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Modelling Grass Land Carrying Capacity from Satellite Remote Sensing

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Abstract. Developments in Remote Sensing (RS) satellite technology have made it possible to apply RS products for agricultural purposes, including modelling grassland carrying capacity (CC) of grazing land. However, determining the grazing land CC using pixel based approach is relatively new. This study modelled CC using pixel based approach and later compare it with the convetional method. Sentinel 2A MSI, in-situ Grass Above-ground Biomass (GAB) of 30 sample points and livestock data were used for the modelling CC of Daware grazing land northeast Nigeria. The result indicate that the available grass in the grazing land can only support 2,377,419 goats/sheep for 6 months or 4909 cattle for 1 month. This indicates that the grazing land was over grazed. The result of this study shows areas of grass available for rotational grazing throughout the season, thereby contributing to accurate modelling of grazing lands in Savannah and similar eco system.

1. Introduction

Advancement in satellite remote sensing (RS) technology including sensors and processing have enable the application of RS widely used at operational level for agricultural purposes. This includes imaging technique for modelling grassland carrying capacity of grazing land. Grazing-lands are still the primary source of livestock feed [1], and thus the amount of grass above-ground biomass (GAB) will determine the grassland's carrying capacity (CC) that can evaluate the optimum number of livestock capable of grazing for a certain period [2-3].

Over the years, growth in population, technological development, increased commercialized agricultural production and climatic changes in African savannah have resulted in shifts in vegetation species distribution, decreased grassland biodiversity, lower production of biomass, increase plant cover erosion [4]. These variables had a dramatic impact on both the primary productivity of the pastureland ecosystem and livestock farming [5 - 6].

A growing body of literature illustrates that the common approach for modelling CC is polygon-based approach [7 - 9], however, the method may prove difficult in quantifying the amount of GAB distribution over space in a grazing land that can aid the rotational grazing. This study uses pixel-based approach in modelling the CC of Daware grazing land NE Nigeria. The specific objectives are (a) obtaining the total GAB of the grazing site from satellite data(b) evaluating the required livestock intake of the grazing area. The results obtained will help in providing an approach for grazing land management processes, specifically for rotational grazing. It also provides a contribution for accurate assessment on CC in grazing lands where such information is vital for livestock farming.

2. Materials and Methods

2.1. Study Area

The study area was Daware grazing land in Adamawa state northeast Nigeria (Figure 1.). They grazing site was located between latitude 9° 20’ - 9° 28’ and longitude 12°00 - 12° 40’. It has an estimated area of 6349.76 hectares. The dominant grass specie in the area was the elephant grass**.** The grass specie is primarily used as a livestock feeds in Nigeria.

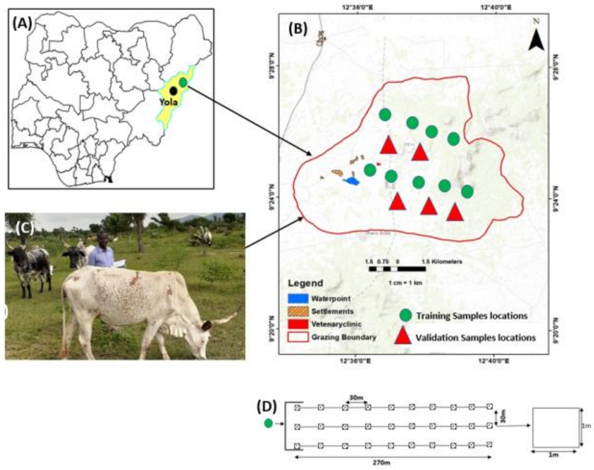

Figure 1. Study area: (A) Nigera states with Yola (inset), capital of Adamawa state; (B) Daware grassland; and (C) Grazing livestock, (D) Sampling technique.

2.2. Material

The materials used in this study are Satellite data, livestock population, Global Positioning System (GPS) and 30 samples of grass dry weight. Sentinel 2B MSI acquired on 10 August 2018 was downloaded from the Earth Explorer (EE) user interface online. Livestock population was obtained from Adamawa state ministry of livestock development, Yola. The number of livestock that was grazing in the year 2018 was (i) 4090 cattle, (ii) 3860 sheep and 2985 goats.

2.3. Method

The method involved in this study were three (A) Grass sampling and harvesting (B) Grass above ground estimation and (C) Carrying Capacity Modelling. The is illustrated below in Figure 2.

