Journal of Remote Sensing & GIS
ISSN: 2469-4134
Fajji et al., J Remote Sensing & GIS 2018, 7:1
DOI: 10.4172/2469-4134.1000233
Research Article
Open Access

A GIS Scheme for Forage Assessment and Determination of Rangeland Carrying Capacity

Nahom Gudeta Fajji[1], **Lobina G Palamuleni**[1], **Victor Mlambo**[2,3]

[1]*Department of Geography and Environmental Sciences, North-West University, Mmabatho, South Africa*

[2]*Department of Animal Sciences, School of Agricultural Sciences, North-West University, Mmabatho, South Africa*

[3]*Food Security and Safety Niche Area, Faculty of Agriculture, Science and Technology, North-West University, Mmabatho, South Africa*

***Corresponding author:** Nahom Gudeta Fajji, Department of Geography and Environmental Sciences, North-West University, Mmabatho, South Africa, Tel: +251944985680; E-mail: nahum2jesu@gmail.com

Rec date: February 24, 2018; **Acc date:** March 23, 2018; **Pub date:** March 26, 2018

Abstract

Several geospatial datasets across the rangelands of the North West province of South African were integrated in order to develop a Rangeland Grazing Suitability Scheme using a GIS environment. Results of the scheme showed that private ranches and protected areas in medium and high rainfall zones are highly productive with higher carrying capacity and available foliage to animals than the communal areas and the low rainfall zones. Private ranches and protected areas are under-grazed while the communal areas are exposed to high exploitation and overgrazing in all rainfall zones. The scheme demonstrates the level of grazing that a particular rangeland should be exposed to and it could be very helpful for cattle ranchers and extension personnel in selecting areas for grazing for a given period of time. The scheme has a capacity for balancing forage availability in relation to forage demands by animal units. It is envisaged that adoption of this scheme by stakeholders and rangeland managers would increase the efficiency of rangeland monitoring process thereby increasing their productivity.

Keywords: Biodiversity; Rangelands; Soil erosion; Natural resources

Introduction

Rangelands have supplied goods and services to human kind for thousands of years and are used largely as a source of livestock feed and also provide secondary resources such as wild food, firewood, water and medicinal plants [1]. However, human interference with these natural resources often alters their natural characteristics [2]. In the North-West province of South Africa, raising livestock is a crucial economic activity and grazing is practiced all-year round. Grazing on rangeland biodiversity translates to the removal of biomass, trampling and destruction of plant root systems and replacement of wild grazers by livestock [3].

Due to high demand of beef domestically and abroad and a conducive marketing system, livestock production is generally one of the agricultural sectors that occupy extensive rangelands. With increasing livestock production, pressure on rangelands is high particularly in communal areas. In this region, potential of rangeland productivity varies depending on the amount of rainfall and rangeland management regime. Most of the communal lands in the province are considered to be degraded as compared to the protected areas and private ranches. In recent decades, the increasing demand for natural resources and animal production to cope with the increasing number of human population has exerted great pressure on these rangelands [4]. Overgrazing, soil erosion, and loss of palatable grass species, bush encroachment and drought [4] are common characteristics of communal and some private and protected rangelands. In addition, fragmentation of rangelands caused by racial discriminations resulted into uneven distribution and privatization of rangelands.

Reversing environmental degradation in the study area and maintaining higher productivity level of rangelands requires balanced grazing. Livestock in some of the study sites such as the communal and protected rangelands move every day from place to place seeking feed. Stocking rate in these areas is not based on range productivity or seasonal conditions of pastures. Snyman and Fouché [5] indicated that these scenarios can lead to rangeland degradation and poor animal conditions. Given the above situation and the importance of livestock production in the province, rangeland evaluation and assessment is very crucial. It is vital for the local government and stakeholders to know and understand their rangeland health conditions and how much livestock/animals their rangelands can support. Regulation of the number of animals which could be adequately sustained by the available forage is the most accepted measurement that can lead to improved rangeland productivity [6,7]. Such regulation can be attained based on the rangelands' resource information that can be used to establish the potential stocking rates. For example, vegetation productivity of rangelands is one of the most relevant rangeland resource information which provides crucial biophysical parameters for calculating livestock carrying capacity of rangelands [8-10]. Consequently, a relevant assessment technique for monitoring and improving the current conditions of rangelands is one of the most important issues facing the future of animal production in the study area regarding livelihoods of the communities.

Remote sensing and GIS are very powerful tools for monitoring natural resources. There are many advanced remote sensing methods that have been utilized worldwide for estimating biophysical parameters of rangeland vegetation such as pasture quantity [11-13] pasture growth rate [14]; and primary production [15,16] among others. Normalized difference vegetation index (NDVI) is strongly correlated with above ground biomass production in several rangelands [17] and is often used as a tool to estimate available forage for grazers [18,19]. Several regression models have been developed between vegetation indices and ground truth site herbaceous biomass and this has greatly improved the accuracy of forage estimations and determinations of rangeland productivity patterns in several geographic locations [20-23].

In the North-West province, studies about rangeland health and general distribution of vegetation have been carried out using small sampling areas or on larger scale using remote sensing to monitor the dynamics of rangeland productivity focusing on vegetation mapping, forage adaptation and impact of biophysical parameters on the spatial distribution of vegetation [24]. These studies emphasised on sustainable usage of rangeland resources that give more attention to conventional land cover estimates. Nonetheless, such estimates require the determination of rangeland productivity and long term carrying capacity by using land conservation parameters and animal output without taking into consideration the importance of reasonable rangeland stocking rates. Therefore, accurate rangeland condition and quantification of their productivity in relation to their potential to support livestock production is required. To this end, to determine the quantity of available forage in rangelands in the North-West province, South Africa, remotely sensed data and GIS ancillary data, ground sample data were utilised to develop a Rangeland Grazing Suitability Scheme using ESRI's ArcGIS Model Builder Tools. Furthermore, a systematic process to calculate usable biomass/forage for cattle grazing using slope and distance-to-water around slope barriers for selected rangelands in various rainfall zones was created. The developed scheme is designed to promote sustainable rangeland management practices by decision makers and stakeholders since it incorporates rangeland conditions and stocking rates.

Study Area

The study area, the North West province is located between 22°39'21" E and 25°17'28" E and 24°43'36"S and 28°00'00"S in South Africa (Figure 1). According to Schulze and FAO annual rainfall distribution and climatic classification in South Africa, the North-West province can be classified into three major rainfall zones based on the average rainfall received, namely: arid (low rainfall zones (200-400 mm)), semi-arid (medium rainfall zones (401-600 mm)), and sub-humid (high rainfall zone (601-800 mm).

