EVALUATION OF THE SUITABILITY OF SOILS FOR IRRIGATION IN LOWER KUJA, NYATIKE DISTRICT, KENYA

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DECLARATION

This is to certify that this project report is my original work and has not been submitted for examination in any other University. Due reference to both published and unpublished previous materials have been acknowledged appropriately.

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Declaration by University Supervisors

We hereby certify that the research project has been submitted for examination with our approval as the University supervisors.

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DEDICATION

To my parents, the late Kipkilach Tirop arap Moek and Anna Cherono Koskei Moek, my loving wife Margaret Tirop and my children.

“That My children May be Inspired and Know the Value of Education”

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ABBREVIATIONS, ACRONYMS AND SYMBOLS

ANOVA	Analysis of Variance
BS%	Percent Base Saturation
cm	Centimetre
cm^3	Cubic centimeter
Ed (s)	Editor(s)
ESP	Economic Stimulus Program
et al	and others
FAO	Food and Agriculture Organisation of the United Nations.
g	Grams
GDP	Gross Domestic Product
hr	Hour
km	Kilometre
LARMAT	Land Resource Management and Agricultural Technology
M.a.s.l	Meters above sea level
Me/L	Milliequivalents per litre
Mg/L	Milligrams per litre
ml	Millilitre
mm	Millimeter
ds/M	Disiemems per metre
ppm	Parts per million.
pH	The hydrogen-ion concentration
NARL	National Agricultural Research Laboratories
KARI	Kenya Agricultural Research Institute
NEMA	National Environment Management Authority
NIB	National Irrigation Board
wt	Weight
KNBS	Kenya National Bureau of Statistics
GOK	Government of Kenya
CEC	Cation Exchange Capacity
ESP	Exchangeable Sodium Percent
AWC	Available Water Capacity
Ksat	Saturated Hydraulic Conductivity

MOA	Ministry of Agriculture
MP&ND	Ministry of Planning and National Development
SOC	Soil Organic Carbon
IR	Infiltration Rate
w	Antecedent moisture content
* (in equations)	multiplication sign.
ha	Hectare
UNEP	United Nations Environmental program
UNDP	United Nations Development program
USDA	United States Department of Agriculture
UNESCO	United Nations Educational, Scientific and Cultural Organization

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ABSTRACT

Soils are important components of the environment and their understanding is essential in planning and management for environmental conservation and sustainable use of natural resources. However, reliable soils information is scarce, not detailed enough and also not site specific. A semi detailed soil survey study was conducted of about 7,000 ha of Lower Kuja Irrigation Development Project area in Nyatike District, Migori county. The sudy aimed at evaluating and classifying the soils for irrigation suitability. The study involved quantitative investigations of soil properties, inventory of land use systems and an assessment of the ecological potential and constraints as determined from a balance sheet anaysis of resources and landuse requirements as related to irrigation.

Six soil mapping units found in four physiographic units, were identified and their distribution and extent are shown in the annexed soils suitability map, at scale 1:50, 000

Soils of Footridges (slopes 6 – 10%) soil mapping unit RBp, are excessively drained, very shallow, very stony and very rocky; considered **Unsuitable** for irrigated agriculture. While soils of the Sedimentary Plains (slopes 0 – 3%) soil mapping unit PSB, are well drained, shallow to moderately deep, clay loam to clay, in most places over murrum. Considered **Marginally suitable** for general irrigation but can be upgraded to **Moderately suitable** if the area is considered for growing shallow rooted crops under suitable irrigation methods. Soils found in the Lacustrine Sedimentary Plains, soil mapping unit PLB1 are Imperfectly drained deep to very deep, (Eutric Vertisols, Sodic phase). These soils cover a large portion of blocks 1;2;3;4/1;4/2 and 4/3. Though considered **Marginally suitable** for general irrigated agriculture; it can be upgraded to **Highly suitable** if paddy rice were to be the main crop. Rice can do well with ESP's of up 20 and the range in this unit is 2.3 to 18.0 and the EC is very low; 0.3 to 0.4ds/M. Workability which puts the unit to marginally suitable would be an advantage to paddy rice and with proper drainage and good water quality the excess salts can be leached.

Soil mapping Unit PLB2 soils are poorly drained to imperfectly drained, moderately deep to deep, sandy clay loam to clay, strongly saline to very strong sodic (sodic solonchaks). These soils cover small portion of blocks 1 and 4/3 and the main area is in block 5/1. The soils are very strongly alkaline pH-H_20>9; extremely sodic ESP%>35; very high exchangeable Sodium 18.0 to 46.0 Cmol/kg. Because of these attributes, the soils are rated **unsuitable** for irrigated agriculture.

Soils found in the Alluvial Plains soil mapping unit AA1 are moderately well drained to well drained, very deep, loam to clay loam, (Eutric Cambisols, Sodic phase). These soils occupy the greater part of blocks 8,7,6 and 5/2 and are rated **Moderately suitable** for general irrigated agriculture but can be upgraded to **Highly suitable** if proper crops are selected since the main problem is the ESP which is slightly sodic to non-sodic. Some suggested crops are paddy rice for the moderately well drained area and horticultural crops like tomatoes; spinach; pepper and kales among others.

Soils of the maping unit AA2 are excessively drained, very deep, loamy sand to sand (Haplic Arenosols). The soils occupy small portions in blocks 4/3 and 8. They are rated **Unsuitable** for irrigated agriculture because of their texture which is very high in the sand fractions 75 to 89%
Soil organic carbon was positively correlated with the infiltration rate at ($P \leq 0.01$) significant levels.

CHAPTER ONE

1.0 INTRODUCTION

1.1. Background Information

Agriculture is the mainstay of the Kenya economy and currently represents 24 percent of Gross Domestic product (GDP). More than one-third of Kenya's agricultural produce is exported and this accounts for 65 percent of Kenya's total exports. The agricultural sector accounts for 18 percent formal employment in the country.

The population of Kenya has continued to grow at a fast rate leading to an ever increasing demand for food (GoK, 1981). In 1969, Kenya's population stood at 11 million and almost doubled to 21 million in 1989, a growth rate of 3.8%, and reached 38.7 million in 2009 (KNBS, 2010); an addition of almost a million people per year. The current rate is estimated at 3.34% and the population is expected to reach 50 million by the year 2020 (GoK, 1994). It has been the Kenya Government's long standing goal that most of the National food requirements be met from domestic production, for self sufficiency and to reduce the strain on the meager foreign exchange resources that would otherwise be used to import food.

According to Kenya Vision 2030 (GoK, 2007), the new long-term development blueprint for the country in its economic pillar; moving the economy up the value chain, Kenya aims to promote an innovative commercially oriented, and modern agricultural sector. Among others, this will be accomplished through developing more irrigable areas. Kenya Vision 2030 aims to transform Kenya into a newly- industrializing, middle – income country providing a high quality of life to all its citizens in a clean and secure environment. Simultaneously, the vision aspires to meet the Millenium Development Goals (MDGs) for Kenya by 2015.

Despite the central role that agriculture plays in the Kenyan economy, the sector continues to face four major challenges that have to do with productivity, land use, markets and value addition. Agricultural productivity is constrained by a number of factors, including high cost of inputs, especially the price of fertilizer, seeds and agro- chemicals, poor livestock husbandry, limited extension services, over-dependence on rain-fed agriculture, lack of markets and limited application of agricultural technology and innovations. Land remains under exploited for agricultural production. There are 9.2 million hectares in ASAL which have the potential for crop production if irrigated (MOA, 2007). This irrigable area is equivalent to the total farmland in high and medium potential areas in the country.

In Kenya, it is possible to substantially raise levels of productivity in agriculture. However, land us eis still a challenge. Land remains under-exploited for agricultural production. In the high and medium potential areas only 31% of the land is under crop production, which represents a mere 5% of the total land in the country as illustrated in figure 1.1 and table 1.1.

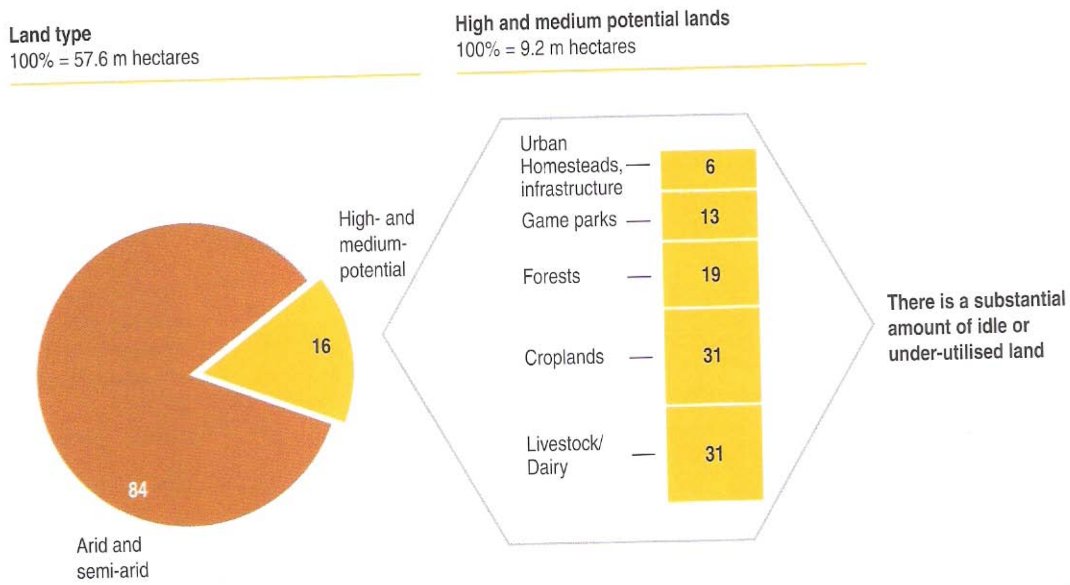

Figure 1.1:Land use in Kenya by function: 2006- Vision 2030

Source: Ministry of Agriculture, 2007

Table 1.1 Main irrigated crops in Kenya,2003.

Crop	Hectarage
Coffee	14,533
Rice	13,229
Pineapples	5,950
Flowers	3,262
Sugarcane	350
Tea	172
TOTAL	37,496

Source : FAO, 2008

Improved irrigation is critical to increasing agricultural productivity. The level of development of irrigation in Kenya is low compared to its potential. Kenya's irrigation potential in 2006 (MOA, 2007), was estimated at 539,000 hectares, but only 105, 800 hectares (about 20 percent of irrigation land) have been exploited for agricultural production. However, with the construction of water storage facilities, the available irrigated land could be increased to 1.3 million hectares. This could be achieved through enhanced water storage capacity, thereby increasing agricultural production. This would also help control floods, which mainly affect poor communities. Under Vision 2030, productivity in the proposed irrigated areas will therefore have benefits on the future of Kenya's economy and society that go beyond increasing agricultural production and value addition as proposed in the economic pillar.

It is estimated that about 13percent of the worlds available lands are irrigated and that about 1400 billion cubic metres of water is used per annum. In Kenya alone, over 83 percent of the land is in the marginal arid and semi-arid zones. In order to do farming in these lands irrigation is necessary

It is well known that the majority of irrigated territories in the world are exposed to the hazard of secondary salinization and alkalization which reduce agricultural potential of these lands and thus threatening humankind's existence. According to the estimates by the United Nations and affiliated agencies (FAO, UNESCO, UNDP) more than 50 percent of all irrigated lands of the world have been damaged by secondary salinization and alkalization and year by year, many millions of hectares of irrigation have to be abandoned.

The Government of Kenya has initiated a comprehensive countrywide irrigation expansion programme geared towards transforming Kenya into a food secure country, more so in these times of adverse climate change (Henrich BÖll Stiftung, 2011)

Despite the noted challenge, the Kenya government in its budget 2011/2012, has rolled out an ambitious irrigation plan (GOK, Budget Highlights 2011/12 Citizens Guide). This is in the strong belief that irrigation farming will ensure food security for Kenyans. Faced with the current challenges of rising food prices and the ever rising inflation rate, the government is investing billions of shillings to expand and construct irrigation projects countrywide and transform agriculture into business. The government will spend Kshs.10.2 billion in Financial Year 2011/12 for expansion and construction of new irrigation projects countrywide. Completion of these projects will ensure food security for Kenyans on a sustainable basis. The economic stimulus programme irrigation projects successfully brought an additional 40,000 acres under rice cultivation in Bura and Mwea and maize in Hola (GOK, 2010, Henrich BÖll Stiftung, 2011)

To deal with food insecurity once and for all, the government will invest huge amounts of money to expand and initiate various irrigation projects spread throughout the country. Notably, one of these projects is the Lower Kuja Irrigation Development projects, which is the subject matter of this report. Out of the government's investments into irrigation programmes, Kshs8.6 billion is a conditional transfer to National

Irrigation Board to complete all the on-going irrigation projects, initiate new projects and fast track completion of designs for new strategic irrigation projects. The completion of on-going projects will bring under irrigation a total of 3.,100 acres of agricultural land that will benefit about 560,000 households, while the new projects will bring under irrigation about 16,000 acres in the 2011/12 out of 70,000 acres planned for completion in the medium and long term. This intervention will benefit about 300,000 Kenyans and expected outcomes will be increased agricultural productivity leading to food security as shown in Figure. 1.2.

Figure1.2. Irrigation farming will ensure food security for Kenyans.

Source : NIB, 2009

1.2 Statement of the Research Problem

It is a prerequisite that the suitability of soils be assessed for irrigation before such a project is undertaken. Global food security and stability depends on the management of the natural resources.

Today some 40% of all world food is obtained from irrigated farmlands. Food production via irrigated agriculture, however, does not correspond to the current rapid population growth. Soil salinity and contamination in addition to the excessive urban development are also the main factors that affect the state of food production by irrigated agriculture (Conway, 2003)

Land is the most important resource in agricultural production. In Kenya, limited availability of productive land is a major constrain to agricultural production. The increasing demand for food due to the rapid population growth estimated at about 3.33% per annum (MP&ND, 2006), necessitates that the country's agricultural potential be fully developed to address this challenge. Irrigation development is one way of dealing with this challenge. National Irrigation Board (NIB) is in process of developing the 8th National Irrigation Scheme to be located in Nyatike district, Migori County.

There is need therefore to carryout study to evaluate the soil suitability for irrigation. Kenya is predominantly an agricultural country with quite limited areas of high potential of land. It is therefore vital that investments, be undertaken that will result in additional areas of productive land. This is why irrigation has gained greater importance as one of the few policy options of expanding food production, providing employment, absorbing the landless, achieving food self-sufficiency and raising levels of income. Therefore the ability of irrigation farming to offer environmentally-based sustainable alternative source of livelihoods to local peasants is critical.

1.3 Research Questions

The research questions to be answered by this research project include:

a) What is the extent and distribution of the different types of soils within the project area?
b) Are soils within the project area suitable for irrigation?
c) What are the irrigation measures to conserve the environment?
d) What are the physio-chemical characteristics of the soils of the project area and how do these affect the environment?

1.4. Objectives of the Study

The study aims to achieve the following three specific objectives

a) To evaluate the suitability of soils for irrigation in the project area and enhance sustainable natural resource utilization
b) To identify, characterize and classify and map the soil resources and their distribution in the project area.
c) To study the physical and chemical properties of the soils of the project area.

1.5 Hypothesis

1) HO: There is no signifant relationship between soil suitability for irrigation and sustainable utilization of the soil resources.

H1: There is significant elationship between soil suitability for irrigation and sustainable utilization of the soil resources

2) HO: There is no significant relationship between soil properties and irrigated agriculture in the environment.

H1: There is significant relationship between soil properties and irrigated agriculture in the environment.

1.6 Justification of the Study

As noted by Kisinyo (1994),physical land attributes are the major criterion for land use recommendations. However, social-economic factors should form an important consideration. Further that soils suitability studies are site specific because of their diverse and heterogenous nature.

According to the World Bank (2007), Kenya is classified among the East and Central African countries in actual or potential difficulty of meeting their populations' food need although it has sufficient irrigation water to produce significant additional food. Therefore appropriate research on irrigated agriculture, that includes the study of soil and water resources and other issues need to be carried out so as to increase yields and prevent land degradation (Oster and Wichelns, 2003; Hussain, 2007). Ensuring food security, increasing small holder real incomes and raising agricultural productivity, is essential for the realization of significant improvement in the standard of living for the Kenyans. The need for research on soils suitability for irrigation therefore becomes critical for sustainable irrigation farming. Irrigation projects are some of the most expensive agriculture investment and therefore to pay for such investment, there is need for careful soil, water and the environmental management in general in order to achieve sustainable development(Blank,2002).

The FAO (1989) advocated a global drive for sustainable agriculture system involving optimizing of agricultural resources to satisfy human needs and at the same time maintaining the quality of the environment and conserving natural resources. Thus, effects of long-term use of different agricultural resources on soil degradation and quality should be monitored to avoid confusing the short-term benefits of increased agricultural production with long-term negative consequences due to non-sustainable land management practices.

1.7 Scope of the Study

The scope of the study involved a study of the soils of the project area and its characteristics and suitability for irrigation farming. A soil study of the proposed lower Kuja Irrigation Development Project area was carried out at semi-detailed soil survey level. The field research work included traversing the entire project area via transects, interactions with the project elders, opinion leaders, block representatives, physical site observations, sitting soil profiles, soil profile opening, description and examination. Representative soil samples were obtained for laboratory analysis and soil fertility evaluation. The generated field and laboratory soil data was used to classify and evaluate the soils for irrigation suitability and environmental conservation and natural resources utilization. This study didt not come up with a conclusive final crop allocation for blocks, but provided a valuable technical and scientific information to be applied by Agronomists and Irrigation Engineers in making such decisions.

1.8 Conceptual Framework

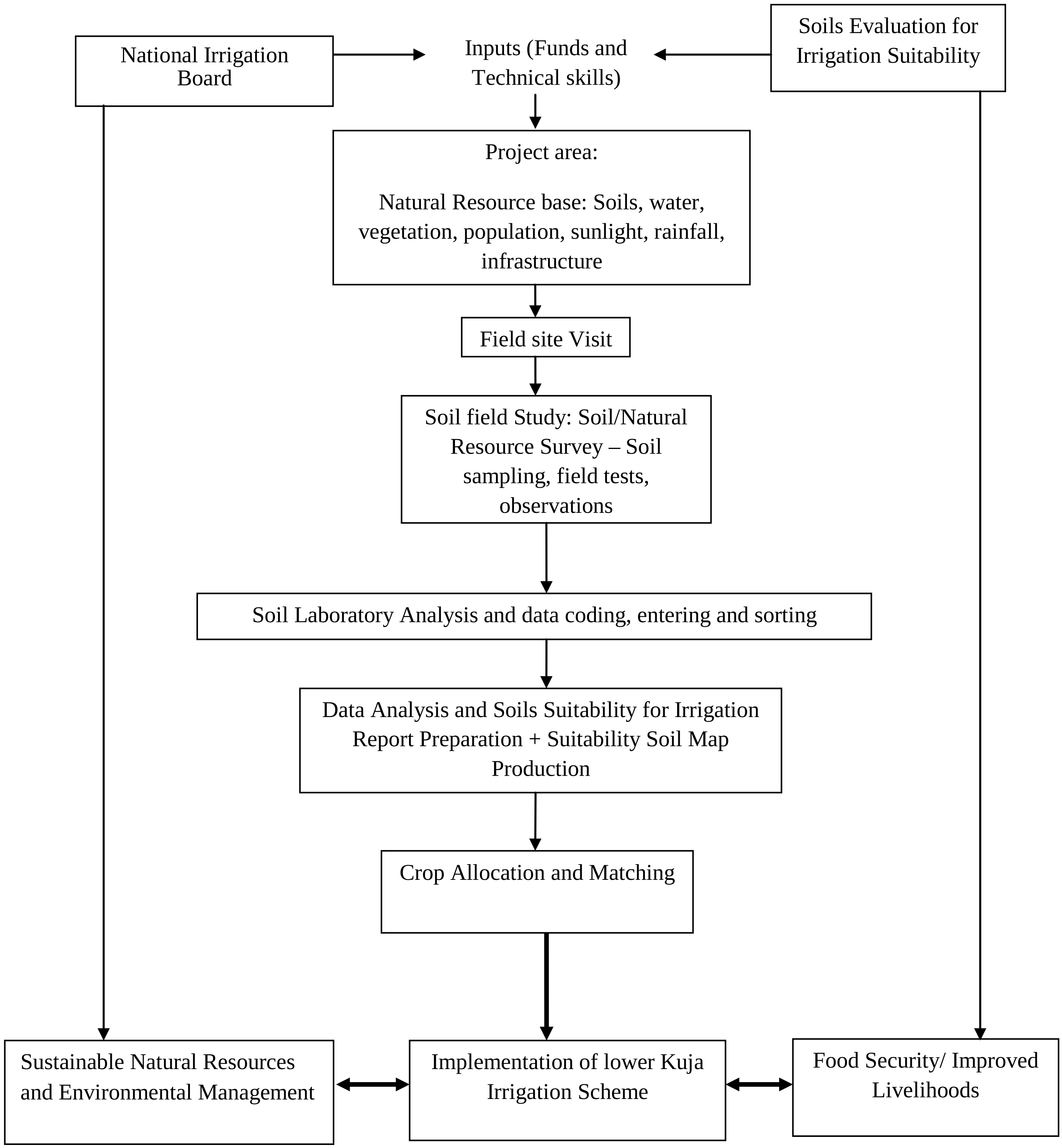

Figure1.3: Conceptual framework

Source: Modified from Conceptual Models in Scientific Research (Woomer, 1999)

The arrows indicate continuous interactions at various levels, times, durations and includes stakeholders' participation in the entire project cycle.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction and Background

The assessment of soils for irrigation involves use of properties that are permanent in nature, which cannot be changed or modified without exorbitant costs. Such properties include soil depth, drainage, texture and slope. These properties are known to constitute some kind of hindrance to irrigated crop production. Chemical properties that ate usually considered, including soil fertility, which can be changed with minor improvement.

The amount and rate of water uptake by plants depends on the ability of the roots to absorb water from the soil with which they are in contact with, as well as the ability of the soil to transmit water towards the roots at a rate sufficient to meet transpiration requirements (Hillel, 1982). These in turn depends on soil and plant properties, which are briefly discussed as follows:

(i) Soil properties: Hydraulic conductivity, diffusivity, water holding capacity, matric
suction, soil wetness and to a considerable extent climatic conditions dictate the rate at which the plant is required to transpire and hence the rate at which it must extract water from the soil in order to maintain its own turgidity.

(ii) Plant properties: Rooting depth, rooting density, rate of plant development, leaf area index and stomata behavior affects the physiological ability of the plant to continue taking in water from the soil at field capacity while maintaining its vital functions even when its own water potential decreases.

Among the factors affecting crop water use is soil. Soil factors include soil water content, texture, structure, depth, salinity/sodicity, fertility, aeration, temperature and drainage. The water content at field capacity and at permanent wilting point gives some indication of availability of water for absorption by plant roots. The difference in soil water content at field capacity and at permanent wilting point defines the range of plant available water. As the soil dries out, the rate of water transmitted through the soil and supplied to the roots will reduce and consequently the rate of water up-take by the plant will be affected (Brady and Well, 2002). Soil texture, organic matter content, structure and depth determines the capacity of the soil to store available moisture for plants and the ease with which the soil water may be reached and absorbed by roots. Indeed, Brady and Weil (2002) documented that root growth and extension are influenced by texture, structure and depth in addition to soil aeration, temperature, fertility and management.

Salt content of the soil can influence soil moisture' stress by affecting the osmotic suction of the soil solution. The osmotic suction tends to increase the wilting coefficient thereby reducing the range of available moisture in saline soils (Brady and Weil, 2002).

It has been established that an efficient management of river basins will assist significantly in solving the problems of poor agricultural productivity in any country. To realize this fact, a lot of countries in the last decade had placed high premium on River Basin development. Agricultural projects under this scheme which involve arable crop production utilized mainly the flood plain and valley bottom soils and to some extent the adjoining uplands. Unfortunately of late most of these river basins lie within regions where rainfall are often inadequate in amount and erratic in timing (Singh, 2000), thus necessitating irrigation in order to satisfy the moisture requirements of the crops needed to meet the demands for food and fiber.

Most of the river basin soils are productive, which necessitated their cultivation all year round to a host of high value agronomic and horticultural crops (Singh and Babaji, 1989). Farming on the river basins depends on rains in the wet season (rice cultivation) and residual soil moisture in the dry season (Horticultural crops). To alleviate the problem of moisture stress during the prolonged gaps between rains as well as in the dry season, supplementary irrigation is provided by lifting the water form perennial surface water bodies, shallow wells and tube wells. Although the irrigation is useful for sustaining agricultural production in any locality, it is imperative that the soils to be used must be evaluated for their suitability. If there is no proper land evaluation for irrigated agriculture technical problems may arise later that would affect both soil quality and crop production adversely.

2.2 Soil Ecosystems and Environmental Quality

Humankind is dependant on soils and their role in providing food and a clean environment in which to live (Pierzynski, *et al,* 2005). There is a strong relationship between food production and environmental quality, and this relationship is quite different from the relationship between the production of manufactured goods and environmental quality. Soil functions are related to the ability of a soil to produce quality food, fibre or feed; construction properties and limitations; the ability to support habitation and recreation and the ability to maintain an ecosystem or desired land use.

Soils are dynamic ecosystems that support plant life by providing the essential requirements for plant growth, including nutrients, water, oxygen and support. Various physical, chemicals and biological processes have resulted in the development of soil over geologic time. Soils are defined comprehensively according to Singer and Munns (2002) as: complex biogeochemical materials on which plants may grow; having structural and biological properties that distinguish them from the rock and sediments from which they normally originates; consisting of dynamic ecological systems that provide plants with support, water nutrients and air; supporting all ecosystems on land including a large population of micro organisms that recycle the materials of life; sustaining the entire human population with food, fibre, water, building materials and sites for construction and water disposal and protecting ground water by filtering toxic chemicals and disease organisms from waste water. However in simpler terms, soils is viewed and defined as a natural, three dimensional array of vertically differentiated material at the surface of the earths crust. The variation in soils throughout the world is a function (f) of five soil forming factors as described by a pioneer soil scientist (Jenny, 1941), which can be expressed as;

$$\text{Soil} = f\ (\rho m, r, cl\ o, t) \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

With ρm, r, cl, o, and t representing parent materials, relief (topography), climate, organisms, and time, respectively. Among the common agricultural uses of soil include irrigation for crop production.

2.3 Studies on Soils Suitability for Irrigation

Determining the suitability of land for irrigation requires a thorough evaluation of soil properties, the topography of the land within the field and the quality of water to be used for irrigation. Few researchers Akinbile et al. (2007), Adefisan *et al*. (2007) and Olowolafe and Patrick (2001) have all investigated on effective factors to be considered when evaluating soils for irrigation, irrigation systems and water supplies. A basic understanding of soil/water/plant interaction will help irrigators efficiently manage their crops, soils, irrigation systems and water supplies. Unfortunately published information on the properties of River basin soils is scarce.

Considering how large hectares of river basin soils which are agriculturally suitable for irrigated agriculture within Kenya and are mistakenly used for construction (residential and industrial), there is therefore the need to stop such a trend and conserve the river basin soils. Such river basin soils when fully harnessed and exploited can be used for irrigated agriculture to alleviate the present food shortage in the country and consequently alleviate poverty.

The available water resources may not be able to meet the various demands that will inevitably result in the irrigation of additional lands in order to achieve a sustainable global food security. Land suitability, by definition, is the natural capability of a given land to support a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability of a defined use. According to the FAO (1976a), methodology this is strongly related to the land qualities including erosion resistance, water availability and flood hazard that are not measurable. As these qualities are derived from the land characteristics, such as slope angle and length, rainfall and soil texture which are measurable or can be estimated, it is advantageous to use these latter indicators in the land suitability studies. Thus, the land parameters are used to obtain land suitability for irrigation purpose. Sys *et al*. (1991) suggested a parametric evaluation system for irrigation methods which is primarily based upon physical and chemical soil properties. In the proposed system the factors affecting the soil suitability for irrigation purposes can be subdivided into four groups:-

The physical properties determining the soil-water relationship in the soil such as permeability and available water content. Chemical properties interfering with the salinity/alkalinity status such as soluble salts and exchangeable Sodium, drainage properties and environmental factors such as slope

Hired *et al*. (1996) and Bond (2002) improved the classification methods for evaluating suitability for effluent irrigation and land suitability for irrigation. These factors influence the land suitability in an irrigation practice included soil properties and topography. Tesfai (2002) investigated a land suitability method for gravity (surface) irrigation schemes in the Sheeba area of Eritrea.

Mbodj *et al.* (2004) performed a land suitability evaluation for two types of irrigation i.e., surface irrigation and drip irrigation in Tunisian Oued Rmel Catchment using parametric evaluation. According to the results, the drip irrigation suitability gave more irrigable areas compared to the surface irrigation practice due to the topographic (slope), soil (depth and texture) and drainage limitations worked out in the surface irrigation suitability evaluation. Rees and Laffan (2004) studied the land suitability for spray irrigation in the Southwood Processing Complex, southern Tasmania. In this research, soil properties such as depth, texture, structure, hydraulic conductivity, massive hardpan, stone content and topographic properties such as slopes, land form, surface rock, frequent water logging and drainage properties were considered as to be the main factors in land suitability evaluation for any spray irrigation practice.

