LAND EVALUATION USING CONVENTIONAL AND SATELLITE DATA TECHNIQUES IN TOMAS IRRIGATION SCHEME, KANO STATE, NIGERIA

BY

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DEPARTMENT OF SOIL SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

NOVEMBER, 2015

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Ph.D/Agric/4689/2009-2010

A THESIS SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN SOIL SCIENCE

IN

THE DEPARTMENT OF SOIL SCIENCE

AHMADU BELLO UNIVERSITY, ZARIA

NIGERIA

NOVEMBER, 2015

DECLARATION

I declare that this thesis entitled **"Land Evaluation and using Conventional and Satellite Data Techniques in Tomas Irrigation Scheme, Kano State"** was written by me in the Department of Soil Science, Ahmadu Bello University. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of the thesis was previously presented for another degree or diploma at any University.

YA`U SULAIMAN LAWAN

....

Name of Student Signature Date

CERTIFICATION

This thesis**,** entitled **"Land Evaluation using Conventional and Satellite Data Techniques in Tomas Irrigation Scheme, Kano State"** by Ya`u, Sulaiman Lawan meets the regulations governing the award of the degree of Doctor of philosophy of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

Dedicated to Mallam Ya'u Family

ACKNOWLEDGEMENT

My sincere gratitude goes to Almighty Allah, Who gave me the endurance and patience to see this work through. I also need to express my sincere appreciation to Prof. Raji B.A., Dr. Malgwi, and Prof. Uyobvisere who contributed immernsely in making this work a reality.

My sincere appreciation goes to my family, brothers, sisters and my friends for their prayers and support through out this work. I most sincerely thank Dr Kabiru Shehu (Former provost, CAS, Kano), who inspired me to go through this journey, and also the management of Kano state college of Arts, Science and Remedial Studies for releasing me to undertake this study.

ABSTRACT

Land evaluation study with the aid of satellite data (SPOT 5), Geographic Information Systems (GIS) and field data was conducted in Tomas irrigation scheme, Kano state. The soil map produced by Ministry of Agriculture and Natural Resources (MANR, Kano) in 1987 was digitized and used for further analysis. The mapping units were Ballauda (Ba), Sansan (Sn), Tomas (To) and Ladi (La). Three major land use types (LUT) were identified through supervised image classification using SPOT 5 imagery, viz; irrigated land use type, rainfed land use type and "others" land use type. Results indicate that, the morphological properties were generally similar. Sand was the dorminant size fraction in all the mapping units ranging from 720 to 900 g kg^{-1}, with textures ranging from loamy sand to sandy loam. Bulk density varied between 1.14 and1.69 Mgm^{-3} and particle density between 1.48 and 2.68 Mgm^{-3}. The available water holding capacity of the soils ranged from 0.1 to 8.2 % revealing the limited capacity of the soils to retain enough moisture for plant growth. The chemical properties of the mapping units indicated a strongly acidic to near neutral soil reaction with pH of 5.2 to 6.6. The values of organic carbon and total nitrogen were generally low, with values ranging from 0.4 to 11.4 g kg^{-1} and 1.1 to 4.2 g kg^{-1} respectively. Available P values ranged from 1.75 to 47.25 mg kg^{-1} and were rated low to high. Cation exchange capacity (CEC) 0.5 to 13.5 cmol(+) kg^{-1} was rated very low to moderate, while base saturation percentage (BSP) was rated low to high, with values ranging from 24.56 to 76.37%. The exchangeable sodium percentage (ESP) with values ranging from 1.7 to 29.0% indicates the soils were non sodic. The electrical conductivity (ECe) values were low with values from 0 to 0.23 dS m^{-1}. Available micro-nutrients levels (Cu, Zn, Fe and Mn) were adequate in all the mapping

