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SPATIAL TECHNOLOGIES IN PASTURE AND RANGE MANAGEMENT: A REVIEW

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ABSTRACT

This paper looked at practical ways in which pasture and range management (P&RM) can benefit from application of spatial technologies; namely Satellite Remote Sensing, Global Positioning System and Geographical Information Science. Brief mention of these spatial technologies' components and ways of their integrations (linear, interactive, hierarchical and complex models) were discussed with specific reference to P&RM. The paper also dwells on salient principles of applied remote sensing and geospatial technics in P&RM using examples and case studies revolving around rangeland management, spatial decision support and resource conservation. Specifically, the relevance of hyper spectral imageries and vegetation indices in cattle population and range roaming determination, grazing land and paddock site-specific management were demonstrated. It is hoped that the review will create awareness for the inclusion and use of remote sensing and geospatial technics in many areas of livestock management in Nigeria.

Keywords: Geographical Information Science, Global Positioning System, Integrated Spatial Information Technologies, Pasture and Range Management, Remote sensing Spatial Decision Support.

INTRODUCTION

The significance of pasture and rangelands to humanity is underscored by the enormous support it provides in the upkeep of the livestock industry (Alkemade *et al*., 2013; Thorne and Harper, 2017) where grassland resources are inadequate for pastoral and arable farming, armed conflicts and genocides often result (Turner *et al*., 2011; Odoh and Chilaka, 2012; Chukwuma and Atelhe, 2014). Many cases in some parts of Africa that are characterized by hunger, starvation and violent armed clashes have been traced to conflicts on natural resources. There has been an unbridled animal rustling amongst herders and resource conflicts between arable farmers and nomadic pastoralists. Herders in many parts of sub-Sahara Africa now require swift relief measures because of intensifying and expanding desertification (Middleton, 2018). Poverty and food shortages have aggravated insurgency and armed banditry in northern Nigeria (Ojo, 2020); this cannot be divorced from degradation of rangeland resources in the region (Maiangwa *et al*., 2012). The rangeland degradation and the concomitant resource conflicts moved the Federal Ministry of Agriculture to propose importation of grasses from South-America (Opejobi, 2016). Animal husbandry (whether milk, meat or egg type) have always had relief from the products and services of rangeland ecosystem (Sayre *et al*., 2012; Sawalhah *et al*., 2019). Apart from contribution to food security, the abundance of natural pastures and grasslands is critical to global carbon sequestration.

The, development of private paddocks to augment natural ones can be confronted with numerous management challenges (Selemani, 2014 and USEPA, 2017), which challenges have also continued to widen with time (Bedunah and Angerer, 2012). The changing patterns of temperature and rainfall for example is leading to incidences of drought, fire outbreaks (Koerner and Collins, 2014) and invasion of new, but highly deleterious, species (Curran and Lingenfelter 2017). There are also incidences of increased toxicity in plants on established paddocks (DAF, 2017; Simberloff *et al*., 2017). Although, animals are known for safe grazing or browsing by instinct, deposits of heavy metals and other toxins could get into the paddocks (Schipper *et al*., 2011; Ebenso *et al*., 2013) and become difficult to avoid during animal grazing. Oxalates in plants have been reported to pose severe threats (Goyal, 2018) to animals on ranches.

Livestock managers have also lost income for lack of good spatial decision particularly, in effective management of large expanse of grazing land. Precise application of fertilizers on a large paddock often require spatial decision support in form of variability and optimum rate of application. Right quantity, right timing and right location makes significant difference in input management on soil or paddock treatment with chemicals or fertilizer doses (Lawrence 2013). Complex and confusing management decision could easily be resolved with robust Spatial Decision Support System built on spatial technologies; Global Positioning Systems, Geographic Information Systems and Variable Rate Technologies. Forage production suitability, monitoring the health of the paddock, monitoring pasture biomass and quality are sometimes difficult but compulsory tasks (Wang *et al.,* 2013) for which spatial information technologies are just right (Ali *et al*., 2016).

The foregoing underscores the urgency of automation of pasture and rangeland management (PRM) through application of information and computer technology (ICT). Incidentally, the advent of Spatial Information Technologies; Remote Sensing (RS), Global Positioning Systems (GPS) and Geographical Information Systems (GIS) created a huge platform for computerizing agriculture. Various aspects of farming including pasture agronomy has been found to give in to computer manipulations (Hedley, 2015). Incorporation of Spatial Technologies (STs) is one way in which the rangeland agronomy and livestock management can gain entry into Information Communication Technologies like other human endeavours. Spatial Technologies, for example, are required for development of management strategies for livestock grazing first as farm management tools (Bligaard, 2014) and also Spatial Decision Support Systems (SDSS) tools (Xiaojun *et al*., 2010).

Integration of the three components of Spatial Technology has been reported to contribute tremendously to agriculture (Merem and Twumasi, 2008). Spatial Technology can be applied in remarkable ways to pasture and range management. Results of past studies (Kumar *et al*., 2012; Boori *et al*., 2015) reveal the relevance of STs in the management of grazing livestock. In order to understand and appreciate the relevance of its application, it is instructive to do a review of the diverse range of application of these technologies in pasture and range management.

