International Journal of Water Resources and Arid Environments 2(2): 64-77, 2013
ISSN 2079-7079
© PSIPW, 2013

Water Harvesting Model for Improved Rangeland Productivity in Central Butana Rangeland, Sudan

[1]*Elsadig A. Elfaki,* [2]*S. Saidi,* [3]*A.M. Adeeb and* [2]*A. Ickowicz*

[1]Department of Agriculture Engineering,
Faculty of Agriculture Sciences, University of Gezira, Wadmedani, Sudan
[2]Centre De Coopération Internationale En Recherche Agronomique Pour Le Développement (CIRAD),
Campus international de Baillarguet 34398, Montpellier, Cedex 5, France
[3]Water Management and Irrigation Institute, University of Gezira, Wadmedani, Sudan

Abstract: Ecological assessment and evaluation of natural resources of Butana rangeland, east central of Sudan was carried out in the rainy seasons of 2006 and 2007 by using remote sensing and field measurement data. Land use and land cover was evaluated and it was found that the rangeland constitute 44.7% of the area where cropland and forest were 47.8% and 7.5% respectively. The spatial distribution of biomass production (kg ha^{-1}) was generated by the mean of Perpendicular Vegetation Index (PVI) and showed that the degraded rangeland of central Butana, produces 0 to 350 kg DM ha^{-1} $year^{-1}$, while the medium rangeland condition produces 350 to 650 kg DM ha^{-1} $year^{-1}$. The good rangeland condition have seasonal biomass production between 650 to 950 kg DM $ha^{-1}year^{-1}$. Rain Use Efficiency (RUE) factor expressed in kg DM $ha^{-1}year^{-1}mm^{-1}$, showed a range of 0 to 4 kg DM $ha^{-1}mm^{-1}$ with an average value of 2.5 kg DM $ha^{-1}mm^{-1}$. Two seasons experiment of water harvesting, to evaluate the impact of water harvesting on rangeland characteristics, were conducted in Butana area. Six sites were selected according to previous surveys in 2005, three different plots (catchments) sizes (1200, 800, 400 m^2) were designed to catch the rainfall water. The results of these experiments showed a positive impact of water harvesting on rangeland vegetation in term of quantity and quality. A general model for water management was designed to simulate the potential of biomass production under the application of water harvesting techniques in Butana rangeland. The model linked the final results of remote sensing and GIS with the results of field measurements of water harvesting experiment and ground survey. The simulated biomass shows an increase from the range of 350 to 650 kg ha^{-1} yr^{-1} to the range of 2000 to 2200 kg ha^{-1} yr^{-1} in the same area, which increases the rain use efficiency factor from less than 1 to 8 kg ha^{-1} mm^{-1}. The standard Soil Conservation Service - Curve Number model was used to estimate the annual direct runoff potentials in this rangeland and the average potential annual runoff depth in the study area, which covers 3600 km^2, was found 52 mm yr^{-1}. Hence, the total runoff volume was estimated for the whole study area as 187.2 x 10^6 m^3 annually.

Key words: Butana rangeland · Water harvesting · Rangeland biomass · Rain use efficiency

INTRODUCTION

Pastoralism and livestock are significant in Sudan's history as well as its present. The livestock sector in Sudan contributes by 25% of national GDP and provides 20% of the hard currency and 40% of the total nutritional requirement. Livestock sector faces a lot of natural crisis and vulnerability which has a negative impact on this sector such as animal diseases and epidemiology, aridification and desertification, removal of plant cover and traditional pastoralism system. Most of livestock have been managed in natural rangeland in central clay plains of Sudan. Northern Sudan is characterised mainly by desert and semi-desert ecological zones as well as low rainfall savannah. Butana Region is considered to be the best rangeland for nomads in the Northern part of Sudan [1]. The area is located in the Sahel zone and determined by climatic and ecological transitions from the savannah

Corresponding Author: Elsadig A. Elfaki, Department of Agriculture Engineering, Faculty of Agric. Sciences, University of Gezira, P.O. Box: 20, Wadmedani, Sudan. E-mail: sadigelfaki@hotmail.com.

in the south to the arid Sahara in the north [2]. Based on long-term averages, the area is marked by annual precipitation from less than 50 mm in the North to 600 mm in the South [3]. 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, Pflaumbaum [4] stated that the high rainfall variability causes considerable interannual variations of dry matter production in natural pastures of the Sahelian Zones. Generally rainfall in Butana is characterized by uneven distribution and long dry spells that affect crops and range vegetation at their 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 [5]. 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 [5]. The rain use efficiency (RUE) factor, which 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 and expressed in kg DM $ha^{-1}year^{-1}mm^{-1}$ [5, 6, 7], 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. Le Houèrou [6] 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 reached, in heavily fertilized small experimental plots, values approaching 30. RUE factor for the herbaceous layer in the Sahel was found to be 2.9 for various range types [8], 2.66 for the overall geographical productivity figure [9] with 2.3 as the mean for the three Sahelian ecoclimatic sub zones [8].

In dry-lands, production is possible only when additional water is made available for cultivation. With declining investments in irrigation in developing countries, alternative methods, such as soil and water conservation, have become more important in recent decades [10]. Water harvesting is one such technology and is based on the collection and concentration of surface runoff for cultivation before it reaches seasonal or perennial streams [11]. Water harvesting is a broad umbrella definition including all methods for concentrating, storing and collecting surface runoff water in different mediums, for domestic or agricultural uses.

Surface runoff information is required for efficient and better implementation of water harvesting techniques. The in situ measurement of runoff is considered more accurate but cannot be operated anytime and anywhere as required because its expensive, difficult and time-consuming. Therefore, the accurate surface runoff modelling developed can serve this purpose with more convenient and less time consuming. With the advent of spatially distributed hydrologic models, it is possible to model hydrologic and related processes and their interactions with topography, vegetation, soils and climate to better model our environment. A hydrological model is a mathematical simulation of the complex hydrological cycle [12] and is a powerful technique in hydrological system investigation for both research hydrologists and practicing water resources engineers involved in the planning and development of integrated approaches for the management of water resources [13]. Satellite imageries that offer multispectral, temporal and spatial information about the earth features are commonly used to map land cover and land use and its temporal dynamics in water resources studies [14]. Use of a Geographic Information System (GIS) helps to spatially integrate all the parameters of the model [15]. The standard Soil Conservation Service - Curve Number model (SCS-CN) [16] is a versatile and widely used procedure for runoff estimation and its one of the most widely used hydrological model. This method includes several important properties of watershed namely soil's permeability, land use and antecedent soil water conditions which are taken into consideration.

