

## Application of Remote Sensing and GIS in Assessment of Rain Use Efficiency and Rangeland Degradation in Central Butana, Sudan

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**Abstract:** Rain use efficiency (RUE) factor is a relationship between the mass of full growth standing crop in the form of dry matter (DM), at the end of the rainy season and the average total annual rainfall. It is expressed in  $\text{kg DM ha}^{-1} \text{ year}^{-1} \text{ mm}^{-1}$ . The spatial distribution of rainfall (mm) in central Butana rangeland was generated from the regression correlation between the rainfall data of eight meteorological stations around the study area and the altitude of these stations ( $R^2 = 0.82$ ). Perpendicular vegetation index (PVI), as one of vegetation monitoring techniques and biomass field survey were used together to generate the spatial distribution of the rangeland biomass production in ( $\text{kg DM ha}^{-1}$ ). The RUE factor of the central Butana area was computed by dividing the biomass layer by the rainfall layer. The results showed that the RUE factor was in the range of 0 to 4 for the rangeland with average value of 2.5, which agreed with Le Houérou (2005) who pointed out that the RUE for the Sahel zone is about 2.7. The low value of RUE was found in the highland at the upper rain water catchment, where water drains very fast to depressions and watercourses. RUE is greater than 4 in areas grown with sorghum because farmers tend to maximize water productivity by many means of water management such as water harvesting. Four classes of RUE in central Butana rangeland were shown by the map of rain use efficiency. The almost desertified areas, which show no production, have RUE from 0 to 1; the high degradation rangeland 1 to 2; the medium degradation rangeland 2 to 3 and the good rangeland condition near rainfed agriculture 3 to 4.

**Key words:** Rain use efficiency • Rangeland biomass • Rainfall • Butana

### INTRODUCTION

Butana area lies in the central clay plains of Sudan. It is situated between the rivers of Rahad, Blue Nile, Nile and Atbara with approximate total area of 120 000  $\text{Km}^2$ . It is located between latitudes  $14^\circ 23'$  and  $17^\circ 34'$  N and longitudes  $32^\circ 32'$  and  $35^\circ 36'$  E. The area is located in the Sahel zone and determined by climatic and ecological transitions from the savannah in the south to the arid Sahara in the north [1]. Based on long-term averages, the area is marked by annual precipitation from less than 50 mm in the North West corner (Atbara) to 600 mm in the South East (Gedarif) [2].

The extreme spatial and temporal variability of rainfall is resulting from the northward drift of the Intertropical Convergence Zone (ITCZ), which leads to unpredictable rainy season and recurring drought events at irregular intervals. The high variability of rainfall also triggers a natural shifting of the vegetation formations by over several hundred kilometres [1]. In addition, [3] stated that the high rainfall variability causes considerable interannual variations of dry matter production in natural pastures of the Sahelian Zones. Generally rainfall is characterized by uneven distribution and long dry spells that affect crops and range vegetation at their

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critical growth and filling stages which leads immediately to a significant reduction in the total production and productivity of the area.

On a seasonal and annual basis, primary production, hence instantaneous or short-term carrying capacity varies greatly depending on local weather conditions, principally rainfall [4]. Variation in primary production is thus closely linked to variation in rainfall amount and distribution and furthermore, variability in both parameters is directly related to aridity in the various arid and semi-arid zones of the world [4]. Many investigators from various parts of the world have attempted to relate range production to rainfall, either on a seasonal or annual basis [5]. Significant to very high significant correlations have been found in the arid and semi-arid zones.

Estimates of aboveground net primary production (ANPP) have been reported for many sites around the world [6]. In recent years relationships between seasonal rainfall and end of season herbaceous biomass have been published for several regions in Africa. For the Sahelo-Sudanian region, data were compiled by [7], who found a very high significant correlation between annual rain and annual range production with  $r = 0.90$  and  $0.89$  for the Mediterranean arid zone and the sahel of Africa, respectively. This was confirmed studies in Mali by Penning de Vries and Djiteye (1982). For Eastern and southern Africa, a relation between annual rainfall and herbaceous biomass were developed by [8] which showed that per unit rainfall biomass production in this region was twice as high as in West Africa. However, similar relations for southern Africa by [9] indicate that productivity of rangelands in Zimbabwe and Botswana is much lower than in East Africa.

