Forests and Forest Products Journal 20: 17-28
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Geoinformatics Evaluation of Land Use Potential in Agroforestry System of *Parkia biglobosa, Piliostigma recticulata,* and *Vitellaria paradoxa* in Ibarapa, Oyo State Nigeria

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Abstract.
To avoid conflicts resulting from pressure on forest and agricultural land for the production of food in Ibarapa area, there is a need to maximize the use of agricultural land using different agroforestry practices. One major way to achieve this is to evaluate agricultural land use using physical and ecological datasets as demonstrated by previous studies. Therefore, this study is set to develop an up-to-date multi-criterion evaluation (MCE) of land-use suitability for Taungya Farming system in the mixed forest zone dominated by Parkia biglobosa, using physical and ecological criteria in the study area. The selected criteria were assembled and the weights of their respective contributions to land suitability for agricultural uses were assessed using an analytic hierarchical process (AHP) in Idrisi, with a weighting sum of one and an acceptable consistency ratio (Cr) of 0.24. The result of this study found about 92% of the area was suitable for crop production, except for areas close to the settlements or developed areas. It also shows that 17% of the total area could support agroforestry, especially in the southern and northern parts of the region. While this study could be useful in assessing the agricultural land use potential, it could also provide guidance for local agricultural offices, agricultural extension workers and farmers to act in more structured and strategic ways for sustainable agricultural planning and programming in the area.

Keywords: *Multicriteria evaluation, Taungya Farming system, Analytic hierarchical process and Sustainable agricultural planning.*

Introduction

The major cause of pressure on world natural and agricultural resources today is the rapid increase in global population especially in the third world countries (Adegbehin *et al.,* 1990; Abdullah *et al.,* 2008 and Goma *et al.,* 2016). The resultant pressure on land resources is capable of causing land degradation (Aguiar *et al.,* 2007). To develop land-use policies that will sustain the development of human society, reliable land use potential evaluation becomes inevitable to the decision-making processes. To achieve self-sufficiency in agricultural production in developing countries such as Nigeria, land assessment systems remain crucial in simulating land's suitability for different agricultural practices (Attual *et al.,* 2014). Multi-criteria evaluation processes have been used in some large-scale planning processes to estimate the potential of land for alternative land uses including agricultural land use (Malczewski J.,1999). A comprehensive evaluation of the land and other ecological resources such as water potential makes way for alternative land uses to meet the needs of the society and ensure future availability of resources (Marinoni, 2004). The land evaluation method is the systematic assessment of the land potential to find out the most suitable area for a particular farming practice. The potential of land suitability for agricultural use is determined by an evaluation process of the climate, soil, water resources and slope (Mashayekhan *et al.,* 2011). The primary concern in multi-criteria evaluation is to combine the information from several criteria to form a single index of evaluation in order to support land-use planning and management (Saaty, 1980 and Meyer *et al.,* 2009). A multi-criteria technique that has been employed in the geospatial land use suitability procedure is the Analytical Hierarchy Process (AHP) (Pourkhabbaz *et al.*, 2014 and HUYNH VAN C., 2008). The AHP technique provides a crystal decision-making system, which is not often used in tropical Africa countries such as Nigeria.

Ibarapa region is endowed with a large area of land and vegetation, but the use of this important resource has been abused, not sustainably used or managed. Ladipo (2010) pointed out that forest has previously been treated as inexhaustible. It has been realised recently that the forest is on the verge of going to extinction if nothing is done to reverse the unsustainable use. There is growing interest in integrating GIS with Analytical Hierarchy Process as an eminent multi-criteria technique in land-use suitability assessment for sustainable environment (Goma *et al.*, 2016). We have utilized a GIS-based multi-criteria evaluation method for land suitability analysis in this mixed forest zone dominated by *Parkia biglobosa, Piliostigma reticulata and Vitellaria paradoxa* tree species. The study area was classified with respect to the potential for Taungya Farming system, which is the production of woody perennials combined with an annual crop. In handling conflicting criteria for effective land-use potential planning and management, the geospatial technique is handy for a time-efficient and cost-effective analysis. For the classification of land suitability in our study area, we adopted AHP to combine different types of input data, and the pairwise comparison method for comparing variables instantaneously. The application of the AHP process involves several steps in order to rank Criteria to the set of suitable criteria.

