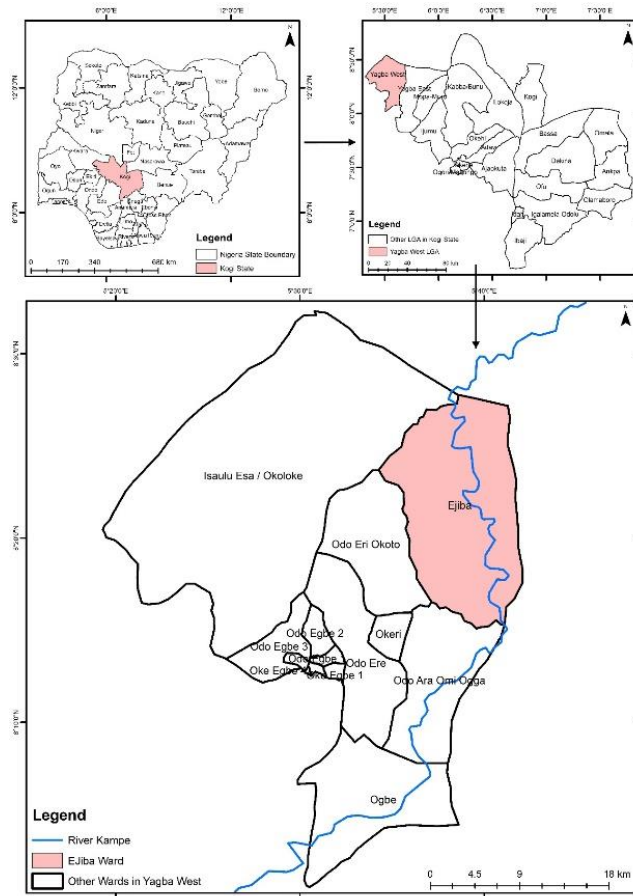


Figure 1 Location map of Ejiba, Kogi State, Nigeria

### 2.3.2 Land use land cover pattern

The image classification technique was used to categorise pixels in satellite data to differentiate the

various earth features (land cover) and obtain the pattern of land use and land cover within the study area. A pixel-based supervised image classification

was used to classify the collected Multispectral raster dataset (Landsat imagery). The maximum likelihood technique was adopted for the classification process.

2.3.3 Personal/oral interview

This type of interview deals with residents of the Ejiba. The residents were asked questions relating to irrigation activities within the study area.

2.4 Mapping irrigation potential site

Using the AHP, the percentage influence of each chosen factor as determined by Satty’s comparison scale would be combined with the processed factor, rasterised using ArcMap 10.8’s weighted overlay tool, and categorised into five categories: most suitable, More Suitable, Suitable, Less Suitable, and Unsuitable. A raster file displaying the irrigation potential depending on the chosen criteria was the end product. With ArcMap 10.8, the raster to polygon function was used to calculate the geographic extent of the appropriateness level statically. The consistency ratio (CR), which measures the degree of consistency between the paired judgements, and the percentage weight for each factor (normalised eigenvector or priority vector) were computed using an online AHP calculator (Ergu et al., 2011).

3 Results and discussion

3.1 Spatial distribution of existing irrigation site along River Kampe in Ejiba

The field survey identified 10 existing irrigation sites along River Kampe, as shown in Figure 2, within the study area. However, the irrigation practice was below the required standard as the farmers involved were more into substance farming systems. Thus, they could not maximally utilise the land. Figure 2 shows the locations where local irrigation systems are currently practised along River Kampe. The dotted green sections show a negligible section of the land mass being used for irrigation, which has affected the agricultural productivity of the people.

3.2 Land use land cover pattern of Ejiba

A pixel-based image classification approach was adopted using a maximum likelihood classification technique to obtain the pattern of land use land cover

(LULC) within the study area (Balha et al., 2021). As stated in the methodology, the processed satellite imagery was classified into five LULC classes: Built-up Area, Bare land, Water body, Vegetation cover, and Agriculture land, as shown in Figure 3. The LULC analysis pattern shows that the agricultural lands are along the water body (River Kampe) (Musa et al., 2022).

