Deductive and Multi-criteria Approach to Ecosystem Modeling and Habitat Mapping of Shea Butter Trees *(Vitellaria Paradoxa)* in the Tropical Savanna

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Abstract— *An ecosystem map for 14 local administrative units of Kwara state North Central Nigeria and Vitellaria paradoxa habitat in the broad Savanna region was produced using multi criteria and integrated GIS models as against the traditional single layer thematic approach. The criteria used in classifying and mapping the ecosystems are: climate (rainfall and temperature), physiography (slope, relief), vegetation/land cover and drainage system. The climate layer was extracted from WorldClim database using DIVA GIS, the topographic layer was produced from 90 m NASA/SRTM digital elevation model. NDVI was run on composite images to produce vegetation layers. All the input data layers were spatially modeled in ArcGIS to generate the 7 classes of ecosystems. The Georefrenced trees sample points from field survey was overlaid on classified images to produce distribution pattern of Vitellaria paradoxa and its habitat in Savanna wood land ecosystems.*

Keywords— ***Ecosystems, Mapping, Shea butter, Multi-criteria.***

I. INTRODUCTION

The use of multi-criteria approach to ecosystem mapping is relatively new and its potential has not been fully explored especially in Sub Saharan Africa (Salako 2016). Most research on ecological classification and mapping in Africa especially Nigeria had used thematic or topical approaches such as vegetation zones and agro climatic zones in their analysis and description of ecosystem. These approaches, however, do not yield a complete understanding of the interrelationships among the various forces driving ecosystem composition and functions (Lugo et al, 1999), coupled with arbitrary drawing of the ecological zones by heavy reliance on expert judgment and instinct thus limiting their use in scientific analysis (Lugo et al. 1999 and Olson et al. 2001). Although multi data layers approach has been widely used in ecosystem mapping in South America and North America (Sayre 2008 and Sayre 2009),it was not until recent times that it was used for ecosystem mapping in Africa, few of such efforts are A New Map of Standardized Terrestrial Ecosystems of Africa (Sayre et al 2013) and Biogeoclimatic ecosystem zones of Mambilla Plateau, Nigeria (Salako et al 2016). Given the rate of deforestation and loss of biodiversity especially in developing countries through carelessness, poor planning and high level of poverty which has put undue pressure on natural resources, it is practically challenging to attain sustainable development without adequate information on the affected ecosystems (Gladstone and Thomas 1990) and its various components.

Geographical Information System and Remote Sensing (GIS/RS) and its capability for modeling has proven to be a very useful tool for large scale mapping of ecosystem and preparation of land cover map (Trisurat, *et al* 2000, Lu and Weng 2007), using GIS/RS techniques is faster and enable wider geographic coverage within short time frame (USGS/GAP, 2002, Lowry, *et al* 2005). Good ecosystem mapping has been the basis for identifying species habitat suitability, and framework for resources planning, conservation and managing species at risk (Province of BC 2006). It provides detail explanations on various environmental variables that characterize an area rather using single thematic layer approach such as vegetation (Guinea Savanna) or climate (Savanna Climate).

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Ecosystem mapping could be deductive by overlaying the available geospatial data to generate new ecosystems (Comers et al. 2003). This approach involve extensive use of remote sensing and GIS techniques to spatially combine several data layers to produce ecosystem map, and was relatively less expensive especially when working in a large area. Alternatively, ecosystem could be mapped by associating environmental attributes of point source data with known ecosystem occurrences at their locations; however this option is data intensive and costly especially when working in a large area (Sayre et al 2009). Effort is made in this study to combine the use of GIS modeling with use of field data to generate ecosystem map.

Vitellaria paradoxa (Shea butter) is a woody plant native to the Guinea Savannah of West Africa, It was reported to contain high fat and oil contents which make it an irresistible fuel wood for it burns longer and steadily compare to other tree species in its habitatand of immense socio economic and health values (Goreja 2004). Thousands of lives especially women in rural areas in West Africa depend on it for their sustenance not only because it is the major source of income but also serves as food and condiments.

Despite the importance of this tree to the socio economic lives of vast number of this people living in fragile environment, even though was classified as vulnerable in IUCN red list (IUCN 2013), It has received little or no global attention as endangered or threatened species. The rate at which this tree was been felled and burn as charcoal in recent times portend a dangerous trend and could result to the extinction of the tree in the next few decades except urgent action is taken. Also the actual location and mapping of Vitellaria paradoxa habitat within the broad Savanna ecosystem has not been well defined. These work objectives are (i) to develop a detail and explanatory ecosystem map of the selected area in Kwara State North central Nigeria, and (2) locate the distribution pattern of *Vitellaria paradoxa* and its habitat within the ecosystem, our comprehensive ecosystem classification can be used by land managers throughout Nigeria to manage and conserve Nigeria's diverse ecosystems, including predicting the potential effects of climate change.