MATERIALS AND METHODS

Study Area: Butana lies in the central clay plains of Sudan and located between latitudes 14° 23' and 17° 34' N and longitudes 32° 32' and 35° 36' E. The study was conducted in central Butana rangeland in a total area of 3600 km², as shown in Figure (1).

Fig. 1: Location Map of Central Butana Rangeland

Data Sources

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. 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) Projection UTM 36 N, Datum WGS84), was used to show the spatial topography of the area.

Field Survey Data: The field survey and data collection was conducted in the study area in the period from 25 September to 10 October. Twenty five points were selected to represent different homogenous ecological zones. Annual plants and biomass is evaluated by aboveground biomass measurement on 1.0 m^2 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 [16]. The biomass samples had been taken at maturity stage and then taken to the laboratory to be dried and weighted for dry matter determination [17].

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, 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 Richardson and Wiegand [18], was defined as the distance from the soil line on a scatter plot of near infrared (NIR) versus red (R) reflectance (equation 1).

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

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 extracted from the satellite image and correlated to each other and the regression line of the bare soil line was obtained, from which the slope of the line (a) and the intercept point (b) was obtained and applied in equation (1) to generate the layer of PVI.

Landuse and Vegetation Map: Remote sensing data (SpotView), dated 5/10/2006, coupled with ground vegetation survey was used to determine the different classes of land use and land cover in central Butana. Spectral reflectance of different landuse and vegetation cover in eighteen field survey points covered by the satellite image was extracted from the image and groups of the vegetation units by the mean of PVI.

Biomass Estimation: The biomass map, which shows the spatial distribution of rangeland biomass in kg ha^{-1}, 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^2 plots [19, 20]. 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, 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^{-1}) by the average annual rainfall layer (mm yr^{-1}) [6, 7].

Water Harvesting Experiment: Six experimental sites namely, Wad nail, Camp1, Camp2, Elsial, Sobohab and Sangir were selected by their coordinates as shown in Figure (1). The first three sites were chosen for clay soil and the last three for sandy clay soil. Rectangular plots (Figure 2) were selected as the layout of the experiment and designed to be parallel to the direction of flow, four different size of plots given the numbers 1, 2, 3 and 4 with the surface area 60x20 m^2, 40x20 m^2, 20x20 m^2 and 20x20 m^2 (control) respectively. The first three plots were considered as separate catchments and totally closed in all sides by earth embankment while the last plot was left open as a control. Each of the first three plots was divided in two main units representing the runoff area and the harvesting area. The experiment was run for two seasons (2006 & 2007). The samples for biomass had been measured on one square meter samples localised on five lines at different locations along the slope. The aboveground biomass had been taken at maturity stage and taken to the laboratory for dry matter determination [17].

Runoff Estimation

Soil Map and Hydrological Soil Group (HSG): The soil map of central Butana rangeland was acquired from Agricultural Research Station (ARC) and digitized in GIS and the Hydrological Soil Group (HSG) was determined according to soil characteristics. United States Soil Conservation Service (SCS) has classified the soils of the world into four hydrologic groups; these have been given symbols of A, B, C and D [21]. The classification is based on the infiltration rate which is obtained for a bare soil after prolonged wetting. The characteristics of these four groups are summarized in Table (1).

Drainage Map: The Digital Elevation Model (DEM) of the study area was used as input data in ArcGis 9.1 software. In ArcToolbox, spatial analyst tool, hydrology option was selected to delineate the watershed boundaries and create the stream network of the drainage system.

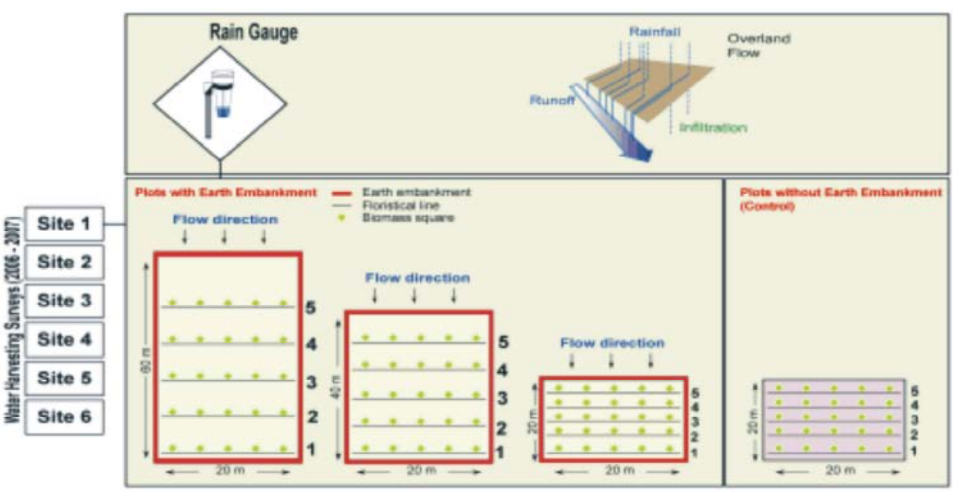

Fig. 2: Layout of the Water harvesting Experiment

Table 1: Hydrologic Soil Groups

Soil Group	Characteristics
A	Low overland flow potential, High minimum infiltration capacity even when thoroughly wetted (> 0.76 cm/h),
	Deep, well to excessively drained sands and gravel.
B	Moderate minimum infiltration capacity when thoroughly wetted (0.13-0.76 cm/h)
	Moderately deep to deep, Moderately to well drained, Moderately fine to moderately coarse grained (e.g. sandy loam).
C	Low minimum infiltration capacity when thoroughly wetted (0.13-0.38 cm/h)
	Moderately fine to fine grained soils or soils with an impeding layer (fragipan).
D	High overland flow potential, Very low minimum infiltration capacity when thoroughly wetted (< 0.13 cm/h),
	Clay soils with high swelling potential, Soils with permanent high water table, Soils with a clay layer near the surface,
	Shallow soils over impervious bedrock.

