Rain Water Management Model for Improved Rangeland Productivity in Central Butana, Sudan

BY

ELSADIG AHMED ELFAKI ABDALLA

B. Sc. (HONOURS) AGRIC. SCIENCES, UNIVERSITY OF GEZIRA, (1996)

M. Sc. WATER MANAGEMENT, UNIVERSITY OF GEZIRA (2000)

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ELSADIG AHMED ELFAKI ABDALLA

Advisory Committee:

Main Supervisor: Prof. Ali Adeebo Mohammed
Co. Supervisor: Dr. Alexandre Ickowicz
Co. supervisor: Dr. Elsadig A. Eljack

Signature

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Examination Committee:

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<tr>
<td>Prof. Ali Adeeb Mohammed</td>
<td>Chairman</td>
<td></td>
</tr>
<tr>
<td>Dr. Salih Hamad Hamid</td>
<td>External Examiner</td>
<td></td>
</tr>
<tr>
<td>Prof. Eltayeb Mohamed Abdelmalik</td>
<td>Internal Examiner</td>
<td></td>
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Date of Examination 12th July, 2010
Dedication

This thesis is dedicated

To my parents and brothers who have supported me all the way since the beginning of my studies.

To my wife who has been a great source of motivation and inspiration.

And to all those who believe in the richness of learning.
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Rain Water Management Model for Improved Rangeland Productivity in Central Butana, Sudan

Elsadig Ahmed Elfaki Abdalla
Doctor of Philosophy in Irrigation Engineering (July, 2010)
Department of Agric. Engineering
Faculty of Agric. Sciences,
University of Gezira

ABSTRACT
Butana is a flat clay plain in North Eastern Sudan, considered as one among the best grazing areas in the country but is one of the poorest area. The area is rich with natural resources, but lacks permanent sources of water. Sometimes the area suffers severe shortage of water which reflects on rangeland condition. This study aimed to maximize benefits from rain water through application of micro and macro water harvesting techniques using remote sensing and Geographical Information System (GIS). An experiment of water harvesting was conducted in the study area during the rainy seasons of 2006 and 2007. Results showed that the production of the biomass is highly positively correlated with the amount of rainfall with high significance level ($P \leq 0.01$). The mean biomass of the three different plots for the six sites is 1.77, 1.63 and 0.96 ton ha$^{-1}$ respectively, compared to the normal 1.03 ton ha$^{-1}$. There are positive correlations between the plots area and the biomass production ($R^2 = 0.72$). The biomass production of rangeland is a function of harvested water. The Perpendicular Vegetation Index (PVI) is calculated using Spot image (October 2006). This index was used to classify land use, land cover and generate the spatial distribution of annual biomass production. Three main classes of land use were found namely; crop land, pasture and forest. The PVI and the field survey conducted during 2006 and 2007 were used to map the biomass distribution. Rain use efficiency factor (RUE) calculated by dividing biomass layer by the total annual rainfall was used to select the potential water harvesting sites in the study area. The standard Soil Conservation Service – Curve Number hydrological model was used to estimate the potential runoff amount in central Butana, with a rainfall and a basin coefficient data (curve number). The average potential runoff depth in the study area was estimated as 52 mm yr$^{-1}$. Hence the annual total expected runoff volume was estimated for the whole study area as 187.2 (10$^6$) m$^3$. A general GIS based model has been designed to manage rainfall water in central Butana rangeland. The model links the results of water harvesting experiment, field survey results and the satellite image output to simulate the potential of biomass production and select appropriate location for water harvesting.
نموذج لإدارة مياه الأمطار لتحسين إنتاجية مراعى وسط البطانة، السودان

الصادق أحمد الفكى عبد الله

دكتوراه الفلسفة فى هندسة الرى ــ يوليو 2010

قسم الهندسة الزراعية
كلية العلوم الزراعية
جامعة الجزيرة

Abstract (Arabic)

البطانة عبارة عن سهل طيني مسطح يقع في شمال شرق السودان، وتعد واحدة من أفضل مناطق الري في البلاد ولكنها في نفس الوقت أقل المناطق نموا. تعتبر المنطقة غنية بمواردها الطبيعية ولكنها تتعرض للمصادر الدائمة. في بعض السنوات تعاني المنطقة من نقص حاد في المياه التي يمكن اكتسابه مباشرة على نوعية وكمية إنتاج الكتلة الحية ومياه الشرب. هذه الدراسة تهدف إلى تطوير الاستفادة من مياه الأمطار من خلال تطبيق تقنيات تحسين حصاد المياه باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية.

أجرت تجربة تقييم أثر تطبيق تقنيات حصاد المياه خلال موسمي الأمطار 2006 و2007. أظهرت نتائج الدراسة أن إنتاج الكتلة الحية يرتبط إرتباطا إيجابياً مع كمية الأمطار مع وجود دلالة إحصائية عالية (F ≥ 0.01). متوسط إنتاج الكتلة الحية من الثلاث أحواض المختلفة في السنة مختلفة وجد 1.77 و 0.96 طن/الهكتار في الظروف العادية. أظهرت النتائج فرقاً كبيراً ومعنواً (F ≥ 0.01) مع الإرتباط الإيجابي (R² = 0.72) بين مساحة الأحواض وإنتاج الكتلة الحيوية كما وجد أن إنتاج الكتلة الحية هو دالة في كمية المياه التي يمكن حصادها.

استعمل معيار النباتات العمودي Perpendicular Vegetation Index (PVI) والذى تم حسابه باستخدام بيانات صورة للأقطار الصناعية لمنطقة الدراسة أخذ في أكتوبر 2006. تم استخدام هذا المعيار لتصنيف استخدام الأرضي والغطاء النباتي والتوثيق المكاني للكتلة الحية ووجد أن هناك ثلاث نوافات رئيسية لاستخدامات الأرضي وهي: الأرضيات الزراعية الطبيعية، المراعي والغابات. استخدم PVI والمسح الميداني الذي أجري خلال عامي 2006 و2007 لعمل خريطة التوزيع المكاني للكتلة الحيوية كما تم استخدام مؤشر كفاءة استخدام الأمطار (RUE) والذى تم حسابه بقسمة خريطة الكتلة الحية على خريطة الأمطار، و الذي تم حسابه بوضع خريطة الكتلة الحية على خريطة الأمطار.

تحديد الأماكن المناسبة لحصاد الأمطار

لتحديد كمية الجريان السطحي المتوقعة Curve Number model تم استخدام نموذج هيدرولوجي يعرف بـ (CN). تم استخدام بيانات الأمطار والخصائص هطول الأمطار وتوفرها بـ (CN) في منطقة الدراسة وذلك باستخدام بيانات الأمطار وخصائص هطول الأمطار والتي تم تحريفها. وجد أن متوسط عمق مياه الجريان السطحي في كل منطقه الدراسة، والتي تبلغ سطوعها الكلية 3600 كلم مربع، هو 52 ملمتراً وبالتالي قدر حجم مياه الجريان السطحي لكل المنطقة بـ (0.1872)كم مكعب. تم تصميم نموذج عام لإدارة نسبة الموارد ووضع نظام هطول الأمطار في مراعي ووسط البطانة وربط هذا النموذج نتائج تجربة حصاد المياه، نتائج المسح الميداني وتجارب بيانات صورة الأقطار الصناعية لمحاكاة إنتاج الكتلة الحية المتوقعة في إطار تطبيق تقنيات حصاد المياه واقتراح المناطق المناسبة لحصاد المياه.
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CHAPTER ONE
INTRODUCTION

Public awareness of environmental issues over the last decades has increased and this has led to an increase in the importance of ensuring that water quality and quantity around the world is maintained at an acceptable level. To achieve this goal, a method of monitoring and management techniques has to be applied. Arid and semi-arid regions are defined as areas where water is at its most scarce. The hydrological regime in these areas is extreme and highly variable, and they face great pressures to deliver and manage freshwater resources.

Dry lands cover about 5.2 billion hectares, a third of the land area of the globe (UNEP, 1992). Roughly, one fifth of the world population live in these areas. Dry lands have been defined by FAO on the basis of the length of the growing season, as zones which fall between 1-74 and 75-199 growing days to represent the arid and semi-arid dry lands, respectively, and receiving rainfall between 0 – 600 mm annually (FAO, 1978).

The main feature of “dryness” is the negative water balance between annual rainfall (supply) and the evaporative demand. Many of the world's drylands are grazing rangelands and characterized by the need to manage and cope with erratic events that constrain opportunities for development. Traditional nomadic pastoralism fully exploits these characteristics, typically by moving from one area to another in response to seasonal conditions. These forms of use were more economically efficient and less ecologically damaging than the sedentary systems that characterize the other landscapes (Squires and Sidahmed, 1998).
In arid and semi-arid regions of Sudan, water is a limiting factor for economical yields and the main source of water for crops, in areas not equipped with irrigation network, and pastures is the annual rainfall. The yield under these conditions is highly dependent on the amount of rainfall and its distribution, the physical properties of the soil and the weather during the different stages of growth of plants. Water, soil and vegetation are the main requirements for human life in rural Sudan because of their essential contribution for both crop and animal production, which are considered the main components of development in these areas. Increasing importance is placed on the need to match properties of the land with its use and management to ensure economical and environmental sustainability. The ability to deal effectively with problems and issues as they arise requires data information knowledge. It is important that these data can be readily processed and integrated with other data from different sources to produce output which is rapidly and easily accessible and comprehensible. In dry-lands, crop 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 (Turral, 1995). 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 (Reij et al., 1988). Water harvesting is practiced in nearly all African dry-lands either in its indigenous form, or as techniques introduced by international donor programmes (Van Dijk, 1995). Its scope as a low-cost alternative to irrigation is increasingly recognised in developing countries in other parts of the world (Napier et al., 1994; Tabor, 1995; Gupta, 1995). Water harvesting has proved it self as a promising technique to overcome the problem of water shortage and drought mitigation in the arid regions of the world.
The greatest potential use of remote sensing (RS), as it’s small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing devices that is not in physical or intimate contact with the object, would appear to be in the management of resources in the tropical regions of the world (Eden 1986). This is especially valid when integrated with Geographical Information System (GIS), which is a set of tools for collecting, storing, retrieving, transforming, and displaying spatial and temporal data from the real world for a particular set of purposes (Burrough 1986). The use of the spatial technique, GIS and Remote Sensing (RS), aimed to assess the capabilities of such technologies in managing the natural resources and localizing sustainable water management systems.

1.1 Justifications and Objectives

The Butana region is a flat clay plain in North Eastern Sudan and is considered as one of the best grazing areas in the country but, at the same time on of the least developed area of rural Sudan. In the central part, permanent settlements have been established around wells, based on a combination of animal husbandry and rainfed sorghum cultivation. Camels, cattle, sheep and goats are all kept in this area (Gunnar 2003). The area contributes to the national gross domestic production through its contribution to livestock and agricultural products. In 1904, during the Anglo-Egyptian Condominium, a grazing agreement was signed which defined Butana as a general grazing area that could be used by all ethnic groups visiting Butana during the rainy season. The area is very rich in its natural resources, but had no permanent sources of water except the haffirs (artificial ponds) which last for only a few months after the rainy season. When these haffirs dry up, the nomads must leave Butana although the pasture is still rich in vegetation. In some years, due to rain variability and uneven distributions of rains, the area suffers from severe shortage of water which reflects on
the quantity and quality of biomass production and drinking water which has a great impact on the available biomass utilization because all of the herders concentrate around water points and leave the area soon after the rainy season. This is because there is no drinking water for their animals. Gunnar (2003) stated that during the last 40 years, the landscape of the Butana and its adjacent areas has been transforming. In some places, it is clearly degrading, both on the rainfed mechanized schemes (where the need for fallow is not sufficiently observed) and in the rangelands adjoining settled areas and, therefore, subject to increasing pressure.

Since the main source for rangeland vegetation and drinking water is rainfall, it is better to find ways and methods to maximize the water use efficiency to produce more biomass and to establish more watering points to ensure homogenous utilization and avoid rangeland degradation due to concentration around rare water points. Water harvesting has proved itself as a promising technique to overcome the problem of water shortage in the arid regions of the world in order to produce more biomass and propose and create suitable watering point or even create big reservoirs for more sustainable development. This can be achieved by estimation of the potential of the amount of runoff that is generated from rainfall in the area and then test the effect of harvested runoff on biomass production and propose the suitable points to establish watering points (haffirs) or small reservoirs.

The general objective of this study is to identify possible improvements of the livelihood of the population of Butana area, through better management of the natural resources with emphasis on water resources. The study specific objectives are:

1. To quantify rain water resources of Butana area (rainfall map).
2. To identify current situation of the natural resources in the area.
3. To test the effect of water harvesting techniques on rangeland production.
4. To develop a relation between biomass production of the rangeland and the annual rainfall of the area.

5. To develop a GIS based model to assist in the management of overall utilization of water resources in the study area.

6. To explore the socioeconomic life and its relationship with the natural resources.
CHAPTER TWO
LITERATURE REVIEW

2.1 Arid and Semi-Arid Areas

Drylands cover about 5.2 billion hectares, a third of the land area of the globe (UNEP, 1992). Arid and semi-arid areas are defined as areas falling within the rainfall zones of 0-300 mm and 300-600 mm, respectively (FAO, 1978). Because of the short growing periods (1-74 and 75-199 days, respectively), these areas are not suitable for cultivation without certain measures. Rainfall patterns are unpredictable and are subject to great fluctuations. One-year droughts are more frequent than multiyear droughts. The occurrence of drought is more frequent in the arid (lower rainfall) areas than in the semi-arid zones. An assessment of the dynamics of drylands requires long-term data collection. However, based on the information available, it has been possible to conclude with a reasonable degree of certainty that plant biomass is greatly influenced by fluctuations in rainfall (Ellis, 1992, 1995; Scoones, 1995). Ecosystems in drylands around the world appear to be undergoing various processes of degradation commonly described as desertification (Hillel and Rosenzweig, 2002). One should be able to differentiate between true climatic desert areas, which have always been deserts (at least during known historic times) and deserts resulting from land degradation that have been caused by different factors, and are concerned with the creep of desert-like conditions into these areas.

2.2 Location, Climate and Geographical Features of Sudan

Situated in Northeast Africa, the Sudan is the largest African country, with a total area of about 2.5 million km². It stretches from 4° to 22° N and 22° to 38° E and occupies 8.3% of the African continent (Blokhuis 1993). On the North-East, it is bordered by the Red Sea. It shares common borders with nine countries; Eritrea and Ethiopia in the
East, Kenya, Uganda and the Democratic Republic of Congo in the South, the Central African Republic and Chad in the West, Libya in the North-west and Egypt in the North as shown in figure (2.1).

Figure (2.1): Location and Geographical Features of Sudan
Sudan consists of a flat internal plain, lying at about 325 meters above mean sea level. The cultivable area is estimated to be 105 million ha, or 42% of the total area. The cultivated land is 7.6 million ha, which is only 7% of the cultivable area. The forest resources of Sudan cover approximately 27% of the total country’s area. Rangelands cover about 117 million ha and spread over most ecological zones: the desert in the North, the semi-desert, the low rainfall savannah in the center and the high rainfall woodlands in the South. Annual herbaceous plants with scattered trees and bushes dominate the Northern rangelands. In the Southern part, perennial herbaceous plants increase with dense stands of woody cover. The population of Sudan was estimated in the last census in 2008 as 39 million (CBS, 2008), mostly living in rural areas.

Climatic conditions are diverse from Sahara in the north to very humid areas in the South. Rainfall varies from 20 mm/year in the north to some 1600 mm/year in the far South. Average annual rainfall is 436 mm (Elagib and Mansell, 2000). Generally rainfall is characterized by uneven distribution, very high variability in time and space 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 productive area. The main rainy season extends from July to September. Mean daily temperatures vary from a maximum of more than 40°C in the North to a minimum of 6°C in Jebal Marra in the West. There are extensive plains of ironstone in the South, clay soils in the central plains, and sand in the North and West, with a few mountainous areas in the South, East and West. The River Nile runs through the country from South to North, a distance of 2258 km. Apart from the Nile system, there are also the seasonal rivers of Gash and Baraka in Eastern Sudan. Water used in Sudan derived almost exclusively from surface water resources. Sudan’s total natural renewable water resources are estimated to be 149 km³ yr⁻¹, of which 30 km³ yr⁻¹ are internally
produced. Of the internal water resources, 28 km$^3$ yr$^{-1}$ are surface water and 7 km$^3$ yr$^{-1}$ are groundwater, while the overlap between surface water and groundwater is estimated at 5 km$^3$ yr$^{-1}$ (FAO, 2005).

Animal production in Sudan is one of the important components of the agricultural sectors in spite of the traditional way of husbandry. Sudan has the second largest animal population in Africa. The livestock population includes camels, sheep and goats, which are raised in the desert and semi-desert, and cattle, that are raised in the medium rainfall savannah and in the flood plain of the Upper Nile. Almost all livestock is raised under nomadic and semi-nomadic systems. In 1997, the contribution of livestock to GDP was estimated at 20%, representing 42% of the contribution of the agricultural sector (MFNE 1997). The last animal census in Sudan showed that there are about 103.45 million heads of livestock animals (30.08 million of cattle, 37.15 million of sheep, 33.32 million of goats and 2.9 million of camels), which represent 40.15 million of animal units (30.08 million of cattle, 4.46 million of sheep, 2.33 million of goats and 3.28 millions of camels) (MAR, 1994/1995). Official estimates of the livestock population in 2001 are as follows (38.3 million of cattle, 47 million of sheep, 39 million of goats and 3.2 million of camels). The annual requirement of roughage is approximately 3.3 tonne DM/year/animal unit. The annual needs of animals in Sudan are estimated to be 132.5 millions tonne DM (AOAD 1981).

2.3 Ecological Zones of Sudan

Sudan is essentially a country of vast plains, interrupted by rolling country and a few widely separated groups of hills or mountains. The Nile and its tributaries divide it from South to North, therefore, the effect of topography on vegetation is small and is confined to mountain massifs (Gebel Marra, Immatong and Dongtona), the smaller
hills (Nuba, Red sea and Angassana), the upland of Southern Sudan and the Nile-Congo watershed and the Nile valley and its tributaries (Andrews, 1952 and 1965). The ecological zones of the Sudan are many and include the following shown in table (2.1).

**Table (2.1): The ecological zones of Sudan**

<table>
<thead>
<tr>
<th>Ecological Zone</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert</td>
<td>The total area of this region is about 72 million hectares. This region is characterized by scarcity in rainfall; rainfall is ranging between 0 - 75 mm yr⁻¹.</td>
</tr>
<tr>
<td>Semi Desert</td>
<td>The total area of this region is nearly 49 million hectares. The rainfall is approximately 75 – 300 mm yr⁻¹.</td>
</tr>
<tr>
<td>Low Rainfall Savannah on sand</td>
<td>The total area of this region is 68 million hectares. The average rainfall in this region is 300 – 400 mm yr⁻¹.</td>
</tr>
<tr>
<td>Low Rainfall Savannah on clay</td>
<td>The total area of this region is 34 million hectares. The annual rainfall in this region is ranging between 400 – 800 mm yr⁻¹.</td>
</tr>
<tr>
<td>High Rainfall Savannah</td>
<td>The total area of this region is about 8 million hectares. The average rainfall is ranging between 800 – 1300 mm yr⁻¹.</td>
</tr>
<tr>
<td>Flood Region</td>
<td>The total area of this region is 0.64 million hectares. The annual rainfall is varying between 800 - 1000 mm yr⁻¹.</td>
</tr>
<tr>
<td>Montane Region</td>
<td>The total area of this region is 0.64 million hectares. The annual rainfall is varying between 800 - 1000 mm yr⁻¹.</td>
</tr>
</tbody>
</table>

The general estimation of the different agro-ecological zones areas as stated by Sudan Meteorological Department (SMD) in 1993 are 71.82 million hectares as desert, 21.5 million hectares as agricultural land (7.77 million hectares are cultivated), 92.82 million hectares as natural pasture and 24.15 million hectares as forest.
2.4 Butana Region

Butana is located in the Northeastern part of Sudan. It extends in 6 states (River Nile, Red Sea, Khartoum, Kassala, Gedarif and Gezira States). Different soil types occupying the flat clay plain characterize Butana Region. This region represents a part of the central clay plain of the Sudan. It lies close to the northern borders of the River Nile, the Wad Medani-Gedarif highway line is usually considered to be the Southern boundary (Barbor 1961). Butana Region is considered to be the best rangeland for nomads in the Northern part of Sudan (Hamad et al., 1992). Butana plain is gently sloping towards the Northwest, i.e. towards the Blue Nile. The Eastern part of the area is composed of cracking clays that are moderately well drained, which merges into another very flat clay plain of non cracking soils that are covered with about 10% fine and medium gravel (Mahmoud, 2000). Abdel Razig (1982) stated that the tropical semi-arid soils in Butana could be divided into two groups: the reddish brown soils on slopes and the brown or black soil occurring on topographic depressions. In general, the elevation of the central clay plain of Sudan varies from 300 to 800 meters above sea level (Dudal, 1965 and Ahmed, 1983). Butana Region is determined by climatic and ecological transitions from the Savannah in the South to the arid Sahara in the North (Akhtar, 1994). In general, the annual rainfall in this area ranges between 100 mm in the North (Khartoum North) and 600 mm in the South (Gedarif). The extreme spatial and temporal variability of rainfall is resulting from the northward drift of the Intertropical Convergence Zone (ITCZ), which leads to an unpredictability in the rainy season and to recurring drought events at irregular intervals. The high variability of rainfall also triggers a natural shifting of the vegetation formations by over several hundred kilometers (Akhtar, 1994). In addition, Pflaumbaum (1994)
stated that the high variability of rainfall causes considerable interannual variations of dry matter production in natural pastures of the Sahelian Zones.