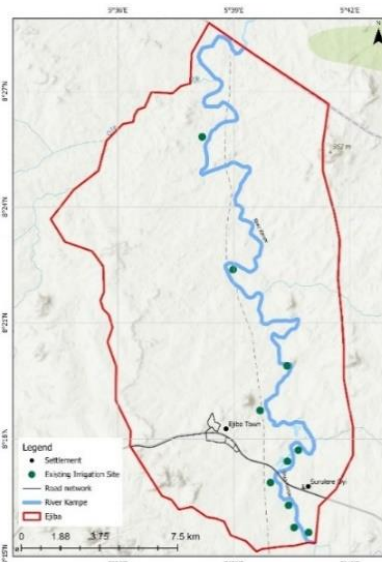


Figure 2 Spatial distribution of existing irrigation site along River Kampe, Ejiba Kogi State

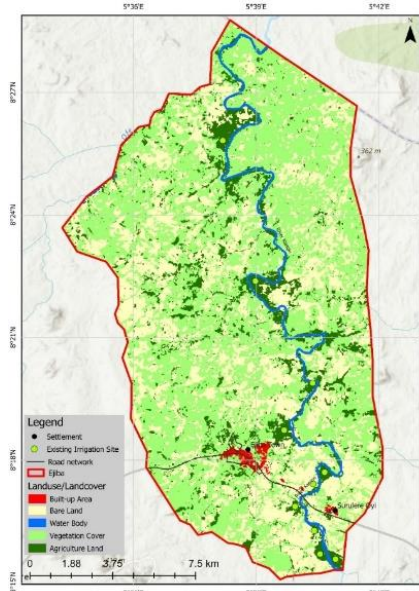


Figure 3 Land use land cover pattern of Ejiba

3.3 Spatial extent of land use land cover in Ejiba

The statistical distribution of the various LULCs is presented in Figure 4, which explains the spatial distribution of the LULC activities within the study area. It was observed that in the year 2023, the built-up area covered a land mass of 1.43 km<sup>2</sup>, accounting

for 0.62% of the total land area, indicating the availability of the land for agricultural services, bare land recorded 81.69 km<sup>2</sup> (35.21%) which is a section of the total land mass that is neither cultivated nor put to use for any purpose, water body recorded 1.22 km<sup>2</sup> (0.53%) shows the areas covered by the water bodies in the study area. The vegetation cover class recorded

the highest with an area of 122.76 km<sup>2</sup> (52.91%), while the agricultural land recorded 24.91 km<sup>2</sup> (10.74%). This is similar to the findings of Musa et al. (2022), who studied the Spatiotemporal Variation of Land Use Patterns and Land Cover Changes in the Gidan Kwano Watershed Area in North Central Nigeria.