Historical perspective of Geospatial or Spatial Information Technologies

Spatial technologies namely, Satellite remote sensing (SRS), Global Positioning Systems (GPS) and Geographic Information System (GIS) were developed at different times and under different circumstances, and they arrived at different periods in history. While Satellite remote sensing is the oldest; originating from the discovery of photography, the Global Positioning System as a military equipment used to secretly capture enemies absolute position (McDuffie, 2017) is a more recent but older technology than GIS which arrived in the late nineteen sixties as a result of the need to electronically capture information on Canadian depleting forest stock in 1967 (Maher, 2016). The tremendous civil benefits of these technologies have now made them available for non-classified uses (Ngo, 2010). Although remote sensing, GPS and GIS were developed quasi-independently, the synergism between the three has become increasingly apparent. Data from all fields of life easily lend themselves to manipulation and analysis in a GIS environment (Bartelme, 2012). Today, the number of its applications in many fields keep growing and the walls of barriers amongst disciplines are fast breaking down (ESRI, 2012).

Satellite Remote Sensing

Remote sensing according to Salomonson, (2015), refers to the branch of science which derives information about objects from measurements made from a distance. Conventionally remote sensing deals with the use of electromagnetic radiation as the medium of interaction. Remote Sensing refers to the identification of earth features by detecting the characteristics of the electromagnetic radiation that is reflected by the earth surface. Every object reflects a portion of electromagnetic radiation incident on it depending upon its physical properties. Objects also emit electromagnetic radiation depending on their temperature and emissivity. Reflectance pattern at different wave lengths for each object is also different. Such a set of characteristics is known as spectral signature of the object. This enables identification and discrimination of objects, which is an advantage in monitoring from space; stock herds, land cover types, terrain morphology, ambient temperature, humidity, precipitation, greenness, phytophenology, temperature and even, minerals underneath the earth (Melillos, 2016). In recent times, unmanned aerial vehicles have provided a new form of remote sensing for real-time monitoring of flocks on paddocks (Sun *et al*., 2018; Lyons *et al*., 2019; Tiscornia *et al*., 2019). Satellite remote sensing is the 'eye' in space that informs man of almost any terrestrial event including soil, fire, typhoons, earthquakes, drought and flood.

Global Positioning System (GPS)

Global Positioning System (GPS); a satellite-based navigation system designed to provide the absolute position (x, y and z) of objects and features on the earth (Hoffman-Wellenhof, 2001) is positively influencing approaches to management in the livestock industry. It consists of a constellation of about 24 satellites orbiting the earth at altitudes of approximately 11000 miles, provides the absolute location of any object on earth using triangulation method. This advantage aids livestock managers in determining the location and roaming range of the flock per time. Animal movements have been monitored on a high resolution image at the comfort of the keeper. Effective integration of GPS with GIS and Variable Rate Technology (VRT) provides a perfect site specific management options for pasture agronomists.

Geographical Information System (GIS)

The youngest of the STs is the Geographical Information System which, unlike the first two satellite-based technologies, is computer-based. It is an information system designed for capturing, storing, imputing, retrieving, manipulating, analysing and displaying geographically referenced information for decision making purposes. GIS is also data and ingenuity driven; implying that its users are limited by data and imaginations for applications.

The definition of GIS shows that it encompasses five components namely:

1. The computer hardware
2. The specialized (GIS) software
3. Data concerned with spatial distribution (Geographical)
4. Method of analysis or innovative analytical methods
5. The Analyst (Driving the system) with innovative imaginations

These five components form the GI system.

Integration

In principle, GPS and RS are the sources of geographic data while GIS is the receiving platform for the two technologies. Remote Sensing and Global Positioning System are designed to collect spatial data; the GIS are designed to receive and process spatially-referenced data into useful information for decision making. It is a sort of clearing house or the receiving platform for the other two technologies. This interoperability amongst the three systems therefore forms the basis for their integration. The diagram in figure 1 shows the pattern of integration of GPS and Satellite Remote Sensing with Geographical Information Systems.

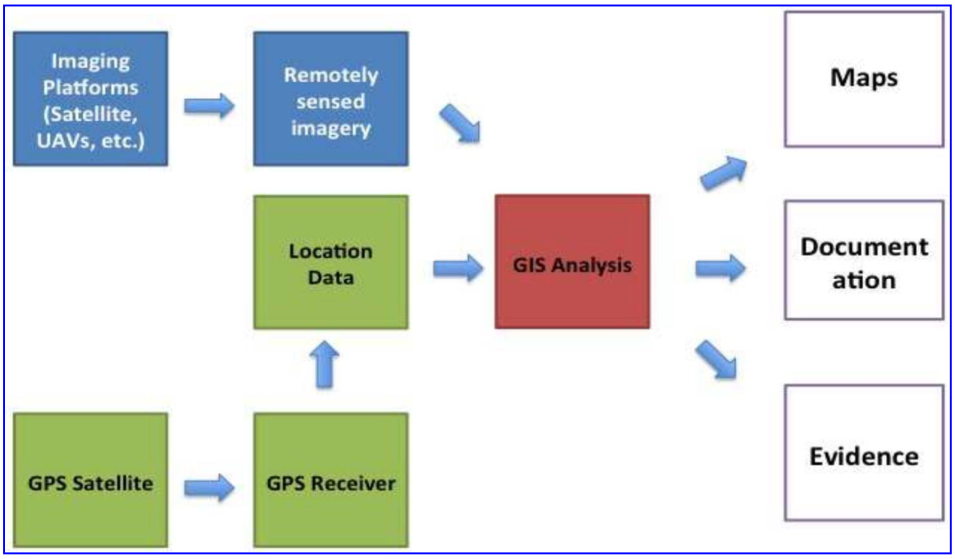

Figure 1: Integration of RS and GPS into GIS

Successful integrations have provided the platform to answer crucial spatial decision questions in management such as: "what is where?" or "what will be where if…?" or "How far is...?" These questions can be effectively answered with a combination of GIS, GPS and RS technologies (Jadhav and Kolap, 2005). The full strength of STs is appreciated in resource management and environmental monitoring applications. An example of such is selective application of pesticides and fertilizers to improve farming efficiency and reduce environmental hazards (Runyon, 1994).