Source: [21]

Table 2: Runoff Curve Numbers

	Hydrologic Soil Group			
Land Use, Crop and Management	A	B	C	D
Row Crops, poor management	72	81	88	91
Row Crops, conservation management	65	75	82	86
Small Grains, poor management	65	76	84	88
Small Grains	61	73	81	84
Meadow	55	69	78	83
Pasture, permanent, moderate grazing	39	61	74	80
Woods, permanent, mature, no grazing	25	55	70	77
Roads, hard surfaces and roof areas	74	84	90	92

Source: [22]

Runoff Depths: The standard Soil Conservation Service - Curve Number model (SCS-CN) [22] is based on the following relationship between rainfall depth, P, in millimetres and runoff depth, Q, in millimetres as shown in equation (2).

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad (2)$$

$$(Q = 0, IF, P\angle 0.2S)$$

The potential maximum retention, S, in millimetres, represents an upper limit of the amount of water that can be abstracted by the watershed through surface storage, infiltration and other hydrologic abstractions. For convenience, S is expressed in terms of a curve number (CN) as shown in equation (3).

$$S = \frac{25400}{CN} - 254 \quad (3)$$

CN is a dimensionless watershed parameter ranging from 0 to 100 (Table 2). A CN of 100 represents a limiting condition of a perfectly impermeable watershed with zero retention and thus all the rainfall becoming runoff; on the other hand CN of zero conceptually represents the other extreme, with the watershed abstracting all rainfall with no runoff regardless of the rainfall amount.

RESULTS AND DISCUSSION

Ecology and Natural Resources Assessment

Rainfall: 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, Le Houérou [23] 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

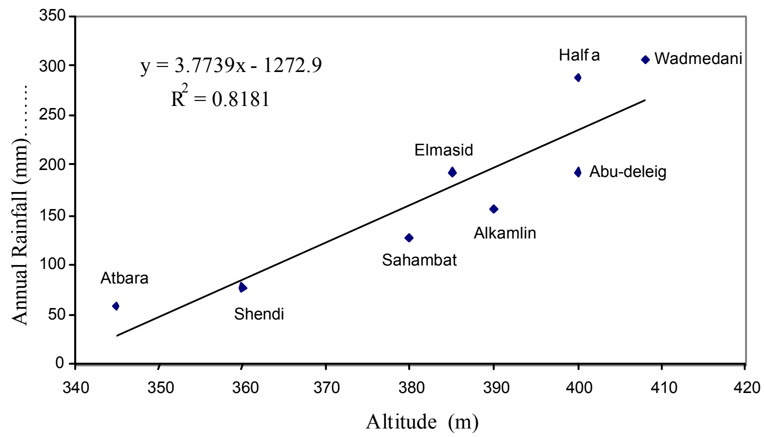

Fig. 3: The Regression Correlation between Annual Rainfall and Altitude of the Meteorological Stations in Butana area

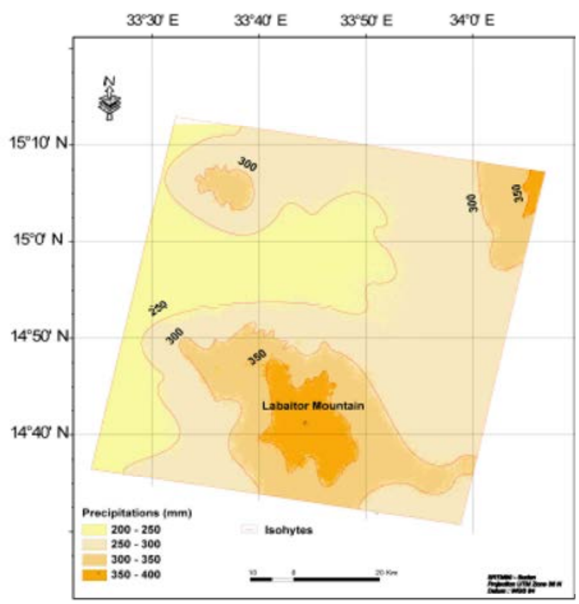

Fig. 4: Rainfall Map of Central Butana Area

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 indicate that the amount of annual rainfall decrease when moving from south to north and east to west. Since the general elevation of Sudan tend to decrease towards the north, it is justified that the mountains receive potentially the highest amount of rainfall in the area. This result agreed with Le Houérou [24] who stated that as a general rule, one may guess a positive altitudinal gradient of 10% + 5 for each increase of 100 m in elevation.

Landuse and Vegetation Pattern: A visual interpretation of PVI was done to differentiate between different landuse type and vegetation units. Different values and classes of PVI represents different land use pattern. The lowest value of PVI was found in water bodies (haffirs), which cover approximately 0.01% of the total area and determined precisely by checking all the pixels cover all around haffirs. The next class to water is bare soil around water points and in the high pressure grazing areas. The third class is rangeland vegetation from which the extreme low value of PVI represents the degraded and poor condition of rangeland around water points and most of the high land and the high value is for good condition rangeland in water courses and adjacent to rainfed agriculture sector. The last PVI class represents the rainfed agriculture and reserved forests. The wide range of this class started from sparse sorghum fields to well mechanized and water managed fields. The reserved forest, which occupied the south western part of the area, showed the same value of rainfed agriculture PVI and precise mapping of these forests was done by visual interpretation. The extreme limits value of PVI of each class was applied in the general model in Figure 4 to generate the spatial pattern of landuse.

Figure (5) explained that there are three main classes of land use in central Butana. Crop land, shown in green colour, comprises the large portion of the study area with the total area of 1695 km^2 (47.8%). The main crop grown in this area is sorghum, which constitute the main source of food for all people living in Butana. Beside that, the crop residue is kept as fodder for animals in the summer season. The second landuse type is rangeland which covers approximately 44.7 % of the total area with a surface area of 1583 km^2. The last landuse type is forest, shown in brown and located in the south western side of the study area and covers an area of 264 km^2 (7.5%).

