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ORIGINAL PAPER

Suitability assessment and mapping of Oyo State, Nigeria, for rice cultivation using GIS

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Abstract Rice is one of the most preferred food crops in Nigeria. However, local rice production has declined with the oil boom of the 1970s causing demand to outstrip supply. Rice production can be increased through the integration of Geographic Information Systems (GIS) and crop–land suitability analysis and mapping. Based on the key predictor variables that determine rice yield mentioned in relevant literature, data on rainfall, temperature, relative humidity, slope, and soil of Oyo state were obtained. To develop rice suitability maps for the state, two MCE-GIS techniques, namely the Overlay approach and weighted linear combination (WLC), using fuzzy AHP were used and compared. A Boolean land use map derived from a landsat imagery was used in masking out areas currently unavailable for rice production. Both suitability maps were classified into four categories of very suitable, suitable, moderate, and fairly moderate. Although the maps differ slightly, the overlay and WLC (AHP) approach found most parts of Oyo state (51.79 and 82.9 % respectively) to be moderately suitable for rice production. However, in areas like Eruwa, Oyo, and Shaki, rainfall amount received needs to be supplemented by irrigation for increased rice yield.

1 Introduction

Rice (oryza, family Gramineae) constitutes one of the most important staple foods of over half of the world's population. Rice requires temperatures ranging from 20 to 30 °C and about 900–2500 mm of rainfall as well as long periods of sunshine for proper growth. It can be grown on any soil type provided the soil retains adequate moisture, but it grows much better on heavy clay soils (Filani 1980). Over the past several decades, rice has established itself as a preferred staple in Nigeria. It is typically planted from April to May and harvested between August and November. With irrigation, it is possible to harvest 2 or 3 times yearly.

Many varieties of rice have been introduced to Nigeria. However, the two major varieties are African rice (Oryza glaberrima) which is resistant to drought and certain rice diseases and high yielding Asian varieties (*Oryza sativa*). Rice grows quickly with some varieties reaching maturity within 3 months as long as fields have adequate moisture. However, the natural crossing between varieties has given rise to thousands of varieties enabling the crop to be grown over a wide range of climatic and cultural conditions: at very high altitudes, on dry land, in fresh or brackish water, or in undrained swamps, in acid and alkaline, or rich and poor soils. However, for good yields to be assured and maintained, proper care and management are needed. In Nigeria, 5 basic types of rice production systems are practiced (Table 1):

1. Upland (dry upland) rice is cultivated on free draining fertile soils and sometimes on hills due to pressure on arable land. It is practiced in most parts of southern Nigeria and the middle belt. The two types are:

   ➢ The rain-fed upland rice system: This system relies completely on rainfall which can lead to crop failure during periods of drought or loss of nutrients when there is heavy rainfall.

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Table 1 Rice growing environments in Nigeria

	ACZ	AEZ	LGP (days)	Annual rainfall (mm)	Rainy season	RGS
1	Arid	Sahel	<75	<550	July–Aug.	IL, DW
2	Semi-arid	Sudan savanna	75–150	550–900	July–Sept.	IL,RU,RL,DW
3	Sub-humid	Northern Guinea savanna	151–180	900–1200	July–Oct	RU, RL, DW, H
4	Sub-humid	Southern guinea savanna	181–200	1500–2000	Jun–Oct	RU, RL, DW, H
5	Sub-humid	Derived savanna	211–270	1500–2000	May–Oct	IL, RU, RL, H
6	Humid	Humid forest	>270	>2000	Mar–Nov.	IL, MS, RU
7	Mid-altitude	Moist savanna	181–270	1200–1500	April–Nov.	RU, RL

Source: Selbut Longtau, 2003

ACZ agroclimatic zone, *AEZ* agroecological zone, *LGP* length of growing period, *RGS* rice growing system: *IL* irrigated lowland, *H* hydromorphic, *DW* deep inland water, *RU* rain-fed upland, *RL* rain-fed lowland, *MS* mangrove swamps

➢The irrigated upland rice system: Rice is grown on generally sandy low water holding capacity soils with the aid of irrigation especially during the critical stages of crop growth. This system is practiced where rainfall is less than 500 mm and length of growing period less than 90 days, e.g., Kano

2. Hydromorphic rice (wet uplands): Rice is grown in the southern and Northern guinea savanna fringes of streams. Yields are generally higher and more stable than those of the dry uplands.
3. The rain-fed lowland rice system is of two types: the deep inland valleys or wetlands and the shallow and deep fadamas. This system as well as the hydromorphic system requires the soil to be covered completely with water at some stage in the crop growth cycle.
4. Irrigated lowland system: Water supplied from rivers, dams, boreholes, etc. is used to supplement rainfall for proper rice growth. It is commonly practiced in the Northern guinea savanna, sudan savanna, and sahel.
5. Deep Inland water (floating rice system): To the far north (e.g., Sokoto-Rima basin), rice is cultivated in the fadamas on heavy soils subjected to annual flooding. However, deep flooding sometimes limits production.
6. Mangrove swamps (tidal wetland system): Rice is grown on flooded rice paddies in the southern areas along the tidal freshwater swamps and floodplains.

Clearly, rice can grow in virtually all the agro-ecological zones in Nigeria, yet local production has been unable to meet demand. This is because most Nigerian farmers engaged in rice cultivation produce rice at subsistence levels; hence, production has not been enough to meet the rapidly increasing demand. Nigerians consume over 5.4 million tonnes of rice annually, while local production only amounts to about 2.3 million tonnes per year. The Nigerian government therefore depends heavily on the importation of large quantities of rice from Southeast Asia to meet growing rice needs. With demands for rice in the country predicted to surge by almost 50 % next year, developing Nigeria's agriculture and irrigation potential could help boost rice production.