Materials and Methods

Study Area

The Ibarapa area falls within latitudes $7^0.15'$ N and $7^0.55'$ N and longitudes 3^0E and $3^0.3^{0'}$ E. It is located approximately 100 km north of the coast of Lagos, and about 95 km west of the Oyo state capital and neighboring city of Ibadan (Femi, 2011). They border Yorubas of Onko extraction to the North (Iwajowa, Kajola and Iseyin LGAs) and Yorubas of Oyo extraction to the East (Ibadan). The Yewas or Egbados to the West, and the Egbas to the South (Kola, 2006).

The area is approximately 2,496 km² in geographical size, and consists mostly of rolling savannah with forests situated along the southern border and in isolated patches along with river courses such as the Ogun. The natural vegetation was originally rainforest but that has been mostly transformed into derived type savanna as a result of several centuries of slash & burn agricultural practices. Ogundele *et al*. (2012) identified the key flora elements currently as savanna tree species of *Parkia biglobosa, Piliostigma reticulata* and *Vitellaria paradoxa*. The main grasses are *Panicum maximum, Imperata cylindrica* and *Andropogon tectorum*. It is well-drained. Most of the land lies at elevations ranging between 120 and 200 meters above sea level, but rocky inselbergs and outcrops can be seen rising to 340 meters. The predominant occupation of the people is farming and Ibarapa land is traditionally made up of seven principal towns and their surrounding villages and farmsteads (Nylander, 1969). These towns include Igangan, Tapa and Aiyete are in Ibarapa North local government area, Idere and Igbo-Ora are in Ibarapa Central, while Lanlate and Eruwa are located in Ibarapa East local government. The three local governments were created by the federal government of Nigeria authorities in 1996 when Ibarapa East was carved out from the old Ibarapa Local Government while Ibarapa Central and North were carved out of the former Ifeloju Local Government area (Femi, 2011).