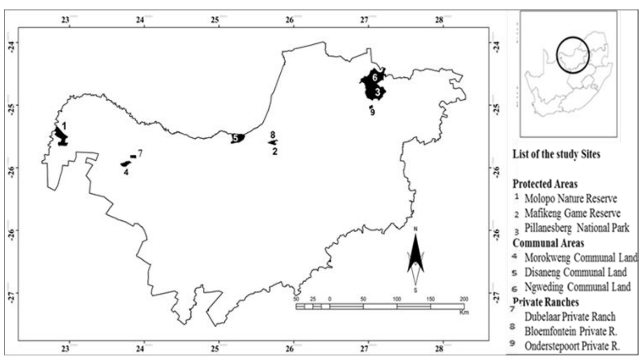

Figure 1: Map of the North West Province and the locations of the study sites.

Rainfall varies from the more mountainous and wetter eastern region to the drier, semi-desert plains of the Kalahari in the west. Climatic conditions vary significantly from west to east. The far western region is arid (receiving less than 300 mm of rainfall per annum), encompassing the eastern reaches of the Kalahari Desert. The rainy season usually occurs from October to March which is summer season with more sunshine days and warm temperatures. The province has a higher average rainfall per annum compared to the South African average. Therefore, the area has a higher advantage for agricultural activity than the country's average. However, most parts of the province have not enough rainfall and surface water. Consequently, shortage of water affects the extent of soil fertility to sustain large scale crop production in the region.

Materials and Methods

Satellite data

SPOT 5 multispectral imagery with spatial resolution of 10 m by 10 m was acquired from the South African National Space Agency (SANSA) for the study areas for late March and early April 2014. The images were georeferenced against existing materials of the study area. These images were atmospherically corrected with ERDAS Imagine using ACTOR model, and all atmospheric effects were rectified with the use of the Cost (t) model [25]. Then the imagery was projected into UTM (WGS 1984). Then the NDVI was obtained by calculating the ratio between the visible red and near-infrared bands of SPOT 5 satellite images for all the study sites.

Field data

More than 170 field sample data were collected from the end of February to mid-April in 2014. From each sampling sites, above ground biomass, canopy cover, latitudinal and longitudinal coordinates (m) by using a Garmin GPS (± 3 m accuracy level), and proportion of bare ground were collected. After other measurements were captured, all the grasses in the sub-plots in which the boundary was established using a quadrat covering 4 m^2 were cut and transported to the laboratory where the samples were dried in the oven at 75°C for 72 h and weighed to determine the total dry biomass. Field data sampling sites were selected based on types of rainfall zones, rangeland management regime and accessibility ensuring an even distribution of sample points across the study sites. For each study sites a transect was established and started at least 50 m away from the fence lines in the protected areas and private ranches and 100 m away in the communal areas to avoid the impact of roads and animal trails that typically run along major roads and fence lines.

Water sources data

Data on watering points and other sources of water were acquired from the Department of Agriculture and Tourism and Parks Boards of the North-West Province, South Africa. Missing data from the departments' database were digitized from satellite imageries. The locations of the watering points were collected using a Garmin GPS during field work.

Integration of ground-based biomass data and remotely sensed data

The location of ground sample points (n=174) were identified from the NDVI derived data. The corresponding NDVI values were collected from the NDVI derived data to perform a regression analysis between the two variables to determine their relationship. The optimal regression models were then developed for each rainfall zone.

Using the ArcGIS spatial analyst tools, the above-ground biomass map was prepared using the regression models. These relationships were applied to the pixels identified as grasslands based on a land cover map which was derived from the satellite data. A land use and land cover map which was produced using a maximum likelihood classification method was used to mask water bodies and built up areas to separate biomass producing rangelands from non-productive parts of the rangelands.

Livestock data

Livestock data was obtained from the Department of Agriculture and the North-West province Parks and Tourism Board for the year 2014 for communal areas and protected areas, respectively. The livestock data for private ranches was obtained from the respective farmers during field data collection in 2014. The data included the number of all species of grazers and browsers and their number was converted to animal unit month concept using the commonly used animal unit equivalent.

Digital elevation data

Features of the landscape terrain have great impact on how livestock utilize vegetation. The Slope of the terrain influences the accessibility of forage to grazers. For example for cattle, steep slopes are hard to move easily; therefore, utilization of forage by cattle on slopes greater than or equal to 60% is very low [26].

The digital elevation data was determined using the Shuttle Radar Topography Mission (SRTM) where the median slope for each 10 m × 10 m grid cell was determined from 30 m grid cells. This data was used to derive a slope map. The study sites are characterized by gentle gradient except for the Pillanesberg National Park where the gradient in some locations exceeds 60°. The study sites suitable for livestock grazing were prepared by dividing the slope map into slope classes according to Holchek et al. [27] classification techniques. A percent slope layer was created for each study site from the 1/3-degree (30 meter) Digital Elevation Model date (DEM). The percent slope layer covered each study site and once it was created, several models were iterated and computed using the slope layer. This process speeded up the analysis process and saved disk storage space without the need to store the derived percent slope layers each time the model was run.

The classification of the percent slope layer created the slope reduction categories using 10 to 30 percent slope groupings developed by Holechek et al. and Guenther et al. [26,28]. The selection of areas with slopes greater than 60% created the terrain boundary layer which was treated as inaccessible forage.

Data Analysis

Correction factor for watering points

Another major aspect of dictating availability of livestock forage is distance to watering points whereby the animal grazing potential decreases as distance from watering points increases [29]. Distribution of watering points across a given rangeland plays a key role on animal grazing patterns [29-31]. Therefore, there is need to evaluate the impact of the spatial distribution of watering points on livestock forage accessibility.

Rivers and natural watering sources were digitized from existing topographic maps of the study sites but locations of artificial watering points (wind pumps) were acquired from the North West Parks and Tourism Board. The values that range between 0-10 km were used in this study to apply restrictions to AU month^{-1} year^{-1}. Distance to watering points map was obtained by combining the digitized natural and artificial sources of water. This map was acquired by buffering the watering points to determine the water distance correction factor which was then rasterized. Distance map was then calculated from the rasterized water sources map.

Correction factor for rainfall distribution

Annual average rainfall data from 2010 to 2014 was acquired from the South African Weather Services for the entire study sites. The weather stations' longitudinal and latitudinal coordinates and the corresponding average rainfall data were entered into a spreadsheet from which a rainfall station map was prepared for the North West Province. The stations' rainfall data were used to create a rainfall distribution raster map using ordinary krigging method. This map was used to determine the rainfall distribution correction factor as vegetation distribution is affected by the dynamics of rainfall [32,33].

Foliage of trees and shrubs was estimated using the Kirms et al. and Bonhan [34] reference unit technique from the entire quadrat measuring 100 m × 100 m. Plant parts such as shoots, which are small units of given dimensions, were selected as reference units [34]. According to Kirms et al. and Kamau [35], the estimated weight of the reference unit was 10-20% of the foliage weight of the average plant in size. However, in this study reference units equated to 10-30% as the low rainfall areas were mainly comprised of woody materials with less foliage. Average green weight of plants was clipped from reference units and green weight was determined. The average weight of clipped reference unit was multiplied by the total number of estimated reference units to determine biomass production [34]. Then the entire reference unit was dried in the oven at 75°C for 72 hours and weighed to determine the dry weight.