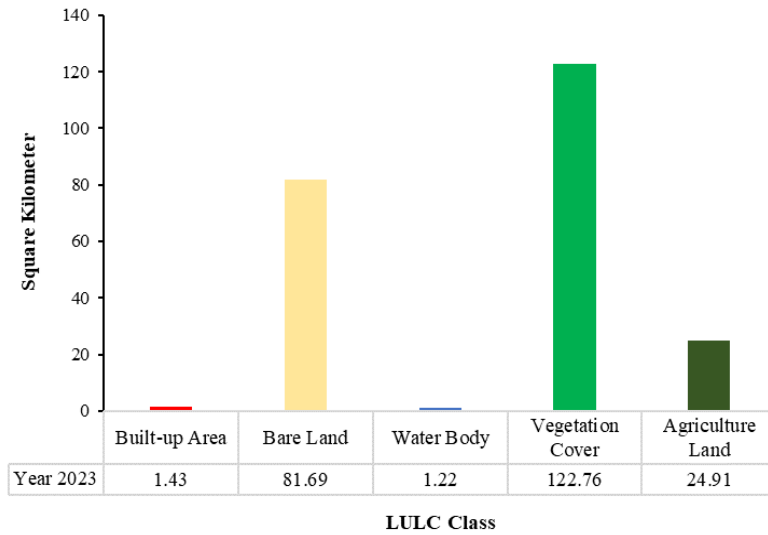


Figure 4 Land cover class statistics of Ejiba

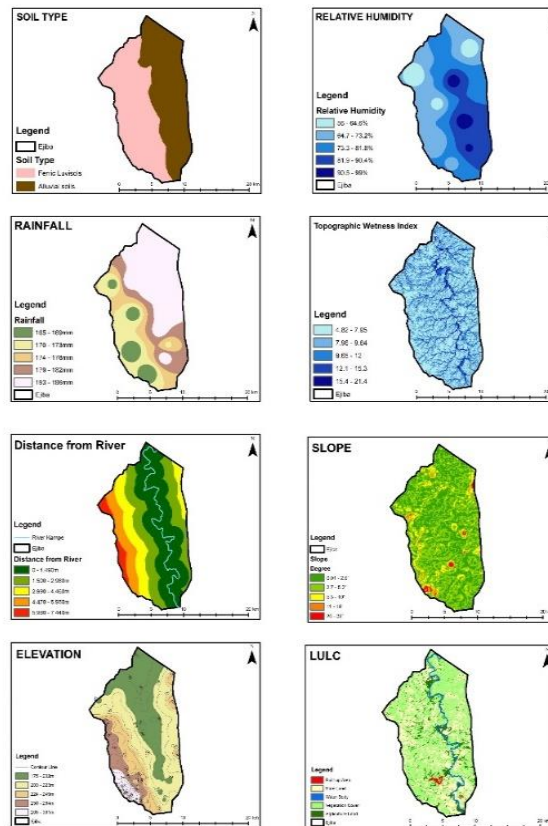


Figure 6 Unprocessed factors for considered Modelling suitable site for irrigation

Figure 5 presents the unprocessed modelled images from the study area, which were based on the

study area's two sets of parameters, climatic and physical factors. This is similar to the study by

Choudhary et al. (2018), where they studied Spatial modelling for natural and environmental vulnerability through remote sensing and GIS in Astrakhan, Russia.

The selected factors were processed to fit the prerequisites for the intended Model. A condition for

each factor was set based on a scale of 1 – 5, as shown in Table 1 (i.e., a requirement for factor attributes to be considered as most suitable, more suitable, suitable, less suitable, and/or unsuitable).

**Table 1 Factor data criterion for suitability**

Parameters	Scale	Score	Classification
Soil	Alluvial Soil	5	Most Suitable
	Ferric Luvisols	4	More Suitable
RH	50% – 60%	1	Unsuitable
	61% – 70%	2	Less Suitable
	71% – 80%	3	Suitable
	81% – 90%	4	More Suitable
	> 90%	5	Most Suitable
Rainfall	160 – 165mm	1	Unsuitable
	166 – 170mm	2	Less Suitable
	171 – 175mm	3	Suitable
	176 – 180mm	4	More Suitable
	> 180mm	5	Most Suitable
Topographic wetness index (TWI)	0 - 5	1	Unsuitable
	6-10	2	Less Suitable
	11-15	3	Suitable
	16 - 20	4	More Suitable
	> 20	5	Most Suitable
Distance from River Kampe	0 – 1 km	5	Most Suitable
	1 – 2 km	4	More Suitable
	2 – 3 km	3	Suitable
	3 – 4 km	2	Less Suitable
	> 4 km	1	Unsuitable
Slope degree	0 - 5°	5	Most Suitable
	6 - 10°	4	More Suitable
	11 - 15°	3	Suitable
	16 - 20°	2	Less Suitable
	> 20°	1	Unsuitable
Elevation	150 – 200 m	5	Most Suitable
	201 – 250 m	4	More Suitable
	251 – 300 m	3	Suitable
	301 – 350 m	2	Less Suitable
	> 350 m	1	Unsuitable
LULC	Built-up Area	1	Unsuitable
	Bare Land	3	Suitable
	Waterbody	1	Unsuitable
	Vegetation cover	4	More Suitable
	Agriculture Land	5	Most Suitable

Therefore, the factors being rasterised and reclassified following the scores allocated in Table 1 above were visualised as presented in Figure 5 within the five scale ranges.

An analytical hierarchy technique was adopted to map out possible areas suitable for irrigation within the study area. At the same time, a pair-wise comparison was made among the factors to determine

their percentage influence on the final suitability map, as shown in Table 1. This is similar to the works by Girma et al. (2020) to determine land suitability evaluation for surface irrigation using spatial information technology in the Omo-Gibe River Basin, Southern Ethiopia and Al-Hanbali et al. (2022). Using a GIS-based AHP, they used this approach to analyse land suitability for paddy fields in Tanzania. The AHP captures both subjective and objective aspects of the decision.

Furthermore, the process includes an added step that checks the inconsistency of the decision-maker's

evaluations to reduce bias in the decision-making process. The AHP process commences with creating a pair-wise matrix where each criterion (factor) is compared and assigned a numeric scale (Judgement Value from 1 to 9). The comparison was done using Saaty's pair-wise comparison, as shown in Table 2. The determined AHP techniques involved the calculation of the CR of the factors, which ranged between 0.1% and 10%, as presented in Table 3, while Table 4 presents the pair-wise comparison matrix.