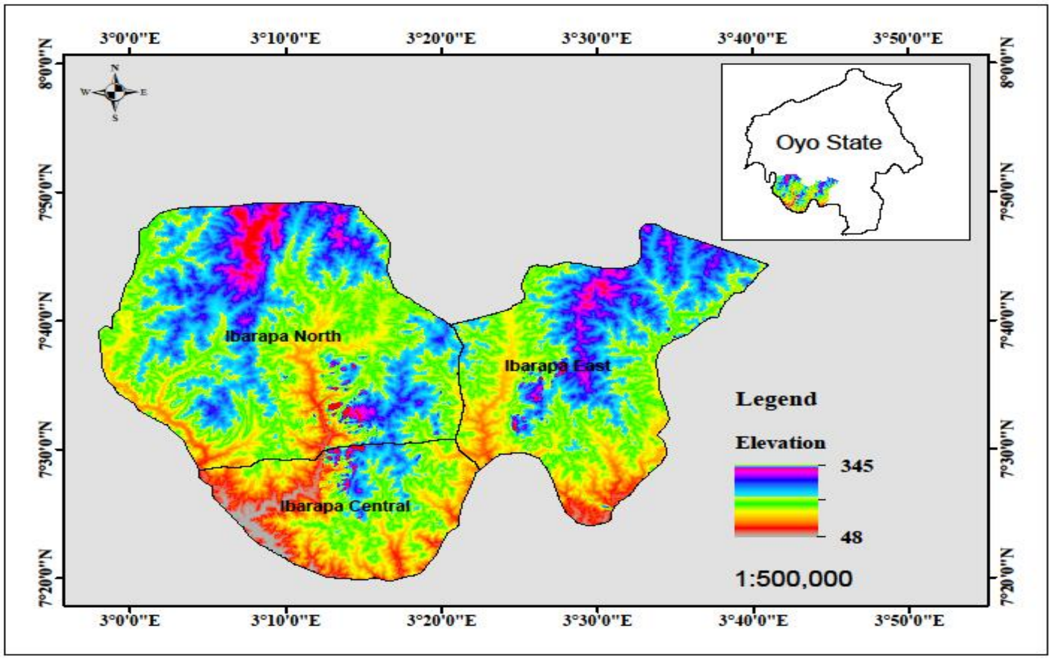


Figure 1. Ibarapa Area of Oyo State

Data collection and preparation using GIS

Landsat 2020 and DEM satellite image was downloaded from the official website of US Geological Survey (USGS) and used in order to achieve the research objectives. The study area is located in Landsat path 191 and row 55. The pixel sizes of the images were 30 × 30 m with the exception of the thermal IR bands (10) respectively, which have 100-m resolution bands (Chander, 2003). All the images were pre-georeferenced to UTM zone 31 North projection using WGS-84 datum. Table 1 presents the specifications of Landsat OLI and DEM images. AsterDEM was acquired for digital elevation modeling. The satellite images and data utilized have been summarized in table 1. For the Data Preparation, ecological (slope and soil), climatic (rainfall and temperature), and proximity (distance from water bodies) criteria that influence land suitability for agricultural uses were aggregated in this study (Malaysia, 2014). All these criteria constitute the maps; and, the maps were projected to the same scale, boundary extent, resolution of $30m^2$ and spatial reference.

Table 1: Satellite Images used for the study

Satellite Sensor	Spatial resolution	Acquisition years	Path	Row
Landsat 8	30m x 30m	2020	190	55
Asterdem	30m interval	2000	190	55

Data Analysis

The images were processed using maximum likelihood classier in ArcGIS software environment to group the pixels into four broad classes: built-up area, forest area, water body, and farm/grassland (Rawat *et al.*, 2015). To ensure effective image classification for land-use land cover (LULC) map, no fewer than 30 pixels were selected randomly to produce a single class (John *et al.*, 2006). The soil data for the study area were derived from the geological map of Nigeria. The soil map was obtained in vector format and were converted into 30m raster data after they were clipped to the boundary of the study area. Slope data were derived from the AsterDEM data using the Surface Analysis module in ArcGIS 10.5. The slope dataset was re-classified based on the NPP classification sequence to represent different suitability situations (Rakesh *et al.*, 2014). To extract water bodies, the DEM image was first processed to fill sinks in order to remove small imperfections in the data. This also removed peaks which is a cell where no adjacent cells are higher, and to remove peaks, the input surface raster was inverted using the analyst tool in ArcGIS. The next step was to determine the flow accumulation areas of streams in the study areas. as the accumulated weight of all cells flowing into each downslope cell in the output image. Distances from water sources (i.e, streams) were calculated using a cost-weighted distance, which modifies Euclidean distance by equating distance with a cost factor, which is the cost to travel through any given cell (Jiansheng. *et al.*, 2010). The climatic factors include rainfall and temperature variables. The rainfall variable obtained from worldclim was aggregated based on the annual averages. Using Ordinary Kriging, a geostatistical method that makes local estimations by linear interpolation of weighted averages, raster surface of rainfall variable (mean annual precipitation) was created from the image pixel values (Jiansheng. *et al.*, 2010). The interpolation was used to determine the spatial approximations and to calculate the value of the variable for each grid. The temperature variable was derived from Landsat image by first converting the DN of the thermal band (equation 2) to $TOAr$ (Top of $Atmosphere$) (Giannini *et al.*, 2015)

$$y = mx + b \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots 1$$

Where

y *=TOAr (Top of Atmosphere) radiance - the radiance measured by the sensor*

m *= Radiance multiplicative value*

x*= Raw band*

b*= Radiance additive value*

Applying the inverse of the Planck function, the thermal band's radiance values were converted to the brightness temperature value using equation 2 (Giannini *et al.*, 2015). This is satellite temperature in Kelvin.

$$BT = \frac{K_2}{\left(ln\left(\frac{k_1}{TOAr}+1\right)\right)} - 273.15 \dots\dots\dots\dots\dots\dots\ 2$$

where

BT = º C

$TOAr$ *=Top of Atmosphere radiance*

K1 = calibration constant 1 (774.89 for OLI band 10)

K2 = calibration constant 2 (1321.08 for OLI band 10).