Finally, the three range-forage determination models, namely: the slope-reduction model, the impact of rainfall distribution model and the distance from watering points' model were used to develop the final reduction model. It is important to stress that the final reduction in grazing suitability is both cumulative and additive. For example, a 10 percent reduction for slope added to a 30 percent reduction for distance from watering points and to 10 percent reduction for impact of rainfall distribution would result in a total reduction of 50 percent. Holechek [26] indicated that a 50 percent reduction is considered 50 percent suitable.

Rangeland carrying capacity and stocking rate determination

Rangeland productivity can be explained through forage availability. Forage availability can also be determined through careful analysis of some biophysical parameters. Some of these parameters have been described in this thesis (e.g., rainfall distribution, slope, water bodies and land cover).

Forage availability in the growing season has been suggested as one of the most significant estimators of rangeland productivity [36-38]. In this study, the available forage was determined through remote sensing techniques and field measurements using Equation 1 using the model that is presented on Figure 2.

Citation: Fajji NG, Palamuleni LG, Mlambo V (2018) A GIS Scheme for Forage Assessment and Determination of Rangeland Carrying Capacity. J Remote Sensing & GIS 7: 233. doi:10.4172/2469-4134.1000233

$$T_{uf} = A_f \times S_f \times W_{df} \times R_f \times A_{(ha)} \quad Equation\ 1$$

where:

T_{uf}=total usable forage,

A_f=total available forage by the end of the growing season,

S_f=slope factor,

W_{df}=watering point distance factor,

R_f=rainfall distribution factor,

$A_{(ha)}$=area in hectare.

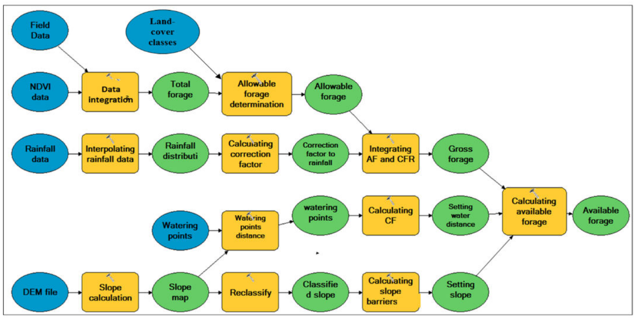

Figure 2: Grazing Suitability Scheme used to determine available forage for grazing using ArcGis 10.3.1 model builder with inputs of the above ground biomass map, elevation data, water sources and rainfall distribution map.

The resultant total usable forage was then classified into forage that should be used sustainably by the grazing animals (i.e., allowable forage) and forage that should be left behind to protect the environment and allow the process of regeneration [39]. To determine the total amount of forage that is available for grazing, the total usable forage was multiplied by the percent of allowable forage for grazing (Equation 2).

$$T_g = T_{uf} \times A_{af} \quad Equation\ 2$$

where:

T_g=total amount of forage that is available for grazing,

A_{af}=percent allowable forage.

To determine the total number of animals that the rangelands can support for a given period of time, the total available forage for grazers was divided by the forage demand of the animal unit time using Equation 3.

$$N_{ga} = \frac{T_{uf} \times A_{af}}{F_d} \quad Equation\ 3$$

where:

N_{ga}=number of grazing animal units,

F_d=forage demand per animal unit (kg).

Results and Discussion

Effects of slope and watering points on the available forage

The determination of the amount of allowable forage methodology involved the integration of slope, watering points and rainfall distribution. The percent slope of each study site was calculated at 10, 30 and 60 percent to determine the quantity of allowable forage for animal intake with reduction rate of 0%, 30%, and 100%. Distances around watering points were calculated at 3, 6 and 10 km from the water sources with reduction rates of 0%, 30% and 100%.

The result showed that slopes of most of the study sites were less than 15% with the exception of the Pilanesberg National Park where the percent slope within the north eastern and southern section of the park reached more than 60%, which limited accessibility of forage to 0%. However, the effect of slope in all other study sites was insignificant as the slope generally was much less than 30%. Therefore, in these study sites, slope barriers did not have any limiting effect on accessing the total allowable forage (Table 1). The high percent slope effects moderately affected the grazing capacity of foragers here. The outcome of the impact of steep slope in this site was a 0-100% change in forage accessibility. Slope is a very important parameter in determining risks of rangeland degradation. A slope plays a vital role in soil erosion, particularly in hilly areas in the absence of vegetation cover.

Study Sites	Total Area	No Slope Barrier	Percent Suitable	60% Slope Barrier	Percent not Suitable
Low Rainfall zone					
Molopo Nature Reserve	240 km^2/24000 ha	240 km^2/24000 ha	100	0 km^2/0 ha	0
Morokweng Communal Area	65 km^2/6500 ha	65 km^2/6500 ha	100	0 km^2/0 ha	0
Dubbelaar Private Ranch	2.80 km^2/280 ha	2.80 km^2/280 ha	100	0 km^2/0 ha	0
Medium Rainfall Zone					
Mafikeng Game Reserve	48 km^2/4800 ha	48 km^2/4800 ha	100	0 km^2/0 ha	0
Disaneng Communal Area	179 km^2/17900 ha	179 km^2/17900 ha	100	0 km^2/0 ha	0
Lenric Private Ranch	1.87 km^2/187 ha	1.87 km^2/187 ha	100	0 km^2/0 ha	0
High Rainfall Zone					

Pilanesberg National Park	490 km^2/49000 ha	416.5 km^2/ 41650 ha	85	73.50 km^2/ 7350 ha	15
Ngweding Communal Area	406 km^2/40635 ha	406 km^2/40635 ha	100	0 km^2/0 ha	0
Onderspoort Private Ranch	17.17 km^2/1717 ha	17.17 km^2/1717 ha	100	0 km^2 /0 ha	0

Table 1: Impact of slope barriers on the availability of forage.

Effects of watering points distances and slope on gross forage production

As distance from watering points increased, the gross forage production increased in all the study sites while the proportion of bare ground decreased. The forage production gradually increased to an asymptote at around 1000 m while the proportion of bare ground rapidly decreased to an asymptote after 600 m with maximum proportion (close to 80%) closer to water sources (Figure 3). A strong positive coefficient of determination was also detected between forage production and distance from water source (R^2=0.98; P<0.05) (Figure 4).