Barberis and Minelli (2005) provided land suitability classification for both surface and drip irrigation methods in Shouyang country, Shanxi province, China. The study was carried out by a modified parametric system. The results indicated that due to the unusual morphology, the area suitability for the surface irrigation (34%) is smaller than the surface used for the drip one (62%). The most limiting factors were physical parameters including slope and soil depth.

Intensive application of water alters water distribution in the surroundings and affects the transfer rate of the pollutants in the soil, soil density, erosion, salinity, alkalinity, water logging. Water and soil compatibility in any irrigation practice is of outmost importance and should it not be so, irrigation water will bring about adverse impacts on the physico-chemical properties of the soil in the long run. To determine such compatibility, detailed evaluation of soil properties and topography is required.

Saturated hydraulic conductivity (Ksat) is one of the soil hydraulic properties which is widely used in environmental studies, especially those related to irrigation development (Wakindiki, et al, 2001). Although some resarechers have showed that when organic matter increases, saturated hydraulic conductivity decreases; Nemes *et al* (2005) investigated the influence of organic matter on the estimation of saturated hydraulic conductivity. Their results showed a strong negative relationship between O.M and Ksat. These scientists justified this explanations by the fact that organic matter retains soil water well and does not allow water to flow freely. On the other hand, O.M may also affect the pore size distribution of the soil through soil structure development which also affects the soil hydraulic conductivity.

From the beginning of time, human beings have carried out evaluation of the soils in which they work, play and live. Terms such as ‘good’ or ‘bad’, worn-out soils’ ‘productive’ or ‘unproductive’, soils have always been used (Brady, 2002). To better understand how the full potential of a given soil can be realized, Soil scientists are using the concept of soil quality and other critical soil parameters to assess soils suitability and fitness for various functions

Kironchi and Tirop (2010), while carrying out a study on the “Evaluation of Soil and Water Resources Suitabilty for Irrigated Agriculture at Kakuma, Turkana West District”, applied six key land qualities and their respective diagnostic factors, and used them to evaluate and rate the suitability of soils for irrigation.The study arrived at key recommendations that included routine use of extra irrigation water to satisfy the leaching requirement; use of gypsum as a soil amendment;to improve soil organic matter by applying adequate amounts of organic residues and/or manure; use of additional nitrogen and phosphorous fertilizers for vigorous crop growth; and application of commercial fertilizers that contain manganese , copper, iron and zinc be used on growing crops in order to control deficiencies of micronutrients.

2.4 Soil Survey and Land Evaluation

The practical purpose of soil survey is to enable more accurate and useful predication for a specific purpose to be made. The assessment of soil properties and their response to management is required in agriculture, forestry, informal decision making in rural and urban planning, feasibility and design studies in land development projects and many engineering works. The main purpose of semi-detailed soil survey is project feasibility studies for a particular kind of project development. It is meant to investigate the ecological, technical and social consequences of the proposed development together with its economic viability. It helps in hazard avoidance and giving guidance for major kinds of land use which has received more attention because it is clearer that an efficient use without degradation can be achieved when the land conditions and all the details relevant to the use are well known (Bennema 1978).

FAO (1976a) defines land as the physical environment, including climate, relief, soils, hydrology and vegetation, to the extent that this influences the potential of land for use. From the concept of land, land evaluation can be defined as the process of estimating the potential of land for one or more alternative uses (Beek, 1978; FAO, 1976; Vink, 1975 and Young, 1980).

For the purpose of evaluation, FAO Framework has come up with some basic concepts that are important. The key terms and concepts are land mapping unit,, land charecteristcs and land quality. Land Mapping Unit is a mapped area of land with specified characteristics, while land characteristic is a measurable attribute of land such as slope angle, rainfall, texture, water availability. On the other hand Land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use e. g. erosion resistance, oxygen availability, nutrient availability and trafficability. Land qualities apart from measuring directly can also be described by means of land characteristics

Major kind of land use is a major subdivision of rural land use such as rain-fed agriculture and irrigated agriculture among others. Diagnostic criterion is a variable that has and influence on the output and serves as basis for assessing the suitability of a given area of land for that use. It may be land quality, a land characteristic or a function of several land characteristics.

Various terminologies are used to refer to land evaluation. These include land classification, land capability classification and land suitability classification. Young (1980) defined land classification to include any method of grouping land or its elements into classes. Land capability is an inherent capacity of land to perform at a given level for a general use while land suitability is the fitness of a given type of land for a defined use. The process of land suitability classification is the appraisal of land grouping of specific area in terms of their suitability for a defined use FAO Framework recognises four categories in land suitability classification (FAO, 1976)

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2.4.1 The USBR Land Suitability Classification for Irrigated Use.

This system is used in pre-feasibility and feasibility studies for irrigation development. It relates soil, topographic and drainage factors to the payment capacity (or net income) per irrigated farm holding and to irrigation engineering aspects. This system (USBR, 1953) is the best example of a system which takes the economic aspects of an irrigation scheme into account in evaluating land for irrigation. Maletic and Hutchings (1967) and FAO (1974, 1979) gives good reviews and discussions.

Each area of land (usually a soil mapping unit) is labelled on a map with a symbol which conveys important information in coded form. In this system land class is defined as a category of land having similar physical and economic attributes which affect the suitability of land for irrigation. The criteria of land classes are set for each individual irrigation project according to the local physical and economic situation, so that land classes are not universally similar. The economic attributes of a piece of land are summed up in the payment capacity, which is the 'residual available to defray the cost of water after all other costs have been met by the farm operate (USBR 1952 as cited in Landon,1991).

There are six land classes, with 1 to 3 irrigable, class 4 restricted irrigable, class 5 provisionally non irrigable and class 6 non irrigable. It can be recommended for general application to irrigation land evaluation.

2.4.2 FAO Framework for Land Evaluation

By 1970 many countries had developed their own systems of land evaluation. This made the exchange of information difficult and there was a clear need for international discussion to achieve some form of standardization. Preparation work taken by two committees one in the Netherlands and another in FAO, lead to production of background document (FAO, 1972) containing principles of the proposed Framework for land evaluation, and a summary of the discussion and recommendations of the meeting was published (Brinkman and Symth, 1973) and this led to the publication of the 'Framework of land evaluations' (FAO, 1976a).

The nature of Framework is such that it does not constitute an evaluation system. The range of possible uses of land and purposes of evaluation is so wide that no one system could hope to take an account of them. In the 'Framework' land evaluation is based on physical land attributes, in so far as these affect economic and other inputs, outputs and benefits within the context of specified land utilization types, protection and enhancement of environment and socio-economic conditions (Brinkman and Symth, 1973). The Framework for land evaluation (FAO, 1976a) is a standard set of principles and concepts on which national or regional land evaluation systems can be constructed. The fundarmental principle to the approach and methods employed in the framework are numerous.

Land suitability is assessed and classified with respect to specified kinds of use. Evaluation require a comparison of the benefits obtained and inputs needed on different types of land. A multi disciplinary approach is required. Evaluation is made in terms relevant to the physical, economic and social contents of the area concerned. Suitability refers to use on a sustained basis and evaluation involves comparisons of more than a single kind of use.

The framework emphasises in particular the importance of explicitly stating the intended land use and the level of management envisaged, and that land evaluation may either be on current suitability, or on potential suitability. It must be emphasised that the system is only a framework, and for most projects, it will need to be qualified with detailed specification as discussed in FAO (1979). Using the concept of the FAO framework semi-detailed or detailed surveys include comparison of costs and returns quantitatively for a more specified 'LUT', such as subsistence levels, rain-fed maize production by small holder.

The FAO Framework uses two approaches in land evaluation. The first one is a two-stage approach in which suitability is assessed based on land qualities which are then subject to socio-economic analysis. The second one is the parallel approach in which both economic and social analysis of the kind of land use proceeds simultaneously with the survey and the assessment of physical factors. The two stage approach is often used in resource inventories for broad planning purposes and in studies for the assessment of biological productive potential. The land capability classifications in the first stage are based on the suitability of land for kinds of land which are selected at the beginning of survey e. g. arable cropping, maize and tomatoes. After this the results are presented in a map which may then be subjected to second stage. Two stage approaches are straight forward, possessing a clear-cut of sequence of activities. It offers a better chance of concentration on survey and data collection needed for land evaluation. In the authors view two stage approach will be used unless otherwise stated. The Framework structure as shown in table 2.1 is comparative with other systems, but allows great flexibility. The Framework recognises four categories in land suitability classification. There are two orders, termed suitable (S) and not suitable (N). Conditionally suitable land (SC) is 'a phase' of the order suitable and approximates to classes 4 and 5 of the USBR. There are three classes in the order S and two classes in the order N. The classes are further divided into subclasses in the order S are further divided into land suitability units (reflecting management requirement within subclasses). The order N is not divided into units. The land classes, subclasses and units are similar categories to those in USBR and USDA systems.

Table 2.1: Structure of the FAO Land Suitability Classification

	Category		
Order (Kind of suitability)	Class (Degree of (UN) suitability)	Subclass (kind of limitation)	Unit (Management requirement)
S Suitable	S1 – Highly suitable	S2m	S2e-1
	S2 – Moderately suitable	S2e	S2e-2
	S3 – Marginally suitable	S2me	
Phase	SC- Conditionally suitable	Sc2	SC2m
N Not suitable	N1- Currently not suitable	N1 m Ni me	
	N2 - Permanently not suitable		

Source: FAO, 1976a

The Framework employs several terms to define or describe land features in particular 'land quality' and land 'characteristic' but care has to be taken in the case of land qualities, because of constructing over complex systems (e. g. involving say moisture (m), oxygen (o), soil erodability (e), nutrients availability (n) and trafficability (c)) when their effects could simply be indicated in terms of one or two characteristics such as soil moisture and depth.

The Framework recommends the following evaluation procedures;- first, initial consultation to establish the objectives, and data and basic assumption on which evaluation is to be based. Secondly, the possible and relevant LUT's or major kinds of use are described and their requirement established. Land mapping units and the relevant land qualities are described and subsequently a comparison of land and the types of land use present is made by the process of matching. Socio-economic analysis is then carried out (incase of two stage approach). Land suitability classification is made and finally the results are presented. A description of the physical and socio-economic context of the study area. A descriptive of the LUT's or major kinds of land use relevant to the area. Maps, tables and textural matter showing degrees of suitability of land mapping units for each relevant use together with the diagnostic criteria. Management and land improvement specification for each land utilization type with respect to each LMU for which it is suitable. Economic and social analysis of the consequences of the various kinds of land uses considered and basic data and maps on which the evaluation is derived, together with information on the reliability of evaluation. Land suitability classification is the appraisal of land and grouping of specific areas in terms of their suitability for a defined use.

The framework is both comprehensive and reliable. Its flexibility allows for easy revision of out dated valuation. The principles and procedures given in the framework can be applied in all the parts of the world. It can be used to construct systems applicable at all levels of intensity ranging from one extreme, national, continental or world scale assessments, and at the detailed level studies, it covers all kinds of land use e. g. arable farming, livestock, forestry etc. The framework is written mainly for those actively involved in rural land evaluation.

2.5 Environmental Impacts of Irrigation

Irrigated agriculture generally produces high yields as long as water is available. This is because the other environmental characteristics of dry lands, plentiful sunshine, and warm temperatures are conductive to crop growth. This high productivity is without its costs, however, and in many areas of the world water logging, salt, accumulation, groundwater depletion, and disease are serous side effects of irrigation. In some areas, salinization is severe enough that it is forcing abandonment of formerly productive land. In parts of the arid Western United states, much of the environmental damage associated with irrigation is attributed to government policies that provided water at artificially low prices. These subsidies encourage inefficient use of water, such as for production of hay. This excessive use has contributed greatly to the salinity problems in the lower Colorado Rivers.

In most of the world's farming regions water already is being used intensively. Worldwide, agriculture accounts for more than 70 percent of the freshwater withdrawals, but use of the water for irrigation accounts for 40 percent of the world's production food (UNEP 2002). Water resources are already stressed in much of the world.

Environmental impacts of irrigation are the changes in quantity and quality of soil and water as a results of irrigation and the ensuing effects on natural and social conditions at the tail- end and downstream if irrigation scheme. The impacts stem from the changed hydrological conditions owing to the installation and operation of the scheme. An irrigation scheme often draws water from the river and distributes it over the irrigated area. As a hydrological result it is found that:

- The downstream river discharge is reduced
- The evaporation in the scheme is increased
- The groundwater recharge in the scheme is increased
- The level of the water table rises
- The drainage flow is increased

These are what may be called direct effects.

The effects on soil and water quality are indirect and complex, water logging and soil salinization are part of these, whereas the subsequent impacts on natural, ecological and socio- economic conditions is very intricate. Irrigation projects can have benefits, but the negative side effects are often overlooked (ILRI, 1988, Thakkar, 2007).

2.5.1 Reduced downstream river discharge

The reduced downstream river discharge may cause:

- Reduced downstream flooding
- Disappearance of ecologically and economically important wetlands or flood forests (WWF, 2007)
- Reduced availability of industrial, municipal, household, and drinking water
- Reduced shipping routes. Water withdrawal poses a serious threat to the Ganges. In India, barrages control all of the tributaries to the Ganges and divert roughly 60 percent of river flow to irrigation (WWF, 2007)
- Reduced fishing opportunities. For example the Indus River in Pakistan faces scarcity due to over-extraction of water for agriculture. The Indus is inhabited by 25 amphibian species and 147 fish species of which 22 are found nowhere else in the world. It harbors the endangered Indus River dolphin, one of the world’s rarest mammals. Fish populations, the main source of protein and overall life support systems for many communities, are also being threatened (WWF, 2007)
- Reduced discharge into the sea, which may have various consequences like coastal erosion such as in Ghana (Timberlake,1985) and salt water intrusion in deltas and estuaries like in Egypt, Aswan dam. Current water withdrawal from the River Nile for irrigation is so high that, despite its size, in dry periods the river does not reach the sea. (WWF, 2007). The Aral sea has suffered an "environmental catastrophe" due to the interception of river water for irrigation purposes.

2.5.2 Increased groundwater recharge, waterlogging, soil salinity

In Huarmey delta of Peru farmers experience waterlogged and salinised irrigated land with poor crop stan. This illustrates an environmental impact of upstream irrigation developments causing an increased flow of groundwater to this lower lying area leading to the adverse conditions

The increased groundwater recharge stems from the unavoidable deep percolation losses occurring in the irrigation scheme. The lower the irrigation efficiency, the higher the losses. Although fairly high irrigation efficiencies of 70% or more (i.e. losses of 30% or less) can be obtained with sophisticated techniques like sprinkler irrigation and drip irrigation, or by precision land levelling for surface irrigation, in practice the losses are commonly in the order of 40 to 60%. This may cause:

- Rising water tables,
- Increased storage of groundwater that may be used for irrigation, municipal, household and drinking water by pumping from wells,
- Waterlogging and drainage problems in villages, agricultural lands, and along roads with mostly negative consequences. The increased level of the water table can lead to reduced agricultural production.
- Shallow water tables are a sign that the aquifer is unable to cope with the groundwater recharge stemming from the deep percolation losses,
- Where water tables are shallow, the irrigation applications are reduced. As a result, the soil is no longer leached and soil salinity problems develop,
- Stagnant water tables at the soil surface are known to increase the incidence of water borne diseases like malaria, filariasis, yellow fever, dengue, and schistosomiasis (Bilharzia) in many areas. (WHO,1983) Health costs, appraisals of health impacts and mitigation measures are rarely part of irrigation projects, if at all. (Thakkar,2007)
- To mitigate the adverse effects of shallow water tables and soil salinization, some form of watertable control, soil salinity control, drainage and drainage system is needed.
- As drainage water moves through the soil profile it may dissolve nutrients (either fertilizer based or naturally occurring) such as nitrates, leading to a built up of those nutrients in the ground water aquifer. High nitrate levels in drinking water can be harmful to humans particularly for infants under 6 months where it is linked to 'blue-baby syndrome'.

There are numerous outstanding case studies .In India 2.189.400 ha have been reported to suffer from waterlogging in irrigation canal commands. Also 3.469.100 ha were reported to be seriously salt affected here, (Singh,2005) . In the Indus Plains in Pakistan, more than 2 million hectares of land is waterlogged. (GLAP,2006) The soil of 13.6 million hectares within the Gross Command Area was surveyed, which revealed that 3.1 million hectares (23%) was saline. 23% of this was in Sindh and 13% in the Punjab. (GLAP,2006) More than 3 million ha of water-logged lands have been provided with tube-wells and drains at the cost of billions of rupees, but the reclamation objectives were only partially achieved. (Bhatti,1987) The Asian Development Bank (ADB) states that 38% of the irrigated area is now waterlogged and 14% of the surface is too saline for use (ADB,2001). In the Nile delta of Egypt, drainage is being installed in millions of hectares to combat the water-logging resulting from the introduction of massive perennial irrigation after completion of the High Dam at Assuan (Abdel-Dayem,1987). In Mexico, 15% of the 3.000.000 ha if irrigable land is salinized and 10% is waterlogged(Pulido,1994). In Peru some 300.000 ha of the 1.050.000 ha of irrigable land suffers from this problem Estimates indicate that roughly one-third of the irrigated land in the major irrigation countries is already badly affected by salinity or is expected to become so in the near future. Present estimates for Israel are 13% of the irrigated land,, Australia 20%, China 15%, Iraq 50%, Egypt 30%. Irrigation-induced salinity occurs in large and small irrigation systems alike(Claudio,2001). FAO had earlier estimated that by 1990 about 52 x 10^6 ha of irrigated land woul need to have improved drainage systems installed, much of it subsurface drainage to control salinity (UN,1977)

2.5.3 Reduced downstream drainage and groundwater quality

- The downstream drainage water quality may deteriorate owing to leaching of salts, nutrients, herbicides and pesticides. This may negatively affect the health of the population at the tail-end and downstream of the irrigation scheme, as well as the ecological balance. The Aral sea, for example, is seriously polluted by drainage water.
- The downstream quality of the groundwater may deteriorate in a similar way as the downstream drainage water and have similar consequences.

2.5.4 Reduced downstream river water quality

Owing to drainage of surface and groundwater in the project area, which waters may be salinized and polluted by agricultural chemicals like biocides and fertilizers, the quality of the river water below the project area can deteriorate, which makes it less fit for industrial, municipal and household use. Polluted river water entering the sea may adversely affect the ecology along the sea shore, as is the case for Aswan dam.

2.5.5 Affected downstream water users

Water has become scarce for nomadic pastoralist in Baluchistan due to new irrigation developments. Downstream water users often have no legal water rights and may fall victim of the development of irrigation schemes.Pastoralists and nomadic tribes may find their land and water resources blocked by new irrigation developments without having a legal recourse.Flood-recession cropping may be seriously affected by the upstream interception of river water for irrigation purposes. In Baluchistan, Pakistan, the development of new small-scale irrigation projects depleted the water resources of nomadic tribes traveling annually between Baluchistan and Gujarat or Rajastan, India (ILRI,1984). After the closure of the Kainji dam, Nigeria, 50 to 70 per cent of the downstream area of flood-recession cropping was lost (Drijver,1985)

2.5.6 Lost land use opportunities

Irrigation projects may reduce the fishing opportunities of the original population and the grazing opportunities for cattle. The livestock pressure on the remaining lands may increase considerably, because the ousted traditional pastoralist tribes will have to find their subsistence and existence elsewhere, overgrazing may increase, followed by serious soil erosion and the loss of natural resources. (Ecosystems Ltd,1983). The Manatali reservoir formed by the Manantali dam (Fig. 2.1) in Mali intersects the migration routes of nomadic pastoralists and destroyed 43000 ha of savannah, probably leading to overgrazing and erosion elsewhere. Further, the reservoir destroyed 120 km² of forest. The depletion of groundwater aquifers, which is caused by the suppression of the seasonal flood cycle, is damaging the forests downstream of the dam. (DeGeorges 2006, Bosshard 1999)

Figure 2.1 Lake Manantali, 477 km², displaced 12,000 people

2.5.7 Simulation and prediction

The effects of irrigation on watertable, soil salinity and salinity of drainage and groundwater, and the effects of mitigative measures can be simulated and predicted using agro-hydro-salinity models like SaltMod and SahysMod (Snellen,2005)

2.5.8 Environmental Impact Check-list.

Different irrigation practices have different impacts on environment, measured by the attributes of land resources and biological life within the ecosystem. For each attribute, the negative and positive impacts can be predicted, based on the anticipated effects of the envisaged technologies or practices. The same environmental check-list can be used in monitoring and comparing the effects of different practices on environment, as detailed in table 2.2.

Table 2.2 Envirnmental impact check-list

For each environmental effect, letter A, B, C or D is given. Remarks are also given where necessary			
Attribute	**Impacts**	**Code**	**Mitigation Measures / Remarks**
Hydrology	Rise in water table Flood regimes Fall in water table River hydrology	C C D D	If the water management regimes are not improved, based on the actual crop and soil requirements, then negative long-term impacts may be realized.
Pollution	Toxic substances Anaerobic effects Siltation on the border strips	A C C	The recommended practices do not involve extensive use of chemicals, hence toxic substances are least expected. Anaerobic effects and siltation are expected if optimum water management regimes are not attained.
Soils	Salinity Sodicity Structure Erosion	C C C C	Although salinity and sodicity problems are not critical at the moment, long-term problem may arise if inappropriate irrigation methods are practiced and correct mitigation measures are not taken in good time. Wind erosion is already a big problem, realized during off-seasons when the field is left bare after harvesting.
Ecology	Animal migration Human migration Rare species Retrieval	A C A	In the irrigation scheme, grass and weeds grow because of the availability of water. These are cut and given to animals, whose population is steadily increasing in the area, which otherwise, would not rare cows due to lack of grass.Hence,some lost plant species are likely to be retrieved if irrigation is continuous.
Health	Food security Nutrition Diseases	A A C	Irrigation practices plus manure from the animals is likely to increase food production in terms of quantity and quality, hence nutritional standards are expected to increase likewise.However,tail standing water, covered with weeds is likely to increase population of mosquitoes, hence incidence of malaria.

Adapted from: KSS/KARI, 2000

KEYS: A-Positive impacts very likely; B-No impacts likely; C-Negative impacts very likely; D-No judgment possible at present.

2.6 Soils Field Study

The need for soil surveys, the importance of soil and land suitability studies for agricultural development projects has long been recognized (Landon, 1991). For example Storie (1964), quoted in FAO Soil Bulletin No. 42 (1979a), lists 11 major areas in which soil and land evaluation studies can contribute significantly to irrigation development. In most irrigation projects, soil and related studies should form an indispensable part of the basic learning process, and without them very costly mistake can be, and have been, made. Again, as noted by Landon (1991), in a appropriate circumstances, soil surveys can be highly cost effective, provided a careful choice is made of scale and intensity relative to the development envisaged.

The principles of soil survey methodology deal with the various kinds of soil surveys and the applicable procedures that ultimately lead to the publication of the soil report and the accompanying soil map.

The types and methodologies of soil surveys carried out in Kenya have been prescribed by Kenya Soil Survey, KARI, and the departments of Soil Science, Land Resources and Natural Resource of Faculties of Universities in Kenya (KSS, 1987, U.O.N 1990).

Whenever a soil is well documented in the field and its properties are further complemented by laboratory data it should be possible to classify it in any soil classification system. The physiogronomic approach used for soil surveys in Kenya facilitates the use of the soil mapping unit as the basis for land evaluation. Various types of soil surveys that include exploratory, reconnaissance, semi-detailed, detailed soil surveys and site evaluation, have different parameters as detailed in Table 2.3.

Exploratory soil surveys have scales of between 1:500,000 and 1:1,000,000 and the purposes include establishment of major soil regions for agricultural development, research planning, international soil correlation and exchange of research data. Reconnaissance soil surveys operate at scales ranging from 1:250,000 to 1: 100,000

Its purpose include systematic inventory of the soil resources of the whole country for multi purpose land use planning at scale 1:100,000 for high and medium potential areas, and at scale 1:250,000 for low potential areas; pre-investment studies for river basin development with emphasis of soil and water conservation at the catchment level and irrigated land use; systematic, inventory of the soils of a particular area for single purpose development such as irrigation project.

Semi- detailed soil surveys apply scales of between 1:20,000 and 1:50,000 and its purposes include obtaining more detailed soil information than is possible from smaller scale soil investigations.

The areas might have been identified during the reconnaissance soil surveys. Other purposes include single purpose land development such as irrigation development studies.

Detailed soil surveys on the other hand, operate at scales larger than 1:20,000with common final publishing scale 1:10,000 or 1:5,000. Its purpose includes farm planning, layout irrigation schemes or characterization of agricultural research sites.

Site Evaluations have variable scales, that are much dependent on the purpose at hand; while its purposes include project identification, such as the broad assessment of sites or areas to be considered for more detailed soil resources inventory studies; and soil problem orientated, that may include poor crop growth, ponding of surface water and /or flooding and soil sealing and crushing and gully susceptibility.

Table 2.3: Parameters for Soil Surveys in Kenya

Type of survey	Scale	Mapping unit	Density 1 obs/..ha	Boundaries
Exploratory	1:1,000,000 and 1:500,000	Physiographic units closing major soil	n.a n.a	All boundaries inferred from others sources
Reconnaissance	1:250,000 and 1:100,000	Physiographic units closing singular soils or phases thereof, association and complexes	625 - 2500 100 - 400	More boundaries inferred from some spot-checking along the entire length
Semi- detailed	1:50,000 and 1:20,000	Singular soils, association or complexes	25 - 100 4 - 20	Most boundaries are checked but not along their entire length
Detailed	1:10,000 And 1:5,000	singular soils or phases thereof	1 - 4 0.25- 1	All boundaries are checked throughout their entire length
Site evaluation	Variable	Physiographic units	Variable	All boundaries inferred; occasional spot check

Source: KSS/ KARI,1987

Table 2.4 : Inventory of Soil Data

DATA/ITEM	PURPOSES FOR WHICH IT MAY BE REQUIRED
A. PHYSICAL	
1. Effective soil depth	Root room, water and nutrient retention; land levelling; drainage; aligning and design of irrigation and drainage channels.
2. Presence of organic or histic horizons	Special problems or opportunities.
3. Grain size distribution (texture)	For establishing homogeneity of land units and for deriving many characteristics.
4. Soil structure and porosity Bulk density. Pore space volume and distribution. Air-filled pore space at field capacity. Structure stability.	Root environment, nutrient, water and soil management. Drainage Bulk density. Pore space and permeability especially of sodic soils. Leaching of excess salts. Tilth and workability for seedbed and land preparation. Ability to puddle riceland. Erodibility.
5. Infiltration rate	Rainfall and irrigation intake or run-off. Selection of irrigation method. Furrow lengths or basin size. Sprinkler nozzle selection. Erodibility.
6. Hydraulic conductivity or permeability	Soil drainage, removal of excess water and salts.
7. Available water capacity (field capacity and permanent wilting point)	Soil water balance, residual water between and following irrigations. Choice of irrigation method and schedules.
8. Plastic and liquid limits	Indicative of mineralogy and physical behaviour.
9. Soil strength, linear extensibility	Mechanical strength for construction works; swelling and shrinking; root penetration
B. CHEMICAL	
1. Soil reaction (pH)	To identify very alkaline, sodic and acid sulphate soils; nutrient deficiencies and toxicities.
2. Carbon and nitrogen	Organic matter content and management.
3. Gypsum and calcium carbonate	Hardpans, gypsiferous layers liable to subside,

	gypsum; requirements for sodic soils.
4. Electrical conductivity of saturation extract (ECe)	Salinity hazard.
5. Soluble salts (Na, K, Ca, Mg, Cl, SO_4, CO_3 and HCO_3)	Interpretation of salinity hazard.
6. Cation exchange capacity (CEC), total exchangeable bases (TEB) and base saturation %	Nutrient retention and chemical fertility status
7. Exchangeable sodium percentage (ESP) or adjusted sodium adsorption ratio of saturation extract (adj. SAR) :	Sodicity or alkalinity problems.
8. Exchangeable cations (Na, K, Ca,Mg)	Base saturation, ESP, potassium status.
9. Available phosphorus	Availability of macro-nutrients.
10. Total contents of P, K, Mg, Na, Cu, Mn, Zn, B, Fe, AI, As, Ni, Cr	Macro and micronutrient content. Toxic elements.
C. MINERALOGICAL	
1. Sand and silt fraction	Indicates parent material and degree of weathering.
2. Clay fraction and iron and aluminium oxides	1:1 clay minerals less sticky swell and shrink less and have a smaller surface area (and less CEC) than 1:2 clay minerals. 1:1 clay minerals with Fe and Al oxides predominating may prove excessively well-drained for wetland rice, and often physically favourable but chemically less fertile for non-rice crops.
3. Calcium and magnesium carbonates	Hardpans restricting rooting depths. Large amounts decrease nutrient retention and fertility; but soils with 60% $CaCO_3$ can be successfully irrigated but with a restricted choice of crops. Deposition under saline conditions of fine grained material blocks pores and reduces permeability. Surface crusting interferes with seedling emergence and infiltration. Lime-induced nutrient deficiencies. Magnesium carbonate soils often very fertile. High exchangeable Mg leads to sodic-like impermeable profile.

4. Gypsum	Gypsiferous hardpans restrict rooting and make installation of drains and channels difficult. Dissolution may lead to land subsidence after irrigation. Gypsum crystals in soil may offset sodicity tendency. If too high, causes nutrient problems due to unfavourable K/Ca, Mg/Ca ratios and extra costs in fertilizers and soil management.

