KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

MAPPING IRRIGATION POTENTIAL IN THE UPPER EAST REGION OF GHANA

Master of Science Thesis

by

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Quotes

- Unless we address poverty, we cannot achieve sustainable development….(Ronnie Kassils, DWAF)

- In order to promote food security in the world, it is not only agriculture that needs to be improved, but also the necessary water supplies. That will require technological transfer, the field carried by the CGIAR, as well as a coherent agriculture trade policy in the rich industrialized countries….(Agnes Van Ardenne)

- Although there have been criticisms of high water consumption by irrigated agriculture and its impact on the environment, it is still a key weapon in the fight to meet future food demand…(Geoff Pearce)

- In Africa, we have hundreds of millions of poor people in rural areas for whom there is no alternative. For these people, agriculture will have to be the key to their development, for the escape out of poverty and water is a crucial constituent in many places. (Salim Ahmed Salim).

Facts about Irrigation

- Irrigated agriculture produces more than double the crop yields produced by rainfed agriculture.

- Although only 17% of the world's total cropped area is irrigated, irrigated agriculture provides 40% of the world food production.

- An estimated 60% of the extra food needed to feed the world growing population will come from irrigated agriculture

Certification

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

Akomeah Eric (1357607) .... Signature .... 08/05/09 Date

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Abstract

The Ghana Poverty Reduction Strategy of 2003 mentions the Upper East Region together with the other two regions in Northern Ghana (Upper West and Northern Region) as locus of perennial food deficit. Despite, the provision of over 200 small scale dams and various mechanisms calculated toward poverty alleviation, the region is still plagued with poverty and yearly food shortages. To achieve food security and alleviate poverty in the region however, modernization of agriculture through irrigation is deemed inevitable. While it is true that considerable potential still exists for future expansion of irrigation, it is also true that water is becoming scarcer in the regions where the need for irrigation is most important, hence mapping the irrigation potential of the region will be the first step toward ensuring sound planning and sustainability of the irrigation developments. In this study, an attempt has been made to map out the irrigation potential of the Upper East Region. The river basin approach was used in assessing the irrigation potential. The catchments drained by The White Volta River, Red Volta River, Sissili River and Kulpawn River were considered in the assessment. The irrigation potential for the sub basins were computed by combining information on gross irrigation water requirements, area of soil suitable for irrigation and available water resources. The capacity of 80%, 70%, 60% and 50% time of exceedance flow of the available surface water resources in the respective sub basins were estimated. The area that can be irrigated with this flow was computed with selected cropping pattern. Combining the land suitability map and the land use map of the respective subcatchments, an irrigation potential map has been generated showing potential sites in the upper east region that can be brought under surface irrigation in the respective subcatchments. The total area that can be irrigated using the flow at 80% and 50% dependability are over 1000 ha and 20000 ha respectively. The results of this study provide a base for the formulation of strategies for irrigation development and also give a bench mark for monitoring progress within the irrigation sector.

Keywords: Irrigation potential, irrigation water requirement, land evaluation, dependable flow

Dedication

I dedicate this work to my mom and dad, your love and care for me is beyond human expression.

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Abbreviations

AAGDS	Accelerated Agricultural Growth and Development Strategy
AVHRR	Advanced Very High Resolution Radiometer
AWC	Available Water Content
CWR	Crop Water Requirement
FAO	Food and Agriculture Organization
FASDEP	Food and Agriculture Sector Development Policy
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
GOG	Government of Ghana
GPRS	Ghana Poverty Reduction Strategy
IFAD	International Fund for Agricultural Development
IFS	International Foundation for Science
IEUWADEP	Interim Evaluation of Upper West Agricultural Development Project
IWMI	International Water Management Institute
LANDSAT TM	Land Satellite Thematic Mapper
LMU	Land Mapping Unit
LU	Land Unit
MOWR	Ministry of Water Resources
NIWR	Net Irrigation Water Requirement
NR	Northern Region
UER	Upper East Region
USDA	United States Department of Agriculture
UWR	Upper West Region

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What do I have that I did not receive? All that I have and hope to be, come from you and I am just a steward. Truly, in thy light we see light. I thank God for carrying me through this programme successfully, granting illumination in all facets of my life and teaching my hands to do research. May His name be glorified.

This study has been one of the most significant academic challenges that I have had to face. I could not have done it alone without the support, patience and guidance of the following people. It is to them I owe my deepest gratitude.

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1.0 INTRODUCTION

The World Vision of Water for Food and Rural Development showed that by 2025 the world population would increase by 2 billion inhabitants to a total of approximately 8 billion people. The water requirement critical to livelihood including food production is $1700m^3$/ capita/year. This water is not available for everybody; nearly one-third of the world's population will live in regions that will experience severe water scarcity (Wageningen Expert Consultation Meeting, 2001).

Africa, with the exception of the Congo (Zaire) River Basin, is the driest continent (apart from Australia) and suffers from the most unstable rainfall regime. Droughts are frequent in most African countries and each year, more people are at risk from the effects of inevitable droughts of greater or lesser severity. Furthermore, Africa's water resources are relatively less developed than those in other regions, (FAO, 2005).

Agricultural productivity in Sub-Saharan Africa has not kept pace with population increase, and the region is now in a worse position nutritionally than it was 30 years ago (FAO, 1995). Both rainfed and irrigated agriculture will need to be intensified, but irrigated agriculture has a higher potential for intensification (only about 10% of the agricultural production comes from irrigated land).

While it is true that considerable potential still exists for future expansion of irrigation, it is also true that water is becoming scarcer in the regions where the need for irrigation is most important. In order to plan the development of water resources carefully, especially for agriculture which is by far the largest user of water, an assessment of the irrigation potential is necessary (FAO, 1995).

According to the (FAO, 2005) estimates, Ghana has a potential irrigable area of over 1.9 million hectares. Of this potential only about 11 000 ha have been developed since formal irrigation started in the early 1960s.

Despite, the provision of over 200 small scale dams and various mechanisms calculated toward poverty alleviation, the Upper East Region of Ghana is still plagued with poverty and perennial food deficit. There are genuine "cries" for more irrigation water in most farming communities especially in the dry season, hence the need for more dams to be built.

Meanwhile, the most recent agricultural policy in Ghana is reflected in the following documents: (i) Accelerated Agricultural Growth and Development Strategy (AAGDS); the Food and Agricultural Sector Development Policy (FASDEP); and the (ii) Ghana Poverty Reduction Strategy (GPRS) 2002-2004 (IFAD, 2005) .The AAGDS broadly aims at the intensification and modernization of agriculture, while the FASDEP further emphasizes the importance of food security. The GPRS of 2003 recognizes that rural farmers and fishermen are particularly at risk, and specifically mentions Northern Ghana (UER, UWR and NR) as a locus of perennial food deficits. Some of the elements of the policy to accelerate irrigation development to support agricultural production are as follows;

- Rehabilitation of existing small and medium scale irrigation projects with a total irrigable area of 3500ha.
- Rehabilitation of 64 dams in the Upper East and Upper West Region.
- Survey, design and development of 4000 ha of small-scale irrigation projects in the northern parts of the country where rainfall is deficient.

Thus, to achieve food security, reduce poverty and to meet the targets as mentioned above in the Upper East Region of Ghana, mapping the irrigation potential will be the first step toward ensuring sound planning and sustainability of the development.

The most logical research unit for the computation of irrigation potential is the river basin, as only at this level can the water availability be evaluated. However, as most of the information is available at regional level, and as information at regional level may also be important for planning purposes, both these research units have been used to define the base on which irrigation potential is assessed (FAO, 1995).

When combining the available land resources suitable for irrigation, expressed in hectares, and the available water resources, expressed in m^3 per year, for assessing the irrigation potential, knowledge of the irrigation water requirements, expressed in m^3/ha per year or in mm per year, is necessary.

This study deals with mapping the irrigation potential of dry season irrigated vegetables production in the UER of Ghana and the use of GIS in that context.

1.1 Problem statement

One of the elements of the policy to accelerate irrigation development is to survey, design and develop 4000 ha of small-scale irrigation projects in the northern parts of the country where rainfall is deficient to curb the perennial food shortages and alleviate poverty.

Are there suitable land and adequate water resources to ensure high yields of cultivated crops to commensurate the capital intensive development of irrigation schemes? It is the aim of this study to identify and estimate the potential irrigation sites to ensure sustainable development of the irrigation schemes.

1.2 Justification

Ghana's current development objectives place a great deal of emphasis on broad based, pro-poor agricultural growth (GOG, 2003). A vital area necessary for the growth in agriculture in Ghana is irrigation (Sant', Anna 1997). The main Government objective is to make Ghana a leading agro-industrial country by the year 2010 through modernization of agriculture-based rural development. This strategy has been mainstreamed into the Millennium Development Goals (MDGs) and Ghana Poverty reduction Strategy (GPRS) inspired budgets for the years 2003-2005. The Ghana Poverty Reduction Strategy 2003-2005 (GPRS) is predicated inter alia on a key role for irrigation in achieving national food security, alleviating rural poverty and equitable economic development.

The Upper East Region (UER) is the second poorest region in Ghana and overall living standards have hardly improved in the past ten years. According to the Ghana Living

Standards Survey (GLSS, 2000), the percentage of the population living in poverty is 88% in UER.

Rainfed agriculture is possible for a period of 4-5 months; cultivation of crops with longer duration is impossible or risky without irrigation. Hence the region is characterized by constant food deficit and very low income levels. Therefore, to achieve food security and reduce poverty in the region, modernization of agriculture through irrigation is deemed inevitable.

For any irrigation development, it is paramount to determine the irrigation potential. The irrigation potential together with other factors determines the feasibility of any irrigation development.

The study is in line with the goals for agriculture mentioned in policies and strategies such as AAGDS (2004) and FASDEP. Its value added consists of a clearer geographical targeting and a set of concrete measures to reduce poverty and ensure food security.

The study when completed will provide a base for the formulation of strategies for irrigation development and also give a bench mark for monitoring progress within the irrigation sector.

1.3 Objectives of the study

The **main objective** of this study is to map out available land suitable for irrigation and for which there is sufficient water resource.

The ***specific objectives*** are;

- To determine land suitable for irrigation, irrigation water requirement, and water resources available for agriculture.
- Compute the irrigation potential in the region.
- Generate a digital irrigation potential map.

1.4 Research Questions

Questions arising from the objectives that need to be answered by the study are;

- Which crops can be cultivated to increase the income levels of the people in the UER?
- Which irrigation method is suitable for the crop or crops production?
- Where in the UER can the irrigation method be practiced?
- How much water resources is available for future irrigation development?

1.5 Hypotheses

- Potential irrigable areas will be along river courses especially in the flood plains (in the alluvial and vertisol soils) and in the valley bottoms.
- Enough water and land resources are available for irrigated agriculture crop production.

2.0 STUDY AREA

The Upper East Region is situated in the north-eastern corner of Ghana, bounded on the north-east by the Republic of Burkina Faso, in the west by Upper West Region, in the south by the Northern Region and in the east by the Republic of Togo. It covers an area of 8,842 km^2, slightly more than 3% of the total land area of the country (Ndemu, 2008).

The region lies in the Sudan savanna belt which features short grass and shrubs interspersed with a few trees. The vegetation generally becomes slightly luxurious where soil and moisture conditions permit, usually along water courses. The region is predominantly agricultural with about 70% of the economically active population engaged in livestock rearing, farming or fishing. Food crops cultivated in the wet season are rice, millet, sorghum and groundnuts.

The region has two big irrigation projects located at Tono and Vea with developed areas covering 2,490 ha .and 850 ha respectively. Crops cultivated include paddy rice, tomatoes, onions, millet, groundnuts, sorghum and maize. There are other 200 dams and dugouts scattered over the region.

Drainage is mainly by the White Volta, Red Volta and Sissili Rivers (Regional Coordinating Unit, 2003). Due to the inadequate and erratic rain fall patterns of about 1000mm per annum, it has made Agriculture, the mainstay of the economy in the north a risky venture. Farmers cannot do effective farm planning to maximize returns from their investment, resulting in low agricultural production which cannot match with the nutritional and disposable income demand of the people. The result is hunger, poverty and migration to the south.

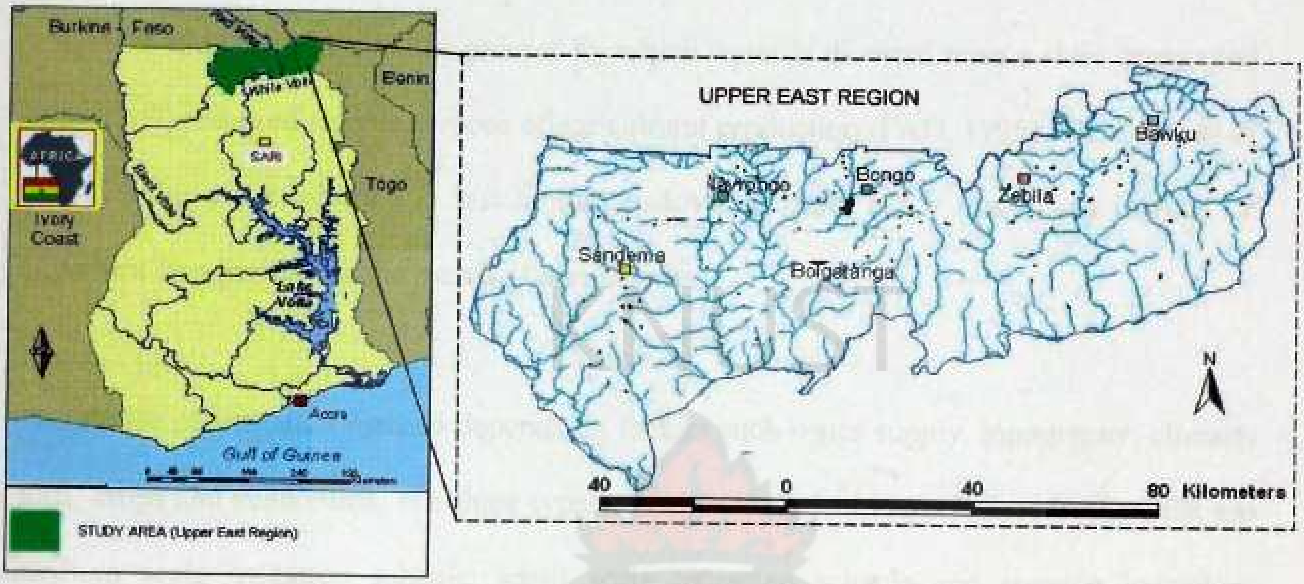

Figure 2-1: The Upper East Region of Ghana and its Districts (source: Mdemu et al, 2008)

3.0 LITERATURE REVIEW

3.1 Irrigation

Irrigation is defined here as the process by which water is diverted from a river or pumped from a well and used for the purpose of agricultural production (FAO, 1995). The first use of irrigation by primitive man is lost in the shadows of time, but it must have marked an important step forward in the march of civilization.