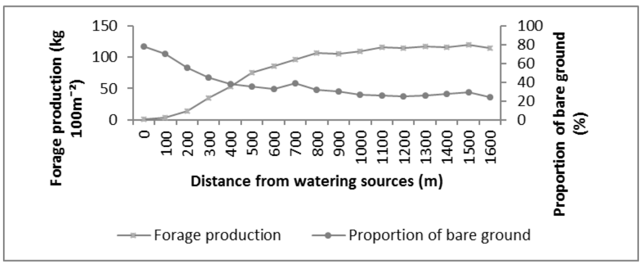

Figure 3: Impacts of distances of watering points on forage productivity and proportion of bare ground in the study sites in Pilanesberg national park.

The decrease of the forage production with the distance to water sources were more likely attributed to animal grazing as they prefer to forage near water sources. This study agrees with previous studies on the effects of grazing on rangelands. Bastin et al. [40] measured herbage litter and total cover in central Australia. The result clearly showed that there was an increase of green vegetation cover as distance from water sources increased. Results from other studies also showed a decrease in vegetation cover as grazing pressure increased near water sources [41,42]. High grazing pressure is considered as one of the major factors that increases proportion of bare soil in most of arid and semi-arid rangelands [41].

In comparison of slope classes, the forage production value was consistently higher on steeper slopes. The scenario that was observed around watering points, as water source distances increased the forage production increased, was also noticed in all slope classes. As slope percent increased, the forage production also increased significantly. Bare soil cover was consistently higher in lower slope classes. There was a consistently higher risk of degradation in slope 15-30%.

The increase of risk of degradation in slope class 15-30% is related to a decrease with vegetation cover. This is attributed to higher rate of surface runoff hindering vigorous vegetation growth [43]. Less forage producing localities in the communal areas and game reserves were found around and near built up areas and watering points. Lessening conditions in rangeland forage productivity as watering distance decreased suggests that there might be long term rangeland degradation in the area. These patterns are characteristics of rangeland degradation due to grazing [40,42,44].

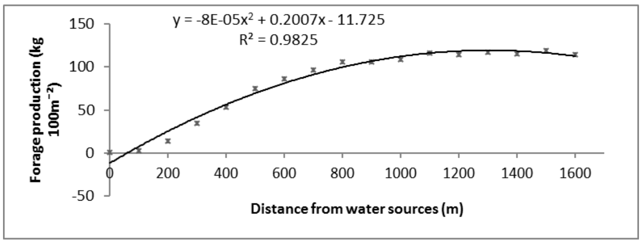

Figure 4: Relationship between the distance from water sources and forage production.

Impact of rainfall distribution on forage production

Weak coefficient of determination was detected between average forage production and rainfall distribution (R^2=0.45, P<0.05) (Figure 5) indicating that rainfall distribution is not the only determinant factor in rangeland forage production but rather there are also other factors that need to be taken into consideration. There was significant coefficient of determination between rainfall distribution and proportion of bare ground. High rainfall areas tend to have lower proportion of bare ground while low rainfall areas tend to have higher proportion of bare ground. Watering points distance affected the protected areas and the communal lands but the three private ranches where the size of these ranches was within 3 kilometer radius from the watering points were not affected.

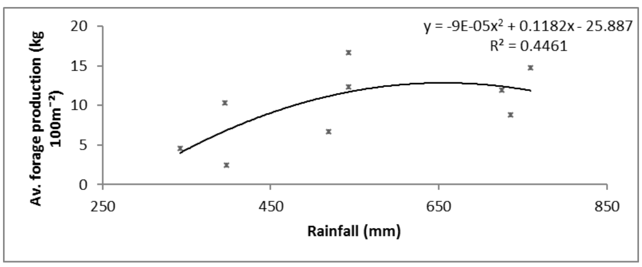

Figure 5: Impact of spatial distribution of rainfall on rangeland forage productivity.

Citation: Fajji NG, Palamuleni LG, Mlambo V (2018) A GIS Scheme for Forage Assessment and Determination of Rangeland Carrying Capacity. J Remote Sensing & GIS 7: 233. doi:10.4172/2469-4134.1000233

Impact of watering point distances on accessing allowable forage

The communal lands are the most affected sites where reduction of allowable forage ranged between 0 to 75%. Reduction of allowable forage due to watering points was significant and this factor affected the accessibility of forages of most of the study sites except the three private ranches where there was a fair distribution of watering points across the sites, particularly in the communal lands of the low and medium rainfall zones. In this study, only perennial sources of water were taken into consideration to avoid over-estimation and under-estimation of available biomasses since seasonal water sources are not reliable. A summary of the analysis of water source sub-models on available forage for grazing are shown in Table 2. This is used to evaluate the applicability of the water source sub-model. In some of the study sites, there was problem of inconsistency of watering points particularly, in Pilanesberg National Park where the average number of watering points was adjusted to avoid confusion.

Rainfall Zones	Localities	Gross biomass (tons)	Net biomass (tons)	Accessible (tons)	Loss of Biomass due to WPD (tons)	Loss of biomass due to WPD (%)
	Morokweng CRL	1630.00	1559.91	1000.00	495	32.42
	Dubbelaar PR	290.00	276.80	264.21	12.5	0.00
	Mafikeng GR	5532.15	5024.00	4562.00	192	3.68
	Disaneng CRL	12070.00	9656.00	7007.00	2764	23.99
MRFZ	Lenric PR	293.00	288.92	265.81	23.1	0.00
	Pilanesberg NP	43126.00	41284.72	30674.55	9260	22.43
	Ngweding CRL	28352.00	27476.8	22539.22	4307	15.63
HRFZ	Onderspoort PR	2722.00	2577.14	2434.11	143	5.30
Total		104906.65	99887.65	93194.64	72914.08	

Table 2: Relationship between total allowable forage and distances to watering points. NOTE: WPD, watering point distance.

Gross and available forage production

Table 2 shows the gross biomass production and distribution at the end of the rainy season in 2014. Out of the 99887.65 tons total forage produced by the study sites, 72903 tons (73% of the total forage) was available for animals. The average gross forage yield was 0.94 ton ha^{-1} with available forage per hectare ranging between 0.25 and 1.7 ton ha^{-1}. The amount of forage per mapping unit is closely related to the amount of average annual rainfall distribution and the efficiency of rangeland management regimes.