II. MATERIALS AND MEETHODS

2.1 Study area

The study area is comprised of 14 local administrative units of Kwara State, Nigeria (Fig 1). With seasonal rainfall mostly in the months of June to September and total annual rainfall of 1200 mm in the southern axis and between 700-900mm in the northern axis and mean annual temperature of 26ºC, it broadly falls under Tropical Savanna climate. The vegetation is characterized by deciduous trees and long grass under story. However, there are clusters of dense forest in the south and south eastern corner of Ifelodun Oke Ero and Ekiti Local Government. Farming and marketing of agricultural products is the major occupation.

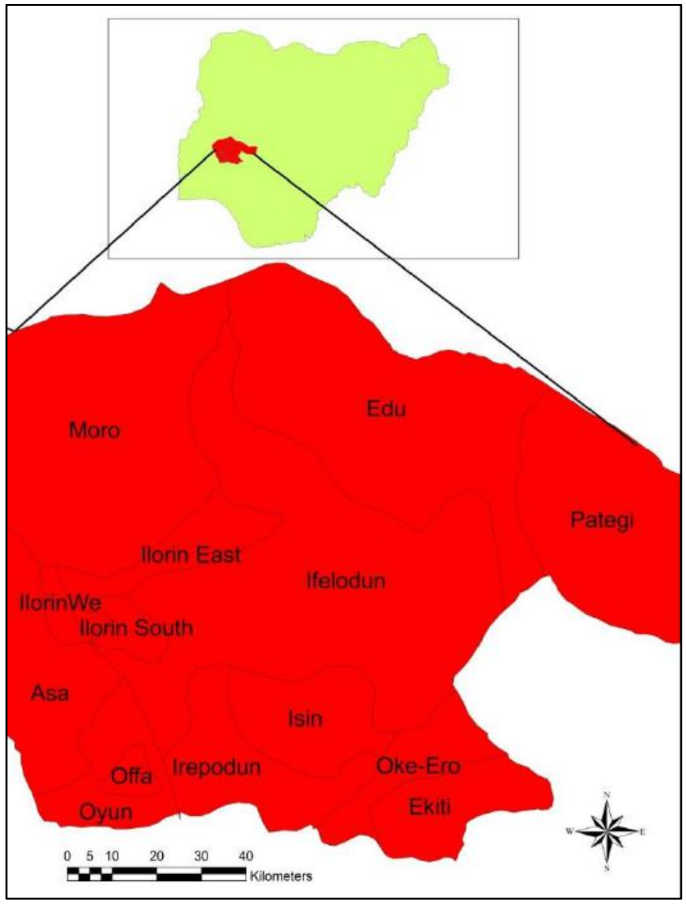

Fig.1: Map of the 14 selected local administrative units of Kwara state (Nigeria as Inset)

2.2Satellite Image Data and Processing

All spectral bands in Satellite images of Landsat 8 OLI on path 190 row 054 in 2016 with 90% cloud free were acquired form USGS. Landsat 8 was launched on February 11, 2013, it is the eighth satellite in the Landsat program; the seventh to reach orbit successfully, providing moderate-resolution imagery, from 15 meters to 100 meters, of Earth's land surface and polar regions, Landsat 8 comprises 2 sensors: The Operation Land Imagers (OLI) and Thermal InfraRed Sensor (TIRS) which see improved signal to noise (SNR) radiometric performance and for better land-cover characterization. OLI collects data from nine spectral bands at 30 m excepts bands 8- Panchromatic which is at 15 m

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while TIRS collects from 2 additional spectral bands at 100 m. OLI two new spectral bands include a deep blue coastal / aerosol band and a shortwave-infrared cirrus band (Table 1). Images were equally obtained Google Earth for features identification needed for classification.