Suitability Classification

This study used four levels of (Table 1): highly suitable, moderately suitable, marginally suitable, and unsuitable (FAO, 1976) and adopted by Goma *et al.* (2016). A complex decision problem was decomposed into its constituent criteria. The criteria were, therefore, prioritized according to their relative importance within each level.

Table 2. Classes of suitability Source

S/N	Class	Description
1	Unsuitable	land with extreme limitations for sustained agricultural productivity
2	Marginally suitable	land with major limitations for sustained agricultural productivity
3	Moderately suitable	land having some limitations that are severe for sustained productivity
4	Highly suitable	land having no significant limitation for agricultural productivity

Multi-criteria decision making

The primary issue in multi-criteria evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. Using continuous factors as given above, a weighted linear combination is most commonly used (Voogd, 1983). With a weighted linear combination, factors are combined by applying a weight to each followed by a summation of the results to yield a suitability map, In the procedure for Multi-Criteria Evaluation using a weighted linear combination, it is necessary that the sum of the weights to one. To measure the consistency of calculated weights, equation 3 was used (Rao, 2007).

$CI = \frac{A_m - n}{n-1}$ ………………………………………… 3

Where

CI = consistency index

A_m = the mean value of A_4,

n = the number of criteria. and

A_4 = ${A_3}/{A_2}$ ……………………………………….4

Where

A_3 = the product of priority matrix A_1 and weights matrix A_2

To check if the weighting is good enough, the consistency ratio was calculated thus:

C_r = ${CI}/{RI}$ ………………………………………… 5

Where RI is the random index value that should be less than one (Rao, 2007).

To determine the suitable areas for agroforestry, the Boolean images of forested areas and all the regions suitable for agriculture were merged to create a single map that represents areas common to both images as the overlapping region. Symbolically, x represents regions identified as suitable for agriculture, A is the forest area and B as the suitability map. Then,

$A \cap B = (x \in \cup : x \in A \; and \; x \in B)$ ……….6

Thus, $x \in A \cap B$ since $x \in A \; and \; x \in B$ (Charles, 2014).

Standardization of criteria

The process of setting the relative importance of each criterion is known as the standardization of the criteria (Saaty *et al.*, 1980). In this process, scales of 0 to 1, was used for the criteria standardization (Goma *et al.*, 2016). A pairwise comparison technique is typically used for rating and standardizing the ordinal values. In order to compare the criteria with each other, all values were transformed to the same unit of measurement scale (from 0 to 1).

Selection of the Criteria

Five criteria were selected for evaluating the agricultural and agroforestry land suitability in the study area (Table 3). These criteria were selected based on the potential factors affecting agricultural land-use and a review of the recommendations of the Malaysian National Physical Plan (Malaysia, 2014).

The weighting of the criteria

Criteria weights are the weights assigned to the output covariate maps (Figures 4). Developing weights for the selected criteria is fundamental in employing the AHP method. For determining the relative importance of the criteria, the pairwise comparison matrix using a nine-point weighing scale was applied (Table 3).

Table 3. Scales for the pairwise AHP comparisons (Saaty, 1980).

Intensity of importance	Description
9	Extreme importance
7	Very strong or demonstrated importance
5	Strong or essential importance
3	Moderate importance
1	Equal importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