Butana Region is an open grazing area, exploited by all groups living in Butana or other entering the area. Only one seventh of this region was left with natural grazing possibilities, as the climatic aridification prevented the frequent development of vast grazing pasture in the central and northern Butana. Beside that, the more humid southern Butana was almost entirely cultivated land (Kirk, 1993).

2.4.1 Butana Rangelands

The dominant vegetation in Butana Region is a varying mixture of grasses and herbs with scattered scrap shrubs (Akhtar, 1994). These natural resources were always affected by unpredictable drought periods; tribal rights formally controlled the grazing and water resources (Kirk, 1993). The pastures of central Butana are characterized by generally dominant grass components mainly Tuffa (*Urochloa trichchopus*), El Gaw (*Aristida adscensions*), Danbolab (*Schoenefeldia gracilis*) and Nal (*Cymbopogon nervatus*), which are favorable for cattle, sheep and goats. Major exception of this is the southern part of central Butana, where woody vegetation, mainly Kitr (*Acacia mellifera*), is available (El Gunaid, 1994). Towards the north, the shortage in water supply, even in a wet season, puts constrains on frequent grazing possibilities (Akhtar, 1994). In general, natural pastures in Butana area are used during the rainy season (July – September/October) and the beginning of the dry season (El Gunaid, 1994).

Akhtar (1994) stated that the areas most regularly exposed to uncontrolled grazing are located between 14° 30’ and 15° 00’ latitude, which results in a rapid decrease in herb-layer vegetation. North of about 15° latitude exposure to grazing is restricted to years with an average or above average rainfall. Akhtar and Mensching (1993) stated that the southward drift of the rainfall isohyets during the last 15 years has led to a
shift of vegetation formation towards the south. This was accompanied by southward migration of the nomads who did not find sufficient fodder supply for their animals in the North. As a result of this movement the carrying capacities of the rangeland in the Centre and South of Butana experienced a significant reduction.

Moreover, beside rainfall, soil textures in the Butana have an immense effect on the distribution of extensive woody vegetation. The soil textures in the western Butana are usually very coarse, where extensive woody vegetation, comprising mainly Seyal (Acacia Tortilis) and Sereh (Maerua crassifolia) (Blokhuis1993). The northern and central Butana soils are characterized by Basement-Peneplain, which restricted the growth of woody vegetation to smaller relief units (such as wadies and shallow depressions, where rainfall is accumulated). Kitr (Acacia mellifera), Sunut (Acacia Arabica), Tundub (Capparis decidua) or Heglig (Balanites aegyptica), which used to be abundant in the eastern central Butana (Akhtar and Mensching, 1993).

Pflaumbaum (1994) stated that Butana region is characterized by the presence of different grazing constraints which will occur according to either fodder scarcity or water shortage. Migration patterns in the Butana region depend partly on available natural resources and, further, on a number of other factors such as tribal politics, quality of fodder and water supply.

2.4.2 Butana Vegetation

In a 75 to 300 mm rainfall zone there is a striking difference between the vegetation of the sandy soil (goz) and that of the clay soil receiving the same amount of rain. In this climatic belt, the goz sands show an open growth of trees, with much different types of Acacia species mainly seyal (Acacia tortilis), and shrubs with a partly bare, partly grass-covered surface (Plate 2.1), whereas the clay plains are virtually void of trees, but have a cover of varying density of annual herbs and grasses which can be
attributed to a history of previous cultivation during which trees were removed completely from the land in the case of clay soil (Plate 2.2) (Blokhuis 1993).

The semi-desert grassland on clay covers the northern part and central Butana clay plain. The northern Butan clay plain has a vegetation of short grass species, mainly *Setaria ssp.*, with *Schoenefeldia gracilis*, *Aristida ssp.*, *Chloris ssp.* and other grasses. Grass areas alternate with areas covered by annual herbs, *Ipomoea ssp.*, *Ocimum basilicum* and many others, often mixed with some grasses (Blokhuis 1993).

Southward, tall annual grasses, mainly *Sorghum ssp.* and *Cymbopogon nervatus*, often form pure stands and are found next to areas dominated by *Setaria ssp.* or sometimes, annual herbs (Blokhuis 1993).

**2.4.3 Butana Water Resources**

Second to pasture potential, it is the water resources which constitute an important factor determining landuse potential in Butana Region. The amount of water and its regional distribution determine to some extent the potential fodder resources may be used (Abu Sin, 1970; Voigt, 1989 and Pflaumbaum, 1994). Butana is very rich in its natural resources, but had no permanent sources of water except some wadis and haffirs, (artificial ponds, Plate 2.3, 2.4 and 2.5), which last for only a few months after the rainy season, (Pflaumbaum 1994). When these haffirs dry up (Plate 2.5), the visiting tribes had to leave the Butana.
Plate (2.1): Vegetation Type on Reddish Sandy Clay Soils (Goz)

Plate (2.2): Vegetation Type on Black Clay Soils
In some years, due to rain variability and uneven distribution of rains, the area suffers from severe shortage of water which is reflected on quality and quantity of biomass production, drinking water which has a great impact on the available biomass utilization because all of the herders concentrate their movements around water points and leave the area soon after the rainy season, although the rangeland vegetation is still rich.

Unfortunately, most of Butana is underlain by basement complex rocks (Ahmed, 1975) of low porosity and permeability which allow little or no water to penetrate downwards to recharge ground water except along temporary water streams (khors) where the upper part of the basement complex is weathered down for a few meters and is therefore porous.

Plate (2.3): Reserved Haffir for Human and Animal Uses in Central Butana (Wad Nail)
Plate (2.4): Unreserved Haffir for Animal Uses in Central Butana (Wad Bughul)

Plate (2.5): Drying Haffir for Animal Uses in North Butana (Nazawi)
2.5 Water Management

2.5.1 Water Resources in Arid and Semi-Arid Areas

Arid and semi-arid regions (i.e. drylands with annual mean rainfall between 25 and 500 mm) cover approximately one-third of the world's land area and are inhabited by almost 400 million people. Because they are a resource in short supply, water in drylands is under increasing human pressure (William, 1999).

The arid and semi-arid regions are characterized by uneven distributed water resources, which constitute sometimes a limitation for development and, in some places, a real political issue. All over the world, the hydrological variability of these regions under arid or semi-arid climates is due to a combination of rainfall, irregularly distributed in time and space, heterogeneous land topography and high anthropogenic pressure. Reference to the prevailing conditions, planning and water resources management for traditional and irrigated farming, human consumption, hydroelectric production, droughts mitigation in rural and urban areas, erosion, etc ...are made difficult. These difficulties clearly point out the real need to deepen our knowledge about the hydrological regimes in arid and semi-arid regions and particularly (i) their spatial and temporal variability, (ii) the surface and groundwater transfer mechanisms over river basins, (iii) the extreme events, (iv) the surface and groundwater resources and their integrated management (William, 1999).

Increased rainfall variability resulting from changes in global climate can rapidly reduce productivity and alter the composition of grassland plants. The impacts of grazing pressure and rainfall variability on rangeland dynamics have been the topic of much debate. Understanding the combined impact of these two factors is crucial for the development of efficient management strategies for rangelands (Hein 2006)
2.5.2 Biomass and Rainfall Relationship

Range development planning is based on a number of criteria such as range inventory and assessment of primary production of the rangeland to be developed, seasonal complementarity of range type in terms of forage availability, soil and water resources, water development potential and a number of highly variable management and socio-economic constraints subject to large fluctuations in space and time. In all cases, however, the carrying capacity of the land ought to be assessed as precisely as possible in order to meet the feed requirements of livestock and wildlife at any point in time and on long-term sustained basis. On a seasonal and annual basis, primary production, hence instantaneous or short-term carrying capacity varies greatly depending on local weather conditions, principally rainfall (Le Houèrou, 1988). 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 (Le Houèrou, 1988).

Many investigators from various parts of the world have attempted to relate range production to rainfall, either on a seasonal or annual basis. Significant to very high significant correlations between the two factors have been found in the arid and semi-arid zones (Le Houèrou, 1984). Estimates of above ground net primary production have been reported for many sites around the world (Lauenroth, 1979, Lauenroth et al, 1986, Daolan, et al, 2004).

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 Le Houèrou and Hoste (1977), 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. These are
followed by 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 Deshmuck (1984) who showed that per unit of rainfall biomass production in this region was twice as high as in West Africa. However, similar relations for southern Africa given by Rutherford (1978) indicate that productivity of rangelands in Zimbabwe and Botswana is much lower than in East Africa.

2.5.3 Rain Use Efficiency (RUE)

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 kgDM ha\(^{-1}\)mm\(^{-1}\) (Le Houèrou, 1984; Le Houèrou, 1988; Guintzburger, et al 2005). In 1984, Le Houèrou defined the RUE as a quotient of annual primary production by annual rainfall, i. e. the number of kilograms aerial dry matter phytomass produced over 1.0 ha in 1.0 year per 1.0 millimeter of total rain fallen. It may be expressed in above ground net primary production, in maximum standing crop (for therophytic or ephemeroid vegetation types), in herbage yield or in any other production measurement system, as long as the reference system is clearly indicated (Le Houèrou, 1984). If all other conditions remain equal, RUE factor tends to decrease when aridity increases together with the 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 factor 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. Also, Le Houèrou (1984) indicated that the actual RUE factor figures throughout the arid zones of the world may vary from less than 0.5 kgDM ha\(^{-1}\)mm\(^{-1}\) in depleted sub desert ecosystems to over 10 kgDM ha\(^{-1}\)mm\(^{-1}\) in highly productive and well managed steppes, prairies or savannas. Reasonably well managed arid and semi-arid pasture are usually in the range of 3 to 6 kgDM ha\(^{-1}\)mm\(^{-1}\), while the biological limit seems reached in heavily fertilized small experimental plots with values approaching 30 kgDM ha\(^{-1}\)mm\(^{-1}\).

RUE factor for the herbaceous layer in the Sahel was found to be 2.9 kgDM ha\(^{-1}\)mm\(^{-1}\) for various range types (Le Houèrou, 1989), 2.66 kgDM ha\(^{-1}\)mm\(^{-1}\) for the overall productivity (Le Houèrou, and Hoste, 1977) with 2.3 kgDM ha\(^{-1}\)mm\(^{-1}\) as the mean for the three Sahelian ecoclimatic subzones (Le Houèrou, 1989).

### 2.5.4 Water Harvesting

As pressure on land rises, more and more marginal areas in the world are being used for agriculture. Much of this land is located in the arid or semi-arid belts where rain falls irregularly and much of the precious water is soon lost as surface runoff. Recent droughts have highlighted the risks to human beings and livestock, which occur when rains falter or fail. While irrigation may be the most obvious response to drought, it has proved costly and can only benefit a fortunate few. There is now increasing interest in a low cost alternative - generally referred to as (water harvesting).

Water harvesting is the collection of runoff for productive purposes. Instead of runoff being left to cause erosion, it is harvested and utilized. In the semi-arid drought-prone areas where it is already practised, water harvesting is a directly productive form of soil and water conservation. Both yields and reliability of production can be significantly improved with this method.
Rain Water harvesting (RWH) can be considered as a rudimentary form of irrigation as shown in figure (2.2). The difference is that with WH the farmer (or more usually, the agro-pastoralist) has no control over timing. Runoff can only be harvested when it rains. In regions where crops are entirely rainfed, a reduction of 50% in the seasonal rainfall, for example, may result in a total crop failure. If, however, the available rain can be concentrated on a smaller area, reasonable yields will still be received. Of course, in a year of severe drought there may be no runoff to collect, but an efficient water harvesting system will improve plant growth in the majority of years.

![Figure (2.2): The Principle of Water Harvesting](image)

The first definition of water harvesting comes from Geddes as quoted by Myers (1975): ‘The collection and storage of any farm waters, either runoff or creek flow, for irrigation use.’ Myers (1975) also quotes Currier’s definition: ‘The process of collecting natural precipitation from prepared watersheds for beneficial use.’ Myers (1975) himself used the following definition: The practice of collecting water from an area treated to increase runoff from rainfall or snow-melt as stated in (Bores and Ben-
Asher 1982). Water harvesting in its broadest sense is defined by FAO (1991) as the ‘collection of runoff for its productive use’.

These definitions show that water harvesting encompasses methods to induce, collect, and store runoff for various purposes. The methods applied depend strongly on local conditions and include such widely differing practices such as farming terraced wadi beds (Evenari et al., 1971), growing trees on micro-catchments (National Academy of Science, 1974), catching runoff from sheet metal roofs (Chiarella and Beck, 1975; Mickelson, 1975), tapping subsurface runoff (Agarwal et al., 1977; Burdass, 1975; Smith, 1978), and storing runoff behind a dam (Bowler and Turner, 1977; Myhrman et al., 1978).

In spite of their differences, all the above methods have three characteristics in common (Bores and Ben-Asher 1982):

1. They are applied in arid and semi arid regions where runoff has an intermittent character. Surface runoff occurs as a direct event and subsurface water may flow part of the year and stop during dry periods. Because of the ephemerality of flow, storage is an integral part of water harvesting (Myers 1967).

2. They depend upon local water such as surface runoff, creek flow, springs and soaks (Burdass 1975). They, therefore, do not include storing river water in large reservoirs or the mining of ground water.

3. They are relatively small scale operations in terms of catchment area, volume of storage and capital investment. This characteristic is a logical consequence of the other two characteristics (Bores and Ben-Asher 1982).
2.5.4.1 Historical Perspectives

Various forms of water harvesting (WH) have been used traditionally throughout the centuries. Some of the very earliest agriculture, in the Middle East, was based on techniques such as diversion of "wadi" flow (spate flow from normally dry watercourses) onto agricultural fields. In the Negev Desert, WH systems dating back 4000 years or more have been discovered (Evanari et al. 1971). These schemes involved the clearing of hillsides from vegetation to increase runoff, which was then directed to fields on the plains.

Floodwater farming has been practised in the desert areas of Arizona and northwest New Mexico for at least the last 1000 years (Zaunderer and Hutchinson 1988). The Hopi Indians on the Colorado Plateau cultivate fields situated at the mouth of ephemeral streams, where the streams fan out; these fields are called "Akchin". Pacey and Cullis (1986) give description of microcatchment techniques for tree growing, used in southern Tunisia, which were discovered in the nineteenth century by travelers. In the "Khadin" system of India, floodwater is impounded behind earth bunds, and crops then planted into the residual moisture when water infiltrates.

The importance of traditional, small scale systems of WH in Sub-Saharan Africa is just beginning to be recognized (Critchley and Reij 1991). Simple stone lines are used, for example, in some West African countries, notably Burkina Faso, and earth bunding systems are found in Eastern Sudan and the Central Rangelands of Somalia (FAO 1991).

2.5.4.2 Recent Developments and Future Directions

A growing awareness of the potential of water harvesting for improved crop production arose in the 1970s and 1980s, with the widespread droughts in Africa leaving a trail of crop failures (FAO 1991). However, much of the experience with
WH gained in countries such as USA and Australia has limited relevance to resource-poor areas in the semi-arid regions of Africa and Asia. In the USA and Australia, WH techniques are mainly applied for domestic and livestock water supply, and research is directed towards improving runoff yields from treated catchment surfaces. A number of WH projects have been set up in Sub-Saharan Africa during the past decade. Their objectives have been to combat the effects of drought by improving plant production (usually annual food crops), and in certain areas rehabilitating abandoned and degraded land (Critchley and Reij 1991). However few of the projects have succeeded in combining technical efficiency with low cost and acceptability to the local farmers or agropastoralists. This is partially due to the lack of technical "know how" but also often due to the selection of an inappropriate approach with regard to the prevailing socio-economic conditions (FAO 1991).

Appropriate systems should ideally evolve from the experience of traditional techniques - where these exist. They should also be based on lessons learned from the shortcomings of previous projects. Above all, it is necessary that the systems are appreciated by the communities where they are introduced. Without popular participation and support, projects are unlikely to succeed.

Water harvesting technology is especially relevant to the semi-arid and arid areas where the problems of environmental degradation, drought and population pressures are most evident. It is an important component of the package of remedies for these problematic zones, and there is no doubt that implementation of WH techniques will expand (FAO 1991).

2.5.4.3 Water Harvesting Classification

Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses. Water harvesting techniques, which harvest runoff from
roofs or ground surfaces fall under the term: Rainwater harvesting, while all systems which collect discharges from watercourses are grouped under the term: Floodwater Harvesting (Bores and Ben-Asher 1982).

A wide variety of water harvesting techniques for many different applications is known. Productive uses include provision of domestic and stock water, concentration of runoff for crops, fodder and tree production and less frequently water supply for fish and duck ponds (FAO 1991).

Hence, the end user of water harvesting is plant production, including fodder and trees; the classification of water harvesting techniques is as varied as the terminology (Reij et al. 1988). Different authors use different names and often disagree about definitions, but in general water harvesting techniques is classified to:

2.5.4.3.1 Micro-Catchments Water Harvesting (MCWH)

Micro-catchment water harvesting is defined as a method of collecting surface runoff from a Contributing Area (CA) over a flow distance less than 100 m and storing it for consumptive use in the root zone of an adjacent Infiltration Basin (IB) as shown in figure (2.3) (Bores and Ben-Asher 1982).

The CA and IB are the two basic elements of the micro-catchment. In the IB there may be a single tree (Evenari et al., 1971), bush (Fink and Ehrler, 1979), row crop (Gardner, 1975), or fodder (FAO, 1991). The main characteristics of this type are:

- overland flow harvested from short catchment length
- catchment length usually between 1 and 100 metres
- runoff stored in soil profile
- ratio catchment: cultivated area usually 1:1 to 3:1
- normally no provision for overflow
- plant growth is even
Typical Examples of these are:

- Negarim Micro catchments (for trees)
- Contour Bunds (for trees)
- Contour Ridges (for crops)
- Semi-Circular Bunds (for range and fodder)

### 2.5.4.3.2 Macro-Catchment Water Harvesting (MCWH)

Macro-catchment water harvesting, also called harvesting from external catchments is the case where runoff from hill-slope catchments is conveyed to the cropping area located at hill foot on flat terrain as shown in figure (2.4). The main characteristics of this type are:

- overland flow or rill flow harvested
- runoff stored in soil profile
- catchment usually 30 - 200 metres in length
- ratio catchment: cultivated area is usually 2:1 to 10:1
- provision for overflow of excess water
- uneven plant growth unless the land is levelled

Typical Examples are:

- Trapezoidal Bunds (for crops, trees and range vegetation)
- Contour stone bunds (for crops)
2.5.4.3 Runoff Farming Water Harvesting (RFWH)

RFWH is defined as a method of collecting runoff from Catchment Area (CA), using channels, dams, or diversion system and storing it in a Surface Reservoir (SR) or in
the root zone of a farmed area for direct consumptive use (Bores and Ben-Asher 1982).

The water collected from CA and stored in SR is often used for livestock drinking water (Burdass, 1975) or regarded as being primarily a source for crop production (ICRISAT, 1978). The main characteristics of this type are:

- Turbulent channel flow harvested either (a) by diversion or (b) by spreading within channel bed/valley floor as shown in figure (2.5).
- Runoff stored in soil profile or surface reservoir
- Catchment long (may be several kilometres)
- Ratio catchment: cultivated area above 10:1
- Provision for overflow of excess water

Typical Examples include:

- Permeable Rock Dams (for crops)
- Water Spreading Bunds (for crops)
- Artificial ponds (for livestock)

Figure (2.5): Runoff Farming Water Harvesting: (a) spreading within channel bed; (b) diversion system
2.5.4.4 Water Harvesting in Sudan

It is predicted that along with the rapid growth of social and economic development and the increasing demand on improving peoples’ lives, water scarcity will be much more critical in the 21st century (Abdalsalam and Naggar, 2003). The most important of the natural resources in the drier environment is rainfall. Many researchers believe that the key solution for Sudan rainfed sector is rain water harvesting (Ahmed and Eldaw, 2003).

In Sudan, where the major part of rain falls within the arid and semi-arid zones, different traditional water harvesting techniques and systems are being practiced since long and are still referred to in the literature by their traditional names, e.g. Haffir and Terus (Oweis et al., 1999). Various forms of techniques have been practiced in Sudan, the well known RWH systems are; terus, which refer to an earth embankment made around the small holdings of rainfed agriculture, haffir (artificial pond), jessour and Sudood, which refer to small earth dams made across small water courses (Ahmed and Eldaw, 2003). Many other examples of traditional soil and water conservation/water harvesting could be found (Reij et al., 1988).

2.6 Remote Sensing and Geographical Information System

2.6.1 Remote Sensing (RS)

Remote sensing technology has received a considerable interest in the field of biological invasion in recent years. It is a tool offering well-documented advantages including a synoptic view, multispectral data, multitemporal coverage and cost effectiveness (Stoms and Estes, 1993; Soule and Kohm, 1989; Van der Meer et al., 2002). It is now widely applied on collecting data. It has proved to be a practical approach to study complex geographic terrain types and diverse inaccessible ecosystems. The term ‘Remote Sensing’ is broadly defined as the technique(s) for
collecting images or other data about an object from measurements made at a distance from the object, and can refer, for instance, to satellite imagery, to aerial photographs or to ocean bathymetry explored from a ship using echo sounder data (Rajitha et al., 2007). Over the last few decades remote sensing technology has been used increasingly by the scientific community to describe and monitor a variety of systems on a local or global scale. This technology has evolved from pure visual imagery (e.g. panchromatic aerial photographs) to multispectral imagery (e.g. Thematic Mapper and Spot View). Orbital remote sensing data due to its synoptic and multispectral nature provide a wide range of information over inaccessible and large areas in frequent intervals. This has made remote sensing technology a useful tool in natural resources assessment (Rajitha et al., 2007).