In an attempt to elucidate the possibilities and realities of integration of the three spatial technologies, Gao (2002) identified four models: linear, interactive, hierarchical and complex and discussed the applications of integration under three categories: resources management and environmental monitoring, emergency response, and mobile mapping. According to him, linear integration is the most common but, hierarchical and complex integration models have found applications in precision farming and environmental modeling. He opined that full potentials of integration of STs has not been achieved because of limited cases of applications under hierarchical and complex models, but as mobile communications technologies improve, full integration will find more applications in many new fields after removal of the obstacles in integration.

Case studies of SIT applications in Pasture and Range Management (P&RM)

To appreciate the introduction of STs in P&RM, a review of a few case studies is presented to present principles of applied integrated spatial technologies.

Case 1: "Evaluation of derived and natural grazing land in parts of South-Western Nigeria using satellite remote sensing technique".

The rationale: Ogun State has been described as part of the lowland rain forest of Nigeria; there is a need to ascertain whether grassland resources are available to support establishment of ranches for large scale grazing of ruminant livestock. Earth observation information will be required for proper planning.

Objectives: The general objective of the above scenario will be to determine the capability of existing rangeland resources within the state to support expansion of ruminant livestock projects in Ogun State.
Specifically, the project wants to:

i. Determine the locations of grazing lands in the state
ii. Determine the size of natural grazing land available

Case 2: "Assessment of condition of natural grazing lands in Ogun State Nigeria using satellite remote sensing technique".

The rationale: Information on the condition of vegetal-cover of existing range lands is important in assisting the design of appropriate intervention programmes for management of pastureland across the State.
Objectives: The main objective in this case is to determine the floristic composition and health status of existing rangeland resources in the plan for extensive ruminant production across the State.

Specifically, the project will strive to attain the following:

i. Determine the status of floristic composition of the existing pasturelands

ii. Determine the health status of the vegetation

Case 3: "Site-specific management of established paddocks in Federal University of Agriculture, Abeokuta."

Rationale: As a follow up to the two scenarios above, establishment of paddocks are encouraged in private and small-holder capacities. A 20-hectare paddock is however large enough to create sufficient agronomic management problems for an individual. Pasture establishment can be fraught with vagaries of bottlenecks arising from variability in the distribution of important soil parameters namely, moisture content, soil texture and nutrient. Often farmers are confronted with the question of where is the best location for paddock establishments among several alternatives. The challenges to the farmer stems from optimum input application to correct targeting of resources on the paddock. Agronomic management of pasture crops (grasses) require knowledge of the distribution of soil nutrient contents, otherwise, uniform treatment with fertilizers and chemicals leads to superfluity on one hand and inadequacy on the other (Hompson *et al*., 2019).

In such scenarios, site-specific agronomic practices and deployment of precision farming procedures are often advised. The desire to improve on productivity and efficiency of grazing systems leads to employment of ST tools in establishment and management of paddocks.

MATERIALS AND METHODS

In all cases listed above, the five components of GIS mentioned earlier are essential apart from relevant Remote sensing images as well as those of GPS coordinates. The specifications for computer hardware required in setting up a GIS for pasture and range management decision include a computer (with 200 GB HDD, 2.5 GHz Processor, 4 GB RAM), GIS software (any of ArcGIS, or ERDAS Imagine and Idrissi selva upwards and a hand-held GPS receiver (any of Garmin products). Digitizing table, scanner and color printer are important but could be optional, but field notes are inevitable during ground-truthing.

Data types

Both data of primary and secondary sources are required. Data of primary origin are the field observations or laboratory analysis with GPS-coordinates including the location of derived and natural grasslands, and for soil samples collected (in the case of site-specific paddock management).

Secondary data include recent satellite images over Ogun State (Landsat TM and Ikonos) with zero percent cloud cover acquired; computed Normalized Difference Vegetative Index (NDVI) of Ogun State; and existing land use and land cover of Ogun State.

Data processing

Image registration and false colour composite

In the case of the first case study, the 8 bands of Landsat TM satellite imageries were subjected to false colour composite (FCC). The FCC image was registered (georeferenced) in a universal coordinate system as to fit into the map of Ogun State. To register the image, GPS coordinates of known features in the field was added to the appropriate point on the image and the georeferencing tool in the GIS software was used to re-assign new sets of coordinates (the GPS reading) to the identified locations on the image, thus shifting the image to the correct geographic position. The Red, Blue and Green bands of the image were stacked in GIS environment to produce a false colour composite (FCC) in preparation for the image classification process.

Reclassification of vegetation index data

In the second case, the vegetation index image was imported into the GIS and ensured to be registered in the same coordinate system as described above to fit into the map of Ogun State. The registered vegetation index was then subjected to reclassification to display areas that are naturally doing well and areas that are not doing well. Details of this analysis are described in the data analysis section below.

Geo-location of soil sample collection

The data collection and processing for the third case is slightly different from the first two cases. Primary data were utilized more in the third case. Soil samples were collected at interval of 5 meters along with the GPS readings of soil sample points. The soil samples were collected using soil auger at 0-15 cm and 15-30 cm respectively. The samples were tested for soil moisture, water holding capacity and textural properties. Soil nutrients were also determined for each sampling position. The analyzed soil sample results, namely: nutrients, moisture, texture and microbes (nematodes) etc. were tabulated against the respective GPS location of the samples on the field.