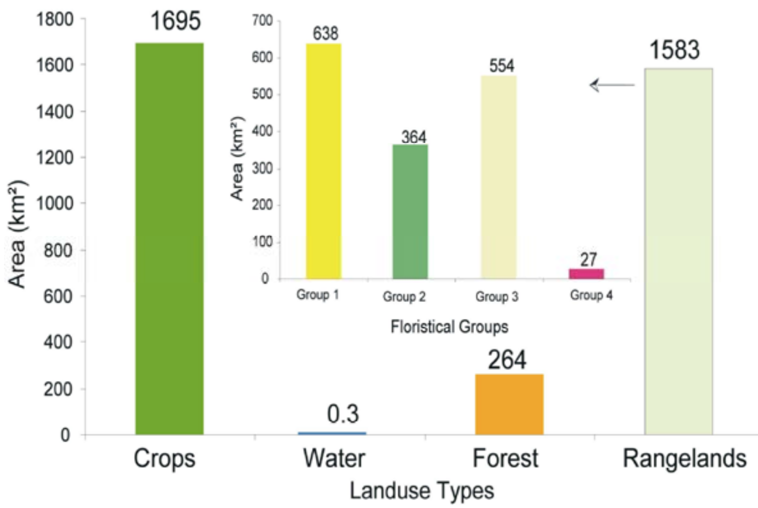

Fig. 5: Landuse Type and Floristical Groups of Central Butana Rangeland

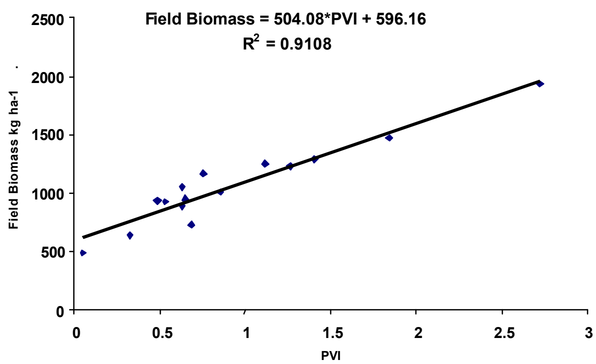

Fig. 6: The Relationship between PVI and Field Biomass

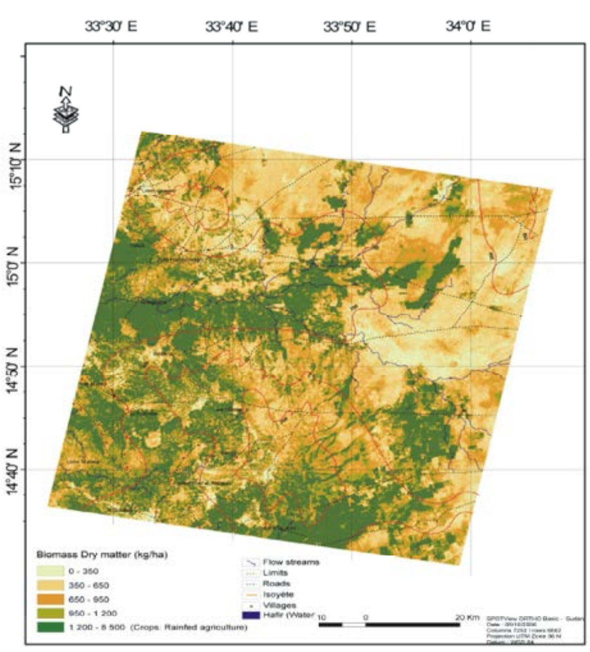

Fig. 7: Biomass Map of Central Butana

Biomass Estimation: 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 [18, 25]. The linear relationship between ground measured biomass and PVI values were analysed. Statistically significant model ($r^2 = 0.91$) as shown in figure (6) was used to prepare regional biomass layer by applying the regression equation in each pixel on PVI layer as shown in Figure (7).

The biomass map in Figure (7) showed that the degraded rangeland of central Butana produces from 0 to 350 kg DM ha^{-1} year^{-1}, while the medium rangeland condition produces from 350 to 650 kg DM ha^{-1}year^{-1}. 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^{-1} year^{-1}. These results are in accordance with Le Houérou [23] 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^{-1} year^{-1} respectively.

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 [9] and other environmental factor such as grazing regimes [26].

The spatial distribution of RUE factor in central Butana rangeland indicated that the RUE factor is in the range of 0 to 4 for the rangeland with an average value of 2.5, which agreed with Le Houérou [5] who stated that the RUE for the Sahel zone is 2.7. The low value of RUE was found in the high land at the upper rain water catchment, where water moves very fast to depressions and water courses. In areas grown with sorghum, RUE is greater than 4 because farmers tend to maximize water productivity by many means of water management such as water harvesting.

The results of this study proved that the current situation of central Butana rangeland showed a very high degradation as indicated by the RUE factor, which has resulted from the high variability of rainfall and high pressure of animal grazing especially in the rainy season. Future development of this rangeland could take place through application of many strategies such as soil and water conservation in term of rain water harvesting to maximize the efficient use of rainfall and increase the rain use efficiency.

Impact of Water Harvesting Application: The results of this experiment proved that there is great potential of water harvesting as a methodology to overcome the problem of water shortage due to the long dry spells occurring from the high variability of rainfall in the arid and semi arid regions of Butana area in Sudan.

The production of rangeland biomass differs from site to site as it's greatly affected by the amount of rainfall (Table 3), type of soil and vegetation cover. The last site (Wad nail) shows a very high biomass production compared to other five sites and this due to the fact that this site is located in the southern heavy clay soil, hence receiving the highest amount of rainfall and also the dominant grass in this site is the Nal (*Cymbopogon nervatus*) which is relatively very high and dense grass.

Table 3: Total Annual Rainfall for the Six Experimental Locations

	Total Annual Rainfall in (mm)	
Site Name	2006	2007
Wad Nail	310	286
Elsial	230	223
Camp1	241	226
Sangir	199	186
Sobohab	190	207
Camp2	225	218
Average	233	224

Both seasons show high biomass production (Table 4) as a result of water harvesting technique, however the biomass is less in season 2007 because most of the rainfall occur in the beginning of the rainy season, 71% of rainfall from late June to late July, followed by long interval showers in August, September and October.