The rain use efficiency (RUE) factor is a relationship between the mass of full growth standing crop in the form of dry matter (DM), at the end of the rainy season and the total annual rainfall. It is expressed in  $\text{kg DM ha}^{-1} \text{ year}^{-1} \text{ mm}^{-1}$  [5, 4, 10]. In 1984, Le Houèrou defined the RUE as quotient of annual primary production by annual rainfall, i. e. the number of kilograms aerial dry matter phytomass produced over 1 ha in 1 year per 1 millimeter of rain fallen. It may be expressed in aboveground net primary production, in maximum standing crop (for therophytic or ephemeroïd vegetation types), in herbage yield or in any other production measurement system, as long as the reference system is clearly indicated [5]. If all other conditions remain equal, RUE tends to decrease when aridity increases together with rate of effective rains and as potential evapotranspiration increases. But, it also

strongly depends on soil condition and, more than any thing, on vegetation condition particularly on its dynamic status. It thus greatly relies on human and animal impact on the ecosystem. In any given type of ecosystem RUE is closely linked to perennial aerial phytomass and ground cover. The RUE factor thus appears as a good indicator of ecosystem productivity allowing, furthermore, valid comparisons between ecosystems for various climatic zones or having totally different botanical and structural characteristics [5]. Indicated that the actual RUE figures throughout the arid zones of the world may vary from less than 0.5 in depleted sub desert ecosystems to over 10 in highly productive and well managed steppes, prairies or savannas. Reasonably well managed arid and semi-arid grazing lands are usually in the 3 to 6 range while the biological limit seems reached in heavily fertilized small experimental plots with values approaching 30.

RUE factor for the herbaceous layer in the Sahel was found to be 2.9 for various range types [11], 2.66 for the overall geographical productivity figure [7], with 2.3 as the mean for the three Sahelian ecoclimatic subzones [11].

## MATERIALS AND METHODS

**Study Area:** Butana rangeland is one of the best native pastures in Sudan. It is located in the east central of Sudan and consider during the rainy season (July-October) as an open grazing area for all the herders in the central clay plains. These rangelands experienced very severe degradation resulting from the high variability of rainfall and overgrazing. The study was conducted in central Butana rangeland in a total area of 3600  $\text{km}^2$ , as shown in Figure (1) to assess the current condition of these rangelands by means of rain use efficiency factor.

**Remote Sensing Data:** A variety of data including satellite image, digital elevation model, soil map and various thematic maps obtained from various sources have been used as data sources together with ground field survey that have also been carried out in the same time. SPOTView image dated 5/10/2006 of 10 m resolution was acquired and used in the analysis. The image is a combination of panchromatic and multispectral bands and has three bands Green (G), Red (R) and Near Infra-Red (NIR). The Digital Elevation Model (DEM) (source [www.mapmart.com](http://www.mapmart.com)) Projection UTM 36 N, Datum WGS84), was used to show the spatial topography of the area.