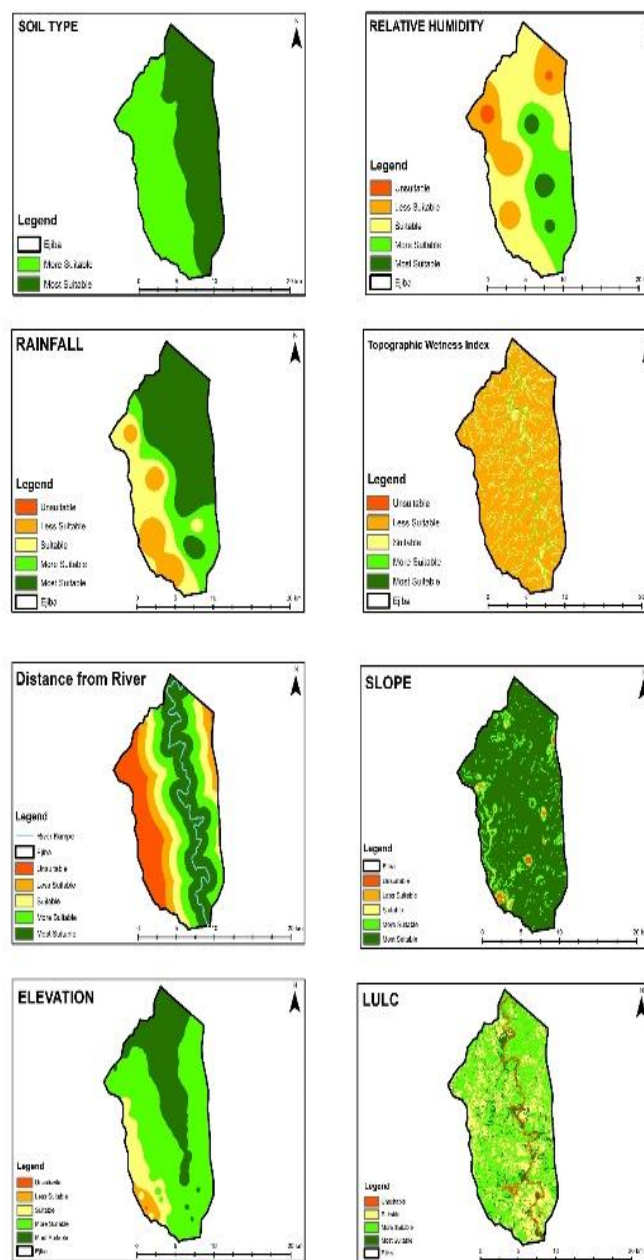


Figure 7 Processed factors for considered modelling suitable site for irrigation

**Table 2 Salty’s pair-wise comparison scale**

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one factor over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one factor over another
6	Strong plus	
7	Very strong or demonstrated Importance	One factor is favoured very strongly over another, and its dominance is demonstrated in practice.
8	Very, very strong	
9	Extreme importance	

**Table 3 AHP pair-wise comparison matrix**

Factor	Soil	Relative humidity	Rainfall	TWI	Distance from River	Slope	Elevation	LULC
Soil	1.00	3.00	3.00	1.00	1.00	3	3	1
RH	0.33	1.00	1.00	1.00	1.00	1	1	1
Rainfall	0.33	1.00	1.00	1.00	1.00	3	5	3
TWI	1.00	1.00	1.00	1.00	1.00	5	3	3
Distance from River	1.00	1.00	1.00	1.00	1.00	5	7	5
Slope	0.33	1.00	0.33	0.20	0.20	1	1	1
Elevation	0.33	1.00	0.20	0.33	0.14	1	1	1
LULC	1.00	1.00	0.33	0.33	0.20	1	1	1

**Table 4 AHP pair-wise comparison matrix**

Factor	Priority	Rank
Soil	0.196	2
Relative humidity	0.100	5
Rainfall	0.152	4
TWI	0.167	3
Distance from river	0.208	1
Slope	0.054	7
Elevation	0.052	8
LULC	0.071	6

Consistency ratio = 0.075

**Table 5 Statistical extent of suitability level**

Suitability scale	Area (km <sup>2</sup> )	Percentage (%)
Unsuitable	45.66	19.68
Less suitable	31.87	13.74
Suitable	44.78	19.3
More suitable	52.47	22.62
Most suitable	57.23	24.67
Total	232.01	1

