ASSESSMENT OF IRRIGATION POTENTIALUSING REMOTE SENSINGAND GIS --ACASE STUDY OF SOUTH SUDAN

A DISSERTATION

Submitted in partial fulfillment of the

Requirements for the award of the Degree

Of

MASTER OF TECHNOLOGY

In

IRRIGATION WATER MANAGEMNET

By

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INDIAN INSTITUTE OF TECHNOLGY; ROORKEEROORKEE – 247 667 (INDIA) May, 2018

CANDIDATE'S DECLARATION

I hereby certify that the work presented in this dissertation entitled, "**ASSESSMENT OF IRRIGATION POTENTIAL USING REMOTE SENSING AND GIS–A CASE STUDY OF SOUTH SUDAN**" "in partial fulfillment of the requirement for the award of degree of **Master of Technology in Irrigation Water Management** submitted in Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during July 2016 to May 2018 under the supervision of Dr. A**shish Pandey**, Associate Professor, Department of Water Resource Development and Management, Indian Institute of Technology; Roorkee, Uttarakhand,India.

The matter embodied in this dissertation has not submitted by me for award of any other degree.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.

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Dedication

I dedicate this dissertation manuscript to my late father, **Wilson Akosh,** to my loving mother **DAK NGOR**, and to my beautiful wife, **Fame Ernesto**, to her land with passion, love, and ambition for the success of my life.

LIST OF ABBREVIATIONS

AFDB	Africa Development bank
AHP	Analytic hierarchy process
DEM	Digital elevation Model
ET	Evapotranspiration
ETC	Crop Evapo- transpiration
ETO	Reference crop - Evapo- transpiration
FAO	Food and Agriculture organization of united Nations
GIS	Geographic information system
GLCN	Global land cover Network
IDW	Inverse Distance weighted
NASN	National Aeronautics and space Administration
NUNIS	Northern Upper Nile irrigation schemes
RS	Remote sensing
RSS	Republic of South Sudan
SPOT	System pour I- observation de Ia Terre
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment tool
USGS	United state geological survey

ACKNOWLEDGEMENT

First and for many, I, d wish to acknowledgement and impart the almighty God's presence in my life. My earnest appreciation and feeling goes to my supervisor Dr. Ashish Pandey, Associate professor, Department of Water Resources Development and Management, IIT Roorkee for his spirited effort, and valuable supervising and support for completion of my dissertation.

I thanks Indian ministry of foreign affairs for funding the M.Tech program, and supporting me to pursue a postgraduate study through ITEC programme.

I am forever grateful to my beloved family, and my friends for his or her encouragement, they besides of me in several aspects of my life.

My special thanks head to all faculty members of the Department of Water Resources Development and Management, IIT Roorkee and colleagues for providing their valuable technical support in preparation of dissertation report.

Special acknowledgement and my grateful appreciation to Dr. S.K Mishra, Head Department of Water Resources Development and Management, IIT Roorkee for his encouragement and support during research work.

I appreciatively acknowledge the offices who have given me data for my study such as Ministry of water resource and irrigation development south Sudan.

And last however not least I'd wish to extent my deepest feeling to my friends, Dr. Loshano Peter and Yohanis Johnson for their words of encouragement and support throughout my study.

Gano Wilson Akush

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ABSTRACT

Assessment of land and water resources for irrigation is significant their use with efficiency and proper crop production to boost food security. But there is no such information associated thereto water and land resource, its agricultural system doesn't nonetheless completely productive. Therefore, assessment of irrigation potential can play a necessary role for better food production. The present study was carried out with the objective of assessing the land and water resources potential of river basins in upper Nile State of South Sudan for irrigation development and development of geo-referenced map of land resources exploitation using Geographic information system (GIS). To identify potential irrigable land, irrigation quality factors like soil type, slope, land cover/use, and distance from installation (sources) has been taken into consideration. These factors were classified as per Food and Agriculture Organization (FAO) guidelines for land analysis suitability classes one by one. The suitableness analysis of these factors indicated that 97.9% slope, 89.04% soil, and 79.82% land use/cover of the area were categorized as potential land for irrigation development within the study area. By weight of these factors 27.36% of the study area is grouped as highly suitable for irrigation; 61.48% is moderate suitable for irrigation and 11.16% of the area was sorted as not suitable for irrigation. Irrigation water requirements (IWR) of four selected crops were calculated from climate information inputs using FAO Penman-Montheith in CROPWAT 8.0 software. Looking into the suitableness map of the study area, most of the area was identified as highly to marginally suitable categories and since water availability is throughout the year from the Nile River there is no limit on the irrigable land. Integration of GIS and weighted overlay approach has been applied to work out the potential irrigable land. The GIS and Remote Sensing techniques verified to be a convenient and powerful platform to integrate spatially complicate land attributes for caring out land quality analysis.

CHAPTER I

1 INTRODUCTION

1.1 GENERAL

Republic of South Sudan (RSS) is blessed with natural resources-.Is still relatively backward as a result of conflicts. Its economy is characterized by permanent dependence on oil resources, currently restricted domestic production, and heavy reliance on imports. Agriculture is characterized by the possibility of howling, but it consists mainly of hand-planted agriculture under rain fed conditions on family plots of less than 2 hectares(Diao, You, Alpuerto, 2012) In addition to livestock breeding, only 2% of grain farming is mechanized. More than half of the population in southern Sudan is poor, however, with US $ 2 as daily expenses and extensive regional disparities
(ADB, 2009)200 poor households depend on agriculture as the main source of dependency, so the agricultural sector is at the forefront of fighting the poor. - 36% of the population is food insecure. Southern Sudan relies on food imports(Piperno & Pearsail, 1998).The main problem attributable to rain-fed agriculture within the country is high rainfall volatility. This change in precipitation results in crop failures as a result; food insecurity often turns into a famine that is exposed to the worst adverse environmental event, resulting in a significant impact on the livelihoods of poor farmers. With low productivity in rain fed agriculture and with the need to double food production over the last 20 years, water has been recognized, because the most important issue has been reduced productivity of rain fed agriculture in better irrigated agriculture(Bengal, Mandal, & Dolui, 2017). It is clear that the employment of water resources in irrigated agriculture provides supplementary irrigation and a full season to overcome rain change and health. Thus, the answer to food insecurity may be to intensify agriculture. In this regard, predictable food production through the optimal development of water resources, coupled with land development, depends on ways of thinking about irrigation (FAO, 2011). These methods are often classified into three categories: surfaces (basin, border, and furrows), sprinklers, and drip roads. Although surface irrigation is the oldest, it is still

at the forefront of intensive uses of water use in agricultural land.

Under these conditions, more than 90 surface irrigation is used worldwide, although local irrigation has little information on how to operate and maintain the system(Saymen San, 2005). These systems are usually developed at the farm level with marginal capital investment. Most capital investments are related to the surface system, particularly land classification, but if the terrain is not extensive, these costs do not seem high. Thus, surface irrigation development wants appropriate topography and information on land and water resources for proper planning (John Wiley, 1994).

Therefore, access to irrigation technology should usually integrate knowledge of land suitability, access to water resources, and water requirements of irrigated areas in time and space(FAO, 1997c).Critical of the suitability of land for surface irrigation, the desire to accurately analyze the soil characteristics and the terrain (slope) of the ground within the field (Sultan, 2013) .Since each area of rural areas is covered by a different land cover and land use, its proper surface irrigation analysis will give guidance in cases of conflict between the use of rural land and concrete or industrial expansion by noting that square measures of land cover /uses most suitable for irrigation(FAO, 1993).The appropriateness of land should be assessed provided that the water is generally equipped for it. The irrigation method would like to integrate information on land and water quality and regional conditions. The demand for irrigation water and its water needs in the unit area The physical factors needed to match the legal supply of requirements, and the physical and chemical properties of land that have a nice contribution to the analysis of the quality of the land for specific use must be assessed provided that the unit of water area is usually equipped. Land analysis explains the choice of viable land, agricultural alternatives, irrigation and applied management, which is a physical, financial and economically (FAO, 1991).However, these factors must be forced to assess in an integrated manner; geographically and mapping the projections of surface irrigation development. With sufficient information, GIS will perform a powerful analytical and industrial tool for irrigation development (Aguilar-Manjarrez & Ross, 1995). The scope of GIS's gigantic space is that its ability to collect, store and deal with many forms of knowledge through abstract knowledge helps to collaborate in many forms of analysis and thus extract information that affects spatially distributed phenomena. The factors involved in assessing the potential irrigation - soil, land cover/use, slope, distance between the water system and the appropriate driving area - should be assessed and evaluated through the use of GIS with irrigation suitability

The Upper Nile State has abundant water and land resources, but its own agricultural production system remains weak and does not have adequate systematic assessment of the land, the lack of clear clarity regarding irrigation suitability, and the surface water of southern Sudan embracing the Nile River system, so the basin of the valley. The river system within Southern Sudan consists of:

1. River system, the upstream of the Sobat River, which arises on good lakes,
2. The Baro / Sobat River system which is established within the Ethiopian Highlands

The Bahr al-Ghazal Basin, a closed basin in western Sudan's south, extends along the north. Both the Sobet and Bahr el Ghazal Rivers are seasonal rivers, in contrast to the river, which can be a permanent waterway. With this vast group of rivers, the exploitation of its water resources for irrigated agriculture is unusually poor in southern Sudan in general and in Upper Nile state significantly. The water resources of these rivers serve mainly as a source of water for domestic enterprises. The potential irrigated areas in Upper Nile State were not known and matched the water requirements of some mature.

1.2 OBJECTIVES OF STUDY

The main objective of this study is to assess the potential of water and land resources of the river basin for irrigation in the Upper Nile State, as well as to provide a geographical reference map for these resources, through the utilization of the Geographic Information System (GIS). In view of the above, the specific objectives of the study are as follows:

1. Assessment of water availability within Upper Nile State - Southern Sudan.
2. Classification and assessment of land suitability for irrigation using remote sensing technology and GIS.

3. Development of land suitability map of irrigation for the Upper Nile State-South Sudan.

CHAPTER II

2 LITERATURW REVIEW

2.1 IRRIGATION POTENTIAL

Irrigation is a technique in which water is diverted from the river or well and used in agricultural production.

However, to assess data on land and water resources at the level of the river basin information of physical resources (soil and water), together with the wishes of irrigation water as determined by the pattern of crops and climate therefore, the possibility of physical irrigation is a mixture of data on the requirements of total irrigation water, the area of soil suitable for irrigation and water resources accessible through the basin (Hillel, 1997).

2.2 IRRIGATION POTENTIAL IN SOUTH SUDAN

The irrigation potential of southern Sudan is estimated at 1.5 million hectares to be brought under irrigation by smallholders and commercial agriculture. The Nile Basin is divided into 654,700 ha and the western and eastern flood plains (in Warab, Unity and Jonglei states) and Manjala area (45 km from Juba at the junction of the White Nile and one in each of its tributaries in the central Euqaya state as well as the Green Belt region). Green, agricultural production sometimes exceeds the subsistence level, and then smart irrigation techniques may increase agricultural production(Fernando & Garvey, 2013). However, few tables and irregular lands hinder large-scale irrigation. These include: lowlands where farmers use floods to complement water to grow rice areas adjacent to waterways, where farmers cultivate short-lived varieties of sorghum areas around swamps; this season can be extended by farming in wetlands left behind Collapsing floods into the shoe, and the unit area of large floodplains placed within the wetlands of large dams, the potential of which was calculated at an angle of 1.6 million hours. But they need intensive.

The area currently equipped for total irrigation management is only 32,100 ha: for an area of 12700 hectares in the case of the upper river, with the theme of Rink about 2000 hectares in Geiger, Magara and Abu Khadra, where the area is irrigated with cotton and hyalanthos and is totally different from three hundred thousand hectares in Jonglei State and five hundred Ha in West Equatoria describe the remainder of the HA 18600 area of land throughout the country, especially individual farmers in areas isolated by water-lifting techniques directly from rivers to support the production of perennial

The irrigated agriculture in Southern Sudan is alleged to be restricted as the area unit is only two (2) government-supported irrigation systems, particularly the irrigation systems AIRS and Upper Upper Nile (NUNIS). There are practices for a small pump or bucket / irrigation by owners Small, but they are still minors(For, Development, Plan, The, & Of, 2015a)

Table 2.1: Summary of the results of the Water Use and Irrigation Survey, which investigates the limited irrigation practice in the country:

Table 2. 1Current Irrigation Situation in South Sudan (Master Plan Studies)

The irrigation potential	_	1500000	ha
Irrigation			
1. Full control of irrigation: Area equipped with	20011	32100	ha
Surface irrigation			ha
Sprinkler irrigation			ha
Local irrigation			ha
The area is equipped with a full control of irrigated land in	2011	18480	ha
As% of area equipped for full irrigation control	2011	58	%
2. Equipped lowlands (wetlands, floodplains, mangroves)		_	ha
3. Spate irrigation	2011	6000	ha
Total area equipped for irrigation (1 + 2 + 3)	2011	38100	ha
AS% of cultivated area	2011	1.4	%
As a percentage of irrigated area of surface water	2011	96	%
As a percentage of irrigated area of groundwater	2011	4	%
As a percentage of the irrigated area of mixed surface water and groundwater		_	%
As of irrigated area of non-conventional sources of water		_	%
The area is equipped with irrigated irrigation already	2011	24480	ha
As a proportion of the total area equipped for irrigation	2011	64	%
Average increase per year		_	%
Irrigated area as% of total area equipped for irrigation	2011	19	%
4. - Wetland cultivated unprocessed and internal valley bottoms		_	ha
5. Non- equipped flood recession cropping areas		_	ha
Total area of water (1 + 2 + 3 + 4 + 5)	2011	38100	ha
As % of cultivated areas	2011	1.4	%
Size of full control irrigation schemes Criteria :			
Small schemes < - ha		_	ha
Medium schemes > - ha and <- ha		_	ha
Large schemes > - ha		_	ha
Total number of households in irrigated		_	

2.3 IRRIGATION LAND SUITABILITY EVALUATION FACTORS

Land suitability is the fitness for a particular type of land to use external lines. The land is also classified in its current condition or once improvements for its specified use. The method of classification of land suitability is to assess and collect specific areas of land in terms of suitability for external uses(FAO,1976).

Land analysis is primarily the analysis of information on land - soil, vegetation and other climate in terms of realistic alternatives to increase the employment of that land. For irrigation, land suitability analysis, explicit attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions for irrigation methods (Fadlalla & Elsheikh, 2016).To take these factors into account, land cover / land use types are a determining factor in assessing land suitability for irrigation(Tsadik, 2012). As widely stated in the FAO Land Assessment Guidelines, the relevance of these factors to surface irrigation technology and to many types of land use given such as subsequent convenience categories can be expressed in such as the subsequent suitability classes and is given in Table 2.2.

Table 2.2 Classification classes

Class S1 highly suitable:	Land without great restrictions This land is not ideal but the best can hope.
Class S2 moderate suitable:	Land is clearly appropriate but has limitations that reduce productivity compared to those required in S1land.
Class S3 marginal suitable:	the land is reduced with a restriction to service that interest and / or the inputs needed to maintain production are increased so that this cost is only marginally justified
Class S4 less Suitable:	Land that cannot support land use on the basis of sustainability, or where benefits do not justify the necessary inputs.

Factors Affecting Surface Irrigation Land suitability analyzes are reported separately in subsequent sub-sections.

2.3.1 Slope

Slope is the incline or gradient surface and is usually expressed as a percentage. The slope is vital for soil formation and management because of its effect on surface runoff, drainage, erosion, and selection of irrigation methods. In accordance with the FAO Standard Guidelines for the Assessment of Slope, the value of the$\leq$ 2%, regression is highly valuable for surface irrigation. However, the slopes, which amount to $\geq$8%, do not seem to be rapid (FAO, 1999).

2.3.2 Soils

Soil assessment for irrigation includes the characteristics of exploitation that measure squares in nature and cannot be altered or modified. These characteristics include drainage, texture, depth, salinity, and alkalinity(Length, 2008). Despite the fact that salinity and pH risks are likely to improve with soil improvement or management practices, they may be thought to be limited factors in the assessment of irrigation soils (Hillel, 1997).Thus, some soil forms that do not apply to surface irrigation can be applied to sprinkler irrigation or small irrigation and land selection.

2.3.3 Land cover and land use

Land cover and land use are often used interchangeably. However, they are quite different. Land cover is a detailed outline, such as the physical cover, as seen from below or through remote sensing, along with plants (natural or cultivated) and human construction (buildings, roads, etc.) covering the earth's surface. Water, ice, clean rocks, or sand surfaces are considered as ground cover. However, the definition of land use establishes a direct link between the land cover and the actions of the individual in its surroundings. Thus, land use is printed as a series of activities undertaken to provide one product or a lot of services or services (Cumani & Latham, 2013). A particular use of land can occur in one or more of the single element of land and many other land uses can occur on identical elements of land cover or land use. Definitions of land cover or land use during these means provide a basis for the suitability of potential irrigation lands with accurate and quantitative economic analysis. Thus, the compatibility with current land cover / use with topographical and soil characteristics to assess the suitability of land for irrigation with the land suitability category, the current potential land of new agricultural production (Boonyanuphap, Wattanachaiyingcharoen, & Sakurai, 2004).