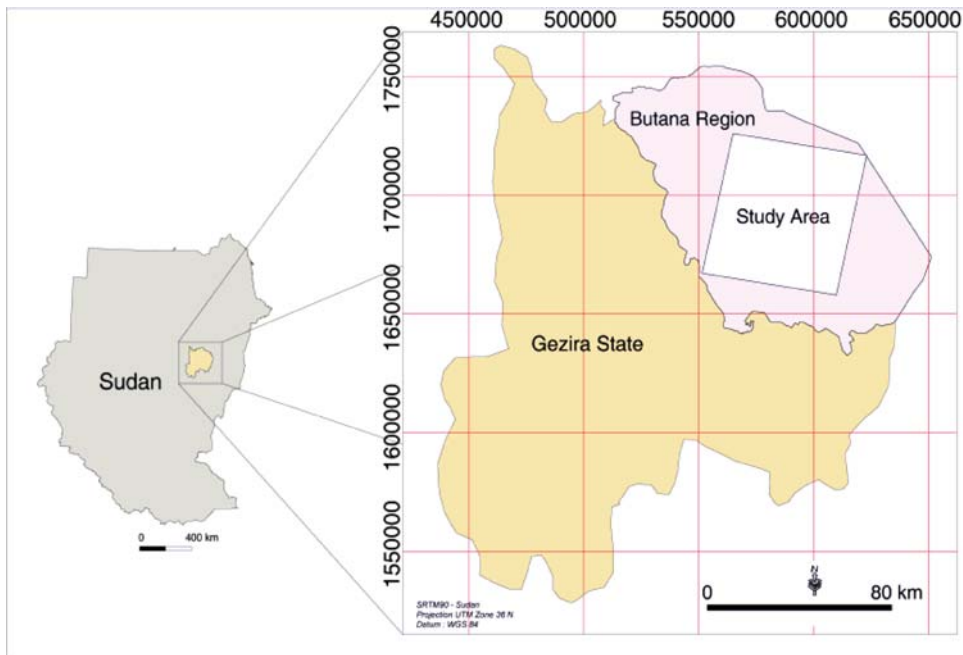


Fig. 1: Location Map of Central Butana Rangeland

**Field Survey Data:** The field survey and data collection was conducted in the study area towards the end of the rainy season of 2006 in the period from 25 September to 10 October. Twenty five points were selected by their coordinates to represent different homogenous ecological zones. Annual plants and biomass is evaluated by aboveground biomass measurement on 1.0 m<sup>2</sup> repeated ten times along and spaced at 10 m intervals (i.e. 100 m long) along an identified GPS location transect. Samples were taken of aboveground part of all vegetation produced during a single growth year, regardless of accessibility to grazing animals (USDA, SCS 1976). The biomass samples had been taken at maturity stage and then taken to the laboratory to be dried and weighted for dry matter determination [12].

**Annual Rainfall:** Central Butana rainfall map was computed from Butana Digital Elevation Model (DEM) and the rainfall data from eight meteorological stations surrounding the area, namely; Wadmedani, Shambat, New halfa, Atbara, Shendi, Elkamlin, Elmasid and Abu-deleig, located around Butana over the period 1981 – 2004. A regression correlation was found between the rainfall data and the altitude of each station, the regression equation was applied in the DEM, in ArcGis 9.1 software, to generate the spatial distribution of the rainfall map.

**Perpendicular Vegetation Index (PVI):** The Perpendicular Vegetation Index, proposed by [13] was defined as the distance from the soil line on a scatter plot of near infrared (NIR) versus red (R) reflectance.

$$PVI = \frac{(NIR - aR - b)}{\sqrt{a^2 + 1}}$$

NIR = Near Infra Red

R = Red

a = Slope of the soil line

b = Intercept point of the soil line

PVI was computed in ERDAS IMAGINE 9.1 software. Thirty eight Points of bare soil (roads and surroundings of haffir) were identified in the field by their coordinates. The mean value of Red (R) and Near Infra Red (NIR) reflectance of these points was obtained from the satellite image and correlated to each other and the regression line of the bare soil line was obtained, the correlation was accurate ( $r^2 = 0.95$ ). From this correlation the slope of the line (a) and the intercept point (b) was obtained and applied in the PVI equation to generate the layer of PVI.

**Biomass Estimation:** The biomass map, which shows the spatial distribution of rangeland biomass in kg ha<sup>-1</sup>, was generated from the field biomass measurements and

PVI. The primary aboveground biomass production was measured as follows; in each 1.0 ha sample plot, the aboveground biomass of all herbaceous species was collected in 25 separate 1.0 m<sup>2</sup> plots [14,15]. Biomass was summed over the different plots in order to obtain the per hectare aboveground biomass production.

The aboveground biomass of eighteen sampling points, covered by satellite image, comprising the central Butana rangeland was determined. The spectral responses of these eighteen points were extracted from Spot View digital data by the mean of PVI. The ground sample points were located on 10 × 10 pixel in PVI map keeping ground sample point in the centre. The value of PVI for each field biomass measurement was extracted. The field biomass measurements of these 18 points were correlated to the mean computed PVI values on 10 x10 pixels (1.0 ha) to compensate for human error on site location.

**Rain Use Efficiency:** The RUE factor of central Butana area was computed by dividing the biomass layer (kg DM ha<sup>-1</sup>) by the average annual rainfall layer (mm) [5,10].