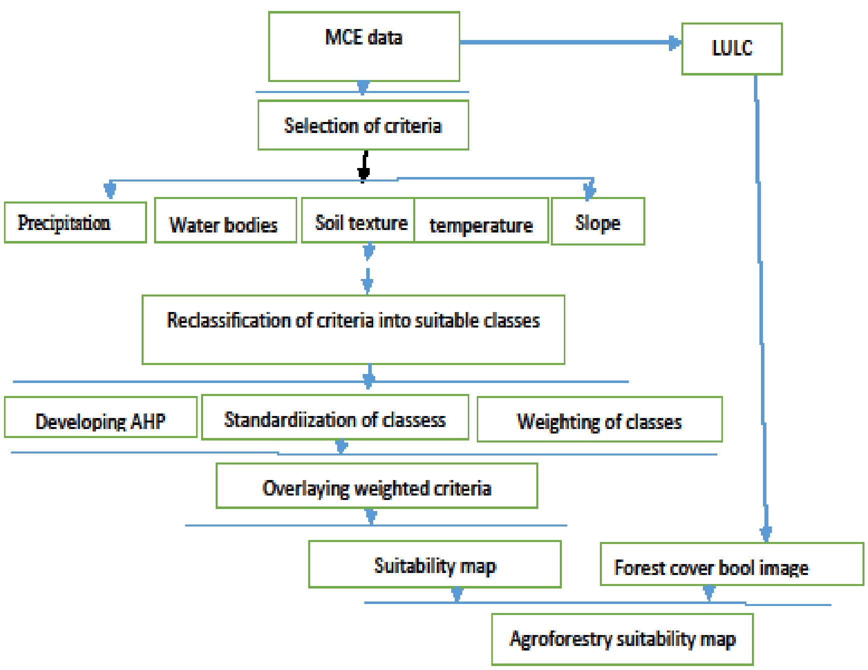


Figure 2. Flowchart of methodology

Results

Land-use land cover (LULC) distribution

The Ibarapa region is endowed with large forest cover, which occupied about 68.1% of the total landmass, distributed in all three local government areas of Ibarapa region. The built-up (developed) area is about 0.7%, whereas farm/grassland and water bodies occupied about 31.1% and 0.1% respectively (Table 5 and Figure 3). The farm/grassland land spread across the area with patches of water bodies.

Weighting and ranking of selected criteria
The weight was derived for each of the independent variables as obtained from the analytical hierarchical process (AHP) presented in Table 5 and Figures 3 and 4b. From the table, rainfall is the most important factor affecting agricultural land suitability followed by water bodies and soil texture respectively, while. the slope had the least effect on agriculture in the study area. These criteria were assembled and the weights of their respective contributions to land suitability were assessed using an analytic hierarchical process (AHP) with weighting sum of one and an acceptable consistency ratio (Cr) of 0.24. It is found that about 92% of the area is suitable for crop production, except areas close to the settlements or developed areas (figure 3) and 17% of the total area could support agroforestry especially in the southern and northern parts of the region (figure 4a). The central and northern parts of the study area are the most suitable locations for agroforestry crops; whereas, the eastern part has been found to be less or unsuitable. The Igangan and Eruwa axis appear most suitable, though with some distance away from the towns. It is also important to state here that the evaluation for agroforestry land suitability was specifically within the forest area.

Overlaying criteria layers,
The weighted overlay is a technique for applying a common scale of values to diverse and dissimilar input data to create an integrated analysis. After weighting of the criteria, regarding their importance for the land suitability analysis, all the maps were overlaid using a suitability index.