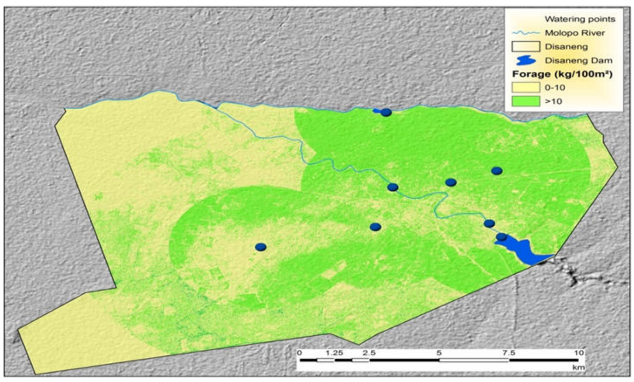

Figure 6: Map of amount of forage production in kilogram (kg) per 100 m^2 of Disaneng Communal land

The influence of rainfall distribution rating had a significant impact as the total forage in the low rainfall zone was assumed that only 40% of end of rainy season grass was available for grazing due to factors such as shortage of water, availability of few watering points and adverse climatic conditions, highly limiting accessibility of forages; medium rainfall zone 45% and the high rainfall zone 50%. The private ranch in the medium (Lenric Private Ranch) and high (Onderstepoort Private Ranch) rainfall zones had the highest average biomass production level followed by Mafikeng Game Reserve, Dubbelaar Private Ranch in the low rainfall zone, Pilanesberg National Park, Ngweding communal area, Disaneng communal area, Molopo Nature Reserve and Morokweng communal land. Comparison of the gross biomass showed that the high rainfall zone generally had higher biomass production. The highest difference between net biomass production and accessible forage was recorded in Morokweng communal area (36%), Disaneng communal land (27%) and Pilanesberg National Park (25.74%). The loss of most of biomass in the communal areas is due to higher distances from watering points particularly, in Disaneng (Figure 6) and Morokweng (Figure 7), inappropriate land uses and poor land suitability evaluations while inside the Pilanesberg National Park inaccessibility is due to the steep gradient of the area (Figure 8).

The lowest difference between gross forage and accessible forage was observed in all private ranches (ranging between 4.5-8%) and Mafikeng Game Reserve (9%) (Figure 9). This might be attributed to the topography of these sites and well-coordinated rangeland management strategies. Overall, the assessment of the accessible forage for animal grazing in relation to watering points showed that on average 15% of the net biomass was inaccessible due to shortage of watering points.

Citation: Fajji NG, Palamuleni LG, Mlambo V (2018) A GIS Scheme for Forage Assessment and Determination of Rangeland Carrying Capacity. J Remote Sensing & GIS 7: 233. doi:10.4172/2469-4134.1000233

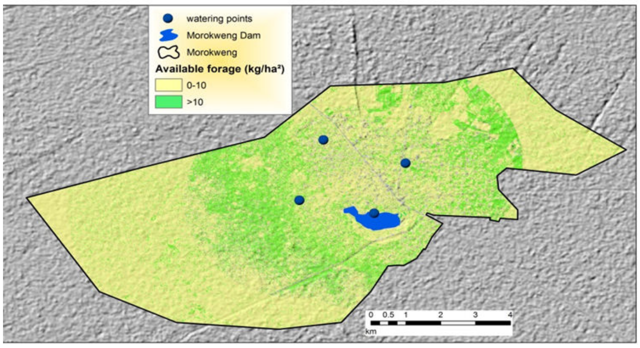

Figure 7: Map of amount of forage production in kilogram (kg) per 100 m^2 of Morokweng Communal Area.

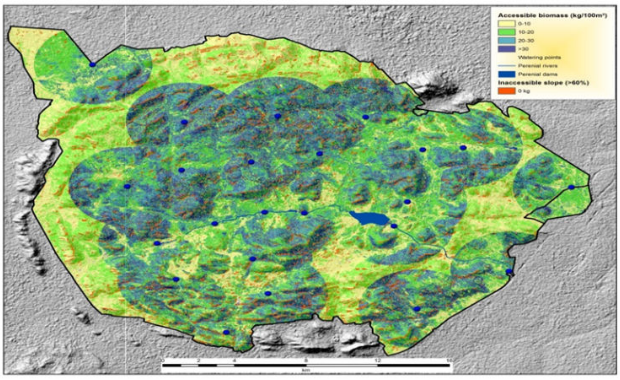

Figure 8: Map of amount of forage production in kilogram (kg) per 100 m^2 of Pilanesberg National Park.

This indicates that consideration of the distribution of watering points is crucial for planning a proper utilization of rangelands since the distribution of watering points influences the grazing potentials of grazing lands.

Among the study sites, Morokweng had the highest inaccessibility proportion of forage probably due to lack of permanent watering points and the erratic nature of rainfall and sandy soils in the region leading to high infiltration rate, higher evaporation of surface water leading to lower water table and this ultimately limits the occurrence of surface water.

Comparison of averages for gross biomass production (ton ha^{-1}) of the study sites is given in Table 3. The result showed that the overall average forage production was 0.94 ton ha^{-1} for all study sites. The maximum biomass production was recorded in the Lenric Private Ranch (1.67 ton ha^{-1}) in the medium rainfall area followed by Onderstepoort Private Ranch (1.59 ton ha^{-1}) in the high rainfall zone, Mafikeng Game Reserve (1.25 tone ha^{-1}) and Dubbelaar Private Ranch (1.04 ton ha^{-1}). The minimum gross biomass production was recorded (0.25 ton ha^{-1}) in Morokweng communal land followed by Molopo Nature Reserve (0.45 ton ha^{-1}) in the low rainfall zone (Figure 10). The major reasons for higher forage production in high quantity forage producing rangelands per unit area are due to introduced grasses and higher maintenance and management standards.

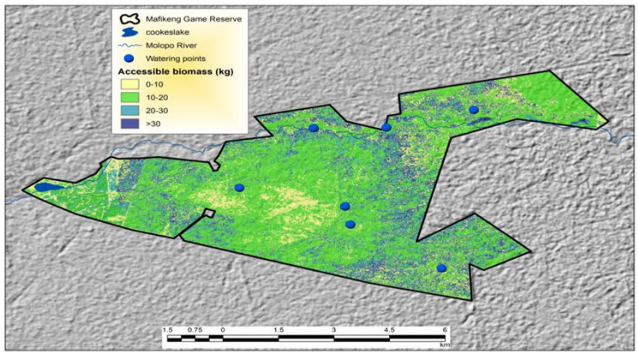

Figure 9: Map of amount of forage production in kilo gram (kg) per 100 m^2 of Mafikeng Game Reserve.

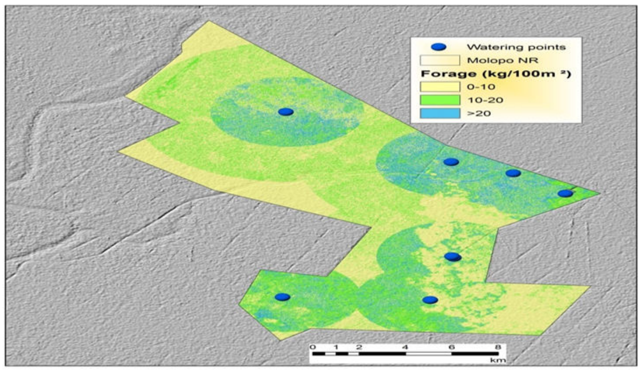

Figure 10: Map of amount of forage production in kilogram (kg) per 100 m^2 of Molopo Nature Reserve.