Data analysis

Land use/land cover classes

The Geo-referenced FCC image was subjected to supervised classification using maximum likelihood method. Supervised classification is achieved by creating training sets on the image in order to guide the computer on how to classify or group all pixels on the image into different land cover categories. The various categories created were assigned unique digital numbers and same colour. Thus an image with 255 colours is used to produce another image where the 255 colours have been collapsed into a fewer number of colours representing the number of land use/land cover classes desired. The final step was to group the categories and calculate the areas occupied by each land cover types.

Vegetation health status assessment

The green pigment (Chlorophyll) in plants strongly absorbs blue and red wavelengths and while also strongly reflecting at the near infrared. Estimation of plant abundance and greenness (which is a function of plant's condition of health) is based on this natural response of vegetation to electromagnetic radiation. In green plants, the degree of greenness is a strong indication of the plant's health. The Normalized Difference Vegetation Index (NDVI) is a simple ratio of (Near Infrared - Red)/(Near infrared + Red) that indicates green plants performance and health. To compute NDVI the red and near infrared bands of the Landsat TM are stacked in GIS map algebra as indicated by the equation $NDVI = (NIR-R) \div (NIR+R)$. NDVI range falls between -1 to + 1. High values close to 1 indicate abundance or health while low values close to zero and -1 indicate plants' distress or complete absence of greenness as the case may be. A map broken into several grid cells with values range of -1 to 1 can be reclassified into two or three groups namely; -1 to 0.2 as group 1, 0.21 to 0.5 as group 2 and 0.51 to 0.99 as group 3. This will guide decision on where to conduct further investigations or direct interventions.

Soil sample analysis and map of sample location

The GPS coordinates of auger position in the third case was prepared in a spread sheet format in MS-Excel added to ArcMap and displayed as XY data. The data was then exported into a directory to convert it into ESRI shape file which when displayed on the GIS workspace, presents the map of soil sample points on the paddock (Figure 2).

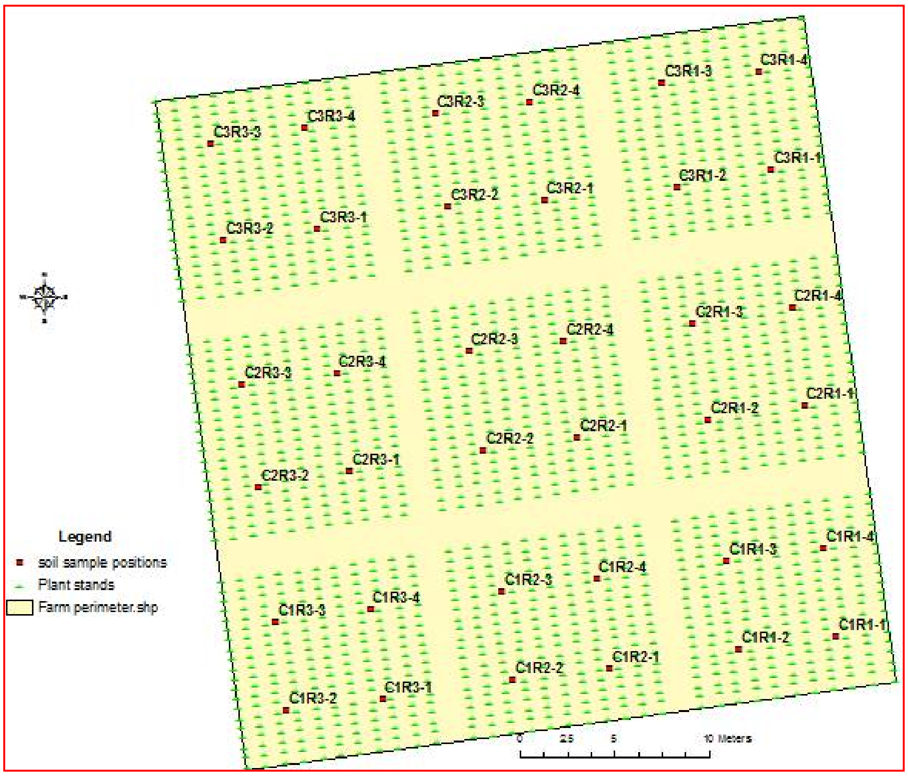

Figure 2: GPS locations of all sampling positions

Surface interpolation

Statistical methods used to estimate an unknown value from related known ones are regarded as interpolations. When this applies to estimating values of parameters along the earth terrain it is termed 'surface interpolation'. In GIS, this is achieved by using established values of parameters with known coordinates and sequence to determine the unknown or missing values. The most frequently used interpolation techniques are "universal Kriging and linear regression models in combination with Kriging" (Childs, 2004; GIS Resources, 2013).

In the third case scenario, the result of the soil analysis from the laboratory was tabulated against the corresponding coordinates of their sampling positions on the farm. This was imported into GIS and subjected to surface kriging to model the data into continuous surface data. This makes it easy for further manipulation in map algebra. The difference in existing soil nutrient and the plant requirement shows variability of nutrient deficiencies or superfluity on the paddock. This is the prescription map for fertilizer application.