Table.1: Landsat 8 OLI and TIRS details

Spectral Band	Wavelength	Resolution	Solar Irradiance
Band 1 - Coastal / Aerosol	0.433 – 0.453 µm	30 m	2031 W/(m²µm)
Band 2 – Blue	0.450 – 0.515 µm	30 m	1925 W/(m²µm)
Band 3 – Green	0.525 – 0.600 µm	30 m	1826 W/(m²µm)
Band 4 – Red	0.630 – 0.680 µm	30 m	1574 W/(m²µm)
Band 5 - Near Infrared	0.845 – 0.885 µm	30 m	955 W/(m²µm)
Band 6 - Short Wavelength Infrared	1.560 – 1.660 µm	30 m	242 W/(m²µm)
Band 7 - Short Wavelength Infrared	2.100 – 2.300 µm	30 m	82.5 W/(m²µm)
Band 8 – Panchromatic	0.500 – 0.680 µm	15 m	1739 W/(m²µm)
Band 9 – Cirrus	1.360 – 1.390 µm	30 m	361 W/(m²µm)
OLI Spectral Bands			

Spectral Band	Wavelength	Resolution
Band 10 - Long Wavelength Infrared	10.30 – 11.30 µm	100 m
Band 11 - Long Wavelength Infrared	11.50 – 12.50 µm	100 m
TIRS Spectral Bands		

2.3 Image processing and Vegetation layer

Unsupervised classification was run on false color composite images of Bands 5, 4, 3 (NIR/Red/Green bands) from Landsat 8 (OLI) vs. R/G/B) . This technique produces clusters or spectral classes based on spectral values or digital number (DN) of the composite images. We map the distribution of the *Vitellaria paradoxa* species by overlaying the georefrenced species point data from the field survey on the unsupervised classified image and further use the DN to establish direct relationship with the species distribution pattern. The spectral values (DN) associated with Vitellaria Paradoxa were used to identify possible occurrence of the tree species in other parts of the study area. However, it was observed that, *Parkia Biglobosa* and *Daniella oliveri* had almost the same spectral values with *Vitellaria paradoxa*, possibly due to the spatial resolution of the satellites images used (28.5-30m),we therefore grouped them into same class in our mapping. The map produced here however should not be interpreted to be entirely representing *Vitellaria paradoxa* distribution.

NDVI is a very simple vegetation index and has been used to quantitatively and qualitatively evaluate vegetation covers (Ghorbani et al. 2012) it compares the measure of infrared reflectance to that of the red reflectance the values for a given pixel value is always in a number that ranges from -1 to +1. A zero means no vegetation and close to 1 indicates the highest possibility of green leaves. We run NDVI on the composite image bands 5,4,3and set the limit to 0.4 to eliminate field points that falls on non-trees feature The result was further reclass from 1 to 7, I means bare land, 4 shrubs and 7 dense forest. Only point data that falls within 4- 7 pixels were used in our tree species distribution analysis.

2.4 Field data

Malete Elemere covering about 500 ha of land was selected as our site for intensive field survey where over 50 sample plots of 10m2 were laid using systematic random techniques. The field data collected include the tree species name and their location (longitude, latitude, and altitude) was determined using hand held Garmin eTrex GPS. Special attention was paid on the identification of Shea Butter in a plot. The field data was used as training data for the identification of the Vitellaria paradoxa on the classified images.

2.5 Ecosystem Mapping Approach:

Our Mapping approach follows the deductive methods used in terrestrial ecosystem mapping of conterminous United

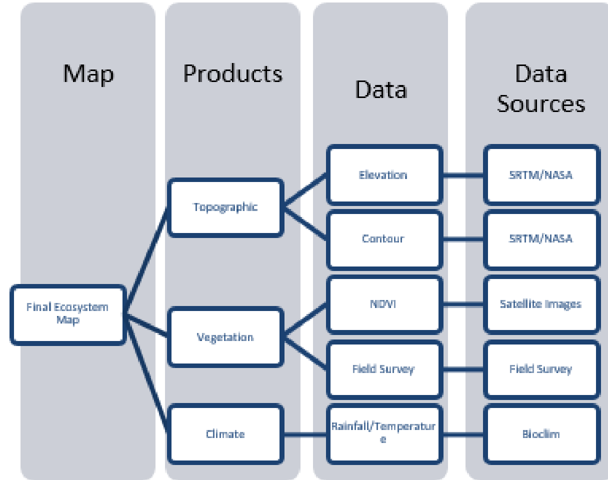
States (Sayre 2009). This approach involves mapping the physically distinct environmental areas which forms the fundamental building blocks of ecosystem. These physical distinct blocks include: the climate, vegetation, lithology, soil, topography/landform among others (Bailey 1996, Comers and others 2003, Sayre et al. 2009).In this study data were obtained and GIS layers created for each of the ecosystem building blocks- climate (temperature and rainfall), vegetation and landcover, Rivers, elevation, landforms, slope (fig. 2) which subsequently were spatially combined in a sequence using boolean fuzzy sum overlay in ArcGIS (Sayre et al 2009, Salako et al 2016).