The choice of irrigation method depends on factors such water supply, topography, climate, soils, crops and economics. The three types of irrigated agriculture practiced in the UER are medium scale irrigation scheme, small scale irrigation scheme and riverine irrigation. Irrigation for both medium and small scale schemes is by gravity irrigation whiles in the riverine irrigation is from wells or water holes by pumping or using buckets, (Mdemu, 2008).

3.2Furrow Irrigation

In the furrow method of irrigation, small channels (furrows) carry water down or across the slope of the land to wet the soil and crops grown on ridges between the furrows. The method is best suited to deep, moderately permeable soils with uniform, relatively flat slopes (preferably not steeper than 3%), and to crops which are cultivated in rows, such as vegetables, tomatoes, cotton, maize and potatoes.

Furrows are usually V-shaped in cross-section, 25cm -30cm wide at the top and 15 to 29cm deep. The spacing of furrows will depend on the crops to be grown, the space needed between rows for tillage and weeding and the lateral movement of water through the soil.The bed or ridges between the furrows may be flat or slightly rounded. Many crops are cultivated in rows 0.75m to 1.00m apart, with one row on each ridge. Vegetables are often planted with two rows 40cm apart on each ridge. The length of a furrow will depend on its slope and the texture of the soil. The time that water is allowed to flow into a furrow depends on the water application required (Stern, 1979).

3.3 Irrigation Potential

The definition of irrigation potential is not straightforward and implies a series of assumptions about irrigation techniques, investment capacity, national and regional policies, social, health and environmental aspects, and international relationships, notably regarding the sharing of waters (IFPRI, 1995). Irrigation potential simply refers to available land suitable for irrigation and for which sufficient water is available (FAO, 1995). It is an important indicator to help assess future irrigation development and it is expressed in units of area. The area which can potentially be irrigated depends on the physical resources, 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate. In this study it is called 'physical irrigation potential', however, environmental and socioeconomic constraints also have to be taken into consideration in order to guarantee a sustainable use of the available physical resources. This means that in most cases the possibilities for irrigation development would be less than the physical irrigation potential.

3.4The Concept of Land Resources Evaluation

The process whereby the suitability of land for specific uses such as irrigated agriculture is assessed is called land evaluation. Land evaluation provides information for deciding 'Which crops to grow where' and related questions. It involves the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (Rossiter, 1994). The spatial entities that are evaluated are land units (LU) or Land Mapping Units (LMU). A LMU comprises an area on a map which is relatively homogenous in terms of soil, climate, topography and drainage. A LMU needs not to be uniform in all aspects. Relevant is whether the variation that occurs affects the functioning of the land under the intended use; therefore the concept of land unit is used for areas that can be considered in view of the requirements of the defined or intended land use (Driessen and Konijn, 1992). Soil is but, one aspect of land, alongside terrain, climate, vegetation, hydrology, infrastructure and the socio economic context within which a land unit occurs.

The main product of land evaluation investigations is a land classification that indicates the suitability of various kinds of land for specific land uses, usually depicted on maps with accompanying reports. Data sources for land evaluation include; soil survey, climate and hydrology.

3.5The Concept of Land Suitability Evaluation

The suitability of a given piece of land is its natural ability to support specific purpose. For irrigated agriculture, there are a number of methods for assessing the land. According to the FAO methodology (1976), the suitability of land for irrigation is strongly related to the "land qualities" such as erosion resistance, water availability, and flood hazard that are not measurable. As these qualities derive from the "land characteristics", such as slope angle and length, rainfall and soil texture which are measurable or estimable, it is advantageous to use these later values to study the suitability. Thus, the land characteristics parameters are used to work out land suitability for irrigation, crops and forest.

The land suitability classification consists of assessing and grouping the land types in orders and classes according to their aptitude.

The order defines the suitability and is expressed by:

- S (suitable) that characterizes a land as having sustainable use and giving the good benefits expected and

- N (not suitable) indicating a land whose qualities do not allow the considered type of use, or are not enough for sustainable outcomes.

The classes (1, 2 and 3 for suitable order; 1 and 2 for unsuitable order) express the degrees of suitability or unsuitability. Thus, there are 5 classes according to Table 3-1

Table 3-1: Land Suitability Classes.

ORDER	CLASS	DESCRIPTION
Suitable	S1 (Highly suitable)	Land having no, or insignificant limitations to the given type of use
	S2 (Moderately suitable)	Land having minor limitations to the given type of use
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use
Not suitable	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (Permanently not suitable)	Land that have so severe limitations that are very difficult to be overcome

Source: (FAO, 1976)

Another method that permits the evaluation of land for irrigation purposes is the parametric evaluation system (Sys and Verheye, 1974). The system is based on the standard granulometrical and physico-chemical characteristics of a soil profile. It has been estimated that the soil as a medium for plant growth under irrigation should in the first place provide the necessary water and plant nutrients in an available form, and in the most economic way. Factors influencing the land suitability for irrigation are subdivided in the following four groups;

- Physical properties, which determine the soil-water relationship in the solum such as permeability and available water content both related to texture, structure and soil depth, also $CaCO_3$ status and gypsum status could be considered here.
- Chemical properties, that interfere in the salinity/alkalinity status, such as soluble salts and exchangeable sodium.
- Drainage properties and
- Environmental factors, such as slope.

The different land characteristics that influence the soil suitability for irrigation are rated and a capability index for irrigation is calculated.

3.5.1 Remote sensing for land evaluation

An important source of information on land characteristics is remotely-sensed data, especially satellite imagery. Devices which can collect information about an object from a distance, without touching it, except perhaps with energy emitted from the sensor are referred to as remote sensors. Remote sensors include near and far remote sensors. 'Near' remote sensors are 'close' to the object, e.g., infrared heat detectors for home insulation, ordinary photographs. 'Far' remote sensors are sensors from aircraft and spacecraft that study areas of the earth's surface.

The products of remote sensing are usually not direct samples of the phenomena of interest, so must be calibrated against reality in order to be useful. This process is called interpretation or ground truthing and may be manual or automated. Principal uses of remote sensing in land evaluation are to;

- Produce land use and land cover maps;
- Identify land mapping units such as geomorphic forms and ecological zones;
- Update base maps without full field survey: new roads, canals, field patterns, urban areas, etc;
- Locate specific points of interest to the evaluation, e.g. settlements;
- Provide time series for temporary or seasonal phenomena, e.g. crop growth, vegetation intensity.

3.5.2 Earth observation satellites

Earth observation satellites are products of the space age. Early appreciation by earth scientists of the potential of satellites was after seeing results from Gemini development of electromagnetic sensors and digital systems for non-recoverable craft (i.e. couldn't recover photographic film) (Rossiter, 1994). Most used systems include LANDSAT TM ('Thematic Mapper') and SPOT (Sistème Pour l'Observation du Terre): thematic multispectral mappers. Thematic is intended for making thematic maps, not cartographic products as such. "Multispectral" has several bands, each sensitive to electromagnetic radiation of specific wavelengths in and near the visible (e.g. blue, red, green, infrared), micrometric wavelengths: 1 μm = 10^{-6}m, corresponding to a frequency of $3x10^5$ GHz (1 GHz = 10**9 Hz).

According to Rossiter (1994), Landsat TM bands:

- blue visible (0.42 – 0.52μm)
- green visible (0.52 – 0.60μm)
- red visible (0.63 – 0.69μm)
- near infrared (IR) (0.76 – 0.90μm)
- medium IR (1.55 – 1.75μm)
- thermal (10 - 20μm) - note longer wavelength than band 7
- medium IR (2.08 – 2.35μm).

The thematic mapper imagery is the most prevalent in land evaluation. Below are some of the characteristics of thematic mappers;

- Grid ('raster') data, fixed spatial resolution, from 1100m x 1100m (AVHRR), 160m x 160m (TM band 6), 80m x 80m (Landsat MSS), 30x 30m (Landsat TM bands 1-5, 7), to 10m x 10m (SPOT panchromatic)
- Each sensor detects the radiance in discrete grades (radiometric resolution), typically from 0 (no radiance) to 255 (the sensor is saturated). The number of levels depends on the sensitivity of the sensor and the amount of storage to be dedicated to each observation (1 byte = 8 bits = 128 = 256 levels).
- The spatial and radiometric resolutions determine the storage requirement for the digital image. For each km² of ground coverage, the requirement is: $(1000r)^2 \times b \times c$

where r is the lineal resolution in meters, b is the number of bands, and c is the number of bytes per cell. For example, for Landsat TM, the requirement is $(1000/30)^2 \cdot 7 \cdot 1$ = 7,777.8 = 7.595Kb approximate bytes per km². For a complete scene of 180km x 165km, or 29 700 km², this is 231 000 000 bytes or approximate 220Mb.

- Each cell contains only one radiance value for a band, which *integrates* the radiances of the actual objects within the cell
- The image has errors due to the spacecraft's orientation, the rotation of the earth under it during the imaging, and the shape of the earth. The cells are not really square, must be re-sampled (Rossiter, 1994).

4.0 MATERIALS AND METHODS

4.1 Materials

Data used for the study include;

- Digital topographic map
- Digital drainage map
- DEM
- Digital soil map and soil survey reports
- Climatic and meteorological data
- Stream flow data

The softwares used include Ms Excel, Cropwat 4.3 for windows and ArcGis 9.2.

4.2 Methods

4.2.1 River Basin Approach

The most logical research unit for the computation of irrigation potential is the river basin, as only at this level can the water availability be evaluated. However, as most of the information is available at regional level, and as information at regional level may also be important for planning purposes, both these research units were used to define the base on which irrigation potential is assessed (FAO, 1995).

To integrate information on land and water at the river basin level, knowledge of irrigation water requirements per unit of land area is necessary. Combining information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin eventually results in an estimation of the physical irrigation potential.

Figure 4-1 is a flow chart of the procedure used to estimate and map out the irrigation potential in a river basin.

4.2.2 Identification of Physical Resources - Land and Water Resources

4.2.2.1 Soil data and characteristics

Existing literatures on soil surveys in the UER were used in the land suitability analysis. The general soil description, profile description and analytical data were derived from the following reports;

- Soils of the Navrongo-Bawku area, UER (Adu, 1969)
- Preliminary soil studies on four sites along the left bank of the White and Black Volta Rivers in the Northern, UER and West Regions (Boateng, 1991)
- Detailed Soil Survey and Land Evaluation of Manga Agricultural Station – UER
- Detailed Soil Survey and Land Evaluation of Tono Agricultural Station, UER
- Characterization and Evaluation of the soils of Binduri-sakpari and Bongo-dua areas in the Upper East Region (Boateng, 1995)
- Ethno-pedology Surveys in the Semi- arid Savanna Zone of Northern Ghana station.

The geological formations covering the Upper East Region are divided into three main groups; the Granitic, Voltaian, and Birrimian rocks. The mapping units employed in the soil survey were soil association and soil complex. The units are defined as:

- Soil association : group of series formed from related parent materials and possessing similar profile morphology but differentiated by relief and drainage;
- Soil complex: group of diverse series which are unrelated topographically but which occur in too close a pattern that it is impracticable to map separately.

Twenty-eight (28) mapping units were identified from the soil map. The mapping units were classified according to the Ghanaian classification system.

4.2.2.2 Land Resources Evaluation

Land suitability assessment provides an estimate of the potential of land for a particular form of land use. Land is assessed on the basis of five land suitability classes with suitability decreasing from class 1 to 5. Land resource information gathered from soil survey reports, as well as the results of laboratory analyses on selected soil profiles in the UER, were used in assessing the land suitability for irrigation.

To evaluate the land suitability for irrigation, the parametric evaluation system of (Sys et al, 1991) was applied, using the soil characteristics. These characteristics concern environmental factors, drainage properties, soil physical properties and soil chemical properties. The factors influencing the soil suitability for irrigation are subdivided in the following four groups:

- Physical properties, that determine the soil-water relationship in the soil such as permeability and available water content (both related to texture, structure, soil depth and calcium carbonates status);
- Chemical properties, that interfere in the salinity/alkalinity status, such as soluble salts and exchangeable Na;
- Drainage properties

The factors were rated and then used to calculate the capability index for irrigation (Ci) according to the formula given below;

$$C_i = A \times {}^{B}\!/_{100} \times {}^{C}\!/_{100} \times {}^{D}\!/_{100} \times {}^{E}\!/_{100} \times {}^{F}\!/_{100}$$

where Ci = capability index for irrigation;

A = Soil texture rating;

B = soil depth rating;

C = $CaCO_3$ status;

D = Salinity/Alkalinity rating

E = drainage rating;

F = slope rating.

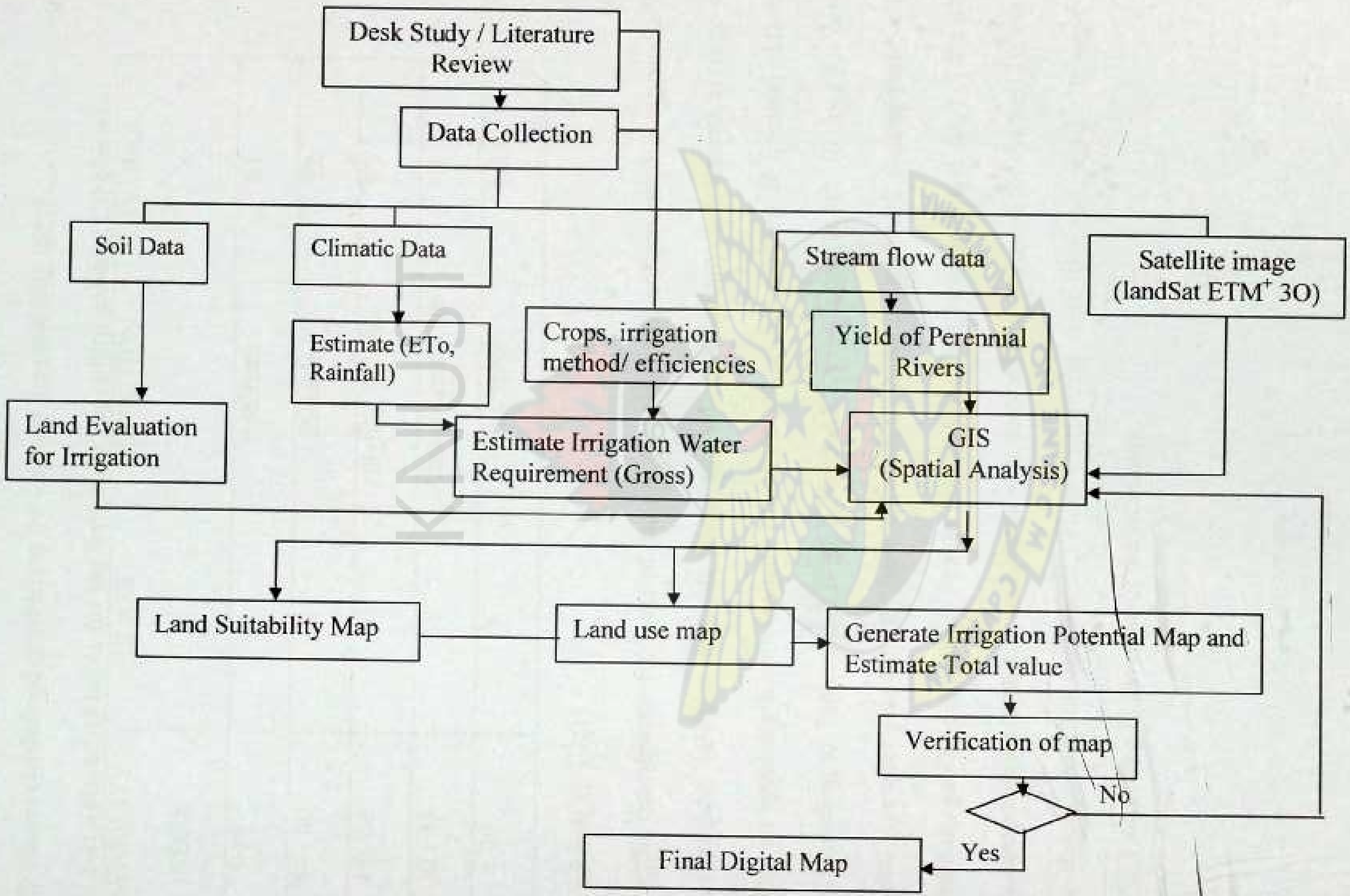

Figure 4-1: Flow chart for the assessment and mapping out of the irrigation potential.