## RESULTS AND DISCUSSION

The statistical analysis of the meteorological data of three stations; Wadmedani in the South, Shambat in the North and New Halfa in the East, are shown in Table (1) and Figure (2). Results showed that there

Table 1: The Trend of the Annual Rainfall and their Probability

Station	Trend	P
Wadmedani	6.16	0.024*
Shambat	9.67	0.015*
New Halfa	8.18	0.011*

Significant at ( $P < 0.05$ )

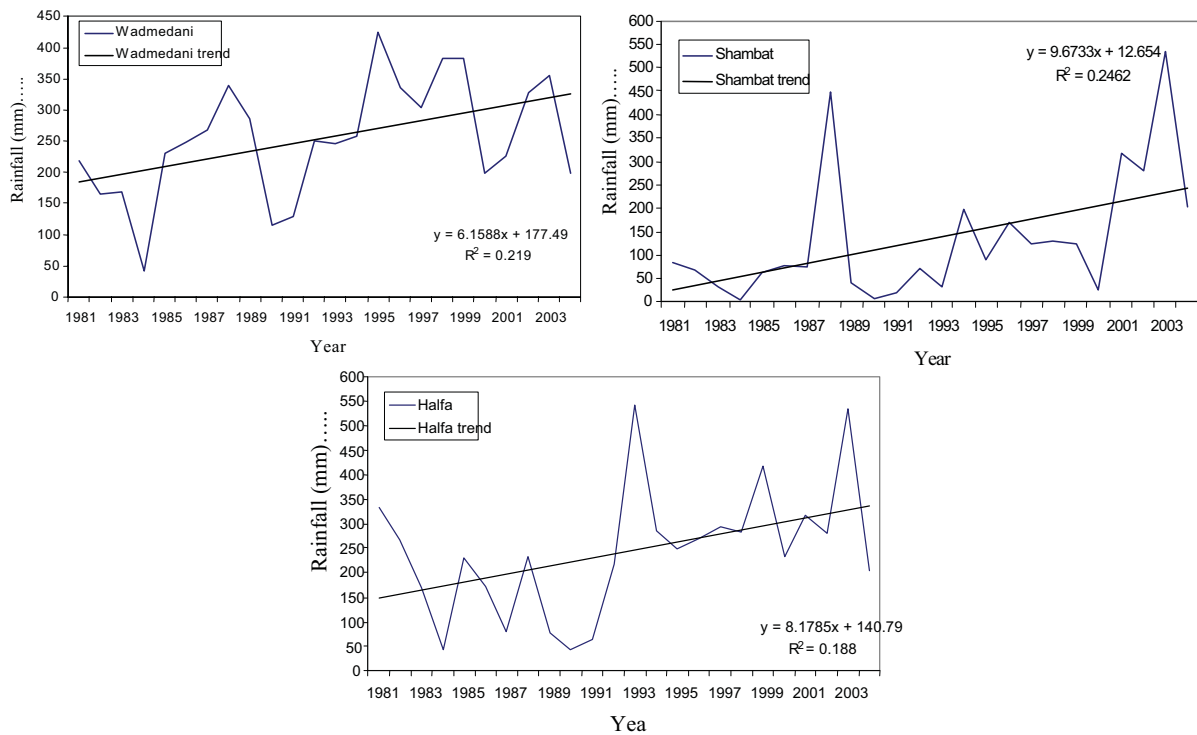


Fig. 2: Annual Rainfall and the Trend Line for the Three Stations surrounding Butana area.

has been a gradual increase in annual rainfall during the period (1981 – 2004), which is statistically significant ( $P < 0.05$ ). The work done by Perry (1986) on the structure of the wet season in the White Nile and central Sudan, demonstrated the virtual collapse in the length, timing and reliability of the wet season from about 1960 onwards [16]. noted that the rainfall decline in the arid zone of central Sudan has continued since 1965 and intensified in the

1980s, but results obtained by [17,18] for these stations and others in central Sudan demonstrate that the rainfall recovery noted in some areas post early 1990s is still below the levels for the period prior to the mid 1960s. This slow recovery from the dry condition is the same results and arguments for the Sahel [19, 20] which suggest that the dry state would tend to persist longer than the wet state.

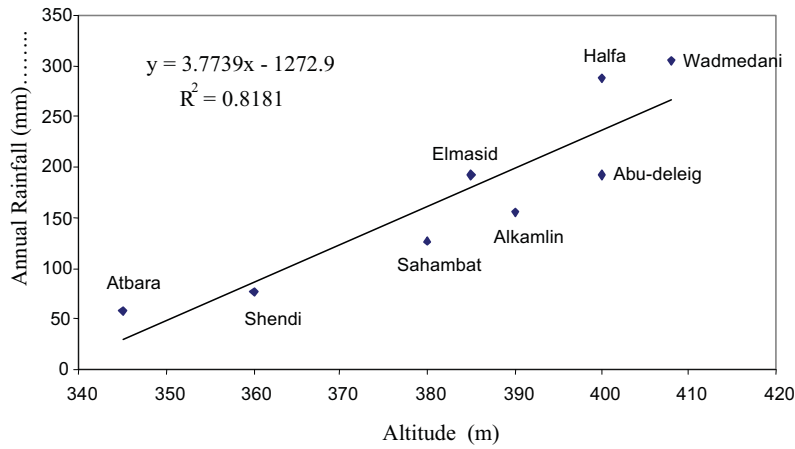


Fig. 3: The Regression Correlation between Annual Rainfall and Altitude of the Meteorological Stations in Butana area