Source: FAO,1985

Note: The characteristics in Table 2.4 should be evaluated in the context of morphological and geographical considerations.

2.7 Oxygen Availability (OXAV).

Since it is difficult to measure volume of Oxygen , the drainage conditions of the soil is used as a measure of oxygen availability as shown in table 2.5

Table 2.5 Rating of the availability of oxygen (OXAV).

Rating	**Internal drainage**
1. Very high	Well drained
2. high	Moderately well drained
3. moderate	Imperfectly drained
4. low	Poorly drained
5. very low	Very poorly drained

Source : KSS/KARI, 2000

2.8 Soil Properties

2.8.1 Soil Chemical Properties

Soil pH

The pH value of a soil or natural water is a measure of its acidity or alkalinity. More accurately stated, the pH value is a measure of the hydrogen-ion concentration in water. pH values are very important because pH influences many chemical elements and biological processes in the soil.

The optimum pH for most crops lies between 6.5 and 7.5. Soil pH greater than 9 dissolves plant roots. The availability of vital nutrients is closely related to soil pH e.g. acid soils are often low in calcium and magnesium. Some elements such as aluminum, iron, copper and zinc become toxic at low pH. pH values are used to determine the lime requirement of the soil in order to raise the pH value of acidic soils to a point that is better suited to effective crop productivity.

pH varies with the neutral salt concentration. It decreases during the hot dry season when soluble salts accumulate in the soil. These are subject to leaching during the relatively cool rainy season when pH increases again. It was specifically to offset the influence of seasonal variations in soluble salt concentration that Schofield and Taylor (1955) proposed a method for the determination of pH in 0.01M $CaCl_2$. The pH measured in the salt reflects better the intrinsic characteristic of the soil and the value obtained is virtually independent of the initial soil: water ratio. Peech (1965) also claims that a 0.01M Cal_2, solution is approximately equivalent to the total electrolyte concentration of the soil solution of a non-saline soil at optimum field work content, the pH measured in 0.01M $CaCl_2$, or in 1N KC1 represents more nearly the pH of the soil solution under actual field conditions.

Electrical Conductivity (EC),

This is a measure of the total soluble salt concentration in the soil solution. A high degree of correlation exists between the EC and osmotic pressure of soil-water extract. The following relationships may be employed for the evaluation of salt concentration as given by Michael (1978).

Salt concentration, mg/1or ppm =

$$640 * Ec \quad \text{………………..} \quad (2.1)$$

Total cation concentration, me/1 =

$$60 * Ec \quad \text{……………….} \quad (2.2)$$

Osmotic pressure, atmosphere =

$$0.36 + Ec \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

The electrical conductivity is given in mS/cm

Cation Exchange Capacity (CEC)

CEC is the total of all exchangeable cations adsorbed expressed in Cmol per kg of soil. Many soil fertility problems such as leaching of fertilizers, potassium fixation and liming are affected by the capacity of the soil to hold cations such as Ca, Mg, Al, Na, in an exchangeable condition (Gupta, 1989). CEC measurements are commonly made as part of the overall assessment of the potential fertility of a soil and possible response to fertilizer application. Cation exchange in irrigated field occurs during percolation of water through the soil profile and the most important reaction in these soils is Na-Ca exchange (Levy, 1984)

Exchangeable Cations

The cations displaced during a cation-exchange reaction are termed exchangeable bases (Richards, 1954). The exchangeable bases (commonly Ca, Mg, K, and Na) are the primary nutrients. They also influence soil pH. Determinations of the amounts and proportions of the various exchangeable cations present in soils are useful because exchangeable cations markedly influence the physical and chemical properties of soils such as soil structure and nutrient uptake by crops (Landon, 1991).

Base Saturation.

This is the proportion of the CEC accounted for by exchangeable bases (Ca, Mg, K, and Na}. This is more frequently used as an indication of soil fertility than the CEC. However, the base saturation does not distinguish between different bases and imbalances in their relative proportions which can cause severe plant nutrition problems (Landon, 1991).

Soluble Salts

Soluble salts (ions) more commonly determined are Na, Mg, Ca, K, CO_3, HCO_3, C1, SO4, and less commonly, B and NO_3. Soluble salts are those that are readily available for plant uptake from the soil solution. Soluble salts, although composed of similar ions, are not synonymous with exchangeable ions since they are only found in the soil solution and are not held on soil exchange sites (Bower and Wilcox, 1965).

Organic Matter

Soil organic matter refers to the organic fraction of the soil. It includes plant, animal, and microbial residue at various stages of decomposition. Climate and vegetation are the most important factors affecting the soil organic content under natural conditions. On average, soil organic matter contains 58% organic carbon giving a conversion factor of 1.72. The importance of organic carbon determination, therefore, lies in its indication of organic content of the soil which is generally used as an index of soil fertility. With the most routine method for organic carbon determination, the Walkley-Black method, the recovery of organic carbon is conventionally taken as 75%, giving a conversion factor of 1.333.

2.8.2. Soil Physical properties .

Particle Size Analysis.

The solid phase of soils consists of discrete units called primary soil particles. These particles may vary widely in size, shape and composition. The particle size distribution or texture, determines to a large extent the physical and chemical behaviour of soils. Soils are given soil textural classes according to weight percentage of sand, silt and clay as given in a textural triangle. The main separates are:-

Clay < 2 μ m

Silt < 2-50 μ m

Sand < 50-2000 μ m

The determination of the amounts of the various soil separates in a soil sample is called particle size analysis (Day, 1953 and 1965).

Bulk Density (ρb)

Soil bulk density, (ρb), is the ratio of the mass of dry solids to the bulk volume of the soil. The bulk volume includes the volume of the solids and of the pore space. Bulk density values are widely used for the conversion of water percentage by weight to content by volume for the calculation of porosity and void ratio when the particle density is known. Bulk density varies with structural condition of the soil, particularly that related to packing.

Porosity (f)

While bulk density *per se* is a satisfactory measure of the state of compaction of a soil, knowledge of the soil particle density allows the porosity and void ratio to be calculated; the latter two being of more interest to crop production and consolidation of soils respectively (Dekkev, 1991.) An adequate supply of soil solution and soil air especially oxygen to plant roots is essential for plant growth. Soil .solution and air are stored and transported within the soil pores. Also plant roots exist in the soil pores. Harrod (1975) found out that sandy soils with a total pore space less than 40% are liable to restrict root growth.

Infiltration Rate (IR)

This is the vertical intake of water into a soil, usually at the soil surface. Its measurement forms a vital part of many surveys involving irrigation development or soil conservation, e.g. in determining the most efficient method(s) of application of irrigation water, crop water demands and in runoff calculations. It is also an important component of the hydrologic cycle crucial to most hydrologic processes e.g. soil water content, runoff and soil erosion (Boers *et al*, 1992). Know-ledge of infiltration process is therefore a prerequisite for efficient soil and water management (Hillel, 1980b).

Infiltration rate is dependent on many factors among them vegetation, slope, bulk density and initial soil moisture (Parr and Bertrand, 1960; Warrick, 1983). According to Horton (1940) and Wood and Blackburn (1981), infiltration rate is mainly governed by conditions at or near the soil surface. Numerous formulations have been proposed over the years in repeated attempts to express infiltration rate as a function of time or of the total quantity of water infiltrated into the soil. Thus:-

$$i - dI/dt \text{ ………………….. } (2.4)$$

Where i = infiltration rate (cm/hr)

I = cumulative vein me of water infiltrated in time t per unit area of soil surface (cm^3)

Three of the equations proposed were used in a bid to fid\nd out which of them fitted best with the observed infiltration rate values. The three were:-

The power function formulated by Kostiakov (1932).

$$i - Bt^{-1} \text{ …………………… } (2.5)$$

Where B and t are the characterizing constants

This strictly empirical function provides an infinite initial infiltration rate but implies that it approaches zero as t increases, rather than a constant non-zero steady state infiltration rate (i_c).

The Mitscherlic equation formulated by Horton (1940).

$$i- i_c+(i_o-i_c)e^{*t} \text{ ………… } (2.6)$$

Where i_c, i_o and t the characterizing constants.

The term e^{*t} determines how quickly infiltration rate will decrease from initial (i_0) to the steady state (I_c). This equation is cumbersome in practice since it contains three constants which must be evaluated experimentally.

The logistic equation formulated by Philip (1957c)

$$i- i_c+S / 2 t^{½} ………… (2.7)$$

Where i_0 and S are the constants. Here the infiltration rate is once again represented as infinite at zero time. The finite, initial infiltration rate of Horton's equation was in this study found to be more realistic and it fitted best with the observed values. The larger number of characterizing constants in the equation helps to provide a better description of the phenomenon (Skaggs *et al,* 1969). A similar mathematical fit of infiltration rate formulations has been performed by Kironchi *et al* (1993) for Kenyan soils.

Two other equations by Green and Ampt (1911) and by Holtan (1961) both quoted by Hillel (1980b) were not used in the mathematical fits because the former was found to be too shallow and is intended to predict infiltration rate from a ponded surface while the latter contains a characterizing constant ‘M’ (water storage capacity of the soil) whose determination was not made clear by Holtan.

Antecedent Moisture Content (w).

Direct or indirect measure of soil water content are needed in practically every type of soil study. In the laboratory, determination and reporting many physical and chemical properties of soil necessities knowledge of water content (Gardner, 1986).

The antecedent water content affects the behavior of infiltration rate hence the ‘wet run’ and the ‘dry run’ curves differentiated by Hillel (1980b). The wetter the soil is initially, the lower will be the initial infiltration rate and the quicker will be the attainment of the final (basic or constant) rate which is itself generally independent of the initial water content (Hillel, 1982).

Saturated Hydraulic Conductivity (K_{sat}).

The hydraulic conductivity of a soil is the ability of a soil to conduct water. It defines the volume of water which will pass through unit cross-sectional area of a soil in unit time, given a unit difference in water potential (hydraulic head). It is of considerable importance since it gives an indication of the rate of movement of water to plant roots, the flow of water to drains and wells and the evaporation of water from the soil surface.

Comparison made of the hydraulic conductivity rates of different soil horizons gives a guide to water movement and possible drainage problems within soil profiles.
The water retention function is primarily dependent upon texture and structure (Salter and Williams, 1969; Macharia, 1982 and Sessanga. 1982). Storage of water by soils is a result of attractive forces between the solid and liquid phases. The solid (matrix) forces enable the soil to hold water against forces or processes such as gravity, evaporation, uptake by plant roots. (Dekkev, 1991).

Salt increases the energy that must be expended by the plant to extract water from the soil and to make biochemical adjustments necessary to grow under stress. This energy is diverted from the processes that lead to normal growth and yield. The influence of water content upon the soil water suction is different for different soils. The relationship between different soils is shown in different ‘moisture characteristic curves’

Organic matter, due to its hydrophilic nature, influences the capacity of a soil to retain available water irrespective of its texture and mineralogical composition (Salter and Williams, 1969). Sanchez (1976) showed that water retention increased with organic matter. Organic matter has a direct effect through its hydrophilic nature and indirect effect through its modification of the soil structure. Kironchi *et al* (1995) observed that vegetation cover, soil type and land use have an influence on water retention and availability to plants.

2.9. The study Area

2.9.0. Physical environment of the study area

2.9.1. Location and communication

The project area is located in the South – Western corner of South Nyanza in Nyanza Province of Kenya. It is bounded by Lake Victoria to the west, Tanzania to the south, the Kisii- Isabania tarmac road to the east and Migori River to the North.
The lower Kuja Irrigation Development Project is specifically located in Nyatike constituency, Nyatike District of Migori County. It is located approximately 10km west of the Nyatike district headquarters, Macalder.
The extent of the project area covers 7,710ha. It can be reached by murram all weather roads from Macalder to Okenga market or to Ayego market. These roads connect to other market centres notably Nyakweri where the field site office is situated. From Nyakweri one can travel to the north toward Ndhiwa using a murram road but access to the study area is through tracks most of which are not motorable. To the western area towards Angugo there is a Murram road from Nyakweri but accessibility to the area is through tracks again not motorable. To the south there is a murram road to Wathong`er market across the Kuja – Migori River. There

are more motorable tracks on this area due to the farming activities taking place. However, the tracks can only be used during the dry season. Most of the field soil observation area where reached through transect walks in the project area.

The National Irrigation Board (NIB) is a government parastatal under the Ministry of Water and Irrigation established in 1966 by an Act of Parliament, Chapter 347, of the Laws of Kenya, (GOK, 1996), and whose mandate is the development, promotion and management of all National Irrigation Schemes in the country. In line with this the Board is currently managing seven irrigation schemes and four research stations in various regions of the country. In addition the Board is supporting community driven irrigation development programmes in several parts of the country. The Board is in the process of developing the 8^{th} National Irrigation Scheme being another community driven irrigation development programme to be located in Nyatike district of Migori county. The proposed project involves delineation of suitable areas for surface irrigation with the adopted option 2 of having a net irrigation area of 7717 ha.

The proposed project is located in Nyatike district, Nyanza province close to the shores of Lake Victoria within the Lower Kuja River Basin.The project area covers seven (7) locations and twelve(12) sub-locations in Nyatike and Karungu divisions.

The study area,the Lower Kuja Irrigation Development Project,is situated between longitudes 34^{0} 10`0"E and $34^{0}$20`0"E and latitudes 1^{0}0`0"S to $0^{0}$10`0``S and covers an area of about 7,000 hectares,near the shores of Lake Victoria in the South-Western Kenya.The area is found on topographical map sheet Nos.129/1/2 HomaBay,scale 1:50,000(Survey of Kenya,1979)

2.9.2 Population Data of the Project Area

Population data provide information on the size, distribution, composition and other social and economic characteristics of the population.

According to the Kenya Population and Housing Census of August 2009 (KNBS, 2010), the Population of Nyatike district/Conctituency – Migori county, was 144, 625, comprising of 69,209 males and 75,416 females in 30,423 households, with a land area of 677.7 square kilometers, and population density of 213 persons per square kilomtres.

Details of the characteristics of the population of the project area are provided in table 2.6

Table 2.6 : Population Distribution by Sex, Number of Households, Area Density and Administrative units of the Project/Study area.

Administrative unit	Male	Female	Total	Household	Area (Km^2)	Density
NYATIKE	40,610	44891	85501	17724	493.7	173
EAST KADEM	3716	3983	7700	1555	48.2	160
BANDE	1892	2057	3949	818	27.9	141
NYANDANGO	1824	1927	3751	737	20.3	185
KALER	4602	5173	9775	1970	58.7	167
OLASI	2128	2288	4416	870	26.3	168
KIASA	2474	2885	5359	1100	32.3	166
NORTH EAST KADEM	3088	2611	6699	1454	52.3	128
OKENGE	1700	2006	3706	797	27.3	136
KIWIRO	1388	1605	2993	657	25.0	120
NORTH KADEM	4072	4386	8458	1779	51.7	164
BALA	1849	1886	3735	738	18.8	199
MAGUNGU	2223	2500	4623	1041	32.9	144
CENTRAL KADEM	7411	8129	15540	3267	100.8	154
KAKELO KAROTH	2056	2358	4414	937	19.5	226
KARAPOLO	2609	2834	5443	1178	38.5	142
EAST KANYUOR	1692	1754	3446	720	28.4	121
WEST KANYUOR	1054	1183	2237	442	14.4	156

Source : KNBS, 2010.

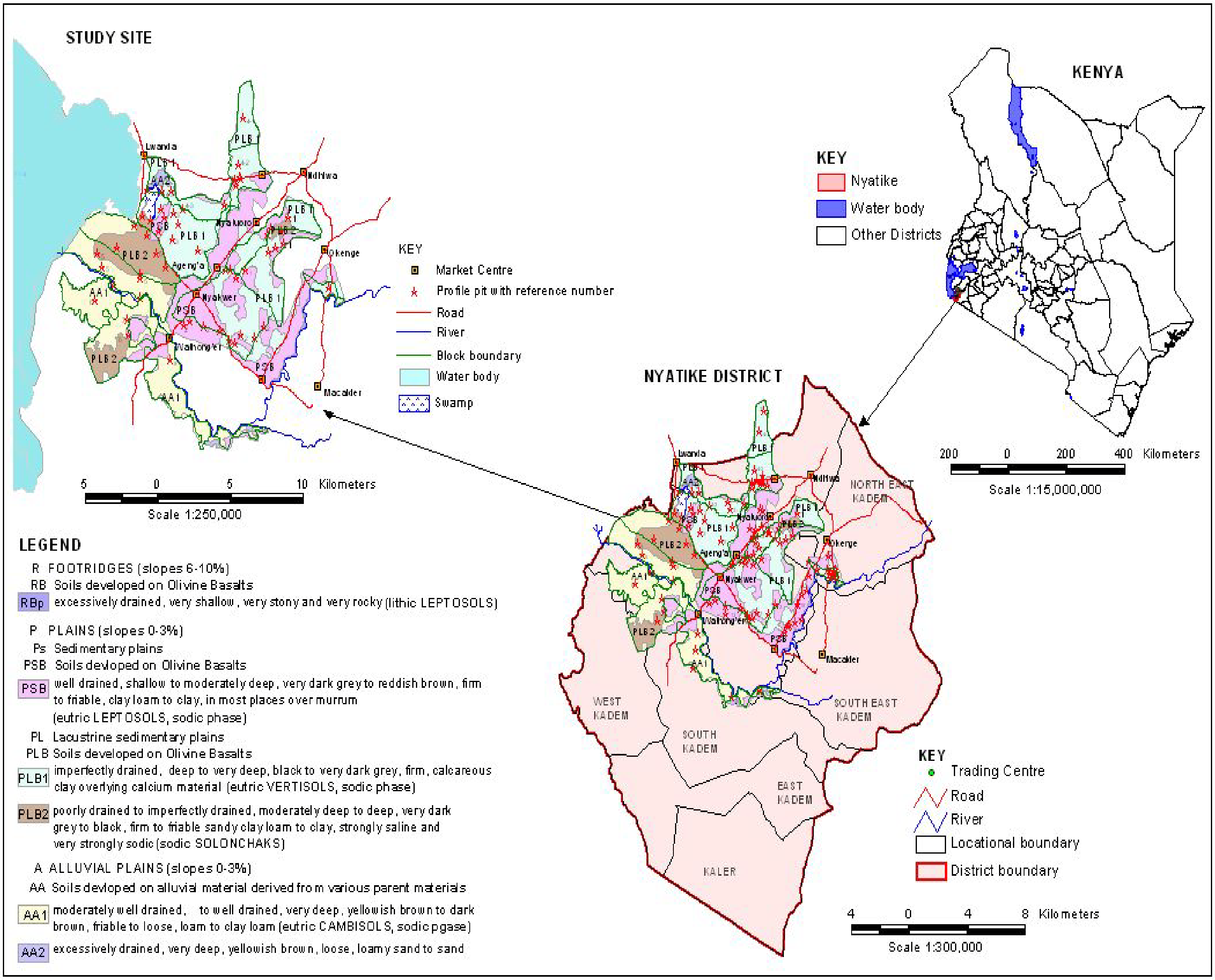

Figure 2.2:Location Map of the Study Area

Source: Kenya Soil Survey(KARI)

2.9.3. Topography

The general topography of the area changes from highlands in the upper Kuja to the plains in the lower Kuja project area. The project area is characterized by an undulating hilly landscape, with elevations ranging from 1130 m.a.s.l near the lake to 1400 m.a.s.l in the east and west, with high peaks and deep and steep valleys, within the river Kuja in the area near Gogo dam before the confluence with Migori River. After the confluence the landscape changes into marshy plain bordering Lake Victoria.

2.9.4. Climate

The climate of the study area is heavily influenced by its geographical location and altitude relative to Lake Victoria. The project area stands in the upper eastern flanks of Lake Victoria, and therefore benefits from the convergence of the easterlies and lake winds. The climate is influenced by two main wind systems, the North Easterlies, and the South Easterlies trade winds. The passage of the Intertropical Convergence Zone (ITCZ) over the catchment results into two seasons.

Rainfall is also influenced by altitude of the area and proximity to the lake. This area is one of the wettest areas within the lake basin. Annual rainfall is about 2100mm on the upper highlands and decreases with altitude eastwards to about 1300 mm in the lower highlands. The mean annual potential evaporation from open water as defined by Penman is between 1300-1600 mm/year.

Daily temperature ranges between 10.1°C - 28.7°C. Average daily temperature is 28.7°C, average night temperature is 10.1°C and night temperature ranges between 8.1°C -11.1°C all the year round. The mean monthly temperature is 19.4°C, while the mean annual temperature ranges between 16.2-18°C, humidity ranges between 50-70%, and rainfall reliability is 60%, The Climate of the catchment changes with altitude from upstream to downstream.

Table:2.7 Rainfall variation in the Kuja - Migori catchment

Month; Station	Kisii F.T.C Alt. 1765 m	Marindi Alti.1600m	Uriri Alti. 1493m	Migori Agric. Alt. 1370m	Macalder mine Alt.1218 m
January	86.9	59	66	55	39
February	91.3	56	73	87	92
March	136	149	192	122	122
April	208.5	288	217	245	201
May	204.5	266	179	195	142
June	134.4	117	90	89	64
July	97.3	77	52	35	37
August	129.4	124	81	59	42
September	137.4	140	97	93	56
October	136.7	191	127	125	89
November	140.3	172	141	148	148
December	97.1	137	111	119	84
Annual aver.	1,591	1,776	1,367	1,371	1,116
60% Reliability		1,481	1,228	1,228	1,000

Source : Nyangaga, 2010

Generally the rainfall decreases from upstream, 1,591mm at Kisii FTC, to downstream 1,116 mm at Macalder mines, it decreases with a decrease in altitude, as shown in Table 2.7 above.

In the project area Lower Kuja, the annual rainfall increases from about 700mm near the lake to 1200mm in the east, with 40% of the precipitation occurring in the long rains (March - May) and 30% in the short rains(October-December). Annual temperature is 23°C at Muhuru Bay and at the lake shore. It ranges between 17-29° C. The absolute minimum and maximum temperatures are 11°C and 37°C respectively. The hottest months are March and October and July is the coldest month.

Rainfall data from four stations neighbouring the project area was used to estimate the rainfall, and the results are shown in Table 2.8.

Table 2.8: The Mean Monthly Rainfall (mm) in the Lower Kuja Project Area

Station	J	F	M	A	M	J	J	A	S	O	N	D	Total
Macalder	56.5	71.7	111.8	196.5	152.8	51.8	31.3	42.5	60.8	83.6	122.3	76.9	1058.5
Karungu	26.8	49.9	98.3	122.8	82.6	30.7	24.9	22.5	23.2	50.	98.5	67.1	697.3
Muhuru 1951-83	51.6	67.5	104.5	168.3	127.7	48.7	27.8	26.6	33.6	62.7	114.9	83.6	917.5
1984-2004 Muhuru	67.1	71.6	138.5	156.7	161.3	27.5	20.2	28.8	30.6	58.3	90.4	82.6	933.5
Rusinga	62.8	51.8	139	211.5	136.5	62.9	41.9	60.1	65.1	58.8	104.9	64.2	1059.5
Mean	53	62.5	118.4	171.2	132.2	44.3	29.2	36.1	42.7	62.7	106.2	74.9	930.3

Source : Nyangaga, 2010

Precipitation is lowest at 42.7 mm in September and 53 mm in January.

There are no rainfall measuring stations within the project area, but there is data from surrounding stations as summarized in the Table: 2.9

Table: 2.9 Annual rainfall at different stations in the project area

Station and Number	Data range	Distance from project area (Km)	Altitude (m)	Mean annual rainfall (mm)
Muhuru Bay -9134009	1951-2004	12	1140	917.5
Macalder - 9034059	1951-83	9	1219	1059
Karungu - 9034074	1956-83	13	1143	697
Ahero Irrigation scheme 9034086	1 970-2009	200	1219	1314
Rusinga	1984-2004	100	1524	1059

Source : Nyangaga, 2010

The project area lies between altitudes 1144m and 1154m, and occurs inside a triangle formed by rainfall stations of Muhuru, Karungu and Macalder. These stations are within about 13 km of Wath Ong'er which is the project area. The other stations of Ahero and Rusinga are far off and at relatively high altitude, 1219m and 1524m respectively, and therefore their data may not give very representative figures for the project area. Based on this argument, the mean annual rainfall for the project area is estimated at 901 mm. Using the rainfall Isohyets, the rainfall for the project area can be estimated at 900 mm, hence the statistical estimated value of 901mm is quite representative. The mean monthly rainfall for the three stations and the low rainfalls (80% probability) are shown in Table: 2.10 and Figure 2.3.

Table: 2.10 Rainfall (mm) and Evaporation (mm) at the Project Area

Month	Rainfall Station			Mean	80% probability	Pan evaporation at Muhuru
	Muhuru	Macalder	Karungu			
January	59.3	56.5	26.6	47.53	13	196
February	69.6	71.5	49.9	63.67	17	175
March	121.5	111.8	98.3	110.6	50	201
April	162.5	196.5	122.8	160.6	103	164
May	144.5	152.8	82.6	126.63	73	156
June	38.1	51.8	30.7	40.2	13	152
July	24.0	31.8	24.9	26.9	6	165
August	27.7	42.5	22.5	30.9	12	179
September	32.1	60.8	23.2	38.7	17	193
October	60.6	83.6	50	64.7	35	206
November	102.5	122.3	98.5	107.77	46	173
December	83.1	76.9	67.1	75.7	35	179

Source : Nyangaga, 2010

Further information on the climate characteristics of the study area is provided in figure 2.3 and Tables 2.11 and 2.12, on mean monthly rainfall, rainfall amounts from selected stations and temperature data respectively.

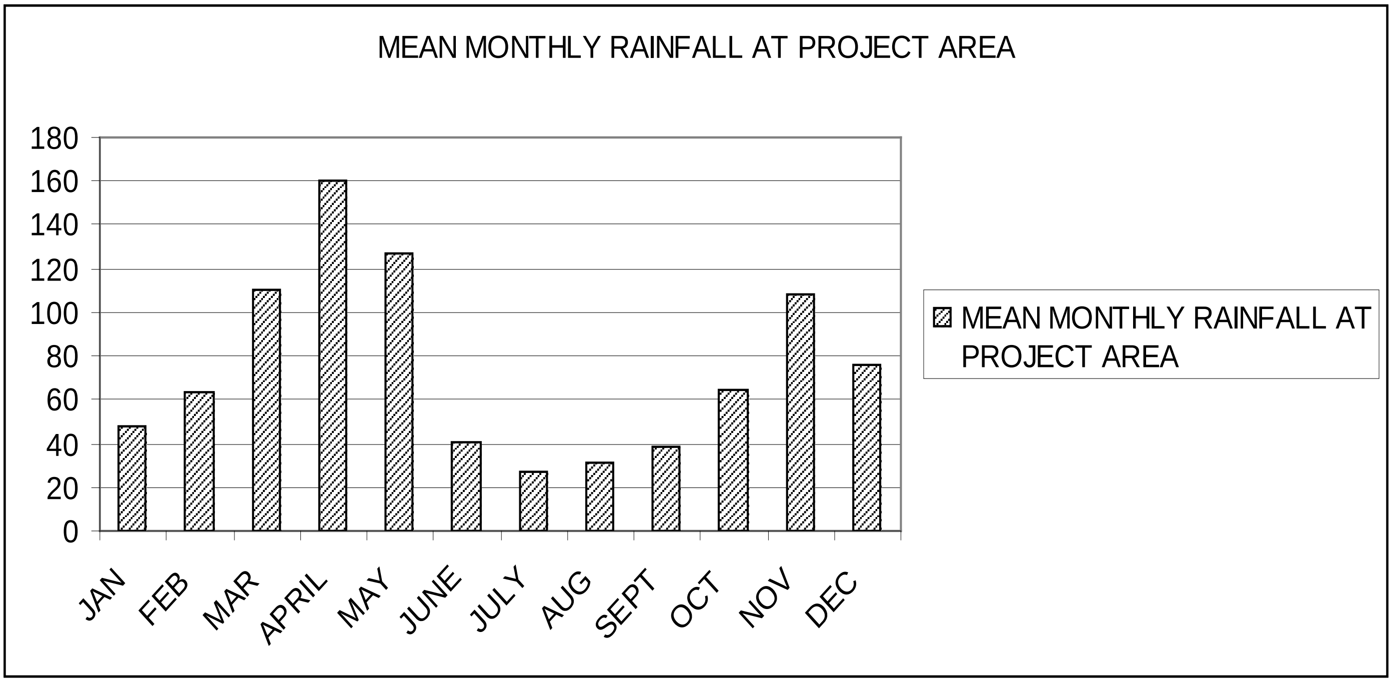

Figure 2.3 Mean Monthly Rainfall Variation over the Year

Source : Nyangaga, 2010

From Figure: 2.3, the rainfall is lowest in the months of June through to September which are generally dry months, before the short rains come in October, rising to a maximum in November. The rainfall then starts to decline in December to reach the lowest amount in January, before it again starts to rise during the long rains period in March. The maximum rainfall occurs in April.

The rainfall characteristics in the project area can be described as being erratic and locolised. This is evidenced by the extreme values at Muhuru and Macalder rainfall stations. The Macalder station has about 142 mm more of mean annual rainfall than Muhuru. However, the maximum monthly falls are high and more frequent at Muhuru than at Macalder, according to the 1951- 1983 rainfall analysis. This is reported by Lotti and Associate's in their report of 1985. For example, over 500 mm of rainfall has been recorded at Muhuru in April 1988 and in November 1961. At Macalder, a maximum of 379 mm was recorded in November 1961.