Suitability classes are defined considering the value of the capability index.

Table 4-1: Suitability index for the irrigation capability indices (CI) classes

CAPABILITY INDEX	CLASS	DEFINITION	SYMBOL
>80	I	Excellent	S1
60 - 80	II	Suitable	S2
45 - 60	III	Slightly Suitable	S3
30 - 45	IV	Almost unsuitable	N1
< 30	V	Unsuitable	N2

Source :(Sys et al, 1991)

The soil profile descriptions for some of the soil mapping units are presented in Appendix A1. For the soil texture, calcium carbonate status and salinity/alkalinity, a weighted average was calculated for an upper depth limit (usually 1m) of the soil profile and then the considered factors were rated according to Tables A2.2.1, A2.2.3 and A2.2.4 in Appendix A2. Ratings for depth, slope and drainage were read directly from Tables A2.2.2, A2.2.5 and A2.2.6 using their values obtained from the profile description. For the texture weighting, two (sand and clay) of the three soil texture composition (sand, clay and loam) were selected and weighted for the first 100cm of the profile description. The texture was then determined from the soil texture triangle in appendix A2.1 according to the score of the weighting.

4.2.2.3 Water Resources Assessment

The volume of water obtainable for irrigation depends on the outcome of hydrological studies of surface water. This is the water supply aspects. The water demand aspects include studies and field work to estimate irrigation water requirements and crop water requirements. The approach adopted for the hydrological studies is the Flow Duration Curve analysis. The analysis shows the frequency of occurrence of the various magnitudes of discharge throughout the entire regime of a river at a given point and is indicative of the percent of time a specified given discharge was equalled or exceeded. It thus represents an integrated effect of all factors that affect runoff at the given point and within the period on which the curve is based. Below is information on data for the assessment of water availability.

Table 4-2: Required information on flows

Flow Parameters	Requirement
Flow data	Monthly averages of Long term flows
Method of estimate	Flow Duration Curve: Ranking Order Method
Percent Exceedance considered	80%,70%, 60%, 50%

Procedure for the flow duration analysis (Rank Ordered Method) is as follows (WRI, 1978);

- The data values are arranged in order of decreasing magnitude and assigned order numbers beginning with highest magnitude number 1, the next as 2, and so on.
- Plotting positions were then assigned to each value using the Weibull's formula:

  $M/N+1$

Where M = the order number or rank

N = number of months of record

The ranked value of flow was then plotted against its plotting exceedance percentage ($100x\ (M/N+1)$) on a logarithmic – normal graph sheet.

- Finally, a smooth curve which properly interprets the plotted points was drawn through the points with a French curve to complete the procedure.

4.2.3 ETo and Gross Irrigation Water Requirement

The assessment of the irrigation potential, based on soil and water resources, can only be done by simultaneously assessing the irrigation water requirements (IWR). Net irrigation water requirement (NIWR) is the quantity of water necessary for crop growth. It is expressed in millimeters per year or in m^3/ha per year (1 mm = 10 m^3/ha). It depends on the cropping pattern and the climate. Information on irrigation efficiency is necessary to be able to transform NIWR into gross irrigation water requirement (GIWR), which is the quantity of water to be applied in reality, taking into account water losses. Multiplying GIWR by the area that is suitable for irrigation gives the total water requirement for that area.

Crop water requirements (CWR) are calculated on the basis of monthly effective rainfall (Peff) and reference evapotranspiration (ETo), the first being calculated from average rainfall following the USDA Soil Conservation Service method and the latter being calculated following the Penman-Monteith approach (FAO, 1992). For a given crop, i, and a given cropping period:

$$CWR = \sum_{t=0}^{T} (Kc_{it} \times ET_t - P_{eff})\,(\text{mm})$$

Where kc_{it} is the crop coefficient of the given crop, *i*, during the growth stage, *t*, and where *T* is the last growth stage.

Each crop has its own water requirements. Net irrigation water requirements (NIWR) in a specific scheme for a given year are thus the sum of individual crop water requirements (CWRi) calculated for each irrigated crop, i. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing crop water requirements for each cropping period.

$$NIWR = \sum_{i=1}^{n} CWR \times S_i \;(\text{m}^3)$$

where Si is the area cultivated with the crop, i.

Dividing by the area of the scheme (S, in ha), a value of irrigation water requirements is obtained, expressed in m^3/ha or in mm (1 mm = 10 m^3/ha).

$$NIWR = \sum_{i=1}^{n} CWR \times \frac{S_i}{S}\,(\text{m}^3/\text{ha})$$

To account for losses of water incurred during conveyance and application to the field, an efficiency factor should be included when calculating the irrigation water requirements for a scheme. The efficiency (E) of water distribution covers the efficiency of water conveyance, the field canal efficiency and the field application efficiency. It results in the gross irrigation water requirement (GIWR) per unit of area.

$$GIWR = \frac{NIWR}{E} \text{(mm)}$$

Based on the above mentioned principles, the CropWat Model was used in estimating the IWR for three selected crops; tomato, pepper and onion. These are the crops mostly cultivated in the dry season.

4.2.4 Map generation

Geographical Information System

GIS is a computer system capable of assembling, storing, manipulating, and displaying data identified according to their location (Falbo et al, 2002). It doesn't hold maps or pictures, but it holds a database. GIS can then link this data base information to spatial features and produce an output. The analytical operations are as presented in Figure 4-2.

GIS helps the user to have better answers on geographical or spatial queries. Upon completion of the assessment of irrigation potential and identification of suitable sites, the results were converted to a digital format. The first step involves registering /georeferencing the digital maps of the area to real world coordinates. Established control points located on the maps were used in the georeferencing process in order to minimize the introduction of registration error. Once the maps were registered, the districts, sub-irrigated lands, suitable sites and other forms of land use were then overlaid in order to identify the available suitable land for irrigation. The irrigation potential map thus created was verified by comparing with field data, survey and existing maps.

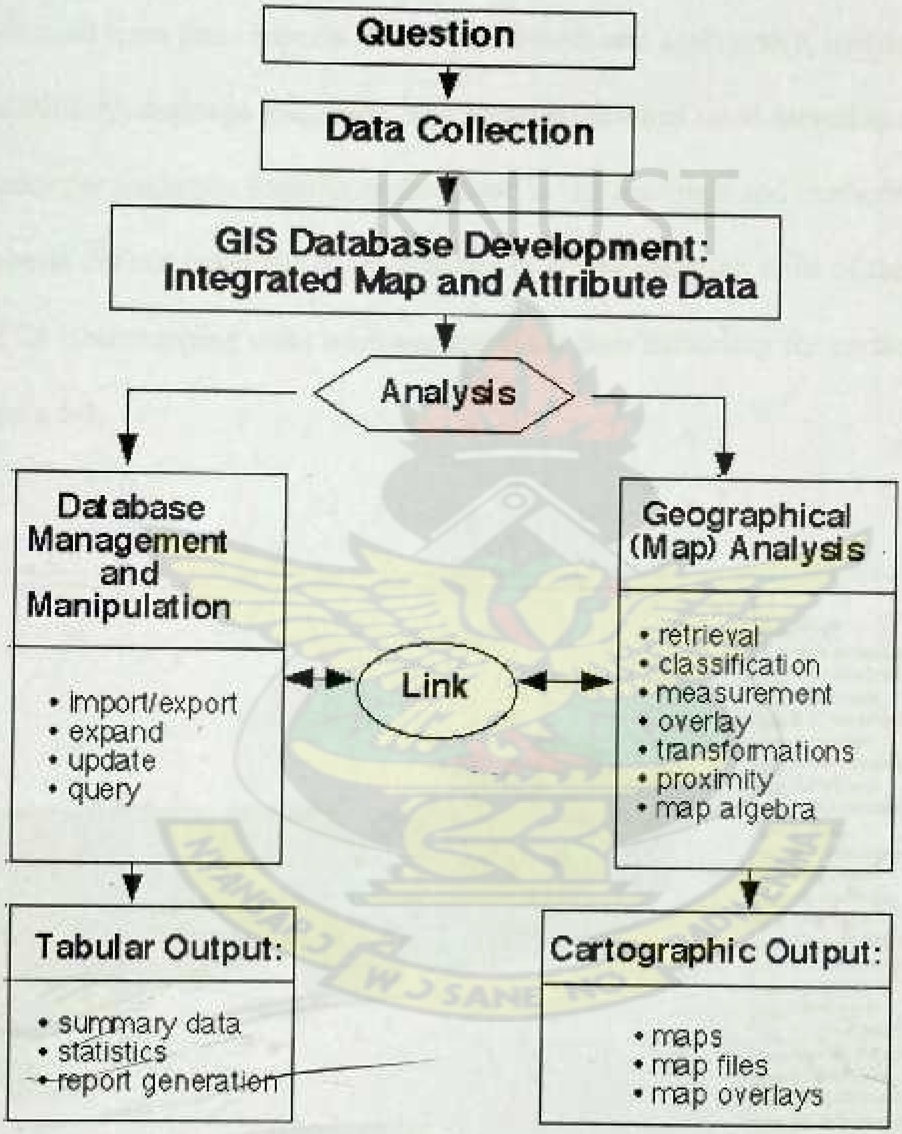

Figure 4-2: Flow chart of operational analysis (Falbo et al, 2002)

5.0 RESULTS AND DISCUSSION

5.1Land Suitability for Irrigation Assessment

Six soil parameters (characteristics) that permit the evaluation of land for surface irrigation purposes were derived from these reports. These parameters are: soil texture, soil depth, $CaCO_3$ status, salinity/alkalinity, drainage and slope. The parameters when rated served as an input into the capability index for irrigation formula as discussed in the materials and methods section. The available soil reports did not cover the characteristics of all the mapping units of the soil map. Hence 16 out of 28 land mapping units were evaluated for their suitability for surface irrigation as shown in Figure 5-3.

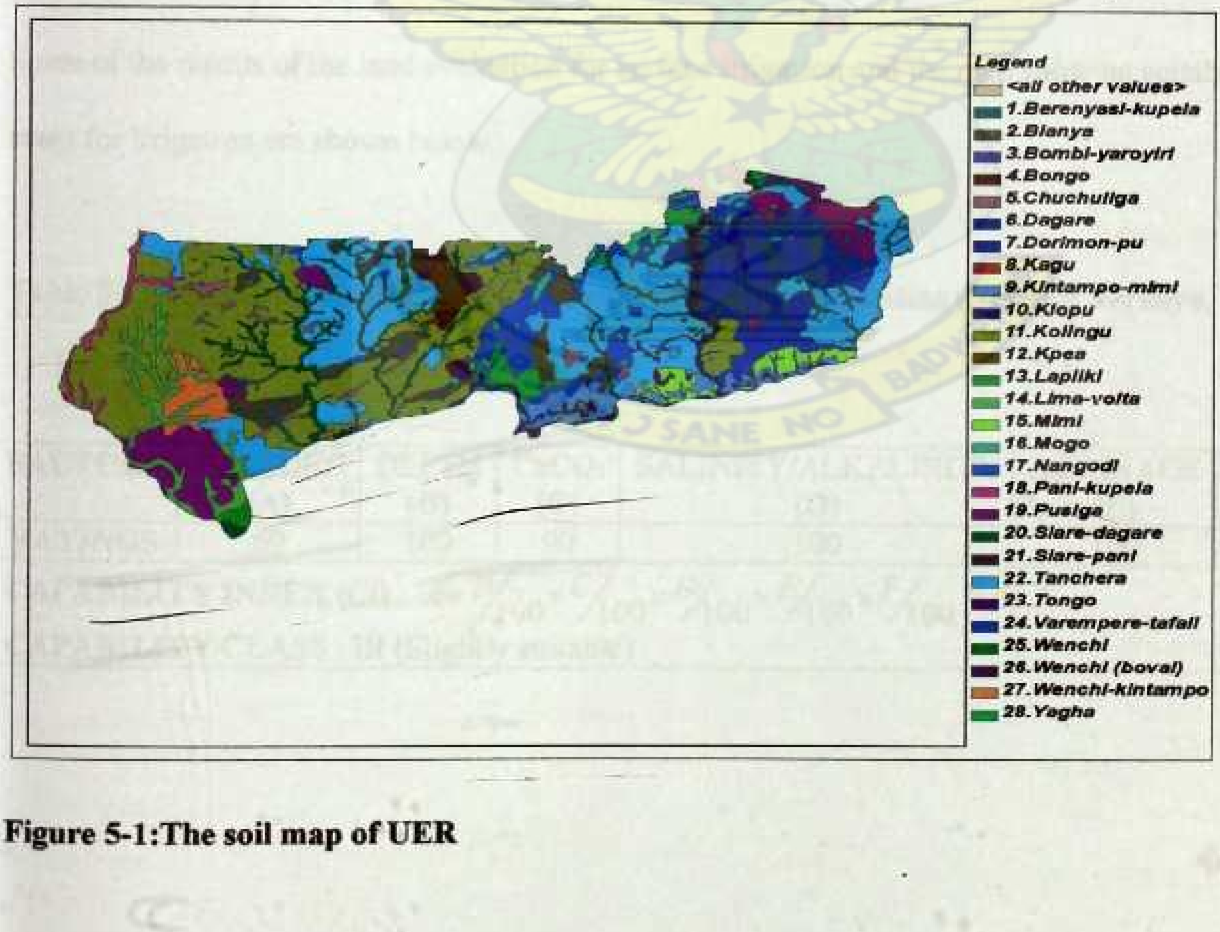

Figure 5-1:The soil map of UER

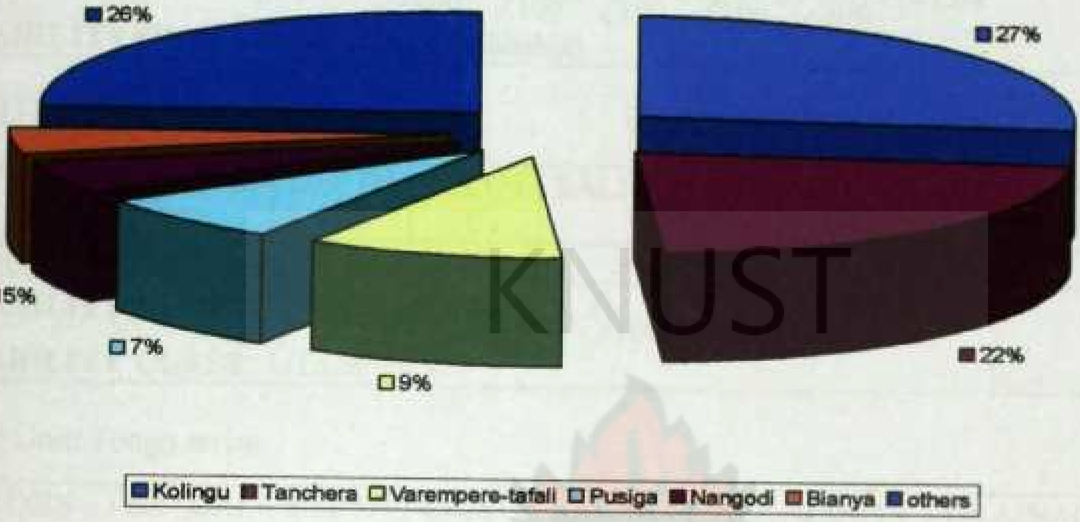

Figure 5-2: Percentage expanse of mapping units

Some of the results of the land evaluation for surface irrigation and the map showing suitable areas for irrigation are shown below.