Previous studies have adopted various techniques and approaches in assessing the suitability of land for rice and a wide variety of crops. Akintola (1983) examined the effects of climatic variables on the yield of rice and other major food crops grown around Ibadan City, Nigeria, and found rainfall and relative humidity to be critical factors influencing yield. Similarly, Gbadegesin (1986) examined soil properties and their relationship with maize yields in Northern Oyo state, Nigeria, using multiple regression. He discovered that organic matter content followed by available moisture in soils contribute significantly to maize growth. Oche (1998) determined the production potential of wheat in Nigeria using multiple regression, hierarchical clustering, and suitability rating. His study revealed the Jos plateau area to be most suitable for wheat production. Also Adebayo (2002) examined the potential for upland rice production in the guinea savanna of Adamawa state, Nigeria. Using correlation analysis and multiple regression, he determined that soil moisture, onset dates of rains, number of dry pentades during the growing season, and rainfall amount in June were critical climatic elements that significantly determine yield. Based on these parameters, he developed a map showing the climatically suitable zones for rice production. More recent studies have adopted multicriteria evaluation (MCE) approaches and GIS techniques. MCE is an effective technique for spatial decision-making especially when integrated with GIS which has the ability to effectively support the capture, management, manipulation, analysis, modeling, and display of geographic data. Hu (2003) adopted GIS techniques in his search for areas in the USA, suitable for rice cultivation under irrigation. Precipitation and temperature isolines created from climatic data collected from 659 stations were overlaid over a slope map to identify potential areas for rice production. Similarly, Dengiz (2013) assessed the suitability of land in the Anatolian region of Turkey for rice cultivation using a GIS overlay approach. Fifty-five percent of the study area was found to be highly or moderately suitable for rice. Statistical analysis further showed a significant relationship between land suitability classes and yields, with the highest yields recorded in rice plots rated most suitable for production. Kihoro et al. (2013) developed a suitability map for rice production in the Great Mwea region, Kenya, based on physical and climatic factors assessed using GIS and a WLC-AHP approach. They found only 12 % of the land area is currently under rice production even though 75 % of the total land area is highly suitable for rice cultivation. In the same way, Isitekhale et al. (2014) assessed the suitability of soils in the lowlands of Edo state, Nigeria, for rice and sugarcane production and found soils to be unsuitable for rice because of soil chemical properties. Dengiz et al. (2015) also determined the most suitable areas for rice cultivation in the Gokimak catchment area, Turkey, based on some physiochemical properties of various alluvial soils in the study area. Results showed that 65.1 % of the area is highly and moderately suitable for rice production. Many other studies (Babatolu and Olaniran. 1987; Gbadegesin and Nwagwu 1990; Yu et al. 2009; Shamla et al. 2010; Mustafa et al. 2011; Hussain and Sohaib 2012; Maddahi et al. 2014; Sezer and Dengiz 2014; Olaniyi et al. 2015) have shown the usefulness of various statistical and GIS techniques in crop–climate and land suitability analysis.

The aim of this study is therefore to employ and compare MCE and GIS techniques in identifying and mapping potential areas for rice cultivation in Nigeria using Oyo state as a case study. The main objective is to collect and process relevant data on soil and climatic variables that influence rice production in the study area as well as to map Oyo state based on suitability ratings for rice cultivation through the spatial overlay of the various agroclimatic and soil variables. Suitability maps for rice production in Oyo state were thus developed, and areas suitable for rice cultivation using irrigation were identified.

1.1 Site and climatic conditions of Oyo State

The study area is Oyo State, one of the six states that form the southwest geopolitical zone in Nigeria (Fig. 1). It falls within the forest and savanna ecological zones of Nigeria.

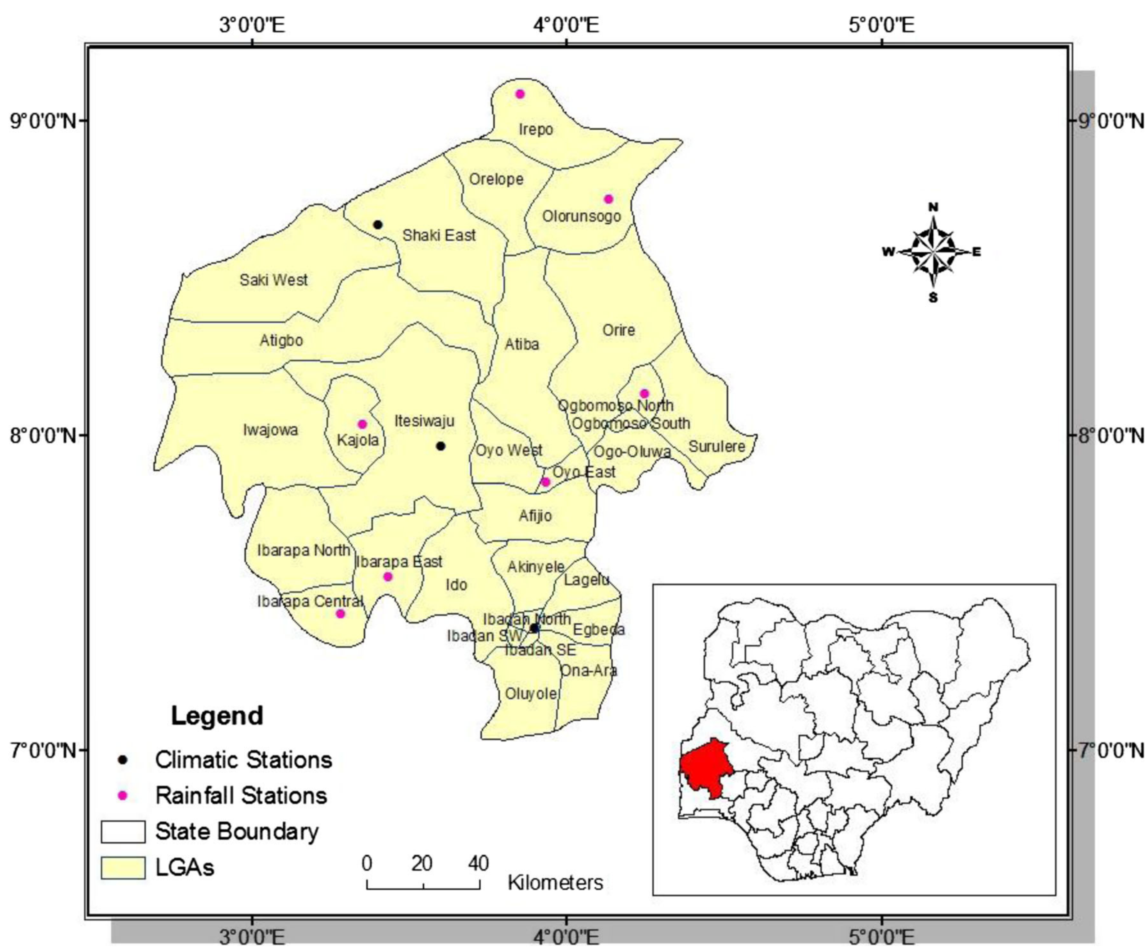

Fig. 1 Map of study area showing climatic stations

The rainforest zone to the south has a tropical humid climate characterized by heavy seasonal rainfall, high temperature, and humidity. Total annual rainfall ranges from 1500 to 2500 mm with two rainfall peaks in June and September. Mean annual temperature is about 27 °C. Relative humidity is high throughout the year with a mean value of 80 %. The guinea savanna zone to the North is drier with a mean annual rainfall of between 900 and 1500 mm with one distinct peak around June–July. Most of the rainfall is concentrated between 4 and 7 months (April to October) unlike the forest zone that usually experiences more than 7 months of rainfall. Temperature is high, varying from a minimum of 20 °C to a maximum of 30 °C. Relative humidity is also high with a mean value of 60–90 %, depending on the time of the year. Most areas of Oyo State are characterized by slopes of 2–6 % except for the steep near vertical sides of the inselbergs in the North.