RESULTS AND DISCUSSION

Evaluation of derived and natural grazing land

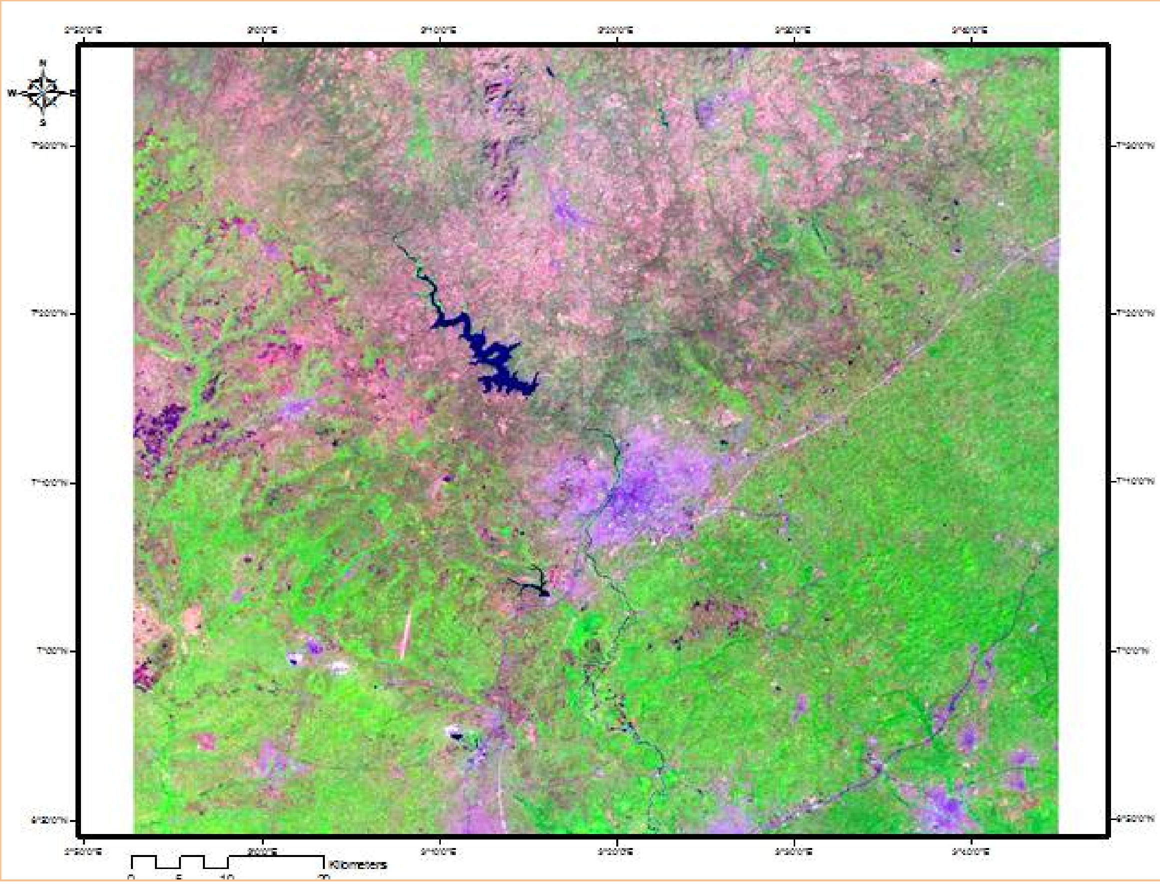

Figure 3: False Colour Composite (FCC) of Landsat image of northern SW Nigeria

The FCC was produced by stacking into one composite, the Red, Green and Blue bands from the seven bands in the Landsat image. The above image does not look meaningful without classifying it into meaningful land use and land cover categories (Figure 3). The FCC was therefore subjected to supervised classification. In this case, the supervised classification was done by creating training sites on the image to guide the computer in grouping all the pixels with 5% likelihood of resemblance (maximum likelihood) as the same feature (category) in figure 3.

The result of the classification shows seven prominent land use and land cover categories in the study area. These includes: Rain-fed agricultural lands, Grazing areas, Bare land, Built-up areas, Riparian vegetation, Water bodies and Rock outcrops (Figure 4).