Table 5-1: Results of the Evaluation of Land for Surface Irrigation (Sys and Verheye, 1974)

1) Soil Unit: Varempere series

FACTORS	TEXTURE (A)	DEPTH (B)	$CaCO_3$ (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	60	100	90	100	100	95
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100 = 51.3$						
CAPABILITY CLASS : III (Slightly suitable)						

2) Soil Unit: Tanchera series

FACTORS	TEXTURE (A)	DEPTH (B)	$CaCO_3$ (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	75	80	90	100	80	95
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$ = 41.04						
CAPABILITY CLASS : IV (Almost unsuitable)						

3) Soil Unit: Bongo series

FACTORS	TEXTURE (A)	DEPTH (B)	CaCO3 (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	95	100	90	100	100	100
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$ = 85.5						
CAPABILITY CLASS : I (Excellent)						

4) Soil Unit: Tongo series

FACTORS	TEXTURE (A)	DEPTH (B)	CaCO3 (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	95	100	90	100	100	100
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$ = 85.5						
CAPABILITY CLASS : I (Excellent)						

5) Soil Unit: Berenyasi series

FACTORS	TEXTURE (A)	DEPTH (B)	$CaCO_3$ (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	75	80	90	100	65	95
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$ = 33.35						
CAPABILITY CLASS : IV (Almost unsuitable)						

6) Soil Unit: Mimi series

FACTORS	TEXTURE (A)	DEPTH (B)	$CaCO_3$ (C)	SALINITY/ALKALINITY (D)	DRAINAGE (E)	SLOPE (F)
RATINGS	95	100	90	100	100	95
CAPABILITY INDEX (Ci) : $A \times B/100 \times C/100 \times D/100 \times E/100 \times F/100$ = 81.23						
CAPABILITY CLASS : I (Suitable)						

Table 5-2: Extent of Suitability Class

SUITABILITY CLASS	MAPPING UNIT [1]	TOTAL AREA (ha)
S1	4, 15, 23	30998
S2	2, 6, 7, 11	267681
S3	3, 17, 19, 20, 21, 24, 28	240749
N1	1, 22	220686
NR	5, 8, 9, 10, 12, 13, 14, 16, 18, 25, 26, 27	100361

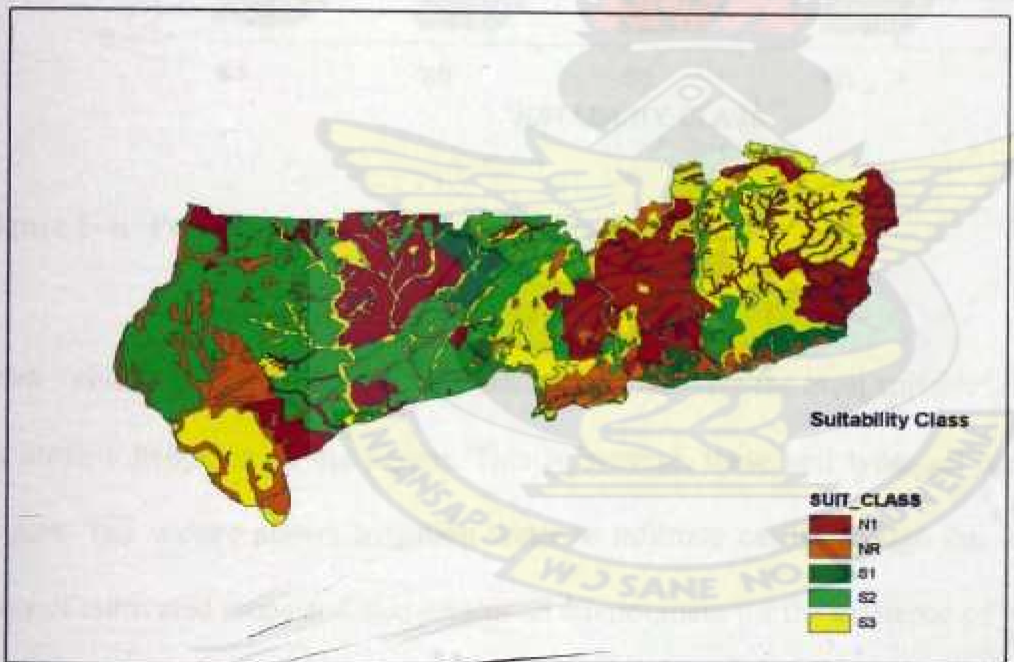

Figure 5-3: Land suitability map

[1] This refers to the legend of the soil map in Figure 5.1

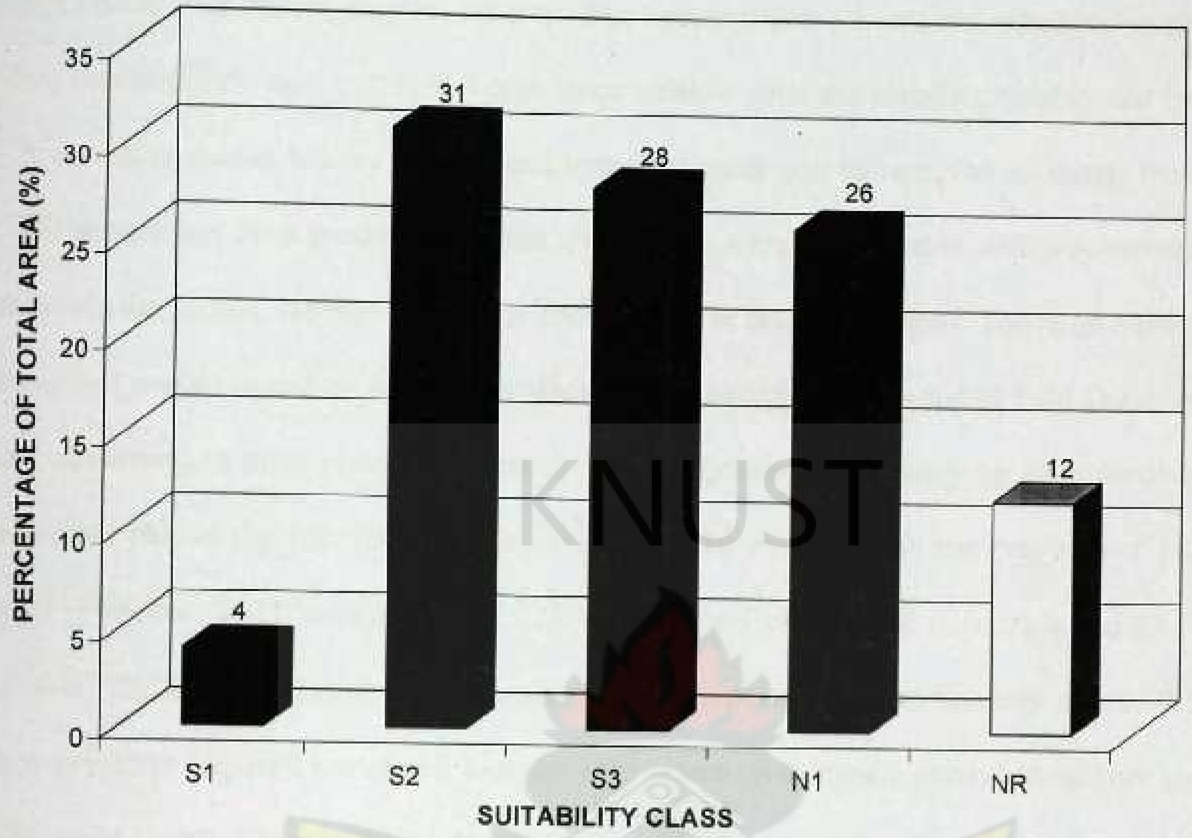

Figure 5-4: Percentage of area of suitability classes

From Table 5-1, Bongo, Tongo and Mimi soil series were the most suitable (excellent) soil types for surface irrigation in the region. This is because, these soil types all had sandy clay loam texture. The texture allows irrigation water to infiltrate easily through the soil structure to the roots of cultivated crops and also creates an environment for the existence of water content in the pores of the soil particles for plant growth (Sys et al, 1991). These excellent soil types cover 4% of the study area.

The Tanchera and Berenyasi soil types happen to be the almost unsuitable for irrigation and these cover 26% of the total area. The limiting factors of the Tanchera soil type were depth and drainage status. This means, deep rooted crops like tomato (0.7m – 1.5m) and water melon (0.8m – 1.5m) would not do well in this soil type since shallow soils are usually droughty and hence will stress plants during hot dry weather and irrigation water will be removed so slowly that the soil will remain wet for a greater part of the time, due to a high water table, a slowly permeable layer within the profile, seepage or to some combination of these conditions. The large quantities of water that remain in and on imperfectly drained soil prohibit the growing of field crops under natural conditions in most years. Artificial drainage is generally necessary for crop production considerable part of the year (Sherer e tal, 1996). Similar evaluation in the Province of Thies, Senegal (Florence, 2003) revealed that 15.23% of the land was almost unsuitable and 57.66% unsuitable. The limiting factors for the unsuitable soil were texture and drainage status. While surface irrigation required heavy soil like clay, the texture was mostly sandy. In another study carried out in Turkey (Dengiz, 2005), 20.9% of the study area was identified as almost unsuitable and unsuitable (N1, N2). The soil handicaps were drainage status and high slopes.

From the results of the land evaluation, the potential suitable land for irrigation (S1, S2 and S3) in the UER covers an extent of 63%.

5.2 Computation of Irrigation Water Requirement

The irrigation water requirement was calculated using the CROPWAT model. The strength of this computer tool kit is that it requires minimum climatic data and it is an established worldwide tool to calculate irrigation water requirement (Camilo, 2008). The required input data are: climatic, crop coefficients, crop area, and planting dates. The climatic data from the FAO

CLIMWAT database were used, as this was the most up to date climate database available. This data set includes long term average rainfall and reference potential evapotranspiration (ETo) data. Estimation of the ETo is based on the Penman–Monteith evapotranspiration equation;

$$\lambda ET = \frac{(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{\gamma_s}{\gamma_a}\right)}$$

where Rn = net radiation; G = soil heat flux; ($e_s - e_a$) represents the vapor pressure deficit of the air; ρ_a = mean air density at constant pressure; c_p = specific heat of the air; Δ represents the slope of the saturation vapour pressure temperature relationship; γ = psychrometric constant; and r_s and r_a = surface and aerodynamic resistances (Allen et al, 1998).

The crops selected represent the average dry season cash crops cultivated in the region. These include tomato, pepper and onion. Data (kc values) on tomato and pepper were selected from the program's data base while data on onion from the FAO guideline (FAO Manual 56). The crop planting dates used represent an average in the region (late October/November) (MOFA-Bolgatanga 2008). The assumed percentage areas of cultivation for the three vegetables (tomato, pepper and onion) are 60%, 15% and 25% respectively. The output of the program includes monthly net irrigation water requirement by crop. Using this value, together with an efficiency of 70% (Savva and Frenken, 2002) the GIWR for a theoretical hectare of irrigated land was computed for the growing season of each of the selected crops. This output of the program is presented in Table 5-3. The GIWR for the three crops = 595 + 124.5 + 142.6 = 862mm.This can also be expressed as 8620m^3/ha.

The CWR of tomato is more than quadruple that of pepper and onion. This is due to the differences in their Kc values. The Kc value is affected by the crop type, climate, soil evaporation and crop growth stages. The kc value for tomato ranges from 0.36 to 0.69 over the growing period while that of pepper and onion are (0.09 – 0.16) and (0.18 – 0.25) respectively. Thus, for the same piece of land, the amount of water needed to irrigate tomato throughout the growing season is four times the GIWR for pepper or onion.

Table 5-3: The Output of CropWat Model

CROP	DATE		ETo (mm/period)	Kc	ETc (mm/period)	Pe (mm/period)	CWR (mm/period)	GIWR (mm/period)	GIWR (mm)
TOMATO	Planting	1/11	132.55	0.36	47.718	0.39	47.328	67.61	
		1/12	139.92	0.49	68.5608	0	68.5608	97.94	
		31/12	153.79	0.68	104.5772	0	104.5772	149.40	
		30/1	170.58	0.69	117.7002	0.34	117.3602	167.66	
	Harvesting	1/3	147.28	0.56	82.4768	3.64	78.8368	112.62	
		Total	744.1			4.37	416.663	595.23	595
PEPPER	Planting	1/11	132.55	0.09	11.9295	0.1	11.8295	16.90	
		1/12	139.92	0.12	16.7904	0	16.7904	23.99	
		31/12	153.79	0.15	23.0685	0	23.0685	32.96	
		30/1	170.58	0.16	27.2928	0.08	27.2128	38.88	
	Harvesting	1/3	58.78	0.14	8.2292	0	8.2292	11.76	
		Total	655.62		87.3104	0.18	87.1304	124.47	124.5
ONION	Planting	1/11	132.55	0.18	23.859	0.16	23.699	33.86	
		1/12	139.92	0.22	30.7824	0	30.7824	43.97	
		31/12	153.79	0.25	38.4475	0	38.4475	54.93	
	Harvesting	30/1	27.52	0.25	6.88	0	6.88	9.83	
		Total	453.78		99.97	0.16	99.81	142.58	142.6

5.3 Estimation of Available Water Resources.

The drainage system of the UER is part of the White Volta sub-basins, the second largest of the Volta's four major sub-basins. In Ghana, the White Volta basin covers an area of 49225.5 km^2. The White Volta is its largest river, which finally assimilates the runoff from all rivers that drain the UER. Its major tributaries are the Red Volta, Sissili and Tono River all flowing into Ghana from Burkina Faso (Ledger, 1964). Other rivers in the region include; Tamne, Morago, Atamore, Bonaponi, Kanyabia, Kulpawn etc. In this study, the catchments drained by the White Volta River, Red Volta, Sissili and Kulpawn rivers in the UER were considered for the assessment of available surface water resources for irrigation. Figure 5-5 shows the selected catchments for the assessment.