2.3.4 Water availability

Access to water is important to create a positive situation and there will be no shortage of irrigation water. If water is supplied briefly during part of the irrigation season, crop production will suffer, yields will drop and part of the investment plans could be weak (Programme, 1998). Therefore, the water system (quantity and seasonality) is the vital factor for assessing the suitability of land for irrigation for each water quantity throughout the year in which it is available (Options, 1993). Measuring the amount of water that can be obtained for irrigation and pinpointing the precise location of the water is very important by calling for its expansion. Where this can be achieved, water supply must be at the top of the water supply that is closed in the middle of the irrigated area to reduce the volume of the conduits and pipelines. Thus, the distance from the water sources to the command area, proximity to the rivers, useful cutting transport system (length of the irrigation channel) and thus the development of the irrigation system economically (Amosson, New, Almas, Bretz, & Marek, 2002).

2.4 OVER VIEW OF GIS APPLICATION

Geographic Information System (GIS) is a computer program used to capture, store, query, analyze, and display documented geographical data (Goodchild, 2003). Geographical reference data describe each location, so the properties of a spatial option such as roads, land terraces, and plants stand on the surface of the earth. Characterize the flexibility of the GIS to address and manipulate geographical reference data GIS from alternative data. In addition, GIS is created as a vital technique for a wide range of applications.Clearly, the cumulative availability of geographically large data sets, improved visualization capabilities, rapid retrieval and manipulation within and within GIS systems will require new ways to search for spatial data analysis specifically designed for current data. Prepared by the wealthy(Murgante, Borruso, & Lapucci, 2009). Using GIS databases, many recent data can be obtained or information that has not been available before and accurate analyzes can be calculated. This ultimate data in the higher understanding of the area will facilitate the formation of effective choice, or events and future conditions are solid. The most common geographic analyzes that can be performed using the GIS system are listed separately in the following sub-sections

2.4.1 Mapping

The main application of GIS is mapping, where objects edit tasks as well as query and analysis on a map basis (Fryman & Sines, 1995). Map is the most common reading for users to learn about geographic information. This is the first application in any geographic information system to include geographic information. The map represents geographic information as a set of layers and alternate parts in a far superior reading. Common map sections contain an info frame with map layers for a certain range, a scale bar, a north arrow, a title, descriptive text, and a logo legend.

2.4.2 Weighted overlay analysis

The weight overlay may be away from the application of the unusual value scale of values on different and unmatched inputs to form an integrated analysis. Geographical problems often seek to analyze different factors such as land cover, slope, soil, and distance from water supply (Green, Teichert-coddington, & Boyd, 1994). To calculate the effect of these factor values, the weighted overlay analysis uses the measurement scale from 1 to 9. For example, 1 is the smallest suitable factor in the analysis, while 9 is the appropriate value factor in the analysis. The weighted overlay only accepts the formation of the figure as an input, such as the formation of the earth cover / use, the soil types, the gradient, and the Euclidean exodus to find suitable land for irrigation (Pareta & Jain, 1992). Euclidean distance is a straight line from the middle of the supply source to the middle of each command area.

2.4.3 Watershed delineation

A watershed is printed in a geographic area or area that is discharged through grooves to at least one outlet. Simply put, the course of a particular outlet is determined as a body that collects rain and sinks through the grooves, into a single outlet. The delimitation of the watershed means a determinant of the watershed, i.e., the line of harvesting. GIS uses DEMS information as an input to the mapping of watersheds with the integration of Arc SWAT or by the GIS tool in spatial analysis(Tuppad, Winchell, Wang, Srinivasan, & Williams, 2009).

2.4.4 GIS as tool for irrigation potential assessment

In the past, several studies have been written to assess irrigation potential and water resources using the GIS tool, some of which are listed in the next section;

(FAO, 1987)conducted a study to assess the potential of terrestrial water resources for irrigation in Africa on the idea of river basins for nations. It was one of the first studies to be conducted on the basis of a continent-wide geographic information system. The natural resource-based approach is expected to assess irrigation potential. Its main limits are the sensitivity of criteria to determining the quality of the land for irrigation and the allocation of water to calculate irrigation potential.

(FAO, 1997a) examined irrigation potential in Africa taking into account the constraints imposed. Mainly targeted quantitative assessment supported by physical standards (land and water), but relied heavily on the knowledge collected from countries. A geographical area approach has been used to ensure consistency at the regional level. GIS facilities have been widely used for this purpose. During this study, the physical approach to irrigation potential was understood as the global limit for irrigation development.

Melaku Yirga, (2003)conducted a study to assess irrigation potentials in the Raxo dam area (Portugal) for the use of remote sensing (RS) and geographical system (GIS). This study only thought about the number of water that can be obtained in the case of dams and geography (slopes) in distinguishing potential irrigated sites in the lower downstream side of the dam the fully irrigated area by considering the annual flow account to the oversized dam from 1.4% to 18.9% of the irrigation environment in Roxo, 5041 ha until the management of the irrigation system in the long term.

(John Wiley, 1994)conducted an assessment, as part of the Aqua stat program, that could be a program for the country's wise diversity of secondary data on water resources and irrigation, where a survey was distributed to all African countries, where data on irrigation potential were always collected of the master plans and sectoral studies. This approach incorporates more concerns than the direct material approach to assessing irrigation potential. However, it is not possible to calculate the potential double number of shared water resources among many countries.

Tariku, (2007) conducted a study on irrigation quality analysis in the Federal Democratic Republic of Ethiopia, a case of Lake Abaya-Chamo basin. A geographical data system (GIS) was based primarily on soil, land use, and appropriate water resources in permanent rivers within the basin to determine the area of irrigable land.

Hailegebrial, (2007)conducted a study on irrigation potential analysis and crop quality analysis using GIS and remote sensing techniques in the Sub-Beles Basin, Beneshangul Gumuz Region. Soil, slope, land cover / use, water resources and climate factors were considered in the assessment of surface irrigation quality. The result found that the area of 41650 hectares (26.9%) is terribly suitable, 24,100 ha (15.6%) moderately appropriate, 44350 ha (28.7%) marginally appropriate 11000 ha 7.3% inappropriate briefly and 332,500 hectares 21.5%

(Ganole, 2010b)conducted a study on the assessment of GIS-based surface irrigation potentials for watersheds for irrigation development in Valera, Siedma and SNNP regions. During the study, irrigation quality factors such as soil type, slope, land use / cover, and distance from installation (s) were taken into consideration. Analysis of the irrigation quality of these factors indicates that 86 require soil and 58.5% of the slope within the study area that differs from being unusually applicable to the marginal surface irrigation system. In terms of cover / land use, 87.1% of land cover / land use is exceptionally applicable where 12.9% of irrigation development has been restricted.

(Sultan, 2013)conducted a study on the assessment of land suitability in irrigation and the development of a map of the GIS Fogera structure model in South Junder. On the basis of the critical, soil salinity, soil pH, soil depth, and groundwater quality, 72% of the study area was likely to be applicable for irrigation and 28 were classified as unsuitable (N) due to flood risk reduction. And texture factors and gradient.

(Hillel, 2015) conducted a GIS study based primarily on land quality analysis of key irrigated vegetables in the Simaz Dam, the Federal Democratic Republic of Ethiopia. In this study, the world was classified into six Earth Mapping Units and samples of the representative sites of these land-mapping units were sampled. The system used in Arc GIS 10.1 was used in the classification of land quality. The results of the study showed that this study is moderately applicable for any irrigated plant functions. Soil texture was the only issue limiting the world to be moderately applicable (S2).

2.5 APPLICATION OF REMOTE SENING

Remote sensing refers to the technique of obtaining information about an object of excellence or advantage through non-inheritable analysis of an instrument that has not been tuned with the element or feature under investigation(John Wiley, 1994) . This is often done by sensing, recording, analyzing, and applying reflective or emitted energy. In remote sensing, the method involves the associated interaction between incident radiation and, therefore, interest objectives. Remote sensing technology produces a real supply of knowledge for measurement, characteristics, classification, mapping, observation, exit from natural resources, disaster mitigation, preparation, and management

Many analysts believe that the use of GIS and RS will make vital advances in research and operational applications. The integration of these technologies may result in a huge increase in information provided to multiple user types. Ground cover / map usage is one in all the most important and typical applications of remote sensing(Wiley & York, 2014)The land cover corresponds with the ground surface fitness, for example, forest, grassland, pier etc.

2.6 COMMAND AREA AND USE OF GIS AND REMOTE SENSING DATA

The Geographic System (GIS) will integrate remote sensing and entire knowledge sets to create a broad outline of the potential irrigation area. While the remotely detected image of a neighboring area provides a real illustration of the ocean-supported cover / use, the knowledge of the desktop climate connected to the network will serve many functions and serve as a knowledge base for the environmental situation in any place where the knowledge of Earth science does not appear to be from networks Measurement is sufficient. The geographical and hydrological characteristics of the land and landscapes such as slope and side, and watershed modeling will be derived directly from the DEM. A thorough review of that knowledge is provided in the following sections.

2.6.1 Satellite imagery

Remote-sensing satellite information is familiar to GIS users. The utility of different remote sensing information from a different satellite module is quite different in many areas such as agriculture, mapping, engineering, environmental consideration, forestry, geography, water resources management, natural resource analysis and land use planning. The use of satellite imagery in any of the above-mentioned areas requires information from the various bands used by each on-board satellite system to require the imagination and modus operandi of this spectrum of spectrum with the choice of the Earth's surface and then the atmosphere(Awassa, 2007).Different types of satellites vary by sensor, flight height, scopes, spatial accuracy, spectral accuracy, etc. Spatial resolution of the way each image element in the image corresponds to a 900 square meter ground image element. The image element, also known as the brightness value, represents light energy reflected or emitted from the (Wiley & York, 2014)and(Bogoliubova & Tymków, 2014).Since several satellites in the region provide remote sensing knowledge, their application can vary according to means of knowledge acquisition.

2.6.2 Digital elevation model DEM

DEMs are the knowledge store height in computer files. This knowledge consists of x, y, network locations, high-purpose or z-variables. They are created in very complex ways in terms of accuracy or metrics. Under an agreement with the National Aeronautics and Space Administration (NASA) and the National Geographic Management Unit of the Department of Defense (NGA), the USGS is distributing altitude knowledge from the SRTM. The Mission (SRTM) is getting to know the altitude on an international scale close to a radar system that has flown on the region's shuttle. For most components of the globe, this group provides a significant improvement in access to high-quality, high-resolution (Jarvis, Rubiano, Nelson, Farrow, & Mulligan, 2004).Digital elevation models (DEMs) may be a commonly used digital height and an important part of victimization to characterize watershed characteristics. Many agencies give DEM 90m, 30m and 10m. Knowing the height of the target is useful as a contribution to the GIS.
This knowledge is used to produce necessary necessities such as slope, side, flow accumulation, flow direction, and bending in the watershed demarcation method.

2.7 APPLICATION OF AHP TECHNIQUE FOR LAND SUITABILITY ANALYSIS

The Analytical Hierarchy Process (AHP), submitted by(Saaty, 1980) , is a good tool for solving complex issues involving multiple criteria and will help the decision maker to prioritize and make the most effective decision. By reducing complex choices to a series of wise comparisons and synthesizing results, the AHP feature is designed to deal with the situation in which individual judgments are an important part of decision making. The AHP can be a fundamental method in breaking down a complex and disorganized situation in the parts element, copying these parts of elements, or factors into a hierarchical order, thereby distributing the numerical values of subjective judgments on the relative importance and synthesis of each factor. Provisions to act on the fact that the factors have a very high priority and action will be taken to influence the outcome of the situation. The method requires a choice maker to produce judgments on the relative importance of each criterion, and therefore a preference for each criterion. The AHP output can be a priority order, indicating preference for each alternative. In addition, AHP includes a useful technique to check the consistency of choice maker ratings, thereby reducing bias within the decision-making process.

2.8 ASSESSMENT OF WATER RESOURCES

Water resources assessment should be considered as an integral part of the analysis of land resources(Ganole, 2010a). The supply quantity is as important as the land and other factors for the success of the irrigation project.(Tariku, 2007).

2.8.1 Precipitation

Precipitation vital components of water supply. Rain and other types of precipitation are measured in depth and are expressed in millimeters(WMO, 2008). More than 90% of all agricultural land and agricultural land around the world depends on rainfall because the water supply for agricultural production. over 90% of (Ganole, 2010a).

2.8.2.1 Estimation of areal rainfall

Rain observations from the measurement station are point measurements, so the rain method shows large spatial differences over short distances. Thus, the correct assessment of central rainfall is a prerequisite and essential input in hydrological analysis. Among the various methods commonly used for such an arithmetic mean function are Theissen Polygon and Isohyetal methods. The choice of technology depends on the quality and nature of the information, the importance of use, the accuracy required and the availability of time(Ganole, 2010a).

The mean arithmetic method is the simplest and includes the average depths of rainfall in a set of measurements. This technique is satisfactory if the scales are distributed regularly. Thyssen's method assumes that for any purpose within a precipitator the rain fall is the same at the nearest scale, so the depth recorded in a given scale is applied at close range to the subsequent station in any direction (Asawa, 2008). Theissen method is given as;-

$$P = \frac{1}{A}\sum_{i=1}^{n} \text{PiAi} \text{ ---1}$$

Where, A= ∑Ai = A1+A2+A3+……………An

P = the weighted average depth of rainfall (mm)

Pi = rainfall recorded at any station I (mm)

A = total area (ha)

Ai = the area represented by station I (ha)

N = number of rain gauge stations

2.8.2.2 Consistency analysis

To prepare precipitation data for the additional application, their consistency is verified by the double-block curve method. The higher the base stations recorded the more homogeneous, the higher the values corrected in the station in the calculation the more accurate. Modification in the slope of the double-block curve is often important only where it lasts for more than five years.

2.8.3 Irrigation water requirements

Irrigation water should be used with no adverse effects on soil fertility or the proper growth of plants. Water suitability for irrigation purposes related to general irrigation problems is represented by salinity, salinity, acidity, and specific ion toxicity of other elements.

In measuring the amount of water required for irrigation, it is necessary to distinguish between crop water requirements, net irrigation water requirements, and total irrigation water requirements, and their components as described below for the irrigated driving area(Ganole, 2010a). Water requirements can be expressed in terms of water depth (mm) or size (m3).

2.8.3.1 *Effective rainfall*

It is part of the rain that the crop may use effectively, calculated at the depth of the root area and thus the soil storage capacity. And contribute to the requirements of crop water, or requirements for irrigation water net or both (Savva & Frenken, 2002).

2.8.3.2 *Evapotranspiration ET*

Evaporation is a collection of two separate processes where water is lost on one side of the soil surface by evaporation and on the opposite side of the crop by transpiration. Evaporation and transpiration occur at the same time as the liquid water is returned to the water vapor and removed from the evaporation surface. Evaporation is loss of water from the surface of free water, or bare soil or intercepting vegetation and various objects.

The transpiration consists of evaporating the liquid water in the plant tissues and removing the vapor into the atmosphere. ET technology is filled by climate factors such as solar radiation, air temperature, air humidity, and wind speed. Where the evaporation surface is the soil surface, the shade of the umbrella and the amount of water that can be obtained at the evaporation surface are other factors that influence the evaporation process.(Fao, 2006).

2.8.3.3 *Reference crop evapotranspiration ETo*

Evaporation from a non-water reference surface evaporates in the reference crop and is labeled ETo. The reference surface can be an inverse reference product with specific properties. The only factors that move ETo are the climatic parameters. Thus, ETo can be a climatic parameter and can be calculated from weather information. ETo expresses the evaporation power of the atmosphere at a given time and time of the year and does not take into account the characteristics of crops and soil factors.

The Panaman-Monteth methodology at FAO proposes the only methodology for determining ETo. This tactic was chosen as a result of its approximation with the ETo grass at the evaluated location, which is primarily physical and explicitly includes all physiological and aerodynamic parameters. In addition, procedures have been developed to estimate missing parameters (Fao, 2006)

The Monteth equation is given by FAO, according to(Testa, Gresta, & Cosentino, 2011)

$$ETo = \frac{0.408\Delta(Rn - G) + \frac{900}{T+273}U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)} \text{-------------------------2}$$

Where:

ETo = reference evapotranspiration (mm/day)

Rn = Net radiation at crop surface (MJ/m^2per day)

G = Soil heat flux density (MJ/m^2per day)

T = Mean daily air temperature at 2m height (^oC)

U2 = Wind speed at 2m height (m/s)

es = Saturation vapour pressure (kpa)

ea = Actual vapour pressure (kpa)

es –ea = Saturation vapour pressure deficit (kpa

Δ = Slope of saturation vapour pressure curve at temperature T (kPa/^oC)

γ = Psychromertic constant (kPa/^oC)

The equation uses standard climatological records of solar radiation (sunshine), air temperature, humidity and wind speed for daily, weekly, ten-day or monthly calculations.