Hofmann and Todd [4], Fischer et al. [45] reported that the combinations of factors, such as overutilization of agricultural lands, unsustainable rangeland management and increased soil erosion; misuse of water resources with intensive irrigation activities resulting into salinization, deforestation, increased aridity, changes in population distribution, inappropriate grazing practices, overgrazing, bush encroachment and reduction in herbaceous forage production and land abandonments might be derivers of rangeland degradations. Loss of large quantity of vegetation from these rangelands can lead to the loss of functionality of ecosystem through reduction in biodiversity and reduced livestock carrying capacities with associated social and economic consequences [46].

The variation in biomass production in the study areas might be attributed to the nature of the corresponding rainfall, behaviors of the grazers' landscape and other biophysical factors. Forage productivity, composition and the spatial distribution of rangeland ecosystems are mainly determined by climate and soil properties and behaviours of herbivores [47,48]. According to Wiegand et al. [47] and Scholes [49] mean annual precipitation of rangelands and animal behaviours are major regulators of grass biomass production The average forage production in the low rainfall zone was significantly low (0.58 ton ha^{-1}) as compared to the medium rainfall zone (1.2 ton ha $^{-1}$) and the high rainfall zone (1.06 ton ha^{-1}).

Rainfall Zones	Locality	Gross biomass (tons)	Net biomass (tons)	Accessible (tons)	Difference between Accessible and net Biomass (%)	ABP (tons) ha^{-1}	Average Forage (tons) ha^{-1} (per rainfall zones)
Low Rainfall Zone	Molopo NR	5872.50	5050.35	4141.00	17.89	0.45	0.58
	Morokwe CRL	1630.00	1559.91	1000.00	36.00	0.25	
	Dubelaar PR	290.00	276.80	264.21	4.50	1.04	
Medium Rainfall Zone	Mafikeng GR	5532.15	5024.00	4562.00	9.19	1.23	1.19
	Disaneng CRL	12070.00	9656.00	7007.00	27.43	0.67	
	Lenric PR	293.00	288.92	265.81	8.00	1.67	
High Rainfall Zone	Pilanesberg NP	43126.00	41284.72	30674.55	25.74	0.88	1.06
	Ngweding CRL	28352.00	27476.8	22539.22	17.97	0.70	
	Onderstepoort PR	2722.00	2577.14	2434.11	5.55	1.59	
	Total	99887.65	93194.64	72914.08	15.90	0.94	0.94

Table 3: Rangeland gross biomass, net biomass and accessible biomass productions. Note: NR (nature reserve), CRL (communal rangeland), PR (private ranch), GR (game reserve), NP (national park)

Carrying capacity (ha AU^{-1} 6 months^{-1}) of the study sites

Table 4 shows the overall carrying capacity of the study sites with average carrying capacity of 4.21 ha AU^{-1} 6 months^{-1}. The result indicates that in 2014 end of growth season biomass production was fair in some of the study sites. The carrying capacity was excellent at Lenric Private Ranch (1.42 ha AU^{-1} 6 months^{-1}) and Onderstepoort Private Ranch (1.53 ha AU^{-1} 6 months^{-1}). Dubbelaar Private Ranch (2.27 ha AU^{-1} 6 months^{-1}), Mafikeng Game Reserve (1.95 ha AU^{-1} 6 months^{-1}), Pilanesberg National Park (3.3 ha AU^{-1} 6 months^{-1}) and Molopo Nature Reserve (5.9 ha AU^{-1} 6 months^{-1}).

From the study sites, more than 26,000 animal units were recorded. Among these sites, ratios of forage demand to forage accessibility for Morokweng (2.7) and Disaneng (1.8) was the highest and this shows that these localities were the most densely stocked rangelands while Onderspoort Private Ranch (0.2), Mafikeng Game Reserve (0.3) and Molopo Nature Reserve (0.3) were the lowest. The map of the rangeland status was derived from differences between the accessible forage and animal forage demand by converting it to kg/100 m^2 (100 m^2=the spatial resolution of the SPOT 5 satellite imagery).

From Table 4, negative values in the differences between the actual and potential animal units (AU) in six months indicate overgrazing while the positive values indicate under-stocking or optimum stocking rates. The poorest carrying capacity was recorded in Morokweng and Disaneng communal lands. The actual stocking rate in two of the study sites Morokweng (63% excess animal units) and Disaneng (40% excess animal units) were far above the grazing capacity of these rangelands. Long term overgrazing in these localities is a common phenomenon. This scenario results in the eventual over utilization and mismanagement of rangeland vegetation [50] owing to higher number of livestock and human population, excessive fire wood collection and higher amount of unpalatable plant species [4].

Most of the commercial farmers own mechanized infrastructures such as tractors, combiners, advanced irrigation systems, modern storage facilities, etc., for rangeland management and they are more likely to invest capital and labor in the rehabilitation process of their ranches because they understand the benefits of improving the productivity of their rangelands and animals that would result in a positive feedback over a long period of time [51]. In contrast, communal rangelands are managed by poorer communities with less or without infrastructure to improve the productivity of their rangelands. In communal areas, the land is freely accessed by every member of the community and have free bridle to make use of any resources. In most cases the users do not have any intension of investing on improvement scheme on the land as they have limited and unsecured control over these resources [51]. This scenario can decrease the ability of the community to maintain the land productivity [52].

Study Sites	ha/AU	Actual Stocking	Actual AU (carrying capacity) 6 month^{-1}	Potential AU (carrying capacity) 6 months^{-1}	Differences between Actual and Potential in 6 months	Area (ha)
Molopo NR	17.39	1380	24592.3	4098.7	2718.7	24000
Morokwe CRL	5.11	1273	2843.0	473.8	-799.2	6500

Dubelaar PR	3.04	210	940.0	123.3	31.3	280
Mafikeng GR	6.86	655	13840.2	2306.7	1651.7	4492
Disaneng CRL	2.69	6647	24129.5	4021.6	-2625.4	17900
Lenric PRL	3.67	51	790.6	131.8	80.8	187
Pillanesberg NP	7.75	6320	88220.4	14703.4	8383.4	49000
Ngweding CRL	4.18	9728	63066.1	9677.7	-50.7	40635
Onderstepoort PR	6.15	279	6722.9	1120.5	841.5	1717

Table 4: The ratio of distribution of rangelands (hectare) per unit animal and carrying capacity of the study sites. Note: ha (hector), AU (animal unit).

Smet and Ward [53] indicated that due to these reasons, communal rangelands are more degraded than protected areas and commercial ranches. The rates of degradations in these communal areas are believed to be increasing. Since the livelihoods of the communities in the communal rangelands depend on subsistence farming and livestock production, the rapidly growing human population had no alternative but to over-exploit the land. Animal stocking rates in communal areas is more than double that of the neighboring commercial farms and protected areas. Similar findings were reported by Shackleton [54] mentioning that high stocking rate was the cause of major degradation in the communal rangelands.