The effect of plot area on biomass, harvested water, soil moisture and number of species in both seasons is clearly explained in Figure (8). The mean value of biomass, harvested water, soil moisture and number of species show a very high significant difference between different plots areas (*$P \leq 0.01$*) with a positive high significant correlation (*$P \leq 0.01$*) except for the number of species which was unlikely found with negative correlation with biomass (*$P \leq 0.05$*), however the difference is not significant between plot (1 & 2) and (3 & 4). In five sites from six sites, it was found that the normal condition represented by control plot produce higher biomass than plot (4) with a surface area of 400 m^2, this result showed that the water harvested in this plot is not sufficient to grow more vegetation compared to the control plot which receives more water by runoff from adjacent areas.

Since the main objective of this study is to produce more biomass and maximize the water productivity to improve the carrying capacity of Butana rangeland and gives better chance to increase the abundance of palatable species, it was found that the production of biomass is a function of harvested water, which depend on the size and design of water harvesting catchment.

Table 4: Mean Biomass Production (ton ha^{-1}) in six Experimental Sites

	2006			2007		
Site	Mean	Std	SE	Mean	Std	SE
Wad nail	2.84	1.53	0.17	2.09	1.21	0.12
Elsial	1.32	0.55	0.06	0.97	0.29	0.03
Camp1	1.32	0.62	0.07	1.03	0.43	0.04
Sangir	1.20	0.84	0.09	0.92	0.41	0.04
Sobohab	1.47	0.82	0.09	0.98	0.44	0.04
Camp2	1.57	0.77	0.09	1.05	0.57	0.06

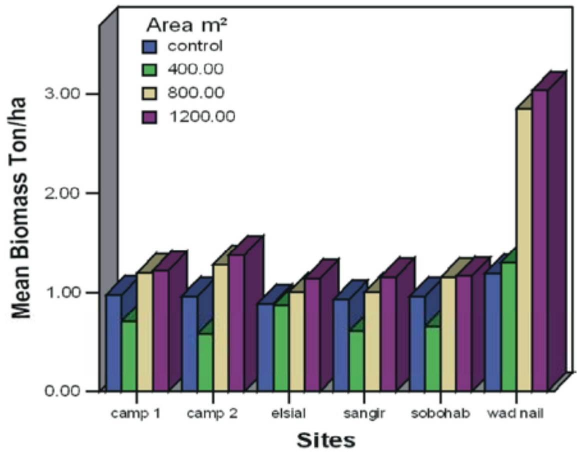

Fig. 8: Average Biomass Production in Different Sites and Different Plot Areas

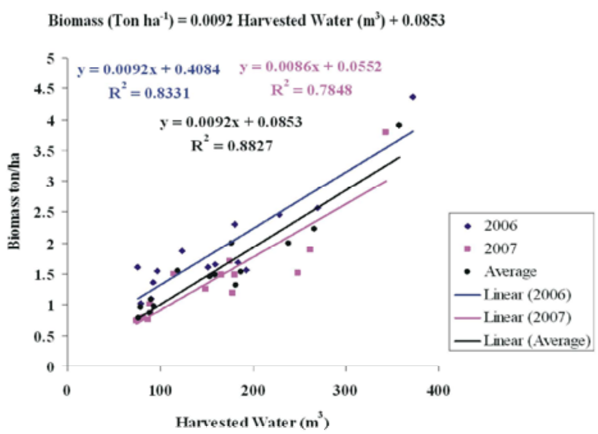

Fig. 9: The Relationship Between Biomass and Harvested Water

The data of biomass production under water harvesting techniques in the six locations were correlated to the value of harvested water in the two seasons as explained in Figure (9). The results showed positive highly significant correlation between biomass production and harvested water (r^2 = *0.88*). A first order equation represents this function for the average biomass and average harvested water was obtained.

However this two seasons result will not be considered as a general model for rangeland water harvesting biomass in Butana area, but it gives a positive indicator to improve the rangeland characteristics in term of quantity and quality. The result indicate that harvesting in catchment less 400 m^2 is not recommended, however harvesting in catchment 800 m^2 and above gives satisfactory results, but should be put in consideration the construction works needed for large catchment area harvesting. The potential of water harvesting for rangeland biomass in Butana could be more than was founded in this study and the success of it's application needs further information concerning the suitable areas, soil type, rainfall map, catchment size, construction requirement, public awareness and social acceptance. For homogenous utilization of rangeland resources, water harvesting for biomass must be accompanied by channel runoff harvesting for drinking water points.

Potential Runoff Estimation

Drainage Watershed Delineation and the Drainage Network: ESRI's ArcHydro tool is used for extracting the watershed area from the DEM by using hydrological model. That is basically the watersheds of central Butana,

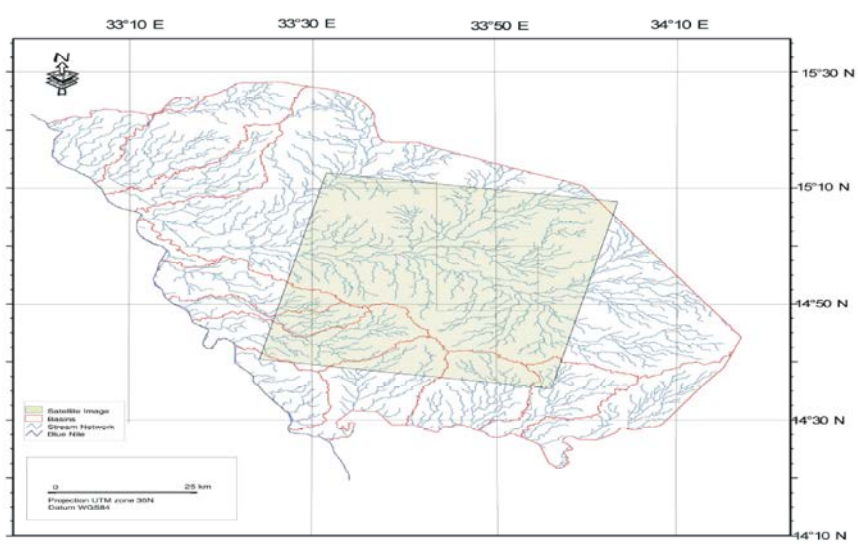

Fig. 10: Drainage System Map of Central Butana

which shown in Figure (10), the map shows that Butana is a compound of a number of catchments different in size, orientation and other hydrological characteristics. Central Butana is covered by a very big catchment which has a relatively long drainage network which starts at the borders of the area in the east and accumulates towards the west to form the catchment outlet on the Blue Nile. Many other small catchments were recognized in the area. Each watershed is a compound of a number of small basins, which accumulate together according to the slope and direction of the flow to form the watershed.