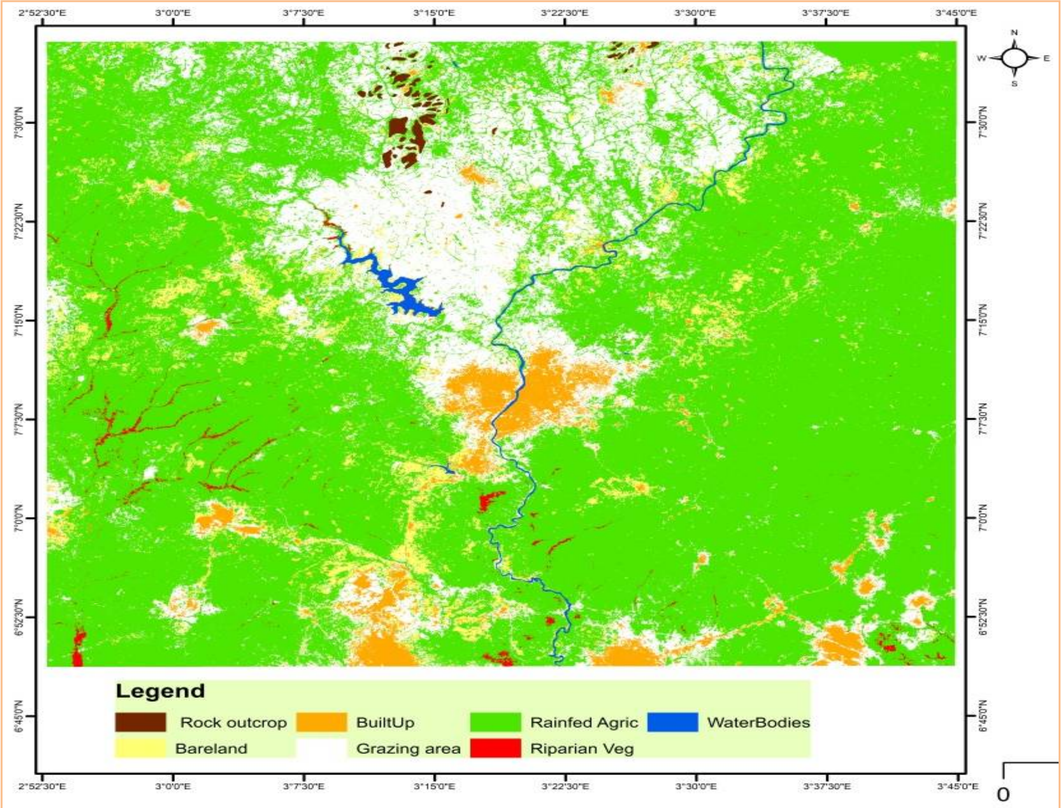

Figure 4: Final classification of the Landsat Image

Table 1 reveals that Rain-fed agricultural lands is the largest with almost 70% land coverage. This is followed by grazing lands with 19%

Table 1: Relative areas of land use/ Land cover categories

S/N	Land use/land cover types	Area (Ha)	% coverage
1	Bare land	49091.59	5.86
2	Built-up	30569.15	3.65
3	Grazing area	159486.51	19.04
4	Rain-fed agriculture	585734.89	69.93
5	Riparian vegetation	4818.02	0.58
6	Water bodies	4910.74	0.59
7	Rock outcrops	3027.80	0.36

The natural grazing areas can be seen on the classified image (white portion), and the area estimate in GIS shows that it covers almost 159,500 hectares about 20% of the total area covered by the image (Figure 4). The classified image also shows areas used for rain-fed agriculture; part of which can be converted into grazing land. The analysis thus, provides spatial decision support through synoptic view of the areas and the map can be further subjected to multi-level evaluation by setting criteria that eliminates the sites that fails to meet the set criteria for selecting suitable areas for grazing.

Vegetation greenness and health status

Another application of Satellite Remote Sensing is to use the derived data such as image of vegetation indices to determine health status of large expanse of vegetal cover. The NDVI image shows that the entire area is distressed; since no area have up to +0.5 as its NDVI value (Figure 5).