2.8.3.4 Crop water requirements (CWR) and crop evapotranspiration(ETc)

The resulting evaporation of crops, referred to as ETc, is the evaporation of crops free from disease-free diseases, growth in large fields under optimum soil water conditions and full production under certain climatic conditions. The crop evapotranspiration can be calculated from climatic data and by direct incorporation of resistance to crop, muscle and air resistance factors in the Penman-Monteith approach. Since there is still a significant lack of data for different crops, Penman-Monthieth is used to calculate the standard reference crop to determine the evapotranspiration evaporation rate, such as ETo. By testing ETc / ETo ratio, known as crop coefficients (Kc), to link ETC to ETo or ETc = Kc x ETo. Differences in paper dissection, critical characteristics, aerodynamic characteristics, and even whiteness result in diffusion of evaporation in the crop from the evaporation of the reference crop under the same climatic conditions. Due to variations in crop characteristics throughout the growing season, the temperature changes from a certain crop from seed to harvest (Testa et al., 2011).

2.8.3.5 Net irrigation water requirement

Irrigation Water Requirements (IWR) refers to water that must be applied through an irrigation system to ensure that the crop receives its crop water needs in full. If irrigation is not the only supply of the plant's water system, the demand for irrigation can be consistently greater than the demand for crop water to allow inefficient irrigation system. If the crop gets some of its water from alternative sources (rainwater, water stored in the ground, underground leakage, etc.), the irrigation requirements can be much lower than the requirements of the crop water(Savva & Frenken, 2002).

2.8.3.6 Gross irrigation water requirement GIWR

The total irrigation water requirements are defined as the net irrigation water requirements and additional transport losses between the water supply and the field and any additional water for filtration above filtration.

CHAPTER III

3 MATERIALS AND METHODS

3.1 DESCRIPTION OF STUDY AREA

3.1.1 Location

The study area is Upper Nile state, that set in South Sudan's north region, geographically it, is between9°53'21.91"N latitude and 32°43'5.29"E longitude. Upper Nile state is one of the Ten state of South Sudan covering a complete area of 77832.8 $km^2$and associated in nursing calculable population of 0.96 million. 75% of the population is rural out of the full population that is inconsistently distributed in thirteen counties. Location map of study area is presented in Figure 3.1.

Farming is the mainly economic activity in study area. Mostly rural populations are involved in both agriculture and cattle keeping.

Local farmer's area is notably vulnerable to the vagaries of the area's unpredictable weather patterns, an element that greatly affects their productivity annually.

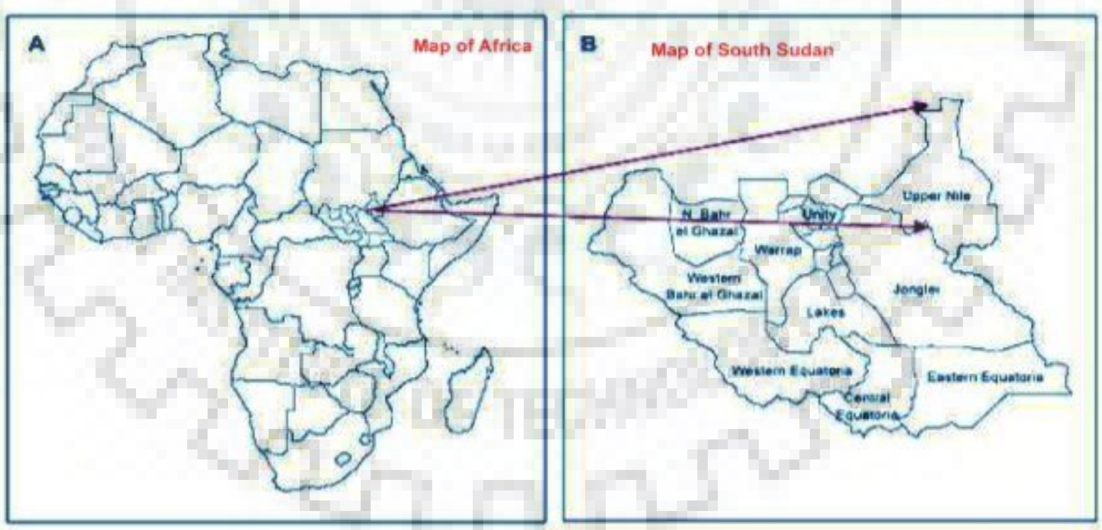

Figure3. 1Location Map of Study Area

3.1.2 Climate condition

Most of the South Sudan features a sublimed climate. There is variation of rainfall within the country, rainfall decreasing from South to north, from approximately 1,800mm to 500mm; the northern part areas are dries and skill additional frequent drought. There's abundant precipitation in the south and southwest areas, about 1,500mm, however less (about 500mm) mutually move from south to north.

The study area experiences six months of unimodal time of year begin from south in late April covering whole Study by late May, with average annual rainfall of (950 – 1,500)mm each year ensuring to high wetness throughout six months of serious rain (May - October), and temperatures (27 – 49) degree centigrade.

It is rare to process throughout time of year (November – April). The soil covers primarily

consists of black cotton soil along river bank and across marshland(For, Development, Plan, The, & Of, 2015b).

3.1.3 Drainage

The river system is that the prevailing physical characteristic, and every single current and the rivers of southern Sudan discharge either towards or towards the Nile. The White Nile enters the country because of the Bahr Al-Jabal from the south crosses the slopes of Nimule on the borders of the Republic of Uganda. Once it meets the tributary of the left bank of the West Bank referred to as Bahr el Ghazal and the Bahr Al- Jabal becomes the White Nile. Further northward, the White Nile receives an abundance of water from the right bank of the Subat River, which flows from the Ethiopian tin land to hit the Nile near Malakal. Of these rivers, the White Nile is the largest river basin. However, the area covered by irrigation from these water resources is very small due to a wide range of challenges such as lack of irrigation facilities, weak or lack of experts, etc.

3.2 DATA USED

3.2.1 Meteorologically and Hydrological Data

Climatological data for this study was collected form Ministry of water resources and irrigation development South Sudan (MWRID SS). These data were used for estimation of irrigation water requirements by using CROPWAT8.0 software for some of the selected crops in the study area, such as maize, sorghum, groundnuts and rice, and the discharge of a measurement plant in Malakal, also obtained from the Hydrology Unit of the Ministry of Water Resources and Irrigation.

3.2.2 Satellite image

Recent satellite imagery of 30 m spatial resolution was downloaded from USGS Earth Explorer website (http://dds.cr.usgs.gov/srtm/) for the classification and development of land use and land cover maps for the study area. The image was rated using the ERDAS Imagine program.

3.2.3 Digital Elevation Modal (DEM)

Digital elevation model of 30 m spatial resolution was downloaded from USGS Erath Explorer website. It was used to delineate both watershed and Slope maps of the study area to analyze the suitability of irrigation using Arc GIS 10.4.

3.2.4 Soil Data

FAO / UNESCO - World map of soil, available in Arc / info format 1: 1500000. This data was used to analyze soil suitability for irrigation.

3.2.5 Software

The software used for data preparation and analysis are ArcGIS10.4, ArcSWAT10.5, Cowpat 8.0 5and ERDAS –Imagine.

3.3 METHODOLOGY

3.3.1 Climate data pre- processing and checking of data

Climate data can contain errors due to faulty measurement and hardware failure. Therefore, it should be examined prior to use to estimate irrigation water requirements through the CROPWAT model.

3.3.2 Consistency analysis of data before used

The rainfall data needs to be analyzed and checked for consistency before it is applied for this study. Double mass curve was drawn by plotting cumulative data from malakal station against other stations in the nearby, those are Kodak, Melut and Renk stations.

3.3.3 Watershed delineation

The process of delineating the watershed requires a digital elevation model (DEM) with an effective display of the UTM format using the Arc Catalog in Arc GIS. Using the digital elevation model in the ESRI network format, Arc GIS and Arc SWAT were used together to determine the water collection line by following Drainage limits in the study area. The step below describes the demarcation process.

3.3.3.1 Importing DEM data

The DEM area of the study area was displayed on a UTM coordinate system using Arc Catalog in Arc GIS and imported to Arc SWAT to start automatic watershed demarcation.

3.3.3.2 Computing flow direction

Stream directions for individual DEM cells were created using the flow direction and the Arc SWAT stacking tool. SWAT calculates the flow direction of individual DEM cells and uses the flow threshold area in hectares to create flows based on these trends.

3.3.3.3 Creating watershed outlets

The outlet is the point at which water flows out of the area. This is the lowest point along the watershed boundaries. Cells are used in the point source as cast points above which the contribution area is determined using the SWAT port selection tool.

3.3.3.4 Delineation of main and sub main watersheds

The main water separator line was determined by using the SWAT Articulation Demarcation Tool based on an automatic procedure using the watershed ports created in Step 3 above. In order to establish sub-watersheds, additional drainage outlets must be identified. After many nodes or headers have been defined in the drainage outlets along the flow brackets, the same method that identifies the watershed ports in step 3 has been used again to determine the watersheds.

3.3.4 Land and water evaluation for irrigation suitability

In this study, the irrigation adequacy of the study area was carried out by considering slope, soil, land cover / use, distance between water supply and potential driving area as factors. The suitability of each factor was analyzed and finally weighted for potential irrigation sites using the following steps;

3.3.4.1 Slope suitability analysis

The slope is a very important topographic factor. Have a direct impact on agriculture. It is a major parameter affecting irrigation, especially surface irrigation. Affect drainage, corrosion, irrigation efficiency, cost of land development, size and shape of work requirements in the field, potential crop range and so on. The slope map of the SRTM-DEM study area was derived from 30 minutes of spatial space using the Arc GIS spatial analysis tool. The slope derived from the risk assessment model has been classified according to the FAO Classification System (1996) using the Reclassification Tool, a feature-mapping technique in Arc GIS. The four shelf sizes (S1, S2, S3, and N) were classified for surface irrigation as shown in Table3.1

Table 3. 1Slope Suitability factor rating

Legend	Slope%	Factor rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

Source FAO (1996)

Layered of map raster have been converted to distinct data to analyze the overlay. Using the data management tools in the tool box, the data layers features have been made to make the map fit the slope more clearly.

3.3.4.2 Soil suitability assessment

Soil is an important determinant of the suitability of land for surface irrigation development. For this study, the FAO Soil Map Unit used FAO's East Africa (1997) map for analysis. The major soil groups classified in the study area were: Vertisols, Pellic Vertisols, Molic Gleysols, Flarvisol Calcric, Eutricl, Nitosols Ferrric Luvsiols and Humic Cambisosl. The physical properties of these soil groups were used in the irrigation adequacy analysis and presented in Table 3.2. The following soil suitability ratings were used based on the FAO Land Assessment Guidelines and the Water Bulletin.

Table 3. 2 Soil Suitability Factor Rating

Soil factors	S1	S2	S3	N1	N2
Drainage classes	Well	Moderate	slightly	shallow	very shallow
Soil depth(cm)	>100	75-100	50-75	50-25	<25
Soil texture	L-SiCL, C	SL			
Soil slope%	0-2	2-5	5-8	>8	

Source: FAO guideline for land evaluation, (1976, 1979, and 1991).

In addition, the soil vector layer was re-created in a bitmap layer using the Raster conversion tool or feature to the raster data unit. "Renewable soil was reclassified by name of soil type, texture, and depth and drainage class. Using an ArcGIS10.4 overlapping tool, a weighted overlay analysis was performed to determine their suitability for surface irrigation. Subsequently, the new values for each soil factor were reclassified to classify their irrigation suitability by supporting the common analysis scale of 1-9 available in the weighted overlay analysis. Value 1 represents the smallest appropriate factor in the analysis, while value 9 is a very appropriate factor in the analysis. The most suitable soil factor was given a value of 9, for the given value with the appropriate intermediate value of 6, for the value given to the marginal column was 3 and the least favorable value was 1.

Once the scale values from 1 to 9 are not assigned to the soil factors in the analysis, that cell deserves to be restricted to surface irrigation and should be excluded from the analysis. As an example, the soil factor is restricted to soil depth 10 cm for surface irrigation and the value of the cell representing this value is allocated as a "restricted scale" and will be excluded from the analysis.

3.3.4.3 Land cover/ use assessment

Land cover / use area is in addition to the case, which used to evaluate land suitable for irrigation. During this study, land cover classification using satellite image land sat8 is completed for land cover images characteristic of estimating potential irrigated land. The rating was managed using the ERDAS image software package in the following steps.

3.3.4.3.1 Image pre- processing

Identification of land cover sometimes requires multi-time images. The landat8 image of the study area was available from 1 January 2017 to 31 December. This image format is IMAGIN image; which can be imported into ERDAS imaging. The imaging of the UTM region was replayed on 36 N systems with the Datum1984. This ensures satellite imagery for having a real-world abstract signal.

Then the real composite color images by combining the spectral spectra, which are almost identical to the human vision of the human eye, which is usually used in terrestrial imagery to analyze land cover. The real color uses the visible red band (band3), the visible green (band2) and the visible blue channel (band 1) to form the images terribly close to what expects in an excess of the same scene to us (Figure 3.2).

Band 3 (visible red) = red

Range 2 (green visible) = green

Band 1 (Blue Visible) = Blue

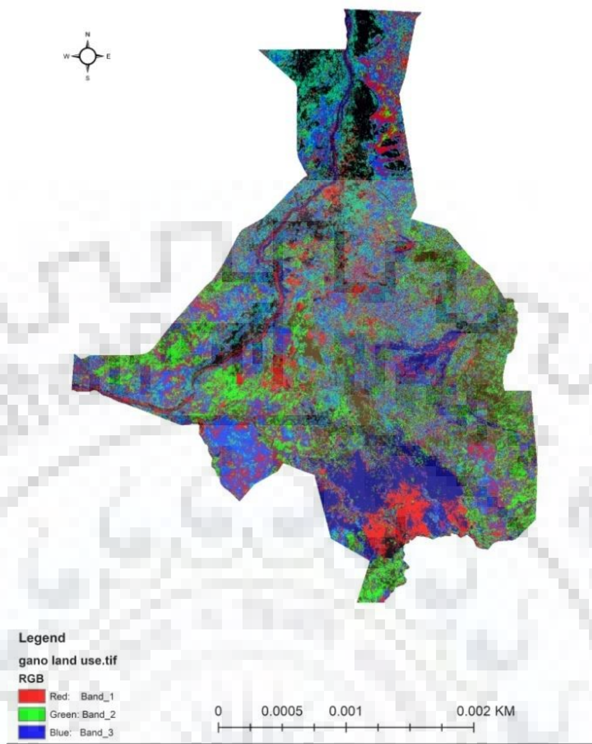

Figure3. 2Landsat8Satelliteimage of The study area shows the real composite color (321)

Pre-treatment steps for alternative images, such as image correction, image restoration, and image smoothing, have been implemented.

3.3.4.3.2 Image classification

There are two ways of extracting spectral information: supervised and non-controlled classification (Richards J, 1986). An unclassified classification is the technique in which image pixels are assigned to spectral groups, while the user does not have previous data relating to the study area, while the supervised classification may be a technique that involves selecting areas within the image that consistently characterize interest categories. Prior to working in the sector, a non-supervised classification of landat8 was conducted to identify the land cover categories in the study area. Results supported by classification and uncensored data From the topographic map of the region, sample training sites were selected to collect geographic.hen, the geographic coordinates of the field images were added to the landat8 image by the ground control points. This method, therefore, determines the GCPs frame of pixels for the output image. This makes your mind better, however, to look at many of the ground cover signatures in pixels within the image and compare the field images of the GCPs with an unclassified image. This information was then used in the field of choice of interest for classification under supervision. Using the supervised classification to the maximum extent possible, 9 categories of land cover were classified in the study area.

3.3.4.3.3 Accuracy assessment

When land use mapping was completed, a related accuracy assessment was performed. This can be attributed to a proven fact that land-use maps derived from imaging operations make some errors or are invariably reversed by many factors. The accuracy evaluation of the signature values of the images classified by the ERDAS image matrix was examined. A confusion matrix may be a table that contains columns that represent the reference or categories selected, and thus a row of categorized or assigned categories (Rossiter, 2001). Bottom-bottom knowledge was used in the maximum likelihood report because the independent dataset was compared from the rating accuracy. The accuracy is actually what the number of pixels within the field of truth of interest (AOIs) is properly classified.

The calculated elements include; overall accuracy, constant Kappa matrix and confusion. Accuracy was calculated by correctly collecting the amount of pixel count and dividing by the total number of pixels. The Kappa coefficient represents a strong agreement between categories of classified land cover, land cover and land use(Ephrem, 2008). Lies between o and 1, where zero represents a weak agreement and represents strong approval. Compatible with (Rahman, MM, Csaolovics,E., Koch B.,& Kohl, 2006) ,The kappa values are often categorized into three: the value greater than 0.8 represents a strong agreement, between 0.4 and 0.8 representing a moderate agreement and a value less than 0.4 representing a weak agreement. The computational relationship of the Kappa coefficient in the ERDAS software package is shown in the equation below;

$$\text{Kappa}\left(K\right)=\frac{po-pe}{1-pe} \text{ ---3}$$

Where,

Po = is the proportion of correctly classified classes

Pe = is the proportion of correctly classified classes expected by chance

3.3.4.4 Distance from facility

To determine the irrigated land near the facility (rivers), the Euclidean distance from the retailers was calculated using the DEM (30mx30m) and reclassified (Fig. 3.3). The re-categorized distances were then used to analyze the weighted overlay in conjunction with completely different maps.