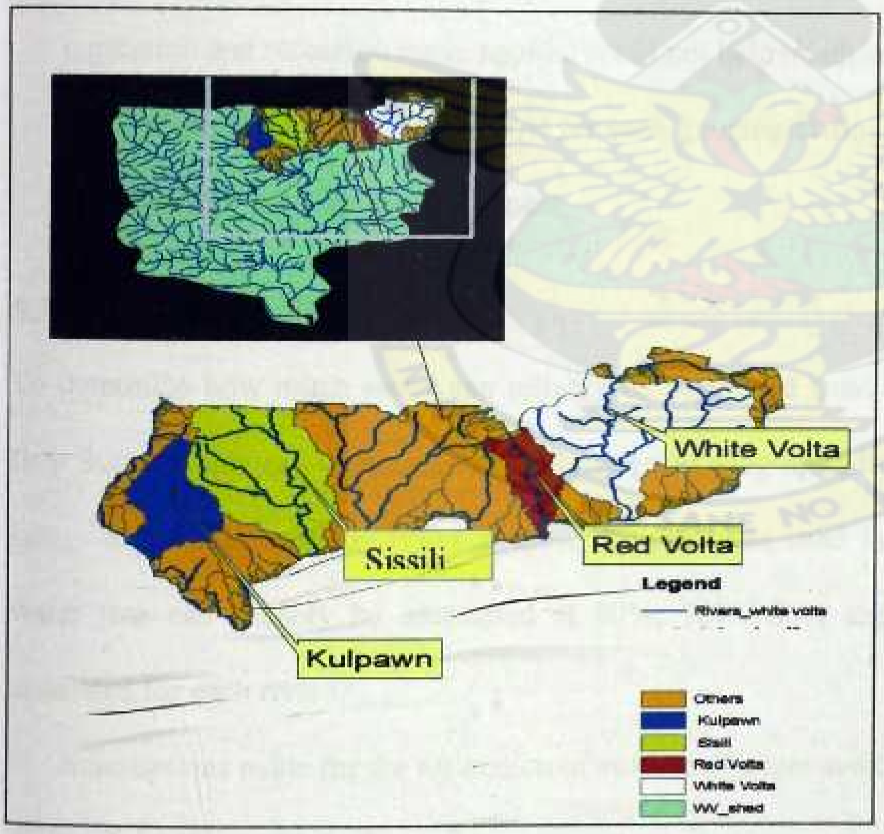

Figure 5-5: Some catchments in the UER

River gauging stations considered for the assessment are;

- White Volta River – Pwalugu gauging station
- Red Volta River - Nangodi gauging station
- Sisili River - Wiasi gauging station
- Kulpawn – Yagaba gauging station

Long-term mean monthly discharge data used for the assessment of the water resources are presented in Tables C1.1 – C1.3 in Appendix C1.

Ideally, a minimum of 30 years of streamflow data was needed for the assessment of available water resources for each of the selected rivers, but a major limitation was the long periods of gaps in the streamflow data at all the gauging stations. Gap filling methods – regression and recession curve applied could not help much as r^2 obtained were in most cases very weak. The mean monthly flow for each gauging station from the Ghana flow statistics was therefore used for the assessment.

5.3.1 Dependable Flow of Rivers

To determine how much water can reliably be abstracted from the major rivers for irrigation, flow duration analyses were undertaken for selected gauging stations on these rivers.

Long- term mean monthly flows at these stations were used for the analysis. The amount of water that can reliably be abstracted at 80%, 70%, 60% and 50% exceedance were then estimated for each river.

Assumptions made for the estimation of volume of water available during irrigation period;

- Irrigation period = 5 months
- Number of hours for irrigation = 9 hours/day.

5.3.1.1 Flow Duration Analysis for the White Volta River

The catchment of the White Volta River (WVR) within the UER starts from north east along the border with Burkina Faso draining all areas along Bawku East and West down south. On the edges of the Gambaga escarpment, the WVR drainage turns south west, separating the region from the Northern region.

Figure 5-6: White Volta River catchment - UER

The catchment covers a total area of 1846 km^2 in the UER. Some of the tributaries of the WVR within this catchment are; Tamne and Morago. The river gauging stations on this river are, from the border of the Upper East with Burkina Faso, Yarugu, followed by Pwalugu and Nawuni in the Northern Region. For the assessment of available surface water resources in the catchment, the Pwalugu gauging station was used. Table 5-4 shows the output of the ranking order Method. The plotting position was computed using the Weibull's formula. Figure 5-7 shows the water availability for the WVR at 80%, 70%, 60% and 50% of the time.

Table 5-4: Ranking Order Method – White Volta River

Mean Flow (m^3/s)	Rank (m)	Percentage Exceedance (100(m/n+1))
563.23	1	7.7
396.22	2	15.4
115.15	3	23.1
97.05	4	30.8
43.04	5	38.5
15.61	6	46.2
12.75	7	53.8
2.41	8	61.5
2.25	9	69.2
0.55	10	76.9
0.24	11	84.6
0.08	12	92.3

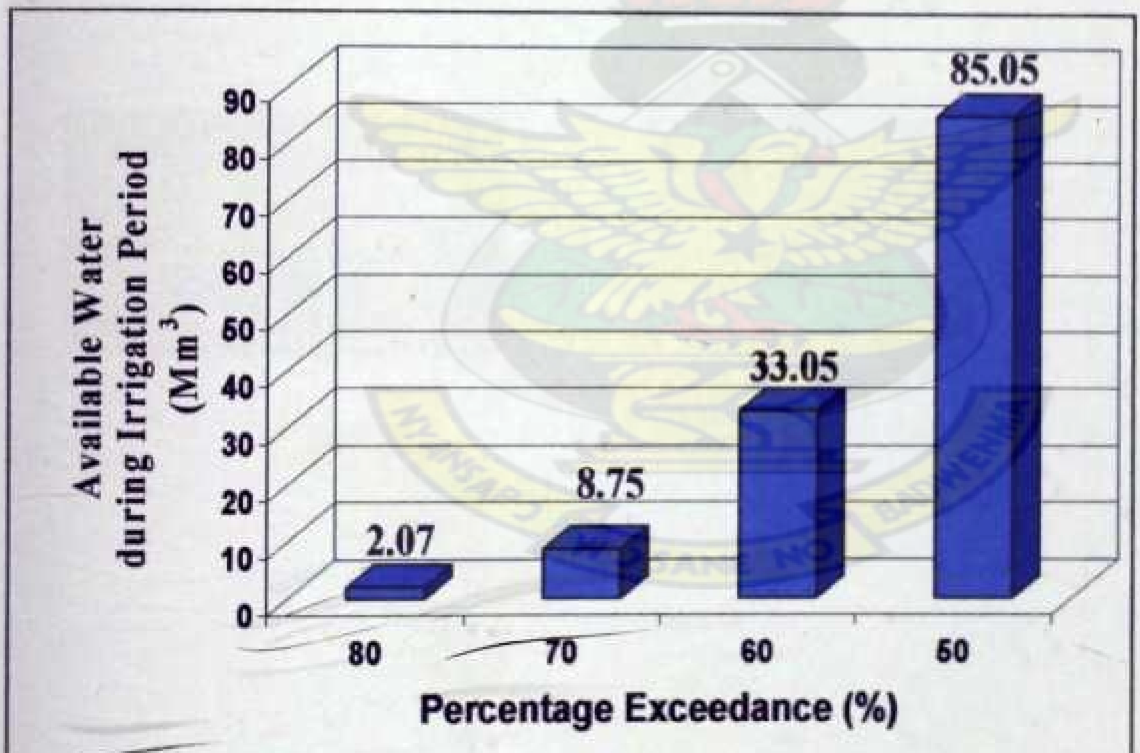

Figure 5-7: Water Available at the WVR catchment at Percent Exceedance

Sample Calculation

Flow at 80% exceedance from the flow duration curve is $0.425m^3/s$. Considering continuous irrigation for a period 9 hours for 5 months, the volume of water at the end of the irrigation period is given by $V = 0.425 \times 5 \times 30 \times 60 \times 60 = 2.07Mm^3$

5.3.1.2 Flow Duration Analysis for the Red Volta River

Areas between Bongo and Zebilla on the western side of the WVR are drained by the Red Volta River, which joins the WVR on the edges of the Gambaga escarpment as WVR turns southwest. The catchment area of the Red Volta River is about $368km^2$ in the UER. The river gauging station considered for Flow Duration analysis is Nangodi. The amount of water equalled or exceeded at 80%, 70%, 60% and 50% of the time are as shown in Figure 5-9.

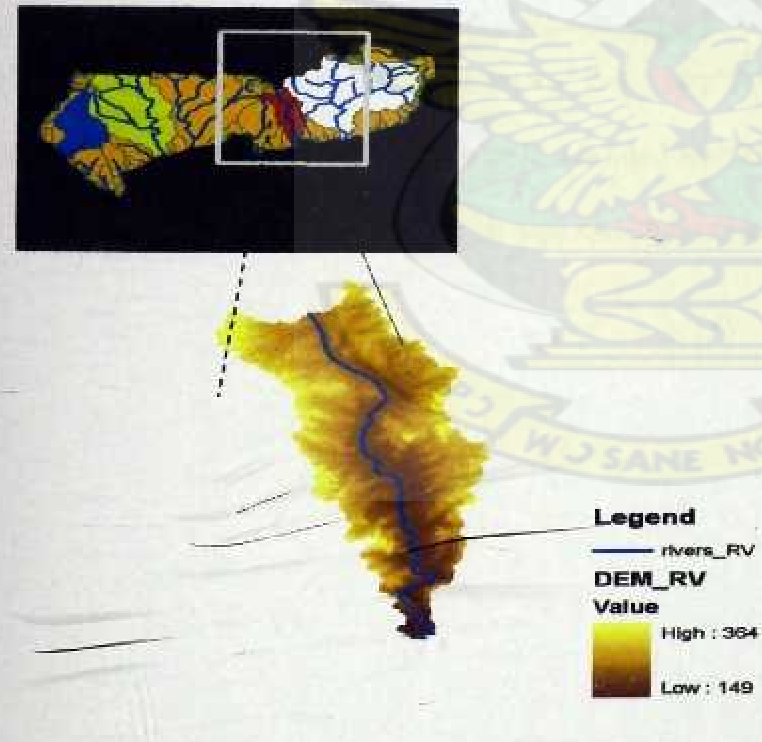

Figure 5-8: Red Volta River catchment-UER

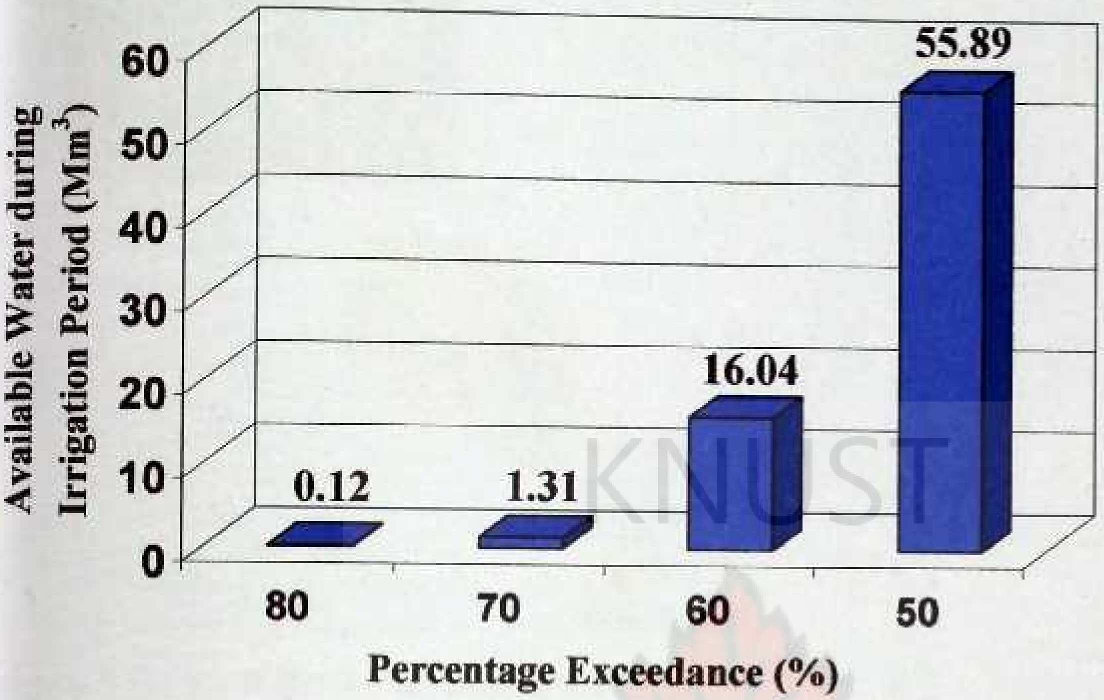

Figure 5-9: Water Available at the Red Volta River catchment at Percent Exceedance

5.3.1.3 Flow Duration Analysis for Sissili River

The Sissili River flows for about 7 months and then either dry or limited to pools of water in the dry season. The river's valleys are more or less eroded and the river flow fluctuates violently after a rainfall event. The Sissili covers an area of 1389km^2 in the UER.