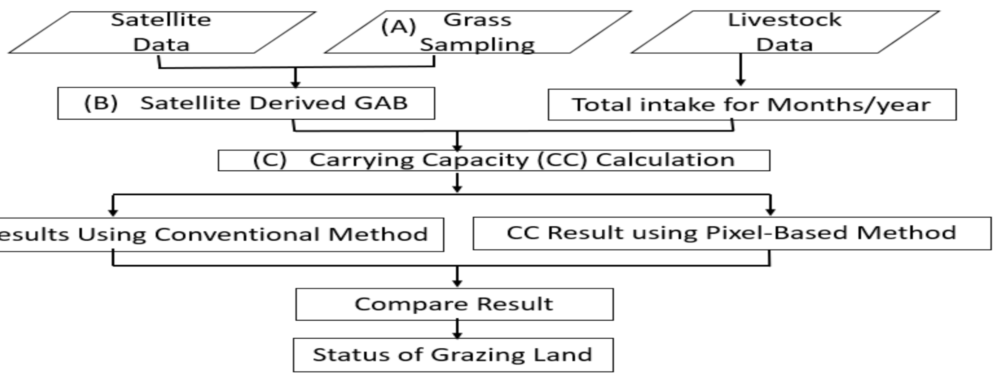

Figure 2. Flowchart of the method involved.

The grass samples were collected using Systematic sampling method. These sampling uses a fixed grid 10 x 10 m to assign plots in a regular pattern for every strip. Each plot has five 1m^2 area of grass samples as demonstrated in Figure 1 D. The method was based on GHG (Green House Gas) Emission Guidelines. Volume II: Above Ground Biomass Field Survey Guide for Baseline Survey; Federal Democratic Republic of Ethiopia Ministry of Agriculture, Addis Ababa, Ethiopia (GHG Guidelines, 2015 [10].

Prior to the main satellite data processing, the satellite data have undergone data pre-processing procedures to minimise random errors. All the above-mentioned main and pre-data processing are carried out in Geoscience and Digital Earth Centre (INSTeG) laboratory, *Universiti Teknologi Malaysia*.

NDVI values of the grass sample points were later extracted from the NDVI map of the study area. GPS coordinates was used in location the position of every grass sample plot. A total of 30 NDVI values of the sample plots were extracted. Using IBM SPSS Statistics version 25.0 (IBM, New York, USA), step wise linear regressions were conducted to obtain the transformation model for GAB calculation. The analysis also evaluates the performance of model level of fitness for GAB estimation. It was presented as R^2. The accuracy of the satellite derived transformation was validated using and the in-situ test set. The criteria for the validation are the root mean square error (RMSE).

The two fundamental data set used for calculation the CC of a grazing land are (a) Total GAB in tonnes obtained from the satellite imagery, and (b) total livestock grass intake for a define period or for a season in kg or tonnes. Previous researchers use conventional approach for calculating CC of a grazing land [11]. This study uses pixel-based approach for calculating CC and compare with the conventional method. Thus, the calculated CC indicates the status of the grazing land. Carrying Capacity was given as:

$$CC\ (AU/hc) = \frac{Total\ usable\ GAB}{Total\ animal\ intake} \quad - \quad - \quad (1)$$

AU = Animal unit in the grazing land
ha = Grazing area in hectares

Previous similar studies suggest that the daily feed intake for 250kg live weight of a cattle was 2.5% of its weight [12]. This assertion has no theoretical basis as malnourished and underfed animals takes more grass than the nourished and well fed. However, some findings revealed that daily dry matter intake for a cow that weights 421.77±28.60 kg to be 18.89±3.21kg per day [13]. The average daily intake of ruminants that weighs 39.4 ± 1.8 kg and 48.2 ± 1.3 kg consume 85.6 ± 2.3 and 104.0 ± 3.5g of grass and take 662 ± 35ml and 875 ± 34ml of water per day [14]. Sheep, goats and other ruminant animals share this characteristic. This study estimates the mean of cow intake per day to be 20kg and sheep and goats to be 0.095kg. This estimate is close to the findings of [15]. Also, [16] identify the asymptotic grass intake rates for deer and elk to be 2.22 and 14.04 g dry matter/minute.

3. Results

3.1 Grass Above-ground Biomass (GAB) Modelling

Results from the linear regressions between the NDVI and the in-situ GAB being calculated at the pixel size of the satellite was presented in Figure 3. The regression equation used as transformation model was used to calculate the GAB of the study area (Figure 4).