Remote sensing, however, with its broad view has the potential to deliver the relevant information. Satellite imagery is available for most of the world since 1972. The multidate nature of satellite imagery permits monitoring dynamic features of landscape and thus provides a means to detect major land cover changes and quantify the rates of change.

Many forms of remote sensing use passive detection, in which sensors measure levels of energy that are naturally emitted, reflected, or transmitted by the target object. Passive sensors are those which are designed to detect naturally occurring energy. Most often, the source of radiative energy is the sun. The sun's energy is either reflected, as it is for visible wavelengths, or absorbed and then red-emitted, as it is for thermal infrared wavelengths. Other forms of remote sensing provide their own energy source for illumination of the target. These devices, known as active sensors.
2.6.2 Satellite data

A large number of earth observation satellites has orbited, and is orbiting our planet to provide frequent imagery of its surface. From these satellites, many can potentially provide useful information for sustainable management of natural vegetation (Rajitha et al., 2007).

The optical satellite sensors, which measure reflection of sunlight in the visible and infrared part of the electromagnetic spectrum, have most frequently been applied in vegetation studies. The parts of the electromagnetic spectrum covered by these sensors include the visible (blue, green, red) and very near-infrared (VNIR) ranging from 0.4 to 1.3 µm, the mid infrared (MIR) between 1.55 and 1.75 µm, and the thermal infrared (TIR) from 3.0 to 15.0 µm. The blue band (0.45–0.52 µm) provides increased penetration of water bodies, as well as supporting analysis of land use, soil and vegetation characteristics. The green band (0.52–0.59 µm), especially was built to sense the top reflection of vegetation in green spectrum that is situated between the blue and red chlorophyll-a absorption bands. Red band (0.62–0.69 µm) is an important channel to separate vegetation. It is also useful for soil boundary and geological boundary delineation. This band exhibit more contrast than blue and green bands because of the reduced effect of atmospheric attenuation. Near-Infrared band (NIR) (0.77–0.86 µm) is especially responsive to the amount of biomass vegetation present in a scene. It is useful for crop identification and emphasizes soil–crop and land–water contrasts. MIR band is sensitive to turbidity or amount of water in plants. In addition, this is one of the few bands that can be used to discriminate between clouds, snow and ice. TIR band measures the amount of infrared radiant flux emitted from surfaces. It is useful for soil moisture studies, vegetation classification and vegetation stress analysis (Rajitha et al., 2007).
Remote sensing is a major source of information required for the study of landscape and vegetation development (Kumar, 2001). Price et al (2001) emphasizes the importance of remote sensing towards monitoring and better management of grasslands to ensure their productivity and sustainability. Colour-infrared aerial photographs have been used for pre-interpretation of potential dry grasslands (Eggenberg, 2001) and multispectral sensors like Landsat TM for discrimination of grasslands types under different management practices (Price et al., 2002). However, technological advancements have produced new and innovative remote sensing sensors, like hyperspectral sensors (Van de Meer et al., 2001), creating new challenges. Hyper spectral sensors record with very high spectral resolution of individual bands of less than 0.01 µm over a continuous spectrum covering the 0.4 – 2.5 µm region. Since band widths are narrow, local variations in absorption features can be detected contrary to multispectral scanners.

Spectral characteristics of vegetation are determined by many factors influencing the absorption, transmission and reflectance of incoming solar radiation (Kumar, 2001 and Curran, 1989). Chlorophyll, carotene and xanthopyll, influence the visible part of the spectrum (0.4 – 0.7 µm) whereas spectral characteristics in the mid and near infrared part of the spectrum (0.7 – 1.3 nm and 1.3 – 2.5 µm) mainly depend on cell structure, water absorption and foliar biochemical contents (Kumar, 2001 and Curran, 1989). Furthermore vegetation species composition, vegetation stress, canopy cover, and the phenological stage of the vegetation have a major influence on spectral response as shown in figure (2.6) developed by Tso and Mather (2001).
2.6.3 Geographical Information System (GIS)

Geographical Information System (GIS) is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modelling, representation and display of geo-referenced data to solve complex problems regarding planning and management of resources. Functions of GIS include data entry, data display, data management, information retrieval and analysis. The applications of GIS include mapping locations, quantities and densities, finding distances and mapping and monitoring change.

GIS is a general-purpose technology for handling geographic data in digital form. Its abilities include: pre-processing data into a form suitable for analysis, supporting spatial analysis and modelling directly, and post processing results (Goodchild, 1993). Integrated GIS and remote sensing have already successfully been applied to map the distribution of several plant and animal species, their ecosystems, landscapes, bio-
climatic conditions. (Stow et al., 1989, 2000; Los et al., 2002; Haltuch et al., 2000; McCormick, 1999; Rowlinson et al., 1999).

Remote sensing integrated with GIS can play a major role in sustainable management and development of arid and semi-arid rangelands by providing information on land use/land cover, water quantity and quality and productivity. These tools help to maintain the sustainability of ecosystem culture through proper site selection by considering the impact of development on other land use activities like agriculture, protected areas, human uses, etc. that are part of the same ecosystem (Rajitha et al., 2007).

2.6.4 Remote Sensing and Biomass

One of the primary applications of remote sensing is to identify patterns of vegetation distribution on the ground and to assess changes in vegetation over time. Remote sensing has several advantages over traditional methods of vegetation mapping, but also some limitations. Vegetation classes that are identifiable by other measurement such as field survey methods must produce a distinct spectral signature in order to be distinguished by remote sensing. An advantage of remote sensing is that the image represents the population given that measurements are made across the entire area of interest, though the resolution of the imagery may limit the degree of accuracy in the interpretation.

Identifying the species composition of vegetated areas is still a major challenge for remote sensing. Computers are better able to discern between changes in the spectral signature of an object but people have a better intuitive sense of the spatial pattern produced by a given type of vegetation. Recent advances in classification methods aim to simulate the heuristic decision making rules followed by trained image interpreters and incorporate them into automated classification algorithms.
2.6.5 Vegetation Indices

Vegetation cover is a key parameter for ecosystem studies on land degradation and desertification. Field inventory survey is a traditional method to conduct vegetation survey, which may be greatly limited by time and cost. Its validity and accuracy were questioned in the checking experiments (Curran and Williamson 1986; Wilson, et al 1987), so field inventory survey can only be used as supporting information for wide range of vegetation investigation. Traditional RS method to acquire vegetation cover is based on mathematical models or vegetation indices.

A vegetation index is a quantitative measure used to measure biomass or vegetative vigour, usually formed from combinations of several spectral bands, whose values are added, divided, or multiplied in order to yield a single value that indicates the amount or vigour of vegetation. The simplest form of vegetation index is a ratio between near infrared and red reflectance. For healthy living vegetation, this ratio will be high due to the inverse relationship between vegetation brightness in the red and infrared regions of the spectrum.

The vegetation index (VI), defined as the arithmetic combination of two or more bands related to the spectral characteristics of vegetation, has been widely used for the phonologic monitoring, vegetation classification, and biophysical derivation of radiometric and structural vegetation parameters (Huete et al, 1999).

Vegetation monitoring has been one of the main focal points of remote sensing study since remote sensing research began. Satellite remote sensing of primary production for Sahel region was studied by Prince, (1991) for years 1981-1988. Field measurements of primary production in semi-arid grassland for three Sahelian countries were analyzed in relation to multi-temporal sums of vegetation indices. The results showed that there is a linear relationship between vegetation index and
seasonal primary production in the range of 0 - 3000 kg/ha with the confidence interval ± (61 - 161) kg/ha.

A comparison and relationship between vegetation response and rainfall in the Sahel and East Africa was studied by Sharon et al in 1990 with the result that the spatial patterns of annual integrated Normalized Difference Vegetation Index (NDVI) closely reflect mean annual rainfall. Besides, there is a good relationship between monthly rainfall variations and NDVI especially for areas where the mean annual rainfall ranges from 200 - 1200 mm. The correlations were good between NDVI and both the previous month's rainfall and were best between NDVI and the total of previous two month's rainfall.

Many vegetation indices, using red and infrared reflectance, have been devised from which the Perpendicular Vegetation Index (PVI), Normalized Difference Vegetation Index (NDVI) and Modified Soil Adjusted Vegetation Index (MSAVI) are among the well known indices of this type:

2.6.5.1 Perpendicular Vegetation Index (PVI)

The Perpendicular Vegetation Index, proposed by Richardson and Wiegand (1977), was defined as the distance from the soil line on a scatter plot of near infrared (NIR) versus red (R) reflectance as shown in figure (2.7). The pixel vectors of bare land in such plots vary with soil moisture content. The PVI was developed as a vegetation index to effectively monitor the vegetation biomass without being affected by differences in soil background. The PVI assumes that the perpendicular distance of the pixel from the soil line is linearly related to the vegetation cover (Richardson and Wiegand 1977). The PVI, an index that takes the soil as a reflectance is computed as follows:

\[
PVI = \frac{(NIR - aR - b)}{\sqrt{a^2 + 1}} \quad \text{………………. (2.1)}
\]
NIR = Near Infra Red
R = Red

\[ a = \text{slope of the soil line} \]
\[ b = \text{intercept point of the soil line} \]

As a result, the more the pixel is far from the soil regression line, the higher the vegetation cover on that pixel (Guintzburger, et al 2005). The values of PVI are as follow:

When PVI > 0, there is vegetation cover on the pixel.

When PVI = 0, there is a bare soil on the pixel.

When PVI < 0, this happens mostly on water or on very low mineral content.

Figure (2.7): Perpendicular Vegetation Index Concept

2.6.5.2 Normalized Difference Vegetation Index (NDVI)

The earliest formal reporting of the NDVI was in 1973 by Rouse et al. NDVI is suitable for monitoring of early booming vegetation or sparsely populated vegetation (Shupeng and Yingshi 1990). After matching field survey data with a series of
vegetation indices, NDVI provided more accurate information of vegetation in areas where soil line was unavailable and density of steppe cover dynamically changes. The NDVI is not directly correlated with the biomass. It varies exponentially with the green vegetation density and saturates with a thick and dense vegetation cover. Furthermore it does not discriminate well the vegetation when the cover drops below 20 – 30 % (Guintzburger, et al 2005). NDVI is computed as follows:

\[ NDVI = \frac{NIR - R}{NIR + R} \]  

(2.2)

### 2.6.5.3 Modified Soil Adjusted Vegetation Index (MSAVI)

Background and formulas of the MSAVI are detailed by Qi et al. (1994). MSAVI introduces a self-adjusting model to minimize soil disturbance, requiring no additional supporting data and has a wide numeric range of application. It is a good index for precisely extracting vegetation information from remote sensing data (Jun Wen et al, 1997). MSAVI yields perfect regression outcome in the swampy regions (Eastwood, et al 1997). MSAVI is computed as follows (Weiguo, et al 2006)

\[ MSAVI = \frac{2R + 1 - \sqrt{(2R + 1)^2 - 8(R - NIR)}}{2} \]  

(2.3)

In this study PVI was used for monitoring and evaluation vegetation cover in central Butana rangeland because it gives better discrimination between vegetation when the vegetation cover is less than 30% (Guintzburger, et al 2005) and it doesn’t affected by soil reflectance

### 2.7 Potential Runoff Estimation

Global climate change and water shortage are just two looming threats to our way of life in the arid and semi-arid areas. The need to plan and account for changing
conditions in our landscapes and watersheds is critical so that we can better manage our resources to ensure that they endure into the future.

Estimation of direct surface runoff in a watershed is necessary for planning, designing, operation and environmental impact analysis of water resources projects. The characteristics of the hydrologic processes governing direct surface runoff vary both in space and time scales (Dutta et al, 2006). Satellite imageries that offer multi-spectral, 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 (Schultz and Engman, 2000). Some earlier studies used visual interpretation analysis of single date imagery to obtain the accurate map of land use and land cover (Chatterjee et al, 2001). Sharma et al. (2001) digitally analyzed multi-date satellite imageries for improving accuracy in mapping land cover and land use in a multi-crop cultivated watershed. Use of a Geographic Information System (GIS) helps to spatially integrate all the parameters of the model (Gangodagamage and Agrarwal 2001). In summary, all the previous studies focused on the mapping of land use and its spatial integration with other parameters in a GIS for improving the performance of the hydrological models.

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. However, the models typically have extensive data requirements and complex inputs that limit their usability.

A hydrological model is a mathematical simulation of the complex hydrological cycle (Athanassios et al, 2006), 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 (Webler, and Tuler, 1999). With advances in computational power and the growing availability of spatial data, it is possible to accurately describe watershed characteristics when determining runoff response to rainfall input (Arwa, 2001).

The rainfall – runoff mathematical simulation is necessary for understanding of the interaction between the climatic, terrestrial, topographic and hydrological elements of a watershed. A number of mathematical models have been developed for the investigation of these physical processes. Additionally, many researchers proposed a variety of surface runoff models that usually interact with Geographic Information Systems (GIS) (DeVantier and Feldman 1993, Olivera and Maidment 1996, Jain et al. 1997, Gorokhovich et al. 2000, Saghaian et al. 2000, Melesse et al, 2003). GIS technology is a very useful platform that is used for the production of digital elevation models (DEMs), the division of the watershed into grid-cells, in order to characterize its terrain. Furthermore, it is also used for preparation of the appropriate input files for the models.

The standard Soil Conservation Service – Curve Number model (SCS-CN) (USDA-SCS, 1972), also known as the hydrologic soil cover complex method, 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. The GIS and SCS-CN method are combined to model rainfall-runoff relations and the watershed parameters are estimated while computation of other parameters requires significant user interaction (White, 1988 and Bhaskar et. al., 1992). Purwanto and Donker (1991) proposed semi distributed hydrologic modeling using the SCS-CN method and assessed the effect of land-use
change for hypothetical cases of reforestation and deforestation conditions. Tauer and Humborg (1992) used RS data and a GIS to determine the potential sites for water harvesting. The surface runoff was estimated for the drainage basin during the wet season to determine the potential irrigation areas using Landsat-TM and/or SPOT data combined with ground truth observations.

Considering the high runoff potential of watershed, developmental structures such as farm pond, check dam, subsurface dyke and percolation tanks are suggested in the watershed for water resource development. An attempt is made to evolve a decision rule based approach for identifying the most appropriate sites for each of the proposed Water Harvesting Structures (WHS). Conventionally, factors such as watershed area, slope, land use, runoff coefficient are considered as criteria in selecting suitable sites for WHS (Padmavathy et al 1993; IMSD 1995; El-Awar et al 2000).

Selection of a rainfall-runoff model is a compromise between model complexity and available input data. While more complex models should better represent the physical processes, the assumption that they lead to more reliable results has been questioned (Loague and Freeze, 1985). The SCS runoff equation is basically an empirical model which came into common use in the 1950s. It is the product of more than 20 years of studies involving rainfall runoff relationships from small rural watersheds. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types (Rallison and Miller, 1981). No other rainfall-runoff model has been used as successfully or as often on ungaged rangeland catchments as the CN (Graf, 1988). A major limitation of the curve number method is that rainfall intensity and duration are not considered, only total rainfall volume.
2.8 Rangeland Management

2.8.1 Rangeland of Arid Areas

Historically, the rangeland dominating arid and semi-arid areas provided primary products (grasses, legumes and shrubs) which were converted into animal protein. The use of the resources for other purposes, such as fuel and building material, intensified with the increase in human population and with sedenterization. These rangelands maintained an ecological balance as a result of the natural defensive mechanisms typical of uncertain and highly erratic climates. Seasonal fluctuations influence the concentration and mix of herbivores, and multiyear droughts reduce the number of animals.

Because livestock is the major user of primary production in arid and semi-arid regions, degradation has always been attributed to this subsector (Sidahmed and Yazman, 1994). The United Nations Environment Programme (UNEP) singled out human impact and, specifically, livestock grazing as the cause of the irreversible degradation which has prevailed during the past two decades (Pearce, 1992). According to the World Resources Institute (WRI, 1992) overgrazing is the most pervasive cause of soil degradation. In Africa and Australia, overgrazing causes 49% and 80% of soil degradation respectively, mainly in semi-arid and arid regions.

Although the share of responsibility on the part of other influences (the introduction of exotic species, fuel-wood harvesting, the suppression of the natural fire cycle, wildlife degradation and the conversion of rangelands to croplands or human settlements, etc.) has been emphasized in subsequent UNEP publications (WRI, 1994), overgrazing has always been considered the most important factor.

However, results from long-term monitoring studies of the International Livestock Research Institute (ILRI) in East and West Africa (Ellis, 1992; Hiernaux, 1993) have
challenged this assumption and provided evidence that climate and not livestock is the main determinant of changes in arid and semi-arid environments and that rangelands are resilient and capable of recover. ILRI studies concluded that the strong seasonality of rangeland production in the Sahel limits the risk of overgrazing damaging the environment to short periods and consequently confined areas. Moreover, related studies in Mauritania concluded that Sahelian vegetation appears very resilient to natural and grazing stresses because of the strong dynamism of seed production, dispersion and germination cycle (Carrière, 1989).

The results and the impact of studies carried out by ILRI and others were discussed in two consecutive workshops supported by the World Bank, the Commonwealth Secretariat, the Overseas Development Institute and others (Behnke and Scoones, 1992; Scoones, 1995). These studies confirmed the conventional wisdom and traditional practices of pastorals and nomads throughout history in these areas. Traditionally, pastorals adopted an opportunistic strategy of mobility and raised mixed species of stock with different preferences for standing vegetation, so as to optimize the use of the limited vegetation available (Sidahmed, 1993). The core of recent interpretations leading to the so-called (rethinking range ecology) is appropriately based on the fact that degradation (or what was considered desertification) is mainly influenced by rainfall patterns.

But, the management of growing vegetation is equally important. According to Behnke (1993), the resilience of drylands vegetation is an outcome of the marked fluctuations between wet and dry seasons. Whereas growing vegetation is vulnerable to damage by grazing and trampling, dry-season vegetation is far below demand and has its own defensive mechanisms, such as the protection of the living parts behind thorns or in the seeds. This was confirmed during more than ten years of range
monitoring by ILRI in Mali. The results by Hiernaux, (1993) indicated the negative influence of repeated grazing during the growing season on the replenishment of the soil seed-bank. Minor changes were found to be caused by the short-term effects of trampling, grazing and burning during the dry season. The studies identified close similarities between the changes induced by drought and those resulting from grazing pressure on the Sahelian rangelands, emphasizing the fact that it is rather the policies (that limit livestock mobility and cause seasonal dependence by providing feed inputs) that lead to degradation.

Several ecologists have attributed degradation around water points to livestock concentration. However, this is a one-sided judgment because it excludes the benefits of the manure deposited in the circle just around the water point, as animals come and go. Andrew Warren, a geographer at University College London, and Hellden at the University of Lund, Sweden, did not find any evidence of desertification around water points in Sudan. A review of the surroundings of 77 water points in central Sudan and 20 on the desert of Senegal was unable to establish a relationship between degradation and animal concentration around the wells. This and other examples by Warren were brought to the attention of the United Nation in 1991 (IFAD, 2007). According to Warren even the view that cattle watering points act as centres or poles of desertification is now questioned. Landsberg et al, (2002) pointed out that heavy grazing can change the composition of plant communities. Lange (1969) discussed that interactions between animals and water points lead to the development of distinct ecological units, called biosphere. These biospheres are at immediate vicinities of livestock watering points and, therefore, are areas of high use. Grazing gradients (biosphere patterns) were defined as patterns that reflect the concentricity of stocking pressure around water points (Andrew and Lange, 1986).
Overgrazing by domestic livestock has been considered as a major degrading factor because it changes vegetation structure and composition as a result of which some species increase in abundance and others decrease (Yates et al., 2000).

**2.8.2 Grazing Systems**

The dynamics of arid and semi-arid grazing systems are prone to the effects of highly variable rainfall, with droughts causing frequent episodic mortality in herbivore populations. This has led to the suggestion that they are nonequilibrium systems, in which animal impacts on plants are strongly attenuated or absent. (Illius and O’Connor 1999).

A grazing system is any type of management program where the key factors of grazing are controlled to some degree. Grazing systems fall into four broad categories; true nomadism, semi-sedentary, transhumant and sedentary (Williams, 1981). Variations within each category are numerous, but each system is characterized by some level of management over one or more of the main controlling factors.

Today, grazing management is evolving towards achieving desired resource conditions rather than trying to recapture some prior existing state (Westoby et al., 1989). This change is occurring both in developed countries that have placed an emphasis on multiple uses of grazing land (i.e., functioning to provide forage for livestock, habitat for wildlife, conserved watersheds for high quality water supplies and open spaces for recreational adventures) and in less developed nations where livestock production is a key component of subsistence agriculture. A future issue is whether grazing animals can be used as tools for managing landscapes while also providing agricultural products. Management objectives could include a variety of goals such as increased native vegetation diversity, improved watershed functions, decreased use of harvested forages, and biological control of introduced plant species.
These objectives require managed control of grazing by livestock in order to minimize or negate effects of grazing.