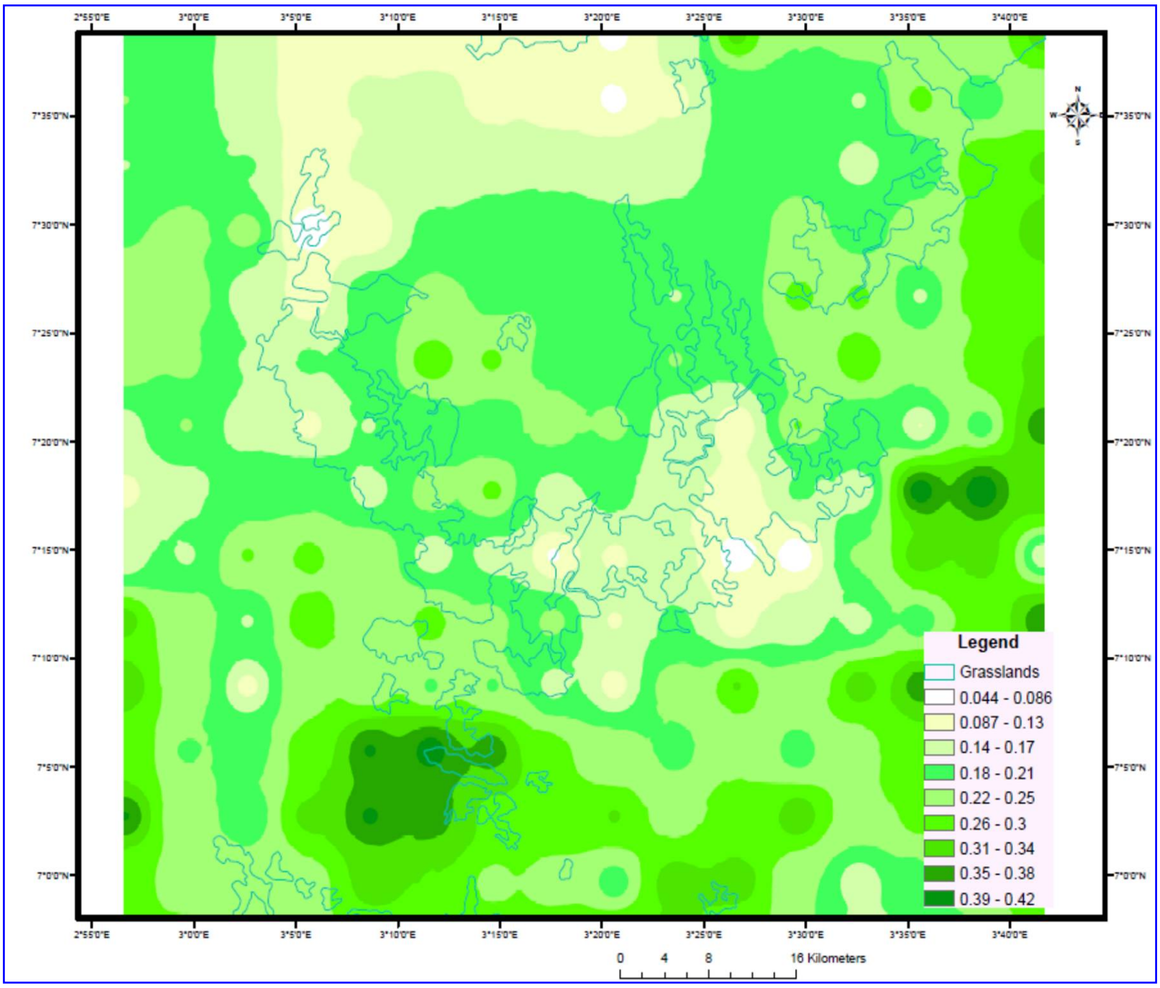

Figure 5: NDVI composed for parts of Ogun State

The areas demarcated as grasslands for instance can be seen in their relative greenness that some parts would require certain intervention to make it suitable for ranching. The low vegetation indices could have resulted from a number of factors. Loss of soil fertility, aridity, grassland fire, low rainfall, over grazing and a host of other explanations could have been responsible for the poor condition of the vegetation. This type of map can serve as a guide in monitoring grazing plant condition on natural rangelands or large ranches

Site-specific management on small paddocks

It is possible to deploy spatial technologies in pasture agronomy. Managing a paddock from a depleted land as described by the vegetation index map in figure 5 will require application of lots of nutrients (manure or fertilisers). Spatial technologies will provide spatial decision support in order to achieve optimal application of the fertilisers such that no area has too little and none has too much.

Table 2: Nutrient deficiencies derived from analysis of soil samples collected across a paddock

S/No	Flag No	Northings	Eastings	pH	% O.C.	N	N deficiency	P deficiency	K deficiency
1	C1R1-1	7.2354970	3.3937780	5.7	0.09	0.01	2.18	1.04	0.96
2	C1R1-2	7.2354910	3.3937320	5.8	0.73	0.05	1.19	1.84	1.00
3	C1R1-3	7.2355310	3.3937260	5.5	0.90	0.07	0.92	1.75	0.67
4	C1R1-4	7.2355370	3.3937720	5.5	0.34	0.03	1.78	1.84	0.42
5	C1R2-1	7.2354820	3.3936700	5.7	0.09	0.01	2.18	2.03	0.78
6	C1R2-2	7.2354770	3.3936240	5.7	0.94	0.07	0.86	2.03	0.89
7	C1R2-3	7.2355170	3.3936190	6.8	0.85	0.06	0.99	2.03	0.82
8	C1R2-4	7.2355230	3.3936640	5.3	0.26	0.02	1.91	1.92	0.93
9	C1R3-1	7.2354680	3.3935620	5.5	0.68	0.05	1.25	2.07	1.04
10	C1R3-2	7.2354630	3.3935160	5.7	0.04	0.00	2.24	2.12	0.96
11	C1R3-3	7.2355030	3.3935110	5.6	0.81	0.06	1.06	2.05	0.82
12	C1R3-4	7.2355090	3.3935560	5.7	0.94	0.07	0.86	2.10	1.11
13	C2R1-1	7.2356020	3.3937630	5.8	0.94	0.07	0.86	2.05	1.11
14	C2R1-2	7.2355960	3.3937170	5.6	0.13	0.01	2.11	1.97	1.18
15	C2R1-3	7.2356400	3.3937100	5.6	0.85	0.06	0.99	1.99	0.93
16	C2R1-4	7.2356470	3.3937570	5.5	0.81	0.06	1.06	2.10	1.00
17	C2R2-1	7.2355880	3.3936550	5.5	0.98	0.07	0.79	1.88	0.31
18	C2R2-2	7.2355820	3.3936100	5.5	0.77	0.06	1.12	1.99	0.96
19	C2R2-3	7.2356270	3.3936030	5.4	0.90	0.07	0.92	2.10	0.75
20	C2R2-4	7.2356320	3.3936480	5.4	1.15	0.08	0.53	2.10	0.71
21	C2R3-1	7.2355720	3.3935460	5.3	1.15	0.08	0.53	2.05	1.07
22	C2R3-2	7.2355650	3.3935030	5.5	1.45	0.11	0.07	2.05	0.67
23	C2R3-3	7.2356120	3.3934950	5.3	1.19	0.09	0.46	1.79	0.93
24	C2R3-4	7.2356170	3.3935400	5.5	1.28	0.09	0.33	2.07	0.78
25	C3R1-1	7.2357100	3.3937470	5.4	1.28	0.09	0.33	2.10	1.00
26	C3R1-2	7.2357020	3.3937020	5.4	1.32	0.10	0.27	1.88	0.86
27	C3R1-3	7.2357500	3.3936950	5.5	1.11	0.08	0.60	1.94	0.93
28	C3R1-4	7.2357550	3.3937410	5.8	1.45	0.11	0.07	1.94	0.60
29	C3R2-1	7.2356960	3.3936390	5.5	1.28	0.09	0.33	2.05	0.71
30	C3R2-2	7.2356930	3.3935930	5.5	0.94	0.07	0.86	1.97	0.89
31	C3R2-3	7.2357360	3.3935870	5.4	0.47	0.03	1.58	1.99	1.00
32	C3R2-4	7.2357410	3.3936320	5.3	1.11	0.08	0.60	1.94	1.00
33	C3R3-1	7.2356830	3.3935310	5.3	1.41	0.10	0.13	1.88	0.93
34	C3R3-2	7.2356780	3.3934860	5.3	1.58	0.12	-0.13	2.07	0.57
35	C3R3-3	7.2357220	3.3934800	5.2	1.37	0.10	0.20	2.03	0.93
36	C3R3-4	7.2357290	3.3935250	5.6	0.30	0.02	1.85	1.88	1.04

The result of analysis of soil samples taken from 36 points on the paddock shows variability distribution across the land. However, the table does not show hidden trends on the paddock as would a graphical presentation like map. The table was therefore transformed into map form using inverse distance weighted method of spatial interpolation in GIS and the results are presented as maps in figure 6.

