Research Article

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Geospatial assessment of wetland soils for rice production in Ajibode using geospatial techniques

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Abstract: Wetlands played an important role in human development and nature nutrient store for rice cultivation. Spatial techniques have gained importance in monitoring wetland changes. The study aimed to assess wetland soils for rice production using spatial techniques. The area was sample using stratified grid sampling. Nutrient availability and rice suitability were assessed in ArcGIS 10.6 environment. The soil was characterized into Eutric fluvaquent (Soil Survey Staff, 2010) and correlated as fluvisols in the World Reference Base system. The results of the land cover changes showed that built-up, waterbody, and farmland have increased by 39, 18, and 29%, respectively, and 13% decrease was observed in vegetation. The study concluded that soils of the studied area varied from marginally (75%), not suitable (20%), and permanently not suitable (5%) for rice production. Therefore, without proper assessment and management of these studied soils, rice production will continue to be futile.

Keywords: rice, land use and land cover, geographic information system, remote sensing, wetlands

1 Introduction

Rice (*Oryza sativa*) serves as an important staple food crop belonging to the Gramineae family [1]. More than half of the world population is dependent upon rice [2]. Supplying the growing human population with safe and adequate staple crops such as rice is an overwhelming challenge [3–5]. About 80% of rice land is cultivated on wetlands, and this accounts for 93% of world rice production (International Rice Research Institute). Optimum rice production is achieved when the land use is put into investigation. Land use and land cover (LULC) change is most important in understanding and investigating changes in wetlands [6]. Wetlands played an important role in human development and are recognized as one of the world's most valuable natural resources [7,8]. Globally, wetlands' benefits and values to the society have attracted great importance. However, wetland soils experience direct and indirect negative impacts through anthropogenic activities [9].

In Nigeria, wetland cultivation is now being emphasized especially for rice production [10–12]. Wetlands are most times being referred to as wastelands [13–15]. According to the Ramsar convention [16], about 64% of the world's wetlands has disappeared. Besides, pressure from urbanization and industrialization has also contributed to the loss of wetlands. Cohen et al. [17] opined that the discharge of anthropogenic activities into wetlands decreases nutrient concentrations in crops and reduces the soil nutrients [18,19]. According to ref. [20], about 25% of Nigeria's rice is conventionally cultivated [21].

Application of technological advances such as geographic information system (GIS) and remotely sensed (RS) data made possible to study the changes in wetland in less time, at low cost, and with better accuracy, especially when consistent and spatial data are essential [22–26]. GIS provided suitable platform for data analysis, update, and retrieval [27]. Integration of RS and GIS has proved to serve as indispensable tools in mapping potential suitability of wetland soils in a study [28]. Hence, this study aimed at the assessment of LULC change in wetland soils for rice production in Ajibode using an object-based analysis tool.

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2 Study methods

The city of Ibadan is the largest in West Africa and it is located in South-Western Nigeria. Ibadan lies essentially in a zone of transition between the humid and sub-humid tropical climates within latitudes 7°16′ North to 7°34′ North, longitudes 3°44′ East to 4°02′ East about, 145 km North of Lagos. The 2006 census puts the total population of Ibadan at 2,550,593, while the average population density was 828 persons per kilometer [29]. The Ajibode part of Ibadan is made up of an agrarian community with man-made and natural wetlands (Figure 1). The studied area has experienced industrialization encroachment with the presence of institutions such as Federal Schools of Statistics, among others.

Plains and river valley are the two major landforms that dominate the landscape. The average elevation is 230 m above the mean sea level. The area is drained by three major rivers, namely, Ogbere, Ogunpa, and Ona, with many tributaries, such as Alaro, Omi, Kudeti, etc. The combination of the plains and river valleys provides a good drainage for the studied area. The western part of the city which consists of most of the industries and more recent residential is drained by river Ona with its tributaries including Alalubosa, Alaro, Oshun, etc.; River Ogunpa drains the Eastern part of the studied area with its tributaries including river Ogbere.

The geology of Ibadan is described as a basement complex of Pre-Cambrian age with mainly granite, quartzite, and migmatite as the dominant rock types. The minor rock types include pegmatite and diorite. The soils of Ibadan are formed from the weathered materials of the underlying basement rocks especially granite gneiss, quartz–schist, schist, and biotite gneiss which are mainly metamorphic rocks and minor pegmatite. As reported by ref. [30], the identification of soil associations in Ibadan is based on parent materials.