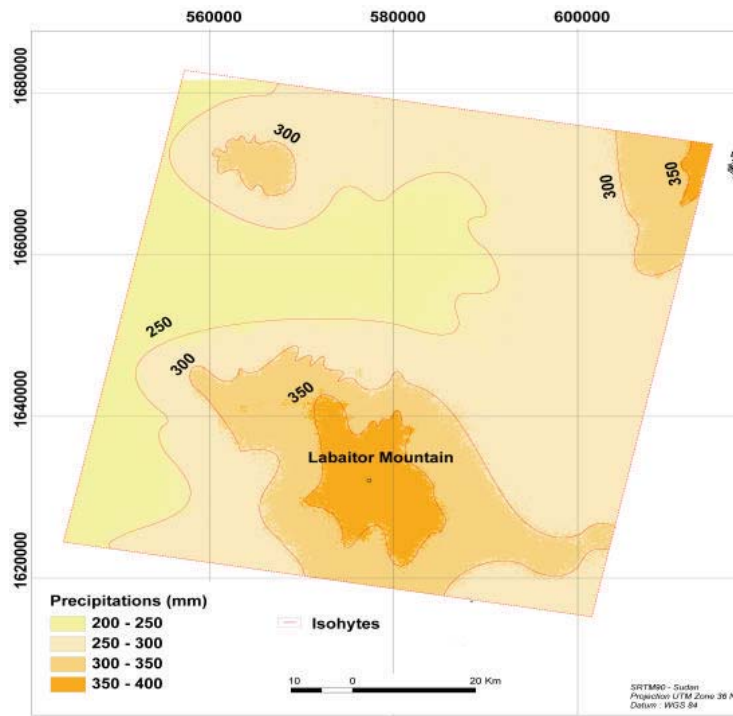


Fig. 4: Rainfall Map of Central Butana Area

The spatial or surface distribution of rainfall was generated from the regression correlation between the recorded annual rainfall in the eight meteorological stations in and around the study area for 24 years from 1981 to 2004 and the altitude of these stations ( $R^2 = 0.82$ ) and plotted in Figure (3). The spatial distribution and the isohyets of rainfall in central Butana area fall within the range of 200 to 400 mm as shown in Figure (4). Since all the stations around the area are classified as dry, [21] stated that in the African belt, the arid region receive annual rainfall between 100 – 400 mm.

The map in Figure (4) showed that the eastern and central part of the area receives annual rainfall between 200 – 250 mm, while the major portion of the western part receives annual rainfall 250 – 300 mm. The areas with high elevation in the southern, north eastern and north western part received annual rainfall between 300 – 350 mm, while the areas around the mountain of Labaitor receive the highest potential annual rainfall 350 – 400 mm. The results from this map and all above figures indicate that the amount of annual rainfall decrease when moving from south to north and east to west, since the general