The forest soils referred to as ferralitic tropical soils dominate the state. These soils are mostly loamy clays, sandy loams, and, in some areas, sandy clay loams. They are deep, friable, and porous soils suitable for mechanized agriculture. The guinea savanna soils are alfisoils collectively referred to as ferruginous tropical soils. According to Areola (1978), they are the most important groups of soils as they support most of the important cash and food crops in Nigeria. Kaolinite is the predominant clay mineral; hence, they have a low nutrient status. Generally, the soils have a coarse- to medium-textured surface layer. A variety of root crops and cereals are grown in Oyo State. The state is well drained with rivers flowing from the upland in the North/south direction. Major rivers are Ogun, Ofiki, Sasa, and Oba rivers. Oyo State therefore has great potential for food production which can be better utilized by the development of large and small scale irrigation schemes. With regard to rice production, the dominant rice production system is the rain-fed lowland and uplands. In the 1970s, Oyo was one of the highest producers of rice recording the second highest yield (4000 kg/ha) in 1978/1979 (Filani 1980). Rice production has however declined in the state both in terms of yield and land extent under rice cultivation especially in places like Shaki where one of the first (now extinct) experimental rice schemes was set up between 1945 and 1953. By 1966, the area under rice cultivation

Table 2 Major sites of reference profile

Soil sample sites	Latitude	Longitude
Ibadan	7.5	3.9
Shaki	8.5833	3.5
Idi-Iya, Iseyin	7.9333	3.6667
Oyo - Iseyin	7.8833	3.8667