*Climate Data/layers***:** To create the climate layers of Mean Annual Temperature (MAT) and Total Annual precipitation (TAP), the climate data CLM files Tiles 26 of Worldclim.org database was downloaded and the data extracted was converted into grid raster files in DIVA GIS and subsequently imported into ArcGIS 10.2 (Scheldeman and Zonneveld 2010) from which MAT and TAP of the study area was subset,

*DEM Layer***:** A 90 m Digital Elevation Model (DEM) from NASA/Shuttle Radar Topographic Mission- SRTM was acquired from which the study area was subsets and imported into GIS environment. The elevation data was processed by using the reclass menu in spatial analyst tool in Arc GIS 10.2 version to reclassify the study area into classes at an interval of 80 m (Fig 6). ESRI vector data on the study area drainage system was subset from national dataset and was overlaid on the contour (Fig 7) to explain the relationship between the relief and rivers system.

GIS Ecosystem modeling

i



ii

Fig. 2: Flow chart for ecosystem modeling (i) and mapping

III. RESULTS AND DISCUSSION

All the inputs layers that form the ecosystem building blocks were spatially combined to produce the ecosystem map for the study area. In naming the ecosystem classes, a combination of local knowledge of plant species, field works, high resolution satellite Image from Google Earth, literatures and classification system used in African Ecosystems Classification (Sayre *et al.*, 2013) were adopted.

3.1 Mapping climatic zones: Climate and its derivative bioclimate strongly influence the differentiation and distribution of ecosystems especially the moisture availability (Sayre et al 2009). Although on average the total annual rainfall in the study area exceeds 1000 mm which is considered to be wet enough for plant productivity, however, three distinct distributional patterns are identified; the southern half which comprises of Ilorin metropolitan area, Offa, Ekiti, Oke Ero and part of Ifelodun Local administrative units had over 1150 mm of total annual rainfall, this section receives the highest total annual rainfall and constitutes the wettest part of the study area. The middle part had annual total of slightly above 1100 mm, while the Northern part of Moro local administrative units receive marginally above 1000 mm (Fig.3) This shows that rainfall decreases northward in line with movement of Inter Tropical Convergence Zone (ITCZ) as typical of the tropics. Mean annual temperature follows an inverse relationship as temperature decreases southward. The highest mean annual temperature of over 27°C were recorded in the northern section and cover four local administrative units of Moro, Ifelodun, Edu and Pategi (Fig. 4)

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There is a difference of over 150 mm in total annual rainfall between the wettest and the less wet part and given the fact that temperature is rarely a limiting factor in the tropics excepts in higher altitude, the differential in moisture availability greatly defines the length of growing periods within the study area and account for vegetation cover and plant species variations.

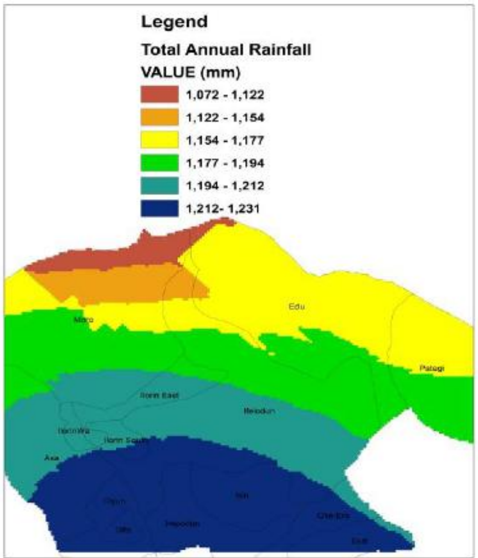

Fig.3: Total Annual Rainfall (mm)

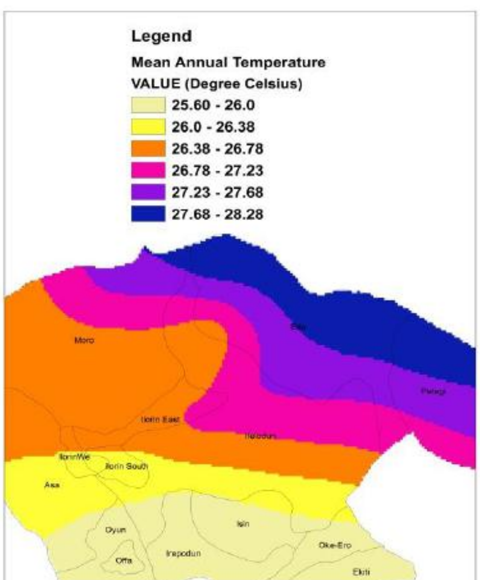

Fig.4: Mean annual Temperature (°c)