The lowest rainfall is experienced more frequently at Muhuru than at Macalder, according to the same report. The coefficient of variation between the monthly and annual rainfall results at Muhuru. has been estimated at 42%, a fairly high value compared with 15% at Macalder. These two stations are about 22km apart and at an altitude difference of about 79m. Based on this observation, Nyanganga (2010) concluded that the rainfall characteristics of the project area (Wath Ong'er), borrows from both the Muhuru and Macalder and the 60 % rainfall values are quite similar for the two stations. The data from these two stations can therefore be used competently to estimate irrigation requirements in the project area.

While carrying out an hydrological study,Nyangaga (2010) compared monthly and annual rainfalls.The Mean annual and monthly rainfall maps for East Africa, based on a 1966 study give the smallest mean annual rainfall value of 785mm, which is a very conservative figure. The 1984 study gave 890mm, and the present study got 901.7 mm, which seems to agree with the isohyets map of the area., which puts the study area at 900 mm.

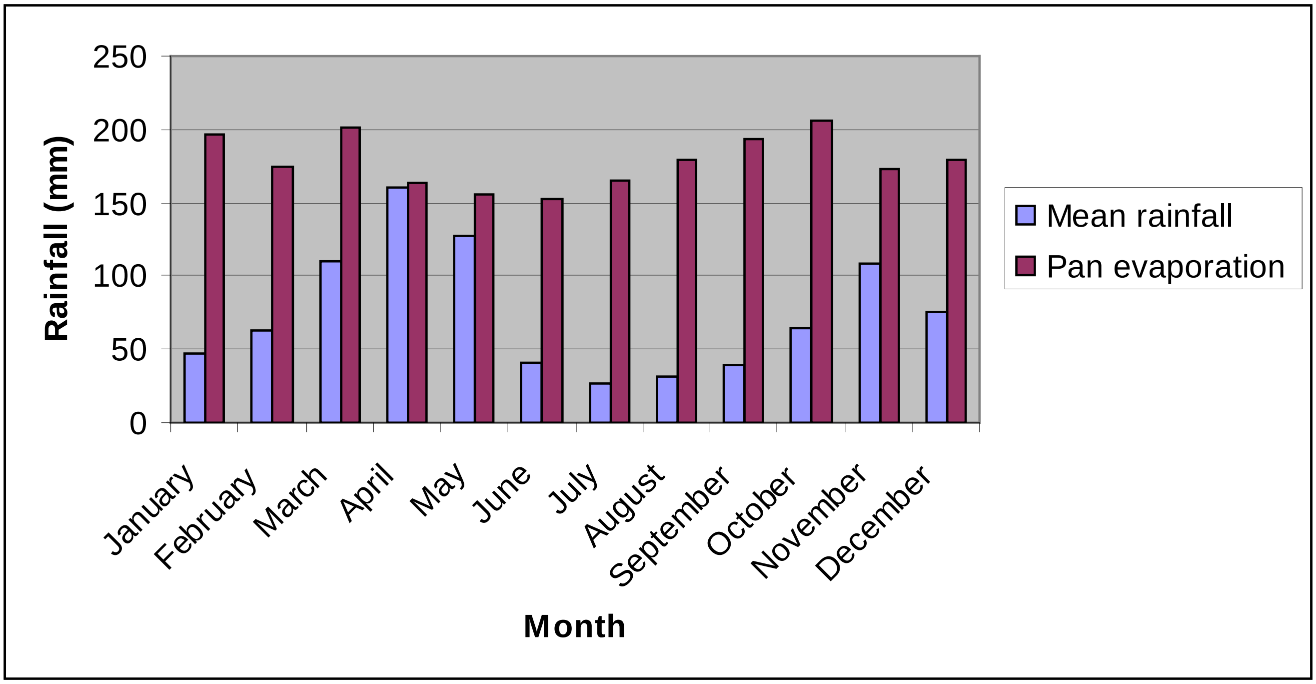

Figure 2.4: Mean Monthly Rainfall and Evaporation relationship at the project area.

Source : Nyangaga, 2010

Table 2.11: Rainfall Figures from Selected Typical Stations Having at Least 15 Years of Recordings

No. and altitude	Name of station	Agro ecol. Zone and subzone	Kind of records	Annual rainfall mm	Monthly rainfall in mm											
					J	F	M	A	M	J	J	A	S	O	N	D
9034059 1220 m	Macalder Agr. Office	LM 4 (m/si +vu)	Av. 66%[1]	618[3] 562	45 32	33 19	97 85	89 68	83 64	28 16	19 5	23 19	38 26	39 25	67 54	58 38
9034074	Karung	LM 4	Av.	740	25	57	115	132	94	30	26	19	22	50	100	70

1142 M	u Bay Chief's Office	(m/si +vu)	66%[1,2]	-	-	-	-	-	-	-	-	-	-	-	-	-
9134009 1218m	Muhuru Bay Hydromet. Stn	LM 5 (s/m +vu)	Av. 66%[1]	775 700	45 24	53 30	101 88	158 138	120 92	44 38	23 15	28 17	25 15	56 47	89 60	71 51
9134010 1370m	Migori, Tree & Fruit Nursery	LM 3 1m i (m/s)	Av. 66%[1]	1369 1226	61 44	87 64	125 87	234 165	185 130	88 60	40 20	61 50	96 83	123 90	153 112	116 85
9134025 1255m	Migori Water supply	LM 2 1/m ^ (m/s) i	Av. 66%[1,2]	1524 -	79 -	102 -	154 -	254 -	187 -	85 -	62 -	89 -	100 -	136 -	187 -	100 -

1. These figures of rainfall reliability should be exceeded normally in 10 out of 15 years.
2. Estimate by correlation, or not calculate because not enough years available to GTZ.

Source: MOA/GTZ,2009

Table 2.12: Temperature Data

No. and altitude	Name of station	AEZ	Kind of records	TEMPERATURE °C													Belt Limits
				J	F	M	A	M	J	J	A	S	O	N	D	Yr.	
9034059 1220m	Macalder Agr. Office	LM 4	Mean max Mean temp Mean min Abs. min	30.4 23.9 17.3 11.7	30.8 24.5 18.1 12.8	30.7 24.4 18.1 13.9	29.8 23.8 17.7 13.9	29.6 23.7 17.7 12.2	29.8 23.6 17.3 12.8	29.5 22.6 16.6 12.2	29.6 23.2 16.7 11.1	30.2 23.5 16.8 13.3	30.5 23.7 16.9 9.4	30.4 23.6 16.8 12.8	29.8 30.4 16.9. 12.8	30.1 23.7 17.3 9.3	1550m LM 1050m

Source: MOA/GTZ,2009

2.9.5. Geology and Hydro-geology

The geologic characteristics of a basin influence the rate and extent of groundwater - surface water interactions. The geology of the River Kuja catchment varies from upstream to downstream as discussed below.

According to the geology of the project area as was surveyed from 1947-1949 and published by Huddleston (1951) the project area forms part of the Kisii highlands. It is a sub-mountainous landscape, shaped by deeply weathered pre-Cambrian volcanic rocks of the Bukoban system within the Nyanzian and Kavirondian rock systems. The rock system consists of mainly basalts and basaltic tuffs, quartzites and cherts, rhyolites and tuffs, porphyritic and non-porphyritic felsites and andesites. The Bukoban non-Porphyritic basalts are exposed west of Kisii town. They are fine grained and grey-blue to greenish in colour. The Bukoban quartzite and cherts outcrops can be seen along the Manga Ridge, North of Kisii town. They are fine - medium grained and white- bluish in colour. They are believed to be as a result of a sedimentation process which took place in shallow water The Bukoban andesite and felsites overlay the quartizites. They are fine grained with deep red or purple colour. The Bukoban rhyolites and tuffs are the youngest of the Bukoban system and cover the highest areas. They are fine grained, light - dark in colour. These rock systems have greatly influenced the soil characteristics of this area and therefore potential agricultural productivity of the area.

In the project area, 50% is covered by granites of Precambn'an age, volcanic and volcano sediments (of the Nyanzian system) cover about 25%, 3% of the area is covered by conglomerate sandstones of the Kavirondian system of the Precambrian age, 4% of the area is covered by tertiary basaltic lavas, 3% by diorites, and 15% of the area is covered by recent sediments.

2.9.6. Present Land Use

Majority of the people practice subsistence farming of crops and livestock, while substantial number grows sorghum mixed with maize. Horticultural crops, notably tomatoes, kales and tobacco are grown at a small scale. Most people in the area keep indigenous cattle and chicken around their homes and community graze the cows in the poorly drained areas, wetlands, during the dry seasons, charcoal burning also exists in the area.

2.10. Previous Soil Studies in the Project Area

The geological report and map at scale of 1:125,000 covers the area in general (McCall,1958). The general description of the soil of the project area is given in the Farm Management Handbook (MOA/GTZ, 2009). A more generalized soil map was produced, covering the whole of Migori and Nyatike districts. The soil information was mainly based on the five (5) adjacent fertilizers use recommendation project sites (FURP) of Kenya Agricultural Research Institute (KARI), conducted between 1986 and 1992 (KARI, 1994).

The fertilizer use recommendation project (FURP) of the GTZ from 1986 till 1992 had 5 trial sites in South Nyanza district:one at Rodi Kopani in Agro-Ecological zone LM2 (on vertisols), one at Rongo in agro-ecological zone LM1 (on Acrisols), one at Homa Bay in Agro-Ecological zone LM3 (on phaeozems), one at Oyugis – Ober in Agro- Ecological zone LM2 (on phaeozems) and one at Mukuyu – Korondo in Agro-Ecological zone LM2 (on Cambisols).

In general terms, the area is also covered by the general countrywide exploratory soil map at a scale of 1:1 million (Sombroek, et al, 1982), the reconnaissance map of the Lake Basin Development Authority are at a scale of 1:250,000 (Anderriesse and Van der Pouw, 1985), and the draft report on the soils of Homa-Bay – Migori area (Oostearom, 1984).

All the above soil reports are based on existing reports, photo-interpretation and extrapolation with limited fieldwork. Therefore they cannot give detailed soil information at the specific proposed lower Kuja irrigation development project area site.

The soil units indentified in the above reports describe the soils in general and lack proper soils characteristics in terms of detailed soils field study work and soil laboratory analysis.

Therefore, the study was aimed at among others, studying the project area in detail to provide soil information in sufficient detail to enable the evaluation of soils suitability for irrigation in Lower Kuja Irrigation development project area. The soil survey in Kano plains (D'costa, 1973),where characterization and interpretation of soils of the Kano plains for irrigated agriculture was carried out,provide useful information.

At a similar scale as this study, Omoto (1994), while carrying out a study on the soil resources of Ruma National Park in Lambwe Valley carried out a semi- detailed soil survey that identified four major physiographic units containing ten soil mapping units . Some of the soil mapping units included calcareous vertisols, shallow topsoil and cambisols,and show some relationship to the soil of the project area,specifically the black cotton soils.

Therefore, the information availed by these previous reports serve as a useful basis for a more detailed survey.

However, part of the project areas, covering approximately 3,150 ha was previously surveyed by the Lake Basin Development Authority a quarter of a century ago (WLPU/LBDA, 1985), and the following two major soils identified;

Soils of the flood plains:

Considered the youngest in the study area; of recent alluvial deposits, river flood plains, meander plains and depressions, going discontinuously from South to North but more represented in the northern section of the study area.

They are characterized by fine texture varying from silt loam to heavy clay; they are deep but generally compact subsoil and badly structured. They are poor or very poorly drained. They belong to the humic Gleysol class, with the interface of chromic Vertisols having a single undifferentiated profile with an acid humic topsoil. Their colour varies from brown-greyish brown into dark grayish brown. They are affected by not noticeable saline concentration and/or

sodicity. In the northern-central part of the area, the recent alluvial deposits - near the water causes – have better physic- structural characteristics. Their characteristics are typical of Fluvisols.

Soils of the ancient alluvial deposits and residual plateau.

These are terraced deposits with a rather rolling surface and are composed of deep stratified soils with a medium texture and rather low clay content; there is usually a fair amount of organic matter in the mollic horizon. The soils of these areas have medium texture and are moderately well drained, they vary from deep to moderately deep, and are dark brown to dark greyish brown in colour and can be included among the haplic Phaeozems. They are characterized in places by a high sodic and saline content, which greatly limits both the permeability and present use of the soils.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Introduction

A semi- detailed level soil survey study at scale 1:50,000, was carried out at the proposed lower Kuja Irrigation Development project area occupying an estimated area of 7000ha.

An office and/or desktop study involving review of previous soil and natural resources survey studied in and around the project area was done. This included examination of the topographic maps, old soil reports, geology report, present land uses, agricultural practices and other related farming activities and utilization of the natural resource- base in the project area.

A pre- field study visit was undertaken to acquaint with the study area and meet local project leaders, Project elders, block representatives, opinion leaders and government and non-governmental organization officials involved with the project. Also conducted were the local farmers, residents and traders.

During this visit, several informal meetings, discussions and interactions were held across the project area.

During the field soil study, a systematic field transects and free surveys across the project area with simultaneous use of soil augering, minipits and physical observations of soil, vegetation and other physiographical land characteristics, were applied to identify and site soil profiles to be opened for detailed soil profile examination. The selected representative soil profiles were examined and described and soil samples obtained for laboratory analysis.

Both disturbed composite samples and undisturbed samples were obtained for respective physical and chemical laboratory tests.

Several auger holes, mini-pits, road cuts, gully and river cuts and soil profile observation were used tentatively to delineate the major soil units in the project area, pending confirmatory soil laboratory analysis.

Photographic data collection was used to augment the field data collections, alongside other land physiographic features.

Representative infiltration tests were conducted at selected soil profiles in the identified and delineated major soil units, as shown in plates 3.1 and 3.2.

PLATE 3.1 Soil Profile

Source:Own Field Data Collection 2010(Soil Profile)

PLATE 3.2 Infiltration Test

Source:Own Field Data Collection 2010(infiltration test)

Soil samples were analyzed for chemical parameters and necessary indices derived and applied for classification of soils and final delineation of soils units within the project area.

Data obtained was subjected to statistical analysis for correlations (Pearsons Correlation) and univariate analysis of variance, among others as outlined by Ebdon (1985). A suitability soil map was finally produced, together with recommendations for soils irrigation suitability.

3.2. Field Soil Study Methods

3.2.1 Field Survey – Soil Inventory

A digital map from aerial photo mosaic was made and formed the base map indicating the tentative soil boundaries. This base map was used to locate the exact position, where observations were made using a global positioning system (GPS).

The actual field soil survey work was conducted during the months of July to September 2010, with the soils laboratory analysis, evaluations of soils suitability for irrigations and the compilation of a suitability soil map following thereafter.

The field surveys begun with a general orientation of the demarcated and blocked project area, to get a broad pattern of the geology, landforms, vegetation, current land uses, agricultural practices and local indigenous knowledge on general soil properties and peculiar occurrences and general drainage in relations to the soils by use of routine soil augering and physical observations and augmented by photography. Auger-hole observations were made upto a depth of 120cm or to the rock and/or parent materials, which ever was shallower, and soil and land characteristics entered in the standards auger hole observation forms. Minipits were dug upto a depth of 50cm or to the rock whichever was shallower.

The density of observations was low where the observed field changes and land physical characteristics were uniform. However, where the two had marked difference or were transitional many observations were made. Land and soil characteristics were fully described, examined and recorded in the standard auger hole and minipit forms as used by Soil Science department, University of Nairobi. Soil descriptions are based on "Guidelines for soil profile description" (FAO, 1977)

At each auger hole observation site information was described and recorded on; land form, relief geology, slope, drainage conditions, vegetation, land use/ human influence, rock outcrop, surface stoniness, sealing/crusting, cracking, and geographic location. vegetation was described in terms of structure type percentage cover by trees, shrubs, grass and bare ground, and a note on the most common or dominant species. The soil material from the anger was, described and examined for colour, texture, mottling, consistency, occurrence of lime, concretions, reaction to HCL/salts, characteristics and thickness of soil horizons and soil depth.

Differences in these features from the top to the bottom of the hole enabled the subdivision of the soil into horizons. The soil colours were determined using soil colour charts (Munsell, 1990).

In order to make detailed description of each soil mapping unit, representative site were selected and profile pits opened. Rectangular soil profile pits with dimensions 1m x 2m with a depth of at least 150cm, or to the bedrock, whichever was shallower, were made. Land and soil properties at each profile pit site were described and examined in detailed and recorded in the standard Kenya soil survey soil profile form.

In addition to the data captured under auger hole observation, the other soil properties considered in the profile pits included; soil structure, horizon boundary topography, horizon designation, root distribution, cutans, cracks, pores, soil fauna, erosion, flooding, effective soil depth and ground water table.

After detailed description of the profile, soil samples were taken from each genetic horizon for both physical and chemical laboratory analysis.

A total of 56 soil augerholes and 116 profile pits, road cuts, river/gully cuts and mini pits were described and examined in detail.

All the soil augering sites, profile pits, mini pits and other observation points were marked, numbered and recorded in GPS and assigned a reference number. All the sites were also photographed.

Some selected profiles were further augered to check if any layers were present deeper in the sopil which might affect water movement during irrigation.

3.2.2. Determination of the Hydraulic Properties of Soils

The hydraulic characteristics of the soils of the study area were assessed both in insitu and in the laboratory. Infiltration rates were measured at the representative soil profile pits using double ring infiltrometer method as described both by Klute, A (Ed), In: Methods of soil analysis part 1 (Bouwer, 1986) and Booker Tropical Soil Manual (Landon, 1991).

From some selected representation profile pits, undisturbed core soil samples were obtained for the determinations of saturated hydraulic conductivity, bulk density and porosity.

3.2.3 Sampling Blocks

The project study area was demarcated into 9 blocks (M, 1, 2, 3, 4, 5, 6, 7, 8) by the project designers for ease of irrigation water distribution and management. Study observations and sampling was carried out per each block. Details of each sampling block in terms of size, mapping, unit class and soil conditions and crop suitability factors are presented in Appendix F.

3.2.4 Source of Irrigation Water

The proposed Lower Kuja Irrigation Development Project will utlize water from the Kuja-Migori River . The Kuja-Migori catchment is made up of two main rivers: River Kuja and River Migori and hence the name (Kuja-Migori Basin) . The Migori River has its headwaters in the hills, Upper Kilgoris in Transmara District, and drains in Mirogi, Kuria , Uriri and Nyatike districts emptying its waters into River Kuja. The Migori River joins Kuja at Karapolo area and then the formed Kuja-Migori drains into Lake Victoria between Karungu and Gurekeri area. The Kuja and Migori rivers join just upstream of Wath'Onger bridge, but downstream of the proposed intake site at Okenge area. The combined Kuja-Migori River system drains the project area into Lake Victoria near Karungu Bay.

3.2.5 Water Quality

Irrigation water must be compatible with both crops and soils to which it will be applied . Historical water quality data for the Kuja-Migori basin is scarce, but data based on some samples analysed between 2006 and 2009 by Lake Victoria Environmental Management Program (LVEMP) and reported by Nyanganga (2010) are shown in tables 3.1 and 3.2

Table 3.1 : Water Quality at Macalder

PARAMETER	UNIT	DATE			
			9/26/2007	9/7/2008	11/20/2008
Discharge	$m/^3sec$		31.11		
Temperature	^0C			24.1	25.2
PH	Ph Scale		6.50	7.56	7.2
DO	Mg/I		96.2		7.6
Turbidity	N.T.U		84.5	171	361

Conductivity	µS		0.200	75	96.9
Tp	mg/I	0.28			
PO4	Mg/I				
Total N	Mg/I	2.00	2.18		
TSS	Mg/I	578	104.33	200	165
TDS	Mg/I		50.8	37	48.5

Table : 3.2 Water Quality at Kuja – Migori

Parameter/date	**9/4/06**	**11/13/06**	**12/9/06**	**6/9/06**	**9/27/07**	**12/13/07**	**6/13/08**	**9/6/08**	**6/6/09**
Discharge (m3/s)	0.927	0.093	309.178	155.72	24.21	130.00	0.5		4.530377
Temperature (c)	27.2	21		23.1		21.10	19.6	24.8	20.9
PH	8.35	8.20		7.17	7.10	7.60	7.70	7.43	8.12
DO	7.16	6.70							7.56
Turbidity	90.8	148	453		70.1	600	75	113	108
Conductivity	168	175	95.3	106.6	142.3	90	157.8	163.2	246
Tp	0.164	0.31	0.50		0.158				
PO4			3.88						
Total N		2.06	3.88		1.97				
TSS	32.75	85		425.9	29.50		150	60	100
TDS			57.3	53	85.5	40	79	82	123

3.3. Laboratory Methods

All soil samples collected from the study project area were analyzed in the laboratory using the standard procedures followed at both the Soil Research Laboratory of the Department of Land Resource Management, Faculty of Agriculture, University of Nairobi and at the National Agricultural Research Laboratory, Kabete, KARI (both NEMA designated laboratories) (GAZETTE NOTICE NO. 6829 of 25.7.2008).

Sample preparation was carried out by breaking of soil aggregates by carefully pounding with pestle and mortar, and sieving through a 2 mm sieve. The fine earth fraction (less than 2 mm) was used for further analysis.

Soil samples were analyzed for both physical and chemical parameters.

3.3.1. Physical Laboratory Methods.

The soil texture was determined by the hydrometer method (Gee and Baunder, 1986; cited in Klute 1986). Limited chemical treatments were used to remove cementing agents. Samples were shaken overnight with calgon (sodium hexametaphosphate and sodium carbonate) solution in an end-to-end mechanical shaker at 40 r.p.m.

A measurement of silt + clay (0-50 mm) and clay (0-20 mm) was done with a hydrometer ASTM 152H hydrometer after 40 seconds and 3 hours respectively. The sand fraction (50-200 mm) was obtained by difference (Day, 1965). Soil textural classes were then read directly from the standard U.S. Department of Agriculture textural triangle (Soil Survey Staff, 1975). Soil bulk density was determined by using the core method (Blake and Hartage, 1986; cited in Klute 1986). The soil samples were oven dried for 24 hours at 105^0C, cooled in a desiccator and then weighed. The bulk density (e_b) was calculated as follows:

$$e_b = \frac{Ms}{Vt}, \qquad \text{where; } \frac{\text{Ms = weight of oven dry soil}}{\text{Vt = volume of the soil at field condition.}}$$

….(3.1)

The saturated hydraulic conductivity (Ksat) was determined by the constant head method as outlined by Klute and Dirkensen (1986).

3.3.2. Chemical Laboratory Methods

Soil Reaction (pH) and Electrical Conductivity (EC):

The pH was measured with a glass electrode pH meter on 1:2:5 suspension of soil in water and on 1N Kcl solution, in all cases after shaking for 1 hour, as described by Black (1965). The electrical conductivity was also measured on the 1:2:5 soil-water suspension using direct reading conductivity meter using electrodes and the results reported in ds/m. For samples with an Ec greater than 0.8 ds/m a saturation extract was prepared for additional pH and Ec determination.

Organic carbon: The percentage organic carbon was determined by the Walkley and Black method (Nelson and Sommer, 1982: cited in Pace *et al*., 1982). The percentage of easily oxidizable organic carbon was determined by digesting the soil samples with potassium dichromate in the presence of concentrated sulphuric acid.

Total nitrogen: The total nitrogen was determined by the kjedhal method (Bremner, 1967: cited in Pace *et al* 1982). Organic nitrogen compound were digested in a mixture of selenium and sulphuric acid. Sodium hydroxide was added to the mixture to make it absorbed in boric acid. The released ammonia was determined by titrating with dilute sulphuric acid.

Phosphorus: The total phosphorus was extracted with 0.5M $NaHCO_3$ solution at pH 8.5, a reagent which controls the removal of calcium phosphate (Hinga *et al*., 1980). The phosphorus in solution, derived from calcium and iron phosphate, was determined calorimetrically as a blue phosphomolybdic complex reduced as a mixed reagent comprising sulphuric acid, and potassium antrinomyl tartrase (Murphy and Ridey, 1962: cited in Pace *et al*., 1982).

Cation Exchange Capacity (CEC) and Exchangeable Bases: 2.5g soil were percolated with 100ml 1N $NH_{40}AC$ at pH 7.0; Na and K were determined directly on the flame photometer; Mg and Ca were then determined by atomic absorption spectrophotometer (AAS), after dilution with lanthium. The samples were leached subsequently with 100ml normal sodium acetate pH 8.2, 100ml 95% ethanol, and 100ml 1N $NH_{40}AC$; Na in the leachate was determined by flame photometer (Black, 1965 and Hinga, *et al*., 1980).

Mass Analysis for Available Nutrients (P, Mg, Ca, K, Na and Mn): This was performed for the composite topsoil samples only. The soil was extracted by shaking for 1 hour at a 1:5 ratio with 0.1 N HCl and 0.025 N H_2SO_4. The Ca, K and Na was determined by flame photometer after and anion resin treatment for Ca, for Mg the same procedure as for exchangeable Mg. For phosphorus the vanadomolybdomophosphoric yellow method was followed. Manganese was measured colorimetrically using phosphors acid-potassium periodate for colour development.

Micronutrients analyzed included iron (Fe), copper (Cu) and zinc (Zn) and were determined by methods outlined by Black (1965), Landon (1991) and Hinga *et al*., (1980).

3.3.3. Derived Parameters

The following soil parameters that are applicable for soil survey studies were derived according to standard calculations as outlined by Landon (1991), Hinga *et al*., (1980) and KSS staff (1987) and as follows:

$$\text{Base Saturation Percentage} = \frac{\text{Sum of Cations}}{\text{Cation exchange capacity}} \text{ X } 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (3.2)}$$

$$\text{Exchangeable Sodium Percentage (ESP)} = \frac{\text{Exchangeable Sodium}}{\text{Cation exchange capacity}} \text{ X } 100 \ldots\ldots\ldots \text{(3.3)}$$

$$C/N \text{ Ratio} = \frac{\text{percentage Carbon}}{\text{percentage Nitrogen}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

Soil porosity was derived from values of bulk density and soil particle density, while available water capacity (AWC) was estimated from values of soil texture and soil depth as outlined by Salter (1972).

3.4. Data Analysis and Presentation.

3.4.1. General Soil Data Interpretation

The generated soil data was subjected to general interpretation to be able to describe general soil properties. Guidelines used are provided in both appendix B and C, in the interpretation of selected soil and land properties and evaluation of selected soil physical and chemical properties . Addional guidelines are provided in table 3.3 – 3.6. Available water capacity (AWC mm/m) was estimated using guidelines provided in appendix D.

3.4.2. Soil Data Analysis

Soil data were analyzed using statistical methods such as ANOVA, Correlations, and The Student-Newman-Keuls (SNK) test. This test is used whenever ANOVA results are statistically significant. It is not a conservative test method. The Student-Newman-Keuls (SNK) method makes all pairwise comparisons of the means ordered from the smallest to the largest using a stepwise procedure. SNK is preferred because it makes adjustments for the error rate for multiple comparisons. In other words, it is not a rigid test like Duncan's Multiple Range Test.

3.5. Soil Map Legend Composition and Construction

In the legend of the soil map the physiographic classification provided the frame work of the map units. The soil survey approach used related the soils to the major landforms and the type of parent material on which they occur, resulting in a physiographic soil map. A three-level hierarchical system of legend construction has been used (KSS, 1987; Van de Weg, 1978). The landform subdivision is at the highest level, a geological subdivision at the second level, and soil mapping units characteristics separated within each physiographic-geological unit at the third level.

Each area delineated on the soil map is identified by a code which is the combination of the relevant codes for physiography, geology and soils of that particular area. In the codes of the map units, the first capital letter refers to the landform. For each landform a description is given of the overall slope class and relief intensity. Some landforms have been subdivided into subunits. Within each landform a further subdivision according to geology takes place, forming the second entry in the code.

The third entry in the legend describes the main soil units. Each mapping unit code contains one or more codes that express the soil properties. The description refers mainly to the characteristics of the subsoil, usually to a depth of 100 cm. The soil colour refers to the moist colour of the subsoil based on the Munsell soil colour chart (Munsell, 1990). All other descriptions follow the FAO guidelines for soil profile description (FAO, 1977; Hodgson, 1978; Soil Survey Staff, 1951). Some of the soil characteristics described include: drainage, depth, calcareousness, salinity, alkalinity, sodicity and stoniness.

In addition each soil map unit area is characterized by the dominant slope class, for which a code is written under the soil map unit code. The map unit description in the legend is followed by the taxonomic classification of the soil using FAO-UNESCO system (1990). All the mapping units are briefly described in the legend of the soil map.

Systematics and Nomenclature

The codes used are as follows

Physiographic units:

- R - Footridges
- P - Plains
- A - Alluvial plains
- S - Swamps

Geology or parent material:

- B - Olivine Basalts
- A - Alluvial material

Soils:

p - Very shallow to shallow

b - brown

Other differentiation in the soils is indicated by numerical numbers.

The degree of salinity, sodicity, alkalinity, stoniness and calcareousness are also mentioned in the description. Some of the terms used are explained in the appendix

Differentiating criteria

Differentiating criteria used in the legend and the description of the mapping units and representative profiles are:

Texture, structure and other characteristics such as concretions and consistence were described according to the "Guidelines for soil profile description" (FAO, 1977). Colour of the soils were described according to the Munsell Soil Colour Charts.