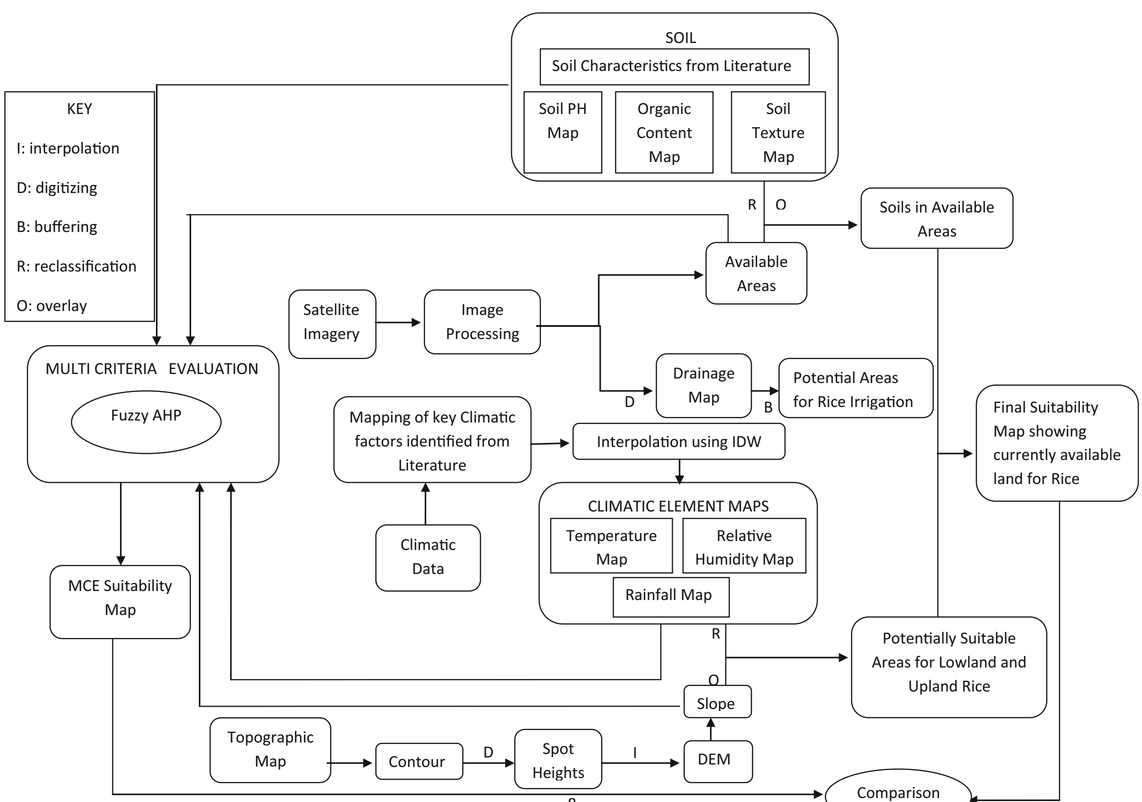

Fig. 2 Cartographic model showing methodology

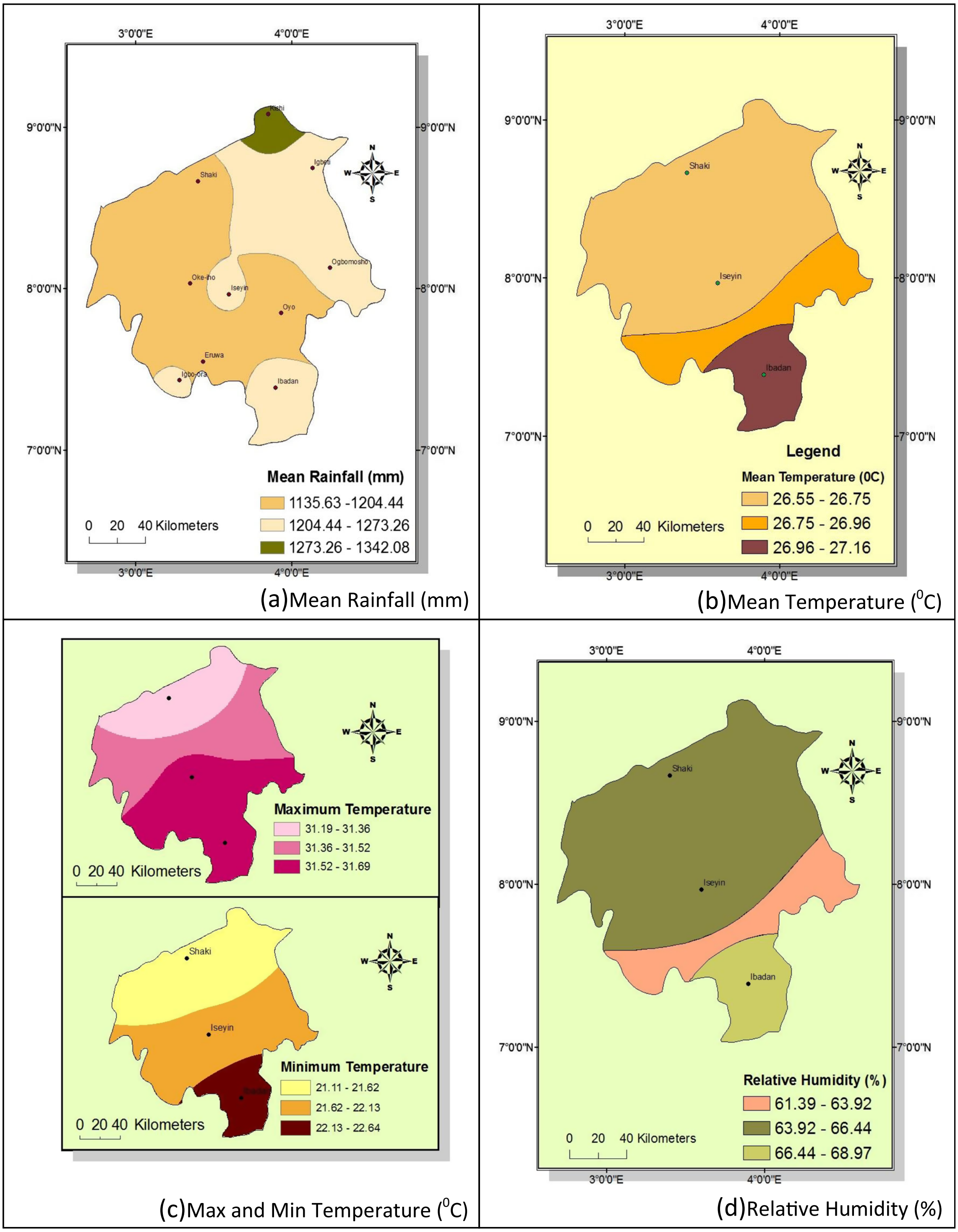

Fig. 3 **a** Mean rainfall (mm). **b** Mean temperature (°C). **c** Max and min temperature (°C). **d** Relative humidity (%)

had dropped from over 10,000 to 3000 ha due to the lack of interest on the part of farmers and other factors. Today, rice is currently cultivated at local subsistence levels except for organizations like the Oyo State agricultural development programme (OSADEP) that have fairly large farms devoted to rice production.

2 Methodology

2.1 Data Sources and Collection

The first phase in identifying and delineating areas for rice production involves determining the critical climatic

Table 3 Suitability classes and values

	Parameter	Range of values	Suitability class	Suitability score
1	Rainfall (mm)	1500–1700	S1	3
		1200–1500	S2	2
		1700–2000	S2	
		<1200	N	1
		>2000	N	1
2	Mean temperature (°C)	24–26	S1	3
		18–24	S2	2
		26-30	S2	2
		<18	N	1
		>30		
3	Relative humidity (%)	60–80	S1	3
		50–60	S2	2
		80–90	S2	2
		<50	N	1
		>90	N	1
4	Slope (%)	0–4	S1	3
		4–8	S2	2
		>8	N	1
5	pH – H_2O	5–7	S1	3
		4–5	S2	2
		7–8	S2	2
		<4	N	1
		>8		
6	Organic matter content (%)	3.5–7.0	S1	3
		0.5–3.5	S2	2
		7.0–10.0	S2	2
		<0.5	N	1
		>10		
7	Texture	SIC, C, Cl, SC, LC	S1	3
		SCL, L, SIL, SL, LS	S2	2
		Sand	N	1

Source: FAO, Ali (2010), Imolehin and Wada(2000)Dengiz et al. (2010)

SiC silty clay, *C* clayey, *CL* clayey loam, *SC* sandy clay, *LC* loamy clay, *L* loamy, *SCL* sandy clay loam, *SiL* silty loam, *SL* sandy loam, *LS* loamy sand

factors influencing yield by carrying out a correlation analysis between data on climatic elements and crop yield (Ayoade 2005). However, currently available data on rice yield tends to be highly aggregated and given on a state basis rather than on the basis of particular areas of production within each state. Hence, the critical soil parameters and climatic elements influencing yield were obtained from previous relevant studies reported in the literature (Akintola 1983; Imolehin and Wada 2000; Adebayo 2002; Olaf et al. 2003; Akinbile 2009). Secondary sources revealed that although various factors are considered rainfall (moisture availability), soil and its management are the major determinants of rice yield in the tropical savanna region. The following data were then collected for the study:

1. Climatic data: rainfall, temperature, and humidity were collected from the Nigerian meteorological services (NIMET) for the period of 1983–2009. Unfortunately, rainfall data for only 10 stations could be obtained, while data for other elements were available for only 3 stations (Shaki, Iseyin, and Ibadan) because most stations are no longer working or cannot observe some elements due to the lack of instruments and funds.
2. Spot heights of the study area were collected from the Regional Centre for Training in Aerospace Surveys (RECTAS), Obafemi Awolowo University Ife, Nigeria. Using interpolation techniques, spot heights were derived from digitized contour lines.
3. Landsat imagery, resolution 28 m was collected from the same source. The image was georeferenced with a