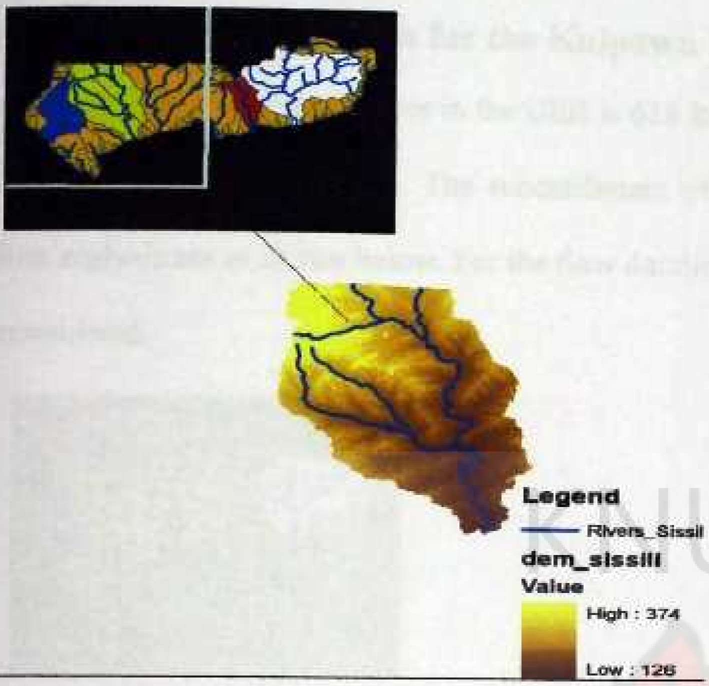

Figure 5-10: Sissili River Catchment-UER

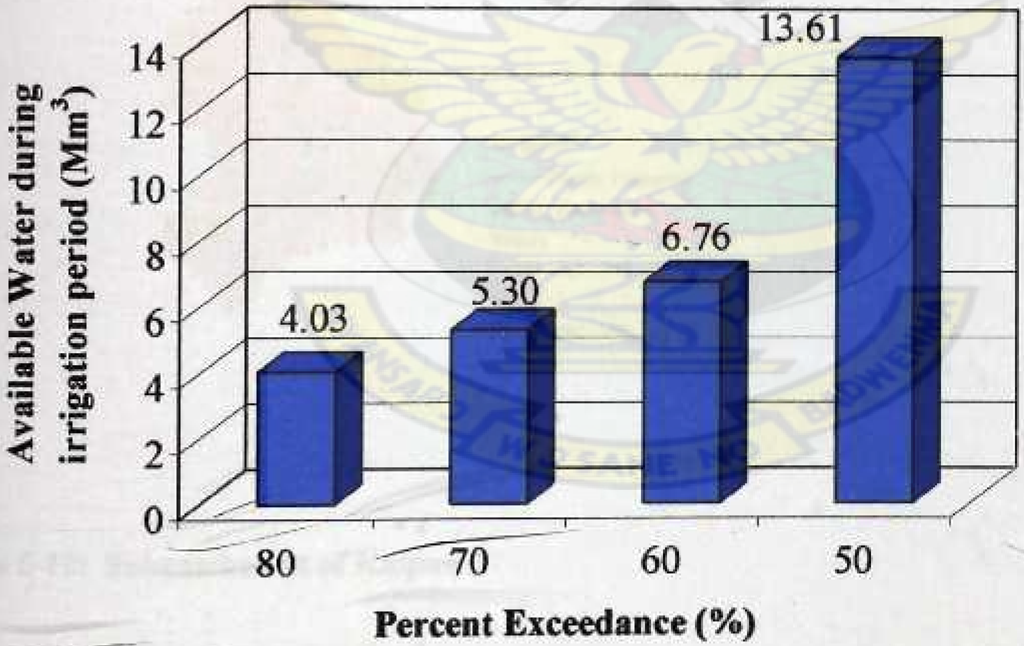

Figure 5-11: Water Available at Sissili River catchment at Percent Exceedance

3.1.4 Flow Duration Analysis for the Kulpawn River

The drainage area of Kulpawn River in the UER is 618 km^2. The major part of the river network occupies the Upper West Region. The subcatchment of the river and the results of the flow duration analysis are as shown below. For the flow duration analysis, the Yagaba gauging station was considered.

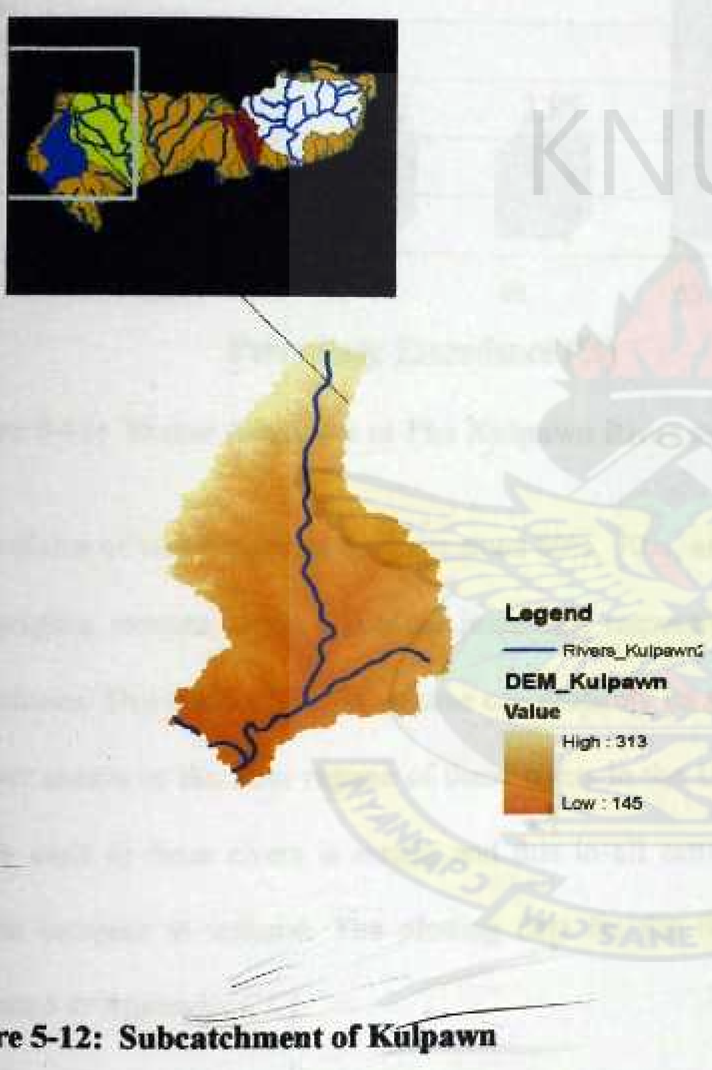

Figure 5-12: Subcatchment of Kulpawn

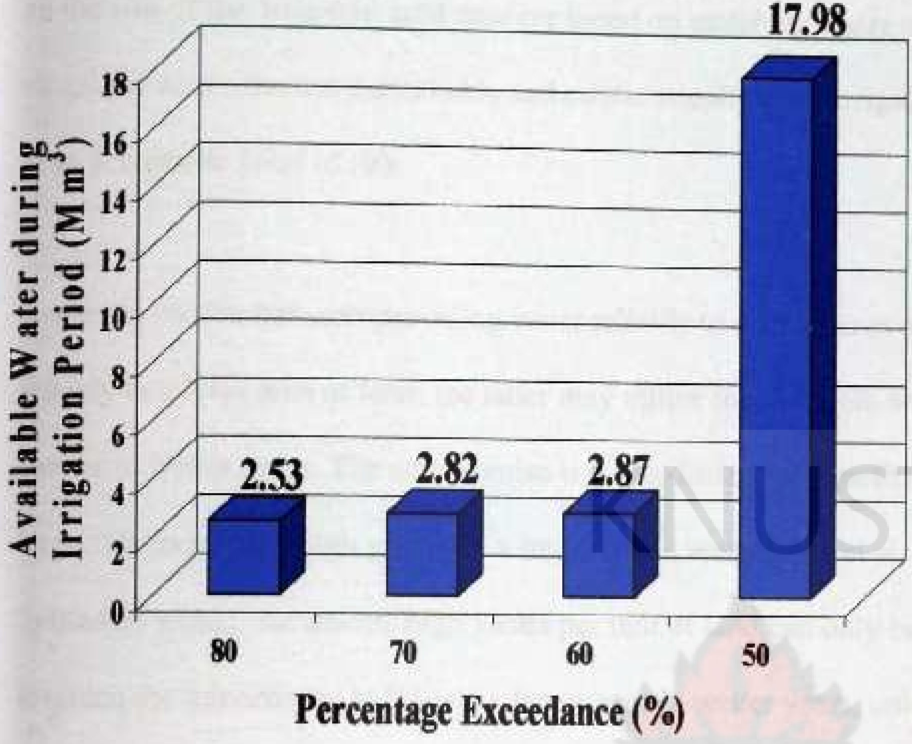

Figure 5-13: Water Available at The Kulpawn River sub catchment at Percent Exceedance

The volume of water that can be guaranteed 80%, 70%, and 60% of the time for irrigation at all the gauging stations show a gradual increment respectively, but a remarkable jump at 50% exceedance. This sudden shot in volume can probably be attributed to the switch from the dry to the wet season in the flow regime of these rivers in the UER. The rainfall in this region which finally ends in these rivers is erratic and this in all estimation is a contributing factor to the sudden increase in volume. The plotting data for the flow duration analysis reveals this as presented in Appendix C1.1.

5.4 Computation of Potential Irrigable Areas

An important part of the evaluation of irrigation potential of an area is the matching of water supplies and water demand. The area which can be irrigated is, in fact, constrained by the amount of water available in the month or period of limited water (Eavis et al, 1979). Decisions on the size of the 'irrigable' land area are based on matching water requirements and supply; in situations where there are unreliable and erratic supplies, the 'irrigable' area would be calculated at an acceptable level of risk.

One must choose between providing water reliably to a small area of land and providing it less reliably to a large area of land; the latter may utilize the available water supply better than the former in wetter years. The compromise is to maximize net benefits per unit of water, rather than be certain to achieve high yields on a smaller land area (Eavis et al, 1978). If water supplies are limited by annual variations, high yields per unit of land can only be achieved regularly by forgoing the opportunity to irrigate a larger area in wetter years, unless adequate storage is possible.

Potential irrigable area of each subcatchment was calculated by dividing the volume of water that could be supplied at varying levels of risk from the major rivers during the irrigation period by the irrigation water requirement for the selected crops computed in the previous section; thus the potential irrigable area is given by ;

$$PIA = IWS / IWR$$

where PIA = Potential irrigable area (ha)

IWS = Irrigation Water Supply from river during the irrigation period (m^3)

IWR = Irrigation Water Requirement (m^3/ha).

The results gave an indication of the areas that could be irrigated with the available streamflow for the different sub-catchments in the region. The output of the computation is shown in Table 5-5

Table 5-5: Potential Irrigable Areas at Selected Catchments in the UER

Sub catchment	Gauging Station	Percent Exceedance (%)	IWS (5months)(Mm^3)	IWR (m^3/ha)	Irrigable land(ha)	Probability of Non-Exceedance
White Volta	Pwalugu	**80**	2.07	8620	**240**	0.2
		70	8.75	8620	**1015**	0.3
		60	33.05	8620	**3834**	0.4
		50	85.05	8620	**9867**	0.5
Red Volta	Nangodi	**80**	0.12	8620	**14**	0.2
		70	1.31	8620	**152**	0.3
		60	16.04	8620	**1861**	0.4
		50	55.89	8620	**6484**	0.5
Sissili	Wiasi	**80**	4.03	8620	**468**	0.2
		70	5.30	8620	**615**	0.3
		60	6.76	8620	**784**	0.4
		50	13.61	8620	**1579**	0.5
Kulpawn	Yagaba	**80**	2.53	8620	**293**	0.2
		70	2.82	8620	**327**	0.3
		60	2.87	8620	**333**	0.4
		50	17.98	8620	**2086**	0.5

The total area that can potentially be irrigated with regard to the major rivers in the UER at 50% exceedance flow is 20016 ha. This figure is however subjected to the availability of the land (current land use), investment capacity, national and regional policies, social, health and environmental aspects, and international relationships, notably regarding the sharing of waters.

5.5 Available land for irrigation

In order to determine the available land resources in the Upper East Region, the land use map of the area was overlaid on the land suitability map for irrigation in ArcGIS environment. Land use shape file from the Ghana at a glance database was used for this analysis. Below is the land use map of the area.

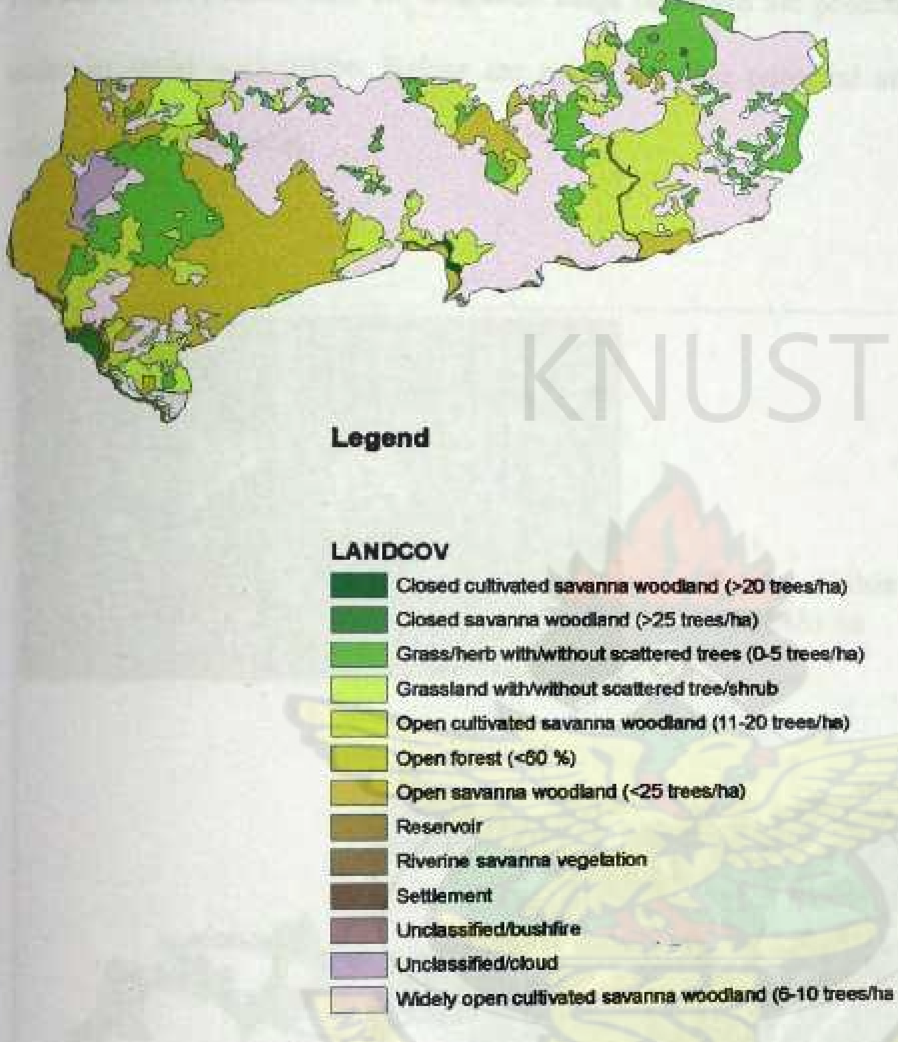

Figure 5-14: Landuse map – Upper East Region

Weighted overlay operation in ArcGIS was performed to aid the selection of available suitable sites for irrigation for all the subcatchments in the UER. The land suitability map for irrigation and the landuse map for each subcatchment were first reclassified on a scale of 1 to 10 with preferred sites scoring 10. The reclassified maps were then weighted and then combined using the raster calculator in ArcGIS. The result was available suitable land for irrigation per subcatchment in the area.