Pastoral nomadism in the Butana area has been undergoing rapid changes in the nature of pastures, as well as strategy and pattern of mobility (Abu Sin, 1990, Akhtar and Mensching, 1993). This change is basically due to climate factors and the expansion in the agricultural development schemes in the Butana area, where two schemes were established, New Halfa with an area of 202,345 ha and Rahad with an area of 121,407 ha, (Elhassan, 1981). These schemes have reduced the area available for natural pasture lands and forced many nomads to settle in one place. Even though such schemes caused a reduction in natural pastures, they have provided the nomads with supplementary fodder from crop residues following the cropping seasons.

A field study in the Butana area during the period between 1970 and 1980 (Abu Sin, 1990) showed that there was a rapidly growing tendency towards a different strategy or combination of the four major types of animals in the region, camels, cattle, goats and sheep. Elhassan (1981) reported that 68% of the stock keepers said that they felt the shortage of pasture and the degradation in the rangeland was due to the recent invasion by other tribes. The nomads in the Butana area cut trees to build houses and animal enclosures or to use for firewood. They also use the green branches or the whole tree to feed their animals. The expansions of rainfed agriculture in the Butana area from the south and the irrigated schemes have also reduced the area of natural pastures.

Grazing systems used by farmers vary widely in the degree of control which they afford the farmer the management of his grassland, but all are designed to help match the nutritional demands of livestock with the supply of forage. We can broadly define two main types of grazing system although in practice there are many variations
around each. These grazing systems are mobile grazing system and sedentary grazing system.

2.8.2.1 Mobile Grazing System

The mobile grazing systems are characterized by annual or seasonal movements of a part or the entire human group with the livestock to new places following availability of water and pasture resources. Mobility must be considered as a technique and is basically the principle of pastoralism. Mobility is based on two main technical acquisitions: the skill of herders and domestication of animals. It is associated with a high degree of flexibility and adapted types of society. There are two main types of mobility; nomadism and transhumance.

- **Nomadism** is a way of life characterized by the more or less frequent moving of the human group with its livestock to find new grasslands. It is an opportunistic practice, in the most arid regions where the rainfall needed for grazing plants to grow is so random that forecasting is impossible. Since water is available for drinking, the herds or flocks are taken to these grazing transitory areas as soon as they become available and remain there long enough to use them.

- **Transhumance** is a seasonal movement of herds or flocks, on a regular basis, between two or more seasonal pasture areas, sometimes very far away. Each of which has a forage value worth exploiting at a particular time of the year. During the seasonal transhumance, the herders guide livestock to available pastures and waterpoints. Sometimes, the transhumance routes are adapted each year according to pasture availability and the conditionality of access to the resource.
2.8.2.2 Sedentary Grazing System

Sedentary grazing system refer to a system where most of the people are agro-pastoralist and they practice rainfed agriculture at the same weight of grazing animal and even the income of the family is shared. This system is characterized by permanent stay of the householder in one location for a long time and the grazing animals are moving around this location making it as a centre. Two types of herd are distinguished:

- Herd which belongs to one or two persons.
- Herd which belongs to more than three.

2.8.3 Rangeland Drinking Water

Shortage of drinking water is a major constraint to animal production in the mobile system. In many countries, lack of community control over the drinking points limits the access of water to the fewer and capable large stock owners. Herders in Morocco, Algeria, Tunisia, Yemen and Sudan can not move their animals to areas of abundant vegetation because of lack of drinking water, and are forced to keep their animals on poor pastures around watering points or to sell some of their animals to buy feed. Such difficulties are not encountered by large animal owners capable of trucking water to better pastures in remote areas (IFAD 2007).

With a high population density, the development of livestock and human drinking water supplies has been a key aspect of rangeland development in semi-arid zones where surface water is a constraint. Proportionally, degraded lands extend over a larger area in the semi-arid zones than in the arid zones, as a result of higher population densities and greater concentration of water points. As in arid zones, a circular area of degradation of 1-5 km radius around the water point is quite normal, although these (sacrifice areas) are normally quite fertile and are surrounded by
bushes at the outer edge of the sacrifice area which balance out the negative effects. Long term studies in Senegal and Sudan (Thomas and Middelton, 1994) did not find a significant expansion of the sacrifice areas of individual water points in these countries.
CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area
Greater Butana is located in the North East of Sudan and is part of the central clay plains of Sudan. It is situated between the rivers Rahad, Blue Nile, the Nile and Atbara with a total area of approximately 120 000 km². The Wad Medani-Gedarif highway line is usually considered to be the Southern boundary (Barbor 1961). Butana region is extending over five different states namely; Gezira, Khartoum, River Nile, Kassala and Gedaref and stretches between latitudes $14^\circ 23' - 17^\circ 34' \text{ N}$ and longitudes $32^\circ 32' - 35^\circ 36' \text{ E}$.

3.1.1 Location
This study covers the central area of greater Butana, which administratively belong to Gezira State and located between latitudes $14^\circ 32' - 15^\circ 17' \text{ N}$ and longitudes $32^\circ 21' - 34^\circ 18' \text{ E}$ as shown in figure (3.1).

3.1.2 Climate
Butana 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. The marginal tropical, arid to semi-arid climate is affected by the location of Intertropical Convergence Zone (ITCZ) in summer (Mensching 1991). Based on long-term averages, the Sahel of Sudan is marked by annual precipitation close to 100 mm in the north and 600 mm in the south (Akhtar 1994). The extreme spatial and temporal variability of rainfall resulting from the interannual fluctuations in northward drift of the ITCZ leads to unpredictable rainy season, and recurring drought events at irregular intervals. Generally, rainfall is characterized by uneven distribution and long dry spells
Figure (3.1): Location of the Study Area, Butana Area of the Gezira, Gezira, Sudan
that affects crops and range vegetation at their critical growth and filling stages which leads immediately to a significant reduction in the productive area. According to Köppen’s world climate classification (Mustoe, 2004), Butana lies in Bshw, which refers to an area where evaporation exceeds precipitation and is a hot steppe desert. Butana can be classified as sub-desert, as 9 - 11 months of drought occur, according to Abu Sin (1990).

Rainfall is the most important single determining factor in the climate of Butana because the temperature is high all the year round. The rainfall determines the vegetative life cycle and annual vegetative cover, land use and thus human activities. It shows a substantial variation in incidence, amount, time received and annual distribution. Most of the rains are from convectional storm clouds. The rainfall variability is greater as one moves towards the north or north east. The annual rainfall in Butana ranges between 100 mm in the north to above 600 mm in the southern part (Oliver, 1965). Butana is characterized by low relative humidity especially in winter reaching its minimum in April and its maximum in August, varying between 16% - 77%. The open nature of the area and free movement of the air accelerates evaporation, whether from the surface or subsoil (Rath, 1936 and Oliver, 1965).

Temperature is high all the year around, the highest temperatures being in April above 40° C and in October around 36° C. January is the coolest month with a maximum average temperature of 17° C. The trend of annual temperature change is a drop in July and August as a result of high relative humidity and cloud cover. Then temperature begins to rise through September and October towards November with the retreating
ITCZ and a declining cloud cover. It drops to a minimum with the advance of cool northerly winds through December, January and February (Van der Kevie, 1976).

3.1.3 Geology

The geology of Butana consists of the following main features as distinguished by Andrew (1948) and Delany (1955); basement complex in the middle and to the south east; Nubian formation in the west and north. The central region is a basement complex with flat surface, with only a few rocky hills breaking the monotony of the plains. The central part is clay plain with numerous water courses. Most of these water courses form their own deltas and do not drain into nearby rivers. At the deltas of these water courses or ‘khors’ the people normally cultivate sorghum crops (Elhassan, 1981).

3.1.4 The Soil

The variation in rainfall, together with variations in relief, drainage and parent material produce clear local differences in the Butana soil. The top soil is mid-brown grey friable clay with round quartz pebbles and stone fragments. The cracks are not wide but medium in size and are more abundant in the soil under grass. The soil is a medium to fine textured light clay, sandy clay or silty clay which contains more than 40% expanding clay (Hunting Technical Services, 1966; Khalil, 1986).

3.1.5 Vegetation Cover

The occurrence and distribution of vegetation in Butana is generally determined by amount and distribution of rainfall but topography and soil texture also play an important role in a detailed description of the distribution within areas receiving the similar amounts of rainfall (Abu Sin, 1970).
There are three main types of the natural vegetation in Butana. Acacia trees that form the major perennial type, including *Acacia tortilis*, *Acacia Seyal* and *Acacia mellifera*. Shrubs are the second perennial type of vegetation in Butana, including bushy grasses scattered all over the region. The third type includes the annual grasses and herbs. Grasses include *Schoenefeldia gracilis* (Gabash) and *Sorghum arundinaceum* (Adar), while herbs include *Ipomoea cardiosepala* (Hantut), *Ipomoea Cordofana* (Taber) and *Blepharis edulis* (Siha). These herbaceous plants are dominant during the wet season, but after the rainy season they wither and disappear and only a few species can be seen during the dry season. During the rainy season, the low areas which are covered by water for a long time will become less vegetated due to the spoilage of seeds. The dominant vegetation in Butana, is *Blepharis edulis* (Siha) (Harrison, 1955), where herbs are abundant and often occupy large areas as pure stands.

**3.1.6 Water Resources**

Water resources constitute an important factor determining land use potential in the Butana area. The amount of water and its regional distribution determine to what extent potential fodder resources may be used (Abusin, 1970; Voigot 1989 and Pflaumbaum 1994). In central Butana, the main source of water is rainfall and this water supply will, at most, last within the few months after the rainy season (Pfloumbaum 1994).

**3.2 Methodology**

**3.2.1 Field Data Package**

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 are evaluated by aboveground biomass measurement on 1.0 m² repeated ten times along and spaced at 10 m intervals (i.e. 100 m long) along an identified GPS location transect as shown in figure (3.2). 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 (Faichney and white 1983). Dominant species of vegetation and trees were identified in each point.

![Figure (3.2): Layout of Vegetation Sample Transect](image)

3.2.2 Water Harvesting Experiment

Water harvesting as a traditional but recently improved strategy to make agricultural production in dry areas more reliable is becoming, especially after the recent drought period in the Sahel, more and more a topic of interest. A preliminary survey was conducted in this area in the rainy season of 2005 which showed that there were two main vegetation units which highly depend on the type of the soil and rainfall variability. The
first type dominates in the high red sandy clay soil (Goz) with much different types of Acacia species mainly *Acacia tortilis* and the second dominates in the black clay soils. Six experimental sites namely, Wad nail, Camp1, Camp2, Elsial, Sobohab and Sangir were selected by their coordinates. The first three sites were chosen for clay soil and the other three for sandy clay soil. Rectangular plots, as shown in figure (3.3), 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 m², 40x20 m², 20x20 m² and 20x20 m² (control), respectively were selected. The first three plots were considered as separate catchments and totally closed in all sides by earth embankment, to capture the whole amount of rainfall inside it, 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 harvested water in this context is the excess water collected over the water received in the normal condition. Plot 1 and 2 were divided in five zones (lines), in season 2006, starting from line 1 at the bottom to line 5 at the top of the plot and plot 3 and 4 were divided in three zones (lines). But in 2007, the four plots were divided in five zones (lines) to have better comparison between them. The experiment was run for two seasons (2006 and 2007) to estimate the primary production which includes the aboveground part of all vegetation produced during a single growth year, regardless of accessibility to grazing animals (USDA, SCS 1976). The samples for biomass had been taken from each line from 1.0 m² from different five locations along each line (5 samples/line and 25 samples/plot). The biomass had been taken at maturity stage then taken to the laboratory for dry matter determination (Faichney White 1983).
Soil samples for soil moisture determination were taken in the middle of the rainy season from two depths 0 - 15 cm and 15 - 30 cm in the harvesting area. The samples were taken to the laboratory for soil moisture determination as in (Rowell 1994). Floral survey was conducted in each line and the numbers of dominant species were identified. Rainfall readings for the two seasons were taken from temporary installed rain gauges at each site in the near village. The reading was recorded by school teachers in these villages. The rainfall gauges reading gives the depths of rainfall in each site which was converted to water volume in each plot by multiplying the depth by plot surface area.

Figure (3.3): Layout of the Water harvesting Experiment
3.2.3 Remote Sensing and GIS package

3.2.3.1 Data Sources

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 truth studies that have also been carried out in the same time. SPOTView image dated 5/10/2006 of 10 m resolution, as shown in figure (3.4), was acquired and used in the analysis. The general characteristics of the image are listed in table (3.1). The image is a combination of panchromatic and multispectral bands and has three bands Green (G), Red (R) and Near Infra-Red (NIR). The specifications of these bands are shown in table (3.2). 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.

![Spot Image of the Study Area](image-url)

Figure (3.4): Spot Image of the Study Area
### Table (3.1): General Characteristics of the Satellite Image

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image Name</td>
<td>SPOTView</td>
</tr>
<tr>
<td>Geometric Processing Level</td>
<td>ORTHO</td>
</tr>
<tr>
<td>Date</td>
<td>05-10-2006</td>
</tr>
<tr>
<td>Radiometric Processing Level</td>
<td>Basic</td>
</tr>
<tr>
<td>Number of Columns</td>
<td>7252</td>
</tr>
<tr>
<td>Number of Rows</td>
<td>6802</td>
</tr>
<tr>
<td>Number of Spectral Bands</td>
<td>3</td>
</tr>
<tr>
<td>Sensor Instrument</td>
<td>HRV1</td>
</tr>
<tr>
<td>Satellite</td>
<td>Spot 2</td>
</tr>
<tr>
<td>Mode</td>
<td>Color</td>
</tr>
<tr>
<td>Sun Elevation Angle</td>
<td>64.65</td>
</tr>
<tr>
<td>Geographic Coordinate System</td>
<td>WGS84</td>
</tr>
<tr>
<td>Projection</td>
<td>UTM 36N</td>
</tr>
<tr>
<td>Image Sampling (Resolution)</td>
<td>10 m</td>
</tr>
</tbody>
</table>

### Table (3.2): Technical Specifications of the Image Bands

<table>
<thead>
<tr>
<th>Band Name</th>
<th>Band Type</th>
<th>Wave Length µm</th>
<th>Physical Bias</th>
<th>Physical Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAN</td>
<td>PAN*</td>
<td>0.500-0.730</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green (SX1)</td>
<td>MS**</td>
<td>0.500-0.590</td>
<td>0.00</td>
<td>1.24648</td>
</tr>
<tr>
<td>Red (SX2)</td>
<td>MS</td>
<td>0.610-0.680</td>
<td>0.00</td>
<td>1.04342</td>
</tr>
<tr>
<td>Near Infra-Red(SX3)</td>
<td>MS</td>
<td>0.780-0.890</td>
<td>0.00</td>
<td>0.86257</td>
</tr>
</tbody>
</table>

*PAN (Panchromatic) refers to black and white imagery exposed by all visible light.

**MS (Multispectral) refers to sets of data obtained simultaneously, but each set obtained by sensing a different part of the electromagnetic spectrum (source: [www.spotimage.fr](http://www.spotimage.fr))
3.2.3.2 Satellite Image Processing

3.2.3.2.1 Geometric and Radiometric Correction

Remote sensing data are distorted by the earth curvature, relief displacement and the acquisition geometry of the satellites (i.e. variations in altitude, aspect, velocity, panoramic distortion). The intent of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map (Lillesand and Kiefer 2000). Rectification is the process of projecting the data onto a plane, and making it conform to a map projection system. Satellite image is rectified using nine GPS points of clear location (i.e. roads intersection and haffirs) and geometrically corrected to the coordinate system using the Universal Transversal Mercator (UTM) projection system.

3.2.3.2.2 Reflectance Correction

For relatively clear SPOTView, a reduction in between-scene variability can be achieved through normalization for solar irradiance by converting spectral radiance to planetary reflectance. This combined surface and atmospheric reflectance of the earth is computed with equation (3.1) (www.spotimage.fr).

$$\rho_p = \frac{\pi * L_v * d^2}{ESUN_v * \cos \theta_s} \quad .................................. (3.1)$$

where: $\rho_p$ = Unitless planetary reflectance.

$L_v$ = Spectral radiance at the sensor’s aperture.

$d$ = Earth-Sun distance in astronomical units. Table (3.3).

$ESUN_v$ = Mean solar exoatmospheric irradiance.

$\theta_s$ = Solar zenith angle in degrees.
The spectral radiance at the sensor’s aperture ($L_{\lambda}$) is calculated from the following equation (3.2) (www.spotimage.fr).

$$L_{\lambda} = \left(\frac{X}{A}\right) + B \quad \ldots \ldots \ldots \ldots \ldots (3.2)$$

Where:

$L_{\lambda} =$ Spectral radiance at the sensor’s aperture

$X =$ Bands

$A =$ Physical gain

$B =$ Physical bias

**Table (3.3): Earth-Sun Distance (d) in Astronomical Units**

<table>
<thead>
<tr>
<th>Julian Day</th>
<th>Distance</th>
<th>Julian Day</th>
<th>Distance</th>
<th>Julian Day</th>
<th>Distance</th>
<th>Julian Day</th>
<th>Distance</th>
<th>Julian Day</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9832</td>
<td>74</td>
<td>0.9945</td>
<td>152</td>
<td>1.0140</td>
<td>227</td>
<td>1.0128</td>
<td>305</td>
<td>0.9925</td>
</tr>
<tr>
<td>15</td>
<td>0.9836</td>
<td>91</td>
<td>0.9993</td>
<td>166</td>
<td>1.0158</td>
<td>242</td>
<td>1.0092</td>
<td>319</td>
<td>0.9892</td>
</tr>
<tr>
<td>32</td>
<td>0.9853</td>
<td>106</td>
<td>1.0033</td>
<td>182</td>
<td>1.0167</td>
<td>258</td>
<td>1.0057</td>
<td>335</td>
<td>0.9860</td>
</tr>
<tr>
<td>46</td>
<td>0.9878</td>
<td>121</td>
<td>1.0076</td>
<td>196</td>
<td>1.0165</td>
<td>274</td>
<td>1.0011</td>
<td>349</td>
<td>0.9843</td>
</tr>
<tr>
<td>60</td>
<td>0.9909</td>
<td>135</td>
<td>1.0109</td>
<td>213</td>
<td>1.0149</td>
<td>288</td>
<td>0.9972</td>
<td>365</td>
<td>0.9833</td>
</tr>
</tbody>
</table>

**3.2.3.3 Meteorological Maps**

**3.2.3.3.1 Rainfall Map**

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 Rufaa, over the period 1980 – 2000. 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 get the spatial distribution of the rainfall map.
3.2.3.3.2 Potential Evapotranspiration Map (PET)

The potential evapotranspiration map of Butana area was computed by Penman-Monteith formula (Allen et al., 1998) shown in equation (3.3) and the meteorological data of the stations around Butana. The meteorological data needed for ETP calculation was found only in four stations (Wad Medani, Shambat and New halfa).

\[
ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_a - e_s)}{\Delta + \gamma (1 + 0.34 U_2)} \\
\text{............... (3.3)}
\]

Where:
- \( ET_0 \) = Reference crop evapotranspiration (mm day\(^{-1}\))
- \( R_n \) = Net radiation at crop surface (MJ m\(^{-2}\) day\(^{-1}\))
- \( G \) = Soil heat flux (MJ m\(^{-2}\) day\(^{-1}\))
- \( \gamma \) = Psychrometric constant (kPa °C\(^{-1}\))
- \( U_2 \) = Windspeed measured at 2m height (m s\(^{-1}\))
- \( T \) = Average temperature (°C)
- \( e_a - e_s \) = Vapour pressure deficit (kPa)
- \( \Delta \) = Slope of vapour pressure curve (kPa °C\(^{-1}\))

The spatial coverage of evapotranspiration was generated on the digital elevation model by applying the equation of correlation between mean annual temperature and the altitude of each station and then the equation of correlation between evapotranspiration and mean annual temperature.

3.2.3.4 Perpendicular Vegetation Index (PVI) map

The Perpendicular Vegetation Index, proposed by Richardson and Wiegand (1977), was defined as the distance from the soil line on a scatter plot of near infrared (NIR) versus red (R) reflectance and can be calculated by equation (3.4).
\[ PVI = \frac{(NIR - aR - b)}{\sqrt{a^2 + 1}} \] .................. (3.4)

PVI was computed in ERDAS IMAGINE 9.1 software. Thirty eight Points of bare soil (roads and surroundings of haffirs) 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. From this correlation the slope of the line (a) and the intercept point (b) was obtained and applied in the above equation for the entire satellite image.

### 3.2.3.5 Biomass Map

The biomass map, which show the spatial distribution of rangeland biomass in kg/ha, was generated from the field biomass measurements for seasons 2006 and 2007 and PVI. Eighteen points of the field survey biomass were covered by the satellite image. The field biomass measurements of these 18 points were correlated to the mean computed PVI values on 10 x10 pixels (1ha) to compensate for human error on site location.

### 3.2.3.6 Rain Use Efficiency Map (RUE)

Rain use efficiency (RUE) is a ratio of the rangeland production (kg DM ha\(^{-1}\)) divided by the total amount of precipitation (mm) during the year. It is expressed in kgDM ha\(^{-1}\)mm\(^{-1}\) (Le Houèrou, 1984; Guintzburger, et al 2005). The RUE of Butana area was computed by dividing the biomass layer (kgDM ha\(^{-1}\)) by the rainfall layer in (mm).

### 3.2.3.7 Landuse and Vegetation Map

The vegetation surveys were completed inside Butana area during the season 2006 and 2007 using the Line Intercept Method (LIM), (Gintzburger, 2005). The vegetation groups were identified using (correspondence Analysis) taking into consideration the line intercept measurement of the species present on each site. Vegetation mapping was
processed using SPOTView satellite image in relation to vegetation groups/site location, field survey data and unsupervised image classification.