units. Total elemental analysis revealed predominance of SiO_2 (quartz) in all the soils. Feldspar, chlorite, kaolinite and muscovite were the dorminant minerals from clay mineralogy of the mapping units. The electrical conductivity (CE) of the irrigation was rated very low ranging from 0.09 to 0.95 dSm^{-1} and low for Sodium adsorption ratio (SAR) with values of 0.013 to 0.09, indicating that the water was safe and suitable for irrigation. According to United State Department of Agriculture (USDA) Soil Taxonomy systems of classification, the soils were classified as Arenic Haplustepts, Typic Haplustepts, Typic Ustifluvents and Aquic Ustifluvents at the subgroup level. In the World Reference Base classification systems, the soils were classified as Haplic Arenosols, Haplic fluvisols and Gleyic fluvisol at the sub unit level. The land capability classification of the soils revealed "marginal"capability class (IIIfs) with major limitations of low fertility status and coarse soil texture. The extent of land utilization indicates that 86.2% of the land in the study area was over utilized. Only 12.81% of the land was properly managed, where current land use fits potential capability. Using the non parametric method, the suitability evaluation of the mapping units for irrigated rice shows that, all the pedons were" marginally suitable"(S3fs), for actual suitability and "moderately suitable" (S2) for potential suitability. For the parametric method, all the pedons had an index of current productivity (IPC) of 5.63(N2); hence classified as "permanently not suitable" for irrigated rice production. However, for the index of potential productivity (IPP), all the pedons were also "permanently not suitable" with a value of 9.0(N2), except pedon Ba1, which was currently not suitable with a value of 20.5(N1). Management options to be employed to improve the low levels SOC, total N and CEC and sandy texture of the soils includes residue mulching and organic manuring

to regulate deep percolation and evaporation losses and conserve soil moisture in the rooting zone. Incorporation of crop residues after harvest, legume based rotation and/ or intercropping, zero or minimum tillage should be encouraged as a measure to increase organic matter build up. Application of recommended rates of N fertilizer in two unequal splits was also recommended. The socio-economic evaluation reveals high cost of labour, unreliable and inadequate water supply for irrigation and inadequate inputs supplies as part of the major challenges faced by farmers. The net farm income (NFI) to the farmers was positive with #216,800, and rate on investments (RRI) of 3.60 for every naira invested, indicating that farmers were benefitting.

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CHAPTER ONE

1.0 INTRODUCTION

Soil is a life supporting system upon which human beings have been dependent from the dawn of civilization. Hence, comprehensive information on soil resources, its potentials, limitations and capabilities, is required for a variety of purposes; such as project area development, soil conservation in catchment areas, sustainable agriculture, reclamation of degraded lands, etc (Sesha Sai *et al.*,2007). In this context, characterization and mapping of different types of soils and developing rational criteria for land evaluation are important and very pertinent.

Land evaluation is defined as the process of making predictions of land performance over time, based on specific types of uses (Van Diepen *et al*., 1991; Rossiter, 1996). These predictions are then used as guide in the strategic land use decision making. Therefore, the primary or traditional basis for land evaluation is knowledge of land resource inventories commonly known as soil survey, which provides accurate and scientific inventory of different soils, their nature and extent of distribution so that one can make predictions about their characteristics and potentialities (Manchanda, *et al*., 2002). Land evaluation can be a key tool in land use planning by individual land users, group of land users or by society as a whole. The function of land use planning is to guide decision on land use in such a way that resources of the environment are put to the most beneficial use by man, while at the same time, conserving those resources for the future (FAO, 1976). Therefore, soil information is a vital component in the planning process, reflecting directly upon land use suitability (Coleman and Galbraith, 2000).The degree of suitability for a land use; regardless of economic conditions is indicated by a physical suitability

evaluation (Rossiter and VanWambeke, 1997). Thus, the process of land suitability classification is the assessment and categorization of specific areas of lands in terms of their suitability for defined uses (FAO, 1976).