Another significant problem in communal grazing areas, particularly in the low rainfall region is bush encroachment. Timberlake and Reddy [55] stated that reduction in rangeland productivity and grazing potential due to expansion of shrub and tree cover are significant and often the impact is larger than the impact of rainfall distribution and soil characteristics. According to Toxopeus [56] increases in woody vegetation cover reduces the palatable forage cover by reducing available space for the forage to grow and increasing competition for minerals.

Conclusion

Satellite remote sensing in conjunction with GIS are useful tools for quantifying and determining forage distribution in rangelands. In this study rangeland carrying capacity of the nine study sites using the GIS model was determined. This methodology managed to accurately account for increased distance around terrain barriers. The results were reasonable when water sources were predominantly perennial streams. The results for Pilanesberg National Park and Disaneng Communal area were not correct due to the absence of a stock pond in the water source layer in the communal area; and over-estimating water availability due to using a named intermittent stream in the Pilanesberg National Park. The water source layer was modified by adding watering points and a stock pond, removing part of the intermittent watercourse, and ran the model again. The modified water source layer was confirmed reasonable with field truthing data. This demonstration supported the advantage of models that would systematically recalculate rangeland carrying capacity.

This rangeland carrying capacity model is very useful to determine optimal placement of additional water sources to increase cattle distribution across rangelands. The rangeland carrying capacity maps identify areas over six kilometers from water and classified these areas as 100 percent inaccessible for grazing. Consideration of placement of new watering points in these inaccessible areas could increase grazing areas available for animals. The model also balances forage supply from the rangelands in relation to forage demands of animal units in the rangelands enabling the range managers to analyze the potential and actual carrying capacity of their rangelands. Holechek et al. [26] and Mapiye et al. [57] recommended that livestock grazing should be monitored in areas of moderate state to avoid over utilization of rangelands. This model shows the level of grazing that a particular rangeland should be exposed to and it could be very helpful for cattle ranchers and extension personnel in selecting areas for grazing for a given period of time. This activity might increase the efficiency of rangeland managers by easing rangeland monitoring process and increasing the productivity of rangelands.

Rangelands are essential sources of forage for livestock production. Raising cattle is a very crucial economic activity in the North West Province, South Africa. Therefore, quantification of available forage is necessary in order to determine the carrying capacity of rangelands for a sustainable rangeland management strategy. In this study forage availability was determined in three rainfall zones (high, medium and low rainfall zones) and three rangeland management regimes, namely: protected, private and communal rangelands in each rainfall zone. The result showed that the rangelands had varied forage productivity with the private ranches from all rainfall zones producing the highest quantity while communal lands produce the lowest forage biomass. Rainfall distribution also had a notable impact on the level of rangeland productivity with the high and medium rainfall zones producing higher quantity of forage and the low rainfall areas producing less amount of forage. Using various variables such as topographic data, rainfall distribution data, remote sensing data, field-based data, water resource data and distribution of animal unit data across rangelands proved to be very useful for rangeland productivity modeling using GIS. In this study, GIS based analysis has shown that consideration of spatial variability in the distribution of rangeland resources and factors that influence them is a significant aspect in rangeland management and assessment process for making an informed decision.

References

1. Lesoli M (2011) Characterisation of communal rangeland degradation and evaluation of vegetation restoration techniques in the Eastern Cape, South Africa. PhD Thesis, University of Fort Hare, Alice, South Africa.
2. Cheng Y, Tsubo M, Ito TY, Nishihara E, Shinoda M (2011) Impact of rainfall variability and grazing pressure on plant diversity in Mongolian grasslands. Journal of Arid Environments 75: 471-476.