3.2.3.8 Drainage Map

The Digital Elevation Model (DEM) of the study area (source www.mapmart.com) Projection UTM 36 N, Datum WGS84), 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.

3.2.3.9 Runoff Estimation

The standard Soil Conservation Service - Curve Number model (SCS-CN) (USDA-SCS, 1972) is based on the following relationship between rainfall depth, \( P \), in millimetres, and runoff depth, \( Q \), in millimetres as shown in equation (3.5).

\[
Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \text{........ (3.5)}
\]

\[ (Q = 0, IF, P \leq 0.2S) \]

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 (3.6).

\[
S = \frac{25400}{CN} - 254 \quad \text{........ (3.6)}
\]

CN is a dimensionless watershed parameter ranging from 0 to 100. 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. The CN values, shown in table (3.4), are a combination of landuse and hydrological soil group. SCS has classified all soils into 4 hydrologic groups; these have been given symbols of A, B, C and D. The classification is based on the infiltration rate which is obtained for a bare soil after prolonged wetting. The characteristics of these four groups can be summarized in table (3.5). For each polygon in the study area the soil type and land use are determined from the soil and land use maps. The CN of these polygons is extracted from table (3.4).

The runoff derived by SCS-CN method is a function of runoff potential which can be expressed in terms of runoff coefficient (ratio between runoff and rainfall) (Ramakrishnan et al; 2009).

**Table (3.4): Runoff Curve Numbers**

<table>
<thead>
<tr>
<th>Land Use, Crop, and Management</th>
<th>Hydrologic Soil Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Row Crops, poor management</td>
<td>72</td>
</tr>
<tr>
<td>Row Crops, conservation mgmt</td>
<td>65</td>
</tr>
<tr>
<td>Small Grains, poor management</td>
<td>65</td>
</tr>
<tr>
<td>Small Grains</td>
<td>61</td>
</tr>
<tr>
<td>Meadow</td>
<td>55</td>
</tr>
<tr>
<td>PASTURE, permanent, moderate grazing</td>
<td>39</td>
</tr>
<tr>
<td>WOODS, permanent, mature, no grazing</td>
<td>25</td>
</tr>
<tr>
<td>ROADS, hard surfaces and roof areas</td>
<td>74</td>
</tr>
</tbody>
</table>

Table (3.5): Hydrologic Soil Groups

<table>
<thead>
<tr>
<th>Soil Group</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Low overland flow potential, High minimum infiltration capacity even when thoroughly wetted (&gt; 0.76 cm/h), Deep, well to excessively drained sands and gravel</td>
</tr>
<tr>
<td>B</td>
<td>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)</td>
</tr>
<tr>
<td>C</td>
<td>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)</td>
</tr>
<tr>
<td>D</td>
<td>High overland flow potential: Very low minimum infiltration capacity when thoroughly wetted (&lt; 0.13cm/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.</td>
</tr>
</tbody>
</table>

Source: (Dingman, 1993)

3.2.4 Socio-economic Characteristics of Central Butana Rangeland

To explore the socio-economic characteristics of central Butana rangeland, two types of questionnaires were used to describe the socio-economic life of the area and how people are using the available natural resources and the interaction between these resources.

The first type of the questionnaire was designed for sedentary people who live permanently in big or small villages in the western part of Butana. The second type was designed for mobile herdiers or transhumants who live either in temporary camps built from local material or people who come from other regions to spend the rainy season in the Butana area. Thirty animal keepers of each type were interviewed during the rainy season of 2007 and the collected data was processed and analyzed using SPSS statistical package.
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Climate Analysis

4.1.1 Characteristics of Rainfall in the Central Butana Area

Rainfall is a major factor controlling the hydrology of the central Butana area. The understanding of rainfall pattern and its distribution in space and time is essential for determination of soil moisture content, the river flows and groundwater recharge. While the amount, rate, duration and quality of rainfall are required to assess, predict, and forecast hydrologic responses. Estimation of regional rainfall is a critical input to water balance and other types of models used in water resources management. The rainfall data for Sudan is mostly available as monthly and total annual values for the main stations. Three main stations surrounding the study area namely, Wad Medani, Shambat and New Halfa, were used to represent different parts and climatic conditions of the area. The climatic data for these stations is available for the period from 1981 to 2004. These stations are classified by Elagib and Mansell (2000) and Van der Kevie (1976) as Arid, while Adam (2008) classified New Halfa and Wadmedani as dry and Shambat as semi-desert. The first classification was adopted in this study.

In all stations, the rainy season extends from April to November and the rest of the year is dry. Figure (4.1) showed that maximum monthly mean rainfall occurs in August for the three stations, (94 mm in Wad Medani, 93 mm in New Halfa and 40 mm in Shambat), while the minimum amount is in April and November.

The annual distribution pattern is a major criterion in the present ecological classification. Seasonality strongly affects annual variability and rain-use efficiency, particularly in arid,
semi arid and sub-humid zones (Le Houérou, 2008). Wad Medani is characterized by the highest mean annual rainfall (254 mm) with the highest annual rainfall in 1995 (424 mm) and the lowest in 1984 (42 mm) followed by New Halfa which receives mean annual rainfall 243 mm with the highest annual rainfall in 1993 (544 mm) and the lowest in 1984 (42 mm). Shambat receives the lowest mean annual rainfall (134 mm) with the highest annual rainfall in 1988 (446 mm) and the lowest in 1984 (3.4 mm) during the period from 1981-2004 as indicated in figures (4.2) and (4.3). The three stations received the lowest annual rainfall in 1984 which is the most famous dry year all over Sudan.

Figure (4.1): Mean monthly rainfall total of the stations located around Butana area (Data from Sudan Meteorological Authority (SMA))
Figure (4.2): Mean Annual Rainfall for the three Stations Surrounding Butana area (Data from SMA)

Figure (4.3): Annual Total Rainfall for the three Stations, around Butana Area (Data from SMA)
The deviation from median for the annual rainfall data for the period from 1981 to 2004 showed that about 72 - 81% of the annual rainfall is below the median for the three stations during the period between 1981 -1993. While the period from 1994 – 2004 showed that about 67 – 76% of the rainfall are above the median as shown in figure (4.4). These results agreed with the results obtained by Elagib and Mansell (2000) and ELhag and Walker (2009) for these stations and others in central Sudan, which demonstrated that the rainfall recovery was noted in some areas post early 1990s but, it is still below the levels for the period prior to the mid- 1960s. This slow recovery from the dry condition is in line with results and arguments for the Sahel (Nicholson, 1999; Nicholson et al., 2000), which suggest that the dry state would tend to persist longer than the wet state. Trilsbach and Hulme (1984) highlighted the occurrence of distinct wet and dry periods in the Sahelian region; however, this condition is random in nature. The characteristics of rainfall in the three stations bordering Butana area indicated that there is a considerable increasing of rainfall sufficient to induce reliable runoff depths for water harvesting.

Climate variability means the fluctuation between the normally experienced climatic conditions and a different, but recurrent, set of climate conditions over a given region of the world (IPCC, 1998) and also refers to a shift in climate, occurring as a result of natural and/or human interference (Wigley, 1999). Rainfall variability in Butana has been assessed via the coefficient of variation (CV), which is a quotient of standard deviation by the mean (\( CV = \left( \frac{\sigma}{\mu} \right) \times 100 \)). Climate variability means fluctuations between the normally experienced climatic conditions. Figure (4.5) showed that variability is much
higher in Shambat station than Wad Medani and New Halfa which is due to the fact that rainfall variability is inversely related to the mean (Le Houérou, 2005).

Figure (4.4): Deviation of Annual Rainfall Total from the Median values at the Three Stations around Butana area (Data from SMA)
Adam (2008) stated that the variation from year to year is large in dry areas and gets smaller as the rainfall increases. Again figure (4.5) proved that the rainfall of central Butana is characterized by very high variability and erratic pattern which is reflected directly on rangeland condition.

The spatial or surface distribution of rainfall was generated from the regression correlation between the recorded annual rainfall in eight meteorological stations in and around the study area, namely Atbara, Shendi, Shambat, Alkamlin, Elmasid, Abu-deleig, New halfa and Wad Medani, and the altitude of these stations ($R^2 = 0.82$) for 24 years from 1981 to 2004 as plotted in figure (4.6). The spatial distribution and the isohyets of rainfall in central Butana fall within the range of 200 – 400 mm as shown in figure (4.7). Since all the stations around the area are classified as dry, Le Houérou (2008) stated that in the African belt, the arid region receive annual rainfall between 100 – 400 mm. The map in figure (4.7) showed that the western and central part of the area receives annual rainfall between 200 – 250 mm, while the major portion of the eastern part receives annual rainfall between 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 of 350 – 400 mm. The results from this map and all above figures indicate that the amount of annual rainfall decreases when moving from south to north and east to west. Since the general elevation of Sudan tend to decrease towards the north and west for Butana, its justified that the mountain receive potentially the highest amount of rainfall in the area. This result agreed with Le Houérou (2005) 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. Again Le Houérou (1976) indicated that in the Sahel, an increase of one mm per km southward from the Sahara border was observed.

Figure (4.5): Rainfall Variability for the three Stations, in Butana Area (Data from SMA)

Figure (4.6): Regression Correlation between Annual Rainfall and Altitude of the Meteorological Stations around Butana area
4.1.2 Evapotranspiration

Evapotranspiration (ET) is the major component of water balance. Hasegawa and Kasubuchi (1993) rightly noted that ET has an effect on water balance almost throughout the year. ET is a central concept in the determination of the potential biomass (the
maximum quantity of vegetation biomass which can be accumulated under a given climatic condition).

ET was estimated by determination of reference evapotranspiration (ET$_{o}$) through the recommended FAO Penman-Monteith equation (Allen et al., 1998) and the climatic data for the selected stations. Figure (4.8) showed that the three stations had very high reference evapotranspiration (ET$_{o}$), but Shambat station has the highest values for the period from 1991 to 2004. The maximum value of ET$_{o}$ in New Halfa and Wad Medani station was obtained in 1983 as 3847 and 3573 mm, respectively, while in Shambat station the maximum value was obtained in 1986 which was 3143 mm.

Evapotranspiration tends to decrease during the winter time (November to February) when temperature reaches its minimum values in these months, while in the summer season (March – June) ET increases rapidly when temperature reaches its maximum in April and May. The rainfall from June to October has a significant effect on temperature and other input parameters, hence on evapotranspiration, which drops in July, August, September and October as shown in figure (4.9). Figures (4.9) and (4.10) explained that in the three stations the annual evapotranspiration values exceeded the rainfall even during the rainy season. This result comes in accordance with Mustoe, (2004) who pointed out that according to Köppen’s world climate classification, Butana lies in Bshw, which refers to an area where evaporation exceeds precipitation. This indicated that there is always a water deficit in Butana area especially in the northern part (Shambat station). The increasing tendency of temperature and the variability of the rainfall amount in the area justify increasing evapotranspiration. Oliver (1965) mentioned that rainfall characteristics, such as length of the rainy season, distribution and time of fall during the
day, are important factors governing evapotranspiration in Sudan. There are also indications of increase in drought stress resulting from deficiency of rainfall (supply) and increased evapotranspiration (demand). The high rate of $ET_o$ combined with high temperature is responsible for the early depletion of the watering points (haffirs) in the study area.

Contrary to rainfall, the spatial distribution of annual evapotranspiration, which was generated from the correlation between temperature and evapotranspiration for the three stations and plotted in figure (4.11), tends to decrease with elevation. The high elevation areas and mountains recorded the lowest temperature values and hence minimum evapotranspiration values. Figure (4.11) showed that the distribution of annual evapotranspiration follows contrariwise the isohyets; the western and central parts have the highest values (2880 – 2927 mm). The high altitude areas around Labitor Mountain and in the north eastern corner have the lowest $ET_o$ value (2616 – 2780 mm).

![Figure (4.8): Annual Evapotranspiration ($ET_o$) for the three Stations, around Butana Area (Data from SMA)](image-url)
Figure (4.9): Monthly Rainfall and Evapotranspiration (ET\textsubscript{o}) for the three Stations, around Butana Area (Data from SMA)
Figure (4.10): Annual Rainfall and Evapotranspiration (ET\(_o\)) for the three Stations, around Butana Area (Data from SMA)
Figure (4.11): Regression Correlation between the Mean Annual Temperature and Evapotranspiration in the three Stations in Butana area

Figure (4.12): Evapotranspiration Map of Central Butana Area
4.1.3 Temperature

The mean annual temperature showed small variations between the three stations, however the maximum value was recorded in New Halfa in 1984 (30.3 °C) and the minimum was recorded in Wad Medani in 1992 (27.8 °C) as shown in Figure (4.13). New Halfa showed the highest mean temperature (29.4 °C) followed by Shambat (29.1 °C) and Wad Medani (28.8 °C). The importance of temperature comes from its great effect on evapotranspiration. Le Houérou (2008) analyzed the meteorological data of 63 stations in Sudan and concluded that the ratio between evapotranspiration (mm) and temperature (°C) is \( \frac{\text{ET}_0}{T} = 77.1 \) with standard error (SE = 2.1). Many authors use the mean monthly temperature to define the length of the rainy season; the length of the growing season is classically assessed as the period when rainfall in mm is above twice the temperature in degrees Celsius (Walter and lieth, 1960). Figure (4.14) showed that the length of the growing season in the three station bordering Butana was 55, 50 and 35 days for Wad Medani, New Halfa and Shambat, respectively. Adam (2008) used \( \text{ET}_0 \) and rainfall to determine the length of the growing season and found that it was 56 and 59 days for Wad Medani and New Halfa, respectively.

Figure (4.13): Mean Annual Temperature for the three Stations, around Butana Area (Data from SMA)
Figure (4.14): Length of the Growing Season for the three Stations, around Butana Area (Data from SMA)
4.2 Water Harvesting

4.2.1 Total Biomass Production and Distribution

In arid and semi-arid regions the limited availability of water, in most cases, is the major constraint to rainfed sector. In these areas the amount of rainfall is usually not sufficient to sustain the growing crop (Huibers, 1985). The uneven distribution of rainfall in time and space makes rainfed agriculture very risky even where the amount of rainfall is sufficient for crop production, part of the rain may be lost as surface runoff before reaching the root zone (Reij, et al., 1988).

An increase in the quantity of water availability to crops, trees and rangeland in arid and semi-arid regions can lead to an improvement of the reliability of production as well as of the level of production, and it can keep a crop over an otherwise damaging dry spell (Critchley, 1986). Water availability for crop and rangeland production can be improved through various soil and water management practices, such as water harvesting. Much research have been conducted on the effect of water harvesting techniques on crop production, but only the sitting of water harvesting reservoir or watering points was concerned for rangeland improvement.

The water harvesting experiments, of this study, were carried out in six locations in central Butana rangeland namely; Wad Nail, Elsial, Camp1, Sangir, Sobohab and Camp2, during the rainy seasons of 2006 and 2007. The results of these experiments proved that there is a 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 regions of central Butana in Sudan. The results showed that the production of rangeland biomass differs from site to site as it is greatly affected by the type of soil,
vegetation cover and amount of rainfall as shown in Table (4.1). Table (4.2) and figure (4.15) indicated clearly that the two seasons (2006 and 2007) showed high average biomass produced in different sites under water harvesting techniques. Season 2007 showed less biomass production than that of 2006, because the total amount of annual rainfall in this season is less than 2006 and also the pattern of the rainfall showed high variability because most of the rainfall occurred at the beginning of the rainy season. About 71% of the rainfall events were confined in one month from late June to late July, followed by long intervals between showers in August, September and October. Wad Nail showed a very high biomass production compared to the other five sites and this is due to the fact that this site is located in the southern area of heavy clay soils as shown in figure (3.1), hence receiving relatively high amount of rainfall. Also the dominant grass in this site is the Nal (Cymbopogon nervatus) which is relatively a very tall and dense grass. In figures (4.16 a) and (4.16 b), the biomass produced in plots 1 and 2 with surface area of 1200 and 800 m², respectively, in the six locations, was very high ($P \leq 0.01$) when compared with the normal condition represented by the control plot.

**Table (4.1): Total Annual Rainfall for the Six Experimental Locations**

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Total Annual Rainfall in (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>Wad Nail</td>
<td>310</td>
</tr>
<tr>
<td>Elsial</td>
<td>230</td>
</tr>
<tr>
<td>Camp1</td>
<td>241</td>
</tr>
<tr>
<td>Sangir</td>
<td>199</td>
</tr>
<tr>
<td>Sobohab</td>
<td>190</td>
</tr>
<tr>
<td>Camp2</td>
<td>225</td>
</tr>
<tr>
<td>Average</td>
<td><strong>233</strong></td>
</tr>
</tbody>
</table>
Table (4.2): Mean Biomass Production (ton ha\(^{-1}\)) in six Experimental Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean</th>
<th>Std</th>
<th>SE</th>
<th>Mean</th>
<th>Std</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wad nail</td>
<td>2.84</td>
<td>1.53</td>
<td>0.17</td>
<td>2.09</td>
<td>1.21</td>
<td>0.12</td>
</tr>
<tr>
<td>Elsial</td>
<td>1.32</td>
<td>0.55</td>
<td>0.06</td>
<td>0.97</td>
<td>0.29</td>
<td>0.03</td>
</tr>
<tr>
<td>Camp1</td>
<td>1.32</td>
<td>0.62</td>
<td>0.07</td>
<td>1.03</td>
<td>0.43</td>
<td>0.04</td>
</tr>
<tr>
<td>Sangir</td>
<td>1.20</td>
<td>0.84</td>
<td>0.09</td>
<td>0.92</td>
<td>0.41</td>
<td>0.04</td>
</tr>
<tr>
<td>Sobohab</td>
<td>1.47</td>
<td>0.82</td>
<td>0.09</td>
<td>0.98</td>
<td>0.44</td>
<td>0.04</td>
</tr>
<tr>
<td>Camp2</td>
<td>1.57</td>
<td>0.77</td>
<td>0.09</td>
<td>1.05</td>
<td>0.57</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Figure (4.15): Average Biomass Production in Different Sites in 2006 and 2007
Also the results of these experiments showed that the amount of harvested water and biomass production is highly affected by plot area. Figures (4.16 a) and (4.16 b) explained the difference in biomass production in different sites and different plot areas in each site. The mean value of harvested water in (m³), statistically was significantly different between different plots \((P \leq 0.01)\), with linear positive correlation \((r^2 = 0.93, 0.92)\) for seasons 2006 and 2007 respectively \((P \leq 0.01)\) as shown in tables (4.3), (4.4 a) and (4.4 b). The mean value of biomass showed a high significant difference \((P \leq 0.01)\) between different plots areas with a positive significant correlation as shown in tables (4.3) and (4.4 a) and (4.4 b), however, the difference between plots 1, 2 and 3, 4 was not statistically significant. It was found that in three sites in 2006 and five sites in 2007, the normal condition represented by the control (plot 4) produced higher biomass than plot 3 with a surface area of 400 m². This result showed that water harvested in this plot is not sufficient to grow more vegetation compared to the control plot which received more water by runoff from adjacent areas. This result proved that biomass production increased when moving from small plot area to large plot area due to water availability resulting from water harvesting, but this should be limited by design calculation and construction work needed.

Within each plot, the biomass showed a gradual increase from the top of each plot (line 5) to the bottom (line 1) due to the variation of availability of soil moisture in the root zone resulting from water harvesting. These results are shown in figures (4.17 a) and (4.17 b). Analysis of variance results showed that the mean value of biomass between different lines (zones) was significantly different \((P \leq 0.01)\), with negative significant correlation \((P \leq 0.01)\) as shown in tables (4.4 a) and (4.4 b). The negative sign in this correlation
comes from that the analysis considered the number of line which started from line 1 at the bottom to line 5 at the top of each catchment plot and the measurements of biomass are decreasing when ascending from the bottom to the top of the plot (from line 1 to line 5).

**Figure (4.16 a): Average Biomass Production in Different Sites and Different Plots in Season 2006**

**Figure (4.16 b): Average Biomass Production in Different Sites and Different Plots in Season 2007**
Table (4.3): Effect of Plot Area and Line Location on Biomass and Harvested Water in 2006 and 2007

<table>
<thead>
<tr>
<th></th>
<th>Biomass (ton ha⁻¹)</th>
<th>Harvested Water (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Season</strong></td>
<td>2006</td>
<td>2007</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>1.62**</td>
<td>1.18**</td>
</tr>
<tr>
<td><strong>Std</strong></td>
<td>1.07</td>
<td>0.76</td>
</tr>
<tr>
<td><strong>r²</strong></td>
<td>0.71</td>
<td>0.72</td>
</tr>
<tr>
<td><strong>SE</strong></td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>CV%</strong></td>
<td>66.05</td>
<td>64.19</td>
</tr>
</tbody>
</table>

** Difference is significant at the 0.01 level.

Table (4.4 a): Correlation between Plot Area, Line, Biomass, Rainfall, and Harvested Water in 2006

<table>
<thead>
<tr>
<th></th>
<th>Plot Area (m²)</th>
<th>Line</th>
<th>Biomass (ton ha⁻¹)</th>
<th>Rainfall (mm)</th>
<th>Harvested Water (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot Area m²</td>
<td>N/A</td>
<td>-0.15**</td>
<td>0.36**</td>
<td>N/A</td>
<td>0.91**</td>
</tr>
<tr>
<td>Line</td>
<td></td>
<td></td>
<td>0.46**</td>
<td>N/A</td>
<td>0.50**</td>
</tr>
<tr>
<td>Biomass Ton ha⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall mm</td>
<td></td>
<td></td>
<td>0.26**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level.
N/A: Not Applicable.