The study assessed LULC and soil suitability using GIS and RS methods. The LULC changes were assessed using RS techniques. Interpolation of soil nutrients for rice production was assessed using GIS.

2.1 Data preparation and analysis

Multi-spectral Landsat satellite data for the years 2000 and 2016 were acquired from the United States

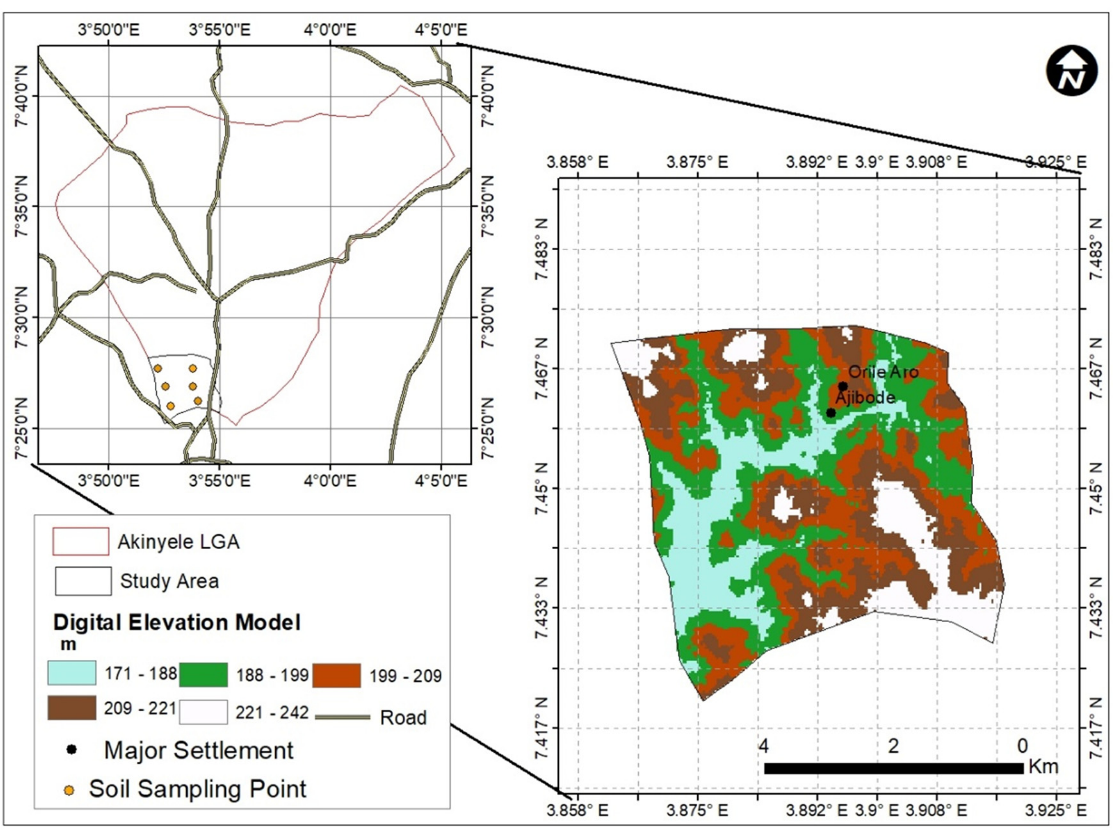

Figure 1: Study area.

Geological Survey (USGS) to measure the LULC change. Due to atmospheric error and avoidance of seasonal variation, the Landsat images with maximum cloud cover were already set as <10%, which made the images free from atmospheric weather condition. Landsat satellite data scene with <10% indicates no need of additional geo-rectification or image-to-image registration for image pre-processing [31]. The acquired Landsat was supported and validated with Google Earth Imagery immediately after ground truthing. The Landsat data sets were subjected to Environmental Visual software (Envi) 5.1 environment for image classification. Information of the images acquired from the USGS online data repository (including date, sensor, spatial resolution, cloud cover, and Path/Row) is shown in Table 1.