3.2 Landforms: The role of landforms in the distribution and differentiation of ecosystems cannot be over emphasized not only that altitude defines temperature distribution pattern but a number of organisms, vegetation are associated with certain landforms and topography (Treitz and Howarth 2000). Also depth of soil, rivers flow are strongly correlated with slope and landforms (Kruckeberg, 2002, Reza
And Abdullahi 2016)

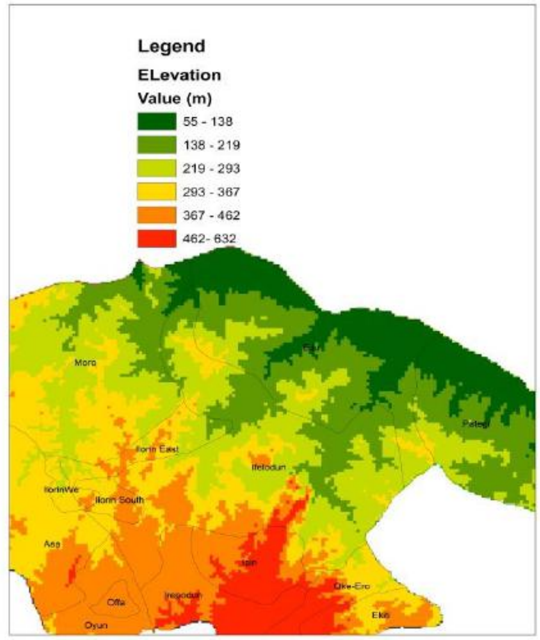

Fig. 5: The relief

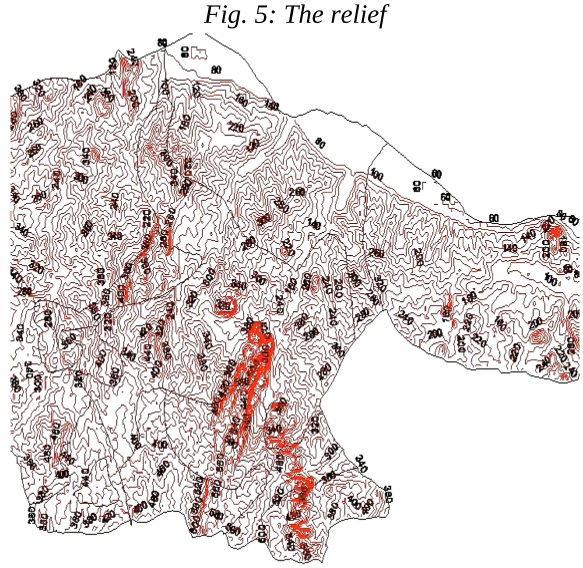

Fig.6: contour at 20 m

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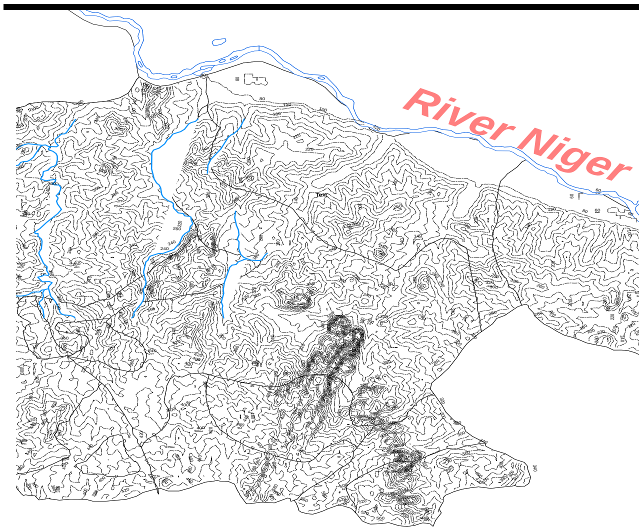

Fig.7: Contour overlaid with river system

From the DEM layers we classified our study area into local relief and slope. The low mountains with an average height of 550 m were found in the south eastern section which was bordered by high plain of 350 m. The northern segment are generally comprises low and flood plain ranges from 55 m to 150 m (Fig. 5 and 6) and river valley system (fig 7)

3.3 Vegetation index: Vegetation has been described as one of the best ways to describe life forms in an environment not only it creates their microclimate but also the direct product of various interacting physical processes on earth. Each vegetation structure reflects not only the climatic conditions but also other ecological conditions (Biodiversity Conservation). Our reclassified NDVI values ranges from 1 to 7, where 1 shows area of little or no vegetation and 7 depicts area of dense vegetation (Fig. 7). There is direct relationship between rainfall pattern, landforms and vegetation distribution in the study area. Dense and close canopy vegetation is found in wet, hilly, steep slope in the south eastern section.