Table (4.4 b): Correlation between Plot Area, Line, Biomass, Rainfall, and Harvested Water in 2007

<table>
<thead>
<tr>
<th></th>
<th>Plot Area (m²)</th>
<th>Line</th>
<th>Biomass (ton ha⁻¹)</th>
<th>Rainfall (mm)</th>
<th>Harvested Water (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot Area m²</td>
<td>N/A</td>
<td>-0.44**</td>
<td>0.37**</td>
<td>N/A</td>
<td>0.92**</td>
</tr>
<tr>
<td>Line</td>
<td></td>
<td></td>
<td>0.51**</td>
<td>N/A</td>
<td>0.45**</td>
</tr>
<tr>
<td>Biomass Ton ha⁻¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall mm</td>
<td></td>
<td></td>
<td>0.18**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level.
N/A: Not Applicable.
Figure (4.17 a): Average Biomass Production in Different Plots and Different Lines in Season 2006

Figure (4.17 b): Average Biomass Production in Different Plots and Different Lines in Season 2007
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. 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 (4.18). The results showed positive highly significant correlation between biomass production and harvested water ($r^2 = 0.88$). A first order equation (4.1) represents this function for the average biomass and average harvested water.

\[ \text{Biomass (Ton ha}^{-1}\text{)} = 0.0092 \text{ Harvested Water (m}^3\text{)} + 0.0853 \quad \ldots \ldots \quad (4.1) \]

\[ y = 0.0092x + 0.4084 \quad R^2 = 0.8331 \]
\[ y = 0.0092x + 0.0853 \quad R^2 = 0.8827 \]
\[ y = 0.0086x + 0.0552 \quad R^2 = 0.7848 \]

Figure (4.18): The Relationship between Biomass and Harvested Water
However, the results of the two seasons should 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 results indicated that harvested water in catchments area less than 400 m² is not recommended, however harvesting water in catchments area 800 m² and more gives better results, but the construction works needed for large catchments area for water harvesting must be considered.

4.2.2 Soil Moisture

Soil water storage is an integral part of water harvesting (Myers, 1975). For crop and rangeland production, soil water storage is far more common (Bores and Ben-Asher, 1982). Soil moisture is significant for studying ecological mechanisms of vegetation distributing status, and it is also important information regarding vegetation classification. The amount of runoff that can be harvested and stored in the root zone is represented by soil moisture content. The results derived from this study proved that the mean soil moisture content, in the two depths 0 – 15 cm and 15 – 30 cm in the harvesting area, is highly affected by plot area and increasing with significant difference ($P \leq 0.01$) as shown in table (4.5) and figures (4.19 a) and (4.19 b). Within each plot the gradient of soil moisture follows the slope of the plot and it was found that the bottom of each plot (line 1) showed the highest soil moisture content in the two depths as shown in figure (4.20), which reflects directly on quantity and quality of rangeland vegetations. The correlation shown in table (4.6) showed high significant level ($P \leq 0.01$) between soil moisture at the two depths and plot area, line location, biomass, rainfall and harvested water. The negative sign in line correlation comes from that the analysis that considered
the number of line which started from line 1.0 at the bottom to line 5.0 at the top of each catchment plot and the measurements of soil moisture at the two depths are decreasing when ascending from the bottom to the top of the plot (from line 1 to line 5).

Figure (4.19 a): Mean Soil Moisture (0 – 15 cm) in Harvesting Area

Figure (4.19 b): Mean Soil Moisture (15 – 30 cm) in Harvesting Area
Table (4.5): Effect of Plot Area and Line Location on Soil Moisture Content and Harvested Water in 2006 and 2007

<table>
<thead>
<tr>
<th>Season</th>
<th>%Soil Moisture 0 – 15 cm</th>
<th>%Soil Moisture 15 – 30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>2006</td>
<td>2007</td>
</tr>
<tr>
<td>Mean</td>
<td>11.31**</td>
<td>12.24**</td>
</tr>
<tr>
<td>Std</td>
<td>2.00</td>
<td>3.13</td>
</tr>
<tr>
<td>$r^2$</td>
<td>0.87</td>
<td>0.85</td>
</tr>
<tr>
<td>SE</td>
<td>0.11</td>
<td>0.17</td>
</tr>
<tr>
<td>CV%</td>
<td>17.68</td>
<td>25.58</td>
</tr>
</tbody>
</table>

** Difference is significant at the 0.01 level.

![Figure (4.20): Mean Soil Moisture in Different Lines](chart)

**4.2.3 Floral Composition**

The floral or botanical composition of the rangeland vegetation is an important factor for determining the quality of pasture. This quality was represented by the number of
dominant palatable species that can be found in one area. In figure (4.21) and table (4.7) the number of species is increasing significantly with line location \((P \leq 0.01)\). The results indicated that increase in soil moisture in the root zone at the bottom of each catchment permits the growing of other palatable species, which did not exist in normal condition such as; Danbolal, Elgaw, Um Fereida, Danab Elnaga \((Schoenfeldia gracilis (L.) Kunth)\), Lukh \((Dichanthium annulatum)\), Um Emeirat, Elmahatraba, Tamaleika \((Acalypha indica L.)\), Soreib, Um Areiga \((Phyllanthus maderaspatensis)\), Turba \((Boehavia erecta L.)\) and Shokal Elkhail \((Blepharis linarifolia)\).

The correlation between the number of species and line number was negative because measurement values are decreasing when ascending from the bottom to the top of the plot (from line 1 to line 5); however the correlation was also found negative with amount of rainfall and biomass.

**Table (4.6): Correlation between Plot Area, Line, Biomass, Rainfall, Harvested Water, Soil Moisture and Number of Species 2006 and 2007**

<table>
<thead>
<tr>
<th></th>
<th>Soil Moisture 0 – 15 cm</th>
<th>Soil Moisture 15 – 30 cm</th>
<th>Number of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot Area m²</td>
<td>0.49**</td>
<td>0.58**</td>
<td>0.52**</td>
</tr>
<tr>
<td>Line</td>
<td>-0.25**</td>
<td>-0.31**</td>
<td>-0.27**</td>
</tr>
<tr>
<td>Biomass Ton ha⁻¹</td>
<td>0.61**</td>
<td>0.55**</td>
<td>0.61**</td>
</tr>
<tr>
<td>Rainfall mm</td>
<td>0.41**</td>
<td>0.42**</td>
<td>0.37**</td>
</tr>
<tr>
<td>Harvested Water m³</td>
<td>0.60**</td>
<td>0.69**</td>
<td>0.60**</td>
</tr>
<tr>
<td>Soil Moisture 0 – 15 cm</td>
<td>0.97**</td>
<td>0.97**</td>
<td>0.21**</td>
</tr>
</tbody>
</table>

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level.
### Table (4.7): Effect of Plot Area and Line Location on Number of Species in 2006 and 2007

<table>
<thead>
<tr>
<th>Season</th>
<th>Number of Species</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2006</td>
</tr>
<tr>
<td>Mean</td>
<td>4.33**</td>
</tr>
<tr>
<td>Std</td>
<td>1.21</td>
</tr>
<tr>
<td>R²</td>
<td>0.82</td>
</tr>
<tr>
<td>SE</td>
<td>0.06</td>
</tr>
<tr>
<td>CV%</td>
<td>27.94</td>
</tr>
</tbody>
</table>

** Difference is significant at the 0.01 level.

### Figure (4.21): Mean Number of Species in Different Lines

#### 4.3 Vegetation Cover

Vegetation cover is a key parameter for ecosystem studies on land degradation and desertification. Field inventory survey is a traditional method to conduct vegetation survey, which may be greatly limited by time and cost. Its validity and accuracy were questioned in the checking experiments (Curran and Williamson 1986; Wilson et al.,
1987), so field inventory survey can only be used as supporting information for wide range vegetation investigation.

Traditional Remote Sensing (RS) method used to acquire vegetation cover is based on mathematical models, from which a vegetation index (VI) is transformed to fractional cover. This method has been widely and successfully applied in large-scale vegetation monitoring of many regions (Duncan et al., 1993). This study, separately constructs linear regression equations for estimating vegetation cover using field survey data and calculated VI data, and analyzes the coherence between estimation outcomes and checkout samples.

Many applications showed that vegetation indices have stronger discrimination in reflecting vegetation cover than single image band, and that they commonly contribute to a much improved results of classification when applied in land-use and land cover investigations and biomass estimations (Qingjiu Tian and Xiangjun 1998; Viegand et al, 1991; Wilson et al, 1987). The Perpendicular Vegetation Index (PVI) is designed to rule out the influence of soil background.

The remote sensing data were provided by SPOTVIEW image dated 5/10/2006 of 10 m resolution. The image is a combination of panchromatic and multispectral bands and has three bands Green (G), Red (R) and Near Infra-Red (NIR). The ground truth was done at the same time in the field. PVI was computed in ERDAS IMAGINE 9.1 software. Thirty eight points of bare soil (roads and surroundings of haffirs) were identified in the field by their coordinates. The mean value of Red (R) and Near Infra Red (NIR) reflectance value 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 where the correlation was accurate ($r^2 =$
From this correlation the slope of the line (a) and the intercept point (b) was obtained as illustrated in figure (4.22).

These figures of the line slope and intercept point together with the formula of PVI as shown in equation (3.4) was applied in each pixel of the corrected image, which includes the Red and Near Infra Red reflectance value, in ERDAS IMAGINE 9.1 software. As a result of this process a new map of PVI was obtained as shown in figure (4.23).

The visual interpretation of PVI map was done to differentiate between different landuse type and vegetation units. Figure (4.23) showed that the maximum value of PVI was 12.1 \( \mu m \) which represents the high vegetation density in rainfed agriculture practiced under traditional water harvesting techniques or dense forest canopy, while the minimum value of PVI - 8.4 \( \mu m \) to represent the water bodies and bare soil. The variability of vegetation cover is increasing from the black color representing very poor vegetation cover to white.
color of the high vegetation density. In ERDAS IMAGINE 9.1 software, model maker was selected to create a model to differentiate between PVI classes as shown in figure (4.24). The geometric, radiometric and reflectance corrected satellite image, by equation (3.1) and (3.2), was used as input data. The bare soil line regression coefficients (a) and (b) were used in PVI equation (3.3) to generate the PVI map in figure (4.23). PVI ranges for different land cover were identified by visual interpretation and applied in the model. The supervised classification of the PVI map showed that four classes of PVI representing different landuse and vegetation cover can be identified in Central Butana rangeland as shown in figure (4.24). The first class is water bodies (haffirs), which cover approximately 0.01% of the total area, and takes the range of -8.4 to -2.4 µm, which was determined precisely by checking all the pixels cover all around haffirs. The next class to water is bare soil taking the value of -2.38 to 0.149 µm, which occupies the dark grey color. The third class is rangeland vegetation with the light grey color and takes the value from 0.149 to 2.68 µm, from which the extreme low value represents the degraded and poor condition of rangeland around water points and most of the high land. The high value is for good condition rangeland in water courses and adjacent to rainfed agriculture sector. The last PVI class, 2.68 – 12.11 µm, 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. These fields were characterized and identified by their regular geometric shape as show in figure (4.23). The reserved forest, which occupied the south western part of the study area, showed also relatively high PVI values.
Figure (4.23): Perpendicular Vegetation Index (PVI) of Central Butana
4.4 Landuse and Vegetation Pattern

One of the prime prerequisites for better use of land is information on existing land use patterns and changes in land use through time. Land use and land cover change has been recognized as an important driver of environmental change on all spatial and temporal scales, which contributes significantly to earth atmosphere interactions, forest
fragmentation, and biodiversity loss (Turner et al., 1994). It has become one of the major issues for environmental change monitoring and natural resource management.

Remote sensing data (SpotView) coupled with ground vegetation survey was used to determine the different classes of land use and land cover in central Butana. Spectral reflectance of the dominant vegetation species in the eighteen field survey points covered by the satellite image was extracted from the image and groups of the vegetation units. Figure (4.25) and (4.26) 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 km² (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 km². 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 km² (7.5%). The forests are dominant on red sandy clay soil (goz) and the dominant trees are Seyal (Acacia tortilis), while sparse trees of Kitr (Acacia mellifera) are found on clay soils.

The vegetation units were determined in each sampling point. The remote sensing digital number for these species was used to generate large scale vegetation units in central Butana rangeland. Supervised classification on vegetation layer extracted from the PVI map was done to extrapolate the vegetation units. Figure (4.26) and (4.27) showed that there were four vegetation units, with their dominant species, identified in the area. The big unit, which is represented by the yellow colour, covers 638 km² (40%) of the rangeland area and includes the following dominant species; Danbolab (Schoefeldia
Gracilis), Gaw (Aristida adscensionis), Umm assabie (Dactyloctenium aegyptium) and Seyal (Acacia tortilis). The second unit shown by the cream colour covers 554 km² (35%) of the rangeland area and includes the following dominant species; Tumam (Panicum turgidum), Tabar (Ipomoea cordofana) and Kitr (Acacia millifera). The third unit shown in light green colour covered 364 km² (23%) of the rangeland area and includes Tuffa (Urochloa trichopus). The last unit is very small and occupied only 27 km² which is only 2% of the total rangeland area and is represented by the pink colour and include Nal (Cymbogon nervatus) and Maharai (Cymbogon proximus). However these species were not the only ones in each unit but, they form the dominant species in each unit. The rest of the study area is either sorghum (Sorghum bicolor) shown by the green or reserved forests shown in orange colour.
Figure (4.25): Land cover and Landuse Map of Central Butana
Figure (4.26): Landuse Type and Floristical Groups of Central Butana Rangeland
Figure (4.27): Floristical Groups of Central Butana Rangeland

4.5 Biomass Estimation

Biomass is considered an important component 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 (Whittaker and Woodwell, 1971).

The present study on biomass estimation using remote sensing data, attempts to couple ground based vegetation quantification with the satellite remote sensing. Earlier studies have investigated the relationship of spectral vegetation indices derived from satellite data to surface vegetation parameters using correlation or regression analysis (Richardson and Wiegand 1977; Tucker et al 1985).

Above-ground biomass is expressed as kg DM biomass ha⁻¹ year⁻¹. The primary above-ground biomass production was measured as follows. In each 1 ha sample plot, the above-ground biomass (peak standing crop) of all herbaceous species was collected in 25 separate 1.0 m² plots (Miehe, 1992, 1997). Biomass was summed over the different plots in order to obtain the per hectare above-ground biomass production.

The above ground 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 linear relationship between ground measured biomass and PVI values were plotted in figure (4.28) ($r^2 = 0.91$). These results were used to prepare regional biomass map by applying the regression equation in each pixel on PVI map as shown in figure (4.29).

The biomass map in figure (4.29) showed that the degraded rangeland of central Butana, represented by white color, produces from 0 to 350 kg DM ha⁻¹ year⁻¹, while the medium rangeland condition produces from 350 to 650 kgDM 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 (2008) 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 depressions, river valleys and water spreading zones. The light and dark green color is forest and rainfed agriculture, which show high biomass production of 950 to 1200 and 1200 to 8500 kg DM ha\(^{-1}\)year\(^{-1}\), 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 its maximum vegetative stage, hence giving high reflectance in red and near infra red bands.

![Figure (4.28): The Relationship between PVI and Field Biomass](image)

Field Biomass = 504.08 x PVI + 596.16

\[ R^2 = 0.9106 \]

The main factor controlling 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 (Le Houerou and Hoste, 1977) and other environmental factors such as grazing regimes (Hein, 2006).

The biomass map showed that high grazing pressures have a significant impact on herbaceous biomass production in central Butana rangeland. This confirms the statements of Le Houérou (1984), Sinclair and Fryxell (1985) and Illius and O’Connor (1999) who proposed that the high grazing pressures may affect functioning and productivity of rangelands, in particular, in the medium and long term.

**Figure (4.29): Biomass Map of Central Butana**
4.6 Rain Use Efficiency (RUE)

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 (Le Houérou, et al. 1988). The rain use efficiency (RUE) factor thus appears as a good indicator of ecosystem productivity allowing, furthermore, valid comparisons between ecosystems for various climatic zones or those having totally different botanical and structural characteristics.

(RUE) is a ratio of the rangeland production (kgDM ha⁻¹) divided by the total amount of precipitation (mm) during the year. It is expressed in kgDM ha⁻¹mm⁻¹ (Le Houèrou, 1984; Guintzburger, et al. 2005). The RUE of Butana was computed by dividing the biomass (kg DМha⁻¹) map by the rainfall map (mm) generating from field collected data.

The spatial distribution of RUE factor in central Butana rangeland shown in figure (4.30) indicated that the RUE factor is in the range of 0 to 4 kgDM ha⁻¹mm⁻¹ for the rangeland with an average value of 2.5 kgDM ha⁻¹mm⁻¹, which almost agreed with Le Houérou (2006) who stated that the RUE for the Sahel zone is 2.7 kgDM ha⁻¹mm⁻¹. 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 kgDM ha⁻¹mm⁻¹, 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 are shown by the map in figure (4.30). The almost desertified areas, which show no production, have RUE from 0 to 1 kgDM ha⁻¹mm⁻¹, the high degraded rangeland has 1 to 2 kgDM ha⁻¹mm⁻¹, the
medium degraded rangeland 2 to 3 kgDM ha\(^{-1}\)mm\(^{-1}\) and the good rangeland condition near rainfed agriculture has 3 to 4 kgDM ha\(^{-1}\)mm\(^{-1}\).

Results of this study proved that the current situation of central Butana rangeland showed a very high degradation as indicated by the RUE factor map, 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 use of rainfall and hence increase the rain use efficiency.

Figure (4.30): Rain Use Efficiency Map (RUE) of Central Butana
4.7 Potential Runoff Estimation

Spatial information on runoff coefficient, slope and drainage plays a critical role in site selection for runoff harvesting/recharging structures. Satellite remote sensing techniques in conjunction with landform-soil vegetation relationships and ground truth are popular for locating suitable sites for the construction of water harvesting structures and soil and water conservation measures. The Soil Conservation Service model (SCS-CN) (USDA-SCS, 1972) computes direct runoff through an empirical equation that requires rainfall and a basin coefficient as inputs. The basin coefficient, known as the runoff curve number (CN), represents the runoff potential of the land cover soil complex. Landform, drainage pattern, slope, soil, vegetation and land use/land cover, all of which control surface runoff and peak flow, can be evaluated and mapped reliably and reasonably through SpotView and the ground survey for the rainy season 2006.

4.7.1 Drainage Watershed Delineation and the Drainage Network

The Shuttle Radar Topography Mission (SRTM) was a space shuttle mission in February 2000. The SRTM data was downloaded in height files. The digital elevation model (DEM) was generated by processing in 3DM visualization software (http://wwwvisualizationsoftware.com/3dem.html, 2004). ESRI’s ArcHydro tool is used for extracting the watershed area from digital elevation model. The first step in this processing is to fill sinks in the DEM. Sinks are sudden change in pixel height values. Using hydrological modelling, shown in figure (4.31), the flow directions raster is generated from DEM. The flow direction raster actually shows the direction of water flow. Each pixel in the flow direction raster is assigned a slope value. The next process is the flow accumulations. The flow accumulation is computed from the flow direction raster. By using this flow accumulation raster the stream definition
raster is generated. The Stream Definition function takes a flow accumulation raster as input and creates a stream raster for a user-defined threshold. To get the stream network in the area, stream segmentation raster is generated from stream definition raster. This function links the stream definition raster to make the streams network for the area.

The catchments delineation raster is computed from stream segmentation. The catchments raster delineation function creates a raster in which each cell carries a value indicating cells belonging to catchments. The value corresponds to the value carried by the stream segment which drains that area, defined in the stream segment link raster. To extract catchments polygon shape file, the catchments polygon processing is done on catchments delineation raster. The adjacent cells in the raster that have the same raster code are combined into a single area, whose boundary is vectorized. Vectorization processes are dissolved automatically, so that at the end of the process there is one polygon per catchment. The drainage lines are generated from the stream definition raster and flow accumulation raster using ArcHydro tool drainage line processing. The drainage line processing function converts the input stream link raster into a drainage line feature class. Each line in the feature class carries the identifier of the catchments in which it resides.

Lastly the watershed extraction is done by adjoint catchments processing function. The Adjoint Catchment Processing function generates the aggregated upstream catchments from the catchment feature class. For each catchment which is not a head catchment, a polygon representing the whole upstream area draining to its inlet point (reservoir) is constructed and stored in a feature class that has an "Adjoint Catchment" that is basically the watersheds of central Butana, which shown in figure (4.32), the map shows that Butana is a compound of a number of catchments different in size 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, and some were sloping towards the west and drain in the Blue Nile and others sloping towards the south and drain in the Rahad seasonal River. 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.

Figure (4.31): Watershed and Drainage Network Model in Central Butana
4.7.2 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 Butan. The soil map was digitized in GIS and HSG was determined according to soil characteristics and table (3.5). Four groups of HSG are found in Butana area, namely; A, B, C and D (Ramakrishnan et al; 2009). The HSG of the Central Butana rangeland shown in figure (4.33) 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 with 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) (Ramakrishnan et al; 2009). In the present study, the SpotView satellite data of the rainy season 2006 coupled with ground
vegetation survey was used for the generation of land use categories. Spectral reflectance of the dominant vegetation species in the eighteen field survey points covered by the satellite image was extracted from the image and grouped in the vegetation units. They are then evaluated to make sure that there is a suitable discrimination of individual classes. After obtaining a suitable grouping for satisfactory discrimination between the classes during signature evaluation, the final classification is carried out. Three major land use classes, shown in figure (4.25), namely; crop land (47.9%), rangeland (44.7%) and forest (7.5%) are observed.