2.2 Image classification

The images obtained from Landsat are classified into four broad LULC classes (namely, vegetation, built up, waterbody, and farmland) for the years 2000 and 2016 based on the Maximum Likelihood Supervised Classification (MLSC) techniques. The MLSC operation is carried out due to its good performance and easy classification algorithm [32,33]. Pixel signatures of the LULC class features were identified and created with a polygon for easy identification of the area of interest. The kappa statistics of the LULC were calculated for accuracy assessment [34].

2.3 Normalized difference vegetation index

Normalized difference vegetation index (NDVI) is an indicator used to identify the photosynthetic activity of land cover. In this study, NDVI was applied to detect loss of vegetation cover change which can be attributed to wetland loss [35]. Here the formula for NDVI calculation is given by ref. [35]:

$$\mathrm{NDVI} = \frac{\mathrm{BAND}\quad 4 - \mathrm{BAND}\quad 3}{\mathrm{BAND}\quad 4 + \mathrm{BAND}\quad 3} \tag{1}$$

where Band 3 is the near-infrared region, and Band 4 is the visible red.

2.4 Geospatial assessment of wetland

Reconnaissance survey was carried out to identify the soil types. Soil sampling coordinate point was taken with the aid of a global positioning system. The study area was sampled using stratified grid sampling and was predominantly made up of lowland topography. Soil sampling was collected at 0–15 cm for soil fertility assessment since rice is a shallow-rooted crop. Representative soil profile pits measuring 2 m by 1.5 m by 2 m were dug. A total of three soil profile pits were dug and were described based on morphology, chemical, and physical in line with the ref. [36] procedure. Soil samples were collected from the different pedogenic horizons and then processed in the laboratory after air-drying at room temperature. Land requirement and suitability ratings for rice production were shown in Table 2 [37–39]. The sampling coordinates were further inserted into the Microsoft excel sheet and plotted into ArcGIS 10.5 environ for production of rice suitability map.

2.5 Soil classification

The study soils were found on the basement parent rock materials in south-western Nigeria. The soils were classified based on morphological characteristics and soil laboratory data using the USDA Soil Taxonomy [40] and the World Reference Base (WRB) system of ref. [41].

2.6 Geostatistical methods

In this study, geostatistical analyses were conducted in three stages which include semi-variogram, model evaluation, and estimations. Semi-variogram is one of the

Table 1: Details of the image used for the study

Image	Acquisition date	Path and row	Band composite	No of bands	Spatial resolution
LandSat 7	19/05/2000	P191, R55	432	5	30 m
LandSat 8	20/05/2016	P191, R55	652	11	30 m

Table 2: Land requirement and suitability classes for rice production

Land qualities	Sl1 100	Sl2 95	S2 85	S3 60	N1 40	N2 25
Climate (c)						
Annual rainfall (mm)	>1,000	900–1,000	800–900	600–800	500–600	<500
Temperature (°C)	>25	22–25	20–22	18–20	16–18	<16
Topography (t)						
Slope (%)	<2	3–4	5–6	7–8	9–10	>10
Drainage (w)						
Wetness	WD	MWD	MD	ID	PD	PD
Soil physical properties (s)						
Texture	L	LfS	LS	S	S	S
Structure	Cr	Cr	SAB	SAB	Col	Col
Coarse fragment (%) (0–45 cm)	<3	3–5	5–10	10–15	>15	—
Soil depth (cm)	>75	65–70	50–65	35–50	30–35	>30
Soil fertility (f)						
pH	5.5–6.5	5.0–5.5	4.5–5.0	4.0–4.5	<4.0	—
ECEC (cmol/kg)	>16	12–16	8–12	5–8	<5	—
Base saturation (%)	>80	70–80	50–70	35–50	25–35	<25
Organic matter (%) (0–30 cm)	>2.0	2.0–1.5	1.2–1.5	1.0–1.2	1.0	<1.0
Macro-nutrients						
Nitrogen (%)	>2.0	1.5–2.0	1.0–1.5	0.5–1.0	<0.5	—
Phosphorus (mg/kg)	>22	13–22	6–13	3–6	<3	—
Potassium (cmol/kg)	>0.5	0.3–0.5	0.2–0.3	0.1–0.2	<0.1	
Micro-nutrients						
Iron (Fe) (mg/kg)	>4.5	3.5–4.5	2.5–3.5	1.5–2.5	1.0–1.5	<1.0
Zinc (Zn) (mg/kg)	>2.0	1.5–2.0	1.0–1.5	0.8–1.0	0.6–0.8	<0.6
Manganese (Mn) (mg/kg)	>1.5	1.0–1.5	0.8–1.0	0.6–0.8	0.5–0.6	<0.5