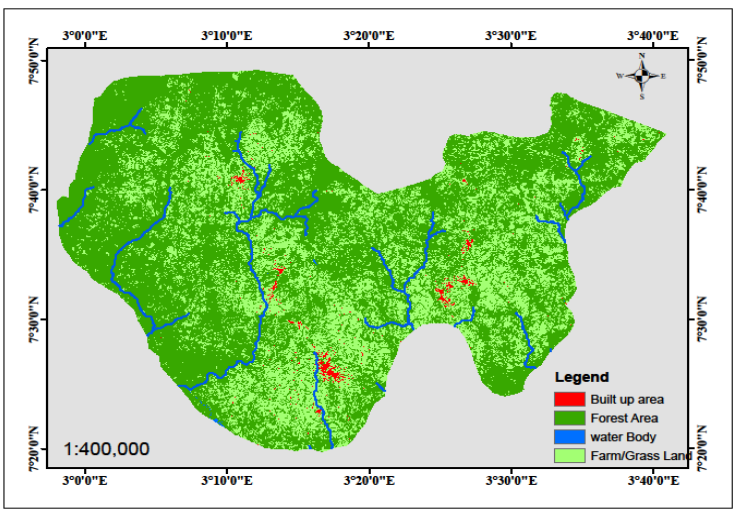


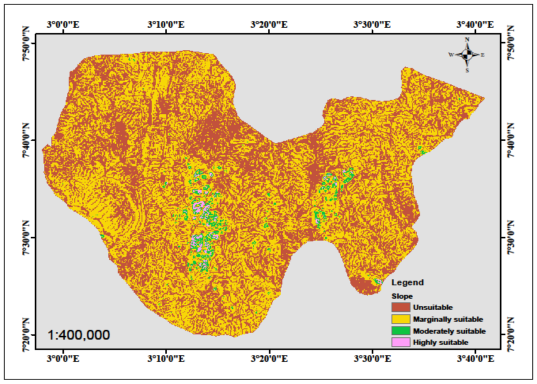
Figure 3. Land-use of Ibarapa region 2020

Table 4: Weighting matrix for the selected criteria.

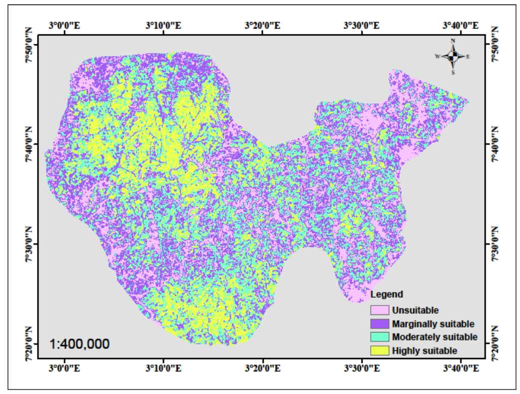
No.	Criteria Weight	Weight
1	Precipitation	0.46
2	Water Bodies	0.32
3	Soil texture	0.13
4	Temperature	0.06
5	Slope	0.02
Total	-	1

Table 5: Land Use Statistics of Ibarapa region

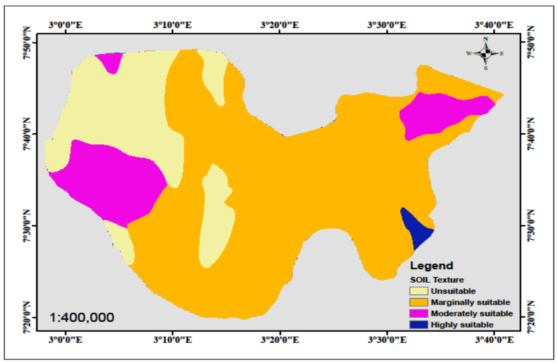
LULU	**Area**	**%**
Built-up Area	17.43	0.69
Forest Area	1711.94	68.11
water Body	1.32	0.05
Farm/Grass Land	782.87	31.15