3.3.5 Developing try wise comparison Matrix

Saaty (2008) describes the AHP (matrix process hierarchy) as a matrix in which rows and columns contain equivalent parameters. Once the matrix is organized, a score of one to nine is selected and allocated to each factor. The top-level factor indicates that the row was much necessary from the column. The diagonal matrix is assigned one degree. In the column that precedes it, the value within the corresponding column below the country line was simply reversed to the results in the corresponding row.

The result in the matrix is the basic measure of judgment, which means 1 equal, 2 between equal and average, 3 moderate, 4 between moderate and strong, 5 strong, 6 between strong and very strong, 7 very strong, 8 between very strong and extreme, 9 Extreme decimal provisions, 3.5, are allowed for fine tuning, and judgments greater than 9 may be entered, although they are suggested to be avoided. The consistency ratio calculation is described in the formula from the target calculation of the matrix.

$$CR=\frac{CI}{RI} \text{ -- 4}$$

Where:

CI = consistency Index and

RI= Random consistency Index.

Moreover, Consistency Index was computed as follows:

$$CI = \left(\frac{\lambda \max - n}{n-1} \right) \text{---5}$$

Where:

λ max = maximum Eigon value and

n= numbers of criteria in each pair wise comparison matrix.

The bigger the matrix is the higher the inconsistency level will be. The average random consistency index is tabulated below.

Table 3. 3 Average Random Consistency Index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.2	1.32	1.41	1.45	1.49

3.3.6 Weighting of irrigation Suitability factors for potential irrigable site

After the irrigation suitability was assessed for each factor and the characteristics of each parameter were developed separately, the overlay analysis was performed to create a single fit map using the model constructor in the toolbox and tools from spatial analysis tools. The irrigation adequacy factors taken into account in this study, such as slope factor, soil factor factor / use factor, and distance factor, were used as an input to the irrigation suitability model to find the most suitable surface irrigation area as shown in(Figure 3.3).

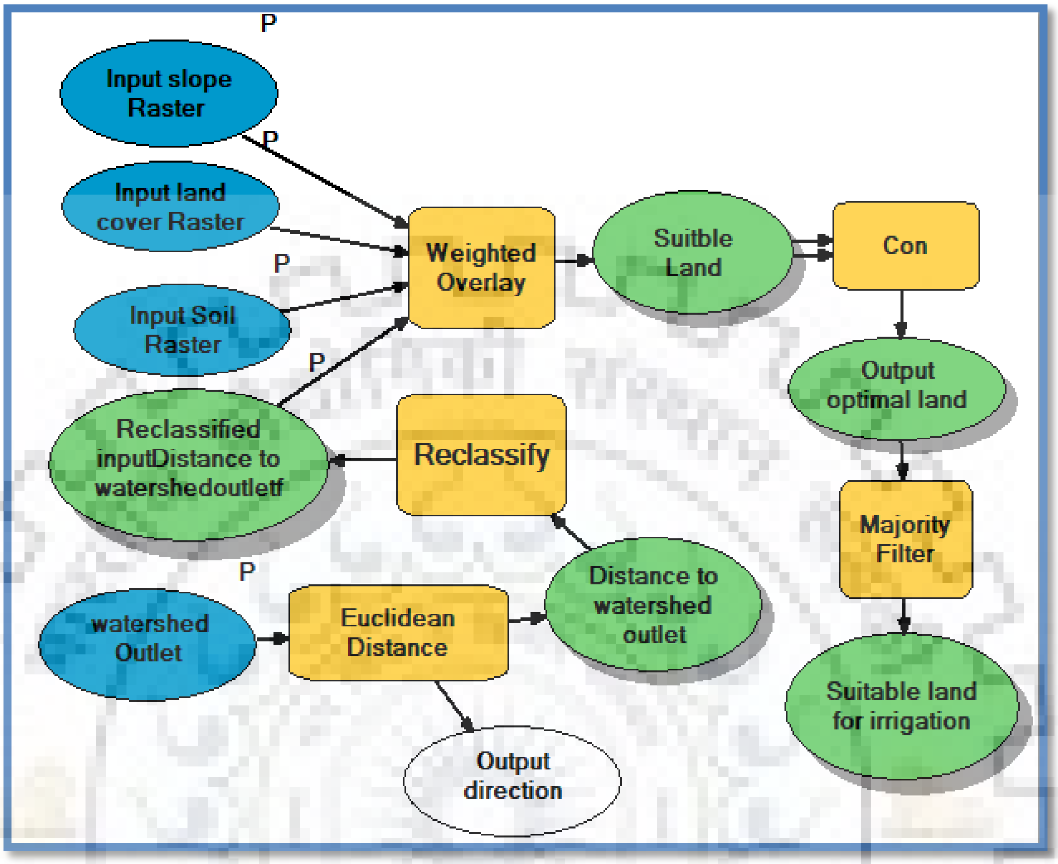

Figure3. 3Irrigation Suitability Model

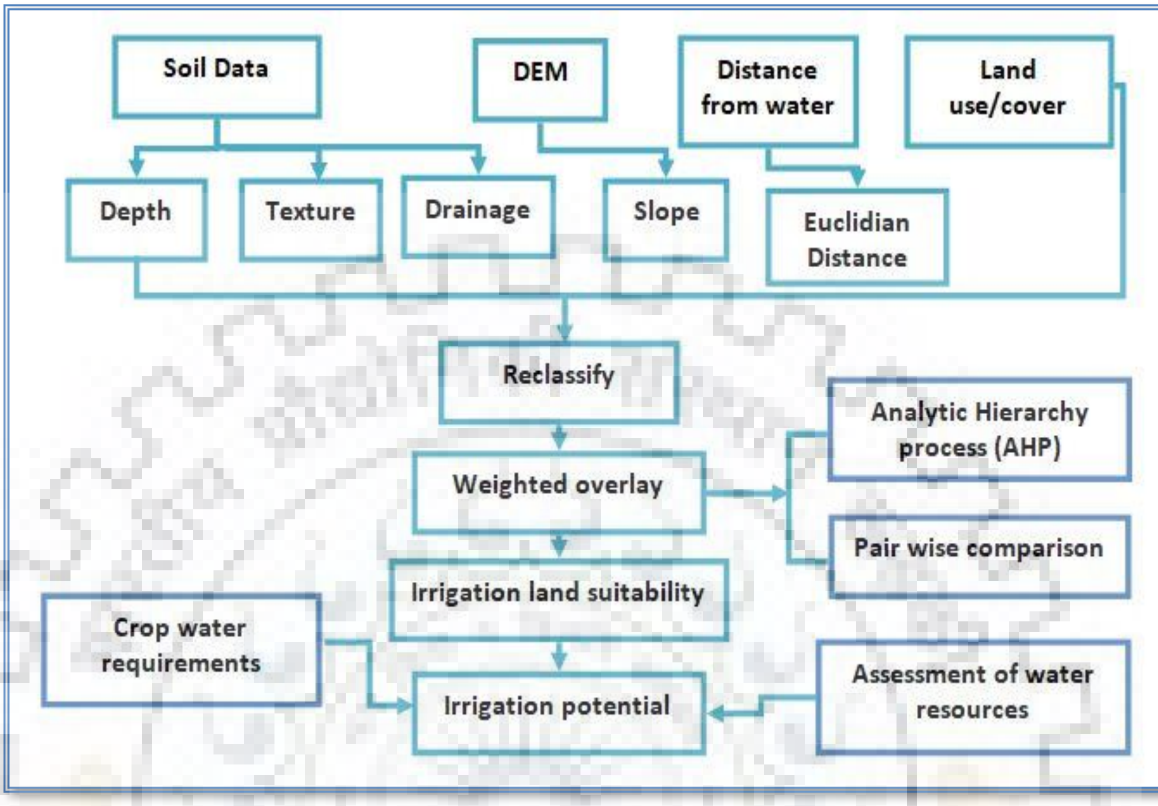

Figure3. 4Flow Diagram Method for Surface Irrigation Suitability Classification

Table 3.4 Soil Suitability rating

	soil depth factor		Soil texture factor		Soil drainage factor		Soil slope factor	
Description	depth cm	class suitability	texture	class suitability	drainage	class suitability	slope	Class suitability
Deep	>100	S1	sandy clay loam	S1	Well	S1	0-2	S1
Moderate deep	75-100	S2	Loam	S2	Moderate	S2	43136	S2
Slightly deep	50-75	S3	Silty clay	S3	poor	S3	43228	S3
Shallow	25-50	N1			Very poor	N	>8	N1
Very shallow	<25	N2						N2

3.3.7 Assessment of irrigation water requirements

In order to estimate irrigation water requirements for selected crops in irrigated locations,

3.3.7.1 Crop evapotranspiration (ETc)

according to (FAO, 2001) Etc can be derived from ETo using the following equation;

$ETc = KcxETo$ --6

Where, Kc is crop coefficient

Crop Evaop- transpiration under non standard condition.

This refers to growth of crops under non-optimal conditions.

3.3.7.2 Reference evapotranspiration ETo

This is ETo rate from a reference plant e.g. maize or grass, not short of water and is denoted as ETo. The ET of other crops can be related to the ET of the reference plant. ETo is a climatic parameter as it is only affected by climatic factors. It was calculated by using FAO penman-Montheith method with the help of CROPWAT 8.0 software program.

3.3.7.3 A cropping pattern

The major crops growth in the area and their areal coverage was first identify from ministry of agriculture and food security. Since each crops had its own water requirements, crop patterns such as the panting date, crop coefficient data files including Kc values, growth stage days use as an input to estimate crop water requirement.

3.3.7.4 Net irrigation water requirement (NIWR)

Net irrigation requirement/depth of evapotranspiration need of the crop minus effective precipitation According to (FAO, 2002)net irrigation requirement can be described in equation.

$$NIWR = ET - PE \text{ --7}$$

Following USDA (1993) and converting the inputs from inches to mm,

$$Peff = 25.4sF\left(0.04931p^{0.82416} - 0.11565\right)x10^{0.000955ETc} \text{ ------------------------8}$$

SF is soil factor and was estimated using equation

$$SF = \left(0.531747 + 0.011621xD - 8.943x10^{-5}xD^{2} + 2.321x10^{-7}D^{3}\right) \text{------------ 9}$$

Where: D is the usable soil water mm equivalent to approximately half the available water capacity.

3.3.7.5 Gross irrigation water requirements GIWR

It is net irrigation requirement divided by irrigation efficiency. Gross irrigation water requirement as described in(FAO, 2002) is given in equation

$$GIWR = \frac{NIWR}{E} \text{---10}$$

Irrigation efficiency accounts for losses in storage and distribution systems, losses in application systems as operation and management losses

CHAPTER IV

4 RESULTS AND DISCUSSIONS

4.1 WATERSHED DELINEATION

The delineated watershed of upper Nile state showed in (figure 4.1) cover a total area of around 61254.93 Km^2. River Nile crosses the watershed.

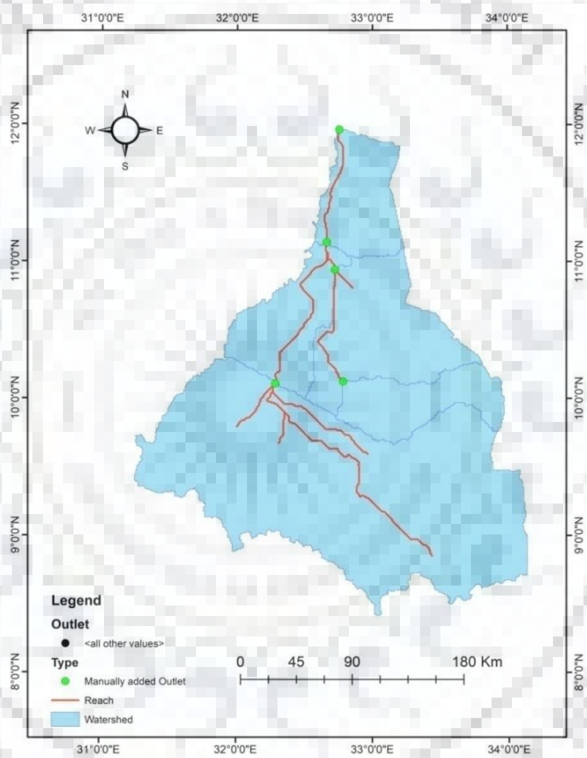

Figure 4. 1Upper Nile State watershed map

4.2 CLIMATIC DATA ANALYSIS

4.2.1 Climate parameters

The climate data used for the irrigation analysis are rainfall, Minimum and Maximum temperature, wind speed, sunshine hours, and relative humidity as described below in (Table4.1).

Table 4.1 (34 years) (1979-2013) monthly average minimum and maximum temperature, Wind speed, relative humidity, and sunshine hours for Malakal Meteorological station

Month	Tmax	Tmin	Tmean	Wind (m/s)	RH%	Sunshine hour
JAN	37.6	22.2	29.9	2.8	20	9.5
Feb	40.1	23.8	31.95	2.8	10	9.4
MAR	42.3	25.4	33.85	2.4	20	8.4
APR	42.1	26.7	34.4	2.2	30	8.7
MAY	37.7	26	31.85	2.3	50	7.4
JUN	34.5	23.8	29.15	2.1	70	5.6
JUL	31.7	21.9	26.8	1.7	70	4.9
AUG	31.7	21.2	26.45	1.6	70	5.5
SEP	34.5	21.4	27.95	1.7	70	5.9
OCT	36.8	22.3	29.55	1.7	60	7.2
NOV	38.8	22.3	30.55	1.9	30	9.4
DEC	375	22.1	29.8	2.6	20	9.6
Average	37.1	23.3	30.2	2.2	40	7.6

4.2.2 Precipitation

Annual average rainfall for Malakal, Kodok, Mulet and Renk stations were 770.28mm, 720mm, 801.7 and 519.3 mm respectively (Figure 4.2).

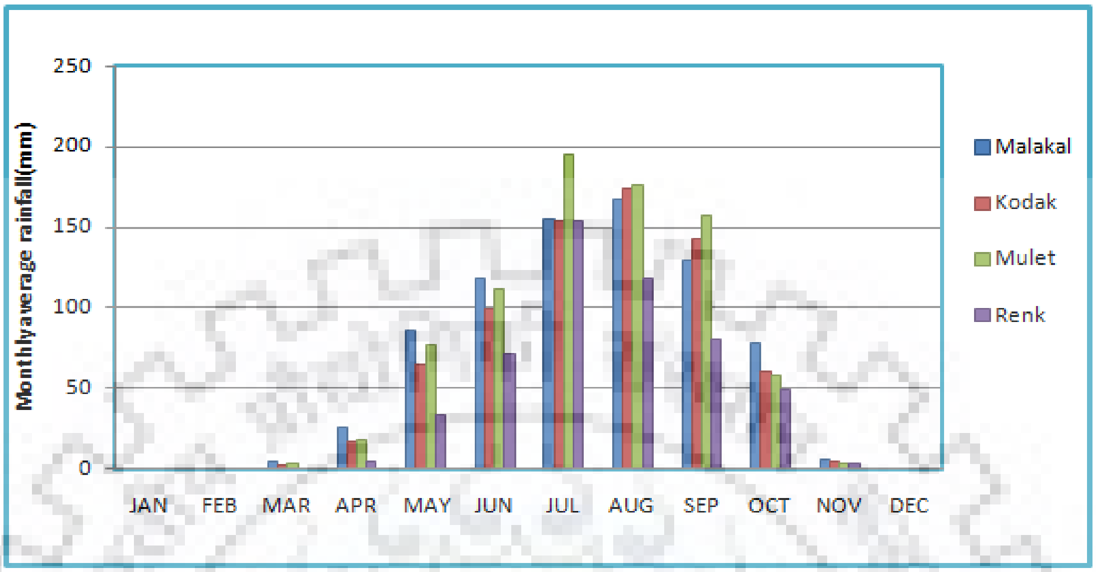

Figure 4. 2 Monthly average rainfall of metrological stations

From the bar graph shown in (Figure 4.2), high rainfall was recorded during May to October whereas the lower rainfall was recorded during November to March in all stations. There is low variation of rainfall distribution within stations in the study area.

4.3 EVAPOTRANSPIRATION PARAMETERS

4.3.1 Temperature

The mean annual minimum and maximum temperatures recorded at Malakal meteorological stations were 23.3°C and 37.1°C respectively whereas the mean annual temperature of the station was about 30.2°C. The mean monthly daily temperature was calculated as the average of the maximum and minimum temperatures (Figure4.3).