WD = well drained; MWD = moderately well drained; ID = imperfectly drained; PD = poorly drained; L = loamy; LfS = loamy fine sand; LS = loamy sand; S = sand; Cr = crumb; SAB = sub-angular blocky; ECEC = exchangeable cation exchanged capacity; Col = columnar. Source: Sys et al. (1991, 1993) and De Datta (1989).

most essential tools in geostatistical analyses to quantify and model the spatial variability degree of data. Semi-variogram analyses were determined and fitted with an exponential model [42,43]. Thereafter, the soil data were subject to ordinary kriging (OK) interpolation method. OK is used for prediction of the values of the unsample points by assuming the equals of the known measured value (field measured value). In order to ensure that their reliability and appropriateness, the variogram models were validated with root mean square error (RMSE). RMSE is used to describe the distance between measured and estimated values. The kriging process is calculated by the following equation [44]:

$$Z^{*}(X_0) = \sum_{i=1}^{n} k_i z(x_i) \qquad (2)$$

where $Z^{*}(X_0)$ is the predicted value at position, $Z(x_i)$ is the known value at sampling site x_i, k_i is the weighting coefficient of the measured site, and n is the number of sites within the otassiumood searched for the interpolation.

2.7 Laboratory analysis

The following soil parameters were determined: nitrogen, potassium, phosphorus, hydrogen ions, soil texture, soil structure, hydraulic conductivity, bulk density (BD), and soil pH. The particle size was determined by the hydrometer method Bouyoucous described in ref. [45]. Total nitrogen was determined calorimetrically. Available phosphorus was extracted by Bray 1 method [46] and phosphorus concentration was determined using an ultraviolet spectrophotometer. Soil organic carbon was determined by dichromate oxidation procedure and organic matter was determined by carbon factor. Exchangeable bases (such as calcium, magnesium, potassium, and sodium) were extracted with neutral ammonium acetate. Calcium and magnesium were determined with atomic absorption spectrometry, while potassium and sodium were determined by flame photometer. Base saturation and effective cation exchange capacity were calculated. Soil pH was determined in a 1:2 soil to water suspension using a glass electrode pH meter. BD was determined from undisturbed core samples, which were oven-dried to constant weight at 105°C.

3 Result

3.1 Soil classification

The mapping units were identified based on established toposequence formed from basement complex soils in south-western Nigeria. The morphological properties of the studied soils varied, concerning colour, texture, structure, and boundary. In this study, three mapping units were identified: soil texture varied from sandy loam to sandy clay from the surface horizon down to the sub-horizons across the three soil profiles. The soil color varied from dark, Yellowish Red (YR) (2/1), very dark brown (7.5YR 2.5/2), dark reddish brown (5 YR 3/3), and yellowish red (5 YR 3/4) across the three soil profile. The structure varies from weak sub-angular blocky to medium sub-angular blocky with clear smooth, wavy, and medium angular blocky boundary. The area has an ustic moisture regime with a mean annual soil temperature of 22°C and classified as isohyperthermic temperature regime. The mapping units were further classified as Eutric fluvaquent and correlated as fluvisols in the WRB system.

3.2 Land use and land cover assessment

Periodical assessment characteristics and colour composite were used to specifically and comprehensively classify the LULC of the studied area [47]. Four major land cover classes were delineated using satellite data, viz., farmland, waterbody, vegetation, and built up. The statistical analysis of the multi-temporal LULC maps revealed that significant changes have taken place from the year 2000 to 2016. Three trends of change were manifested (Figure 2). First, a sudden increase in the built-up area, waterbody, and farmland, and second decrease in vegetation over the study period (Table 3). Accuracy assessment of the LULC classified maps for the years 2000 and 2016 is shown in Table 4.