Figure (4.33): Hydrological Soil Group (HSG) of Central Butana Rangeland
As the SCS-CN method is very sensitive to CN value, accurate determination of this parameter is very important (Ramakrishnan et al; 2009). 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 (3.4). 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 (4.34) 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 0.1% are between 60 to 69 and the rest 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 as shown in figure (4.35).

4.7.3 Annual Runoff Potential

The standard SCS-CN method is based on the relationship between rainfall depth, \( P \), in millimetres, and runoff depth, \( Q \), in millimetres as shown in equations (3.5). The result of potential runoff depends on CN values, which is a combination of land use and soil type. The high CN values produce high amount of runoff and vice versa. In addition to CN variation, spatial variability of rainfall over the area was incorporated for accurate runoff prediction. Woodward and Cronshey (1990) noted that the part of the drainage basin, which is represented by another rain gauge, significantly affects the runoff distribution under uniform rainfall conditions. White (1988) and Stuebe and Johnston (1990) have estimated runoff for larger areas under uniform rainfall conditions. For the present study, the rainfall for the six measurement sites was used to predict the potential of runoff through the model.
Figure (4.34): Curve Number (CN) of Central Butana Rangeland

Figure (4.35): Percentage of CN values in Central Butana Rangeland
The spatial distribution of annual runoff depths was displayed in figure (4.36) which showed big variation from the minimum annual potential runoff of 13 mmyr\(^{-1}\) in the forest to the maximum amount of 64 mmyr\(^{-1}\) in some areas usually occupied by rainfed agricultural activities.

According to Blokhuis (1993), who noted that the reddish sandy clay soils (goz) showed an open growth of trees, with much different types of Acacia species mainly seyal (\textit{Acacia tortilis}), and sparse shrubs and grass covered surface. The lowest annual runoff 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 (4.36). 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 mmyr\(^{-1}\)).

On the basis of runoff coefficient, which is a ratio between the rainfall and runoff (Ramakrishnan et al; 2009), the histogram distribution displayed in figures (4.37 a) and (4.37 b) showed these runoff coefficient classes and grouped them into three broad classes such as high (>25%), moderate (20 to 25%) and low (<20%). It is evident from these figures that only 16% of the study area falls under the high runoff potential class. The moderate and low runoff coefficient classes occupy 57% and 27% of the total area, respectively.
Figure (4.36): Runoff Potential of Central Butana Rangeland

Figure (4.37 a): Frequency distribution of different runoff coefficients
The average potential runoff depth in the study area, which covers 3600 km², is 52 mm. Hence, the total runoff volume was estimated for the whole study area as 187.2 x 10⁶ m³ 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.

4.8 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 (4.38).
Spot satellite image was used as input data from which the PVI was generated by equation (3.4). PVI and biomass ground survey were linked together to create the current spatial distribution of biomass production in kgDM 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 equation (4.1). 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\(^3\)). Equation (4.1) and rainfall map (m\(^3\)) were used together to simulate the potential of rangeland biomass production resulting from water harvesting application.
Figure (4.38): General Model of Water Management
Figure (4.39) 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 (4.39) represents the increase in dry matter production in the most degraded areas of the rangeland shown in figure (4.29) 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 kg ha\(^{-1}\) mm\(^{-1}\) 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 (4.39) 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.
Figure (4.39): Water Harvesting Simulated Biomass
4.9 Perception of the Pastoralism on Socio-economic Characteristics of Central Butana Region
A field survey was conducted during the period from July-September 2007, by visiting a number of villages and livestock watering points (haffirs), which are sites used by nomads during the dry period. Questionnaires and open discussions were used at randomly selected villages as shown in plate (4.1). This was in an attempt to cover as many villages as possible in order to get a broad view about the socio-economic characteristics of central Butana region.

Plate (4.1): Field Survey Discussion

The interviews covered the following aspects:
1. Soil Types
2. Social life
3. Income generating activities
4. Water Resources Management
5. Rangeland condition and animal mobility

4.9.1 Soil Types
The results of the field survey in the central Butana rangeland showed that the general topography of the landscape is almost flat occupied by 65% dark heavy clay soil in
the southern part and 35% reddish sandy clay soils in some parts of the west and north. The soil types determine to a large extend the vegetation cover and hence the human activities and cultural practices.

4.9.2 Social Life

Social survey by using non-structured questionnaires was carried out during 2007 for about 60 respondents; 50% of them are sedentary and the other 50% are transhumant. In the southern part, where the rainfall is sufficient to grow grain crops besides livestock raising, 80% of the respondents are agro-pastoralist and they grow grain crops besides raising considerable number of livestock and live in permanent villages, while in the northern part, 90% of the people depend mainly on livestock and they are transhumant always looking for water and good pasture.

4.9.3 Income Generating Activities

The permanent villages in Butana area are located in the western part, where their access to water from groundwater and the Blue Nile River is reasonable, 47% of the respondents generating their income from agricultural production, while 33% from raising animal herds, and 20% from different trade activities. The main crop grown is sorghum as it is the main stable food for the people beside that the straw is an important aliment for animals in the dry season. The production of sorghum per unit land is low and is highly affected by the erratic nature and variability of the rainy season. The average land production rate of the sorghum grains is in range of 600 to 1190 kg ha⁻¹.

The majority of people in Butana are raising animals in various numbers and ways. The small ruminants constitute about 57% of the animals kept in the area followed by cows 20% while camels are about 23%. The majority prefer to breed small ruminants because it is easy to manage and consume less fodder and water. Two categories of
herds were recognized in these villages; in the first the animals belong to a number of families and in this case they should rent someone to look after the herd and he must practice day grazing only and should come back at the end of the day usually before sunset, while in other type the animals belong to one or two people and they prefer to stay out of the village moving around looking for good pasture and water for their animals and therefore become transhumant rather than sedentary.

The rainy season is characterized by sufficient rainfall in the southern part which is enough for the growing season. Moving towards the north, the growing season is always limited by water shortage at the end. People try to make efficient use of the natural resources available during the four months of the rainy season; they start growing the sorghum crop in small holdings under traditional water harvesting practices and feed their animals in a circle pasture around their villages. The family income for transhuman is either from livestock products (77%) or from agricultural products beside the animal’s products (23%).

4.9.4 Water Resources Management

Rainfall is the main source of water for agriculture and rangeland vegetation. The drinking water for inhabitants, herders and animal, is an important factor controlling the use of natural vegetation resources in the area. In the sedentary life, about 33% of respondents derive drinking water for them and their animals from surface wells, while 37 % from pumping stations and the rest use haffirs. These wells and pumping stations did not exist in each village; so many villages share the same source of water. This situation makes 20% of people travel more than 3 km to reach a water source and 30% from 1 to 3km and the other 50% travel less than 1 km.
The transhumants arrange their movement according to water points (haffirs), so 80% of them use haffirs as the main source of drinking for them and their animals and 20% move around permanent villages and use surface wells and water pumping stations.

### 4.9.5 Rangeland Condition and Animal Mobility

Butana Region is considered to be the best rangeland for nomads in the Northern part of Sudan (Hamad et al., 1992; Gunnar, 2003). It is an open grazing area, exploited by all groups living in Butana or others entering the area, from adjacent areas, in the rainy season, looking for good pasture for their animals according to their own grazing strategies. Transhumant follow the local classification of the season in Butana area; Kharif (*rainy season*), Shitaa (*winter*) and Saif (*summer*) and 70% of the transhumant enter Butana in August after being sure that the area receives sufficient rain and the vegetation cover is enough for their animals, while 17% in July and 13% in September. High percentage of these people (87%) tends to come every year and don’t stay in one place, but moving all a round searching for good vegetation and water.

In the rainy season, where the pasture status is good, 77% of the transhumant uses the natural grasslands while 23% prefer natural grassland and shrubs. This depends to a large extent on the type of animals. Small ruminants and cows prefer grasses while camels like trees and shrubs areas. During the rainy season the quantity and the quality of the rangeland vegetation is very good and since the grasses are green and contain appreciable percentage of water, the shepherd don’t arrange their movement according to water points, which is mainly haffirs and they visit it intervals between 2 – 10 days for small ruminants and cows and at more than 30 days in case of camels. They try to look for good pasture as far as possible as they can. The herders try to make efficient use of their stay in Butana hence 27% of them practice day and night
grazing while they are moving especially for camels and cows herders. They don’t use any kind of complementary alimentation except for dairy cows.

At the end of the rainy season, the quantity and quality of the natural vegetation starts to deteriorate, and the area becomes devoid from favorable species such as tabar (*Ipomea cordofana*), siha (*Belpharis linarifolia*), tuffa (*Urochloa trichopus*) and tumam (*Panicum turgidum*). The rest of the vegetation starts to dry up. The rare water points, which are subjected to high pressure, start also to dry up. As a result of these circumstances the herders concentrate near and around water points to avoid long distance traveling, although the pasture is still sufficient and better in remote areas.

In the cold dry season (Shitaa), the herders face many difficulties with their animals due to lack of water and the low quality of rangeland. About 13% of herders migrate southward to reach Rahad Irrigated Scheme during this season. The rest of the herders (87%), mainly small ruminants herders, prefer to stay, and they are able to escape the worst effects of the shortage of water, by using lorries and pick-up trucks to transport livestock or water. In the hot dry season (Saif), the herders can not survive any more under this harsh environment and usually look for other options such as Rahad Irrigated Scheme in the south or New-Halfa Sugar Scheme in the east. The two schemes were mainly established as government intervention aimed towards encouraging settlement of the transhumant livestock nomads inhabiting Butana region as well as diversifying the activities of these pastoralist people towards agropastoralism (*Abbas et al.*, 1992; *Saint-Martin et al.*, 1992). Others cross the Blue Nile to the Gezira scheme in the west.

The results of this survey proved that the socio-economic life of central Butana area is affected by water resources. There is a great interaction between the natural resources and the socio-economic life of Butana population. The general life of the sedentary
people is controlled to a large extent by the water resources specially rainfall, which determines the success or failure of the agricultural season beside its effect on livestock through rangeland vegetation and drinking water points. The whole life of transhumant is controlled by the pattern and distribution of rainfall; their first decision to come in Butana, their movement, the duration of stay, the family income and the date of opposite migration are all factors controlled by the situation of water resources in the rangeland.

It is evident from these results that the area suffers from severe shortage and uneven distribution of water during the hot dry season, which have a great impact on rangeland utilization. To overcome this problem, this study presents rainwater harvesting decision support model that have been built to assist decision makers and stakeholders by indicating the suitability of rain water harvesting in any selected part of central Butana and quantifying the potential of runoff depths.

The potential of water volume that can be harvested was estimated at about 187.2 x 10^6 m^3. Constructions of surface water storage and groundwater recharge structures are proposed to augment both surface and sub-surface storage. Firstly, these activities reduce runoff velocity, thereby minimizing erosion and secondly, allow the retained water to percolate and result in increased recharge. However, efficiency and performance of these structures depend on appropriate structural design, site selection procedure (Ramakrishnan and Rao, 2008) and stakeholder participation.
CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Satellite remote sensing techniques in conjunction with Geographical Information System (GIS) were used as new and advanced techniques in water management in central Butana rangeland. A general model, which analysing remotely sensed data with the ground truth findings, is designed to evaluate the current condition of the water resources available, improve the scarce rain water use efficiency and assist decision makers and stakeholders by indicating the suitability of rain water harvesting in any selected part of central Butana and quantifying the potential of runoff depths.

The results and findings of this study can be concluded as follow:

- The annual evapotranspiration values in the three stations exceed the rainfall even during the rainy season, which indicates that there is always a water deficit in Butana especially in the northern part.

- There is a 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 regions of central Butana in Sudan. The production of biomass is a function of harvested water, which depends on the size and design of water harvesting catchment. The larger catchment area produces better results, but the construction works needed for large catchments area harvesting must be considered.

- Remote sensing integrated with GIS can play a major role in sustainable management and development of central Butana rangelands by providing information on land use/land cover, land productivity and
water quantity. Remote sensing data is a reliable and precise tool to map and evaluate concurrent condition of the natural resources in Butana.

- Spatial distribution of rangeland production is affected by rainfall pattern, variability and distribution.
- Rain Use Efficiency (RUE) factor appears as a good indicator of ecosystem productivity and degradation allowing, furthermore, appropriate determination of suitable areas for water harvesting application.
- The use of Soil Conservation Service model (SCS-CN) to compute direct runoff through an empirical equation that requires rainfall and a basin coefficient as inputs produce reliable estimates that can be used for better design and location of water harvesting structures.
- 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 the study area. The model linked the final results of remote sensing and GIS, which include maps of rainfall, PVI, biomass, rain use efficiency and drainage, together with the results of field measurements of water harvesting experiment and ground survey.
- Application of this model improves the RUE factor in central Butana rangeland appreciably.
- The social survey results have proved that the socio-economic life of central Butana is affected by the water resources and showed the great
interaction between the natural resources and the socio-economic life of Butana population.

- The general life of the sedentary people is controlled to a large extent by the water resources specially rainfall, which determines the success or failure of the agricultural season beside its effect on livestock through rangeland vegetation and drinking water points. The whole life of transhumant is controlled by the pattern and distribution of rainfall; their first decision to come in Butana, their movement, the duration of stay, the family income and the date of opposite migration are all factors controlled by the situation of water resources in the rangeland.

- It’s evident from these results that the area suffers from severe shortage and uneven distribution of water during the hot dry season, which have great impact on rangeland utilization. To overcome this problem, this study presents the rainwater harvesting decision support model that has been built to assist decision makers and stakeholders by indicating the suitability of rain water harvesting in any selected part of central Butana and quantifying the potential of runoff depths.

**Recommendations**

Population growth together with changes in lifestyle and economic development in developing countries has put high pressure on water resources that are already limited. Environmental problems, especially climate change, add to these pressures. Since it is a resource that is essential for life, the supply, improvement and sound management of water are key elements for livelihood improvement in Butana. This study aimed to find appropriate management methodology for the
scarce water resources in central Butana rangeland but, for better results in the future development the study recommends the following.

- Creation of reliable database and Metadata for meteorological information by establishing a number of weather stations to cover the area.
- Merging the new techniques such as satellite images and hydrological models to calculate the potential runoff water.
- The increase of annual rainfall in Butana area post 1994 should be efficiently utilized.
- Water harvesting structure must be built in the area with sufficient volume of runoff water.
- It is recommended to distribute watering points to cover large areas and ensure homogenous utilization of rangeland forage and avoid concentration in few sites which may lead to rangeland degradation.
- Environmental Impact Assessment studies are prerequisite before any further expansion of rainfed agriculture over the rangeland in Butana area.
REFERENCES


## Appendices

### Appendix 1: Biomass Measurements in Water Harvesting Sites

<table>
<thead>
<tr>
<th>Line number</th>
<th>Square number</th>
<th>Ground Cover (%)</th>
<th>Fresh grass Weight (g)</th>
<th>Dry grass Weight (g)</th>
<th>Dry matter Rate (%)</th>
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* : For A2 or A3 : Run off area
Confidence interval of dry grass weight: \( \text{Av} +/\text{t SD}/(N-1)^{1/2} \)
Appendix 2: Experimental Site Study Form in Water Harvesting Sites

Photo N° : ……… Date / / 2006 Author :……………

Site N° :……………… Plot type: A0 A1 A2 A3
Coordinate : Latitude :….. Longitude: :…..

Vegetation study lines

<table>
<thead>
<tr>
<th>Grass species</th>
<th>Line 1</th>
<th>Line 2</th>
<th>Line 3</th>
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<tbody>
<tr>
<td>Grass</td>
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Other Observations

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152
Appendix 3: Vegetation Map Study Form (25 sites)

Site N° : .......... Photo N° : .......... Date / / 2006 Author : ..............

Coordinate : Latitude : ..... Longitude : ..... 

Type of soil : Soil Colour : Slope : %

Vegetation structure : Grasslands; Bush and grass Steppe;
Grass cover : % Tree cover : % Bare soil : %

Abundance/Dominant species

<table>
<thead>
<tr>
<th>Grass and ligneous species</th>
<th>Species Type</th>
<th>Cotde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td></td>
<td></td>
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<tr>
<td>Shrub and trees</td>
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</tbody>
</table>

Abundance/Dominance Code: + : Rare. Species type: Graminae
1: Regular. Around 1 % cover Leguminosus grass
2: From 1 to 5 % cover other grass
3: From 5 to 35 % cover Shrub
4: From 35 to 75 % cover Tree
5: Over 75 % cover other

Observations: ...........................................................................................................
Appendix 4: Biomass Measurements (25 sites)

<table>
<thead>
<tr>
<th>Square number</th>
<th>Ground Cover (%)</th>
<th>Fresh grass Weight (g)</th>
<th>Dry grass Weight (g)</th>
<th>Dry matter Rate (%)</th>
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<tr>
<td>Std Dev.</td>
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Confidence interval of dry grass weight: \( \text{Av} \pm t \left( \frac{SD}{(N-1)^{1/2}} \right) \)
Appendix 5: Pastoral Investigation Form (Mobile system)

No.: (            )
Date: /       / 2006
Author: ………………………………………………….
Village name:…………………………………………..
GPS coordinates: X ……………………….……. Y ……………………………..
Farmer name: …………………………………………………..

1- General Information

1.1 General topography of the area
   a) Very flat
   b) Flat
   c) Not flat

1.2 Type of soil
   a) Clay soil
   b) Sandy soil
   c) Sandy clay

1.3 Type of practiced culture
   a) Rainfed agriculture
   b) Irrigated agriculture
   c) pastures
   d) Rainfed and pastures

1.4 Type of crops and productivity in kg/acre

<table>
<thead>
<tr>
<th>Type of crops</th>
<th>&lt; 250</th>
<th>250-500</th>
<th>500-750</th>
<th>&gt; 750</th>
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<tbody>
<tr>
<td>sorghum</td>
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<td>millet</td>
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<tr>
<td>vegetables</td>
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<tr>
<td>others</td>
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</table>

1.5 Do people use machinery?
   a) Yes
   b) No

1.6 What type of machinery they usually use?
   a) Disc plough
   b) Disc harrow
   c) Wide level disc
   d) Ridger

1.7 Do they practice water harvesting techniques?
   a) Yes
   b) No

1.8 What type of water harvesting techniques they practiced?
   a) Terraces
   b) Contour line
   c) Haffir
   d) others (specify) ……………

1.9 What is the source of people drinking water?
   a) Water pump stations
   b) Surface wells
   c) Haffir
   d) others (specify) ……………

1.10 How far the drinking water point from village?
   a) < 500 m
   b) 500 m - 1 km
   c) 1 - 3 km
   d) > 3 km

1.11 State of water
   a) v. good
   b) good
   c) bad
   d) v. bad

1.12 Do people breed animals?
   a) Yes
   b) No

1.13 Do you own the animals?
   a) Yes
   b) No

1.14 Type and number of animals
<table>
<thead>
<tr>
<th>Type of animals</th>
<th>&lt; 10</th>
<th>10-20</th>
<th>20-50</th>
<th>50-100</th>
<th>&gt;100</th>
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<tr>
<td>Small ruminants</td>
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<td>cows</td>
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1.15 what are the most important animal diseases?
1. .................................................................
2. .................................................................
3. .................................................................

1.16 what are the most important animal parasites?
1. .................................................................
2. .................................................................
3. .................................................................

1.17 who ensure the health treatment?
 a) Veterinary authorities       c) No health treatment
 b) Herder themselves            d) others (specify) ............

1.18 what are the main sources of your family income (put numbers 1, 2, 3 & 4 for order of importance)?

<table>
<thead>
<tr>
<th>sources</th>
<th>order</th>
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<tbody>
<tr>
<td>1- Agricultural products</td>
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<td>2- Animals products</td>
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<td>3- Trade</td>
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<td>4- ...........................................</td>
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2. Rangeland management

2.1 General herd management

2.1.1 from which area do you come from?
 a) Gezira area        b) Rahad area
 c) other (specify)

2.1.2 why do you come to Butana?
 a) looking for good pastures        b) looking for water
 c) because of the regulation        d) other

2.1.3 when do you usually come to Butana area?
 a) June b) July
 b) August d) September

2.1.4 when do you usually leave Butana?
 a) September b) October
 b) November c) December

2.1.5 do you come every year to Butana area?
 a) yes b) no

2.1.6 do you stay in one place or you move around all the area?
 a) stay in one place b) move around

2.1.7 do you face any troubles from the local people?
 a) yes b) no

2.1.8 How many types and number of herds do you manage separately?
2.1.9 Do you manage your herds in the same way for the whole year?
  a) Yes  
  b) No

2.1.10 If no what are the different periods you identify

<table>
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<tr>
<th>Name of period</th>
<th>Beginning</th>
<th>End</th>
<th>Characteristics</th>
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**2.2 In the rainy season (Kharif)**

2.2.1 beginning and end of the rainy season
  a) Begins in ....................................................
  b) Ends in ..........................................................