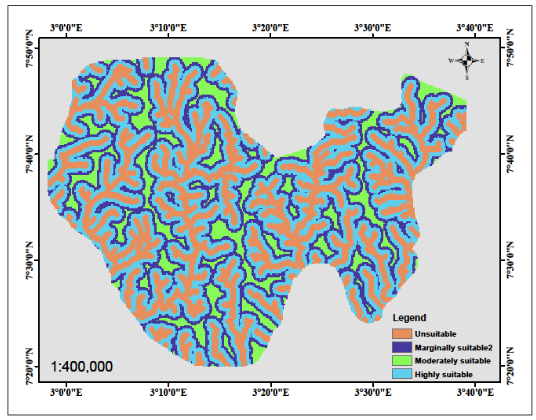
a. Slope



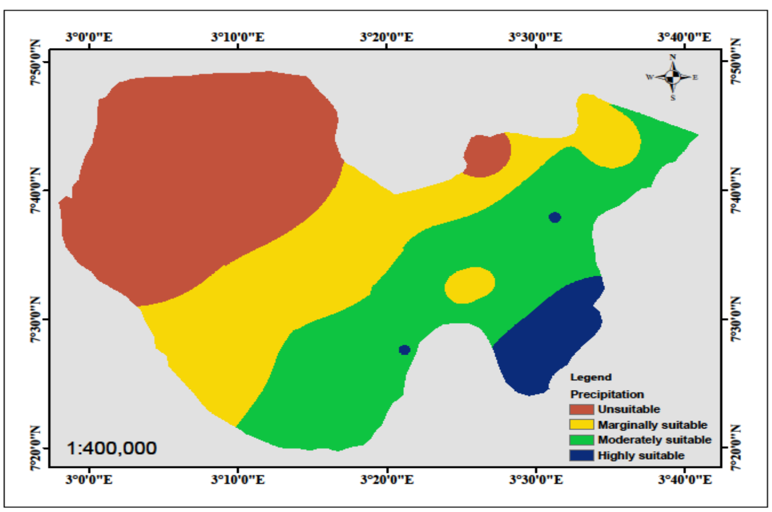
c. Temperature



b. Soil Texture



d. water body distance



e. Precipitation

Figure 4: Multi-criteria layers for land use suitability model (a) Slope (b) Soil texture (c) Temperature (d) Water Body Distance (e) Precipitation.

Table 6 Land Use Suitability Statistics of Ibarapa region

LUSE	Area	%
Unsuitable	196.63	7.82
Marginally suitable	1169.77	46.54
Moderately suitable	1030.87	41.01
Highly suitable	116.28	4.63

Table 7: Taungya Land Use Suitability Statistics

LUSE	Area	%
Unsuitable for	2081.19	82.7988
Agroforestry	4	3
Suitable for Agroforestry	432.360	17.2011
	9	7

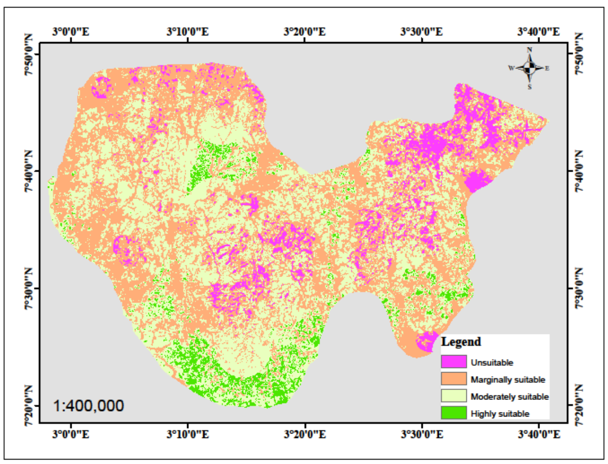
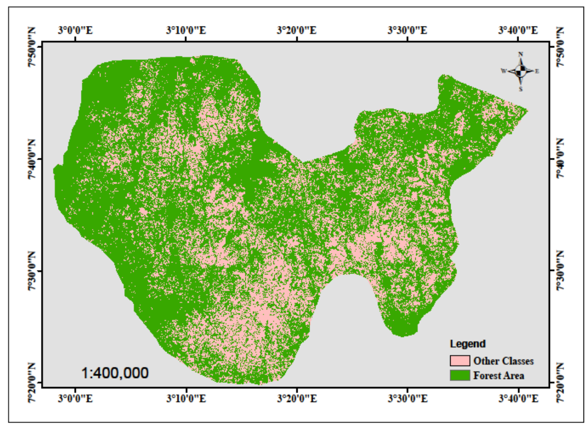
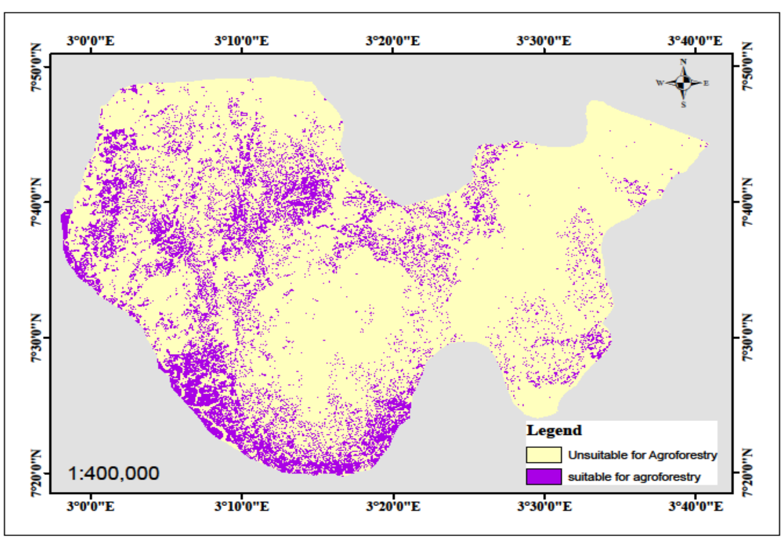