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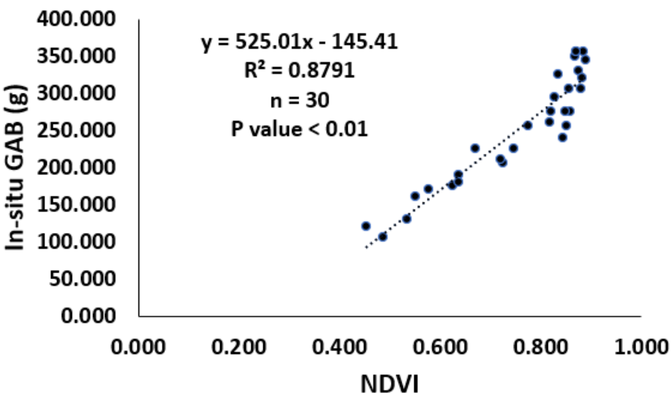

Figure 3. *GAB Modelling*

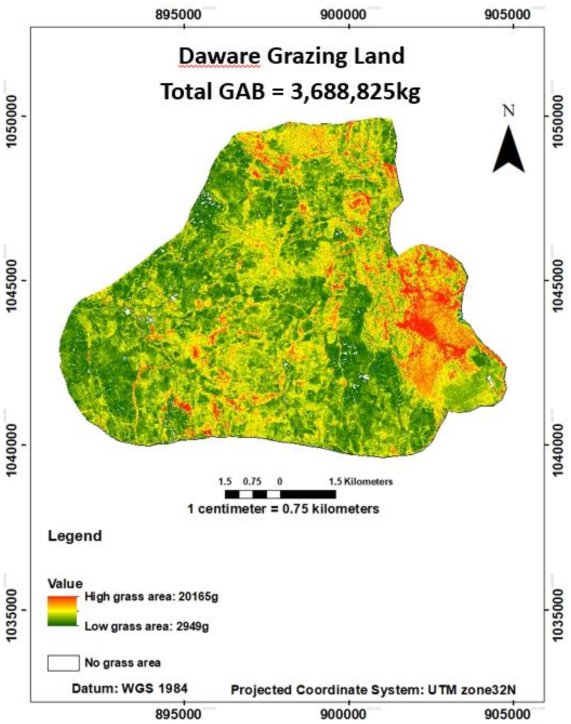

Figure 4. *Satellite derived GAB*

3.2 Model Validation

The GAB results derived from spectral transformation model was validated at an accuracy RMSE = ±25.475g with the pixel 10m size of satellite data used. The model has a good fitness of R^2 = 0.879 (p =0.01).

3.3 Carrying Capacity Calculation

Daware grazing site was overstressed due to the large number of livestock grazing with the limited GAB availability. This study considers using a proper use factor of 75 percent due to the absence of grass during the dry season. The study assumes that at least 25 percent may be left before the commencement of rain. Conventionally, the existing CC of Daware grazing land was as follows:

$$CC = \left[\frac{Usable\ \ GAB}{Animal\ intake}\right] kgha^{-1} \qquad - \qquad - \qquad (2)$$

The calculated livestock intake for every category of livestock was tabulated in Table 1.

Table 1. Calculated CC for Daware

Livestock	Period	Population
Sheep/goat	1 month	9707434
Sheep/goat	6 months	1600126
Sheep/goat	1 year	79787
Cow	1 month	4611

Remote sensing approach was used to calculate the available intake for cattle, sheep, or goats for a period 1 month to a year from the maximum GAB of September 2018. The grass availability per $10m^2$ (pixel size) was indicated in the map. The available grass intake for cattle, sheep, or goat within the period from 1 month to 6 months was presented as maps in figure 5 to 7. One-month available intake for goats or sheep (figure 5); six months available intake for goats/sheep and one-month available intake for cattle (Figure 5).