3. Alkemade R, Reid RS, Van den Berg M, De Leeuw J, Jeuken M (2012) Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences 110: 20900-20905.
4. Hoffman MT, Todd S (2000) National review of land degradation in South Africa: The influence of biophysical and socio– economic factors. Journal of South African Studies 26: 743-758.
5. Snyman HA, Fouché HJ (1993) Estimating seasonal herbage production of a semi-arid grassland based on veld condition, rainfall and evapotranspiration. African Journal of Range and Forage Science 10: 21-24.
6. Nestel B (1984) Development of Animal Production Systems. Elsevier, Amsterdam, Netherlands.
7. Kassahun A, Snyman HA, Smit GN (2008) Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia. Journal of Arid Environment 72: 1265-1281.
8. Harrison YA, Shackleton CM (1999) Resilience of South African communal grazing lands after the removal of high grazing pressure. Land Degradation & Development 10: 225-239.
9. Hunt ER, Miyake BA (2006) Comparison of Stocking Rates from Remote Sensing and Geospatial Data. Rangeland Ecology and Management 59: 11-18.
10. Hunt ER, Daughtry ST, Walthall CL, McMurtrey JEIII, Dulaney WP (2003) Agricultural remote sensing using radio-controlled model aircraft. In: Digital Imaging and Spectral Techniques: Applications to Precision Agriculture and Crop Physiology, ASA Special Publication, Madison, Wisconsin, USA, pp: 191-199.
11. Schino G, Borfecchia F, De Cecco L, Dibari C, Iannetta M, et al. (2003) Satellite estimate of grass biomass in a mountainous range in central Italy. Agroforestry Systems 59: 157-162.
12. Samimi C, Kraus T (2004) Biomass Estimation Using Landsat-TM and -ETM+. Towards a Regional Model for Southern Africa? GeoJournal 59: 177-187.
13. Boschetti M, Bocchi S, Brivio PA (2007) Assessment of pasture production in the Italian Alps using spectrometric and remote sensing information. Agriculture, Ecosystems and Environment 118: 267-272.
14. Hill MJ, Donald GE, Hyder MW, Smith RCG (2004) Estimation of pasture growth rate in the south west of Western Australia from AVHRR NDVI and climate data. Remote Sensing of Environment 93: 528-545.
15. Todd SW, Hoffer RM, Milchunas DG (1998) Biomass estimation on grazed and ungrazed rangelands using spectural Indices. International Journal of Remote Sensing 19: 427-438.
16. Paruelo JM, Oesterheld M, Di Bella CM, Arzadum M, Lafontaine J, et al. (2000) Estimation of primary production of subhumid rangelands from remote sensing data. Applied Vegetation Science 3: 189-195.
17. Diouf A, Lambin E (2001) Monitoring land-cover changes in semi-arid regions: remote sensing data and field observations in the Ferlo, Senegal. Journal of Arid Environments 48: 129-148.
18. Tucker CJ, Sellers PJ (1986) Satellite remote sensing of primary production. International Journal of Remote Sensing 7: 1395-1416.
19. Nemani RR, Keeling CD, Hashimoto H, Jolly WM, Piper SC, et al. (2003) Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science 300: 1560-1563.
20. Wylie BK, Denda I, Peiper RD, Harrington JA, Reed BC, et al. (1995) Satellite-based herbaceous biomass estimates in the pastoral zone of Niger. Journal of Range Management 48: 159-164.
21. Mutanga O, Skidmore A (2004) Narrow band vegetation indices overcome the saturation problem in biomass estimation. International Journal of Remote Sensing 25: 1-16.
22. Brinkmann K, Dickhoefer U, Schlecht E, Buerkert A (2011) Quantification of aboveground rangeland productivity and anthropogenic degradation on the Arabian Peninsula using Landsat imagery and field inventory data. Remote Sensing of Environment 115: 465-474.
23. Gao X, Chen Y, Lu S, Feng C, Chang X, et al. (2012) A ground spectral model for estimating biomass at the peak of the growing season in Hulunbeier grassland, Inner Mongolia, China. International Journal of Remote Sensing 33: 4029-4043.
24. Munyati C, Mboweni G (2013) Variation in NDVI values with change in spatial resolution for semi-arid savanna vegetation: a case study in north western South Africa. International Journal of Remote Sensing 34: 2253-2267.
25. Chavez PS (1996) Image-Based Atmospheric Corrections–Revisited and Improved. Photogrammetric Engineering & Remote Sensing 62: 1025-1036.
26. Holechek JL, Pieper RD, Herbel CH (2001) Range Management Principles and Practices. Prentice Hall, Upper Saddle River, New Jersey, USA.
27. Holechek JL, Gomez H, Molinar F, Galt D (2009) Grazing studies: What we've learned. Rangelands 21: 1645-1677.
28. Guenther KS, Guenther GE, Redick PS (2000) Expected-Use GIS maps. Rangelands 22: 18-20.
29. Adler PB, Hall SA (2005) The development of forage production and utilization gradients around livestock watering points. Landscape Ecology 20: 319-333.
30. Pringle HJR, Landsberg J (2004) Predicting the distribution of livestock grazing pressure in rangelands. Australian Ecology 29: 31-39.
31. Howes AL, McAlpine CA (2008) The impact of artificial watering points on rangeland biodiversity: A review. Water Smart Pastoral Production Project literature review, Working paper 15.
32. Li JL, Zhang J, Zhang C, Chen QG (2006) Analyze and Compare the Spatial Interpolation Methods for Climate Factor. Pratacult Science 23: 6-11.
33. Chu SL, Zhou ZY, Yuan L, Chen QG (2008) Study on Spatial Precipitation Interpolation Methods. Pratacult Science 25: 19-23.
34. Bonham CD (1989) Measurements for terrestrial vegetation. Wiley, New York, USA, p: 354.
35. Kamau P (2004) Forage Diversity and Impact of Grazing Management on Rangeland Ecosystems in Mbeere District, Kenya. LUCID Working Paper Series Number, p: 36.
36. Tueller PT (1996) Near Earth Monitoring of Range Condition and Trend. Journal of Geocarta 11: 53-62.
37. Diaz-Solis H, Kothmann MM, Hamilton WT, Grant WE (2003) A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazinglands. Agricultural Systems 76: 655-680.
38. Mutanga O, Mansour K, Everson T, Skidmore A, Kumara L (2012) High density biomass estimation for wetland vegetation using WorldView- 2 imagery and random forest regression algorithm. International Journal of Applied Earth Observation and Geoinformation 18: 399-406.
39. Angerer BJ, Han G, Fujisaki I, Havstad K (2008) Climate change and ecosystems of Asia with emphasis on Inner Mongolia and Mongolia. Rangelands 6: 46-51.
40. Bastin GN, Pickup G, Chewings VH, Pearce G (1993) Land degradation assessment in central Australia using a grazing gradient method. Rangeland Journal 15: 190-216.
41. Beymer RJ, Klopatek JM (1992) Effects of grazing on cryptogamic crusts in pinyon–juniper woodlands in Grand Canyon National Park. American Midland Naturalist 127: 139-148.
42. Harris AT, Asner P (2003) Grazing gradient detection with airborne imaging spectroscopy on a semi-arid rangeland. Journal of Arid Environments 55: 391-404.
43. Mwendera EJ, Mohamed MAS (1997) Infiltration rates, surface runoff, and soil loss as influenced by grazing pressure in the Ethiopian highlands. Soil Use and Management 13: 29-35.
44. Pickup G, Chewings VM, Nelson DJ (1993) Estimation changes in vegetation cover over time in arid rangelands using Landsat MSS data. Remote Sensing of Environment 43: 243-246.

45. Fischer G, Hizsnyik E, Prieler S, Wiberg D (2010) Scarcity and abundance of land resources: competing uses and the shrinking land resource base. SOLAW Background Thematic Report – FAO, Rome.
46. Griffin G (2002) Indigenous people in rangelands. In: Global Rangelands: Progress and Prospects. CABI Publishing, New York, USA.
47. Wiegand K, Saltz D, Ward D (2006) A patch dynamics approach to savanna dynamics and woody plant encroachment- Insights from an arid savanna. Perspectives in Plant Ecology, Evolution and Systematics 7: 229-242.
48. Higgins SI, Bond WJ, February EC, Bronn A, Euston-Brown DIW, et al. (2007) Effects of four decades of fire manipulation on woody vegetation structure in savanna. Ecology 88: 1119-1125.
49. Scholes RJ (2009) Syndromes of dry-land degradation in southern Africa. African Journal of Range & Forage Science 26: 113-125.
50. Ainalis AB, Platis PD, Meliadis IM (2009) Grazing effects on the sustainability of an oak coppice forest. Forest Ecology and Management 259: 428-432.
51. Stocking MA, Murnaghan N (2001) Handbook for the field assessment of land degradation. Earthscan Publications Ltd., London, UK, p:169.
52. Meadows ME, Hofmann MT (2002) The nature, extent and causes of land degradation in South Africa: Legacy of the past, lessons for the future? Area 34: 428-437.
53. Smet M, Ward D (2005) A comparison of the effects of different rangeland management systems on plant species composition, diversity and vegetation structure in a semi-arid savanna. African Journal of Range and Forage Science 22: 59-71.
54. Shackleton CM (1993) Are the communal grazing lands in need of saving? Development Southern Africa 10: 65-78.
55. Timberlake JR, Reddy SJ (1986) Potential pasture productivity and livestock carrying capacity over Mozambique. Inst Nac Invest Agronl Publ, Maputo, Mozambique.
56. Toxopeus AG (2000) Rangelands Management: Notes on Rangelands. Unpublished Manuscript.
57. Mapiye C, Chimonyo M, Dzama K, Raats JG, Mapekula M (2009) Opportunities for improving Nguni cattle production in the smallholder farming systems of South Africa. Livestock Science 124: 196-204.