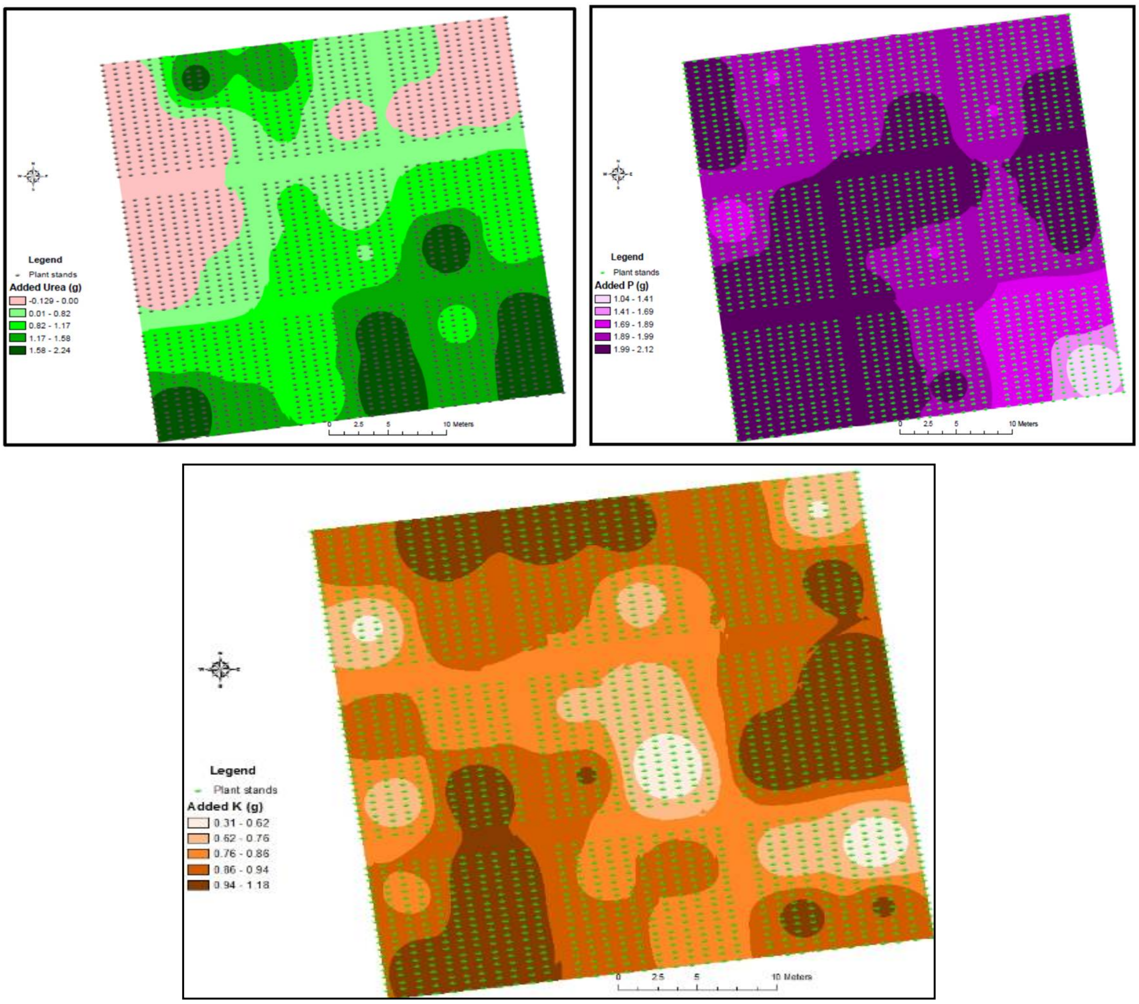

Figure 6: Spatial maps of soil nutrients from soil analysis data

The interpolations of the N. P. K. deficiencies obtained as net of analyzed soil nutrient value and crop requirement would serve as prescription map for variable rate application of fertilizer along the paddock.

CONCLUSION

Spatial technologies have proved extremely useful in pasture and range management as demonstrated by the few illustrations above. It can provide information on the condition of a ranch or paddock and the health status of large hectares of pastureland. Potentially, GIS has been used as a synthesizing tool for management of interventions aimed at invasive species control. Today there are a growing number of studies addressing various applications of Spatial Information Technologies in pasture and range management related issues. Most of the studies revolved round management issues and spatial decision support while, a number of others are on resource conservation and maximum livestock production. This paper may not have provided the details contained in tailor-made or short-time courses, but the paper has taught salient principles of space-tech application in pasture and range management. One of the important conclusions of this paper is that ruminant production has improved substantially with the application of spatial technologies since the discovery of the science in the later part of the 20th century. The trend as projected would continuously increase in the 21st century.

At the moment, the rate of application of these technologies in Nigeria is rather low, and the agricultural industry could not cope with the numerous management challenges as to guarantee sustainability of ruminant production. The future of rangeland resources development and management are greatly dependent upon increased scientific capability. Geo-spatial technologies or SIT can contribute immensely for a variety of rangeland resource management applications.

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