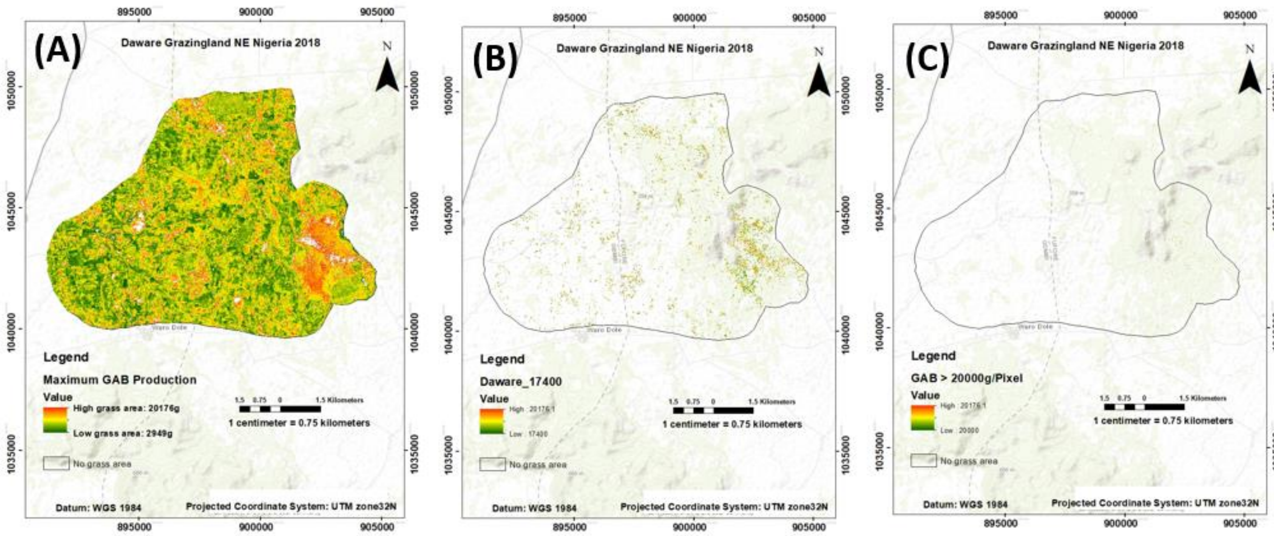

Figure 5. Goats/sheep intake for every $10m^2$ for: (A) 1 month intake; (B) 6 months intake (C) Cattle intake for 1 month.

The minimum intake for sheep/goat for every $10m^2$ must be greater than 95g to sustain at least 1 sheep or goat for a day. The minimum grass intake for sheep/goat within $10m^2$ must be greater than 17400g for a period of 1 to 6 months. Cow has the highest minimum intake per $10m^2$ ($20000g/10m^2$). These were translated in Table 1. The minimum intake for sheep/goat for every $10m^2$ must be greater than 95g to sustain at least 1 sheep or goat for a day. The minimum grass intake for sheep/goat within $10m^2$ must be greater than 17400g for a period of 1 to 6 months; cattle have the highest minimum intake availability of 20kg for every $10m^2$ (Figure 4 c).

Table 2. Grass intake available in Daware site

Livestock	Period	Max. Intake (g)/$10m^2$	Min. intake (kg)/$10m^2$	Total (kg)
Sheep/Goat	1 – 30 days (1 month)	20.176	2.949	735354.641
Sheep/Goat	1 – 182 days (6 months)	201.76	17.400	596354.786
Cow	1 – 30 days (1 month)	20.176	20.000	25992.428

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The stocking rate within $10m^2$ for cattle, sheep/goats were evaluated for a period from 1 to 6 months. The site will sustain 31 to 212 sheep or goats for a period of 1 month for every $10m^2$ within the grazing field (Figure 8). However, the sites will only sustain 183 to 212 sheep or goat for a period from 1 to 6 months per $10m^2$ (Figure 6 A & B). There are only few areas of 10m x 10m that can sustain a cow for a month (Figure 6 C)

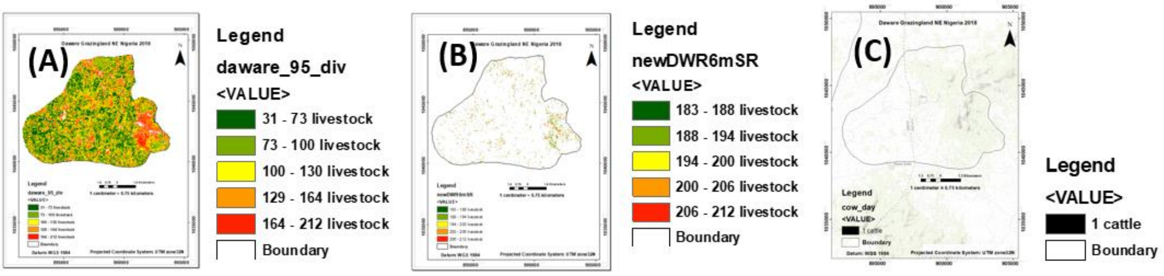

Figure 6. 10 x 10 m stoking rate (SR) for Goats/sheep for (A) 1 month (B) 6 months (C) SR for Cow 1 month

Table 3. Calculated livestock population that was required for grazing for a period of one to six months.