Table 3.3: Soil reaction: The following classes in soil reaction and the corresponding rates are used.

Class	**pH-H_2O**
extremely acid	<4.5
strongly acid	4.5-5.5
slightly acid	5.6-6.5
neutral	6.8-7.3
moderately alkaline	7.4-8.4
strongly alkaline	8.5-9.0
very strongly alkaline	>9. 0

Table 3.4: Soil salinity: The following salinity classes and corresponding rates are used.

Salinity class	**EC(mmho/cm)**	**ECe (mmho/cm)**
Non-saline	<4	>1.2
Slightly saline	4-8	1.2-2.5
Moderately saline	8-15	2.5-5.0
Strongly saline	>15	>5.0

Table 3.5: Soil sodicity: The following sodicity classes and corresponding rates are use

Sodicity class	ESP%
Non sodic	0-5
Slightly sodic	6-10
Moderately sodic	11-15
Strong sodic	>15

Table 3.6: Soil fertility class

Parameters	Deficient	Sufficient	Rich
K me%	< 10 ppm	0.2-1.5	> 80
Ca me%	<5 ppm	2-10	>3
Mg me%	< 1 ppm	1-3	> 10
Mn me%	0-20 ppm	0.1-2	> 1.5
P	<0.1	20-80 ppm	> 80 ppm
Cu	<1.0		
Zn	<2.0		
Fe	<0.2		

C% <1.0 low 1-2 moderate 2-4 adequate > 4 rich

N% <0.2 low

A cording system was employed to name the soil units identified in the map and a brief description (legend) given on the map accompanying this report. Physiography was given the first preference hence the first entry in the legend represents the physiographic unit. The second one represents the geology or parent material, while numerical numbers were used to differentiate units based on their characteristics like depth, colour, stoniness, rockiness.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.0 General Soil Properties and Interpretations

The results are presented in various tables, figures and appendices . Detailed descriptions are presented in appendices A1 – A12 , while chemical and physical data is presented in tables 4.1 – 4.8 . Soil chemical characteristics and soil fertility are presented in tables 4.9 – 4.13

4.1 Description of the Soil Mapping Units

4.1.1 The Soils of the Footridges .

The footridges occur along the river Kuja going from north to south before joining the river Migori. They have convex slopes of 6-10%. Originating from Olivine Basalts, the soils are excessively drained, very shallow and very stony and rocky. This is a narrow strip of land along the river Kuja and is predominantly bush. There was no observation in this unit. The soils classify as Lithic LEPTOSOLS.

4.1.2 The Soils of the Plains

4.1.2.1 Soils of the Sedimentary Plains – PSB

The soils of this unit are developed from aggregation of Basalts and Iron rich materials. The soils are considered older than those of the other plains. They are also slightly raised than the other soils of the plains with flat to gently undulating macrorelief 1-3%. The soils are well drained, shallow to moderately deep. The colour ranges from very dark grey to reddish brown. They are firm to friable, clay loam to clay in most places over murram. The structure is weak to moderate, medium angular to subangular blocky.

The soils are mainly mildly alkaline to moderately alkaline with pH-H_2O values of 7.4 to 8.2. There are inclusions which are neutral in the top soil and slightly acid in the subsoil 6.9 and 6.4 respectively; they are non saline throughout the profile with Electrical Conductivity (EC) ds/M values of 0.3 to 1.3. They are slightly to moderately sodic. Exchangeable sodium percentage (ESP) % values of 7.6 to 8.5 and m10.7 to 11.4. The inclusion are non sodic with values of 0.5 to 3.0. Percent carbon (%C) is moderate in the topsoil with values of 1.4 to 1.7 while it is low to moderate in the subsoil with values ranging between 0.6 to 1.3 Percent nitrogen (%N) is low both in the topsoil and subsoil ranging between 0.02 to 0.08. Cation Exchange Capacity (CEC) (Cmol/kg) has values of 16.3 to 48.2 in the topsoil and 16.6 to 29.4 in the subsopil. Base saturation percent (BS%) is very high with values of 92 to 97 in the topsoil and 97 to 99 in the subsoil.

Most areas where these soils occur are used as settlement areas and also for subsistence farming with sorghum as dominant and maize as a minor crop. They classify as Eutric LEPTOSOLS Sodic phase.

Table 4.1. Chemical and physical data for profile No. BLK 2-2 soil mapping unit PSB.

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-17	7.7	0.3	1.4	0.15	16.3	16.0	98	7.9	38	28	34	CL
17-23	8.2	0.4	1.3	0.06	26.4	26.0	98	7.6	29	23	48	C

Soil classification; FAO/UNESCO 1994, Eutric LEPTOSOLS sodic phase

4.1.2.2 Soils of the Lacustrine Sedimentary Plains. PLB1

The soils of this unit are developed from aggregation of Basalts and calcium rich material. The soils occur is broad depressions with flat to very gently undulating macrorelief of 0-2%. They are imperfectly drained, deep to very deep, black to very dark grey. They are firm when moist, very sticky and very plastic when wet moderately calcareous clay overlying calcium rich materials. The structure is moderate to strong, medium subangular to angular – blocky.

The soils are neutral to mildly alkaline in the topsoil pH 7.1 to 7.4 and moderately alkaline in the subsoil 7.8 to 8.4. The soils are non saline throughout the profile with EC ds/M values of 0.2 to 0.8 % carbon is quite variable both in the top soil and the subsoil with values of 1.5 to 4.0 moderate to adequate in the top soil and 0.4 to 2.6 low to adequate in the subsoil. The % C fluctuations in the subsoil indicate that materials rich in organic matter (O.M) were deposited at different times. % Total Nitrogen is generally low throughout the soil unit with values below 0.2. The soils are non sodic to moderately sodic with ESP % of values 2.2 to 13.4. However there are some profiles which are strongly sodic. CEC Cmol/Kg is high with topsoil values of 30.1 to 43.9 and subsoil values of 20.0 to 47.9. Base saturation percent is high in this unit and range from 93 to 100.

Most areas of this soil are used for grazing and charcoal burning. Few places in the northern end of the project area in block 4/1 are used for growing maize and sugarcane. The soils are classified as Eutric VERTISOLS, sodic phase.

Table 4.2. Chemical and physical data for profile No. 4/1-1 soil mapping unit PIB1

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-23	7.5	0.3	2.1	0.18	42.6	39.7	93	2.3	19	17	64	C
23-57	7.2	0.4	1.8	0.10	41.4	39.4	95	11.8	26	15	59	C
57-80	7.8	0.3	2.6	0.14	7.9	7.6	96	6.3	33	13	54	C

Soil classification; FAO/UNESCO 1994 Eutric VERTISOLS sodic phase

4.1.2.3 Soils of the Lacustrine Sedimentary Plains PLB2.

This unit occur together with unit PLB1 and is difficult to differentiate in certain cases especially in block 5/1. However the soils found in blocks 1 and 7 are easy to distinguish from the whitish salt crystals accumulating in patches and the brackish water also formed on the surface.

The soils developed from Basalts and calcium rich materials and also rock rich in sodium in block 1 and 7. The source of high sodium in block 5 appears to come from external sources from a small stream passing through the "bala" area of block 1 and disappearing at the contact of blocks 2 and 3. This extremely saline water seems to find its way to depressed areas of block 5 which are flood for a reasonable period of the year. The soils are poorly drained to imperfectly drained, moderately deep to deep, very dark grey to black and with light yellow brown bands. The soils are firm to friable sandy clay loam to clay, weak, medium, subangular to angular blocky structure.

These are neutral to extremely alkaline with pH-H_2O values of 6.8 to 10.6 in the topsoil and 7.9 to 10.5 in the subsoil.

They have very high levels of exchangeable sodium (Na) Cmol/kg of between 18.0 and 46.0. They are non-saline with EC (ds/M) value m0.3 to 5.2. % C is very low to high in the topsoil with values of 0.4 to 3.0 and very low to medium in the subsoil values of 0.1 to 1.7. Total N % is very low to low throughout the profiles 0.01 to 0.21. Cation Exchange Capacity Cmol/kg is high to very high in the topsoil values of 26.5 to46.7 and medium to very high in the subsoil values of 23.8 and 60.4. Base saturation is very high with values of 80 and 100 in the topsoil and subsoil. The soils are strongly sodic to extremely sodic in the topsoil values of 20.1 to 69.2 and very strongly sodic in the subsoil values of 39.1 to 81.7.

The area is used for grazing and is covered by wooded bushland. Some of the plants which are indicative of high salinity found in the area include "Ong'ono" *Capparis erythriocarpos*; "Osani" *Leptochloa obtusiflora*;

“Mswaki” *Salvandora bressica*. These soils with high salt accumulation have saline properties and high sodium accumulation as indicated by high ESP values, hence they classify as Sodic SOLONCHAKS.

Table 4.3 and 4.4: Chemical and Physical data for Soil Mapping Unit PLB2

Table 4.3 BLK 5-10

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-11	10.6	1.0	0.4	0.04	29.6	28.0	95	69.2	63	22	15	SL
11-25	10.5	2.0	0.1	0.04	23.8	23.8	97	75.6	40	27	33	CL
25-50	10.3	1.5	0.1	0.03	29.5	29.5	98	64.7	17	32	51	SiCL

Soil classification; FAO/UNESCO 1994; Sodic SOLONCHAK

Table 4.4, BLK 1-6

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-15	9.0	2.0	3.0	0.21	46.7	37.5	80	42.8	26	29	45	C
15-30	10.5	5.2	1.4	0.06	52.8	52.6	100	81.7	26	41	33	C
30-42	10.5	5.0	1.1	0.06	60.4	60.4	100	72.8	26	33	41	CL
42-74	10.3	2.3	1.0	0.03	53.9	53.6	100	72.3	28	29	43	C
74-100	10.3	2.5	0.7	0.04	42.3	41.4	98	67.1	28	26	46	C

Soil classification; FAO/UNESCO 1994; Sodic SOLONCHAK

4.1.3 Soils of the Alluvial Plains

4.1.3.1 Soil Mapping Unit AA1

This unit comprises the old alluvial floodplain bordering the Kuja Migori River in block 5, 6, 7 and 8. Generally, it is flat to gently undulating with slopes of 0-3%. The soils are developed from alluvial deposits originating from various parent materials.The soil of this unit are moderately well drained to well drained, very deep, yellowish brown to dark brown, friable to loose, loam to clay loam. The structure is weak, fine to medium subangular blocky and massive. They are slightly acid to neutral in the topsoil with pH-H_2O values of between 6.3 to 7.3 and slightly acid to mildly alkaline in the subsoil ranging between 6.1 and 7.8. They are non saline because of the low EC (ds/M) values between 0.2 and 0.3 in the topsoil and subsoil. Cation exchange capacity values range from 12.6 to 26.1 in the topsoil and 10.2 to 29.1 in the subsoil. Therefore they range from medium to high in the topsoil and low to high in the subsoil. Base saturation is high both in the topsoil and sub soil with values of 70 to 100. Exchangeable sodium percentage values indicate the soils are non sodic in the topsoil with values of 2.0 to 5.7 and non-sodic to slightly sodic in the subsoil with values of 2.1 to 8.8.

Percentage carbon is low to medium in the top soil with values between 0.9 and 2.1 and very low in the subsoil with values ranging between 0.4 to 1.0, while total Nitrogen is very low to low both in the topsoil and subsoil with values between 0.01 and 0.1 7.

The greater part of this unit is cultivated with sorghum and maize as the dominant crops with horticulture as the minor crop.

The soils classify as Eutric CAMBISOLS, sodic phase.

Tables 4.5, 4.6 and 4.7 chemical and physical data for soil mapping unit AA1

Table 4.5 BLK 7-2

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-17	7.3	0.3	2.1	0.17	26.1	25.8	99	5.7	48	32	20	L
17-45	7.2	0.3	1.1	0.11	28.7	28.8	100	7.3	50	33	17	L
45-87	7.8	0.3	1.0	0.08	26.6	26.5	100	7.8	18	45	37	SiCL
87-120	7.4	0.2	1.0	0.10	27.1	27.1	100	8.8	22	43	35	CL

Soil classification; FAO/UNESCO 1994; Eutric CAMBISOL Sodic phase.

Table 4.6 BLK 8-4

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-13	6.3	0.2	0.9	0.11	13.6	12.6	92	2.0	22	25	53	C
13-34	6.1	0.2	0.6	0.08	10.2	7.1	70	2.1	20	37	43	C
34-100	6.3	0.2	0.5	0.07	7.6	6.8	89	3.7	22	45	33	CL

Soil classification; FAO/UNESCO 1994; Eutric CAMBISOL.

Table 4.7 BLK 5-6

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-18	6.9	0.2	1.6	0.04	21.6	21.1	98	6.9	31	36	33	CL
18-34	7.2	0.2	0.8	0.01	26.2	26.0	99	5.7	38	33	29	CL
34-82	7.4	0.2	0.4	0.08	21.1	20.2	96	7.1	70	17	13	SL
82-150	7.4	0.2	0.8	0.08	29.1	28.7	99	5.2	32	33	35	CL

Soil classification; FAO/UNESCO 1994 Eutric CAMBISOLS, Sodic phase

4.1.3.2 Soil Mapping Unit AA2

The soils of this unit are excessively to well drained, very deep, very dark grey to yellowish brown sandy loam to sand.

They are mildly alkaline in the top soil pH-H_2O values 7.5 and neutral to mildly alkaline in the subsoil pH values 7.0 to 7.7. They are non saline EC values of 0.2. Organic carbon percentage values are medium in the topsoil and low in the subsoil 1,5 and 0. 7 respectively. Total Nitrogen is adequate in the topsoil 0.3 and very low in the subsoil 0.08. CEC is adequate in the topsoil and low in the subsoil with values of 14.3 and 10.2 respectively. Base saturation is high both in the topsoil and subsoil with values between 91 and 95. The soils are non sodic to slightly sodic with ESP values of 4.2 to 7 in the lower part of the profile.

Some parts of this unit in block 4/3 is used for sand harvesting. The soils classify as Haplic ARENOSOLS.

Table 4.8 Chemical and physical data for profile No. 4/3-4 soil mapping unit AA2.

Depth cm	pH-H_2O	EC ds/M	C%	N%	CEC Cmol/kg	Sum of cations	BS%	ESP%	Sand	Silt	Clay	Texture Class
0-35	7.5	0.2	1.5	0.3	14.3	13.0	91	5	75	8	17	SL
35-57	7.0	0.2	0.8	0.08	11.8	11.2	95	4.2	89	4	7	S/LS
57-97	7.7	0.2	0.7	Trace	10.2	9.6	94	7.0	83	3	14	LS/SL

Soil classification; FAO/UNESCO 1994; Haplic ARENOSOLS.

4.1.4 Classification of Soils in the Study Area

The soils classification is based on FAO-UNESCO Soil Map of the World Revised Legend 1994. The required characteristics for these particular soil classification units which occur in the project area are summarized.

Leptosols:

These soils are limited in depth by continuous hard rock or highly calcareous material; diagnostic horizons may be present, mollic, umbric or orchric A horizon; with indurated layer within 30cm of the surface. In the survey area both Eutric and Lithic leptosols occur.

Vertisols:

Soils having, after the upper 18cm have been mixed 30 percent or more clay in all horizon to a depth of 50cm; developing cracks from the soil surface downwards which at some period in most years are at least 1cm wide to a depth of 50cm. In the survey area Eutric Vertisols are found.

Cambisols:

Soils having a cambic B horizon and no diagnostic horizon other than an Ochric or Umbric A horizon or a Mollic A horizon overlying a cambic B horizon with a base saturation by NH4AOC of less than 50 percent; lacking salic properties, lacking the characteristic diagnostic for vertisols or Andosols; lacking gleyic properties within 50cm of the surface. In the survey area Eutric Cambisols are found.

Solonchaks:

These soils have salic properties and do not show fluvic properties. They have an A horizon, a histic H horizon, a cambic B horizon, a calcic or a gypsic horizon. In the project area Sodic Solonchaks are found.

4.1.5 Soil Chemical Characteristics and Soil Fertility

4.1.5.1 Soil Reaction (pH)

Soil reaction which is a measure of the degree of acidity or alkalinity of a soil is normally expressed by the negative logarithm of the hydrogen activity in the soil/water suspension or extract.

The bulk of the soils in the project area are neutral to moderately alkaline pH values 6.6 to 8.4, however a few are strongly alkaline to very strong alkaline pH values 8.6 to 10.6.

4.1.5.2 Cation Exchange Capacity and Exchangeable Bases.

The cation exchange capacity (CEC) Cmol/kg of the majority of the soils in the area are medium to high CEC values between 13.4 to 40 with a few in the very high bracket more than 40 and very few in the low 6-12. The base saturation is the degree to which the exchangeable bases saturate the exchange complex of the soil. The major exchangeable bases are Calcium (Ca), Magnesium (Mg), Potassium (K) and Sodium (Na) normally expressed in Cmol/kg. The soils of the project area have a high base saturation of between 70 and 100 percent. The exchangeable bases are adequate to high. The CEC and the base saturation are important in that they influence chemical and physical soil properties. Normally soils with a high CEC and a high base saturation are potentially fertile soils as they may provide adequate supply of plant nutrients. In this survey the bulk of the soils have medium to high CEC and a high base saturation, therefore providing adequate plant nutrients. It is important to note that the majority of the soils are low in organic carbon percent values between 0.60 to 1.25 and total nitrogen is very low to low between 0.10% to 0.20%. The availability of nutrients for uptake by plants depends not only upon absolute levels but also on nutrient balances.

4.1.5.3 Salinity and Sodicity.

Saline soils have an electrical conductivity EC greater than 4 ds/M at 25^{o} and an exchange Sodium percentage (ESP) less than 15. The pH value of the saturated soil is usually less than 8.5. Saline sodic soils have EC values greater than 4 ds/M at 25^{0} C and ESP values greater than 15. Sodic soils have ESP values greater than 15 and EC less than 4 ds/M at 25^{o} . Using the differentiating criteria, the majority of the soils have a sodic phase.

4.1.5.4 Soil Fertility Aspects

The soil fertility is based on composite samples which were collected around the profile pits. These samples were not collected on the normal practice of 0-30 cm. This procedure is only suitable where no profile pits exist. To ensure uniformity with the actual top soil the sampling depth was that of the particular profile which is more realistic. The availability of nutrients for uptake by plants depends not only upon absolute levels but also on nutrient balances. In the majority of these soils the balances are favourable for most crops – as indicated in the following tables which are presented per soil mapping unit.

Table 4.9 Mapping unit PSB Eutric Leptosols; sodic phase

Profile Nos. Top Soil	2/2	2/3	M/11	M/15	1/1
pH-H_2O	7.7	6.9	6.0	7.2	7.4
Na cmol/kg	1.3	Trace	0.9	1.0	1.0
K cmol/kg	0.3	3.0	0.5	1.5	0.8
Ca cmol/kg	12.7	11.5	8.1	10.7	7.5
Mg cmol/kg	1.7	3.6	5.0	7.0	37.5
Mn ppm	0.7	0.6	0.4	0.5	0.4

P ppm	15	12	22	12	7
N %	0.15	0.20	0.16	0.11	0.08
C %	1.4	1.7	1.5	0.9	1.4
Fe ppm	0.1	0.1	62.1	48.7	0.1
Cu ppm	0.1	0.1	4.6	4.7	0.1
Zn ppm	0.1	0.1	1.8	2.3	0.1

Soil pH is medium acid to mildly alkaline, sodium is adequate, potassium mostly low with two sites having high to very high; calcium is medium to high; magnesium is dominantly high. Manganese is adequate, phosphorous is low in the whole unit; nitrogen is generally low in the whole unit; organic carbon is moderate throughout the unit; most units have low iron with few places where it is adequate; most areas are deficient in copper, with few places which have adequate supply. Zinc is deficient throughout the unit.

Table 4.10: Mapping unit PLB1 Eutric Vertisols; sodic phase

Profile Nos. Top soil	4/1-1	4/3-1	3/1	1/13	M/13	2/12	4/2-3
pH-H_2O	7.5	6.9	7.5	7.7	6.0	7.0	7.4
Na cmol/kg	1.0	3.3	0.5	1.5	0.8	0.3	3.3
K cmol/kg	4.8	2.8	3.3	1.3	0.4	1.5	3.6
Ca cmol/kg	31.7	18.7	17.2	17.1	8.5	6.2	29.6
Mg cmol/kg	2.2	4.3	2.7	5.7	3.1	5.4	6.8
Mn ppm	0.8	1.0	0.9	0.9	0.4	1.0	1.1
P ppm	280	10	633	26	5	18	40
N %	0.18	0.10	0.29	0.10	0.10	0.1	0.3
C %	2.1	1.2	4.0	0.7	0.8	0.7	1.7
Fe ppm	0.1	0.3	0.1	54.1	23.0	45.1	0.1
Cu ppm	0.1	0.1	0.1	3.8	3.2	4.4	Trace
Zn ppm	0.1	Trace	0.2	4.4	0.6	0.6	Trace

Soil pH is medium acid to mildly alkaline, sodium is adequate but very high in block 4/3-1 and 4/2-3; potassium is high to very high; calcium is generally high to very high; magnesium is predominantly high; while manganese is sufficient; phosphorous is predominantly deficient except for blocks 4/1-1, 3/1 and 1/13; total nitrogen is predominantly low while organic carbon is low to adequate; iron is low but adequate in blocks

1/13; M/13 and 2/12. Copper is deficient except in block 1/13; M/13 and 2/12 while Zinc is deficient in the whole unit.

Table 4.11: Mapping unit PLB2 Sodic Solonchaks.

Profile Nos. Top soil	5/3	1/6	5/10	3/2
pH-H_2O	6.1	9.0	10.6	7.4
Na cmol/kg	2.5	20.0	20.5	1.5
K cmol/kg	2.3	2.0	0.1	0.8
Ca cmol/kg	6.5	13.3	6.9	0.7
Mg cmol/kg	4.5	2.2	0.5	0.3
Mn ppm	2.0	1.6	1.8	0.4
P ppm	10	255	155	32
N %	0.3	0.21	0.04	0.17
C %	3.2	3.0	0.4	0.6
Fe ppm	2.9	0.1	0.5	0.4
Cu ppm	0.2	Trace	0.1	0.1
Zn ppm	0.1	Trace	0.1	Trace

Soil pH is mainly mildly alkaline to strongly alkaline, while sodium is predominantly high; which means that the soil are extremely sodic, potassium is medium to high while calcium is basically adequate; magnesium is low to medium; manganese is adequate while phosphorous is sufficient; total nitrogen is low to sufficient and organic carbon is low to adequate; iron, copper and zinc are deficient in the whole area.

Table 4.12: Mapping AA1 Eutric Cambisols; sodic phase.

Profile Nos. Top soil	5/6	7/2	8/4
pH-H_2O	6.9	6.7	6.3
Na cmol/kg	1.5	2.7	0.3
K cmol/kg	2.3	0.2	1.6
Ca cmol/kg	13.7	16.4	5.6
Mg cmol/kg	3.6	4.3	5.0
Mn ppm	0.3	0.9	1.4
P ppm	70	8	67
N %	0.04	0.18	0.1

C %	1.6	1.7	0.9
Fe ppm	0.4	0.7	55.7
Cu ppm	0.1	0.2	3.4
Zn ppm	0.1	0.1	6.8

Soil pH is slightly acid to neutral the most ideal for plant growth; sodium is generally adequate; though very high in 7/12 while potassium is adequate; calcium is adequate in the whole area – as well as magnesium and manganese; phosphorous is sufficient except in 7/2; total nitrogen is deficient in these soils while organic carbon is moderate; both copper and zinc are deficient including iron except in 8/4 for the three micro nutrients.

Table 4.13: Mapping unit AA2 – Haplic Arenosols

Profile Nos. Top soil	5/6
pH-H_2O	7.5
Na cmol/kg	1.0
K cmol/kg	1.3
Ca cmol/kg	9.6
Mg cmol/kg	1.1
Mn ppm	0.6
P ppm	400
N%	0.3
C %	1.5
Fe ppm	0.18
Cu ppm	0.1
Zn ppm	Trace

Soil pH is mildly alkaline, sodium is adequate as well as potassium, calcium and magnesium. Manganese is sufficient as well as phosphorous; both total nitrogen and organic carbon is moderate, iron, copper and zinc are deficient.

4.1.6 Soil Infiltration Rate

Physical characteristics of the soil which determine to a large extent the water retention and transmitting properties, the workability and structure stability are of importance for assessing the irrigation suitability. Chemical characteristics, particularly Sodicity and its interaction with salinity influence and possibly determine the physical characteristics of the soil.

Infiltration rate is the vertical intake of water into a soil, usually at the soil surface. Its measurement forms a vital part of many soil surveys involving irrigation development. It is also an important component of the hydrological cycle, crucial to most hydrological processes. Knowledge of infiltration process, through data generated during field surveys is therefore a prerequisite for efficient soil and water management.

Irrigation water management require accurate information on the rate at which different soils will take in water under different conditions. The infiltration rate determines how much water will enter plant root zone during irrigation. Restricted infiltration rates affect the water economy of plant communities by denying them sufficient moisture for growth. It is therefore apparent that full utilization of the soil profile for water storage is necessary and that the infiltration process is an important phenomenon affecting not only agricultural production but also ecological and hydrological aspects of the land.

Measurements of the infiltration rate were carried in the field by means of cylinder infiltrometer, in the proximity of selected soil profiles in the major identified soil mapping units in all the blocks of project area. Values obtained are given on tables 4.14 and 4.15. and infiltration curves presented in figures 4.1 – 4.5.

Table 4.14: Infiltration values of the major soil units identified:

Blocks	**Soil unit**	**Profile Nos.**	**Infiltration Rate (cm/hr)**	**Infiltration Class**
1,2,7,8,M	PSB – (Eutric LEPTOSOLS, Sodic phase)	2/1, 1/1,7/1,8/10,M/14	4.2	Moderate
1,2,4,3,M	PLB1 – (Eutric VERTISOLS, Sodic Phase)	4-1/1, 3/1, 3/5, 2/5, 1/7,2/2,M/2,M/1	2.4	Moderate
1,3,5,7	PLB2 - (Sodic SOLONCHAKS)	1/6, 5/2, 3/7,7/3	3.2	Moderate
5,6,7,8	AA1 (Eutric CAMBISOLS, Sodic phase)	6/1, 7/2, 8/1, 5/9,	7.4	Moderately Rapid
4/3, 8	AA2 (Haplic ARENOSOLS)	4-3/4	21.7	Rapid
2,M	RBp (Minor) (Lithic LEPTOSOLS)	M/18		

Table 4.15: Infiltration characteristics of the soil units:

Time	PSB: Eutric LEPTOSOLS	PLB1: Eutric VERTISOLS	PLB2: Sodic SOLONCHAKS	AA1: Eutric CAMBISOLS	AA2: Haplic ARENOSOLS
1	167	210	130	132	290
2	142	205	110	96	180
3	135	200	100	60	108
4	130	190	90	36	98
5	120	186	72	35.8	72
6	90	168	60	30	66
7	72	120	60	24.6	54
8	70	108	48	24.0	52
9	70	100	48	19	46
10	68	90.0	42	18.6	46
12	58	66	40	18.0	44.8
14	45	54	36	15.0	42.0
16	36	30.0	30	14.8	35
18	33	24.0	27	12.5	33.9
20	30	18.0	24	12.0	33.9
25	25	15.0	21	11.2	33.1
30	21	12.0	18	10.5	33
35	20.3	9.0	15	9.0	32.0
40	17.2	6.0	12	8.8	31
45	15.0	5.0	9.6	8.0	28
60	13.6	4.8	9.0	7.9	25.2
75	9.0	3.6	7.2	7.5	24.5
90	6.0	3.0	6.0	7.5	22.0
120	4.2	3.0	4.8	7.4	21.7
150	4.2	2.4	3.6	7.4	21.7
180	4.2	2.4	3.2	7.4	21.7

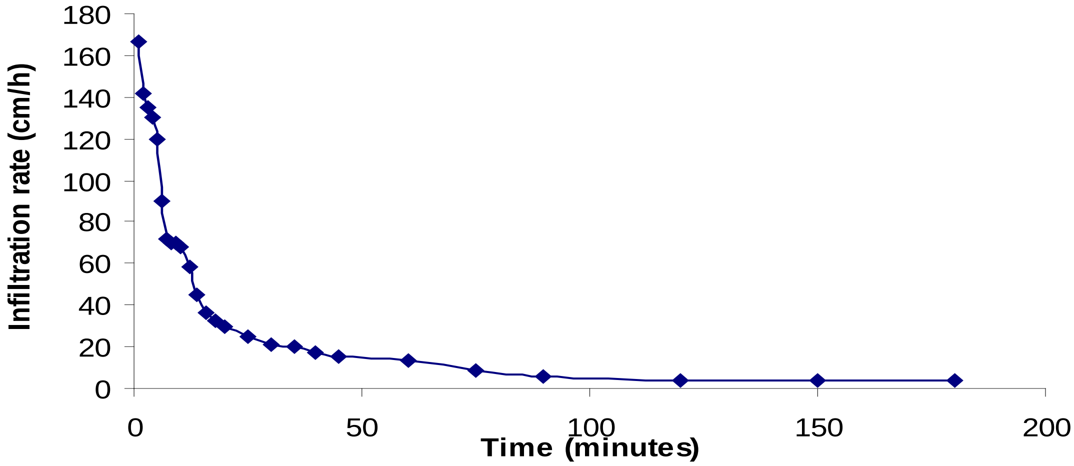

Figure. 4.1: Infiltration curves: PSB Eutric LEPTOSOLS

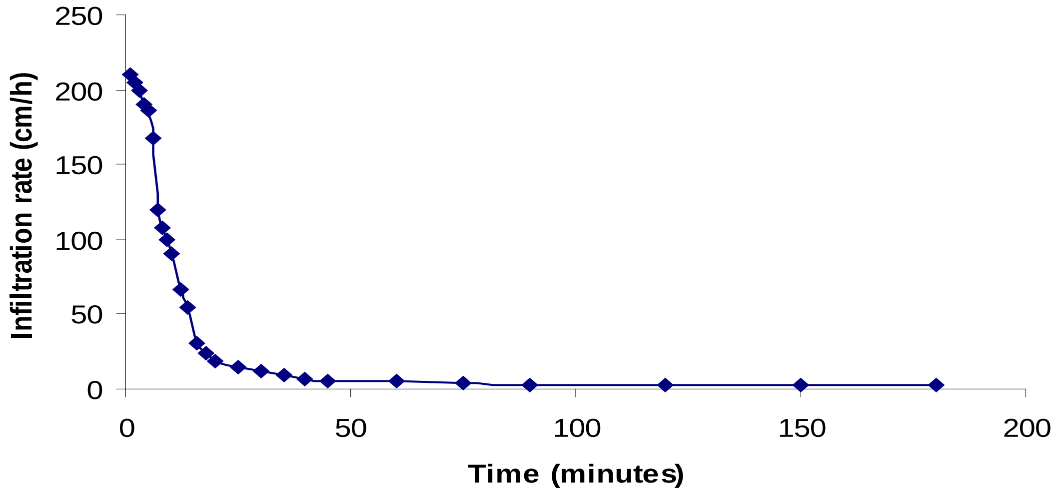

Figure 4.2: Infiltration curves: PLB1 Eutric VERTISOLS.