Figure 5. Land Use suitability model



(a) Forest area



(b) Taungya Land Use suitability

Figure 6: (a) Forest area and (b) Taungya Land Use suitability

Discussions

The large extent of forest cover in the study area shows the potential of such a region being able to support an agroforestry system. Considering the area extent of only 17.2% identified most suitable for food and wood production, there is an urgent need for a proper land use management system such as Taungya Farming, to avoid overexploitation of the land for agricultural purposes and the impending environmental implications of this practice. According to Adekunle (2005) and Oke (2008), agroforestry practices have the potential of improving agricultural land use systems, providing lasting benefits and alleviating adverse environmental effects at the local and global levels. They equally argued that an agroforestry system is capable of providing solutions to ugly outcomes of increased agricultural production practice that ensure environmental sustainability. Agroforestry such as the Taungya system should therefore be seen as a system that can increase farmers' income and at the same time ensure food security. The retention of trees in farming systems as reported by Ajake (2012), can increase crop output and also recognized the function of forest trees as a source of income, good medicare, employment, raw materials, and provision of food among others. Richard *et al*, (2009), argued that to restore forests, degrade the environment, and reducing greenhouse gases, an agroforestry system must be in place.

The 31.1% of cultivated land revealed by this study could close up in an area with the forest land through logging and land slashing in a short while, therefore, converting forest land to farm and eventually grassland should be discouraged (Gandhiv, 2011). The felling of trees for crop cultivation must have led to the 17.2% landmass left for a system that could support both food and wood production simultaneously. The conversion of forests to non-forestland uses for crop production could be detrimental to our environment. FAO (2001), reported that this is capable of reducing forest carbon stock through land clearance, and that reduced deforestration, forest regeneration, increased plantations development and agroforestry accounts for 12 to 15% of global sequestration of carbon emission from fossil fuels. The taungya agroforestry system has high potential to reduce atmospheric concentration of carbon dioxide (CO_2) and mitigate climate change. Also, increasing productivity would support growing more from the land already under production, which eliminates the need to open new land for agriculture and helps reduce the emissions associated with deforestation resulting from agricultural expansion (Allara, *et al*., 2012 and Batello *et al* 2013).

The practise of shifting cultivation in Ibarapa area is capable of promoting deforestation, therefore, reducing the existing forest cover. Continuous loss of forest to shifting cultivation can affect the local and regional energy balance (Kerkhoff *et al.*, 2005). This is in agreement with Nowak *et al.*, (2002) that forest loss intensifies air pollution, alter rainfall pattern in our environment, change the composition of biodiversity, and also contributes to global warming. Taungya system, for example, would be instrumental in increasing food production without destroying the forest (Kerkhoff *et al.*, 2005). Again, an improved fallow system, which is a rotational system that uses preferred tree species as the fallow species in rotation with cultivated crops as in traditional shifting cultivation can improve the rate of soil amelioration (Sobola *et al*, 2015). The potential of improved fallow systems according to Jacob *et al*; (2013), has been tested by the world agroforestry centre for controlling soil erosion and improving soil moisture content using fast-growing shrubs. As standing trees, *Parkia biglobosa* for example, which dominated the study area could have a positive effect on the yield of other nearby crops (Melissa *et al*, 1995).

Conclusion

This study has revealed the potential agricultural land in the three local government areas, unfortunately, available evidence showed that most of these agricultural lands are being taken up by non-taungya uses and this has the potential of negatively affecting the state's green economy. Again, the situation could create a condition where the region may be achieving its food security at greater economic and environmental costs. For crop production to be matched with that of wood, physical and ecological variables such as climatic, edaphic and forest cover become eminent in identifying suitable areas for agroforestry.

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