Table 3. Carrying Capacity for Daware site

livestock	Period	RS				Conventional		Diff.
		Max. SR/$10m^2$	Min. SR/$10m^2$	Total Livestock	CC (AU/kg/ha)	Total Livestock	CC (AU/kg/ha)	
Sheep/Goat	1 month	212	31	10890354	1,310.186	9707434	1,310.186	159.656
Sheep/Goat	6 months	212	183	2377419	215.964	1600126	215.964	104.91
Cow	1 month	1	1	4909	0.622	4611	0.622	0.041

The two approaches used in calculating the total livestock was graphically presented in Figure 7.

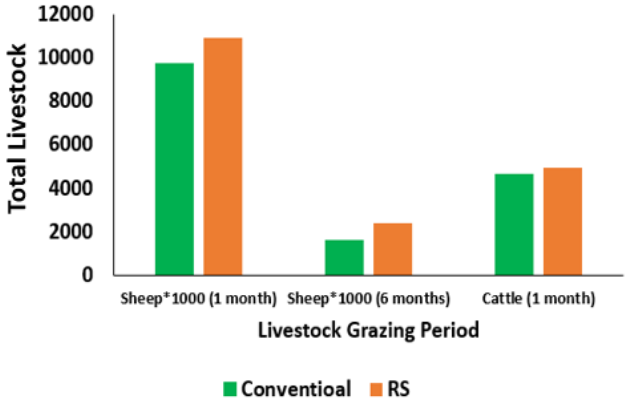

Figure 7. Comparism of Conventional and Satellite RS methods

Sustainability of Daware grazing site was assessed by comparing the existing livestock population and the calculated. It is evident that there is indeed a significant difference between the calculated and the existing stocking rate. This is because the existing stocking rate of 4090 cattle, 3860 sheep and 2985 goats for 1 grazing calendar was far more than the calculated. The average calculated stocking rate was 10,890,000 goats/sheep for 1 month or 2,370,000 sheep/goats for 6 months or 4,900 cattle for 1 month. This indicates the existing grasses in the grazing area will not sustain the current livestock population. Hence, the grazing land was over-grazed.

4. Discussion

Carrying Capacity (CC) was calculated based on the improvements on previous methods [18, 19-20]. The basic procedure was the calculation of mean GAB obtained at the end of the rainy season, multiply it by the proper use factor and then divide by a livestock intake requirement. This study considers using a proper use factor of 75 percent due to the absence of grass during the dry season. The study assumes that at least 25 percent may be left before the commencement of rain. The study also estimates the mean of cow intake per day to be 20kg and sheep and goats to be 0.095kg. This estimate is close to the findings of [15] and [16].

Sustainability of Daware grazing sites was assessed by calculating the CC using both the conventional method and Remote sensing method. It is evident that there is indeed a significant difference between the calculated SR and the existing. This is because the existing stocking rate has grazing pressure in excess for both the cattle, sheep, and goats if the grazing will last for a complete grazing calendar. If this pattern of grazing continues, there could be overgrazing burdens and soil degradation increase, that will have enormous implications for the future sustainable usage of the grazing land.

The introduction of remote sensing method for CC evaluation will be useful for rotational grazing. The grass availability for certain areas in the grazing was easily identified and mapped out. With rotational grazing, the basic principle is that it will allow a rest time for the grasses to regrow before being grazed again. Other benefits include putting livestock on a more even nutritional level compared to continuous grazing; more resistance to drought in pasture; more GAB produced in a season compared to continuous grazing; and a more consistent botanical composition of pasture.

5. Conclusion

Livestock farming is an essential part of the Nigerian society and economy. Therefore, this study provides a scientific contribution for accurate modelling carrying capacity of grazing lands in Nigeria and similar eco system. It also adds to the limited yet increasing number of studies on the evaluation of GAB for modelling CC. Application of satellite RS for CC modelling provide an excellent opportunity for further work for sustainable grazing land eco systems.

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