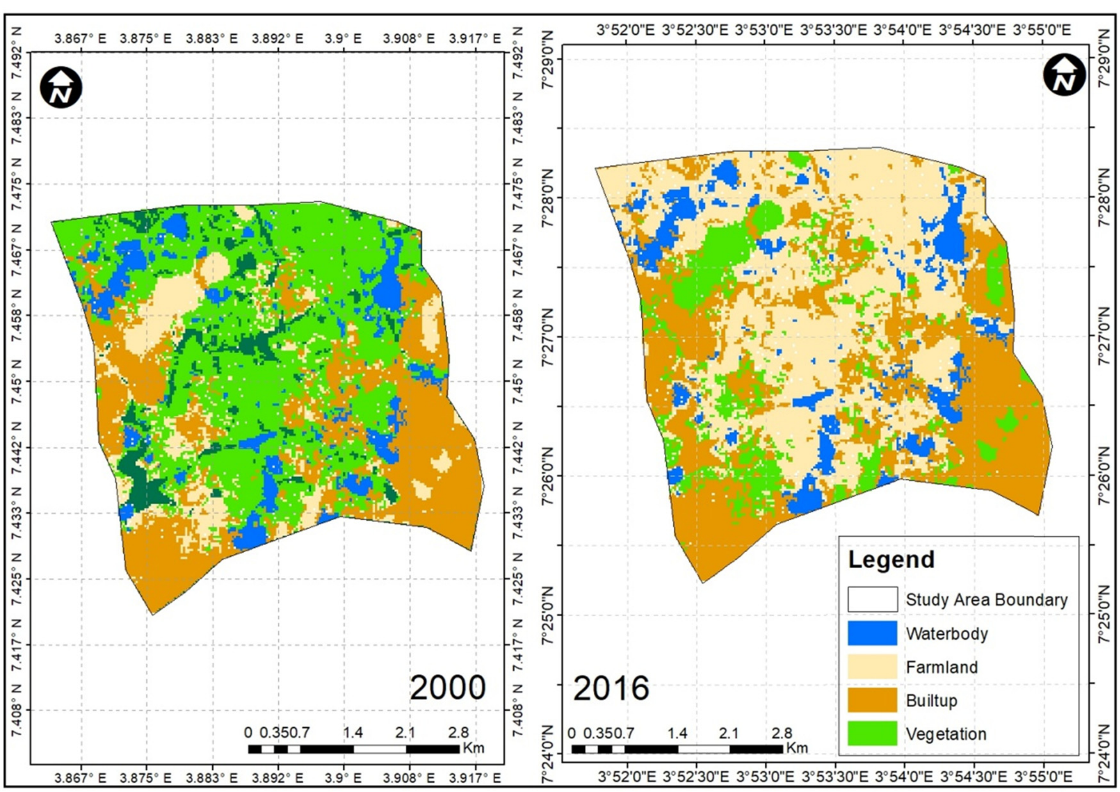

Figure 2: Land use and land cover.

Table 3: Area and percentage of LULC changes from 2000 to 2016

LULC class	Rate of change			
	Year			
	2000		2016	
	Area (km^2)	%	Area (km^2)	%
Waterbody	2.87	14.03	3.69	18.03
Built up	4.91	23.99	7.99	39.05
Vegetation	9.79	47.85	2.79	13.64
Farmland	2.89	14.13	5.99	29.28
Total	20.46	100	20.46	100

3.3 Fertility distribution of the studied soils

Soil fertility distribution of the studied soils shows that nitrogen varied from 0.6 to 1.00%, and the organic matter also varied from 1.60 to 5.37%. Soil pH (KCl) varied from 3.59 to 4.80, and soil pH (H_2O) varied from 4.61 to 5.88. Exchangeable potassium in the soil varied from 0.41 to 1.00 cmol/kg. The exchangeable cation exchanged capacity (ECEC) of the soil varied between 3.33 and 8.04 cmol/kg. The calcium carbonate content of the soil ranged from 0.76 to 4.27 cmol/kg, and magnesium ranged from 0.62 to 2.56 cmol/kg. Available phosphorus ranged from 1.59 to 8.14 mg/kg. The micronutrients such as iron ranged from 100.64 to 212.32 mg/kg, zinc ranged from 1.17 to 4.20 mg/kg, and copper ranged from 1.84 to 5.97 mg/kg down the profile (Table 5).

3.4 Geostatistical assessment of the studied soils

The nugget/sill ratio falls between the strong, moderate, and weak. Of the selected soil properties, pH (H_2O) and pH (KCl) indicate a strong spatial correlation and nitrogen and potassium indicate moderate spatial correlation, while zinc and phosphorus indicate weak spatial correlation. The RMSE values ranged from 0.966 to 0.894, respectively, which indicates a good fit (Table 6).