The available suitable sites for irrigation maps represent the potential sites that can be brought under irrigated agriculture. Below are maps showing potential sites for irrigation at all the selected subcatchments

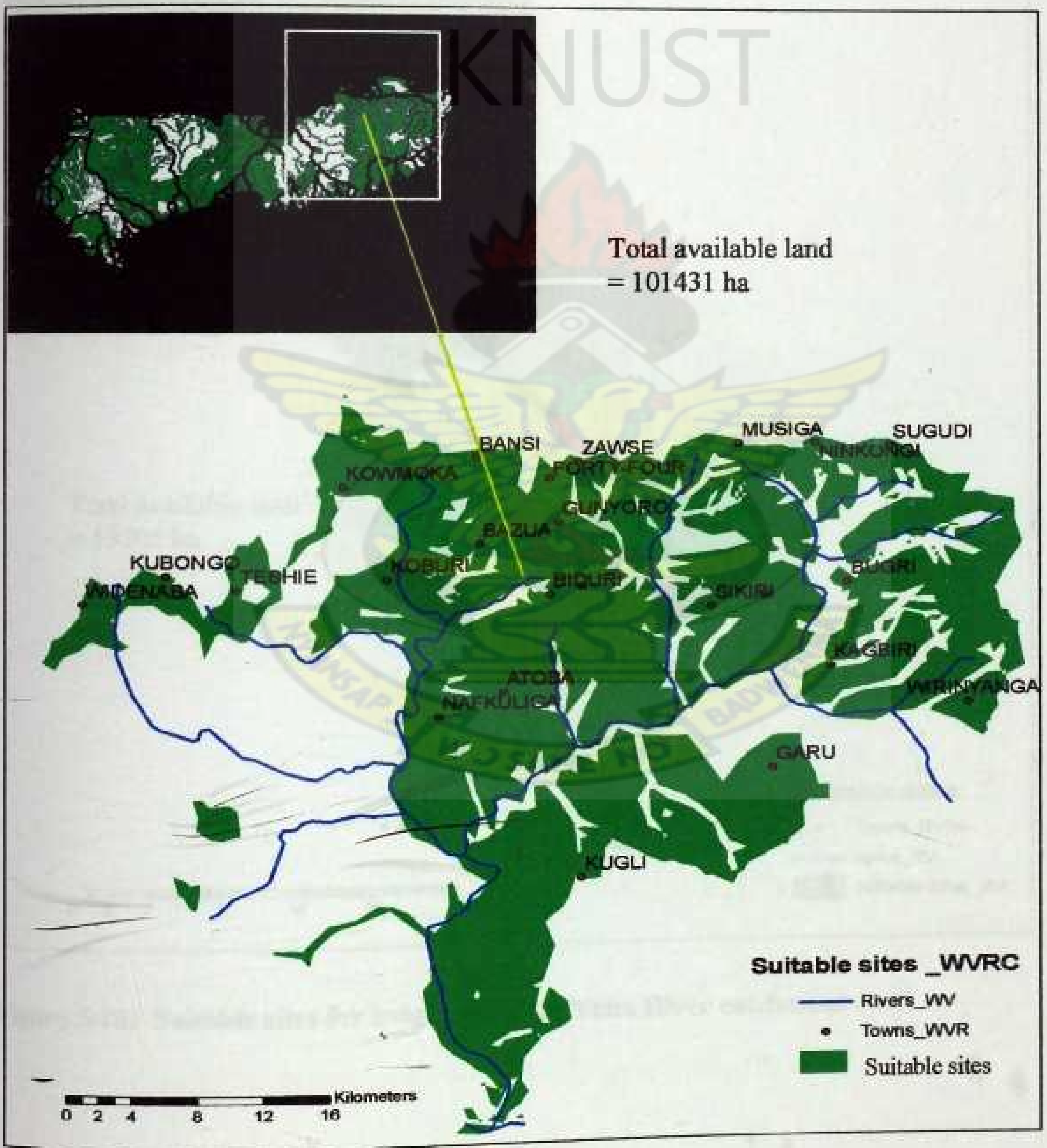

Figure 5-15: Suitable sites for irrigation – White Volta River catchment

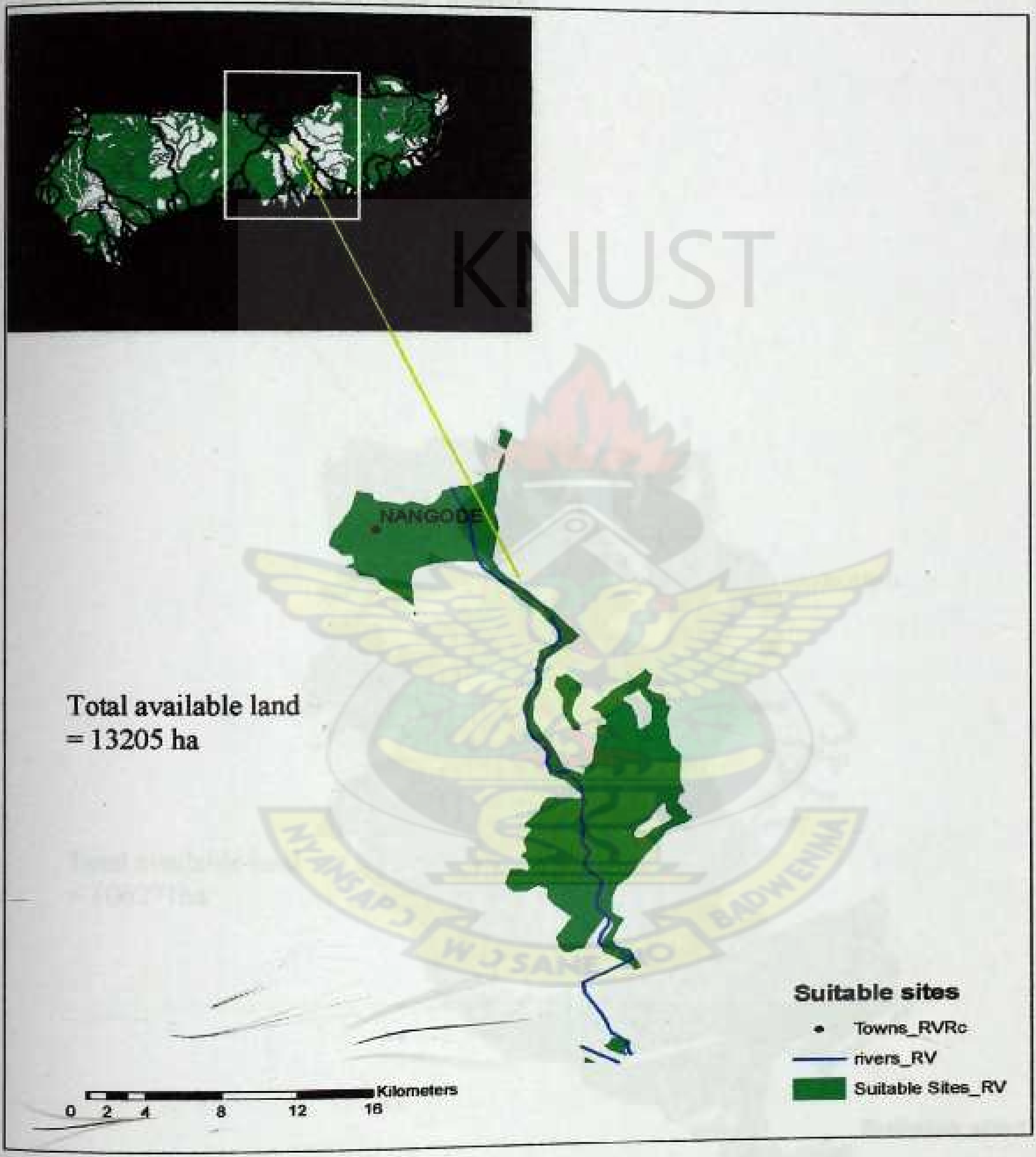

Figure 5-16: Suitable sites for irrigation – Red Volta River catchment

Figure 5-17: Suitable sites for irrigation – Sissili River catchment

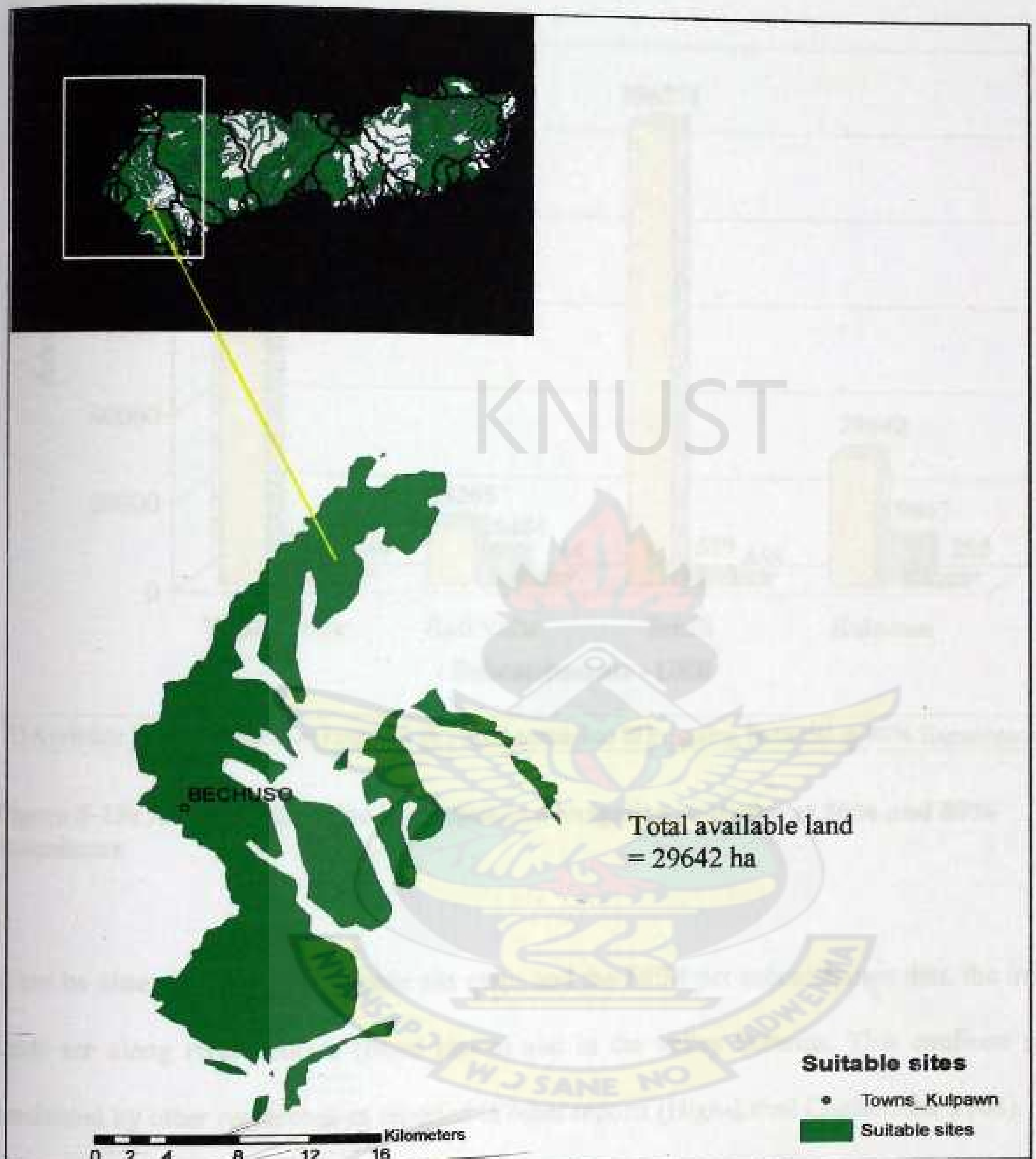

Figure 5-18: Suitable sites for irrigation – Kulpawn River catchment

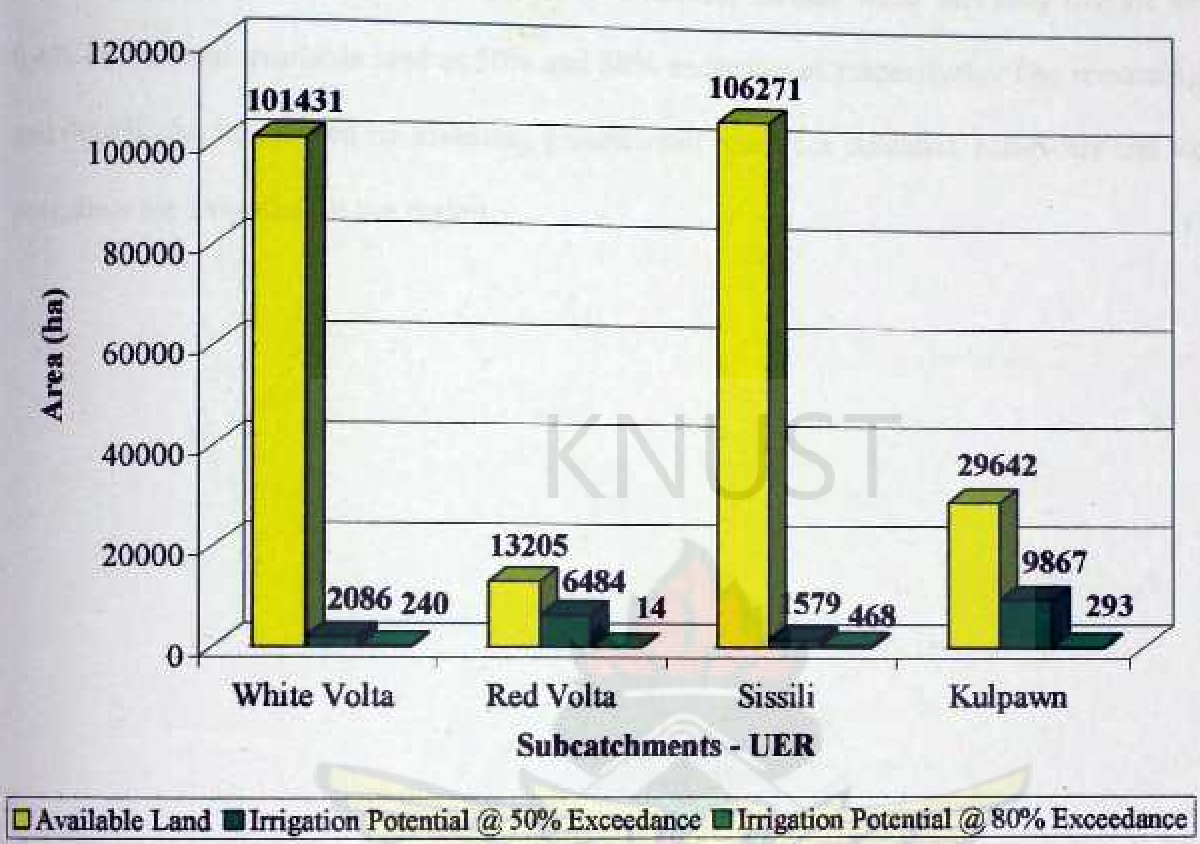

Figure 5-19: Available land for irrigation and irrigation potential at 50% and 80% exceedance

It can be observed from the suitable site maps and the DEM per subcatchment that, the irrigable lands are along river courses (flood plains) and in the valley bottoms. This confirms studies conducted by other researches as reported in other reports (High-Level Conference, 2008).