Table 4 presents the final result of the AHP, which shows that distance from river factor has the highest percentage influence with a value of 20.8%, soil factor is ranked second with 19.6%, topographic wetness index 16.7%, rainfall factor 15.2%, RH factor 10%, LULC factor 7.1%, slope factor 5.4% and the elevation factor 5.2%. Saaty and Vargas (2012) state that the judgment allocated to each factor (Table 3) passes the consistency test as it’s less than 0.1. The percentage influence (priority vector) was integrated with each processed factor using the weighted overlay

tool of ArcGIS 10.8 to produce the final suitability map showing the irrigation potentials in Ejiba, as shown in Figure 6. The statistical extent of the suitability level was calculated using the raster to polygon tool of ArcGIS 10.8, as presented in Table 5.

Table 5 indicated that 19.68% (45.66 km<sup>2</sup>) of the total land area in Ejiba is unsuitable for irrigation activity, 13.74% (31.87 km<sup>2</sup>) less suitable, 19.30% (44.78 km<sup>2</sup>) suitable, 22.62% (52.47 km<sup>2</sup>) more suitable and 24.67% (57.23 km<sup>2</sup>) most suitable. This result shows that a substantial amount of land is

suitable for irrigation activity within the study area. The map of the existing irrigation sites in Ejiba was overlaid with the suitability map (Figure 6), which showed that the 10 identified irrigation sites were

located along the most suitable zones of the suitable area. This is similar to the works by Vogels et al. (2019) in the central Rift Valley of Ethiopia.

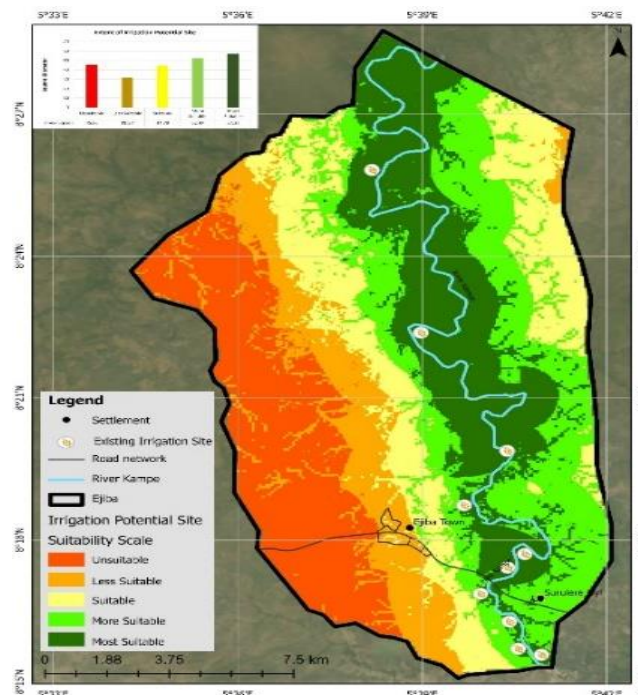


Figure 8 Map showing irrigable land in Ejiba, Kogi State, Nigeria

#### 4 Conclusion

Using the integration of GIS, remote sensing, and the AHP approach, a final map of the site’s suitability for surface irrigation was prepared in this study by assessing eight features, which are soil type, topographic wetness index, RH, slope, elevation, distance from the waterbody, land use pattern and rainfall. In the normalised pair-wise comparison matrix, distance from the river (20.8%), rainfall (15.2%), topographic wetness index (16.7%), and RH (10.0%) received high ratings ahead of other factors like elevation (5.2%), slope (5.4%), and LULC (7.1%). This shows that establishing an irrigation scheme within the study area will increase agricultural activities and be cost-effective in the infrastructural facilities provided by the various policymakers and stakeholders. The final suitable map was constructed with five classifications: most suitable (5), more suitable (4), suitable (3), less suitable (2), and unsuitable (1) after a load of each parameter was chosen. This map will aid in surface irrigation’s ability to support rain-fed agriculture. It

was also concluded that the most suitable, more suitable, suitable, less suitable, and unsuitable land uses account for 24.67%, 22.62%, 19.30%, 13.74%, and 19.68% area of the area, respectively. Therefore, the map created using this platform might be a rough guide when choosing appropriate sites for surface irrigation in the area.

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