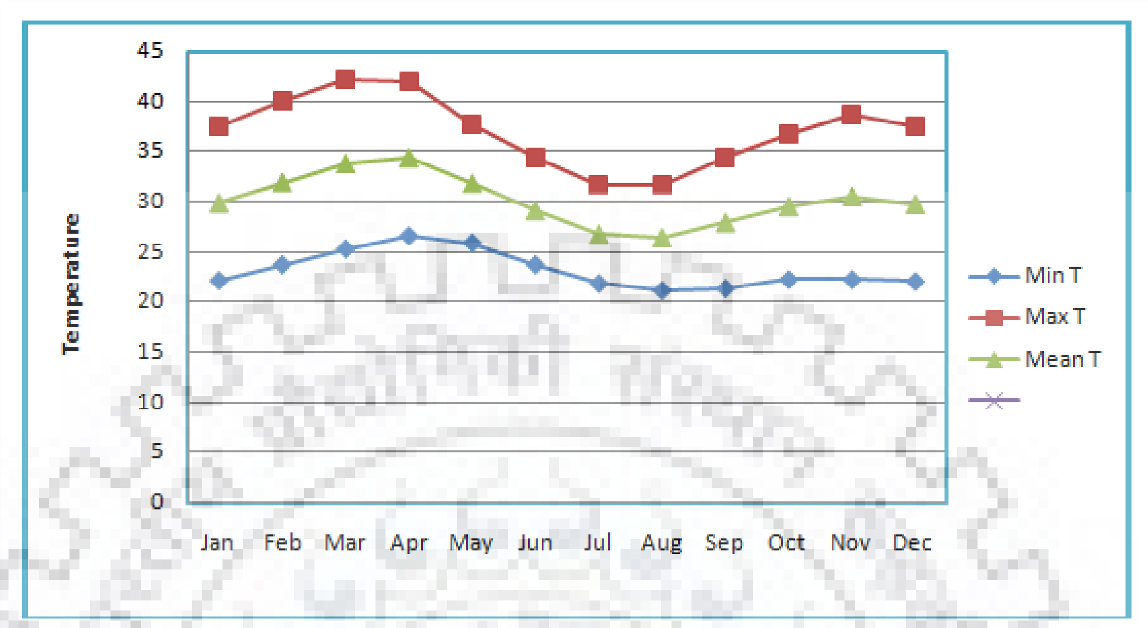

Figure 4. 3Mean monthly temperatures at Malakal station

4.3.2 Wind speed

Wind characteristics such as wind velocity, frequency, and direction of winds are important regarding to selection of irrigation methods, the rate of transpiration of crops. The average wind speed taken at 2m height was observed as 2.2 m/s (Table 4.1).

4.3.3 Relative humidity

Relative humidity was one input parameters in ET calculation. The 35 years (1977-2012) average daily relative humidity taking from Malakal meteorological station was 40% (Table 4.1).

4.3.4 Sunshine hours

The maximum sunshine hour was observed in the Malakal meteorological station is December (Average sunshine 9.6) and the month with least sunshine was July (average sunshine 4.9) (Table 4.1)

4.3.5 Data consistency

The double mass curve resulted from the consistency analysis of all stations in the study area were found to be consistent. The double mass curve analysis is shown in the (Figure 4.4), which is virtually an unbroken straight line with strong direct correlation (r^2 =0.997) between the cumulative rainfall recorded at Malakal gauge station and the cumulative rainfall average of the three neighboring stations. This indicates that the rainfall data recorded at Malakal rain gauge station was consistent although the points scatter slightly on both sides of the line (James, K.S. and Clayton, 1960). The double mass curve for other stations is given in Appendix Figures 1, 2, and 3 respectively).

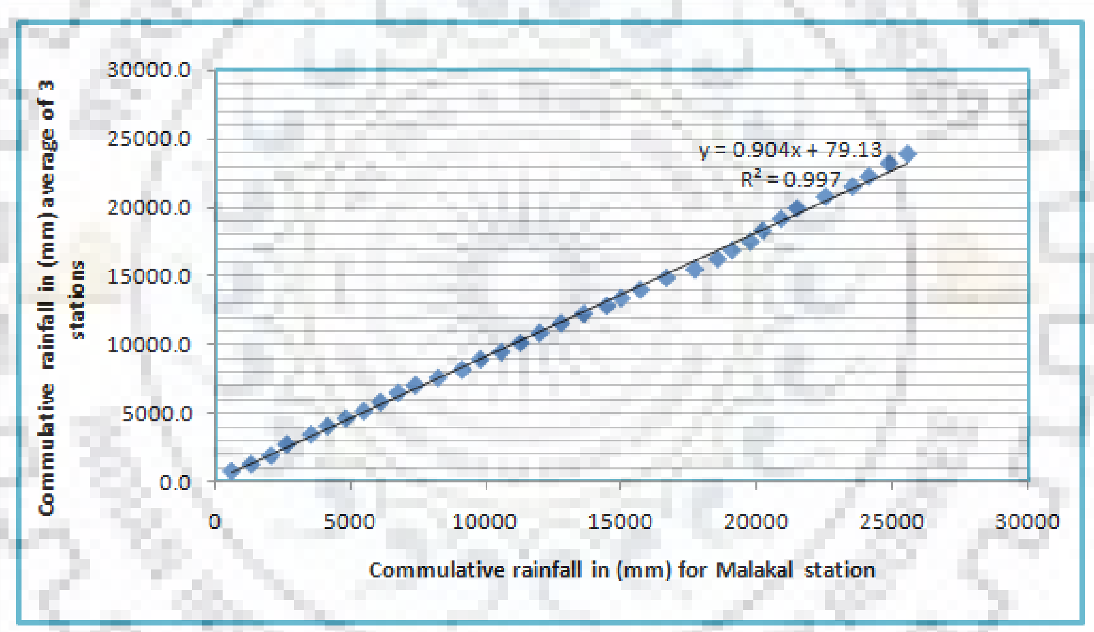

Figure 4. 4 Double mass curve of Malakal rain gage station

4.4 IRRIGATION SUITABILITY EVALUATION

The results of the irrigation suitability factors are presented in the following sections;

4.4.1 Suitable Slope

Slope is very important factor and critical limiting irrigation implementation even if other evaluation parameter like land cover, suitable soil, water availability, and agro-climatic conditions are suitable. The slope was derived in the study area from DEM

The slope of the study area was derived from the DEM 30- meter by using Arc GIS 10.4 spatial analyst tool. Then, on spatial analyst tool reclassified digital map of slope in percent was produced, as presented in (Figure4.5), the final slope suitability map was developed accordingly.

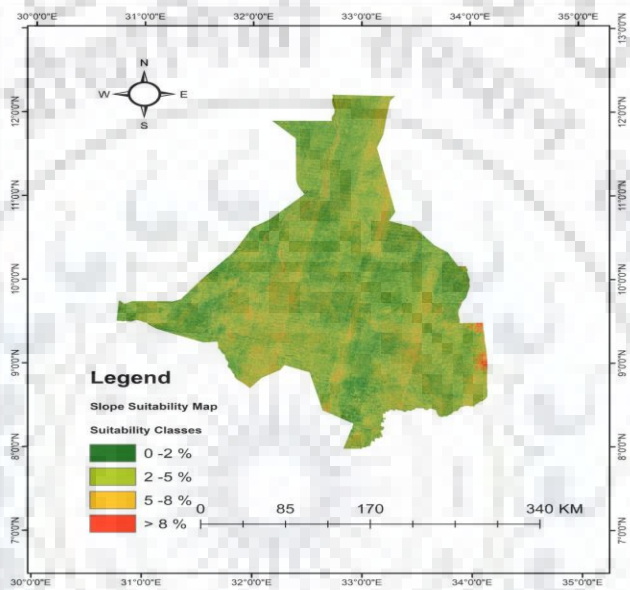

Figure 4.5 Slope Suitability Map of Study Area for surface Irrigation

The slope of the study area was classified in four appropriate seasons (S1, S2, S3 and N), based on FAO's suitability category in irrigated land (Table 4.2), approximately 97.9% of the study area of 76276Km2 was classified as appropriate Very marginal condition suitable for surface irrigation. 2.06% of the area (covering an area of 1600.8 sq km) is still inadequate. Thus, the majority of the study area is highly to marginally suitable for surface irrigation in terms of slope suitability.

Table 4.2 Slope Suitability range of the study area for surface irrigation

Slope range (%)	Area in Km^2	% of Total area	Suitability classes
0-2	29572	37.97	S1
2-5	33550	43.08	S2
5-8	13154	16.89	S3
<8	1600.8	2.06	N
Total	77876	100	

4.4.2 Soil Suitability

The main soil groups identified in this study are: Chromic Vertisols, Pellic Vertisols, Mollic Glysols, Calcric Fluvisols, Eutricl Nitosols Ferrric Luvsiols and Humic Cambisol as shown in Figure 4.6. A summary of the soil suitability classification results ispresented in Table 4.3

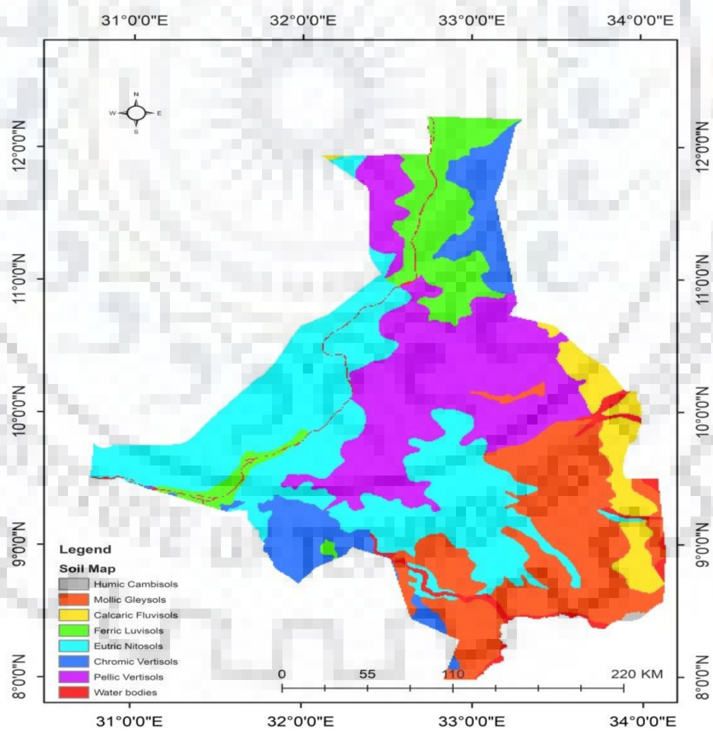

Figure 4.6 Study Area Soil Map classification

The results of this analysis indicate that the study area can generally be classified into three categories suitable for irrigation depending on soil suitability as a factor:

S1 (very suitable) S2

(Medium suitable)

And N (Inappropriate)

The, Humic cambisols, Giulysol mollic, ferric levisols and Nitosols Eutric cover an area of 6937 km2 representing 89.04% of the total area and have been classified as highly suitable for surface irrigation. These soils are characterized by deep soils, good drainage conditions,clay loam, loam, sandy-clay and clay texture respectively.Calcaric Fluvisols and pellic vertisols are classified as S2 (medium suitable class) and both have optimal surface irrigation system conditions in that all factors predict that both are limited by moderate drainage

In general, about 10.87% of the land in the study area (8477.6 sq km) can be classified as moderately suitable for surface irrigation. This soil is classified as S2 due to land-limiting factors for specific use based on FAO in 1979. However, S2 can be transferred to S1 using the most appropriate irrigation methods such as sprinkler irrigation and drip irrigation in these soils.

Table 4.3 Soil Suitability Classification result for surface irrigation

Soil type	Soil map unit	Texture	Depth(cm)	Drainage	Irrigation suitability	Area	Area%
Humic Cambisols	Bh	Clay Loam	360	well	S1	24.17486	0.03
Mollic Gleysols	Gm	Loam	360	well	S1	14060.98	18.06
Calcaric Fluvisols	Jc	Loam	140	Moderate	S2	1557.014	2.00
Ferric Luvisols	Lf	Sandy-Clay-Loam	360	well	S1	2.197714	0.00
Eutric Nitosols	Ne	Clay	246	well	S1	13.18629	0.02
Chromic Vertisols	Vc	Clay	250	well	S1	55266	70.97
Pellic Vertisols	Vp	Clay	100	Moderate	S2	6920.6	8.89
Water body	WBD	_			N	31.38279	0.04
Total						77876	100.00

However, the study confirms that there is no land in the study area containing soil types that can be classified as S3 (marginal event) for surface irrigation. Therefore, the area covered by the water body was classified as N (an inappropriate category). In general, land under category N accounted for 0.04% of the total area of study (31.38279Km2). (Figure 4.7) shows the soil suitability map for the study area.

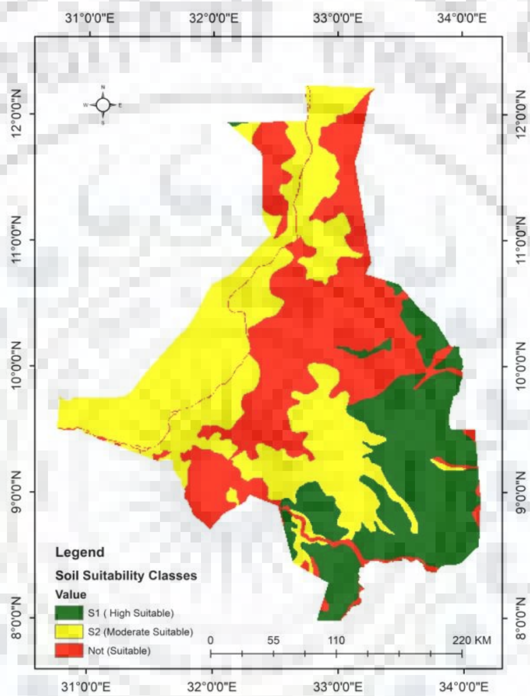

Figure 4.7 Soil Suitability Map of the Study Area

4.4.3 Land cover/use evaluation

In the study area nine lands cover/use classes were identified i.e. Shrubs lands, Agriculture land, bore land, Herbaceous land, tress land, crop land, urban land, flood land, and water bodies and are presented in Fig.4.8 These categories of land sat_8 were derived based on the unclassified classification with a total accuracy of 84% and Kappa 0.8039, indicating that the land cover / use classification has a strong agreement according to.(Wijedasa, Sloan, Michelakis, & Clements, 2012).

Table 4.4 Classification Accuracy report of land use/cover

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy	Kappa(K^) Statistics
Unclassified	0	0	0	---	---	0
Water Bodies	1	1	1	100.00%	100.00%	1
Flood land	1	1	1	100.00%	100.00%	1
Urban	35	30	18	66.67%	100.00%	1
Tree land	27	34	21	66.67%	40.00%	0.3182
Herbaceous land	9	9	9	100.00%	83.33%	0.7917
Crop land	23	23	23	100.00%	100.00%	1
Agriculture land	25	25	25	100.00%	100.00%	1
Shrubs land	9	9	9	100.00%	100.00%	1
Bore land	20	18	14	56	77.78	0.7422
Totals	150	150	121			

Overall rating accuracy = 84%

STATISTICS Kappa General = 0.8039

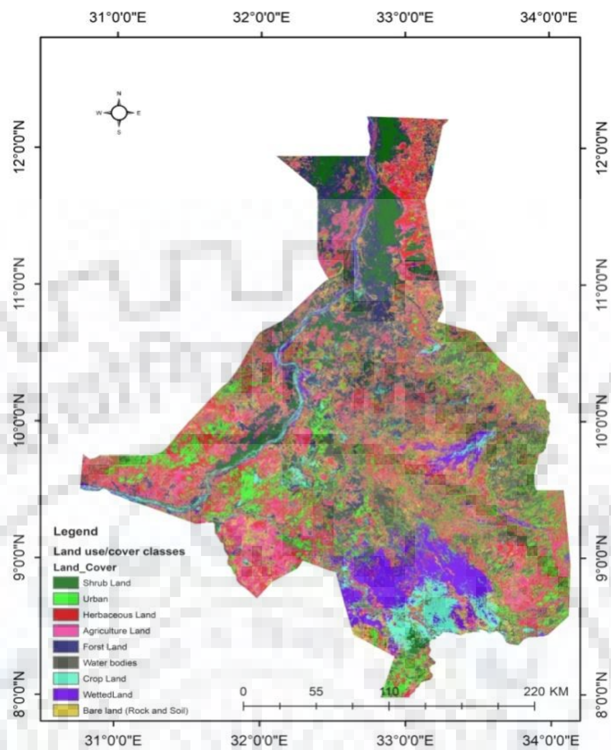

Figure 4.8 Land cover/use classes of the study area

Table 4.5Area Coverage of land cover/use classes of the study area

Land cover type	Area inkm^2	Percentage %
Herbaceous Land	5752.24	7.39
Shrubs land	11191.8	14.38
Agriculture land	12082.6	15.52
Bore land	3698.74	4.75
Tress Land	11487.7	14.76
Crop Land	11715.7	15.05
Urban	10076.3	12.94
Flood Land	6217.69	7.99
Water Bodies	5633.08	7.24
Total	77855.85	100

Reference was made to land use in FAO, cover assessment, agriculture and crop land use , which were classified as highly suitable for irrigation for surface irrigation with a total area of 23,798.3 km2 covering 30.57% of the study area.. Flood and herbaceous lands were classified as moderate suitable cover area of 11969.9 (15.37%), shrubs, tree and bare lands were classified as marginally suitable which accounts an area of 26378.2 (33.88%) and water bodies and urban were classified as land not suitable for irrigation covering area of 15709.4 (20.18%) of total land cover/use of the study area they consider as restricted for irrigation, as in (Table 4.6).