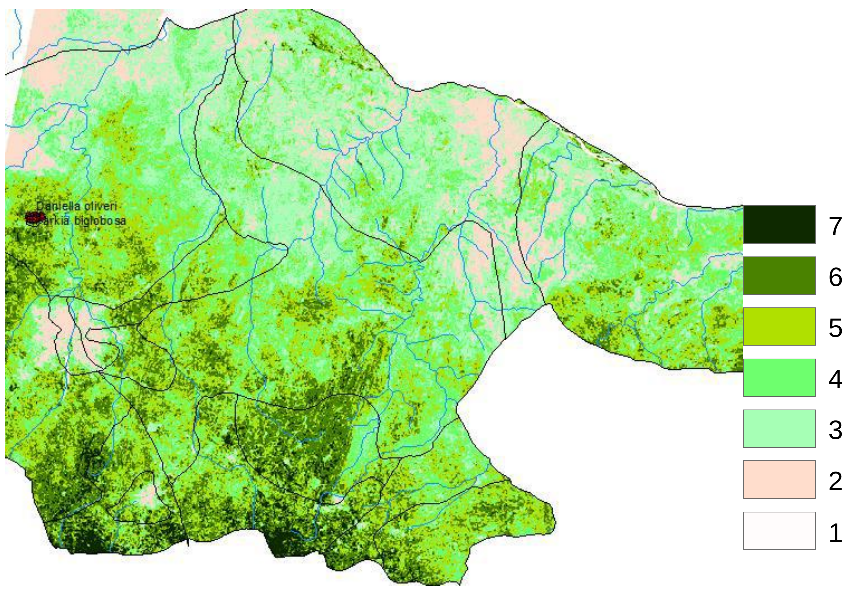

Fig.7: Vegetation Index

3.4 Ecosytem Units and Shea Butter habitat

A total of seven classes of ecosytem units were mappped in addition to urban/agricultural farm settlements land use ecosystem (Table 2) which can be described as diverse for it compose the terrestrial, aquatic, hilly and forest ecological units (Rezza and Abdullahi 2016) and the disribution of the ecosystem by local adminstrarive units are presened in (Table3).

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Table.2: Ecosystem Classes by area coverage in Hectares

S/N0	Class	Pixel samples	Area (Ha)	Percent of total area
1	Upland Forest Ecosystem	888	75,840	4.39
2	Low Land Forest Ecosystem	1,495	127,681	7.39
3	Savanna Grassland Ecosystem	8,677	741,068	42.94
4	Savanna Wood Land Ecosystem	2,388	203,948	11.82
5	River Basin/Valley Ecosystem	5,345	456,492	26.44
6	River Basin Ecosystem (Intensive)	1,389	118,628	6.88
7	Urban/Agric Land Use Ecosystem	27	2,306	0.14
	Total	20,209	1,725,963	100

Climate especially rainfall, vegetation and topography greatly defined the pattern of ecosystem in the study area (Treitz and Howarth 2000, Sayre eta l 2013). In the Upland forest ecosysytem, hardwoods and Palm trees are the dominant plant species with long grasses as undergrowth. Adjoining the upland forest ecosystem is the lowland forest ecosystem, the latter has similar plant compositions with the former excepts that it was found in the lower elevation (between 300 -350 m) and less dense.