3.5 Normalized difference vegetation index

The NDVI is most often used for vegetation assessment [48]. The NDVI result for 2016 varied from 0.09 to 0.04, while NDVI for 2000 varied from 0.29 to 0.05 (Figure 3).

3.6 Soil suitability assessment

Soil suitability of the study was conducted by merging the land requirement and soil suitability for rice production. The study revealed that the annual rainfall ranged from moderately to marginally suitable for rice production (800–900 mm), while the drainage is moderately drained, with 22 to 25°C temperature. The soil pH, iron, nitrogen, potassium, phosphorus, organic matter, and ECEC coupled with land qualities indicated that the studied soil is marginally suitable, covering 75% marginally suitable, 20% non-suitable, and 5% permanently not suitable (Figure 4).

4 Discussion

The essential importance of geospatial techniques over the past decades is unavoidable. Geospatial techniques such as GIS and satellite remote sensing have been extensively applied in assessing the LULC changes of the studied wetlands. Wetlands are vital and sensitive to rice production. However, they are also faced with a lot of threats from anthropogenic activities. This study showed a better understanding of LULC assessment of wetland soils and accurate mapping of soil properties for precision farming. The soil hydraulic conductivity of the

Table 4: Accuracy assessment of the LULC classified maps for the years 2000 and 2016

	User accuracy (%)					Producer accuracy (%)				
LULC	WB	BA	VG	FD	Overall classification accuracy	WB	BA	VG	FD	Overall statistic kappa
2000	98.4	98.9	98.5	94.3	95.87%	98.5	96.4	95.8	88.8	0.9488
2016	98.2	97.5	98.7	94.9	94.00%	99.8	95.9	88.2	96.8	0.9365

LULC = land use and land cover; WB = waterbody; BA = built-up area; VG = vegetation; FD = farmland.

Table 5: Soil physical and chemical properties

Depth (cm)	pH (H_2O)	pH (KCl)	OM	Total	Exchangeable bases				Ex-acidity	Av.P	CEC	BS	Micro-nutrients			
				N	K^+	Ca^{2+}	Mg^{2+}	Na^{2+}	H^+	mg/kg	(cmol/kg)	(%)	Fe^{2+}	Zn^{2+}	Mn^{2+}	Cu^{2+}
			(%)		(cmol/kg)								(ppm)			
Lowland 1																
0–11	5.27	4.33	2.99	1.4	0.97	2.74	0.78	0.40	0.15	1.98	5.04	97.9	212.32	4.20	77.40	3.11
11–30	5.40	4.45	2.55	1.5	0.61	1.88	0.74	0.58	0.14	3.18	3.95	96.4	100.64	2.41	40.39	2.65
30–50	5.21	4.00	2.06	1.2	0.68	0.88	1.02	0.60	0.12	3.55	3.33	95.1	103.45	1.17	40.09	3.31
50–85	5.00	4.05	1.60	0.9	0.84	1.06	1.77	0.88	0.16	3.47	4.72	96.0	108.46	2.39	42.91	2.49
85–110	4.84	3.59	1.87	0.8	0.55	1.18	1.40	0.60	0.17	3.44	3.90	95.1	101.42	2.28	30.64	2.88
Lowland 2																
0–9	5.76	4.61	3.11	1.8	1.00	2.14	1.23	0.43	0.12	2.34	4.92	97.3	208.08	3.64	89.30	3.20
9–24	5.53	4.52	1.74	1.2	0.64	2.03	0.62	0.53	0.13	3.84	3.96	96.3	130.58	2.64	40.58	1.84
24–38	4.61	4.49	2.13	1.3	0.56	0.76	1.14	0.60	0.18	2.45	3.24	94.7	139.88	2.46	25.44	2.26
38–79	5.01	4.45	1.93	0.6	0.41	1.42	1.55	0.92	0.16	1.60	4.45	96.1	137.30	2.96	33.07	3.48
79–112	4.82	4.29	1.53	0.7	0.60	1.09	1.22	1.57	0.17	1.59	4.65	96.3	140.68	1.70	31.62	2.90
Lowland 3																
0–4	5.88	4.51	5.37	2.6	0.75	3.34	1.45	0.38	0.12	8.14	6.03	98.1	161.08	3.81	58.08	5.97
4–13	5.23	4.59	4.09	2.1	0.84	2.87	1.31	0.57	0.15	4.14	5.74	97.2	110.54	2.69	26.24	4.16
13–24	5.85	4.80	3.37	1.7	0.94	3.13	0.89	0.57	0.12	5.09	5.66	97.2	177.91	3.71	83.83	2.80
24–42	5.72	4.01	2.30	1.6	0.77	2.22	0.89	0.52	0.12	5.12	4.52	97.2	167.01	2.14	48.26	2.45
42–90	5.52	4.01	2.15	3.1	0.63	4.27	2.56	0.45	0.13	2.03	8.04	98.3	142.47	3.79	109.35	3.56