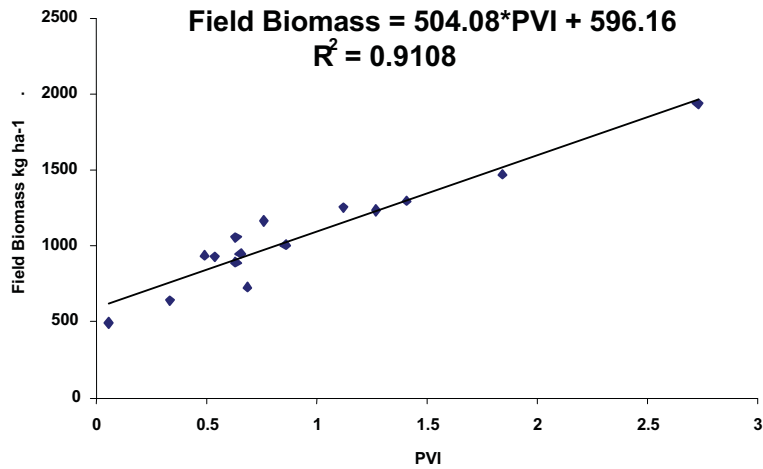


Fig. 5: The Relationship between PVI and Field Biomass

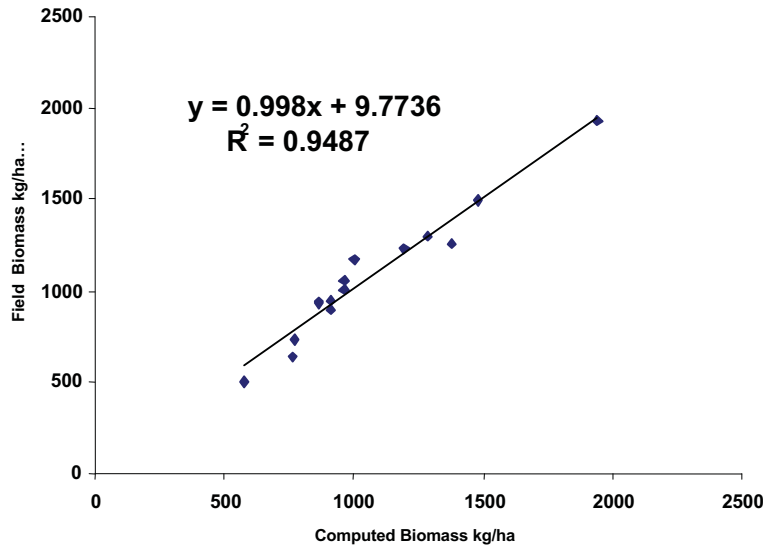


Fig. 6: The Relationship between Computed and Field Biomass

elevation of Sudan tend to decrease towards the north and its justified that the mountain receive potentially the highest amount of rainfall in the area. This result agreed with [22] who stated that as a general rule, one may guess a positive altitudinal gradient of  $10\% \pm 5$  for each increase of 100 m in elevation. Again [23] indicates that in the Sahel, an increase of one mm per km southward from the Sahara border was observed.

Biomass is considered as important components affecting biosphere-atmosphere interactions. The quantification of biomass is required as the primary inventory data to understand changes and productivity of tropical forest and rangeland [24].

The present study, on biomass estimation using remote sensing, attempts to couple ground based

vegetation quantification with the satellite remote sensing data. Earlier studies have investigated the relationship of spectral vegetation indices derived from satellite data to surface vegetation parameters using correlation or regression analysis [25].

The linear relationship between ground measured biomass and PVI values were analysed. Statistically significant model ( $r^2 = 0.91$ ) as shown in Figure (5) was used to prepare regional biomass layer by applying the regression equation in each pixel on PVI layer as shown in Figure (7). Biomass field measurements were correlated with computed biomass value on  $10 \times 10$  pixel to compensate for error on site location and the result was found to be very good ( $r^2 = 0.95$ ) as shown in Figure (6).