The total available land suitable for irrigation for the synoptic area is 250549ha (i.e. 28% of the total area of UER). Meanwhile the irrigation potential at 50% [2] and 80% [3] exceedances are 20016

[2]Percentage of time considered by some consultants in assessing water availability for irrigation
3Percentage of time of flow considered by IDA for the design of small scale irrigation schemes

ha and 1015ha respectively. This means, the available surface water can only irrigate 8% and 0.4% of the total available land at 50% and 80% exceedances respectively. The remaining 92% and 99.4% can be utilized by assessing groundwater resources potential, reservoirs and wetland potentials for irrigation in the region.

6.0 CONCLUSION AND RECOMMENDATION

The results of the research showed that for the selected catchments (White Volta, Red Volta, Sissili and Kulpawn), a total of 250549ha (28% of the total area) of land was suitable and available for irrigation. Unavailable areas were either reservoirs or settlements. The suitable areas are mostly along river courses and in floodplains. The irrigation water requirement for the selected cash crops (Tomato, pepper and onion) was 8620m^3/ha for the irrigation period of 5 months.

The capacity of the yield of the major rivers (White Volta, Red Volta, Sissili and Kulpawn) in the region at 80% and 50% exceedances ranged from 0.12Mm^3 to 4.03Mm^3 and 13.61Mm^3 to 85.05Mm^3 respectively. The irrigation potential of the region at 50% and 80% exceedance flows are 20016ha (8% of the available land for irrigation) and 1015ha (0.4% of the available land for irrigation) respectively. Thus the remaining 92% or 99.6% available land can only be irrigated by resorting to other sources of water like ground water and reservoirs in the region.

Nearest towns that can be irrigated in the region include; Wirinyanga, Kagbin, Bugri, Musiga, Atoba, Koburi, Kubongo, Nangodi, Kayoro, Chiana, Chuchuliga, Sandema, Katiu Bechuso.

6.1 Recommendation

The storage requirement of reservoirs needed to irrigate the identified area (suitable and available land) should be estimated in order to know the full irrigation potential of the major rivers.

The irrigation potential of ground water should be assessed in order to know the percentage of the available land that could be irrigated by the water resources in the region.

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APPENDIX A1 – SOIL PROFILE DESCRIPTION AND ANALYSIS

APPENDIX A1
Relevant Soil Characteristics of some Soil types from Various Soil Survey Reports

1) THE VAREMPERE ASSOCIATION

a) General Information
- Reference: Detailed Soil Survey And Land Evaluation of Manga Agricultural Station – UER
- Soil unit: Varempere – tafali
- Effective Soil depth : > 120cm
- Drainage : Well drained
- Slope/ Gradient : 1-2%

b) Table A1: Physical Properties of Varempere – tafali

Depth (cm)	Sand (%)	Silt (%)	Clay (%)
0-2	81.5	15.47	6.64
2-17	80.53	14.17	5.3
17-37	71.45	17.86	10.69
37-60	59.19	18.14	22.67
60-97	55.8	21.31	22.89
97-120	58.41	19.84	21.31

c) Chemical Properties
- $CaCO_3$ status : Not reported
- Salinity/Alkalinity status : Not reported

2) THE TANCHERA ASSOCIATION

a) General Information
- Reference: Tanchera series, T. Adjei Agyapong and Seneyah
- Soil unit: Tanchera
- Effective Soil depth : 57cm
- Drainage : Imperfect
- Slope/ Gradient : 2.5%

b) Table A2: Physical Properties of Tanchera

Depth(cm)	Sand (%)	Silt (%)
0 - 5	84.5	5
5-22	78.3	5
22.- 45	71	13
45 – 57	57.3	21
57 - 79	54.2	26
79 – 120	43	30

c) Chemical Properties
- CaCO3 status : Not reported
- Salinity/Alkalinity status : Not reported

3) THE KOLINGU ASSOCIATION

a) General Information
- Reference: Ethno-pedology Surveys in the Semi- arid Savanna Zone of Northern Ghana station
- Soil unit: Kolingu series
- Effective Soil depth : > 150cm
- Drainage : Moderately well drained
- Slope/ Gradient :2%

b) Table A3: Physical Properties of Kolingu series

Depth(cm)	Sand (%)	Silt (%)
0-5	70	5
5-12	70	8
012-20	60.5	18
20-29	56	19.5
29-76	31.5	46.5
76-100	31.8	41

c) Chemical Properties
- CaCO3 status : Not reported
- Salinity/Alkalinity status : Not reported

4) BONGO ASSOCIATION

a) General Information
- Reference: Soils of the Navrongo-Bawku area, UER, Ghana
- Soil unit: Bongo series
- FAO classification:
- Effective Soil depth : 160cm
- Drainage : Well drained
- Slope/ Gradient :1-0%

b) Table A6: Physical Properties of Bongo series

Depth(cm)	Sand (%)	Silt (%)
0-8	84.8	7.1
8-20	74.1	18.8
20-41	73.6	18.3
41-71	51.8	36.9
71-107	51.4	34.8

c) Chemical Properties
- $CaCO_3$ status : Not reported
- Salinity/Alkalinity status : Not reported

5) MIMI ASSOCIATION

a) General Information

- Reference: Soils of the Navrongo-Bawku area, UER, Ghana
- Soil unit: Mimi series
- FAO classification:
- Effective Soil depth : 167cm
- Drainage :Well drained
- Slope/ Gradient :2.5%

b) Table A12: Physical Properties of Mimi series

Depth(cm)	Sand (%)	Silt (%)
0-8	90.9	5.1
8-28	88.3	7.1
28-69	53.3	40.6
69-119	55.8	37.7

c) Chemical Properties
- $CaCO_3$ status : Not reported
- Salinity/Alkalinity status : Not reported

APPENDIX A2 – SOIL PARAMETER RATING TABLES (PARAMETRIC EVALUATION SYSTEM)

APPENDIX A2.1

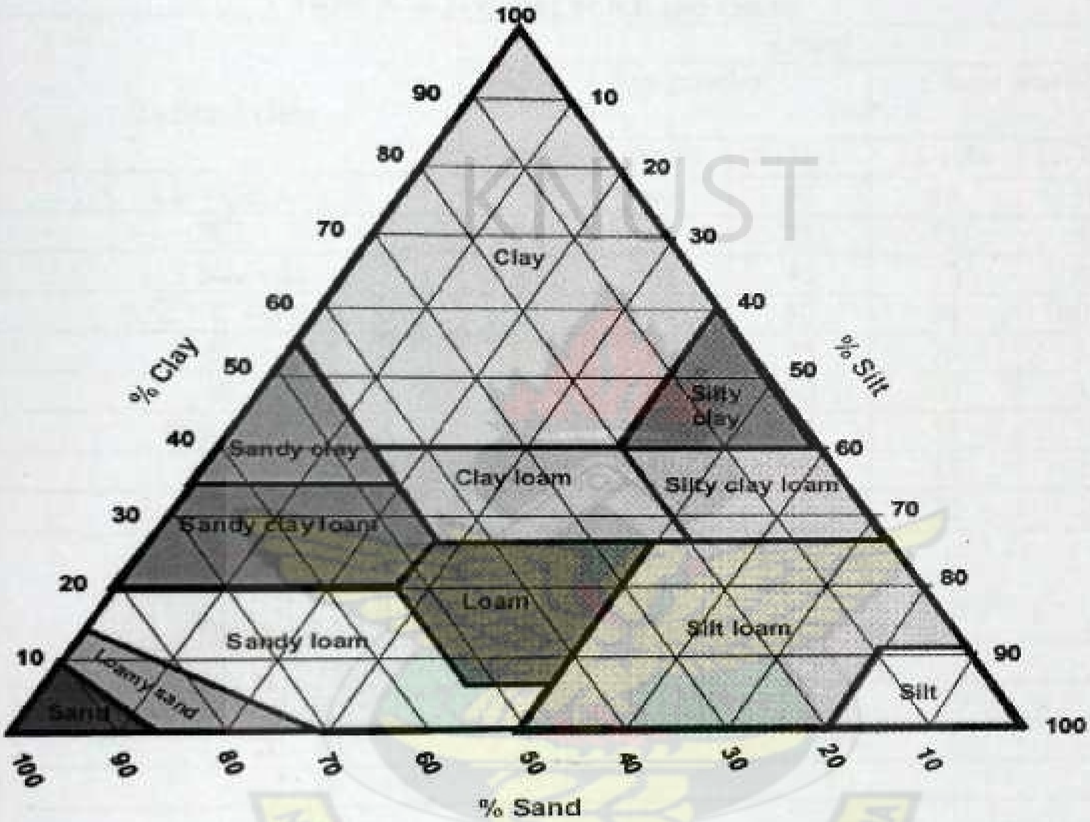

Figure A2.1: Soil Texture Triangle

Appendix A2.2

Ratings for Surface Irrigation

Source: 1) Land Evaluation, Part II: Methods in Land Evaluation, pages184-191

2) Land Evaluation in the Province of Thies – Senegal

Table A2.2.1: Rating of textural classes

Textural class	Rating				
	-15%	Fine gravelly		Coarse gravelly	
	Gravel	15-40%	40 -75%	15-40%	40-75%
CL + SiCL	100	90	80	80	50
SCL	95	85	75	75	45
L + SiL + Si	90	80	70	70	45
SiC + C – 60%	85	95	80	80	40
SC	80	90	75	75	35
SL	75	65	60	60	35
C + 60%	65	65	55	55	30
LS	55	50	45	45	25
S	30	25	25	25	25

Table A2.2.2: Rating of depth for Surface Irrigation

SOIL DEPTH (cm)	RATING
< 20	30
20 - 50	60
50 - 80	80
80 - 100	90
> 100	100

Table A2.2.3: Rating of CaCO3 content

CaCO3 (%)	RATING
> 50	80
25 - 50	90
10 - 25	100
0.3 - 10	95
< 0.3	90

Table A2.2.3: Rating for Salinity and Alkalinity

ESP (%)	ELECTRIC CONDUCTIVITY (Ec) (IN mmhos) (on sat. extr.)				
	0-4	4-8	8-16	16-30	30+
0-8	100 100(*)	95 90(*)	90 80(*)	85 70(*)	80 60(*)
8-15	95 90(*)	90 80(*)	85 70(*)	80 60(*)	75 50(*)
15-30	90 80(*)	85 70(*)	80 60(*)	75 50(*)	70 40(*)
30+	85 70(*)	80 60(*)	75 50(*)	70 40(*)	65 30(*)
(*) Clay, silty clay, sandy clay					

Table A2.2.4: Rating for Drainage

DRAINAGE CLASS	RATING			
	Clay, Silty clay,sandy clay, silty clay loam		Other Texture	
	Non saline	Saline Groundwater	Non saline	Saline Groundwater
Well drained Soils Gley at >3m 2-3m 1.2-2m	100 95 90	100 85 75	100 100 95	100 100 95
Moderately well drained with gley at 80-120 cm	80	50	90	70
Imperfectly drained with gley at 40-80cm	70	35	80	60
Poorly drained soils with gley at < 40cm	60	30	65	40
Very poorly drained reduction horizons at < 40cm	40	20	65	30

Table A2.2.5: Rating of slopes

Slope class (%)	Rating	
	Non terraced	Terraced
0-1	100	100
1-3	95	95
3-5	90	95
5-8	80	95
8-16	70	85
16-30	50	70
>30	30	50

APPENDIX C1 (STREAM FLOW DATA – PWALUGU, NANGODI, AND YAGABA GAUGING STATIONS)

APPENDIX C1

Long-Term Mean Monthly Discharge Data for the Assessment of Water Resources Availability
(Source: White Volta Basin Starter kit – Ghana flow statistics)

Table C1.1 Flow statistics – Pwalugu gauging station

	Pwalugu (m^3/s)											
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Mean	0.55	2.25	15.61	43.04	97.05	396.22	563.23	115.15	12.75	2.41	0.24	0.08
Max	8.48	11.75	66.19	183.05	380.94	928.26	1139.2	276.98	56.41	11.34	1.19	0.94
Min	0	0	0	0	0	146.05	106.05	27.93	0	0	0	0

Table C1.2: Flow statistics – Nangodi gauging station

	Nangodi (m^3/s)											
	Mar	April	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Mean	0	16	3.54	61.2	39.04	91.01	147.21	24.73	1.47	0.36	0.03	0
Max	0	2.32	14.83	505.59	224.11	153.77	287.65	69.34	11.65	2.54	0.17	0.02
Min	0	0	0	0.55	7.45	35.82	23.87	5.02	0	0	0	0

Table C1.3: Flow statistics – Yagaba

	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Mean	0.36	0.58	1.88	3.42	22.35	90.15	200.56	57.97	9.22	1.34	0.49	0.55
Max	2.35	2.29	12.94	17.50	147.21	364.14	579.82	385.38	54.57	4.13	1.64	3.46
Min	0.00	0.00	0.11	0.23	0.76	1.27	16.14	4.25	0.25	0.08	0.00	0.00

APPENDIX C1.1

GRAPHS OF FLOW DURATION CURVE ANALYSIS FOR SUBCATCHMENTS IN THE UER

Appendix C1.1

1) River: White Volta
Station: Pwalugu

Month	Mean Flow (m^3/s)	Rank (m)	Percentage Exceedance (100(m/n+1))
Sep	563.23	1	7.7
Aug	396.22	2	15.4
Oct	115.15	3	23.1
Jul	97.05	4	30.8
Jun	43.04	5	38.5
May	15.61	6	46.2
Nov	12.75	7	53.8
Dec	2.41	8	61.5
Apr	2.25	9	69.2
Mar	0.55	10	76.9
Jan	0.24	11	84.6
Feb	0.08	12	92.3

(2) Red Volta
Station: Nangodi

Month	Monthly Mean (m^3/s)	Rank(m)	Percentage Exceedance(100(m/n+1)
Sep	147.21	1	7.7
Aug	91.01	2	15.4
Jun	61.2	3	23.1
Jul	39.04	4	30.8
Oct	24.73	5	38.5
Apr	16	6	46.2
May	3.54	7	53.8
Nov	1.47	8	61.5
Dec	0.36	9	69.2
Jan	0.03	10	76.9
Mar	0	11	84.6
Feb	0	12	92.3

(3) River: Kulpawn
Station: Yagaba

Month	Monthly Mean (m^3/s)	Rank(m)	Percentage Exceedance 100(m/n+1)
Sept	200.56	1	7.7
Aug	90.15	2	15.4
Oct	57.97	3	23.1
Jul	22.35	4	30.8
Nov	9.22	5	38.5
Jun	3.42	6	46.2
May	1.88	7	53.8
Dec	1.34	8	61.5
April	0.58	9	69.2
Feb	0.55	10	76.9
Jan	0.49	11	84.6
Mar	0.36	12	92.3