Table 6: Soil parameters for rice suitability

Soil properties	Model	Spatial class	Nugget	Sill ($C_o + C$)	Nugget/Sill	RMSE
pH (H_2O)	Ex	Strong	0.15	1.143	0.13	0.966
pH (KCl)	Ex	Strong	0.14	0.611	0.23	0.963
Zinc	Ex	Weak	0.73	1.074	0.68	0.894
Nitrogen	Ex	Moderate	0.74	4.092	0.18	0.966
Potassium	Ex	Moderate	0.42	0.956	0.44	0.932
Phosphorus	Ex	Weak	0.25	1.077	0.23	0.962

RMSE = root mean square error; Ex = exponential.

studied has no definite sequence down the profile, while the BD was decreasing with depth within the soil profile. The sandy nature of the soils could be traced to soil erosion experienced in the studied area. NDVI values in the year 2000 and 2016 can be attributed to moderate density, which is gradual loss of vegetation due to human activities such as built-up expansion and intensive farming practices [49]. The soil temperature classified as isohyperthermic in the present study agrees with the work done by ref. [50], which states that soil temperature regime in south-western Nigeria can be classified as isohyperthermic. Total nitrogen values range from medium to high and the soil pH in the studied area is acidic. The acidic nature in the studied soils can be attributed to the discharge of industrial waste and blanket use of fertilizer in the studied area. The blanket use of fertilizer and discharge of waste into the river which flows through the study area was noticed during the reconnaissance survey. The value of exchangeable potassium, available phosphorus, and ECEC obtained in this study is comparatively lower. Effect of the low available phosphorus, exchangeable potassium, and ECEC can be attributed to continuous or yearly cultivation of the study soils for rice production [51–55]. Geostatistic assessment of the study soil followed the order of strong (0.25) > moderate (0.25–0.75) > weak (0.75), which shows a good fit of the soil properties also in