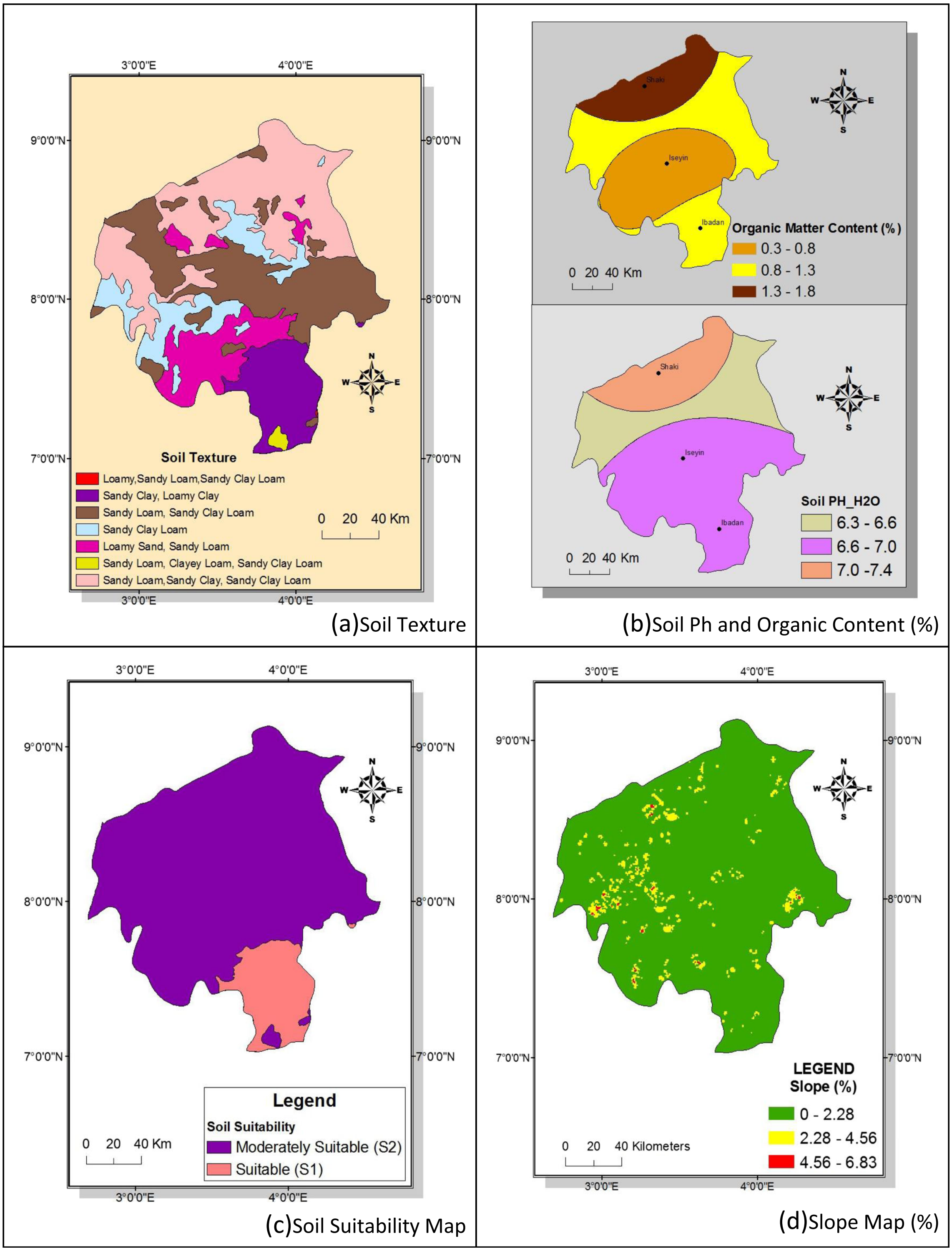

Fig. 4 **a** Soil texture. **b** Soil pH and organic matter content (%). **c** Soil suitability map. **d** Slope map

geographic coordinate system defined by the Minna datum. Both a drainage Map and land use/land cover map were derived from the imagery after processing.

4. Soil map of the study area was clipped from a soil map of south western Nigeria sheet 7 of 8 which was obtained from the Soil Survey Division, Department of Agricultural Land Resources, Kaduna. Data on soil sample reference points were obtained from the International Soil Reference and Information Centre (ISRIC) and other secondary sources (Table 2). Soil sample points located

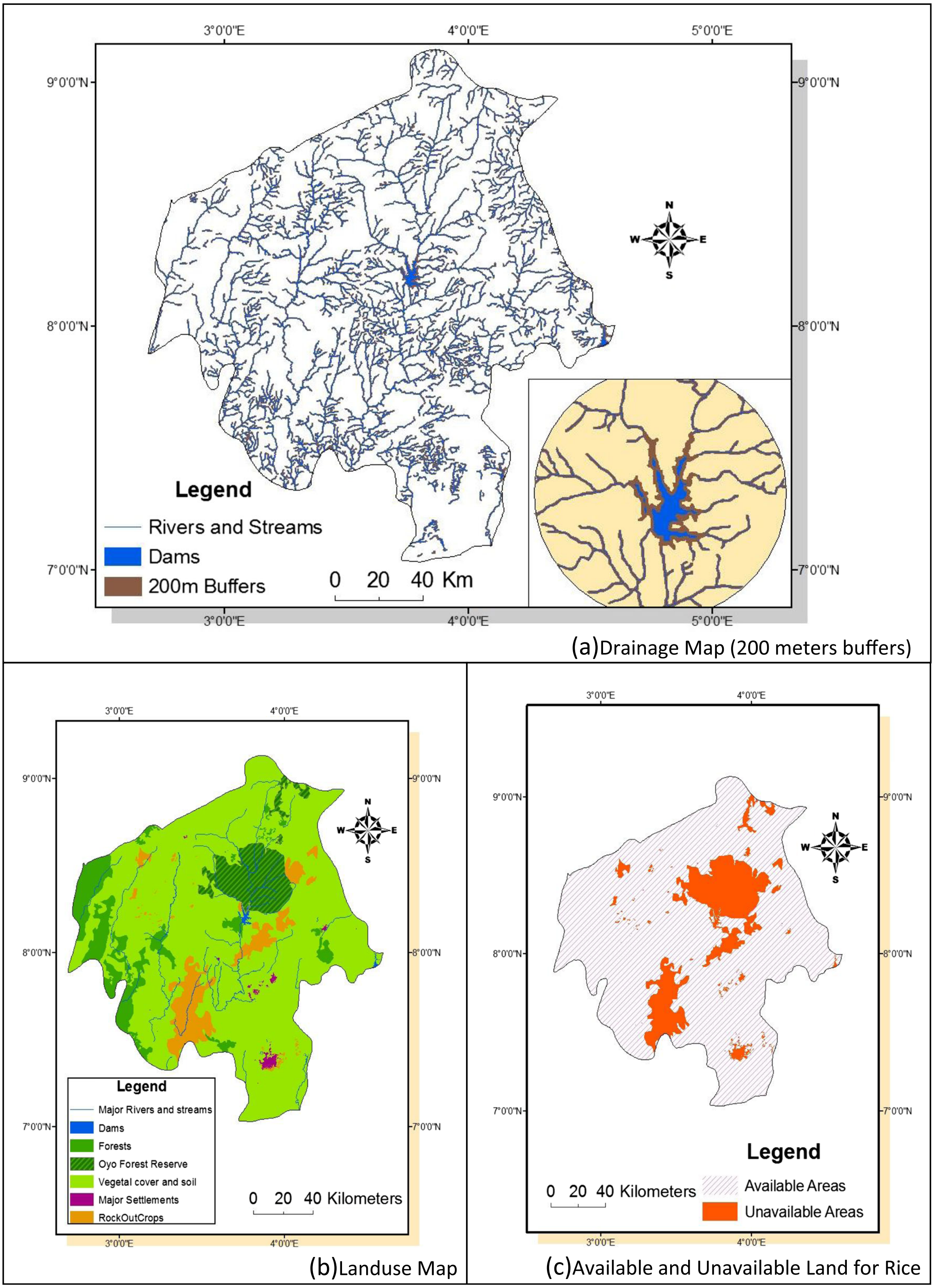

Fig. 5 a: Drainage map (200 m buffers). **b** Land use map. **c** Map showing available and unavailable land for rice cultivation

outside Oyo state but falling within the soil series in Oyo state were also used in the study. Findings from previous studies (Gbadegesin 1987; Gbadegesin and Nwagwu 1990; Omotayo et al. 2007; Nuga and Akinbola 2010; Babalola et al. 2011) indicate that soil physiochemical properties have a far more significant influence on yields