Table.3: Ecosystems classes distributions by local administrative units in Km²

S/No	Class	Asa	Edu	Ekiti	Ifelodun	Ilorin East	Ilorin south	Ilorin West	Irepodun	Isin	Moro	Offa	Oke Ero	Oyun	Pategi
1	Urban/Agric land Use Ecosystem	1	58	0	1	0	0	4	0	0	2	2	0	0	110
2	River Basin Ecosystem (Intensive	0	474	0	49	4	0	0	0	0	57	0	0	0	643
3	River Basin Ecosystem	1	992	1 5	354	12	0	7	1	0	277	1	0	1	1238
4	River valley Ecosystem	25	770	180	369	10	8	12	4	0	311	3	4	1	999
5	Savanna Grassland Ecosystem	1508	436	178	1845	381	168	87	177	79	2349	60	87	142	376
6	Savanna Woodland Ecosystem	276	155	186	1122	83	21	4	178	177	609	42	157	210	126
7	Lowland forest Ecosystem	54	5	68	246	19	1	0	128	178	101	7	154	189	16
8	Upland Forest Ecosystem	16	0		61	0	0	0	370	128	0	0	82	0	0

These ecosystem units are restricted to Irepodun, Isin and to lesser extent Oke ero, however, Oyun has a significant land mass about 189 hectares under lowland forest ecosystem (Table 3). The dense vegetation that characterise upland forest ecosystem in the south easten section is a product of rugged topography and ample rainfall which make the length of growing period in this ecosystem units longer than the rest.

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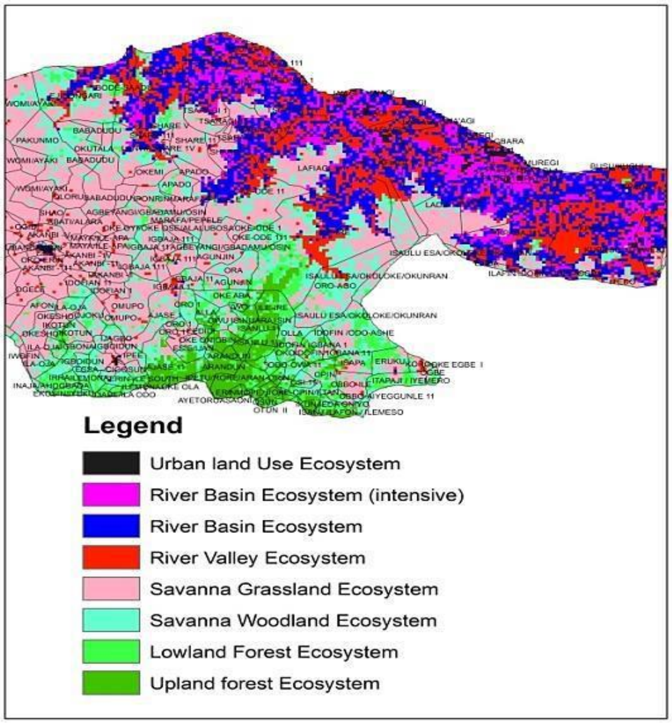

Fig. 8: Ecosystem classes in selected Local administrative units of Kwara State, Nigeria

Fig. 9i riparian vegetation in river basin ecosystem *ii cluster forest in river basin ecosystem*

iii Dense canopy in upland forest *iv Savanna woodland ecosystem*

River Ecosystems are mostly found in the northern segment in Edu and Pategi local administsrative units, these ecosytem generally consist of lowland and flood plain with elevation ranges from as low as 50 m to 150 m and are subdivided into three subclasses: i the river basin ecosystem (intensve) characterised by intensive subsitense agriculture, ii river valley ecosystem consists numerous tributaries of river Niger and riparian vegetation of cluster forests , iii

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river basin ecosystem include other areas within the river basin not dierectly related to the two erlier identified (Fig 8, i- iv). Aquatic plants are commonly found and the soil is conststanly covered by water thus made the ecosystem vulnerable to flooding and soil erosion

The Savanna Ecosystems is subdivided into savanna wood and grass land depending on the presence of woody plants. This ecosytem is dominated by grasses and bushes of smaller trees, It covered about 1 million hectares of land and it's the largest ecosytems classes in the study area. These ecosystems are found in all local admministsrative units but has areacover of over 60% of Moro and Asa, and about 30% of Ifelodun and Ilorin (Table 3). Plant communities include grasses, graminoid, and other herbaceous plants in addition to woody plants (trees and shrubs) in Savanna woodland ecosystem. The rainfall (average of 1000 mm total annual) is suffiecnt to support grasses and woody plants in moister areas. Geomorphological this ecosytem is classified as low (300 m) but punctuated by undulating lowland in its border with river basin ecosystem.