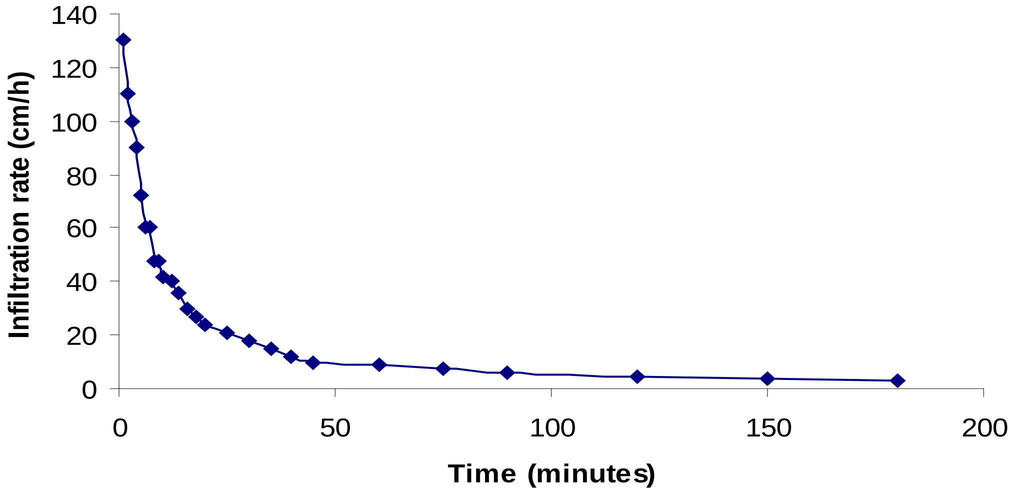

Figure 4.3: Infiltration curves: PLB2 Sodic SOLONCHAKS

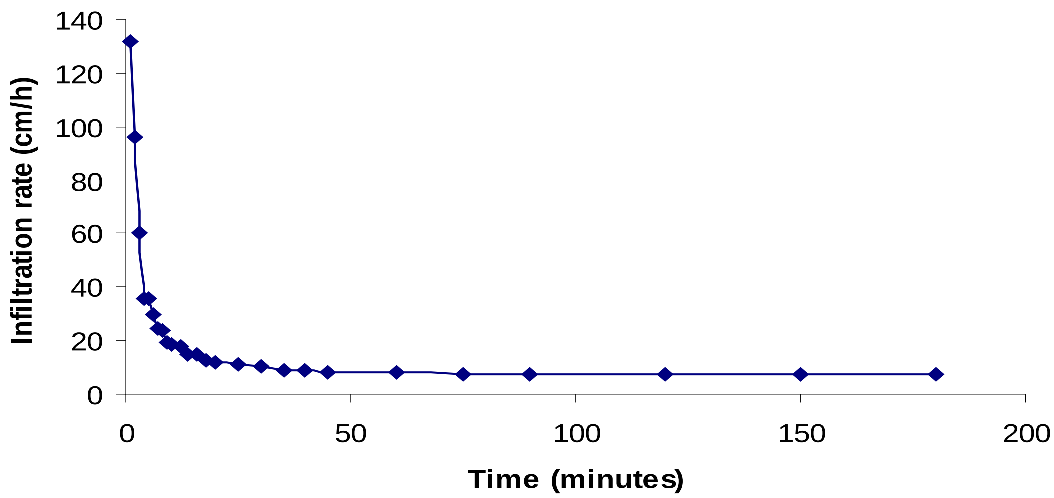

Figure 4.4: Infiltration curves: AA1 Eutric CAMBISOLS

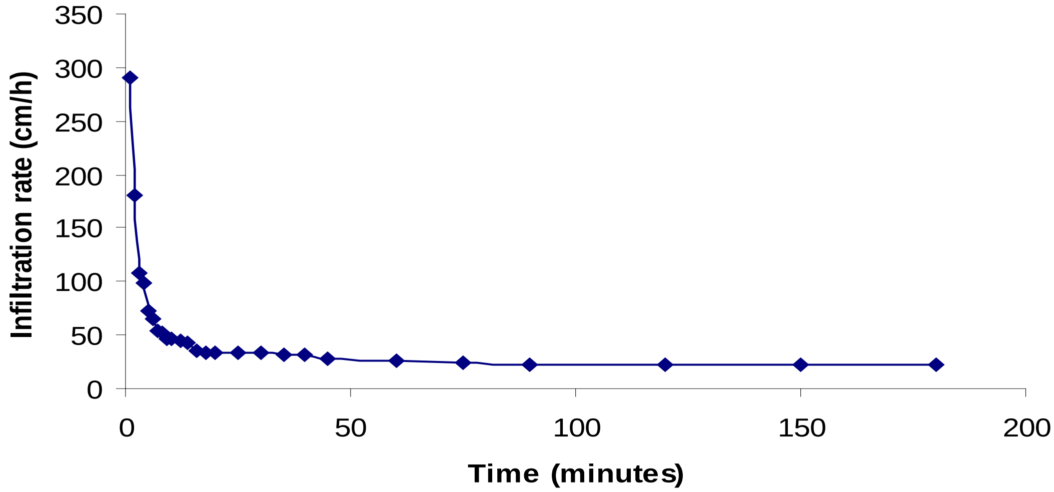

Figure 4.5: Infiltration curves: AA2 Haplic ARENOSOLS

4.1.7 Saturated Hydraulic Conductivity (Ksat), Bulk Density and Soil Porosity:

Soil physical properties profoundly influence how soils function in an ecosystem and how they can best be managed. Success or failure of both agricultural and engineering projects often hinges on the physical properties of the soil used. Physical and chemical properties of the soil horizons are used together with other classifying soil profiles and making determinations about soil suitability for agricultural and environmental projects. Soil texture describes the size of the soil particles and is the most fundamental physical property of a soil.

The bulk density is a key physical property of any porous material which changes in response to disturbance or soil management practices. Soil texture together with packing controls the range of possible values. Bulk density varies with the packing of the soil particles. Soil texture, bulk density and porosity influence both water retention and water movement in the soil.

Hydraulic conductivity is the effective flow velocity or discharge velocity of water in soil at unit hydraulic gradient; it is the ratio of the flux to the hydraulic gradient.

Bulk density is the ratio of mass of dried soil to its total volume, and is an important soil parameter as it is related to soil structure and a good index for soil porosity.

Due to its direct influence on porosity therefore, bulk density determines the rate of water movement into soils. Indeed the swelling and shrinking characteristics of a soil that influence the bulk density also affect the water movement into and within the soil profile.

Soil type and land use have an influence on the soil bulk density, with landuse mainly affecting the bulk density of surface horizons.

The constant head method was used to determine saturated hydraulic conductivity as outlined by Klute and Dirkensen (1986). Soil bulk density was determined by core method according to the procedure described by Blake and Hartage (1986), while soil porosity was derived from values of bulk density and soil particle density, and available water capcity (AWC) (mm/m) was estimated from values of texture and soil depth using guided in appendix D. Values obtained are tabulated on Table 4.16.

Table 4.16: Hydraulic Conductivity, Bulk Density Soil Porosity and available water Capacity(mm/m)

Blocks	Soil Unit	Profile Nos. / Depth(cm)	Texture	Ksat (cm/hr)	Conductivity Class	Bulk Density (g/cm^3)	Porosity %	Mean I Rate (cm/hr)	Available Water Capacity (mm/m)
1,2,7, 8,3,M	PSB: Eutric LEPTOSOLS, sodic phase	1/1, 0-14 2/1, 0-26 7/1, 0-25,3/10,0-18,M/22,0-20	SCL CL C	1.21 0.72 0.73	Slow V. Slow V. Slow	1.08 1.13 1.16	59 57 56	4.2	180
1,2,4, 3,M	PLB 1: Eutric VERTISOLS, sodic phase	1/7, 0-18,2/2,0-7, 4/2, 0-23 3/1, 0-18,M/1,0-7	C C CL	0.3 1.65 0.85	V. Slow Slow Slow	1.06 1.14 1.25	60 57 53	2.4	204
1,3,5, 7	PLB 2: Sodic SOLONCHAKS	1/6, 0-15 5/2, 0-20,7/3,0-15	C L	0.38 2.43	V. Slow Moderate	1.20 1.22	55 54	3.2	187
5,6,7, 8	AA1: Eutric CAMBISOLS, Sodic phase	5/11, 0-38 6/1, 0-17 8/1, 0-16,7/2,0-17	SL C CL	5.65 4.24 3.55	Moderate Moderate Moderate	1.26 1.19 1.16	52 55 56	7.4	176
4/3	AA2: Haplic ARENOSOLS	4-3/4, 0-35	SL	15.6	Rapid	1.26	52	21.7	154

4.2.0 Statistical Data Analysis and Presentation

This section presents the results and discussions on the statistical data analyses for both field and laboratory soil data. These include results obtained for test for significant differences, correlations, univariate analysis of variance and student-newman-keuls test for soil texture. The results are presented in table 4.17 and in appendices E1, E2 and E3.

4.2.1 Tests for Correlations

Soil infiltration rate was correlated with the soil chemical characteristics and the correlation coeficiencies obtained are presented in appendix E1. The partial correlation matrix indicated that pH water was positively and significantly ($P \leq 0.05$) correlat ed with phosphorous and negatively correlated with copper. Carbon was significantly correlated with magnesium and Zn positively and negatively respectively. Potassium was positively and significantly ($P \leq 0.05$) corrected with magnesium and negatively correla ted with manganese. The CEC was also positively correlated with phosphorous. The soil Organic carbon was also positively correlated with the infiltration rate at ($P \leq 0.01$) significant levels. Similarly, the CEC was also positively correlated with infiltration rate at ($P \leq 0.01$)

4.2.2 Pearson Correlation between soil texture in the soil mapping units to mean infiltration rate

Table 4.17 : Correlations

Correlations					
		SAND%	SILT%	CLAY %	Infiltration rate (cm/hr)
SAND%	Pearson Correlation	1			
SILT%	Pearson Correlation	-0.366***	1		
CLAY%	Pearson Correlation	-.740***	-0.349***	1	
Infiltration rate (cm/hr)	Pearson Correlation	.225**	-.017	-0.22**	1
* Correlation at 5% significance level					
** Correlation at 1% significance level					
** Correlation at 0.1% significance level					

The resuts obtained for pearson correlation coefficient between soil texture in soil mapping units to mean infiltration rate showed a significant positive correlation (0.225), for sand propotion at 1% significance level. The value obtained for silt proportion was a negative significant corelation (-0.017) at 5% significant level. The case of clay proportion, a key portion of soil texture that forms an important colloidal fraction of soil , a negative significant correlation (- 0.22) at 1% significant level was obtained.

On the intra-relationships between the three soil texture proportions, significant negative correlations (- 0.366, - 0.740, - 0.349) at 0.1% significant level was recorded.

4.2.3 Student – Newman – Keuls Test for soil Texture .

This test yielded the results presented in the appendix E2.

For the sand proportion of soil texture, results obtained showed that it is not significantly different for all the blocks, while for silt proportion, it was significantly diffeferent for blocks 5, 1, 2, 4, 5, and M .

For the case of clay proportion of soil texture, it was observed that results were not significantly different for blocks 3 and 7, while it was significantly different for blocks 2, M, 4, 6, 5 and 8.

4.2.4 Univariate Analysis of Variance

This was done to obtain estimated marginal means for the soil physical characteristics for the soil mapping units and results obtained are represented in appendix E3.

High initial infiltration rates were recorded for all the major soil mapping units in the delineated blocks. This initial high water infiltration rates makes the soils well suited for irrigation since with good management high irrigation efficiency can be realised as water losses through run off are minimised, particularly considering that surface irrigation will be used. As outlined in appendix E3 , it was observed that the Ksat showed a high correlation with average mean of about 3.00 with block 2 and M registering less values. Saturated hydraulic conductivity (Ksat) for blocks 4 and 6 had some distinct characteristics based on the present land use, followed closely with blocks 3, 5, 7 and 8.

Bulk density on the other hand was nearly the same across the blocks as was the Soil porosity possing no limitation to irrigation.

CHAPTER FIVE

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Sumamry

Nyatike District like most parts of Kenya lacks soil information at sufficient detail for proper land use planning. The current proposed project area covers 7,710ha, that was surveyed at semi-detailed level; scale 1:50,000 during the soil survey fieldwork.

The soil survey report describes the environmental attributes of Lower Kuja Proposed Irrigation Development Project. The study involved quantitative investigations of soil properties, inventory of land use systems and an assessment of the ecological potential and constraints as determined from a balance sheet analysis of resources and land use requirements.

For geology and landform, the lower Kuja area is covered by quaternary and recent deposits of volcanic rocks. The stratification of the volcanic rocks have resulted into vertisols in the poorly drained area which dominate the study area, with minor areas of better drained rocks covered by dark reddish brown soils. The later areas are slightly raised and mostly form the settlement areas. A small area adjacement to Kuja River is undulating to rolling 6-10%; such areas are stony and rocky.

In soils studied, six mapping units were distinguished in the area – and their distribution and extent are shown on the soil map which is presented at the scale 1:50,000. The soils of lower Kuja are:

(1) Footridges (slopes 6 – 10%) RBp excessively drained, very shallow, very stony and very rocky; considered unsuitable for irrigated agriculture.

(2) Sedimentary Plains (slopes 0 – 3%) PSB well drained, shallow to moderately deep, very dark grey to reddish brown, firm to friable, clay loam to clay, in most places over murrum. Considered Marginally suitable for general irrigation but can be upgraded to Moderately suitable if the area is considered for growing shallow rooted crops under suitable irrigation methods.

(3) Lacustrine Sedimentary Plains: PLB1

  (a) Imperfectly drained deep to very deep, black to very dark grey, firm calcareous clay overlying calcium rich material (Eutric Vertisols, Sodic phase). These soils cover a large portion of blocks 1;2;3;4/1;4/2 and 4/3. Though considered Marginally suitable for general irrigated agriculture; it can be upgraded to Highly suitable if paddy rice were to be the main crop. Rice can do well with ESP's of up 20 and the range in this unit is 2.3 to 18.0 and the EC is very low; 0.3 to 0.4ds/M. Workability which puts the unit to marginally suitable would be an advantage to paddy rice and with proper drainage and good water quality the excess salts can be reclaimed.

(b) PLB2

Poorly drained to imperfectly drained, moderately deep to deep, very dark grey to black, firm to friable sandy clay loam to clay, strongly saline to very strong sodic (sodic solonchaks). These soils cover small portion of blocks 1 and 4/3 and the main area is in block 5/1. The soils are very strongly alkaline pH-H_20>9; extremely sodic ESP%>35; very high exchangeable Sodium 18.0 to 46.0 Cmol/kg. Because of these attributes, the soils are rated unsuitable for irrigated agriculture.

(4) Alluvial Plains

(a) AA1

Moderately well drained to well drained very deep, yellowish brown to dark brown, friable to loose, loam to clay loam (Eutric Cambisols, Sodic phase). These soils occupy the greater part of blocks 8,7,6 and 5/2 and are rated Moderately suitable for general irrigated agriculture but can be upgraded to Highly suitable if proper crops are selected since the main problem is the ESP which is slightly sodic to non-sodic. Some suggested crops are paddy rice for the moderately well drained area and horticultural crops like tomatoes; spinach; pepper and kales among others.

(b) AA2

Excessively drained, very deep, yellowish brown, loose, loamy sand to sand (Haplic Arenosols). The soils occupy small portions in blocks 4/3 and 8. They are rated Unsuitable for irrigated agriculture because of their texture which is very high in the sand fractions 75 to 89%

In case of soil fertility, the availability of nutrients for uptake by plants depends not only upon absolute levels but also on nutrient balances. In the majority of these soils the balances are favourable for most crops however the three farming units i.e. PSB; PLB1 and AA1 will each require additions of organic matter, Nitrogen and Phosphorus. If and when high value crops are grown then micro nutrients will need to be added.

5.2 Suitability Classification and Evaluation

5.2.1 Suitability Classification

Suitability classification is a process in which land is evaluated for its capacity for sustaining a particular type of use .This process takes into account environmental factors and soil physical and chemical properties which are later on refereed to as land qualities. The use being evaluated in this case is irrigated agriculture. Out of a long list of land qualities. A few were selected for this assessment as in table 5. 1.

Table 5.1: Land Qualities and Diagnostic Factors

Land Quality	Diagnostic Factor (s)
1) Rooting conditions	Effective soil depth
2) Oxygen availability	Drainage class
3) Nutrient availability	Soil reaction (pH), Cation Exchange capacity (CEC), available nutrients
4) Moisture availability	Available water capcity (AWC), Soil depth
5) Excess of salts	Salinity (EC), Sodicity (ESP),
6) Soil workability	Texture, bulk density, Slope class, Presence of stones on the surface

Source : FAO (1976a)

5.2.2 Factor Rating

The land qualities selected were compared by the use of diagnostic factors with the land characteristics to establish the suitability of each defined land (soil) mapping unit with regard to irrigation. In this process quantitatively or qualitatively established properties of mapping units i.e. what the soil can supply were compared with the set requirements for irrigated agriculture.

This led to the establishment of suitability subclasses as follows:

S1 -Highly Suitable

S2 -Moderately Suitable

S3 -Marginally Suitable

N -Not Suitable

These factors were rated using the following values

Table 5.2: Factor Rating

Land quality	Diagnostic factors	S1	S2	S3	N
Oxygen availability	drainage class	Well	Moderate-well	Imperfectly	Poor/Excess
Nutrient availability	Soil reaction (pH) CEC	6.1 – 7.8 ≥ 24	7.9-8.4 24-16	8.5-9.0 15-10	>9.0 < 10
Rooting conditions	Soil depth (cm)	≥ 120	120-50	49-25	< 25
Excess of salts	Salinity (EC) Sodicity (ESP)	< 4 < 6	4-8 6-10	9-15 11-15	>16 >16

Soil workability	Texture Presence of stones Slope class (%)	L-SCL < 1 0-5	CL-SC 2 6-12	C 3 13-16	C 4 >16

5.2.3 Matching

The matching process involves the comparison of the rated factor ratings and establishing's their response for every defined land mapping unit. The process gave the following results, as tabulated in table 5.3.

Table 5.3: Matching Process

Land mapping unit	**Land Quality**					
Class	Oxygen Avail. (w)	Nutrient Avail. (n)	Rooting Cond. (r)	Excess Salts (z)	Soil Workability (k)	Final rating
RBp	S1	-	N	-	N	Nrk
PSB	S1	S1-S2	S3	S2-S2	S3	S3rk
PLB1	S3	S1	S1-S2	S1-S2	S3	S3zk
PLB2	S3-N	S1	S2-S3	N	S3	Nzw
AA1	S1-S2	S1	S1	S2	S1	S2zw
AA2	N	S3	S1	S1-S2	S1	Nwn
Swamp	N	-	--	-	N	Nwk

Key :

Nrk – Not suitable, limiting rooting conditions, excess salts and soil workability

S3rK – Marginally suitable, limiting rooting condition and soil workability

S3zK – Marginally suitable, limiting excess salts and soil workability

Nzw – Not suitable, limiting excess salts (Salinity)

S2zw – Moderatelt suitable, Limiting excess salt and oxygen availablibity

Nwn – Not suitable, limiting oxygen, availability and nutrient availablibity

NwK – Not suitable, Oxygen availability and soil workability

Table 5.4: Mapping Unit and Current Suitability for General Irrigation

	Mapping unit and suitability class							
Block	**AA1; S2,S3**	**PLB1; S1,S2, S3**	**PSB; S3**	**PLB2:S3**	**AA2:S3,N**	**RBp; S3,N**	**SWAMP**	**TOTAL**
Block 1 – 1	0	361	179	23	0	0	0	**563**
Block 1 – 2	0	161	329	17	0	0	0	**507**
Block 2 – 1	7	17	407	0	0	13	0	**444**
Block 2 -2	0	433	317	0	0	0	0	**750**
Block 2 – 3	101	148	1039	0	0	0	0	**1288**
Block 3	0	798	86	30	0	0	55	**969**
Block 4 – 1	0	266	0	0	0	0	0	**266**
Block 4 – 2	0	285	78	0	0	0	0	**363**
Block 4 - 3	0	263	97	0	15	0	23	**434**
Block 5 – 1	248	0	12	524	0	0	0	**784**
Block 5 – 2	568	0	8	130	0	0	0	**706**
Block 6	467	0	0	0	9	0	0	**476**
Block 7	366	0	83	273	0	0	0	**722**
Block 8	556	0	121	0	7	0	0	**684**
Block M	0	68	15	0	0	6	0	**89**
Total	**2313**	**2800**	**2771**	**997**	**67**	**19**	**78**	**9045**

Key and description

Table 5.4 above provides the current suitability for general irrigation per mapping unit, giving suitability sub-classes per block and sub-blocks before irrigation improvements are incorporated. Irigation improvements and management practices will upgrade most of the suitability classes upwards.

5.3 Conclusions

Table 5.5: Final Suitability Classification

Mapping Unit	**Current Suitability For General Irrigation**	**Potential Suitability for Specific Crops and Agronomic Management**
RBp	Nrk – Rooting condition -Soil workability	NrK
PSB	S3rk – Rooting condition - Soil workability	S2rK – Shallow rooting crops - Irrigation springler/drip - Selection of crops tolerance of ESPs <10.
PLB1	S3 zk – Excess salts, - Soil workability	S1 – Paddy rice, rice can do well with ESP's of up to 20, with proper drainage and good water quality, excess salts can be managed. - Workability would be an advance because it will hold water for paddy rice.
PLB2	Nzw-Excess salts - Oxygen availability	Nzw
AA1	S2Zw-Excess salts, - Oxygen availability.	S1 – Proper crop selection and agronomic practices. Crop tolerance of ESP's <10.
AA2	Nwk	NwK

Key :

Nrk – Not suitable, limiting rooting conditions, excess salts and soil workability

S3rK – Marginally suitable, limiting rooting condition and soil workability

S3zK – Marginally suitable, limiting excess salts and soil workability

Nzw – Not suitable, limiting excess salts (Salinity)

S2zw – Moderatelt suitable, Limiting excess salt and oxygen availablibity

Nwn – Not suitable, limiting oxygen, availability and nutrient availablibity

NwK – Not suitable, Oxygen availability and soil workability

The study area is dominated by Eutric Vertisols, sodic phase, Eutric Cambisols, sodic phase, Eutric Leptosols, Sodic phase and Sodic Solonchaks. Haplic Arenosols and Lithic Leptosols represents minor soil mapping units in the project area.

A semi-detailed soil map of the Lower Kuja Irrigartion Project is annexed (ANNEX 1).

In conclussion therefore, soils of mapping unit RBp, Lithic LEPTOSOLS as marked in the soil map are unsuitable for irrigation; while soils of mapping unit PSB, Eutric LEPTOSOLS, Sodic phase are considered marginally suitable for general irrigation, but can be upgraded to moderately suitable. Soils of mapping unit PLB1, Eutric VERTISOLS, Sodic phase, are rated marginally suitable for general irrigated agriculture, and can be upgraded to higly suitable especially for paddy rice production. Soils of mapping unit PLB2, Sodic , SOLONCHAKS, are rated unsuitable for irrigated agriculture.

Soils of mapping unit AA1, Eutric CAMBISOLS, Sodic Phase are rated moderately suitable for general nirrigated agriculture but can be upgraded to higly suitable. Soils of mapping Unit AA2, Haplic ARENOSOLS, are rated unsuitable for irrigation.

Table 5.6: Crop Allocation per Block – Final Feasibility

		UPLAND CROPS				
		HORTICULTURE			**INDUSTRIAL CROPS**	
BLOCK	**PADDY**	**FOOD**	**VEGETABLES**	**FRUIT TREES**		**TOTAL**
Block – M	67	9	6	0	0	82
Block 1-1	240	182	45	18	61	545
Block 1-2	74	25	62	21	83	490
Block 2-1	0	264	66	22	88	440
Block 2-2	0	450	112	37	150	750
Block 2-3	0	775	194	65	258	1292
Block 3	798	52	13	4	17	884
Block 4-1	213	32	21	0	0	266
Block 4-2	286	47	12	4	16	364
Block 4-3	266	53	13	4	18	355
Block 5-1	136	74	18	6	25	259
Block 5-2	169	245	61	20	82	577
Block 6	0	280	70	23	93	467
Block 7	145	184	46	15	61	451
Block 8	0	406	101	34	135	676
Total	**2393**	**301**	**842**	**274**	**1087**	**7897**
Grand total	**2393**	**5504**				
% Area	**30%**	**42%**	**11%**	**3%**	**14%**	

Table 5.6 provides a final feasibility for crops allocation per block and sub-blocks in the project areas

5.4 Recommendations.

5.4.1 Recommendations for policy makers

In view of the findings of the study, general and specific recommendations are made with respect to six (6) soil mapping units identified by both the analysis and evaluations.

Recommendations are also provided for some specific soils characteristics evaluated by utilizing soil conditions and crop suitability factors.

1) For soil mapping unit PLBI Eutric Vertisols sodic phase, Nitrogen, phosphorous and Zinc are deficient. Soil organic matter, iron and copper should be improved. During planting time 250kg/ha of diamonium phosphate (DAP) may be beneficial.

2) In soil mapping Unit PLB2 Sodic Solonchaks, the soils in this unit are both Saline and Sodic and this makes their reclmamation a bit problematic and special management to be utilized for irrigation.

3) In soil mapping unit AA1, Eutric Cambisols, sodic phase, Nitrogen is deficient and soil organic matter needs improvement. During planting time 250 kg/ha of calcium ammonium nitrate (CAN) may be beneficial.

4) Zinc is deficient throughout the soil mapping unit PSB Eutric Leptosols, sodic phase, and its applications together with other elements in fertilizer application is recommended.

5) In soil mapping unit AA2 of the soils of the project area, Haplic Arenosols there are two small units in 4/3 and 8 and because of the sandy nature of the soils they would be difficult to farm, except for livestock grazing

6) For soil infiltration rate, the final and/or basic infiltration rates recorded for each of the identified soil unit were classified according to Booker (1991). Soil units PSB (Eutric LEPTOSOLS), PLBI (Eutric Vertisols) and PLB2 (Sodic SOLONCHAKS) had rates falling into moderate class. Because water infiltration into the soil profile plays a critical role in agriculture and especially with regard to irrigated farming the values obtained are marginally to moderately suitable, notwithstanding other soil factors. Irrigation water management practices, with respect to irrigation water scheduling, together with agronomic practices will upgrade upwards suitability for irrigation under surface irrigation methods. However, Sodic SOLONCHAKS require special management because these types of soils normally seal up and do not allow water to infiltrate through during wetting.

7) Soil Unit AAI (Eutric CAMBISOLS) had an infiltration rate value classified as moderately rapid. This supports moderate suitability for irrigated farming. However, more frequent irrigation intervals (water application) will be necessary, thus affecting the water productivity levels.

8) Soil units AA2 (Haplic ARENOSOLS) is predominated by sandy textures, and had the highest infiltration rate classified as rapid. Although rated unsuitable for irrigated agriculture, this unit can slowly be upgraded and improved to very marginally support irrigated practice by improvement in agronomic practices, especially with continuous incorporation and application of organic matter and other conservation agriculture practices.

Application of soil organic matter is recommended as a good agronomic practice.