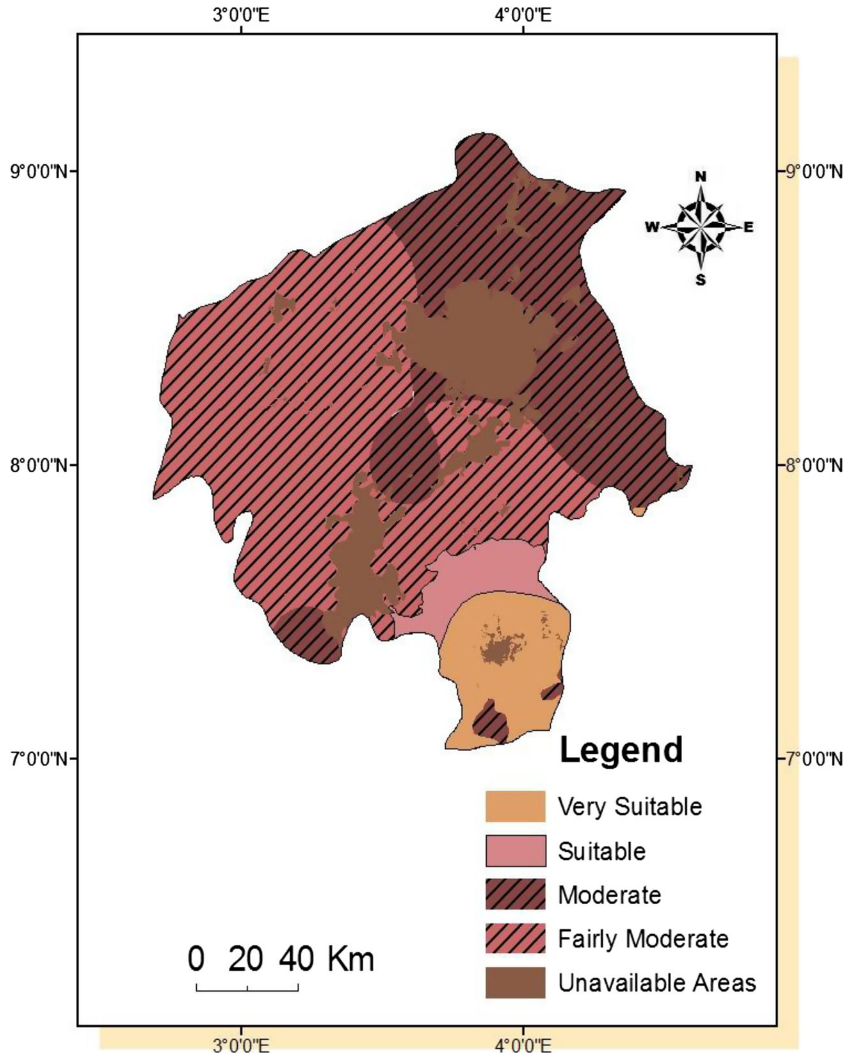

Fig. 6 Suitability map for rice production in Oyo state

of rice and other cereals in the region. Two key factors identified are organic matter content and soil PH.

2.2 Data Analysis and GIS Mapping Procedure

Using GIS software (ArcGIS 9.3, Idrisi and Erdas Imagine) as data processing tools, the suitability mapping procedure designed for this study is schematically shown in Fig 2.

The monthly climatic data was used in calculating annual total and mean annual values of rainfall, temperature, and relative humidity. After the computation of the meteorological indicators, the following spatial layers were generated by performing geostatistical analysis:

- Values and station coordinates were entered into excel, imported into ArcGIS as comma delimited (.csv) files, and interpolated using inverse distance weighted algorithm (IDW) to derive isopleths maps.
- The land use map used in this study was derived from a 28-m resolution imagery of southwest Nigeria. The landsat image was georeferenced to the same projection as the other maps (geographic coordinate system defined by the minna datum) with the aid of a resampled image of Nigeria. The clip tool in ArcGIS was used in clipping the image with the administrative boundary of Oyo state. Iterative self-organizing data analysis (ISODATA) clustering algorithm was applied to the image to produce natural clusters of pixels of similar brightness values. The results of the unsupervised classification and prior knowledge of the area served as a guide in selecting training sites. Supervised classification using a maximum likelihood ''hard'' classifier was then used to process the image. The maximum likelihood parametric rule computes the probability that a pixel belongs to a land use type and assigns each pixel to the category with the highest probability value. Classes identified were recoded into fewer classes relevant to the study. The digitized land use map

Table 4 Suitability Indices for Rice Production

Stations	Rainfall	Temperature	Relative humidity	Slope	Soil pH	Organic matter content	Soil Texture	Suitability scores
Shaki	1	2	3	3	2	2	2	144
Iseyin	2	2	3	3	3	1	2	216
Ibadan	2	2	3	3	3	2	3	648

shows the drainage network, forest reserve, forests, major settlements, rock outcrops, and savanna. Post-classification techniques (5 × 5 majority filter and region group function) were carried out in ArcGIS 9.3 to smoothen the image. The land use map was later divided into a boolean land use map showing available and unavailable areas for rice cultivation.

- Using the spatial analyst extension in ArcGIS, the 2318 spot heights obtained for Oyo state were interpolated using the inverse distance weighted algorithm (IDW) to derive the Digital Elevation Model (DEM). Slope map was then derived from the spot heights. The drainage map was derived by digitizing the drainage network and dams easily visible on the landsat imagery. This was time consuming since almost 1406 stream segments and 11 dams were digitized using the editor tools in ArcGIS. Buffers of 200 m were then generated around rivers and dams to select areas potentially suitable for rice irrigation.
- The soil map was clipped by overlaying an Oyo state boundary shape file on the soil map of southwest Nigeria. The clipped map was georeferenced appropriately and soil type polygons digitized to obtain digital files of each soil type. Data on soil reference points imported into ArcGIS provided the needed physiochemical information on the digitized soil types. Data on soil pH and organic matter content were also interpolated in ArcGIS. The maps derived as well as the soil texture map were then vectorized and overlayed to derive a soil suitability map.
- A total of 7 thematic layer maps were produced and reclassified: soil, slope, drainage, landuse, rainfall, elevation, and temperature. Based on the requirements for rice growth, suitability classes were determined using an adaptation of the United Nations Food and Agriculture Organization (FAO) framework for land evaluation.

Table 5 Suitability rating

Suitability indices	Suitability class	Suitability rating
>480	3	Suitable
144 – 480	2	Moderately suitable
<144	1	Marginally suitable/unsuitable

To identify potential areas for rice production in the state two, multicriteria evaluation approaches were used—the simple overlay and the weighted linear combination approach. The Boolean overlay approach is a very extreme form of decision-making whereby all criteria are reduced to logical statements of suitability and then combined by means of intersection (AND) and/or union (OR) operators. If the criteria are combined with a logical AND, a location must satisfy every criterion to be included in the final map (risk averse). On the other hand, if a logical OR is used, a location will be included if it satisfies one criterion (risk taking). For this study, the factor maps were derived based on defined suitability scores and combined using the UNION and DISSOLVE tool in ArcGIS. Isopleth maps, DEM, and slope were generated in ArcGIS using IDW, soil map was clipped, and soil type polygons digitized while land use and drainage maps were derived from the landsat image in Erdas and ArcGis after processing. Soils in currently available areas were determined by overlaying the reclassed land use map with the soil suitability map and then overlaying the resultant map with the potential maps (derived from the union of climatic and slope maps) to obtain the final suitability map showing areas which could be currently brought under rice cultivation while buffers of 200 m were generated around the drainage network showing potential areas for rice irrigation.