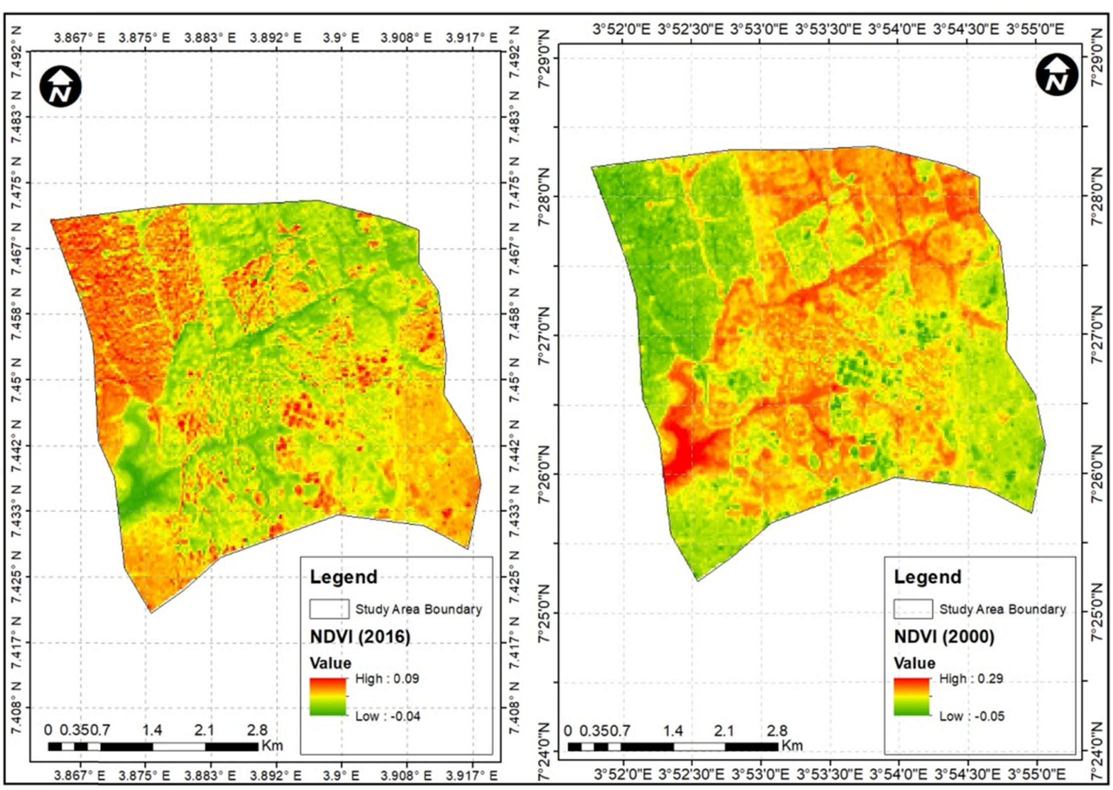

Figure 3: Normalized difference vegetation index.

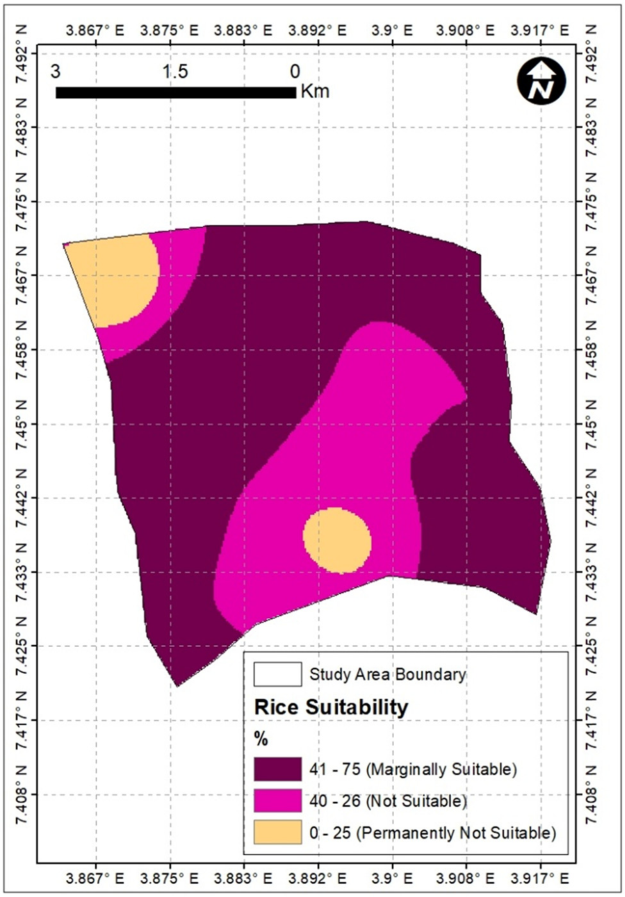

Figure 4: Rice suitability.

consonance with the work carried out by ref. [56]. The studied soil shows that marginally suitable area can be managed and increased by applying agricultural management techniques, while the permanently and not suitable can be planted with cover crops to improve the soil nutrients over time. Rice suitability production in the studied area has been affected through intensive farming, blanket use of fertilizer, and discharged of industrial waste materials from the communities and surrounding industries within the studied area. The present study suggested that the built-up area should not be allowed to increase at the expense of prime farmland. In addition, land use policy should be strictly followed. It is therefore recommended that the current land use pattern needs to be modified according to soil potential suitability classes. The use of geospatial techniques has offered easy assessment, proper monitoring, and potential suitability of the studied soils for rice production. RS and GIS can be potential tools for monitoring, planning, and decision making for government officials and policymakers of Ibadan and environment.

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Author contributions: Tobore Anthony prepared the manuscript with contribution from all co-authors, developed original idea for this research, drafted the methodology, interpreted and analysed the data set, and finalized the impact of LULC on the study soils. Professor Senjobi provided guidelines for writing, proofread the full manuscript, gave critical review, and finalized the full manuscript. Ogundiyi Temitope suggested some analysis and language editing. Samuel Bamidele made language correction.

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