Table 4.6 Land use/cover suitability classes

S. No	Land use/cover	Area Km^2	Suitability class	Area%
1.	Agriculture land/crop land	23798.3	S1	30.57
2.	Flood land/ herbaceous land	11969.9	S2	15.37
3.	Shrubs land/ Tree land/ bare land	26378.2	S3	33.88
4.	Water bodies/urban	15709.4	N	20.18
	Total	77855.9		100.00

4.5 LAND SUITABILITY FOR SURFACE IRRIGATION

In order to find the potential land for irrigation, weighting of Suitable irrigation factors such as slope, soil, land cover / use and distance of water supply are required For weighed overly analysis the weight of each factor is needed. To do that irrigation factors is compared pair wisely. Based on the relative importance of each factor the scoring is given in the below (Table 4.7).

The following steps provide a good approximation of irrigation factor priorities:

- ✓ Collect the values in each column of the wise comparison matrix of the pair.
- ✓ Divide each element in the couple matrix by the sum of its column. The resulting matrix is referred to as the wise matrimonial matrix.
- ✓ Calculate the average elements in each row of the resident matrix.

These averages provide an estimate of the relative priorities of the elements being compared. Weight ratio was calculated by multiplying the mean of each row by 100 (Table 4.8).

Table 4.7 pair wise comparison for surface irrigation suitability

	Slope	Soil	Land use	Water distance
Slope	1	3	7	9
Soil	0.33	1	5	7
Land use	0.14	0.2	1	3
Water distance	0.11	0.14	0.33	1
Sum	1.58	4.34	13.33	20

Table 4.8 Normalized table for pair wise comparison score for irrigation suitability factors

	Slope	Soil	Land use	Water distance	Weight	%
Slope	0.632911	0.691244	0.525131	0.45	0.574822	57.48
Soil	0.208861	0.230415	0.375094	0.35	0.291092	29.11
Land use	0.088608	0.046083	0.075019	0.15	0.089927	8.99
Water distance	0.06962	0.032258	0.024756	0.05	0.044159	4.42
Sum	1	1	1	1	1	100.00

4.5.1 Consistency ratio

Consistency was calculated through the following steps:

Multiply each value within the initial column of the judicious use comparison matrix according to the relative priority of the underlying element that was considered. Same procedures for different things, add values across rows to get a vector of named values (weighted weight)

$$0.574822 = \begin{bmatrix} 1 \\ 0.33 \\ 0.14 \\ 0.11 \end{bmatrix} + 0.291092 \begin{bmatrix} 3 \\ 1 \\ 0.2 \\ 0.14 \end{bmatrix} + 0.089927 \begin{bmatrix} 7 \\ 5 \\ 1 \\ 0.33 \end{bmatrix} + 0.044159 \begin{bmatrix} 9 \\ 7 \\ 3 \\ 1 \end{bmatrix} = \begin{bmatrix} 2.6475 \\ 1.07083 \\ 0.54195 \\ 0.17615 \end{bmatrix}$$

Divide the weather of the vector of weighted sums by the corresponding priority value as within the below step

$$\begin{bmatrix} 2.4705 / 0.574822 \\ 1.07083 / 0.291092 \\ 0.54195 / 0.089927 \\ 0.17615 / 0.044159 \end{bmatrix} = \begin{bmatrix} 4.2382 \\ 3.4401 \\ 6.0265 \\ 3.7504 \end{bmatrix}$$

Then the average of the values computed in step 2 is donated as lambda ($\lambda \max$)

$$\lambda \max = \frac{4.2382 + 3.44007 + 5.787 + 3.7504}{4} = 4.25943$$

Calculate consistency index (CI)

$$CI = \frac{\lambda \max - n}{n-1} = \frac{4.25943 - 4}{4-1} = 0.086$$

Where n is the number of elements that have been compared to irrigation suitability factors.

Calculate consistency ratio (CR)

CI = 0.086

Where RI = 0.9

$$CR = \frac{CI}{RI} = \frac{0.086}{0.9} = 0.0955 < 0.1$$

Based on recommendation by Saaty, 1990 the degree of consistency exhibited in the pair wise comparison matrix for comfort is acceptable.

4.6 IRRIGATION LAND SUITABILTY

Based on the analysis of physical parameters, a qualitative land assessment of irrigation suitability indicates that the majority of the study area has been identified as highly suitable for surface irrigation with regard to the slope, soil types, land cover / use and distance of water from the command area. . Finally, the results of the irrigation suitability analysis involving weighting values for each data indicate that a large part of the study area has been classified under suitable conditions for surface irrigation applications with 27.36% (19595.34 sq km) of the total area. (S) And 61.49% (44045.07) were classified as moderately suitable (S2), while 11.16% (7992.901Km2) of the region was known to be marginally suitable for surface irrigation development (Figure 4.9)

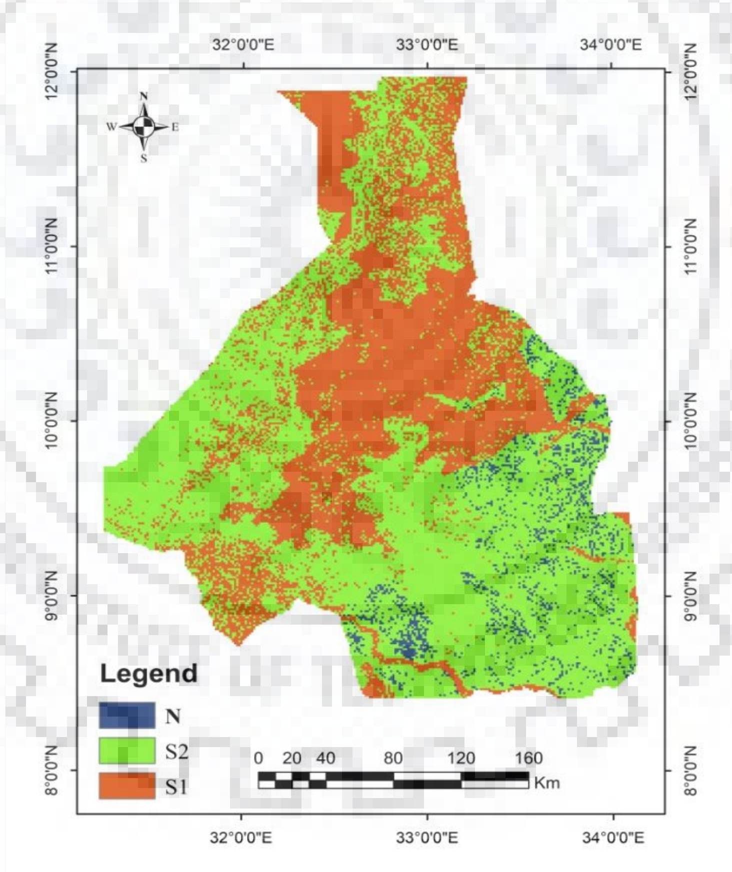

Figure 4.9 Surface irrigation land suitability map of the study area

Table 4.9Final Suitable Land for surface irrigation

S. No.	Area(Km^2)	Area%	Suitability Class
1	19595.34	27.36	S1
2	44045.07	61.49	S2
3	7992.901	11.16	N
Total	71633.311	100.00	

4.7 IRRIGATION WATER REQUIREMENTS

The total irrigation water requirements for four selected crops were calculated in the potential irrigated areas identified each month. (Table 4.10) provides monthly aggregate conditions for irrigation water to be met from the Nile River in the Malakal basin. The result showed that in the months of June, July and August, the need for irrigation requirements was higher than in other months.

Based on the (FAO, 1997b) recommendations on the irrigation efficiency of different irrigation schemes, irrigation efficiency for upper Nile state (South Sudan 36b zone) is given as 50% therefore; the annual total gross irrigation water requirement was found to be 3.4m3/s for Malakal gauge station.

Table 4. 10Irrigation water requirements for selected four crops

		Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mean Eto(mm/day)			3.01	2.97	3.68	4.33	4.26	3.76	3.38	3.50	3.67	3.81	3.43	2.93	42.73
Eff. RF(mm/month		Crops	0.00	0.20	4.20	20.30	69.00	94.40	123.80	133.80	103.80	62.90	5.00	0.20	617.6
ETc (mm/month)		Sorghum	0.00	0.00	0.00	0.00	27.80	67.60	95.90	88.20	21.40	0.00	0.00	0.00	300.90
		Maize	0.00	0.00	0.00	0.00	27.90	78.30	116.20	102.10	18.90	0.00	0.00	0.00	343.40
		Groundnut	0.00	0.00	0.00	0.00	36.80	72.80	113.70	114.50	41.10	0.00	0.00	0.00	378.90
		Tomato	0.00	0.00	0.00	0.00	53.10	123.40	118.50	121.80	118.80	26.40	0.00	0.00	562.10
		Sorghum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Maize	0.00	0.00	0.00	0.00	0.10	10.70	20.30	13.90	0.00	0.00	0.00	0.00	45.00
		Groundnut	0.00	0.00	0.00	0.00	8.90	0.00	0.00	12.40	22.20	0.00	0.00	0.00	43.50
NIR(mm/Month)		Rice	0.00	0.00	0.00	0.00	16.30	50.60	4.80	7.30	77.70	26.40	0.00	0.00	183.10
Area (ha)															
TNIR(Mm^3)	5670	Sorghum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1967	Maize	0.00	0.00	0.00	0.00	0.00	0.21	0.40	0.27	0.00	0.00	0.00	0.00	0.89
	840	Groundnut	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.10	0.19	0.00	0.00	0.00	0.37
	1150	Rice	0.00	0.00	0.00	0.00	0.19	0.58	0.06	0.08	0.89	0.30	0.00	0.00	2.11
		Sorghum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Maize	0.00	0.00	0.00	0.00	0.00	0.42	0.80	0.55	0.00	0.00	0.00	0.00	1.77
		Groundnut	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.21	0.37	0.00	0.00	0.00	0.73

GIR (Mm^3) 50% efficiency	Rice	0.00	0.00	0.00	0.00	0.37	1.16	0.11	0.17	1.79	0.61	0.00	2.27	6.48
	Sorghum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Maize	0.00	0.00	0.00	0.00	0.00	0.16	0.30	0.20	0.00	0.00	0.00	0.00	0.67
	Groundnut	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.08	0.14	0.00	0.00	0.00	0.28
GIR (m^3/s)	Rice	0.00	0.00	0.00	0.00	0.14	0.45	0.04	0.06	0.69	0.23	0.00	0.85	2.46

4.8 IRRIGATION POTENTIAL AT RIVER BAISN AT MALAKAL GUAGE STATION

It is necessary to examine the availability of irrigation water for the production of crops in the study area, after evaluating the irrigation able lands. The average annual flow of the Nile River at the cubic plant station was estimated at 1043.65Mm3. The irrigation potential of the sub-river basin was obtained by comparing the water demand for the four crops normally grown in the study area, given the appropriate land for irrigation and monthly management which is 80% reliable from the Nile River at Malakal Station (Table 4.11). The results of this analysis showed that the monthly flow available for river flows was greater than irrigation water requirements for all crops in their own suitable area.

Table 4. 11Comparing of irrigation demands and available river flows at Malakal gagged station for four selected crops

GIWR(m^3/s)						
Month	Sorghum	Maize	Groundnut	Rice	Sum	80% dependability Monthly flow at Malakal sub -basin (m3/s)
Jan	0	0	0	0	0	32.53
Feb	0	0	0	0	0	28.13
Mar	0	0	0	0	0	22.43
Apr	0	0	0	0	0	22.07
May	0	0	0.06	0.14	0.2	22.75
Jun	0	0.16	0	0.45	0.61	28.82
Jul	0	0.3	0	0.04	0.34	33.44
Aug	0	0.2	0.08	0.06	0.34	37.5
Sep	0	0	0.14	0.69	0.83	41.99
Oct	0	0	0	0.23	0.23	42.82
Nov	0	0	0	0	0	44.61
Dec	0	0	0	0.85	0.85	39.71

Looking into the suitability map of study area, most of the areas were classified under fairly high categories. Since the water will be available throughout the year from the Nile River, there is no real boundary for the irrigated area. However, all the water required for irrigation water needs to be pumped from the river, and although the slope difference is not significant, this has a significant impact on water transport costs. Therefore, in order to enhance the efficiency of irrigation water, it is an option to focus more on sprinkler irrigation as well as drip irrigation.

CHAPTER VI

5 SUMMARY AND CONCLUSION

5.1 SUMMARY

A study was carried out to assess the irrigation potential of the Upper Nile State located in the northern part of Southern Sudan. The total coverage of the area obtained through watershed demarcation is approximately 61254.93 square kilometers. It has been carried out to assess and assess the appropriate irrigation lands and irrigation potentials of Upper Nile State and develop final suitability map.

The main irrigation factors considered for this study were slope, soil physical properties (depth, texture, and drainage), land cover / use, distance from the water facility, and the FAO-supported analysis of surface irrigation compatibility such as S1, S2, S3, N1, and N2. The results of the irrigation adequacy analysis indicate that 97.9% of the slope, 89.04% of the soil and 79.82% of the land cover / use of the area of study known to be highly variable are marginally suitable for surface irrigation suitability while the remaining 2.06% 20.18% of land cover / use of the study land as unsuitable for surface irrigation.

This study revealed that the first part of the area may be suitable for irrigation development. These factors were weighted using the weighted overlap in the ARC GIS. A suitable irrigation map was developed. Potential irrigation sites for surface irrigation were obtained by 27.36%, 61.49%, and 11.16% for S1, S2, and several N. The results revealed that most of the area suitable for the development of surface irrigation (88.85% of the total area) with reference to the slope, type of soil, cover / land use, and distance from the stones of water.

Irrigation water was calculated for selected crops according to the methods of FAO's Panamanian Monteth. The CROPWAT 8.0 models were used to calculate the irrigation water needs of selected crops. The results indicated that the total demand for irrigation water on sorghum, maize, groundnuts, and rice in a known area of command varied and supported information from the meteorological station.

Quantitative comfort of water resources was considered to analyze the appropriateness of water resources, and water was found to be available throughout the season from the Nile River.

The potential irrigation site was driven by checking the monthly total demand for irrigation water at a known irrigation site with the average monthly flow available to reach it. This indicates that there is no limit of irrigated land because water is accessible throughout the year from the Nile River, which means that the possibility of surface irrigation is prohibited in the area of acquiescence to irrigate along the Nile River.

5.2 CONCLUSION

Irrigation plays a very important role in improving rural income and in maintaining sustainable food security through improved agricultural production. However, this can be achieved by assessing available land and water resources for irrigation. Therefore, the possibility of irrigation of river watersheds can be identified in the study of policy decisions during the development of irrigation projects in the study area. However, based on the result obtained in this study, the following result is sent: -

- Surface irrigation potential was obtained by looking only at soil types, slopes, distance from water sources and land cover / use. However, the effects of other factors, such as water quality and environmental, economic, and social constraints, must be assessed to produce a reliable outcome.
- In this study, irrigation water requirements for specific cultivated areas were estimated by selecting only four crops. But for future research many crops must be selected to calculate the total irrigation requirements of the irrigation area identified.
- The calculation of irrigation water requirements and the assessment of water potential require the existence of accurate meteorological data and flows so that these data are carefully recorded at their own stations.
- The application of remote sensing and GIS was found to be useful in assessing land suitability and developing a description of land suitability for irrigation of potential resources in the study area.