Since the primary basis for land evaluation is soil survey, soil data to be used in evaluation studies must be obtained from detailed soil survey (Lekwa, 1999), and soil management units should be based on the lowest category level, that is, soil series which will satisfy the criterion for an effective land use planning. But our conventional (traditional) survey methods follow a specific methodology to identify, characterize, and fit the mapping units in to a classification system and to have a final product in the form of maps. These methods suffer from a number of inherent deficiencies that limit their usefulness as a tool for effective land use planning. They are time consuming, labour intensive and expensive to generate adequate data (Mohammd *et al*., 2011). There is also a large time gap between the time when information is collected and when it is disseminated. Ameyan (1995), was of the view that the conventional methods still have difficulty in coping with more than one data set for a given area at the same time. This view is further supported by Nair *et al*. (1996), who opined that the manual methods of soil data handling are slow and inefficient in managing large volumes of information.

Due to the above problems, part of the challenges now in land evaluation consists of improving the conventional surveys in order to make them less time consuming, less expensive and more rapidly available. Therefore, different stages of conventional surveys must necessarily take into account the use of new technologies such as Global Positioning Systems (GPS), satellite data imagery, Digital elevation model (DEM) and Geographic Information System (GIS), to support the different activities involved. The

use of such techniques may contribute to a faster and more realistic field data collection and to make the delineation of mapping units more precise, make the availability of the final product easier and potentialise the use and application of results (Aronoff, 1999; Morris *et al*., 2000; Hempel *et al*. 2006). In addition, soil survey data such as soil depth and texture, gathered for individual locations in the field, can be stored and retrieved for use in land evaluation.

The use of earth resource satellites for natural resource mapping and monitoring in providing cost effective approach to data generation has been emphasized (Wilde *et al*., 1996; Raji, 2004). Integration of SPOT 5 satellite image data with Geograhic information systems (GIS) technology; which is a computer software used for capturing, storing, querying, analyzing and displaying geographically referenced data (Goodchild, 2000), and field work in a land resource inventory exercise for land evaluation will facilitate rational and effective land use planning with appropriate and sustainable use of human and natural resources.

The main aim of this study is to use information acquired from SPOT 5 (2005) as a satellite data and use GIS as a tool to assess the current and potential land use in Tomas irrigation scheme and evaluate the same for irrigated rice production.

The specific objectives are to:

1. Map and delineate the different land uses/ cover in Tomas irrigation scheme.
2. Characterize the various soil mapping units morphologically, physically and chemically.

3. Classify the soils using United State Department of Agriculture (USDA) Soil Taxonomy and Food and Agricultural Organization (FAO) world reference base for soil resource.
4. Generate potential land capability classification and asses the extent of land utilization in Tomas irigation scheme.
5. Evaluate the soils for their suitability to irrigated rice production.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Land Evaluation Concept

In the context of land evaluation, land is more than the solid surface of the earth. It includes the soil and the rocks beneath the atmosphere with its climate, the cyclic interchange of water beneath the sky, the ground, the rivers and sea, the whole mantle of living things, both plants and animals (Whyte 1976; Sys, 1985). The art of land evaluation is to predict the most important changes, to decide whether these changes are desirable or acceptable and thus, to categorize the proposed action as appropriate (Young and Goldsmith, 1977). The FAO (1976), broadly defined land evaluation as the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of land use, vegetation, land forms, soils, climate and other aspect of land in order to identify and make a comparison of promising kinds of land use in termsof being applicable to the objectives of the evaluation.

Brinkman (1973), defined land evaluation as the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and make a first comparison of promising land use alternatives in simple socio-economic terms. Van Diepen *et al*. (1991) and Rossiter (1996), viewed land evaluation as the process of making predictions of land performance over time based on specific types of uses. These predictions are then used as guides in strategic land use decision making. Davidson *et al*. (1993), maintained that, the aim of land evaluation is to provide a

judgement or assessment of land quality for defined uses. However, Beek (1978), considered it as a process of matching series of selected land qualities and comparing them with land use requirements. In all, whatever the definition or concept of land evaluation may be, majority of land evaluators agree that, the primary basis of land evaluation is soil resource inventories commonly known as soil surveys, which pave the way to soil characterization, classification and evaluation (Onyekanne *et al*., 2012).