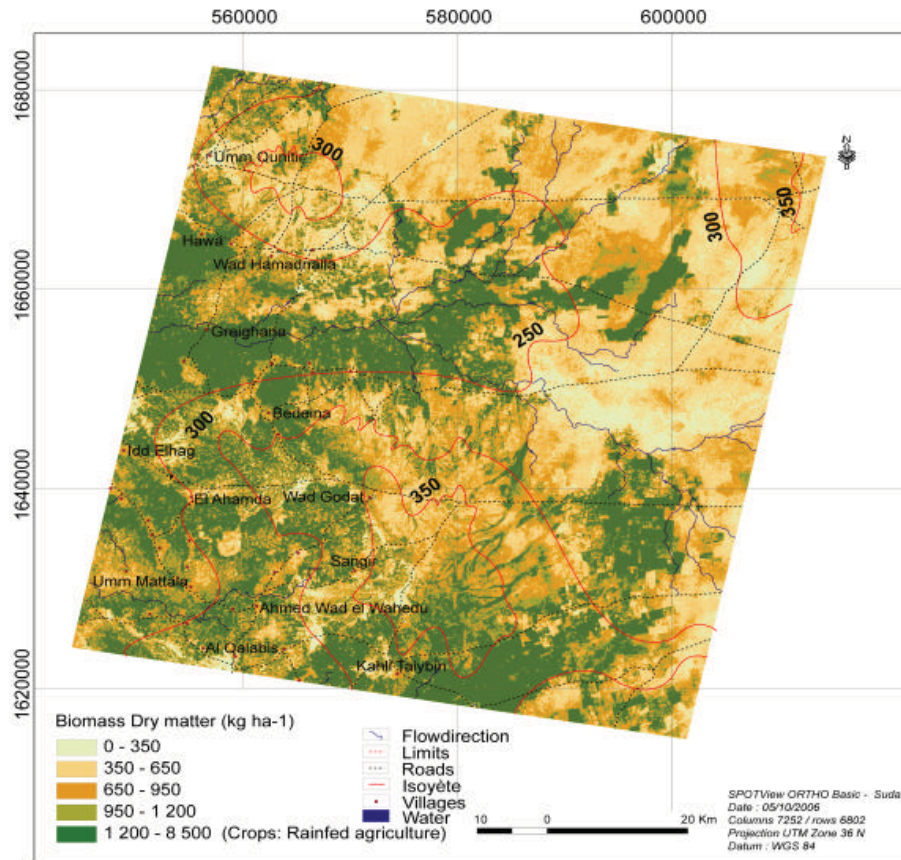


Fig. 7: Biomass Map of Central Butana

The biomass map in Figure (7) showed that the degraded rangeland of central Butana produces from 0 to 350 kg DM ha<sup>-1</sup> year<sup>-1</sup>, while the medium rangeland condition produces from 350 to 650 kg DM ha<sup>-1</sup> year<sup>-1</sup>. The good rangeland condition around water courses and wadis located in depressions and benefiting from runoff and between the rainfed agriculture have seasonal biomass production between 650 to 950 kg DM ha<sup>-1</sup> year<sup>-1</sup>. These results are in accordance with [21] who stated that in hyper arid and semi arid zones of the Sahel, range production is low, most irregular and it is always limited in space to depression, river valleys and water spreading zones. The light and dark green colour is forest and rainfed agriculture, which show high biomass production 950 – 1200 and 1200 – 8500 kg DM ha<sup>-1</sup> year<sup>-1</sup> respectively. The high value of biomass in rainfed agriculture and forest canopy is due to the fact that the satellite image was acquired in the beginning of October. At that time the crop (*sorghum bicolor*) is at maximum vegetative stage, hence giving high reflectance in red and near infra red bands.

The main factor controlling the rangeland production is rainfall; however average rainfall is obviously not the only factor of importance for range production in the Sahelian and Sudanian zones of Africa, average rainfall amount is correlated with a number of other climatic factors such as rain variability, number of rainy days, length of dry and rainy seasons and potential evapotranspiration [7] and other environmental factor such as grazing regimes [26].

The biomass map showed that high grazing pressures have a significant impact on herbaceous biomass production in central Butana rangeland especially around watering points, hence decreasing RUE factor. This confirms the statements of [5, [27] who state that high grazing pressures may affect functioning and productivity of rangelands, in particular in the medium and long term. In arid and semi arid rangelands, primary production, hence carrying capacity, is closely linked to the amount and distribution of rainfall, but variability in annual production appears to be relatively greater than variability in annual rainfall [4].