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7 APPENDICES

Appendix. I monthly average precipitation of Malakal station (mm)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1977	0	0	0	0	140.2	107.7	100.6	132.6	39.1	77.6	0	0	597.8
1978	0	0	0.4	78.9	0	42.8	158.3	163.3	140.4	144.8	0	0	728.9
1979	0	4.5	5.8	53.1	210.7	188.2	45.9	88	106.6	9.9	12	0	724.7
1980	0	0	2	0.5	77.3	59.1	114.7	149.3	105.9	81.8	0	0	590.6
1981	0	0	11.6	18.7	100.4	193.7	215.7	205	109.7	41.5	0	0	896.3
1982	0	0.2	6.2	7	98.5	184	95.2	71.5	69.5	69.8	0	0	601.9
1983	0	0	0	0	75.7	123.2	63.3	180.8	158.5	72.8	6.3	0	680.6
1984	0	0	0	22	81.8	81.2	261.1	74.7	51.6	81.7	0	0	654.1
1985	0	0	0	10.4	120.5	73.4	137.7	149.8	59.6	59.9	4	0	615.3
1986	0	0	0	40	2.4	73.9	167.1	152.4	135.3	83	0	0	654.1
1987	0	0	0	6.5	67.8	200.2	100.7	157	84	11	14	0	641.2
1988	0	0	10.3	1	28	100.5	229.7	172.1	206.3	83.7	0	0	831.6
1989	0	0	7.5	5.3	135	106.8	153	243	77	158	5	0	890.6
1990	0	0	0	37	6	82.1	253.5	134.7	133.4	19	6	0	671.7
1991	0	0	0	22.7	183.9	127.9	213.6	76.8	66.3	73.6	0	0	764.8
1992	0	0	5	42	54	105	112	193	120	50	27	0	708
1993	0	0	0	82	111	105	115	132	136	36	0	0	717
1994	0	0	1.3	15.5	168.9	55.4	175.2	159.2	99.1	109.8	1.5	0	785.9
1995	0	0	3.5	18	106	206	212.5	98	104	79.5	7	0	834.5
1996	0	0	0	27.5	117.3	78.7	169.3	254.7	193.9	8.7	0	0	850.1
1997	0	0	4	48.7	39.1	83.2	130.7	0	46.5	181.7	0	0	533.9
1998	0	0	58.6	21.5	64	38	145.9	136.8	109.1	126.1	1	0	701
1999	0	7.9	0	23.1	150.8	199.1	152.8	147.7	172	112.1	0	0	965.5
2000	0	0	3.3	43.2	180	79.5	219	283.2	153.3	85.2	1	0	1047.7
2001	0	0	0	77.1	76.3	149.5	135.4	234.7	59.5	95.7	10.3	0	838.5
2002	0	0	4.3	0.4	30.9	43.2	140.9	96.2	59.7	131.3	24.2	0	531.1
2003	0	0	0	15.4	26.3	151.5	103.9	140.7	94.3	109.5	40.7	0	682.3
2004	0	0	0	26.1	32	78.6	67.4	177.9	32	45.6	0	0	459.6

2005	0	0	0	3.5	85.1	103.7	113.2	155	124.6	85.1	0	0	670.2
2006	0	0	0	0	38.2	94.8	49.5	190.3	151.1	66.6	0	0	590.5
2007	0	0	0	111	51	239.4	230.5	180.6	144.6	79.5	11.7	0	1048.3
2008	0	0	0	123	108.6	258.4	164.9	122.9	178	43.8	0	0	999.9
2009	0	0	0	10.1	13.8	101.9	85.6	114.8	170.6	100.4	0	0	597.2
2010	0	0	0.2	7.8	46.6	105.5	212.2	153.8	90.9	126.6	0	0	743.6
2011	0	0	0	0	92.1	103.1	139.9	129.3	138.3	87.7	0	0	690.4
2012	0	0	0.1	23.7	51.6	162.2	297.3	92.3	139.3	53.6	3.9	0	824
Average	0	0.2	5.2	25.4	86.2	118	154.8	167.3	129.7	78.6	6.3	0.3	770.28

Appendix. IIMonthly precipitation of Renk station (mm)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1976	0	0	0	4	18	87	194	82	89.5	22.5	34.8	0	531.8
1977	0	0	0	0	68	39	120	82	106	32	0	0	447
1978	0	0	0	9	5	94	152.5	107.2	77.8	39	0	0	484.5
1979	0	0	0	8	46	87.4	193.7	151.8	114	82.3	7.6	0	691.1
1980	0	0	0	0	15.1	190	184.2	78.9	67.3	17.6	0	0	552.9
1981	0	0	3.6	4.6	62.5	51.5	329.3	72.3	88.9	18.2	0	0	630.9
1982	0	0	0	0	57.9	7	122.4	151.4	76.8	52.6	0	0	468.1
1983	0	0	0	0	3.5	88.4	77.1	23.2	140	2.2	0	0	334.2
1984	0	0	0	0	56	19.5	99.8	75	32.7	42	0	0	325
1985	0	0	0	0	42.7	137	89.9	114	104	11	0	0	497.8
1986	0	0	0	3	0	58.1	143.4	97.4	68	53.7	0	0	423.6
1987	0	1.5	0	0	21.5	43	80.2	67.6	86.7	41.3	0	0	341.8
1988	0	0	3.8	0	28.7	129	51	144.9	196	11.8	0	0	565.2
1989	0	0	4.5	0	145.9	110	102.6	65.3	59.4	107.3	7.7	0	602.2
1990	0	0	0	9.2	1.5	13.3	137.2	85.1	38.7	17.3	0	0	302.3
1991	0	0	0	5	44.3	13.5	169.3	134.1	45	68.2	0	0	479.4
1992	0	0	0	0	21	59.4	161	232.4	63.2	103.7	0	0	640.7
1993	0	0	0	1.5	44.9	77	127	139.3	72.1	47.2	12	0	521
1994	0	0	0	0	33.5	78	258.8	175.9	89.3	0	0	0	635.5
1995	0	0	0	27	27	106	41.2	123.8	81	46.3	0	0	452.3
1996	0	0	0	0	85.8	112	48	154	117	42	0	0	558.8
1997	0	0	0	1.5	11.3	108	180.5	145.5	48.3	65.5	51	0	611.6
1998	0	0	7	5	17	22.3	255	261.5	95	52.2	0	0	715
1999	0	0	0	0	48.5	53.8	71	234	94.5	105	0	0	606.8
2000	0	0	0	0	26.3	56	214	125	22.5	47	0	0	490.8
2001	0	0	0	0	41	41	103.8	86.7	111	20	4	1	408.5
2002	0	0	0	0	64	11	290.7	76	30	81.3	0	0	553
2003	0	0	0	0	17	57	124	97	102	57	12	0	466.3

2004	0	0	0	23	23	84.3	110.3	82.1	113	36	12	0	484
2005	0	0	0	2	7	159	112.6	197	147	44	0	0	669
2006	0	0	0	0	58	50.4	207.6	93	113	115.5	0	0	637.8
2007	0	0	0	14	46	60.6	350.4	84.6	55	52.2	2.5	0	665.3
2008	0	0	0	31.6	13	76.7	159.9	94.9	86.4	48.6	0	0	511.1
2009	0	0	0	0	12.6	115	152.1	123.6	44.7	59.4	0	0	507.3
2010	0	0	0	0	3.2	8.9	79.8	122.6	26.7	63	10.2	0	314.4
2011	0	0.1	0	33.8	20.6	79.8	245.6	98.8	19.8	68	0.7	0	567.2
Average	0	0	0.5	5.1	34.4	71.7	153.9	118.9	81.2	49.2	4.3	0	519.3

Appendix. IIIMonthly precipitation of Mulet Station (mm)

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1979	0	1.3	0	1	160	126.6	265.6	365	90.5	17.8	0.5	0	1028.4
1980	0	0	0.7	5.1	21.3	92.8	236.1	74.5	37.2	44.9	0	0	512.8
1981	0	0	9.1	1.6	44.2	38.3	280	162	113.7	58.4	5.6	0	712.5
1982	0	0	0.1	5.6	144	57	154.5	314	86.6	57.4	0	0	819.5
1983	0	0	0	0.7	56.8	172.8	267.6	181	103.8	26.7	0	0	809.6
1984	0	0	0.2	12.4	39.9	42.1	127.9	53.2	171.7	1.2	0	0	448.6
1985	0	0	15.1	17.8	74.1	40.2	160.9	168	80.6	42.7	7.4	0	606.3
1986	0	0	0	1.2	0.9	43.9	156.1	156	99.4	142	0	0	600
1987	0	0.3	0.9	57.2	189	188.3	80.2	241	119.5	35.9	5.7	0	917.3
1988	0	0	7.8	0.4	40.8	136.7	203.4	158	254.4	38.2	0	0	840.2
1989	0	0	53.4	12.4	52.6	160.8	119.6	62.7	121.9	42.6	0.1	0	626
1990	0	0	0	5.2	53.4	46.6	352.3	149	140.5	30.1	0.8	0	777.9
1991	0	0.3	0.7	43.2	23.6	40.6	258.1	84.3	22	16	0	0	488.7
1992	0	0	0	5	25.5	51	328.3	225	146.6	44.3	0.1	0	825.8
1993	0	0	0	24.6	59.5	57.2	106.2	142	54	23.3	1.5	0	468.3
1994	0	0	0	0.9	115	32.9	166.6	184	127.8	10.3	0.2	0	637.6
1995	0	0	3.5	5.2	88.3	199.2	170	94.5	122.2	84.4	0	0	767.3
1996	0	0	36.9	3.4	124	156.4	174.3	251	171.3	33.3	0	0	950.9
1997	0	0	0.1	16.3	73.9	115.6	198.6	109	96.3	29.6	9	0	648.3
1998	0	0	2.7	8.5	36.8	55.8	127.4	258	65.5	31.1	1.1	0	586.4
1999	0	0	0	51.6	38.6	32.7	109.7	140	104.2	18.6	0	0	495.7
2000	0	0	0	63.5	184	20.4	59.5	105	48.5	18.6	5.5	0	504.9
2001	0	0	0	10.9	59.9	173.2	288.5	230	244.4	66.8	3	0	1076.5
2002	0	0	1.8	9.6	33.5	122.5	97.4	108	193.9	111	4.3	0	682.7
2003	0	0	0	1.7	24.1	160.2	179.5	164	386.1	60.7	11.1	0	987.4
2004	0	0	0	14.1	51.5	102.9	121.5	156	197.9	47.4	2.4	0	693.4
2005	0	0	1.9	8.7	66	228.1	186.9	141	84.8	38.9	0	0	756.2
2006	0	0	0	0.2	173	91.9	309.2	210	260.6	171	3.5	0	1220.4

2007	0	0	0	12.3	45.7	137	314.5	205	273.3	274	21.4	0	1282.9
2008	0	0	0	191.9	57.3	71.6	108.7	185	269.8	48.1	0	0	932.6
2009	0	0	0	30.9	35.5	208.2	200.7	228	343	75.7	4.2	0	1126
2010	0	0	1.8	0.2	43.7	161	138.2	180	317.6	89.1	6.2	0.7	938.4
2011	0	0	0.1	1.3	102	139	167.9	179	330.2	53.3	0	0	973.1
2012	0	0	0	1.8	325	223.1	442.1	249	140.2	58.5	17.8	0	1457.4
2013	0	0	0	2.4	49	167.1	191.8	256	98.9	89.1	6.6	0.2	860.5
Average	0	0.1	3.9	18	77.5	111.2	195.7	176	157.7	58.1	3.4	0	801.7

Appendix. IVMonthly precipitation of Kodak station (mm)

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1929	0	0	0	7	76	116	258	93	139	25	9	0	723
1930	0	0	0	28	65	93	72	166	51	77	0	0	552
1931	0	0	0	1	14	64	71	275	163	135	0	0	723
1932	0	0	0	17	47	148	196	188	215	112	0	0	923
1933	0	0	0	0	36	49	206	182	261	60	0	0	794
1934	0	0	0	13	95	69	202	180	103	20	16	0	698
1935	0	0	0	26	50	148	142	91	166	17	0	0	640
1936	0	0	0	105	20	103	151	155	36	53	0	0	623
1937	0	0	0	0	45	223	186	121	127	61	0	0	763
1938	0	0	0	26	9	112	129	168	157	104	3	0	708
1939	0	0	0	4	75	91	192	99	58	63	13	0	595
1940	0	0	0	1	54	27	218	74	75	24	0	0	473
1941	0	0	0	12	241	65	89	216	14	91	18	0	746
1942	0	0	0	0	174	36	126	230	213	14	0	0	793
1943	0	0	0	0	81	218	164	219	171	30	3	0	886
1944	0	0	32	76	73	48	144	182	144	140	0	2	841
1945	0	0	2	6	60	114	58	173	304	38	1	0	756
1946	0	0	0	14	78	142	117	146	83	76	8	0	664
1947	0	0	0	18	128	91	133	239	164	38	0	0	811
1948	0	0	0	0	42	97	123	132	271	18	0	0	683
1949	0	0	0	10	81	46	208	148	131	18	0	0	642
1950	0	0	0	26	28	95	198	231	52	53	0	0	683
1951	0	0	0	0	24	147	163	177	161	113	28	0	813
1952	0	0	0	6	38	51	141	186	112	20	0	0	554
1953	0	0	0	45	177	74	211	120	75	102	0	0	804
1954	0	0	0	21	23	90	170	132	264	76	0	0	776
1955	0	0	0	0	18	70	115	162	197	40	0	0	602
1956	0	0	0	1	24	95	30	280	168	103	0	0	701

1957	0	0	66	55	39	57	203	293	44	24	30	0	811
1958	0	0	0	55	58	201	132	186	40	54	0	0	726
1959	0	0	0	5	103	107	105	135	196	70	0	0	721
1960	0	0	0	6	28	44	303	98	101	46	0	0	626
1961	0	0	0	8	22	141	140	165	222	28	0	0	726
1962	0	0	2	1	31	135	184	318	125	91	16	0	903
1963	0	0	0	5	128	114	191	234	187	18	5	0	882
1964	0	0	0	3	38	63	78	76	173	123	0	0	554
Average	0	0	2.8	16.7	64.5	99.6	154.1	174	143	60.4	4.2	0.1	720

Appendix. VMonthly average river flow at Malakal (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1967	115.3	85	69.1	63.17	60.3	72	88.4	104.6	118.67	136	136.3	130.67	1179.63
1968	120.3	92	73.2	61.6	60.9	74	87.17	99.9	111	119	123.7	105.67	1128
1969	83.73	74	70.6	67.97	68.63	84	98.87	106.3	114.67	123	129	123	1143.57
1970	90.93	76	69.9	64.3	63.57	79	92.17	104.7	118.67	128	133	133.67	1154.4
1971	112.3	86	76.6	68.87	64.2	73	89.33	105.3	119.33	128	132	131.67	1186.6
1972	105.6	77	66.8	61.2	74.4	82	97.27	105.3	107	107	100.8	80.6	1065
1973	65.97	58	54.7	52.7	61.57	76	86.73	95.97	106.5	109	112.3	106.63	986.33
1974	78.87	62	56.2	53.53	56.93	75	88.6	100.4	109.08	118	122.5	117.82	1038
1975	85.67	65	59.9	57.3	58.53	72	85.43	96.53	111.67	126	132.7	129	1078.97
1976	118	83	66.4	61.6	62.87	79	89.1	97.93	105	111	115.3	107.33	1096.4
1977	76.17	63	60	58.17	55	72	89.2	98.73	111.67	114	117	111.67	1026.57
1978	91.83	65	59.9	59.37	70.53	82	91.47	100.3	107.67	114	116.7	114	1072.37
1979	99.93	82	71.2	64.53	67.57	82	95.93	108	117	121	119.7	93	1122.27
1980	74.13	65	60.9	58.93	61.57	81	89.1	100.4	108	114	117.3	98.4	1028.63
1981	68.37	60	56.9	56.53	61.43	72	82.53	95.6	109.67	121	114.3	112.67	1010.83
1982	71.87	64	58.9	55.77	56.23	65	75.97	90.17	98.87	104	104.3	81.37	926.17
1983	66.63	58	53.7	51.77	52.23	62	77.03	85.53	95.7	105	110.7	113.67	932.7
1984	93.83	70	59.9	57.07	57.83	69	76.8	98.2	103.33	107	99.43	66.1	959
1985	55.7	51	47.3	48.7	53.57	66	85.83	95.53	103.33	107	109	89.37	912.73
1986	60.53	53	50.4	48.93	48.63	54	75.03	89.17	96.2	100	91.9	60.1	828.4
1987	50.83	49	47.4	47.9	50.33	71	82.87	90.63	96.03	98.8	99.23	91	874.53
1988	59.03	52	50.3	45.63	48.07	65	88.43	98.33	109	124	123.7	126.67	990.17
1989	117.8	71	55	53.43	57.83	74	83	95.5	105.33	112	115.3	100.5	1041.27
1990	79.93	64	58.3	54.5	56	68	88.2	95.77	98.95	102	103.7	87.4	956.52
1991	60.3	54	52.6	53.17	59.3	71	97.03	108	113.67	119	122.3	119.33	1030.33
1992	86.07	69	60.7	56.43	60.97	68	87.4	95.73	105.33	111	116	118	1034.97
1993	103.7	76	61.2	62.6	68.57	84	95.17	101.1	105.33	109	109	100.77	1075.9
1994	71.83	61	56	53.27	58.7	73	87.03	103.5	114	118	117.7	107.33	1020.77

1995	80.13	59	54.3	54.2	57	66	86.53	94.53	101.83	107	104.7	96.77	961.22
1996	75.27	63	56.7	57.33	64.4	77	95.37	108.3	117	120	120	118.67	1073.35
1997	113.3	87	65.1	61.3	69.3	80	98.57	104.7	108.33	110	107.7	103.67	1108.8
1998	87.29	71	67.8	62.85	66.34	81	96.34	108.9	118.51	123	124.1	123.84	1130.4
1999	115.6	77	58.3	53.04	73.01	94	107.6	118.1	121.44	126	126.1	126.14	1196.04
2000	117.5	76	63.3	59.92	70.78	90	98.64	106	110.16	113	113.2	110.16	1129.13
2001	83.51	65	55.7	54.01	58.84	83	95.47	104.5	111.74	114	113.5	112.46	1051.06
2002	99.17	68	58.1	58.13	57.44	74	94.85	103.8	108.29	111	108.9	79.81	1020.35
Mean	87.14	68	60.1	57.21	60.93	75	89.57	100.4	108.83	115	115.6	106.36	1043.65
(m^3/s)	1009	788	695	662.2	705.17	865	1037	1163	1259.6	1328	1338	1231	12079.27