5.4.2 Recommendations for further research

i) In view of the need to ensure sustainable irrigated agriculture and in order to maintain and achieve maximum utilization of the natural resources in Lower Kuja Irrigation Project, detailed water – use efficiency studies should be carried out once the project becomes operational.

ii) In order to forestall, secondary salinization at the irrigation project, from slowly building up, there is need to carry out predictive studies to determine and isolate its causes, and manage them to avoid project abandonment.

iii) While use of organic fertilizers is highly recommended , its sources and quality should be subjected to continuous monitoring studies.

iv) In addition to the mandatory Environmental Audit (EA), the Environmental Management and Monitoring Plan (EMMP) , as prescribed in the Environmental Impact Assesesment study report of the proposed project should strictly be adhered to.

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APPENDICES

APPENDIX A

Appendix A1: Representative of Soil Profile Description of Mapping Unit PSB; East Kanyuol

General Site Information

Geology:	Olive Basalts
Physiography	: Plains
Relief, Macro	: Flat to very gently undulating
Slope at site	: 0.2%
Vegetation	: Wood/bushland
Land use	: Cultivation/grazing
Erosion	: Nil
Rock outcrops	: Non rocky
Effective soil depth	: shallow, 38cm
Flooding	: Moderate
Groundwater Depth	: Deep
Drainage Class	: Excessively drained

Soil Profile Description

AP 0 – 15cm	: Dark reddish brown (5YR 3/3) clay, weak, fine and medium, crumbs structure; soft when moist, sticky and plastic when wet; many fine pores; many fine and few medium roots; gradual and smooth transition to:
Bs 15 – 38cm	: Reddish brown (5YR 4/3) gravely clay: sub angular blocky moderate to strong structure, soft when dry; friable when moist, sticky and plastic when wet; many fine to medium pores; few fine and medium roots; smooth and clear transition to:
C 38 – 75cm	: Murram layer

Appendix A2: Representative of Soil Profile Description of Mapping Unit;

PLB1; Profile No. 47- Block 3 – Site 1

General Site Information

Geological formation :Kavirondo basement system

Physiography : Alluvial plains

Relief, macro : Flat to very gently undulating

Slope at site : 0 – 2% plain

Vegetation : Wooded bushland

Land use : : Grazing and charcoal burning

Erosion : Splash (slight)

Rock outcrop : Nil

Effective soil depth : 100cm moderately to very deep

Flooding : Moderate

Ground water depth : Deep

Drainage class : Moderate well drained

Soil Profile Description

A 0 – 18cm : Dark brown (7.5YR 3/2) dry, dark reddish brown (5YR2.5/2) moist clay, medium to strong structure; hard when dry, friable when moist, sticky and plastic when wet; many very fine pores, very fine few roots, many fine medium roots ; gradual and smooth transition to:

AB 18 – 38cm: : Dark brown (7.5YR 3/2) dry, dark reddish brown (5YR 2.5/2) moist clay; medium to strong structure; hard when dry, friable when moist, sticky and plastic when wet; few fine and medium pores, few fine and medium roots; gradual and smooth transition:

Bu_1 38 – 52cm : Dark brown (7.5YR 3/2) dry dark brown (7.5YR3/2) moist clay, sub angular blocky (sbk)and prismatic (pr) fine and weak, structure ; hard when dry friable when moist and sticky and plastic(sp)when wet; very few fine pores, very few fine roots, clear and smooth transition to:

Bu_2 52 – 70cm : Dark brown (7.5YR3/2) dry, dark to dark brown (7.5YR4/2) moist clay, crumb structure, soft when dry, friable when moist, sticky and plastic when wet, few fine and medium pores very few fine roots, gradual and smooth transition to:

BU_3 70 – 100cm : Brown (7.5YR5/2) dry dark to dark brown (7.5YR 4/2) moist clay sub angular blocky (sbk) structure, soft when dry, friable when moist, sticky and plastic when wet few fine pores very few fine roots.

Appendix A3: Representative of Soil Profile Description of Mapping Unit: AA1; Eutric Cambisols, sodic phase, Block 6/1

Geology	: Alluvial Deposits
Physiology	: Alluvial plain
Relief, macro	: Flat to gently undulating
Slope at site	: 0 – 2%
Vegetation	: Wood/bush land
Landuse	: Cultivation
Erosion	: Slight wind erosion
Rock outcrops	: None
Effective soil depth	: Very deep >140cm
Flooding	: Seasonal after heavy rains
Ground water depth	: Moderate to deep
Drainage class	: Moderately well drained

Soil Profile Description

A 0 – 17cm	: Weak red (7.5YR5/2) clay; weak fine to medium subangular blocky (sbk) very hard when dry, very firm when moist, very sticky and very plastic and when wet; very fine pores, fine and medium roots; gradual and smooth transition to:
AB 17 – 40cm	:Weak red (7.5YR4/2) dry, dusky red (7.5YR 3/2) moist clay; very fine to fine subangular blocky (sbk) hard when dry, firm when wet; fine pores, clear and smooth transition to:
Bt_1 40 – 90cm	: Very dark gray (10YR3/1) dry, very dark gray (10YR3/1) moist, clay moderate subangular blocky, hard when dry, firm when moist sticky and plastic when wet, fine pores, clear and smooth transition to:
Bt_2 90 – 140cm+	: Very dark grayish brown (10YR3/1) moist clay gray 10YR3/1 moist clay, moderate subangular blocky (sbk) hard when dry, firm when moist, sticky and plastic when wet; fine pores:

Appendix A4: Representative of Soil Profile Description of Mapping Unit: - AA2 Haplic Arenosols; Bloc 4 - 3

Geology	: Alluvial material derived from tertiary volcanic rocks
Physiography	: Alluvial plains
Relief, macro	: Gently undulating
Slope at site	: 0 -3%
Vegetation	: Grassland
Landuse	: Grazing and sand harvesting
Erosion	: Gully
Rock outcrops	: None
Effective soil depth	: >100cm
Drainage class	: Excessively
Flooding	: Seasonally flooding
Ground water depth	: Very deep

Soil Profile Description

0 -35cm	: Very dark grayish brown (10YR 3/2) dry, very dark brown (10YR2/2) moist, sand, structure less, loose when dry, friable when moist, non sticky and non plastic when wet, gradual and diffuse transition to:
35 – 57cm	: Dark grayish brown (10YR4/2) dry very dark brown (10YR4/2) moist, sand structure less, loose when dry, nonsticky and non plastic when wet, gradual and diffuse transition to:
57 – 97cm	: Brown to dark brown (10YR4/3) dry, dark yellowish brown (10YR3/4) moist, sand structure less, loose when dry, non sticky and non plastic when wet, iron and manganese concretion present

APPENDIX A5: Representative of Soil Profile Description of Mapping Unit: - RBp , Lithic LEPTOSOL, Block M - 6

Geology	: Olive Basalt
Physiography	: Foot ridges
Relief, macro	: undulating
Slope at site	: 6 -10%
Vegetation	: Shrubs and herbs
Land use	: Grazing
Erosion	: Gully
Rock outcrops	: very stony
Effective soil depth	: 30cm
Drainage class	: excessively

<u>Soil Profile Description</u>

A 0 – 15cm	: Dark brown (10YR3/3) dry, dark yellowish brown (10YR3/4) moist, sandy clay loam, soft when dry, friable when moist, slightly sticky and slightly plastic when wet clear and smooth transition to:
Bs 15 – 30cm	: Gray (10YR5/1) dry very dark grayish brown (10YR3/2) moist gravely sandy clay, slightly hard when dry, friable when moist, slightly sticky and plastic when wet

Appendix A6: Representative of Soil Profile Description of Mapping Unit: PSB, Eutric LEPTOSOL

Geology	: Kavirondo Basement system Sedimentary
Physiography	: Plain
Relief, macro	: Flat to gently undulating
Slope at site	: 0 – 2%
Vegetation	: Wooded bushland
Land use	: Grazing
Erosion	: slight (wind)
Rock outcrop	: None
Effective soil depth	: 23cm
Drainage class	: moderately well drained

Soil Profile Description

A 0 – 17cm	: Brown (10YR5/3) dry, very dark grayish brown (10YR3/2) moist, clay hard when dry, friable when moist, sticky and plastic when wet, angular blocky structure breaking to subangular blocky structure, strong, fine to medium size, pores common and fine gradual and smooth transition to:
Bt 17 – 23cm	: Brown to dark brown (10YR4/3) dry, very dark grayish brown (10YR3/2) moist, clay, hard when dry , friable when moist, sticky and plastic when wet, angular blocky and subangular blocky, strong fine to medium size, common fine pores, clay cutans common medium pores, gradual and smooth transition to:
C 23 – 32 cm	: Murram

Appendix A7 : Representative of Soil Profile Description of Mapping Unit: , PLB1- Eutric Vertisols, sodic phase-Block 3/5; West Kanyuol

Geology	: Olivine Basalts
Physiography	: Lacustrine sedimentary plain.
Relief, macro	: Flat to gently undulating
Slope at site	: 0-2%
Vegetation	: grassland/wooded bushland
Land use	: Grazing
Erosion	: Water
Rock outcrops	: None
Effective soil depth	: 120cm
Flooding	: Seasonally
Groundwater depth	: Temporary moderately deep
Drainage class	: Imperfectly

Soil Profile Description

A 0-18 cm	:Black (10 YR 2/1)moist ,clay very hard when dry, friable when moist, sticky and plastic when wet, angular blocky and sub angular blocky structure, weak moderate, very fine few roots, fine very few roots, clear and smooth transition to:
AB 18-29 cm	:Black (10YR 2/1)moist, clay, very hard when dry, friable when moist sticky and plastic when wet angular blocky and sub angular blocky structure, weak moderate, very fine few roots, diffuse and smooth transaction to:
BU,29-45cm	**:**Very dark gray (2.5 YR 3/0)moist, clay, hard when sticky and plastic when wet, angular blocky and sub angular blocky structure weak moderate, very fine ,very few roots, diffuse and smooth, transition to:
$B4_2$45-82 cm	**:**Very dark gray (2.5 YR3/0) moist, clay, hard when dry, firm when moist, sticky and plastic when wet, sub angular blocky structure weak moderate, slightly calcasious,clear and smooth transaction to.
$B4_3$ 82-120cm	**:** Very dark gray (10YR3/1) clay, hard when dry firm when moist, sticky and plastic when wet, angular blocky structure moderate, slightly calcarious.

Appendix A8 : Representative of Soil Profile Description of Mapping Unit, PLB2-Solonchaks-Block 5/2, Karapolo

Geology	: Olivine Basalts
Physiography	: Lacustrine sedimentary plain.
Relief, macro	: Flat to gently undulating
Slope at site	: 0-2%
Vegetation	: Grassland and wooded bush land
Land use	: Grazing
Erosion	: Sheet erosion
Rock outcrops	: None
Effective soil depth	: 120cm deep
Flooding	: Seasonally
Groundwater depth	: Very deep
Drainage class	: Moderately well drained

Soil Profile Description

A 0-20cm	**:**Grayish brown (10YR 2/3)dry very dark grayish brown(10YR 3/1)moist,clay,hard when dry friable when moist, sticky and plastic when wet,subangular blocky, fine to medium ,strong, common fine pores, very fine common roots gradual and smooth transition to:
AB 20-40cm	: Very dark grayish brown (10YR 3/2)dry black(10YR 2/1)moist, clay hard, when dry, friable when moist sticky and plastic when wet sub angular blocky, fine to medium,strong,common fine pores, very fine very few roots, gradual and smooth transition to:
BU_1,40-77cm	**:**Very dark grayish brown (10YR 3/2)dry, black 10YR2/1)moist, clay hard when dry, friable when moist, sticky and plastic when wet, sub angular blocky fine to medium, strong structure, common fine to medium pores, clear and smooth transition to:
BU_2 77-120cm	: Dark brown (10YR4/3 dry dark brown (10YR4/3) moist, silty clay, soft when dry very friable when moist, slightly sticky and slightly plastic when wet, angular blocky and sub angular blocky, fine to medium moderate grable, common fine to medium pores.

Appendix A9: Representative of Soil Profile Description of Mapping Unit: PLB1 Eutric Vertisol, Block 4/1, Obware

Geology	: Olivine Basalts
Physiography	: Lacustrine sedimentary plain.
Relief, macro	: Gently to very gently undulating
Slope at site	: 0-2%
Vegetation	: Grassland
Land use	: Cultivation
Erosion	: Nil
Rock outcrops	: Nil
Effective soil depth	: 80cm, moderately deep
Flooding	: Seasonally
Groundwater depth	: Very deep
Drainage class	: Imperfectly to moderately well drained.

Soil Profile Description

A 0-23 cm	:Very dark gray (2.5YR 3/0) dry, black (2.5 YR 2/0) moist, clay, hard when dry, friable when moist sticky and plastic when moist sub angular blocky,prismatic,medium weak, few fine pores, few medium roots, gradual and smooth transition to:
AB 23-57 cm	: Black (2.5YR 2/0) moist, clay, hard when dry, friable when moist, sticky and plastic when wet, sub angular blocky and prismatic medium weak structure, few fine pores, very fine very few roots. gradual and smooth transition to:
B 57-80cm	**:** Black (2.5 YR 2/0) moist, clay, hard when dry, friable when moist, sticky and plastic when wet subangular, blocky medium weak structures, few medium pores.

Appendix A10: Representative of Soil Profile Description of Mapping Unit: PLB1-Vertisol, sodic phase-block 4/2, North Kadem

Geology	: Olivine Basalts
Physiography	: Lacustrine sedimentary plain.
Relief, macro	: Gently to very gently undulating
Slope at site	: 0-2%
Vegetation	: Grassland and woodland bush land
Land use	: Grazing
Erosion	: Slight wind
Rock outcrops	: Nil
Effective soil depth	: 74cm, moderately deep
Flooding	: Seasonally
Groundwater depth	: Very deep
Drainage class	: Imperfectly to moderately well drained.

Soil Profile Description

A 0-24 cm	**:**Dark gray (2.5 YR 4/0)dry, very dark gray (2.5 YR 3/0) moist, clay, hard when dry, friable when moist stick and plastic when wet,subangular blocky medium, strong structure, many fine pores, very fine common roots, gradual and smooth, transitional to:
AB 24-48cm	**:**Very dark gray (2.5 YR 3/0),clay, hard when dry, friable when moist, sticky and plastic when wet, sub angular blocky medium strong structure, many fine pores, few fine roots, clear and smooth, transition to:
B 48-74cm	**:**Brown (7.5 YR 5/2)dark brown (7.5 YR 4/2) moist, clay, hard when dry, friable when moist, sticky and plastic when wet, angular and sub angular blocky, medium strong structure, many very fine pores, fine few roots, calcium carbonate concretions.

Appendix A11 : Representative of Soil Profile Description of Mapping Unit: Eutric Leptosols-sodic phase-Block 2/2, Upper Karapalo

Geology	: Olivine Basalts
Physiography	: Sedimentary plain.
Relief, macro	: Undulating
Slope at site	: 4-8%
Vegetation	: Grassland and woodland
Land use	: Grazing/woodcutting
Erosion	: Slight
Rock outcrops	: None
Effective soil depth	: 60cm, moderately deep
Flooding	: None
Groundwater depth	: very deep
Drainage class	: Moderately to well drained.

<u>Soil Profile Description</u>

A 0-20 cm	**:**Brown (7.5YR 5/3)dry, brown (7.5 YR 5/4),moist, sand loam, soft when dry, friable when moist, slightly sticky slightly plastic when wet, sub angular blocky, fine to medium weak structure, common and fine pores, very fine few, very few fine roots, clear and smooth transition to:
AB 20-40cm	**:**Brown (7.5 YR 5/4) dry, brown (7.5 YR 5/2)moist, sand clay loam, soft when dry, friable when moist, sticky and plastic when wet, sub angular blocky fine to medium structure, common fine pores, very fine very few ,roots, clear and smoth,transition to:
BC,40-50 cm	**:** Brown (7.5 YR 5/4)dry brown to dark brown (7.5 YR 4/4) moist, sand clay loam, soft when dry, friable when moist, sticky and plastic when wet, sub angular blocky, fine medium weak, common medium pores, transition to:
C, 50-60 cm	**:** Brown (7.5 YR 5/4) dry, dark brown (7.5 YR 4/4) moist, gravely sandy clay hard when dry, friable to fine when moist, sticky and plastic when wet, sub angular blocky, fine to medium, weak structure, common fine, common medium pores.

Appendix A12: Representative of Soil Profile Description of Mapping Unit: AA1-Eutric Cambisols-sodic phase-Block 5/10

Geology	: Alluvial materials
Physiography	: Alluvial plains.
Relief, macro	: Flat to very gently undulating
Slope at site	: 0-3%
Vegetation	: Grassland and woodland
Land use	: Grazing
Erosion	: Wind erosion
Rock outcrops	: None
Effective soil depth	: 50cm
Flooding	: None
Groundwater depth	: Very deep
Drainage class	: Well drained.

Soil Profile Description

A_{K1} 0-11cm	: Light yellowish brown (10 YR 6/4) dry, brown to dark brown (10 YR 4/3) moist, loamy sand, soft when dry, loose when moist, non sticky non plastic when wet, angular blocky, medium weak, calcareous, clear and smooth boundary, transition to:
AB $_{K2}$ 11-25cm	**:**Dark yellowish brown (10 YR 3/5)moist, loamy sand, soft when dry, loose when moist, non sticky non plastic when wet, angular blocky, medium weak structure, slightly calcareous, clear and smooth transition to:
B_{K3} 25-50cm	**:** Dark yellowish (10 YR 3/4) moist, loamy sand, soft when dry, loose when moist, non sticky, non plastic when wet, angular blocky, fine to medium weak structure, slightly calcareous.

APPENDIX B

KEY TO INTERPRETATION OF SELECTED SOIL AND LAND PROPERTIES

The soil characteristics and properties considered here are: drainage conditions, sodicity, salinity, calcareousness ,oil raction (pH), cation exchange capacity (CEC), fertility status of some individual elements, soil depth and slope class.

The classification for these factors is based on the Kenya Soil Survey manual (Kenya Soil Survey, 1977 and 1987), derived and modified FAO "Guidelines profile description(FAO, 1977) and partly based on Booker Tropical Soil Manual (Landon, 1991)

Table B1: Key to soil depth

Class	Description	Depth (cm)
0	- extremely shallow	< 10
1	- very shallow	10 – 25
2	- shallow	25 – 50
3	- moderately deep	50 – 80
4	- deep	80 – 120
5	- very deep	120 – 180
6	- extremely deep	> 180

Table B2: Key to slope classes

Slope (%)	Description of topography	Code
0 – 2	- Flat to very gently undulating	A
2 – 5	- Gently undulating	B
5 – 8	- Undulating	C
8 – 16	- Rolling	D
16 – 30	- Hilly	E
>30	- Steep	F

The slope gradient refers to differences in topography over a large distance, usually more than 100m long. The slope is measured and expressed as percentage.

Table B3: Key to soil drainage conditions:

Class	Description
0 – very poor drained	Water is removed from the soil so slowly that water table is at or above surface for most of the time. Usually occupy level or depressed sites: frequently ponded
1 – poorly drained	Soil remains wet for a large part of the year. The water table is commonly at or near the surface for a large part of the time.
2 – Imperfectly drained:	Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time.
3 – moderately well drained	Water removal is somewhat slow and soil profile is wet for small but significant periods , Mottles may occur in the sub soil.
4 – well drained:	Water is removed from the soil readily but rapidly . These soil retains enough amount of moisture for plant growth after rains.
5 – Somewhat excessively drained	Water is removed from the soil rapidly. Many of these soils are sandy and very porous.
6 – excessively drained	Water is removed from the soil very rapidly. These soils are usually very slow and may be situated on steep slopes or may be very porous.

Drainage refers to the speed and extend of the removal of water from the soil. Poor drainage may be caused by the position of the site in level or depressed land, by a permanently high water table, by seepage from associated higher lands or by presence of slowly permeable layer in the soil, or a combination of any of these factors. Flooding refer to superficial passage of water originating from areas outside the land concerned, while ponding refers to the accumulation of water in and on the land concerned due to its relatively low and flat position.

Calcium carbonate estimate: classification of calcareousness:

This is based on estimate in relation to reaction of soil with 10% HCI to approximate free $CaC0_3$ content

Table B4: Key to calcium carbonate estimate

Class	Reaction with 10% HCL	Calcareousness	Approximate caerbonate content
0	- None detectable no hissing	- Non calcareous	< 0.5%
1	- Non to slight hissing close to the ear	- Slight calcareous	0.5 – 2%
2	- Slight effervescence audible hissing	- Moderate calcareous	2 – 5%
3	- Strong effervescence audible hissing	- Strong calcareous	>5%

Table B5: Key to salinity classes (Classification of the electrical conductivity (EC) reading:

Measured $EC_{2.5}$ (ds/m	Approximate EC. (ds/m	Salinity description
0 – 1.2	0 – 4	- None saline
1.2 - 2.5	4 – 8	- slightly saline
2.5 - 5.0	8 – 15	- moderately saline
5.0 - 10	15 – 30	- strongly saline
> 10	> 30	- excessively saline

The content of soil soluble salts is usually measured as the electric conductivity (EC) of the soil water extract, EC2.5 = for the saturated paste water extract*I* EC2.5 = for 1:2.5 soil to water solution.

Table B6: Key to sodicity classes:

ESP (%)	Sodicity class description
0 – 6	- Non sodic
6 – 10	- Slightly sodic
10 – 15	- Moderately sodic
> 15	- Strong sodic

Table B7: Key to soil reaction

Measured pH	Class descripotion	Level of pH
< 4.5	- extremely acid	Very low
4.5 – 5.0	- very strongly acid	Low
5.1 – 5.5	- strongly acid	
5.6 – 6.0	- medium acid	Medium
6.1 – 6.5	- slightly acid	
6.6 – 7.3	- neutral	
7.4 – 8.4	- mildly alkaline	High
8.5 – 9.0	- strongly alkaline	
> 9.0	- very strong alkaline	Very high

Table B8: Key to CEC of the topsoil

Measured CEC (cmol /kg)	Class description
< 5	Very low
5 – 15	Low
15 – 25	Medium
25 – 40	High
> 40	Very high

Table B9: Key to fertility classes for single elements

Available nutrients (cmol/kg soil)					
	Pppm	K	Ca	Mg	Total N%
Very high	> 200	> 3.5	> 20	> 20	> 1.0
High	80 – 200	2.0 – 3.5	10 – 20	6 – 12	0.5 – 1.0
Moderate	40 – 80	1.0 – 2.0	6 – 10	3 – 6	0.5 – 0.2
Low	20 – 40	0.3 – 1.0	2 – 6	1 - 3	0.1 – 0.2
Very low	< 20	< 0.3	< 2	< 1	< 0.1

APPENDIX C

Guide to general evaluation of selected soil chemical and physical properties

(i) Soil profile depth classes

Depth (cm)	Description
0-25	Very shallow
26-50	Shallow
51-80	Moderately deep
81-120	Deep
121-180	Very deep
>180	Extremely deep

(ii) Organic matter and total nitrogen

	Very low	Low	Medium	High	Very high
Organic matter (%)	<1.0	1.0-2.0	2.1-4.2	4.3-6.0	>6.0
Organic C (%)	<0.60	0.60-1.25	1.26-2.50	2.51-3.50	>3.50
Total N (%)	<0.10	0.10-0.20	0.21-0.50	0.50-1.00	>1.0

(iii) Soil reaction (pH-H_2O)

Soil condition	pH value
Strongly acid	5.1-5.5
Medium acid	5.6-6.0
Slightly acid	6.1-6.5
Neutral	6.6 to 7.3
Mildly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0

(iv) Available phosphorus

P (ppm)	low	Medium	High
(Mehlich method)	20	20-80	>80

(v) Cation exchange capacity (CEC) and base saturation (BS)

	Very low	Low	Medium	high	Very high
CEC(cmol/kg)	<5	5-15	15-25	25-40	>40
BS (%)		<20	20-60	>60	

(vi) Exchangeable calcium

Ca (cmol/kg)	Very low	Low	Medium	High	Very high
Clayey soils rich in 2:1 clays	<2.0	2.0-5.0	5.1-10.0	10.1-20.0	>20.0
Loamy soils	<0.5	0.5-2.0	2.1-4.0	4.1-6.0	>6.0
Kaolinitic and sandy soils	<0.2	0.2-0.5	0.6-2.5	2.6-5.0	>5.0

(vii) Exchangeable Magnesium

Mg (cmol/kg)	Very low	Low	Medium	High	Very high
Clayey soils	<0.3	0.3-1.0	1.1-3.0	3.1-6.0	>6.0
Loamy soils	<0.25	0.25-0.75	0.75-2.0	2.1-4.0	>4.1
Sandy soils	<0.2	0.2-0.5	0.5-1.0	1.1-2.0	>2.0

Ca/Mg ratios of 2 to 4 are favorable

(viii) Exchangeable potassium

K (cmol/kg)	Very low	Low	Medium	High	Very high
Clayey soils	<0.20	0.20-0.40	0.40-1.20	1.21-2.00	>2.00
Loamy soils	<0.13	0.13-.0.25	0.26-0.80	0.8-1.35	>1.35
Sandy soils	<0.05	0.0-0.10	0.11-0.40	0.41-0.70	>0.70

Favorable Mg/K ratios for most crops are in the range of 1 to 4.

(ix) Exchangeable sodium

Na (cmol/kg)	Very low	Low	Medium	High	Very high
	<0.30	0.31-0.70	0.71-2.00	0.71-2.00	>2.00

More important than the absolute level of exchangeable Na is the exchangeable sodium percentage (ESP) calculated by dividing exchangeable Na by CEC (x 100). ESP values indicate the sodicity of a soil.

(x) Soil salinity and sodicity

Saline soils have an electrical conductivity of saturation extract (ECe) greater than 4 microsiemens per centimeter (4 $mScm^{-1}$) at 25^0C and ESP less that 15. The pH is usually less than 8.5.

Saline-sodic soils have ECe value greater than 4 $mScm^{-1}$ at 25^0C and ESP value greater than 15.

Sodic soils have ESP value greater than 15 and ECe values less than 4 $mScm^{-1}$ at 25^0C.