2. Oliver, J., 1965. Evaporation losses and rainfall regime in central and northern Sudan. *Weather*, 20: 58-64.
3. Pfloumbaum, H., 1994. Rangeland Carrying Capacity in the Butana. *Animal Research and Development*, 39: 41-52.
4. Le Houèrou, H.N., 1988. Interannual Variability of Rainfall and Its Ecological and Managerial Consequences on Natural Vegetation, Crops and Livestock. In: F. Di Castri, C.h. Floret, S. Rambal and J. Roy, (Eds), *Time Scales and Water Stress – Proceedings of the 5<sup>th</sup> International Conference on Mediterranean Ecosystems*, pp: 323-346. Paris: I.U.B.S., pp: 677.
5. Le Houèrou, H.N., 1984. Rain Use Efficiency: A Unifying Concept in Arid – Land Ecology. *J. Arid Environment*, 7: 213-47.
6. Lauenroth, A.W., 1979. Grassland Primary Production: North American Grassland in Perspective. Pages 3-24 In N.R. French, Editor. *Perspectives in Grassland Ecology. Ecological Studies, Volume 32*. Springer-Verlag, New York, USA.
7. Le Houèrou, H.N. and C.H. Hoste, 1977. Rangeland Production and Annual Rainfall Relations in the Mediterranean Basin and In the African Sahelian and Sudanian Zones. *J. Range Management*, 30: 181-189.
8. Deshmukh, I.K., 1984. A Common Relationship between Precipitation and Grassland Peak Biomass for East and Southern Africa. *Afr. J. Ecol.*, 22: 181-186.
9. Rutherford, M.C., 1978. Primary Production Ecology in Southern Africa. In: M.J.A. Werger, (Ed.), *Bibliography and Ecology of Southern Africa*. Dr. W. Junk Publishers, The Hague., pp: 621-659.
10. Gintzburger, G., S. Saidi and V. Soti, 2005. The Rangeland of Ravnina Farm in Turkmenistan: Current Vegetation Condition and Utilization, Darca (Mluri Aberdeen) and Cirad Montpellier, France, pp: 120-32 Figures and Maps.
11. Le Houèrou, H.N., 1989. The Grazing Land Ecosystems of the African Sahel. *Ecological Studies*, 75. Heidelberg: Springer-Verlage., pp: 282.
12. Faichney, G.J. and G.A. White, 1983. *Methods for the analysis of feeds eaten by ruminants*. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia.
13. Richardson, A.J. and C.L. Wiegand, 1977. Distinguishing Vegetation from Soil Background Information. *Photogram. Engineer. Remote. Sensing*, 43: 1541-1552.
14. Mieke, S., 1992. L'évolution de la strate herbacée au cours de la nouvelle sécheresse 1990–1992. Rapport d'une mission à court terme. GTZ, Eschborn, Germany.
13. Richardson, A.J. and C.L. Wiegand, 1977. Distinguishing Vegetation from Soil Background Information. *Photogram. Engineer. Remote. Sensing*, 43: 1541-1552.
15. Mieke, S., 1997. Inventaire et suivi de la végétation dans le périmètre expérimental à Widou-Thiengoly dans le cadre du projet Sénégal-Allemand d'autopromotion pastorale dans le Ferlo (PAPF). Rapport 1997. GTZ, Eschborn, Germany.
16. Walsh, R.P., M. Hulme and M.D. Campbell, 1988. Recent rainfall changes and their impact on hydrology and water supply in the semi-arid zone of the Sudan. *The Geographical J.* 154(2): 181-198.
17. Elagib, N.A. and M.G. Mansell, 2000. Recent Trends and Anomalies in Mean Seasonal and Annual Temperature over Sudan. *J. Arid Environ.*, 45: 263-288.
18. Nicholson, S., 1999. Land surface processes and Sahel climate. *Reviews of Geophysics*, 38(1): 117-139.
19. Nicholson, S.E., B. Some and B. Kone, 2000. An analysis of recent rainfall conditions in West Africa, including the rainy season of the 1997 El Nino and the 1998 La Nina years. *J. Climate*, 13(14): 2628-2640.
20. Le Houèrou, H.N., 2008. *Bioclimatology and Biogeography of Africa*. Springer-verlag, Berlin Heidelberg.
22. Le Houèrou, H.N., 2005. *Atlas of Climatic Diagrams for the Isoclimatic Mediterranean Regions*, pp: 220. Copymania, Montpellier.
22. Le Houèrou, H.N., 1976. *Nature et désertisation. Comité permanent inter-états de lutte contre la sécheresse dans le Sahel. Consultation. CILSS/UNSO/FAO sur le rôle de la foresterie dans un programme de réhabilitation du Sahel*. FAO, Rome, pp: 21.
23. Whittaker, R.H. and G.M. Woodwell, 1971. Measurement of NPP of forests; in *Productivity of forest ecosystems* (ed.) P. Duvigneaud (Paris: UNESCO), pp: 159-175.
24. Tucker, C.J., C.L. Vanpraet, M.J. Sharman and G. Van Ittersum, 1985. Satellite remote sensing of total herbaceous biomass production in the Senegalese Sahel, 1980-1984; *Remote Sensing Environ.*, 17: 233-249.

25. Hein, L., 2006. The Impacts of Grazing and Rainfall Variability on the Dynamics of a Sahelian Rangeland. *J. Arid Environments*, 64: 488–504.
26. Sinclair, A.R.E. and J.M. Fryxell, 1985. The Sahel of Africa: Ecology of a Disaster. *Canadian J. Zoology*, 63: 987-94.
27. Illius, A.W. and T.G. O'Connor, 1999. On the relevance of non-equilibrium concepts to arid and semiarid grazing systems. *Ecological Applications*, 9(3): 798-813.