For comparison purposes, the MCE weighted linear combination method using the analytical hierarchy process (Saaty 1977) was also employed. This approach differs from the Boolean overlay as it allows the full tradeoff of factors. It is neither risk averse nor risk taking. This approach involves standardizing maps to a common numeric range (0–1 or 0–255) before they can be combined. Using the decision wizard in Idrisi, each factor map was standardized using the fuzzy module which provides a range of fuzzy set membership functions. Each standardized "Fuzzy" factor map is then multiplied by its corresponding weight. In developing weights, individuals or groups compare every possible pairing of the variables and enters the rating into a pairwise matrix based on a 9-point continuous scale. The principal eigenvectors are computed to produce the weights which must sum up to 1. Factor weights indicate the importance of each factor, i.e., the degree to which a factor compensates for another. The consistency ratio (CR) is also computed which indicates the probability that the ratings were randomly generated. A consistency

Table 6 Pairwise comparison 9-point continuous rating scale

Less important					More important			
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Extremely	Very strongly
1/9	1/7	1/5	1/3	1	3	5	7	9

ratio more than 0.10 is unacceptable and must be re-evaluated. Each map was then multiplied by its weight, summed, and then divided by the number of factors being evaluated to derive the final suitability map. Suitability classes were determined using an adaptation of the FAO framework for land evaluation:

➢Suitable (S1): Land can successfully support rice growth without significant limitations and benefits justify inputs.
➢Moderately suitable (S2): Suitable but with little limitations that could reduce productivity or increase inputs and management is needed to sustain productivity.
➢Not suitable (N): Land having limitations that prevent successful growth of rice on a sustainable basis.

3 Results and discussion

3.1 Description of factor maps

Climatic maps Rainfall map (Fig.3a) based on data from 10 rainfall stations shows that the mean annual rainfall values varying from 1135.6 mm in Eruwa to 1342.1 mm in Kishi do not fall completely within the amount required for the successful growth of rice (see Table 3). Most areas of the state are moderately suitable while Eruwa, Oyo, and Shaki do not meet the moisture requirements of rice, but with a combination of rainfall and irrigation rice systems, high yields can easily be realized and maintained in these areas. Temperature map (Fig. 3b, c) shows that with temperature values ranging from 26.61 °C (Shaki), 26.55 °C (Iseyin), to 27.16 °C (Ibadan), the study area is moderately suitable for rice production. Similarly, the relative humidity map (Fig. 3d) shows that Oyo state is suitable for rice growth with values of 61.39 % in Shaki, 62.74 % in Iseyin, and 68.97 % in Ibadan.

Soil map Soils in the study area are collectively referred to as ferruginous tropical soils. They are mainly loams, clays, and sandy clay loams (Fig. 4a) which are generally well suited for rice cultivation. Representative soil sample data on soil pH and organic matter content were overlayed with the soil texture map to derive a soil suitability map which shows that most (88.6 %) of the soils are moderately suitable while soils around Ibadan to the south are suitable (11.33 %) for rice production (Fig. 4b, c).

Slope map With contour lines of 50 m (Fig. 4d), elevation values range from 91.45 m in the south to as high as 538 m. The highest points are in Shaki northwest, Ogo Oluwa, and Orire Local Government Area to the northeast. The study area is therefore generally flat or almost flat and gently undulating to hilly terrains. A slope map of the area expressed as percent slope was derived from the spot heights. The shaded relief and slope show that the topography of Oyo state is suitable for rice cultivation.

Drainage map The drainage system which develops in an area is dependent on the slope and nature of bedrock. In the study area, rivers flow in a north–south direction forming a dendritic "tree"-like pattern. Figure 5a shows the 200-m buffered areas (11.7 %) that are potentially suitable for irrigation. However, after removing unavailable areas, only 9.7 % can currently be used for rice irrigation systems.

Land use map A current land use map of the study area could not be obtained; hence, the map was derived from the satellite imagery as discussed earlier. In the land use map (Fig. 5b, c), the purple areas represent major settlements in the state, e.g., Ibadan. The map also shows that Oyo state has a huge forest resource with the major forest reserve located towards the northern part of the state. Most of the farm lands in the state are located in the savanna zone. There are also series of hills and masses of rocky outcrops around areas like Shaki and Igbeti. These are mainly schist and quartzite inselbergs.

Table 7 Pair wise matrix

Rainfall	1					
Organic matter Content	1/3	1				
Soil pH	1/4	1/2	1			
Relative humidity	1/5	1/3	1/4	1		
Slope	1/6	1/6	1/5	½	1	
Temperature	1/8	1/7	1/6	1/3	1/2	1

Table 8 Factor weights

Factors	Weights
Rainfall	0.4370
Organic matter content	0.2316
Soil pH	0.1786
Relative humidity	0.0749
Slope	0.0467
Temperature	0.0313

3.2 Analysis and mapping results

The final suitability map (Fig. 6) obtained from the overlay of factor maps shows the following suitability zones for rice cultivation: very suitable (8.12 %), suitable (3.1 %), moderate (51.79 %), and fairly moderate (36.8 %). Rating scores assigned to each variable were used to classify the major weather stations (Table 4)

Clark's (1951) product method was used to determine the index of suitability for the area. This method involves multiplying the scores of the factors evaluated to derive the suitability index of each station for rice production. The class interval used was obtained by dividing the differences between the highest and lowest scores by the total number of stations (Table 5). The rationale behind this is to eliminate bias in obtaining a common ratio while also accommodating all the station scores. The scores obtained were interpolated in ArcGIS. This helped to confirm the suitability zones that were earlier derived. Thus, far factors evaluated have been treated as equally important which is often not the case in reality. Hence, the WLC approach using the analytical hierarchy process (AHP) was implemented for comparison purposes. Using the decision wizard in Idrisi factor, maps were standardized by specifying the appropriate fuzzy set membership functions using the threshold values, compared in pairs and rated based on a 9-point continuous scale (Table 6).

In rating factors for multicriteria evaluation, some studies have depended on face-to-face discussions with experts and farmers. This is subjective as perceptions regarding a problem differ from one individual to another. As a result, a more objective approach was used here whereby factors were rated based on quantitative analysis of the relationships between rice yield and environmental variables from the literature rather than on perceptions of such relationships. Ratings were entered into the pairwise matrix (Table 7) using the WEIGHT module. The module computed the principal eigenvectors producing a set of weights for the factors with a consistency ratio of 0.05 which falls within the acceptable consistency ratio of 0.10 (Table 8).