2.2.2 what type of rangeland you use?
  a) Natural Grasslands
  b) Natural Shrublands
  c) a and b
  d) Crop residue

2.2.3 who is looking after herd?
  a) The owner of the animals
  b) Wife and children
  c) Adult sons
  d) Rent people

2.2.4 where do you keep the animals?
  a) in villages
  b) In the field

2.2.5 what is type of practiced grazing?
  a) Day grazing only
  b) Night grazing only
  c) Day and night grazing

2.2.6 Distance cover by animals in the day (circle radius)
  a) < 2 km
  b) 2 - 4 km
  c) > 4 km

2.2.7 do you use complementary alimentation?
  a) yes
  b) no

2.2.8 Type of complementary alimentation used
  a) Straw
  b) crop residues
  c) Green fodder
  d) Others (specify)

2.2.9 Do you face any problems from crop people?
  a) Yes
  b) No

2.2.10 the quantity of rangeland vegetation in the area
  a) more than needed
  b) Sufficient
  c) Not sufficient
  d) very poor

2.2.11 the quality of rangeland vegetation in the area
  a) v. good
  b) good
  c) bad
  d) v. bad
2.2.12 what are the most favourable and consumed species?
1. ..........................................................
2. ..........................................................
3. ..........................................................

2.2.13 what are the most unfavourable species?
1. ..........................................................
2. ..........................................................
3. ..........................................................

2.2.14 Do you use the same pasture every year?
a) Yes    b) No

2.2.15 for how long do you stay in the same place?
a) 2-4 days  c) 6-8 days
b) 4–6 days  d) More than 8 (specify)

2.2.16 Do you change your place according to rain and good vegetation?
a) Yes    b) No

2.2.17 what is the main factor for changing your place?
a) vegetation  b) drinking water
c) vegetation and drinking water  c) other

2.2.18 water management
2.2.18.1 do you arrange your movement according to water point?
a) yes    b) no

2.2.18.2 what is the main source of animal drinking water?
a) Pump stations  c) Haffirs
b) Surface wells  d) River

2.2.18.3 the quantity of water
a) More than needed  c) Not sufficient
b) Sufficient  d) Little

2.2.18.4 State of water
a) v. good  b) good
c) bad  d) v. bad

2.2.18.5 How many times for animals to take water
a) Once every day  b) Every other day
c) Twice a day  c) Other (specify)

2.2.18.6 How far the drinking water point from animals?
a) 1-3 km  c) 5-10 km
b) 3-5 km  d) more than 10 km

2.3 In cold dry season(Darat)
2.3.1 Beginning and end of cold dry season
a) Begins in .............................................
b) Ends in ..................................................

2.3.2 Do you stay in the same place or you move to another place?
a) Stay    b) Move

2.3.3 why do you move?
a) Looking for good pasture  c) Looking for security
b) Looking for water  d) Other (specify)

2.3.4 Do you migrate to other regions?
a) yes    b) no

2.3.5 If yes, when do you start migration?
a) October  b) November
b) December  c) January
2.3.6 To where do you migrate?
   a) Gezira irrigated scheme
   b) Rahad irrigated scheme
   c) Halfa irrigated scheme
   d) other (specify)

2.3.7 What type of rangeland you use?
   a) Natural Grasslands
   b) Natural Shrubslands
   c) a and b
   d) Crop residue

2.3.8 Who is looking after herd?
   a) The owner of the animals
   b) Wife and children
   c) Adult sons
   d) Rent people

2.3.9 Where do you keep the animals?
   a) in villages
   b) outside the village
   c) In the field

2.3.10 What is type of practiced grazing?
   a) Day grazing only
   b) Night grazing only
   d) Day and night grazing

2.3.11 Distance covers by animals in the day (circle radius)
   a) < 2 km
   b) 2 - 4 km
   c) > 4 km

2.3.12 Do you use complementary alimentation?
   a) yes
   b) no

2.3.13 Type of complementary alimentation used
   a) Straw
   b) crop residues
   b) Green fodder
   c) Others (specify)

2.3.14 Do you face any problems from crop people?
   a) Yes
   b) No

2.3.15 The quantity of rangeland vegetation in the area
   a) more than needed
   b) Sufficient
   c) Not sufficient
   d) very poor

2.3.16 The quality of rangeland vegetation in the area
   a) v. good
   b) good
   c) bad
   d) v. bad

2.3.17 What are the most favorable and consumed species?
   1. ................................................
   2. ................................................
   3. ................................................

2.3.18 What are the most unfavorable species?
   1. ................................................
   2. ................................................
   3. ................................................

2.3.19 Do you use the same pasture every year?
   a) Yes
   b) No

2.3.20 For how long do you stay in the same place?
   a) 2 - 4 days
   b) 4 - 6 days
   c) 6-8 days
   d) More than 8  (specify)

2.3.21 Do you change your place according to rain and good vegetation?
   a) Yes
   b) No

2.3.22 What is the main factor for changing your place?
   a) vegetation
   b) drinking water
   c) vegetation and drinking water
   c) other
2.3.23 Water Management:

2.3.23.1 What is the main source of animal drinking water?
   a) Pump stations  
   b) Surface wells  
   c) Haffirs  
   d) River

2.3.23.2 The quantity of water
   a) More than needed  
   b) Sufficient  
   c) Not sufficient  
   d) Little

2.3.23.3 State of water
   a) v. good  
   b) good  
   c) bad  
   d) v. bad

2.3.23.4 How many times for animals to take water
   a) Once every day  
   b) Every other day  
   c) Twice a day  
   d) Other specify ...........

2.3.23.5 How far the drinking water point from animals?
   a) 1-3 km  
   b) 3-5 km  
   c) 5-10 km  
   d) more than 10 km

2.4 In hot dry season (Saif)

2.4.1 Beginning and end of hot dry season
   a) Begins in ............  
   b) Ends in ............

2.4.2 Do you stay in the same place or you move to another place?
   a) Stay  
   b) Move

2.4.3 Why do you move?
   a) Looking for good pasture  
   b) Looking for water  
   c) Looking for security  
   d) Other specify ............

2.4.4 Do you migrate to other regions?
   a) yes  
   b) no

2.4.5 If yes, when do you start migration?
   a) October  
   b) November  
   c) January

2.4.6 To where do you migrate?
   a) Gezira irrigated scheme  
   b) Rahad irrigated scheme  
   c) Halfa irrigated scheme  
   d) other specify ............

2.4.7 What type of rangeland you use?
   a) Natural Grasslands  
   b) Natural Shrub lands  
   c) a and b  
   d) Crop residue

2.4.8 Who is looking after herd?
   a) The owner of the animals  
   b) Wife and children  
   c) Adult sons  
   d) Rent people

2.4.9 Where do you keep the animals?
   a) in villages  
   b) outside the village  
   c) In the field

2.4.10 What is type of practiced grazing?
   a) Day grazing only  
   b) Night grazing only  
   d) Day and night grazing

2.4.11 Distance cover by animals in the day (circle radius)
   a) < 2 km  
   b) 2-4 km  
   c) > 4 km

2.4.12 Do you use complementary alimentation?
   a) yes  
   b) no
2.4.13 Type of complementary alimentation used
   a) Straw               b) crop residues
   b) Green fodder       c) Others    specify………
2.4.14 Do you face any problems from crop people?
   a) Yes               b) No
2.4.15 the quantity of rangeland vegetation in the area
   a) more than needed   c) Not sufficient
   b) Sufficient         d) very poor
2.4.16 the quality of rangeland vegetation in the area
   a) v. good             c) bad
   b) good                d) v. bad
2.4.17 what are the most favourable and consumed species?
   1) ………………………………………
   2) ………………………………………
   3) ………………………………………
2.4.18 what are the most unfavourable species?
   1) ………………………………………
   2) ………………………………………
   3) ………………………………………
2.4.19 Do you use the same pasture every year?
   a) Yes               b) No
2.4.20 for how long do you stay in the same place?
   a) 2- 4 days            c) 6-8 days
   b) 4 – 6 days            d) More than 8 specify………
2.4.21 Do you change your place according to rain and good vegetation?
   a) Yes               b) No
2.4.22 what is the main factor for changing your place?
   a) vegetation           b) drinking water
   c) vegetation and drinking water    c) other
2.4.23 Water Management:
2.4.23.1 what is the main source of animal drinking water?
   a) Pump stations       c) Haffirs
   b) Surface wells       d) River
2.4.23.2 the quantity of water
   a) More than needed  c) Not sufficient
   b) Sufficient         d) Little
2.4.23.3 State of water
   a) v. good             b) good
   c) bad                d) v. bad
2.4.23.4 How many times for animals to take water
   a) Once every day      b) Every other day
   c) Twice a day         c) Other specify …………
2.4.23.5 How far the drinking water point from animals?
   a) 1-3 km            c) 5- 10 km
   b) 3-5 km            d) more than 10 km
Appendix 6: Pastoral Investigation Form (Sedentary and transhumant)

No.: 
Date: / / 2006
Author: 
Village name: 
GPS coordinates: X …………  Y …………
Farmer name: 

1- General Information
1.1 General topography of the area
   a) Very flat
   b) Flat
   c) Not flat
1.2 Type of soil
   a) Clay soil
   b) Sandy soil
   c) Sandy clay
1.3 Type of practiced culture
   a) Rainfed agriculture
   b) Irrigated agriculture
   c) pastures
   d) Rainfed and pastures
1.4 Type of crops and productivity in kg/acre

<table>
<thead>
<tr>
<th>Type of crops</th>
<th>&lt; 250</th>
<th>250-500</th>
<th>500-750</th>
<th>&gt; 750</th>
</tr>
</thead>
<tbody>
<tr>
<td>sorghum</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>millet</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vegetables</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>others</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.5 do people use machinery? 
   a) Yes
   b) No
1.6 what type of machinery they usually use? 
   a) Disc plough
   b) Disc harrow
   c) Wide level disc
   d) Ridger
1.7 Do they practice water harvesting techniques? 
   a) Yes
   b) No
1.8 what type of water harvesting techniques they practiced? 
   a) Terraces
   b) Contour line
1.9 what is the source of people drinking water? 
   a) Water pump stations
   b) Surface wells
   c) Haffir
   d) others specify .............
1.10 How far the drinking water point from village? 
   a) < 500 m
   b) 500 m - 1 km
   c) 1 - 3 km
   d) > 3 km
1.11 State of water 
   a) v. good
   b) good
   c) bad
   d) v. bad
1.12 do people breed animals? 
   a) Yes 
   b) No
1.13 Do you own the animals? 
   a) Yes
   b) No
1.14 Type and number of animals

<table>
<thead>
<tr>
<th>Type of animals</th>
<th>Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Small ruminants</td>
<td></td>
</tr>
<tr>
<td>cows</td>
<td></td>
</tr>
<tr>
<td>camels</td>
<td></td>
</tr>
<tr>
<td>mixture</td>
<td></td>
</tr>
</tbody>
</table>

1.15 what are the most important animal diseases?
1- .................................................................
2- .................................................................
3- .................................................................

1.16 what are the most important animal parasites?
1- .................................................................
2- .................................................................
3- .................................................................

1.17 who ensure the health treatment?
a) Veterinary authorities       c) No health treatment
b) Herder themselves           d) others specify ............

1.18 what are the main sources of your family income (put numbers 1, 2, 3 & 4 for order of importance)?

<table>
<thead>
<tr>
<th>sources</th>
<th>order</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- Agricultural products</td>
<td></td>
</tr>
<tr>
<td>2- Animals products</td>
<td></td>
</tr>
<tr>
<td>3- Trade</td>
<td></td>
</tr>
<tr>
<td>4- .................................</td>
<td></td>
</tr>
</tbody>
</table>

2. Rangeland management
2.1 General herd management

2.1.1 How many types and number of herds do you manage separately?

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td></td>
</tr>
<tr>
<td>2)</td>
<td></td>
</tr>
<tr>
<td>3)</td>
<td></td>
</tr>
<tr>
<td>4)</td>
<td></td>
</tr>
</tbody>
</table>

2.1.2 Do you manage your herds in the same way for the whole year?

a) Yes ( )     b) No ( )

2.1.3 If no what are the different periods you identify

<table>
<thead>
<tr>
<th>Name of period</th>
<th>Beginning</th>
<th>End</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 In the rainy season(Kharif)

2.2.1 beginning and end of the rainy season

a) Begins in ..................................................

b) Ends in ....................................................
2.2.2 what type of rangeland you use?
   a) Natural Grasslands
c   b) Natural Shrublands
d) Crop residue
2.2.3 how far the rangeland from the village?
   a) < 2 km
c   b) 2-4 km
d) > 6 km
2.2.4 who is looking after herd?
   a) The owner of the animals
c   b) Wife and children
d) Rent people
2.2.5 Origin of the herder
   a) From the same village
   b) Not from the same village but from the same area
d) From outside the region
2.2.6 where do you keep the animals?
   a) At home
c   b) outside the village
   c) In the field
2.2.7 what is type of practiced grazing?
   a) Day grazing only
c   b) Night grazing only
d) Day and night grazing
2.2.8 Distance cover by animals in the day (circle radius)
   a) < 2 km
c   b) 2-4 km
d) > 4 km
2.2.9 do you use complementary alimentation?
   a) yes
   b) no
2.2.10 Type of complementary alimentation used
   a) Straw
   b) crop residues
   b) Green fodder
c) Others specify………..
2.2.11 Do you face any problems from crop people?
   a) Yes
   b) No
2.2.12 the quantity of rangeland vegetation in the area
   a) more than needed
c   b) Sufficient
   d) very poor
2.2.13 the quality of rangeland vegetation in the area
   a) v. good
c   b) good
   d) v. bad
2.2.14 what are the most favorable and consumed species?
   1) ..................................................
   2) ..................................................
   3) ..................................................
2.2.15 what are the most unfavorable species?
   1) ..................................................
   2) ..................................................
   3) ..................................................
2.2.16 Do you use the same pasture every year?
   a) Yes
   b) No
2.2.17 for how long do you stay in the same place?
   a) 2–4 days
   c) 6-8 days
   b) 4–6 days
d) More than 8 specify………..
2.2.18 Do you change your place according to rain and good vegetation?  
   a) Yes  
   b) No  
2.2.19 what is the main factor for changing your place?  
   a) vegetation  
   b) drinking water  
   c) vegetation and drinking water  
   c) other  
2.2.20 water management  
2.2.20.1 what is the main source of animal drinking water?  
   a) Pump stations  
   b) Surface wells  
   c) Haffirs  
   d) River  
2.2.20.2 the quantity of water  
   a) More than needed  
   b) Sufficient  
   c) Not sufficient  
   d) Little  
2.2.20.3 State of water  
   a) v. good  
   b) good  
   c) bad  
   d) v. bad  
2.2.20.4 How many times for animals to take water  
   a) Once every day  
   b) Every other day  
   c) Twice a day  
   d) Other specify ……….  
2.2.20.5 How far the drinking water point from animals?  
   a) 1-3 km  
   b) 3-5 km  
   c) 5-10 km  
   d) more than 10 km  
2.3 In cold dry season(Darat)  
2.3.1 Beginning and end of cold dry season  
   a) Begins in ………………………………………………  
   b) Ends in …………………………………………………  
2.3.2 Do you stay in the same place or you move to another place?  
   a) Stay  
   b) Move  
2.3.3 why do you move?  
   a) Looking for good pasture  
   b) Looking for water  
   c) Looking for security  
   d) Other specify……….  
2.3.4 Do you migrate to other regions?  
   a) yes  
   b) no  
2.3.5 If yes, when do you start migration?  
   a) October  
   b) December  
   c) January  
2.3.6 when do you come back?  
   a) April  
   b) May  
   c) June  
   d) July  
2.3.7 To where do you migrate?  
   a) Gezira irrigated scheme  
   b) Rahad irrigated scheme  
   c) Halfa irrigated scheme  
   d) other specify…………….  
2.3.8 What type of rangeland you use?  
   a) Natural Grasslands  
   b) Natural Shrubslands  
   c) a and b  
   d) Crop residue  
2.3.9 How far the rangeland from the village?  
   a) < 2 km  
   b) 2-4 km  
   c) 4-6 km  
   d) > 6 km  
2.3.10 who is looking after herd?  
   a) The owner of the animals  
   b) Wife and children  
   c) Adult sons  
   d) Rent people
2.3.11 Origin of the herder
   a) From the same village
   b) Not from the same village but from the same area
   d) From outside the region
2.3.12 Where do you keep the animals?
   a) At home               b) outside the village
   c) In the field
2.3.13 What is type of practiced grazing?
   a) Day grazing only     d) Day and night grazing
   b) Night grazing only
2.3.14 Distance cover by animals in the day (circle radius)
   a) < 2 km   c) > 4 km
   b) 2 - 4 km
2.3.15 Do you use complementary alimentation?
   a) yes               b) no
2.3.16 Type of complementary alimentation used
   a) Straw               b) crop residues
   b) Green fodder        c) Others  specify………
2.3.17 Do you face any problems from crop people?
   a) Yes               b) No
2.3.18 The quantity of rangeland vegetation in the area
   a) more than needed   c) Not sufficient
   b) Sufficient        d) very poor
2.3.19 The quality of rangeland vegetation in the area
   a) v. good            c) bad
   b) good              d) v. bad
2.3.20 What are the most favorable and consumed species?
   1) ..............................................
   2) ..............................................
   3) ..............................................
2.3.21 What are the most unfavorable species?
   1) ..............................................
   2) ..............................................
   3) ..............................................
2.3.22 Do you use the same pasture every year?
   a) Yes               b) No
2.3.23 For how long do you stay in the same place?
   a) 2-4 days           c) 6-8 days
   b) 4 – 6 days         d) More than 8 specify………
2.3.24 Do you change your place according to rain and good vegetation?
   a) Yes               b) No
2.3.25 Water Management:
2.3.25.1 What is the main source of animal drinking water?
   a) Pump stations      c) Haffirs
   b) Surface wells      d) River
2.3.25.2 the quantity of water
   a) More than needed
   b) Sufficient
   c) Not sufficient
   d) Little

2.3.25.3 State of water
   a) v. good
   b) good
   c) bad
   d) v. bad

2.3.25.4 How many times for animals to take water
   a) Once every day
   b) Every other day
   c) Twice a day
   d) Other specify …………

2.3.25.5 How far the drinking water point from animals?
   a) 1-3 km
   b) 3-5 km
   c) 5-10 km
   d) more than 10 km

2.4 In hot dry season (Saif)

2.4.1 Beginning and end of hot dry season
   a) Begins in …………………………………………………
   b) Ends in …………………………………………………

2.4.2 Do you stay in the same place or you move to another place?
   a) Stay
   b) Move

2.4.3 why do you move?
   a) Looking for good pasture
   b) Looking for water
   c) Looking for security
   d) other specify………..

2.4.4 Do you migrate to other regions?
   a) yes
   b) no

2.4.5 If yes, when do you start migration?
   a) October
   b) November
   c) January

2.4.6 when do you come back?
   a) April
   b) May
   c) June
   d) July

2.4.7 To where do you migrate?
   a) Gezira irrigated scheme
   b) Rahad irrigated scheme
   c) Halfa irrigated scheme
   d) other specify………………

2.4.8 What type of rangeland you use?
   a) Natural Grasslands
   b) Natural Shrubslands
   c) a and b
   d) Crop residue

2.4.9 How far the rangeland from the village?
   a) < 2 km
   b) 2-4 km
   c) 4-6 km
   d) > 6 km

2.4.10 who is looking after herd?
   a) The owner of the animals
   b) Wife and children
   c) Adult sons
   d) Rent people

2.4.11 Origin of the herder
   a) From the same village
   b) Not from the same village but from the same area
   c) From outside the region

2.4.12 where do you keep the animals?
   a) At home
   b) outside the village
   c) In the field

2.4.13 What is type of practiced grazing?
   a) Day grazing only
   b) Night grazing only
   d) Day and night grazing
2.4.14 Distance cover by animals in the day (circle radius)
   a) < 2 km          c) > 4 km
   b) 2- 4 km

2.4.15 Do you use complementary alimentation?
   a) yes             b) no

2.4.16 Type of complementary alimentation used
   a) Straw
   b) crop residues
   b) Green fodder
   c) Others          specify……..

2.4.17 Do you face any problems from crop people?
   a) Yes             b) No

2.4.18 the quantity of rangeland vegetation in the area
   a) more than needed c) Not sufficient
   b) Sufficient      d) very poor

2.4.19 the quality of rangeland vegetation in the area
   a) v. good         c) bad
   b) good            d) v. bad

2.4.20 what are the most favorable and consumed species?
   1) ..........................  
   2) ..........................  
   3) ..........................  

2.4.21 what are the most unfavorable species?
   1) ..........................  
   2) ..........................  
   3) ..........................  

2.4.22 Do you use the same pasture every year?
   a) Yes             b) No

2.4.23 for how long do you stay in the same place?
   a) 2- 4 days        c) 6-8 days
   b) 4 – 6 days       d) More than 8   specify…….. 

2.4.24 Do you change your place according to rain and good vegetation?
   a) Yes             b) No

2.4.25 what is the main factor for changing your place?
   a) vegetation       b) drinking water
   c) vegetation and drinking water c) other

2.4.26 Water Management:

2.4.26.1 what is the main source of animal drinking water?
   a) Pump stations    c) Haffirs
   b) Surface wells    d) River

2.4.26.2 the quantity of water
   a) More than needed c) Not sufficient
   b) Sufficient      d) Little

2.4.26.3 State of water
   a) v. good         b) good            c) bad        d) v. bad

2.4.26.4 How many times for animals to take water
   a) Once every day   b) Every other day
   c) Twice day       c) Other   specify ………...

2.4.26.5 How far the drinking water point from animals?
   a) 1-3 km          c) 5- 10 km
   b) 3-5 km          d) more than 10 km