Appendix. VIMonthly maximum temperature of Malakal Meteorological station (^{o}c)

year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	37	41.1	42.8	42.4	36.8	34.5	31.3	30.8	34.6	37.5	39.7	36.7
1980	40	39.7	41.9	44.1	39.9	35.3	32.3	34.5	36.7	38.1	39.2	37.5
1981	39	40.2	41.3	42	37.4	37.1	32.8	31.6	33.8	37.9	38	38.1
1982	38	38.3	41.3	42.6	38.1	34.2	31.2	29.6	35	36	37.4	32.6
1983	34	39.4	40.6	43.2	39.6	35	32.3	29	33	34.2	38.7	37.1
1984	36	40.9	42.9	42.3	38	35.9	33.2	34	36.3	40.3	38.6	36.8
1985	40	36.5	40.9	39.7	35.7	34.5	31.7	32.1	36.3	38.6	38.2	37.1
1986	37	41.6	43.5	43.4	42.3	33.5	32.2	34.3	36.5	38.7	39.3	37
1987	38	41.2	42.4	40.3	35.2	34.1	34.1	33.3	36	37.9	39.4	37.1
1988	37	40.2	42.1	43.1	38.4	34.6	31.2	31.4	33.4	35.7	38.2	37.9
1989	34	36.9	40.6	42	36.7	35	31.9	34.1	35.5	38.3	39.7	36.9
1990	37	38.5	40.8	42.6	38.7	37.5	32	32.5	36.5	38.5	41	39.5
1991	37	40.6	42.5	39.5	39.5	36.3	32.7	34	37.8	39.4	39.9	37.2
1992	36	37.2	42.5	42.6	39.4	35.7	31.6	30	35.8	36.3	38	36.5
1993	36	37.9	42.4	40.1	37.7	34.5	32.2	32.4	36.4	39.5	39	38.3
1994	39	39.1	42.1	44.3	37.4	33.6	31.2	31.7	37	40.5	38.8	35.9
1995	38	39.9	41.8	43.4	37.4	36.2	31.3	33	35.8	37.8	38.8	37.2
1996	38	41.2	41.4	40.9	36.9	33.3	30.5	30.2	32.3	36.8	38.2	37.9
1997	38	37.7	41.9	39	36.5	36.9	33.9	33.7	38.5	37.2	39.5	38.5
1998	37	39.7	42.2	44.1	41.3	35.8	31.2	32	35.4	38.6	40.2	38.6
1999	39	43.5	43	42	36.6	34.9	30.7	31	34.9	34.3	39.3	37.9
2000	38	40.2	42.1	40.9	38.1	37.2	34.2	33.7	37.2	38.1	40.3	37.7
2001	37	39.8	43.8	43.3	39	34.2	31.7	30.9	33	36.7	39.4	38.7
2002	36	41.2	43.7	44.6	43.6	37.4	35.7	34.2	35.5	35.2	39.9	37.6
2003	39	42.1	43.1	43.8	42.1	34.5	33.2	31.9	33.9	38.4	39.6	38.5

2004	40	39.1	43.2	42.7	39.8	34.9	34	30.5	33.2	37.4	39.9	38.3
2005	37	43	43.5	44.7	38.5	33.8	31.8	32.4	31.8	35.7	39	39.2
2006	40	41.8	43.4	42.9	38	35.1	32.5	31.3	33.3	34.8	38.4	36.1
2007	36	40.7	43.1	43.6	38.8	33	29.3	29.7	33.2	35.5	39.1	37.9
2008	38	39.5	43.8	36.8	36.9	34	32.4	33.4	33.8	36.6	39.5	38.5
2009	38	41.4	43.1	40.2	40.2	39.1	35.4	32.3	33.3	35.4	36.9	39.7
2010	40	42	42.3	44.1	37.3	32.6	31.8	31.8	33.2	37.7	40.5	38.2
2011	37	41.3	42	43.9	32.7	30.3	29.2	27.6	28.5	30.4	33.5	36.4
2012	37	41.5	42.6	42.2	31.8	28.3	26.8	27.4	27.8	31.3	34.6	36.7
2013	39	41.6	44	43.5	34.5	31.3	27.6	27.2	29.2	30.5	34.5	36.5
Mean	38	40.2	42.4	42.3	38	34.7	31.9	31.7	34.4	36.7	38.7	37.5

Appendix. VII34 years (1979-2013) monthly average monthly average minimum and maximum temperature Wind speed, relative humidity, and sunshine hours for Kodak metrological station

Month	Max T	Min T	Mean T	Wind	Relative H	Solar radiation
JAN	37.3	22.5	29.9	3.3	0.2	22.8
Feb	39.9	24.2	32	3.2	0.1	25.1
MAR	42.1	25.8	34	2.6	0.2	26.3
APR	41.7	26.8	34.2	2.3	0.3	24.6
MAY	37.2	26	31.6	2.5	0.5	19.6
JUN	33.7	23.9	28.8	2.3	0.6	17.6
JUL	31	21.9	26.4	1.9	0.7	15.7
AUG	31.6	21.1	26.4	1.7	0.8	16.7
SEP	34.4	21.3	27.9	1.8	0.7	18.2
OCT	36.9	22.4	29.7	1.7	0.6	18.9
NOV	38.6	22.9	30.7	2	0.3	21.9
DEC	37.3	22.6	30	3	0.2	22
Average	36.8	23.4	30.1	2.4	0.4	20.8

Appendix. VIII 34 years (1979-2013) monthly average monthly average minimum and maximum temperatures, Wind speed, relative humidity, and sunshine hours for Renk meteorological station

Month	Max T	MinT	MeanT	Wind	Relative H	Solar radiation
JAN	34.2	19.3	26.7	2.3	0.2	22.9
Feb	37.1	21.1	29.1	2.3	0.2	25.4
MAR	40.3	23.6	31.9	2	0.1	27
APR	42.1	25.1	33.6	1.7	0.2	27
MAY	38.9	26.1	32.5	1.9	0.4	22.1
JUN	35.2	24.9	30	2.3	0.5	19.9
JUL	31	22.2	26.6	1.9	0.7	16.6
AUG	31.2	21.5	26.4	1.7	0.7	17.1
SEP	35.3	22.1	28.7	1.6	0.6	19.3
OCT	37.7	23	30.3	1.4	0.5	19.3
NOV	37.6	22.2	29.9	1.8	0.2	22.3
DEC	34.7	20.1	27.4	2.2	0.2	21.9
Average	36.3	22.6	29.4	1.9	0.4	21.7

Appendix. IX 34 years (1979-2013) monthly average minimum and maximum temperatures, Wind speed, relative humidity, and sunshine hours for Mulet Meteorological station

Month	Max T	Min T	Mean T	Wind	Relative H	Solar radiation
JAN	36	21.1	28.5	3.8	0.2	22.9
FEB	38.7	22.8	30.7	3.7	0.1	25.2
MAR	41.3	24.7	33	2.9	0.1	26.6
APR	41.7	26.1	33.9	2.4	0.2	25.3
MAY	37.7	25.9	31.8	2.6	0.4	20
JUN	33.9	23.8	28.9	2.6	0.6	17.7
JUL	30.5	21.7	26.1	2.1	0.7	14.9
AUG	30.6	21	25.8	1.9	0.8	15.8
SEP	33.7	21.2	27.4	1.9	0.7	17.6
OCT	36.5	22.5	29.5	1.9	0.5	18.3
NOV	38	22.3	30.2	2.5	0.3	22
DEC	36.2	21.4	28.8	3.5	0.2	22.1
Average	36.2	22.9	29.6	2.7	0.4	20.7

Appendix. X CWR and IWR for Sorghum

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	1	Init	0.3	1.29	1.3	1.8	1.3
May	2	Init	0.3	1.28	12.8	24	0
May	3	Deve	0.3	1.25	13.7	26.5	0
Jun	1	Deve	0.43	1.69	16.9	28.5	0
Jun	2	Deve	0.6	2.26	22.6	31.3	0
Jun	3	Deve	0.77	2.81	28.1	34.6	0
Jul	1	Mid	0.9	3.15	31.5	38.6	0
Jul	2	Mid	0.9	3.05	30.5	42.2	0
Jul	3	Mid	0.9	3.08	33.9	43	0
Aug	1	Mid	0.9	3.12	31.2	44.7	0
Aug	2	Late	0.85	2.97	29.7	46.5	0
Aug	3	Late	0.7	2.48	27.3	42.5	0
Sep	1	Late	0.55	1.97	19.7	38.3	0
Sep	2	Late	0.47	1.71	1.7	3.5	1.7
					300.9	446.1	3

Appendix. XICWR and IWR for Maize crop

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr.Req. mm/dec
May	1	Init	0.3	1.29	1.3	1.8	1.3
May	2	Init	0.3	1.28	12.8	24	0
May	3	Deve	0.31	1.25	13.8	26.5	0
Jun	1	Deve	0.47	1.85	18.5	28.5	0
Jun	2	Deve	0.7	2.62	26.2	31.3	0
Jun	3	Deve	0.92	3.36	33.6	34.6	0
Jul	1	Mid	1.09	3.81	38.1	38.6	0
Jul	2	Mid	1.09	3.7	37	42.2	0
Jul	3	Mid	1.09	3.74	41.1	43	0
Aug	1	Mid	1.09	3.78	37.8	44.7	0
Aug	2	Late	1	3.51	35.1	46.5	0
Aug	3	Late	0.75	2.65	29.2	42.5	0
Sep	1	Late	0.49	1.76	17.6	38.3	0
Sep	2	Late	0.35	1.28	1.3	3.5	1.3
					343.3	446.1	2.6

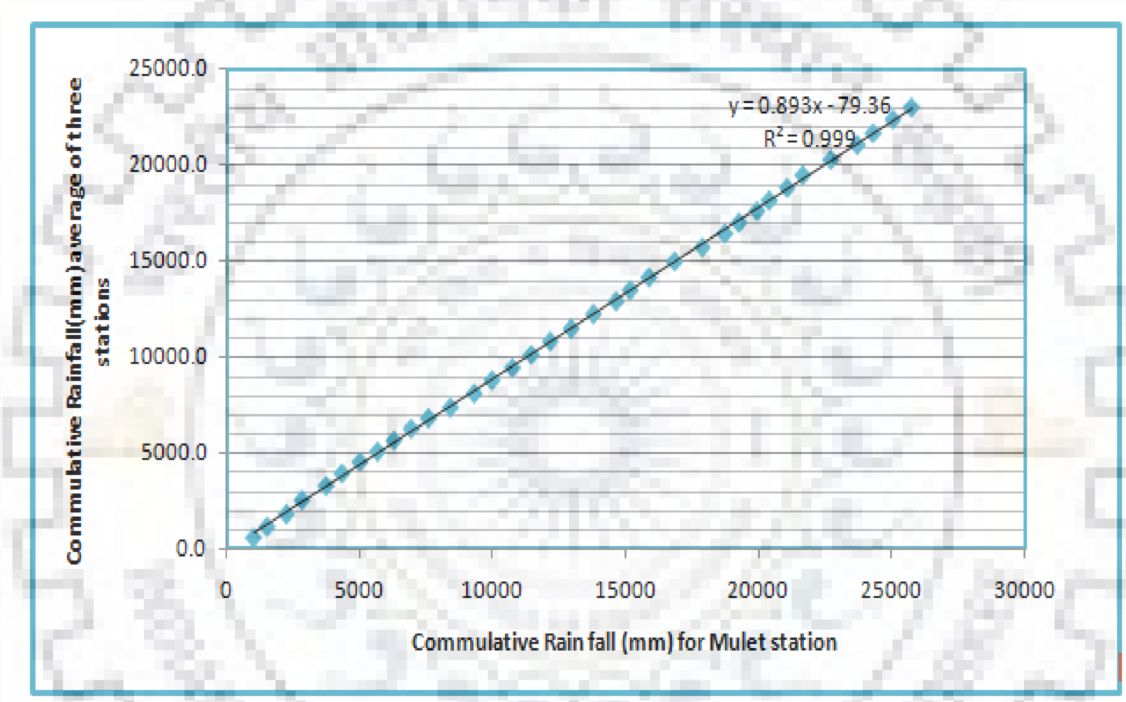
Appendix. XII CWR and IWR for groundnut crop

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr.Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	1	Init	0.4	1.71	1.7	1.8	1.7
May	2	Init	0.4	1.71	17.1	24	0
May	3	Init	0.4	1.64	18	26.5	0
Jun	1	Deve	0.45	1.79	17.9	28.5	0
Jun	2	Deve	0.64	2.43	24.3	31.3	0
Jun	3	Deve	0.84	3.06	30.6	34.6	0
Jul	1	Mid	1.03	3.62	36.2	38.6	0
Jul	2	Mid	1.08	3.67	36.7	42.2	0
Jul	3	Mid	1.08	3.71	40.8	43	0
Aug	1	Mid	1.08	3.75	37.5	44.7	0
Aug	2	Mid	1.08	3.8	38	46.5	0
Aug	3	Late	1	3.54	39	42.5	0
Sep	1	Late	0.77	2.79	27.9	38.3	0
Sep	2	Late	0.6	2.2	13.2	21.1	0
					378.8	463.7	1.7

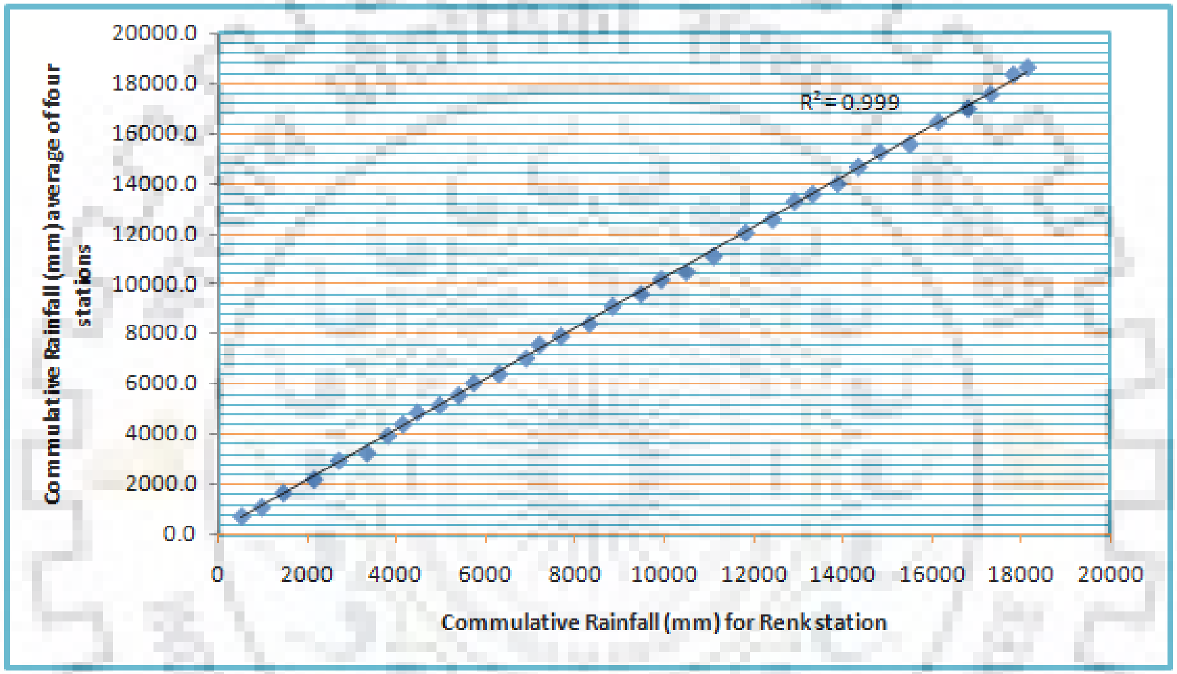
Appendix. XIIICRW and IWR estimation for Rice crop

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr.Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	2	Nurs	1.2	0.51	5.1	24	0
May	3	Nurs/LPr	1.06	4.36	48	26.5	113.2
Jun	1	Init	1.07	4.2	42	28.5	103.5
Jun	2	Init	1.1	4.14	41.4	31.3	10.1
Jun	3	Deve	1.1	4	40	34.6	5.4
Jul	1	Deve	1.1	3.88	38.8	38.6	0.2
Jul	2	Deve	1.11	3.76	37.6	42.2	0
Jul	3	Mid	1.12	3.83	42.1	43	0
Aug	1	Mid	1.12	3.88	38.8	44.7	0
Aug	2	Mid	1.12	3.92	39.2	46.5	0
Aug	3	Mid	1.12	3.99	43.8	42.5	1.3
Sep	1	Late	1.12	4.04	40.4	38.3	2.1
Sep	2	Late	1.08	3.97	39.7	35.1	4.7
Sep	3	Late	1.04	3.87	38.7	30.4	8.3
Oct	1	Late	1	3.78	26.4	18.2	0.4
					562.1	524.5	249.1

Appendix Figure 1Double mass curve for mulet station



Appendix Figure 2Double mass curve for Renk station



Appendix Figure 3Double mass curve for Kodak station