The analytical hierarchy process (AHP) was then selected in the decision wizard to derive the weights to produce the

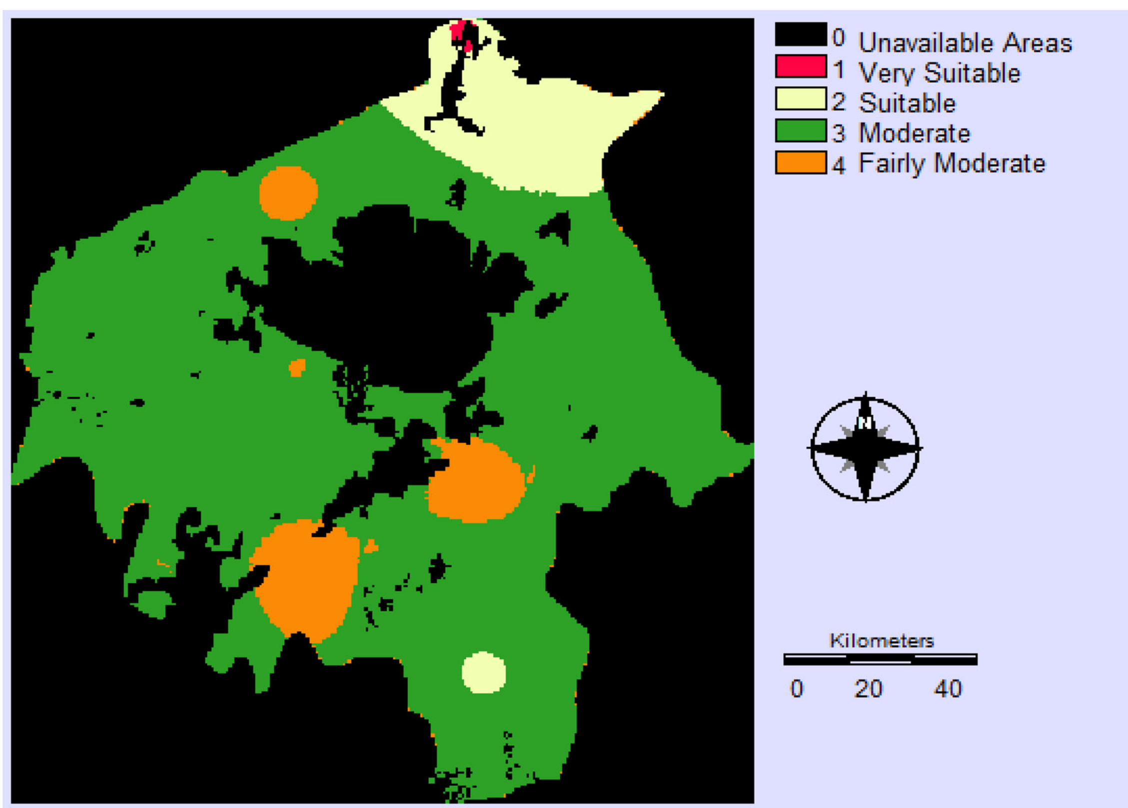

Fig. 7 Reclassified MCE suitability map

final map. The higher the factor weight, the more influence that factor has on the final suitability map. For instance, rainfall has more influence on the final map than slope. The final suitability map was masked by the Boolean constraint map specified in the decision wizard showing areas that are unavailable for rice production. In the final suitability, map areas in black are unavailable, areas in green are moderately suitable, while areas in light yellow to red are suitable for rice production. To derive more defined suitability zones, the map was reclassified (Fig. 7) into the following zones: very suitable (0.1 %), suitable (9.3 %), moderate (82.9 %), and fairly moderate (7.6 %).

4 Conclusion and recommendations

The major objective of this study was to assess the suitability of Oyo state for rice cultivation in the light of the prevailing environmental conditions so as to determine the most suitable areas for upland rice cultivation thereby increasing rice yields. This was achieved by evaluating the environmental factors identified in the literature as major determinants of rice yield.

Suitability assessment was conducted using the two most popular MCE-GIS approaches: Boolean overlay and weighted linear combination (WLC). Both the WLC and overlay suitability maps show that only some areas around Ibadan to the south and to the far north around kishi are very suitable for rice cultivation. Rice production should therefore be intensified in these areas. However, the WLC approach identified 82.9 % of Oyo state as moderately suitable while the overlay approach identified 51.79 % of the state as moderately suitable for rice cultivation. Another difference is that the WLC approach identified areas to the far north as suitable and not moderately suitable as indicated by the overlay approach. This is probably due to the influence of rainfall on the final WLC suitability map. Both maps however agree that most areas in the state are moderately suitable for rice cultivation. This result is in agreement with the findings of similar studies (Akintola 1983; Omotayo et al. 2007; Akinbile 2009) carried out in the region.

This study shows the ability of MCE-GIS approaches to integrate spatial and attribute data with higher efficiency and accuracy to form a single index of evaluation which enables sound management decisions to be made by both public and private operators in the agricultural sector. In other words, by identifying the most suitable areas for rice cultivation, land users and planners can direct resources to these areas. Although some of these areas are already unavailable for agricultural use, available areas can be protected from being invaded by non agricultural activities.

The results of the study reveal that in terms of climate rice can be successfully grown in the state especially with a combination of rainfall and irrigation. However, drought tolerant and high yielding varieties should be encouraged particularly in areas that do not always receive enough rainfall to successfully grow rice such as Eruwa, Oyo, and Shaki. Similarly, the study shows that soils in the state range from moderately suitable to suitable for rice production although available soil nutrient is low. The quickest way to increase fertility is therefore to apply fertilizers. In cases of extreme soil acidity, an annual minimum of 150–200 kg of magnesium limestone should be applied per hectare. Rice crop residues should also be incorporated into the soil to improve fertility. It is therefore important that the government provide farmers with easy access to fertilizers and other agricultural inputs at affordable prices. In terms of topography, mostly flat terrain is suitable for rice cultivation. In situations whereby hilly terrains have to be used, the soils must be fertile and farmers must be well informed on how best to control the effects of erosion. The abundant surface and ground water means that rice irrigation can be practiced in the state. Water supply for irrigation can be increased through the damming of rivers. Water can also be transferred from areas of high rainfall by pipeline and canals to areas in need of more moisture for rice crops. The government however has to pay attention to the health and socio-economic problems that result from irrigation projects.

One major obstacle to the success of the rice industry in the state and the country as a whole is that local rice cannot compete with imported rice in terms of quality, cleanliness, and packaging. It is therefore not enough to just intensify rice production or improve rice yields. Post-harvest handling activities (i.e., drying, milling, storage, packaging, and marketing) must be improved. This could be achieved by the government granting loans to industrialists interested in rice milling, setting up rice mills in major producing areas, and setting and enforcing standards in the quality of rice marketed in the country. Organizations such as the New Rice for Africa (NERICA) and West African Rice Development Association (WARDA) have contributed in recent years to the development of new and improved varieties of rice. However, the interaction and exchange of information among farmers, researchers, and extension workers need to be improved to enable the development and implementation of even better and up-to-date production technologies. The government also needs to implement clear policies on the production and importation of rice especially as demand continues to increase.

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