Hydrological Soil Group (HSG) and Curve Number (CN): Hydrological soil groups (HSG) of central Butana were determined on the basis of information from the basic soil map of Butana. The soil map was digitized in GIS and HSG was determined according to soil characteristics and Table (1). Four groups of HSG are found in Butana area, namely; A, B, C and D [27]. The HSG of the Central Butana rangeland shown in figure (11) indicated that the HSG (C) occupied almost 60 % of total area followed by HSG (D), which covers 30 % and HSG (B) and HSG (A) are 9 and 1%, respectively.

Information on land use and pattern of their spatial distribution is one of the criteria used for selecting a curve number (CN) [27]. Three major land use classes namely; crop land (47.9%), rangeland (44.7%) and forest (7.5%) are observed Butana rangeland.

As the SCS-CN method is very sensitive to CN value, accurate determination of this parameter is very important [27]. In each watershed, the combination or intersect between HSG and land use was assigned a special CN value, ranging from 0 to 100, extracted from Table (2). The maximum value of CN was found to be 88, while the minimum was 25 and the average value was 75. The result of the CN map in Figure (12) showed that 31.5 % of the CN values in the study area are found within the range of 80 to 88, 52.6% in the range of 70 to 76 and only 0.1% are between 60 to 69 and the rest of the area is less than 60. Forty percent of the area is dominated by CN value of 74, which represents in most cases the rangeland area around and in between the rainfed agriculture, while 22.4% of the area was covered by CN value 84, which represent the high potential runoff area used in rainfed agriculture. The rest values of CN are less contributing and they are less than 10% of all values.

Annual Runoff Potential: The spatial distribution of annual runoff depths was displayed in Figure (13) which showed big variation from the minimum annual potential

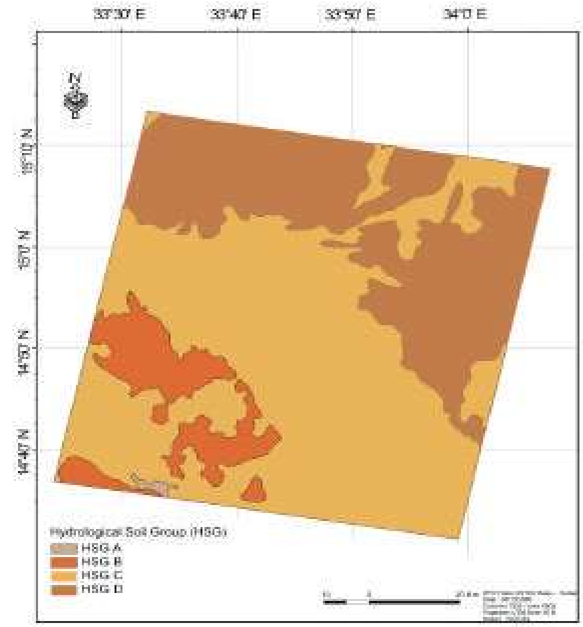

Fig. 11: Hydrological Soil Group (HSG) of Central Butana Rangeland

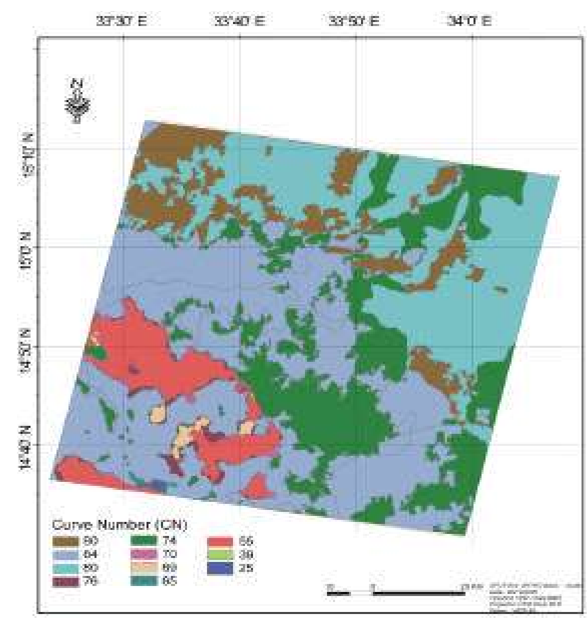

Fig. 12: Curve Number (CN) of Central Butana Rangeland

runoff of 13 mm yr^{-1} in the forest to the maximum amount of 64 mmyr^{-1} in some areas usually occupied by rainfed agricultural activities. According to Blokhuis [28], who noted that the reddish sandy clay soils (goz) showed an open growth of trees with much different types of Acacia species mainly seyal (*Acacia tortilis*) and sparse shrubs and grass covered surface, the lowest annual runoff

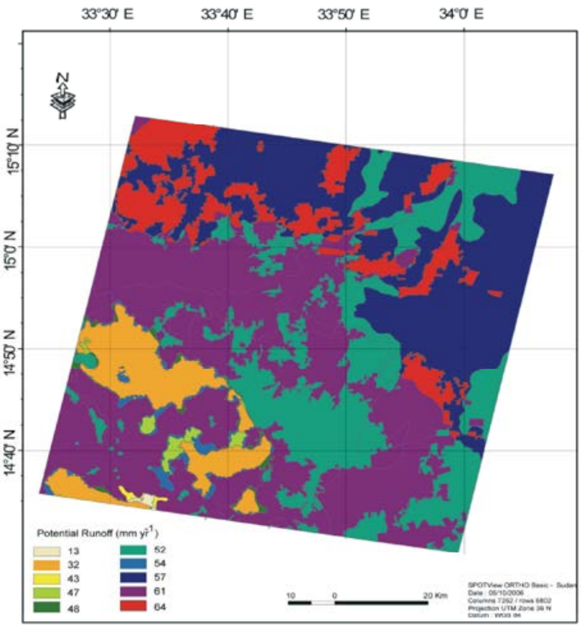

Fig. 13: Runoff Potential of Central Butana Rangeland

potential was observed in the forest area which dominates the reddish sandy clay soils and produced the minimum potential of runoff (13 to 32 mmyr^{-1}) as shown in figure 13. This was due to the fact that the sandy soil shows high infiltration rate values and also the dense canopy of trees increases the interception and water losses through evaporation. The rainfed agriculture areas in the central part and the open rangeland in the centre, north and east, dominated by clay soils, produce high to moderate runoff potential (61 to 64 mm yr^{-1}).