3.5 Shea Butter Habitat Map

The result of overlaying field sample points on ecosystems map reveals that Shea butter*(Vitellaria Paradoxa)* habitat is commonly found in the Savanna Woodland Ecosystem and within the boundary of Savanna Grassland and Savanna Wood land (Fig 10). The mean annual temperature of 26°c and total annual rainfall of 1120 mm in the ecosystems support the growth of deciduous trees and shrubs. As stated earlier this habitat is equally associated with Locust beans *(Parkia biglobosa)*. Other trees and shrubs species found in this ecosystem are: *Daniella oliveri*, *Azadiracta indica, Piliostigma thonningii and Acacia nilotica.* It was also observed that locust bean (Parkia biglobosa) has become alternative target for illegal burning for charcoal in the absence of Shea butter in a logging site. Savanna Woodland Ecosystem which constitute Shea butter habitat although cover about 12% of the total land cover yet it is the most threatened ecosystem in terms of bush burning, overgrazing and tree burning for charcoal with dire consequences on biodiversity (Meerman and Sabido 2001). There is an ongoing project to monitor and quantified changes that has happened to Shea butter and the ecosystem over the last 20 years and project possible consequences.

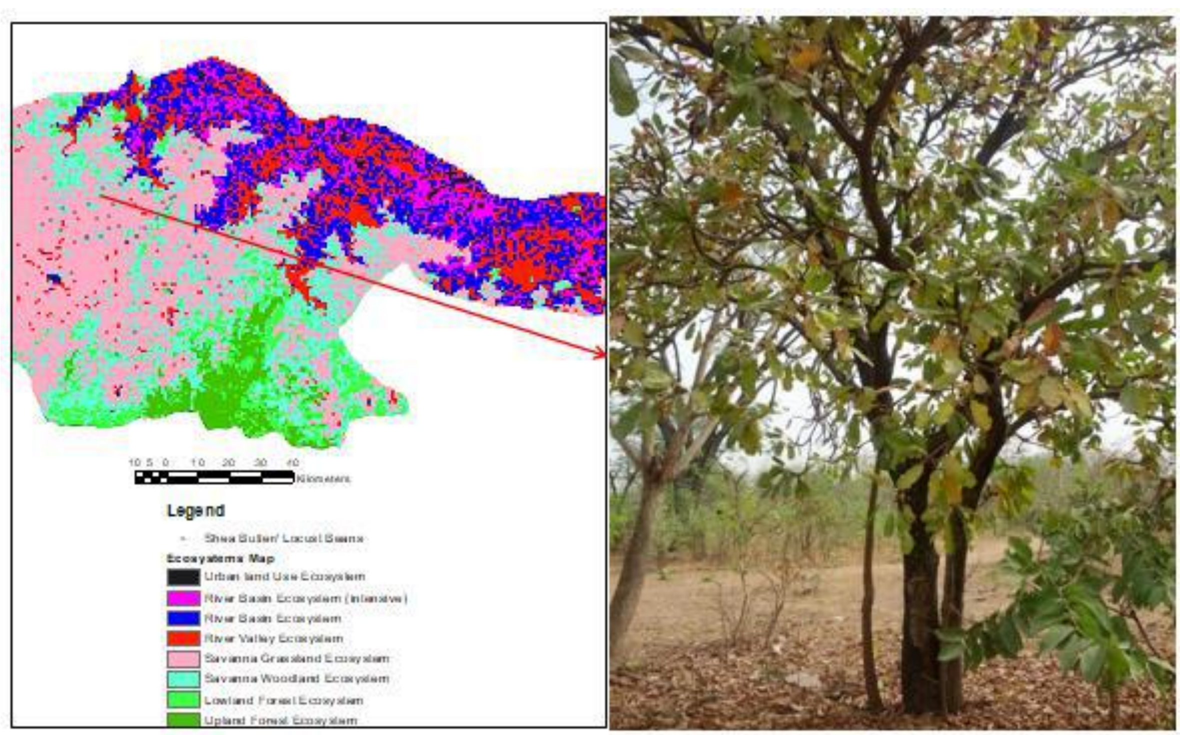

Fig.10: Shea Butter trees distribution in Savanna Woodland Ecosystem

IV. CONCLUSION

This mapped ecosystem is based on the current environmental variables without assessing human disturbance even though we acknowledged significant changes in land cover over times in our study area (Loveland et al 2002). Mapping ecosystem through spatial combination of the distinct environmental variable helps in predicting the possible changes that may occurs in the event of any alteration in any of the variables. For instance future climate change will alter the location and perhaps the areal extent of ecosystems and invariably the plant and animal habitat. Resource management is key to sustainable development, the distribution of the mapped ecosystems across the administrative units provide a good working tools to land and environmental managers for rational spatial resource planning (Grooves 2003, Sayre et al 2009).

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