	Non-sodic	Slightly sodic	Moderately sodic	Strongly sodic	Very strongly sodic	Extremely sodic
ESP (%)	<6	6-10	11-15	16-25	26-35	>35

ESP <15 %: Up to 50 percent yield reduction of sensitive crops (maize, beans)
ESP 16-25%: Up to 50 percent yield reduction of semi-tolerant crops (rice, wheat, sorghum, sugarcane)
ESP 35%: Up to 50 percent yield reduction of tolerant crops (barley, cotton)

(xi) Bulk density

Rating	Bulk density (g/cm^3)
Low	<1.00
Medium	1.00-1.40
High	>1.40

Bulk densities above 1.46 to 1.63 g/cm3 for loams and clays cause hindrance to root penetration

(xii) Hydraulic conductivity (permeability)

Class	Conductivity	Hydraulic conductivity (cm h^{-1})
1	very slow	<0.8
2	Slow	0.8-2.0
4	moderate	2.0-6.0
5	Moderately rapid	6.0-8.0
6	Rapid	8.0-12.5
7	Very rapid	>12.5

(xiii) Available water capacity (AWC)

Rating	Available water capacity (mm m^{-1})
Low	<100
Medium	100-150
High	150-200
Very high	>200

APPENDIX D

AVAILABLE WATER CAPACITY OF ADAS FIELD TEXTURES

ADAS TEXTURE CLASS	UPPER LIMIT (FIELD CAPACITY) (% WATER W/W)	LOWER LIMIT (PERMANENT WILTING POINT) (% WATER W/W)	AVAILABLE WATER CAPACITY (MM M_{-1})
Coarse sand	8	4	83
sand	14	4	150
Fine sand	19	4	200
Very fine sane	20	4	225
Loamy coarse sand	13	7	108
Loamy sand	18	7	158
Loamy fine sane	22	7	217
Loamy very fines sand	25	7	217
Coarse sandy loam	19	9	125
Sandy loam	26	9	175
Fine sandy loam	28	9	192
Very fine sandy loam	28	9	217
Loam	30	13	175
Silty loam	34	10	200
Silt loam	39	16	192
Sandy clay loam	26	15	150
Clay loam	34	18	183
Silty clay loam	43	20	192
Sandy clay	29	19	142
Silty clay	47	25	183
Clay	42	25	175

Source : Salter and Williams 1969, 1972

APPENDIX E1

CORRELATIONS

Correlations	pH_water	pH-0.01MCacL2	ds_M Ec	C%	N%	K%	Na (CmoL_kg)	Ca (CmoL_kg)	Mg (CmoL_kg)	Cec (CmoL_kg)	P (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	Zn (ppm)	Infiltration rate (cm/hr)
pH_water	1															
pH-0.01MCacL2	0.95***	1														
ds_M Ec	0.238***	0.462***	1													
%C	-.130	-0.293***	-.088	1												
%N	-0.214**	-0.298***	-.068	0.581***	1											
%K	.122	-.010	-.020	0.424***	0.271***	1										
Na (CmoL_kg)	0.584***	0.678***	0.368***	-.052	-0.2**	.052	1									
Ca (CmoL_kg)	-.009	.036	-.126	0.346***	0.199**	0.35***	.020	1								
Mg (CmoL_kg)	-.126	-.131	-.121	0.16*	.054	0.148*	-.073	0.181**	1							
Cec (CmoL_kg)	.339***	.382***	.015	0.25***	-.009	0.491***	0.493***	0.497***	0.396***	1						
P (ppm)	.172*	.019	-.091	.110	.010	0.284***	-.019	.302***	-.062	.157*	1					
Fe (ppm)	-.186	-0.331*	-.027	-0.274**	-.171	-.191	-.107	-.024	.182	-.065	-.159	1				
Mn (ppm)	-.094	.124	-.066	-0.39***	-0.297**	-0.23*	-.194	-.071	.122	-.007	-.186	0.472***	1			
Cu (ppm)	-0.249*	-.274	-.005	-0.559***	-0.429**	-0.449***	-.162	-.051	.034	-.053	-0.286*	0.405***	0.625***	1		
Zn (ppm)	-.174	.123	.008	-0.256*	-.215	-.158	0.303**	0.258*	-.005	-.036	-.104	.194	.087	0.254*	1	
Infiltration rate (cm/hr)	.035	-.030	.045	-0.236**	-.007	-.077	-.144	-.088	-.125	-.206**	0.175	.125	-.122	.186	.113	1
* Correlation at 5% significance level																
** Correlation at 1% significance level																
** Correlation at 0.1% significance level																

APPENDIX E2

Student-Newman-Keuls Test for SAND

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	Block
A	40.357	14	7
A			
A	39.833	6	6
A			
A	39.026	39	4
A			
A	37.846	13	M
A			
A	36.000	35	5
A			
A	32.750	20	3
A			
A	32.059	17	2
A			
A	28.741	27	1
A			
A	25.920	25	8

Student-Newman-Keuls Test for SILT

SNK Grouping	Mean	N	Block
A	38.480	25	8
B	29.786	14	7
B			
C B	26.343	35	5
C B			
C B	23.222	27	1
C B			
C B	21.882	17	2
C B			
C B	21.256	39	4
C B			
C B	21.167	6	6
C B			
C B	19.538	13	M
C			
C	16.450	20	3

Student-Newman-Keuls Test for CLAY

A	50.850	20	3
A			
B A	48.037	27	1
B A			
B A	46.059	17	2
B A			
B A	42.615	13	M

Block	Sand	Silt	Clay
1	28.74	23.22	48.04
2	32.06	21.88	46.06
3	32.75	16.45	50.85
4	39.03	21.26	39.97
5	36.00	26.34	37.31
6	39.83	21.17	37.33

B	A			
B	A	39.974	39	4
B	A			
B	A	37.333	6	6
B	A			
B	A	37.314	35	5
B	A			
B	A	35.600	25	8
B				
B		29.714	14	7

7	40.36	29.79	29.71
8	25.92	38.48	35.60
M	37.85	19.54	42.62

APPENDIX E3

Univariate Analysis of Variance

Between-Subjects Factors

		N
Blocks	1	8
	2	6
	3	9
	4	4
	5	5
	6	3
	7	8
	8	6
	M	6

Tests of Between-Subjects Effects

Dependent Variable:Ksat (cm/hr)

Source	Sum of Squares	df	Mean Square	F	P-value
Blocks	77.971	8	9.746	1.052	.413
Error	426.336	46	9.268		
Corrected Total	504.307	54			

Estimated Marginal Means

1. Grand Mean

Dependent Variable:Ksat (cm/hr)

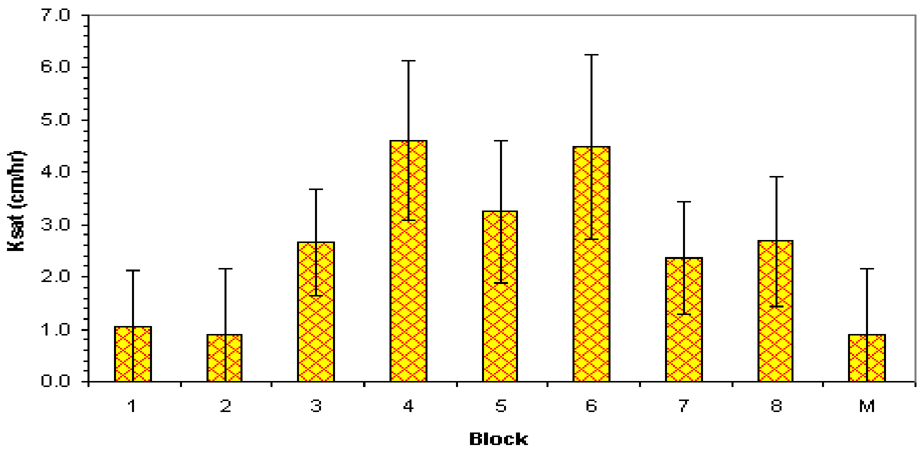
Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
2.543	.434	1.669	3.416

2. Blocks

Dependent Variable:Ksat (cm/hr)

Blocks		Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
	1	1.034	1.076	-1.133	3.200
	2	.910	1.243	-1.592	3.412
	3	2.652	1.015	.610	4.695
	4	4.600	1.522	1.536	7.664
	5	3.250	1.361	.509	5.991
	6	4.480	1.758	.942	8.018

	7	2.364	1.076	.197	4.530
	8	2.683	1.243	.182	5.185
	M	.910	1.243	-1.592	3.412



Univariate Analysis of Variance

Between-Subjects Factors

		N
Blocks	1	8
	2	6
	3	9
	4	4
	5	5
	6	3
	7	8
	8	6
	M	6

Tests of Between-Subjects Effects

Dependent Variable:Bulk Density (g/cm3)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	.025	8	.003	.731	.664
Error	.194	46	.004		
Corrected Total	.219	54			

Estimated Marginal Means

1. Grand Mean

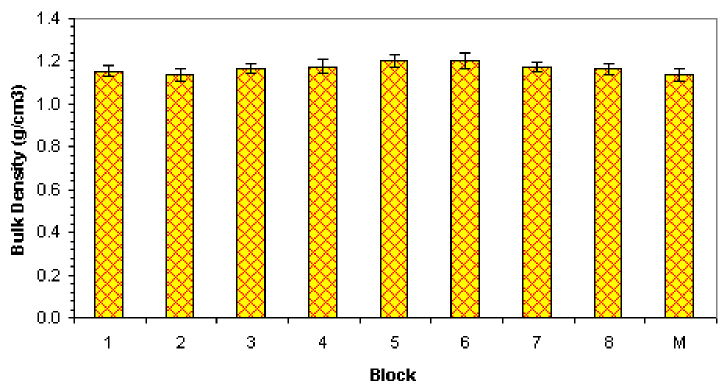
Dependent Variable:Bulk Density (g/cm3)

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
1.169	.009	1.150	1.188

2. Blocks

Dependent Variable:Bulk Density (g/cm3)

Blocks	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	1.155	.023	1.109	1.201
2	1.137	.027	1.083	1.190
3	1.167	.022	1.123	1.210
4	1.178	.032	1.112	1.243
5	1.206	.029	1.148	1.264
6	1.203	.038	1.128	1.279
7	1.175	.023	1.129	1.221
8	1.163	.027	1.110	1.217
M	1.137	.027	1.083	1.190



Univariate Analysis of Variance

Between-Subjects Factors

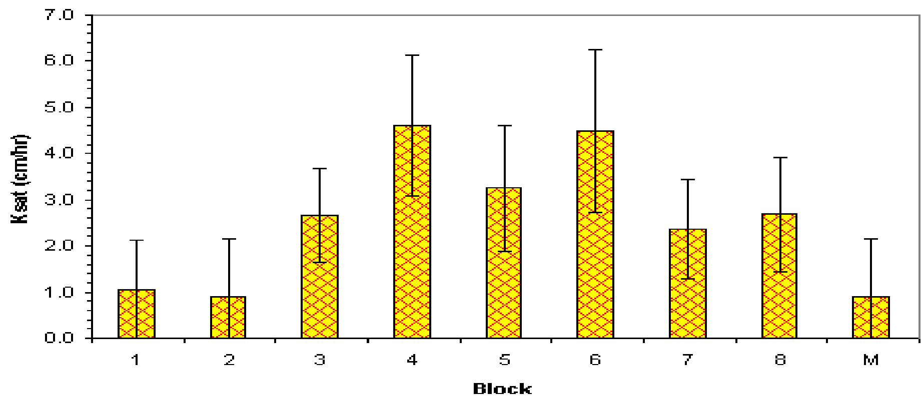
		N
Blocks	1	8
	2	6
	3	9
	4	4
	5	5
	6	3
	7	8
	8	6

	M	6

Tests of Between-Subjects Effects

Dependent Variable:Porosity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	36.882	8	4.610	.778	.624
Error	272.464	46	5.923		
Corrected Total	309.345	54			



Estimated Marginal Means

1. Grand Mean

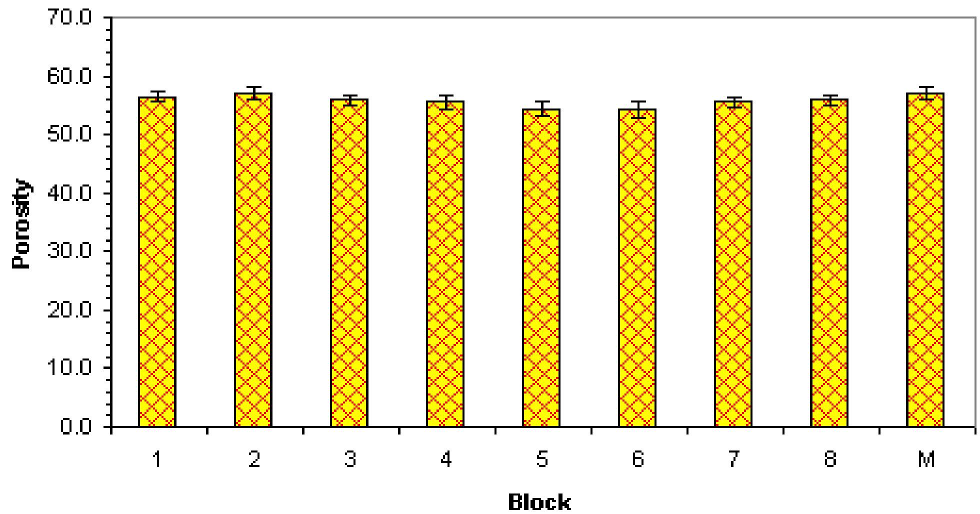
Dependent Variable:Porosity

Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
55.759	.347	55.061	56.457

2. Blocks

Dependent Variable:Porosity

Blocks	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	56.375	.860	54.643	58.107
2	57.000	.994	55.000	59.000
3	55.889	.811	54.256	57.522
4	55.500	1.217	53.051	57.949
5	54.400	1.088	52.209	56.591
6	54.333	1.405	51.505	57.162
7	55.500	.860	53.768	57.232
8	55.833	.994	53.833	57.833
M	57.000	.994	55.000	59.000



Univariate Analysis of Variance

Between-Subjects Factors

	N

Blocks	1	8
	2	6
	3	9
	4	4
	5	5
	6	3
	7	8
	8	6
	M	6

Tests of Between-Subjects Effects

Dependent Variable:Mean Infiltration Rate(cm/hr)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	102.544	8	12.818	.890	.533
Error	662.626	46	14.405		
Corrected Total	765.170	54			

Estimated Marginal Means

1. Grand Mean

Dependent Variable:Mean Infiltration Rate(cm/hr)

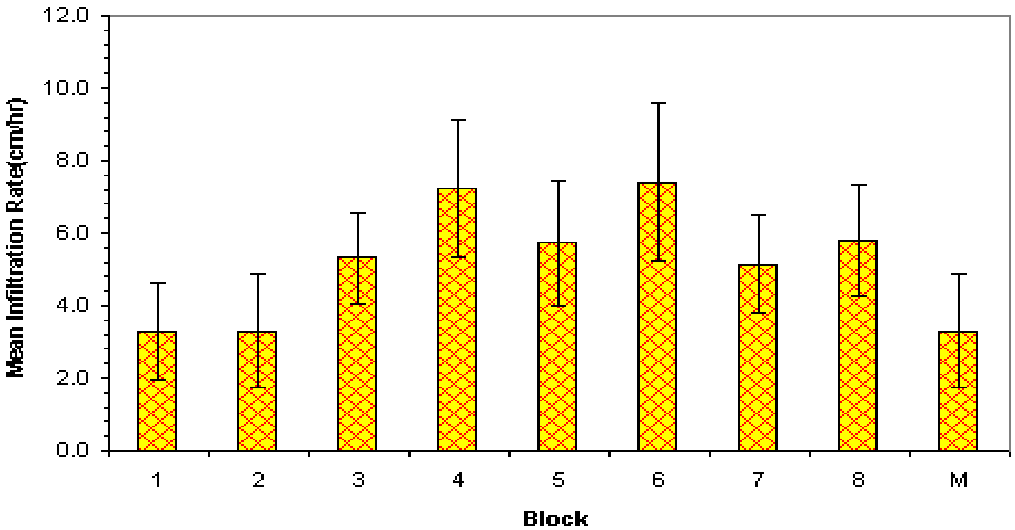
Mean	Std. Error	95% Confidence Interval	
		Lower Bound	Upper Bound
5.166	.541	4.077	6.254

2. Blocks

Dependent Variable:Mean Infiltration Rate(cm/hr)

Blocks	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	3.275	1.342	.574	5.976
2	3.300	1.549	.181	6.419
3	5.322	1.265	2.776	7.869
4	7.225	1.898	3.405	11.045
5	5.720	1.697	2.303	9.137
6	7.400	2.191	2.989	11.811
7	5.150	1.342	2.449	7.851

8	5.800	1.549	2.681	8.919
M	3.300	1.549	.181	6.419



APPENDIX F

SAMPLING BLOCKS

Block/sub-block		Mapping Unit & Class	Soil conditions and crop suitability factors
Tertiary	**Net area**		
TM-1	42	PLB1;S3	Imperfectly drained, deep to very deep vertisols (80-120 cm); Soils are mildly alkaline to moderately alkaline (pH 7.1 to 8.4); Soils are non-saline and non-sodic with ESP values of 2.2 to 13.4; Total % nitrogen is low at below 2%; 80% each of each tertiary has been allocated to paddy; 20% of the land is on footridges (6-10%) slope and is allocated to food and horticultural crops
TM-2	25	PLB1;S3	
TM-2	15	PSB;S3	Well drained and shallow (25-49 cm); Mildly alkaline to moderately alkaline (7.4 to 8.2); Soils are low in total nitrogen and potassium;
TM-1	6	RPB	Very shallow, very stony and very rocky: Lithic leptosols; Not suitable for irrigation
TOTAL	**88**		
T1. 1 – 1A	86	PLB1:S3	Imperfectly, drained, deep to very deep vertisols (80-120cm); soils are mildly alkaline to moderately alkaline (P7.1 to 8.4); Soils are non – saline and non-sodic with ESP values of 2.2 to 13.; total % nitrogen is low at below 2%; 80% each of each tertiary has been allocated to paddy.
T1.1-1B	40	PLB1:S3	
T1.1-2	109	PLB1:S3	
T1. 1-3	97	PLB1:S3	
T1. 1-4	33	PLB1:S3	
T1.1-5	1	PLB1:S3	
T1.1-	2	PSB;S3	
1B	6	PSB;S3	Well drained and shallow (25-49cm); mildly alkaline to moderately alkaline (7.4to8.2); soils are low in total nitrogen and potassium
T1. 1-2	85	PSB;S3	
T1.1-3	20	PSB;S3	
T1. 1-4	26	PSB;S3	
T1.1-5	38	PSB;S3	
T1.1-3	1		Sodic Solonchaks; Not suitable for irrigation
T1.1-4	20		
TOTAL	**564**		

T1.2-1	1	PLB1:S3	Imperfectly drained, deep to very deep vertisols (80-120cm); soils are mildly alkaline to moderately alkaline (pH 7 – 1 to 8.4); soils are non-saline and non-Sodic with ESP values of 2.2 to 1.3.4; Total % nitrogen is low at below 2%; 80% each of each tertiary has been allocated to paddy; 20% of the land is on footridges
T1.2-2	1	PLB1:S3	
T1.2-3	15	PLB1:S3	
T1.2-4	3	PLB1:S3	
T1.2-5	23	PLB1:S3	
T1.2-6	106	PLB1:S3	
T1.2-7	12	PLB1:S3	
T1.2-1	123	PSB;S3	Well drained and shallow (25-49cm); mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium.
TA.2-2	105	PSB;S3	
T1.2-3	35	PSB;S3	
T1.2-4	19	PSB;S3	
T1.2-5	9	PSB;S4	
T1.2-6	5	PSB;S5	
TA2-7	33	PSB;S6	
TOTAL		**490**	
T2. 1-1A	26	PSB;S3	Well drained and shallow (25-49cm); firm to friabe, clay loam to clay, in most places over murram; Mildly alkaline to moderately alkaline (7.4to 8.2); soils are low in total nitrogen and potassium.
T2.1-1B	21	PSB;S3	
T2. 1-2	43	PSB;S3	
T2.1-3	36	PSB;S3	
T2.1-4	44	PSB;S3	
T2.1-5	20	PSB;S3	
T2.1-6	38	PSB;S3	
T2.1-7	47	PSB;S3	
T2.1-8	87	PSB;S3	
T2.1-9	44	PSB;S3	Imperfectly drained , deep to very deep vertisols (80-120-cm); soils are mildly alkaline to moderately alkaline (pH 7.1 to 8.4); soils are non-saline and non-sodic with ESP values of 2.2 to 13.4; total % nitrogen is low at below 2%
T2.1-1A	2	PLB1;S3	
T2.1-1B	4	PLB1;S3	
T2.1-4	3	PLB1;S3	

T2.1-8	2	PLB1;S3	
T2.1-9	6	PLB1;S3	
T2.1-8	7	AA1;S2	Moderately well drained and very deep (120-180cm); friable to loose, loam to clay loam, slightly acidic to neutral (pH 6.3 to 7.3); Non-saline and non-sodic (ESP values; 2.0 to 8.0); Total nitrogen is very low in both topsoil and sub-soil.
T2.1-1A	3	RPb	Very shallow, very stony and very rocky; Lithic Leptosols; Not suitable for irrigation.
T2.1-2	3	RPb	
T2.1-3	2	RPb	
T2.1-4	1	RPb	
T2.1-6	3	RPb	
T2.1-1B	1	RPb	
TOTAL	**443**		
T2.2-1	23	PLB1;S3	Imperfectly drained, deep to very deep vertisols (80-120cm); soils are mildy alkaline to moderately alkaline(pH 7.1 to 8.4); Soils are non-saline and non-sodic with ESP value of 2.2 to 13.4; Total % nitrogen is low at below 2%
T2.2-2	93	PLB1;S3	
T2.2-3	20	PLB1;S3	
T2.2-4	14	PLB1;S3	
T2.2-5	47		
T2.2-6	51	PLB1;S3	
T2.2-7	18	PLB1;S3	
T2.2-8	4	PLB1;S3	
T2.2-9	69	PLB1;S3	
T2.2-10	69	PLB1;S3	
T2.2-11	26	PLB1;S3	
T2.2-1	28	PSB;S3	Well draied and shallow (25-49cm); firm to friable, clay loam to clay, in most places over murram; mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium;
T2.2-2	12	PSB;S3	
T2.2-3	15	PSB;S3	
T2.2-4	29	PSB;S3	
T2.2-5	44	PSB;S3	

T2.2-6	48	PSB;S3	
T2.2-7	11	PSB;S3	
T2.2-8	47	PSB;S3	
T2.2-9	24	PSB;S3	
T2.2-10	20	PSB;S3	
T2.2-11	38	PSB;S3	
TOTAL	**749**		
T2.3-1	98	PLB1;S3	Imperfectly drained, deep to very deep vertisols (80-120cm); soils are mildly alkaline to moderately alkaline (pH7.1 to 8.4); soils are non-saline non-sodic with ESP values 2.2 to 13.4 total%
T2.3-2A	34	PLB1;S3	
T2.3-5	12	PLB1;S3	
T23-6	4	PLB1;S3	
T2.3-1	144	PSB;S3	Well drained and shallow (25 -49sm); firm to friable, clay loam to clay, in most places over murram; mildly alkaline to moderately alkaline (7.4 to 8.2(; soils are low in total nitrogen and potassium;
T2.3-2A	202	PSB;S3	
T2.3-2B	85	PSB;S3	
T2.3-3	97	PSB;S3	
T2.3-4	73	PSB;S3	
T2.3-5	27	PSB;S3	
T2.3-6	80	PSB;S3	
T2.3-7	66	PSB;S3	
T2.3-8	38	PSB;S3	
T2.3-9	86	PSB;S3	
T2.3-10	141	PSB;S3	
T2.3-2A	8		Moderately well drained and very deep (120-180cm), friable to loose loam to clay loam, slightly acidic to neutrak (pH 6.3 to 7.3); Non-saline and non-sodic(ESP values: 2.0 to 8.0); Total nitrogen is very low in both topsoil and sub-soil
T2.3-2B	30	AA1;S2	
T2.3-3	29	AA1;S2	
T2.3-6	5	AA1;S2	
T2.3-7	29	AA1;S2	
TOTAL	**1288**		

T3-1	138	PLB1;S3	Imperfectly drained, deep to very deep vertisols (80-120cm); soils are mi ldly allakine to moderately alkaline (pH 7.1to 8.4); soils are non-saline and non-sodic with ESP values of 2.2 to 13.4 ; total % nitrogen is low at below 2%.
T3-2	178	PLB1;S3	
T3-3	94	PLB1;S3	
T3-4	25	PLB1;S3	
T3-5	22	PLB1;S3	
T3-6	14	PLB1;S3	
T3-7	230	PLB1;S3	
T3-8	48	PLB1;S3	
T3-9	46	PLB1;S3	
T3-10	3	PLB1;S3	
T3-9	86	PSB;S3	Well drained and shallow (25-49cm); mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium;
T3-10	30	PLB2.S3	Sodic Solonachaks; not suitable for irrigation.
T3-10	55	Swamp/ PLB2	
TOTAL	**969**		
T4. 1-1	76	PLB1 S3	Imperfectly drained, deep to very deep vetisols (80-120cm); soils are mildly alkaline to moderately alkaline (pH7.1 to 8.4); soils are non-saline and non-sodic with ESP values of 2.2 to 13.4 ; total % nitrogen is low at below 2%; 80% each of each tertiary has been allocated to paddy; 20% of the land is on footridges (6-10%) slope and is allocated to food and horticultural crops.
T4. 1-2	51	PLB1;S3	
T4.1-3	61	PLB1;S3	
T4.1-4	45	PLB1;S3	
T4.1-5	34	PLBA;S3	
TOTAL	**267**		
T4.2-1	83	PLB1; S3	Imperfectly drained, deep to very deep vertisols (80-120cm); soils are mildy alkaline to moderately alkaline (pH 7.1 to 8.4); soils are non-saline and non-sodic with ESP values of 2.2 to 13.4; total % nitrogen is low at below 2%
T4.2-2	54	PLB1; S3	
T4.2-3	43	PLB1; S3	
T4.2-4	23	PLB1; S3	
T4. 2-5	14	PLB1; S3	
T4.2-6	56	PLB1; S3	
T4. 2-7	14	PLB1; S3	

T4.2-1	59	PSB; S3	Well drained and shallow (25-49cm); firlm to friable, clay loam to clay, in most places over murram; mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium;
T4.2-2	13	PSB; S3	
T4.2-8	6	PSB; S3	
TOTAL	**365**		
T4. 3-1	36	PLB1;S3	Imperfectly drained, deep to very deep vertisols; soils are mildly alkaline to moderately alkaline (pH 7.1 to 8.4); soils are non-saline and non-sodic with ESP values of 2.2 to 13.4 Total % nitrogen is low at below 2%
T4.3-2	41	PLB1;S3	
T4.3-3	47	PLB1;S3	
T4.3-4	44	PLB1;S3	
T4.3-5	15	PLB1;S3	
T4.3-6	24	PLB1;S3	
T4.3-7	57	PLB1;S3	
T4. 3-1	12	PSB, S3	Well drained and shallow (25-49cm); firn to friable, clay loam to clay, in most places over murram; mildly alkaline to moderately alkaline (7.4 t 8.2); soils are low in total nitrogen and potassium;
T4.3-2	6	PSB, S3	
T4.3-3	10	PSB, S4	
T4.3-4	4	PSB, S5	
T4.3-7	11	PSB, S3	
T4.3-8	55	PSB, S3	
T4.3-7	70	AA2 & swamp	Excessively drained, very deep sandy soils; Arenosols: Not suitable for
T4.3-8	4	AA2	
TOTAL	**436**		
T5.1-1	147	PLB2:S3	Sodic solonchacks; Not suitable for irrigation
T5. 1-2	220	PLB2:S3	
T5.1-3	104	PLB2:S3	
T5.1-4	37	PLB2:S3	
T5.1-5	17	PLB2:S3	
T5.1-1	1	PSB:S3	
T5.1-2	11	PSB:S3	

T5.1-1	8	AA1;S2	Moderately well drained and very deep (120-180cm); friable to loose, loam to clay loam, slightly acidic to neutral (pH 6.3 to 7.3); Non-saline and non-sodic (ESP valus: 2.0 to 8.0); Total nitrogen is very low to low in both topsoil and sub-soil.
T5.1-2	6	AA1;S2	
T5.1-3	62	AA1;S2	
T5.1-4	35	AA1;S2	
T5.1-5	70	AA1;S2	
T5.1-6	64	AA1;S2	
TOTAL	**784**		
T5.2-1 T5.2-2	76 89	AA1: S2 AA1: S2	Moderately well drained and very deep (120-180cm); friabe to loose, loam to clay loam, slightly acidic to neutral (pH 6.3 to 7.3); Non-saline and non-sodic (ESP valus: 2.0 to 8.0); Total nitrogen is very low to low in both topsoil and sub-soil.
T5.2-3	117	AA1: S2	
T5.2-4	59	AA1: S2	
T5.2-5	59	AA1: S2	
T5.2-6	169	AA1: S2	
T5.2-1	8	PSB; S3	Well drained and shallow (25-49cm); firm to friable, clay loam to clay, in most places over murram ; mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium
T5.2-1	17	PLBS; S3	Sodic solonchacks; Not suitable for irrigation
T5.2-2	8	PLBS; S3	
T5.2-3	6	PLBS; S3	
T5.2-4	42	PLBS; S3	
T5.2-5	37	PLBS; S3	
T5.2-6	20	PLBS; S3	
TOTAL	**707**		
T6-1	153	AA1:S2	Moderately well drained and very deep (120-180cm); friable to loose, loam clay loam, slightly acidic to neutral (pH 6.3 to 7.3); Non-saline and non-sodic (ESP values: 2.0 to 8.0); Total nitrogen is very low to low in both topsoil and subsoil.
T6-2	76	AA1:S2	
T6-3	42	AA1:S2	
T6-4	41	AA1:S2	
T6-5	51	AA1:S2	
T6-6	37	AA1:S2	

T6-7	67	AA1:S2	
TOTAL	**467**		
T7-1	93	AA1;S2	Moderately Well Drained And Very Deep (120-180cm); Friable To Loose, Loam Clay Loam, Slightly Acidic To Neutral (Ph 6.3 To 7.3); Non-Saline And Non-Sodic (ESP Valus: 2.0 To 8.0); Total Nitrogen is very low to low in both topsoil and sub-soil
T7-2	6	AA1;S2	
T7-3	138	AA1;S2	
T7-4	6	AA1;S2	
T7-5	19	AA1;S2	
T7-6	40	AA1;S2	
T7-8	66	AA1;S2	
T7-1	5	PSB;S3	Well drained and shallow (25-49cm); firm to friable, clay loam to clay, in most places over murram, mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total Nitrogen and Potassium;
T7-2	8	PSB;S3	
T7-3	1	PSB;S3	
T7-4	55	PSB;S3	
T7-5	6	PSB;S3	
T7-6	7	PSB;S3	
T7-5	9	PLB2;S3	Sodic solonchacks, Not suitable for irrigation.
T7-6	42	PLB2;S3	
T7-7	56	PLB2;S3	
T7-8	78	PLB2;S3	
T7-9	73	PLB2;S3	
TOTAL	**708**		
T8-1	66	AA1; S2	Moderately well drained and very deep (120-180cm); friable to loose, loam to clay loam, slightly acidic to neutral (pH 6.3 to 7.3); Non-saline and non-sodic (ESP valus: 2.0 to 8.0); Total nitrogen is very
T8-2	55	AA1; S2	
T8-3	66	AA1; S2	
T8-4	18	AA1; S2	

T8-5	93	AA1; S2	low to low in both topsoil and sub-soi .
T8-6	80	AA1; S2	
T8-7	36	AA1; S2	
T8-9	46	AA1; S2	
T8-10	10	AA1; S2	
T8-11	7	AA1; S2	
T812	39	PSB; S3	Well drained and shallow (25-49cm); mildly alkaline to moderately alkaline (7.4 to 8.2); soils are low in total nitrogen and potassium;
T8-13	17	PSB; S3	
T8-14	16	PSB; S3	
T8-15	7	PSB; S3	
T8-8	17	PSB; S3	
T8-9	76	PSB; S3	
T8-12	16	PSB; S3	
T8-13	2	PSB; S3	
T8-14	8	PSB; S3	
T8-15	2	PSB; S3	
T8-14	7	AA2;S3	Not irrigable
T8-10	11	NA	
T8-11	1	NA	
TOTAL	**696**		

ANNEX 1