The average potential runoff depth in the study area, which covers 3600 km^2, is 52 mm. Hence, the total runoff volume was estimated for the whole study area as 187.2 x 10^6 m^3 annually. This water is sufficient to support 10 millions animal units and human for nine months at a consumption rate of 30 litres per individual per day and a loss of half the quantity by evaporation and deep percolation. If this water is captured it is sufficient to cause dramatic improvements in the livelihood of Butana people and the herder community.

General Model: A general model for water management, which uses the output results of remote sensing data, ground survey and water harvesting experiment findings in the central Butana rangeland, is designed to simulate the potential of biomass production in this rangeland. The model linked the final results of remote sensing and GIS, which include rainfall map, PVI, biomass map, rain use efficiency map and drainage map, together with the results of field measurements of water harvesting experiment and ground survey as illustrated in Figure (14).

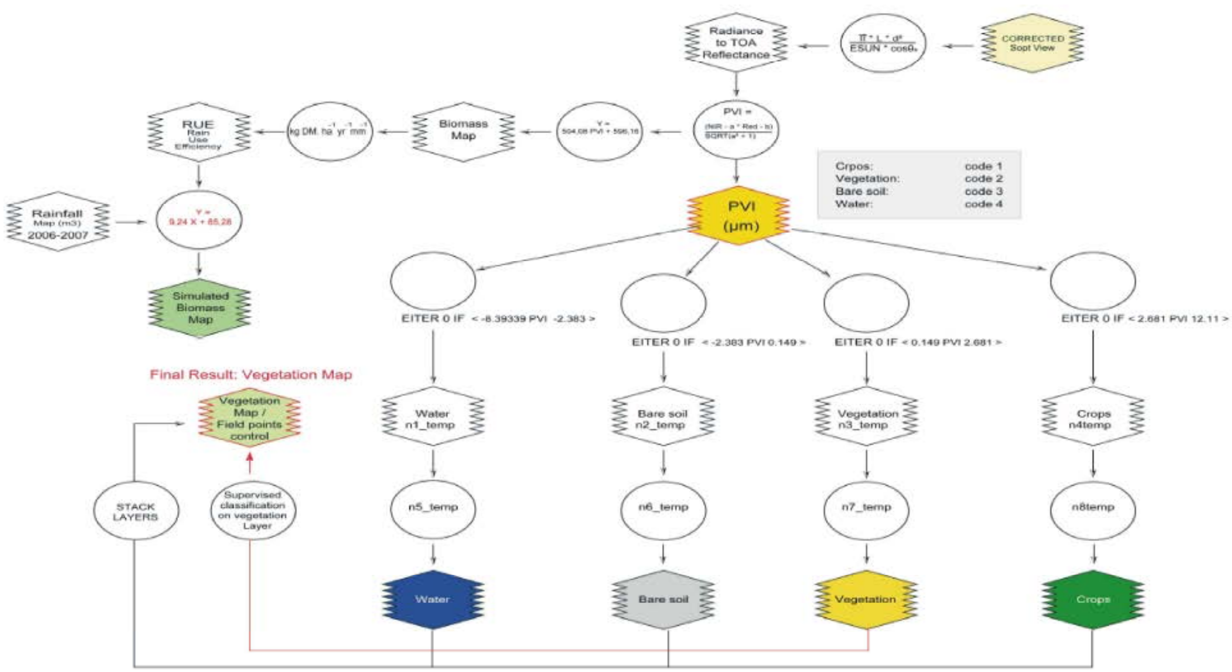

Fig. 14: General Model of Water Harvesting Simulated Biomass

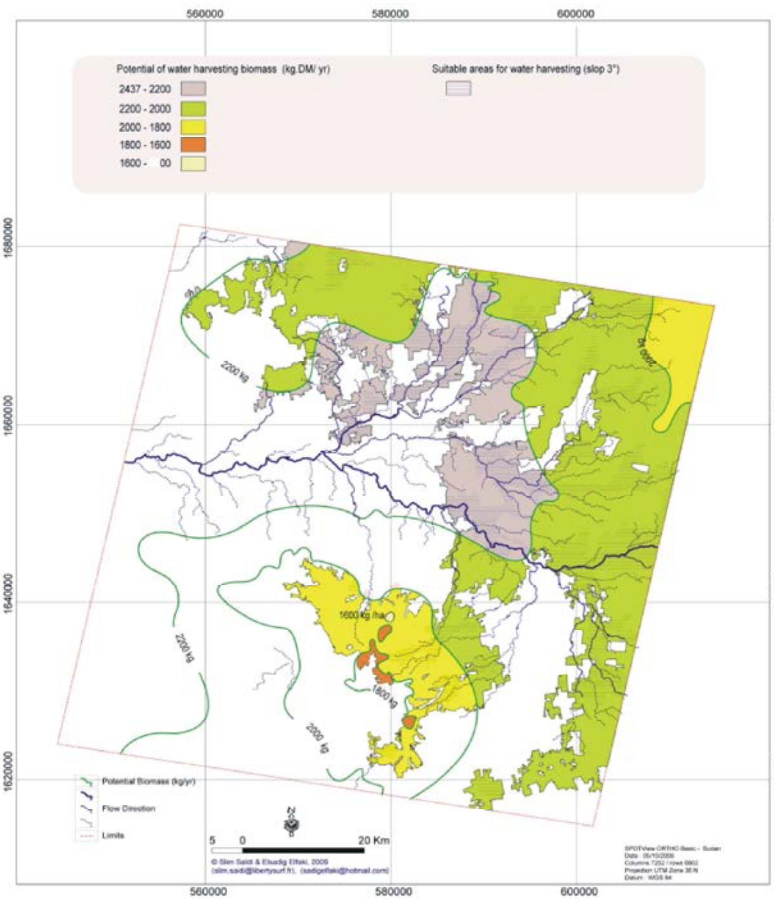

Fig. 15: Water Harvesting Simulated Biomass

Spot satellite image was used as input data from which the PVI was generated. PVI and biomass ground survey were linked together to create the current spatial distribution of biomass production in Kg DM ha^{-1}. The biomass map was divided by the annual rainfall to get the actual rain use efficiency in kgDM ha^{-1} year^{-1} mm^{-1}. Water harvesting experiment results showed that the biomass production, in low rain use efficiency or degraded rangeland, is a function of harvested water as shown in Figure (9). The average rainfall map of seasons 2006 and 2007 in (mm) was converted to rainfall map in (m^3/m^2) in the six water harvesting sites using linear correlation between the rainfall in (mm) and the harvested water data in each site in (m^3). Figure (9) and rainfall map (m^3) were used together to simulate the potential of rangeland biomass production resulting from water harvesting application.

Figure (15) shows the simulated biomass which can be produced in central Butana rangeland under application of water harvesting, as one of the promising water management techniques. The western part of the area, which is shown in white colour, is excluded because it represents the rainfed agriculture and the rest of the area was divided into different homogenous simulated biomass according to rainfall map and potential of runoff. The green colour sector shown in Figure (15) represents the increase in dry matter production in the most degraded areas of the rangeland from the range of 350 to 650 kg ha^{-1} yr^{-1} to the range of 2000 to 2200 kg ha^{-1} yr^{-1}, which increases the rain use efficiency ratio from less than 1 to 8 kg ha^{-1} mm^{-1}. In some areas near the drainage network the dry matter production reaches its maximum (2400 kg ha^{-1} yr^{-1}). The RUE factor clearly indicates the degraded area in which application of water harvesting is much appropriate. The drainage and potential runoff maps have given general orientation about the catchment characteristics to select the suitable areas for water harvesting shown in Figure (15) by shadowy areas along the drainage network. The PVI is used through the model to determine the land use and vegetation pattern in the area which has great influence on runoff inducement.

REFERENCES

1. Hamad, M.E., M.B. Hussein, A.I. Elhagwa and A.A. Elmubarak, 1992. Butana Survey for Evaluation of Land Degradation. L.W.C.R. (ARC) Wad Medani, Sudan.
2. Akhtar, M., 1994. Geo-Ecosystems and Pastoral Degradation in the Butana. Animal Research and Development, 39: 17-26.
3. Oliver, J., 1965. Evaporation losses and rainfall regime in central and northern Sudan. Weather, 20: 58-64.
4. Pfloumbaum, H., 1994. Rangeland Carrying Capacity in the Butana. Animal Research and Development, 39: 41-52.
5. 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 5th International Conference on Mediterranean Ecosystems, pp: 323-346. Paris: I.U.B.S. pp: 677.
6. Le Houèrou, H.N., 1984. Rain Use Efficiency: A Unifying Concept in Arid - Land Ecology. Journal of Arid Environment, 7: 213-47.
7. 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.
8. Le Houèrou, H.N., 1989. The Grazing Land Ecosystems of the African Sahel. Ecological Studies, 75. Heidelberg: Springer-Verlage, pp: 282.
9. 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. Journal Of Range Management, 30: 181-189.
10. Turral, H., 1995. Recent Trends in Irrigation Management. Changing Directions for the Public Sector. Natural Resource Perspectives No.5. London, UK. ODI., pp: 4.
11. Reij, C., P. Mulder and L. Begemann, 1988. Water Harvesting For Plant Production. World Bank Technical Paper No. 91, Washington D.C., USA.
12. Athanassios, B., B. Evangelos and M. Maria, 2006. Rainfall-Runoff Modelling For an Experimental Watershed of Western Greece Using Extended Time-Area Method and GIS. Journal of Spatial Hydrology, 6: 93-104.
13. Webler, T. and S. Tuler, 1999. Integrating Technical Analysis with Deliberation in Regional Watershed Management Planning, Applying the National Research Council approach. Policy Studies Journal, 27(3): 530-543.
14. Schultz, G.A. and E.T. Engman, 2000. Remote Sensing In Hydrology and Water Management, Springer, Berlin, 483, Germany.
15. Gangodagamage, C. and S.P. Agrarwal, 2001. Hydrological Modelling Using Remote Sensing and GIS, 22nd *Asian Conference On Remote Sensing*, 5-9th November, Singapore, Organised By Centre For Remote Imaging, Sensing and Processing, National University Of Singapore.
16. USDA, SCS (United States Department of Agriculture, Soil Conservation service). 1976. National range handbook. Washington, D.C., USA.
17. 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.
18. Richardson, A.J. and C.L. Wiegand, 1977. Distinguishing Vegetation from Soil Background Information. Photogram. Engineer. Remote. Sensing, 43: 1541-1552.
19. Miehe, 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.
20. Miehe, S., 1997. Inventaire et suivi de la végétation dans le périmètre expérimental à Widou-Thiengoly dans le cadre du projet Sénégalo-Allemand d'autopromotion pastorale dans le Ferlo (PAPF). Rapport 1997. GTZ, Eschborn, Germany.
21. Dingman, L.S., 1994. *Physical Hydrology*, Prentice-Hall, Inc, New Jersey, USA.
22. USDA, SCS (United States Department of Agriculture, Soil Conservation Service), 1972. National Engineering Handbook. Hydrology Section 4. Chapters 4-10. Washington, D.C.: USDA.
23. Le Houérou, H.N., 2008. Bioclimatology and Biogeography of Africa. Springer-verlag, Berlin Heidelberg.
24. Le Houérou, H.N., 2005. Atlas of Climatic Diagrams for the Isoclimatic Mediterranean Regions. Copymania, Montpellier, pp: 220.
25. 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.

26. Hein, L., 2006. The Impacts of Grazing and Rainfall Variability on the Dynamics of a Sahelian Rangeland. Journal of Arid Environments, 64: 488-504.
27. Ramakrishnan, D., D.H.V. Rao and K.C. Tiwari, 2008. Integrated Approach of Remote Sensing and GIS in Delineation of Sites for Water Harvesting Structures, Kali Watershed, Dohad, Gujarat, India: Geocarto International, 23(2): 95-108.
28. Blokhuis, W.A., 1993. Vertisols in the Central Clay Plains of Sudan / W.A. Blokhuis-Iii Thesis Wageningen, The Netherland.