2.2 The Need for Land Evaluation

In defining land evaluation, there is the need to take into account problems which in most cases, relate to inappropriate land use. This leads to inefficient exploitation of natural resources, destruction of land resources, poverty and other social problems, and even the destruction of civilization (De Ridder *et al.*, 2007). Land evaluation is preceded by recognition of the need for a change in use to which land is put. This may be the development of new productive uses such as agricultural development schemes, forestry plantation or production of services, such as the designation of national park or recreation area. This maximizes most beneficial use of the finite land resources and at the same time conserves them for the future.

A report by Federal Department for Agricultural Land Resources (FDALR, 2013), stated that, rapid human population , increase and human competitive demand for food and fiber with changing economic and social conditions have undermined or destroyed traditional systems of land resources management. For instance, over cropping the land or intensive grazing with reduced fallow periods and without effective system of maintaining fertility have resulted to massive soil degradation through loss of plant nutrients, erosion, salinity build up etc. These damages which could at times be economically irreversible have

destroyed natural ecosystems and modified or eliminated natural populations of flora and fauna.

All these problems call for recognition of the need for a change in the use to which land is put, as traditional land use system should be preserved and strengthened where ever possible. The need for land evaluation becomes necessary when:

1. Land users feel there is need for land use change.
2. There is political will and ability (instruments, manpower, and budget) to support and implement the plan.
3. Planned change is acceptable to the people (land users) involved.

When the need for land evaluation is accepted, consideration should be given to the economics of proposed enterprises, social concern for people of the area and the country concerned, as well as the consequences; beneficial or adverse, to the environment (FAO, 1989). To minimize risks, land use requirements are matched with the land qualities. This is the role of land evaluation which implies a process of prediction (Alves and Nortcliff, 2000). Application of the FAO frame work for land evaluation (FAO, 1976), can identify the most limiting land qualities and provide a good basis for advising farmers on appropriate management practices for optimum production in a particular agro-ecological zone (Chinene, 1992).

2.3 Types of Land Evaluation

The Food and Agricultural Organization (FAO, 1976) proposed two approaches to land evaluation viz; the two stage approach (qualitative), and the parallel approach. The two stage approach or qualitative evaluation is used in resource inventory for broad planning

purposes, and in some situations for assessment of bio physical production potentials. Contributions of economic and social analysis to the first stage are limited to check the relevance of kinds of land use (Bronsveld *et al*., 1994). Economic and social analysis is then followed immediately or after any interval of time.

The parallel approach is the one in which analysis of relationship between land and land use proceeds concurrently with socio-economic analysis (Dent and Young, 1980). In other words, the economic and social analysis of all kinds of land use proceeds simultaneously with the survey and assessment of its physical problems. Dent and Young (1980), identified three types of land evaluation; namely, qualitative, quantitative and economic. The qualitative evaluation assesses suitability of land in general physical terms (e.g. soil, topography, climate etc), while a quantitative system specifies the input (e.g. fertilizer, seeds, labor) and the output (e.g. crop yield), in addition to physical parameters.

Nuga (2001) reviewed the works of Beek (1980), and Smith *et al*. (1984), and identified two basic types of land evaluation. The physical evaluation; which attempts to assess performance of specific land areas in terms of constraints imposed by the land. Performance is rated using indices such as capability, suitability, vulnerability or productivity. These evaluations, according to them, are useful in the identification and comparison of potential land use alternatives and for broad regional land use planning.

On the other hand, integral land evaluation synthesizes information on the nature and productivity of land resources with information on goals and objectives for the use of land. It is an extension of physical land evaluation, in that, it identifies land use options and the importance of maintaining particular land uses in certain land areas in economic

terms. Part of the limitations by Smith (1984) was that, they do not provide sufficient information for establishing land use policies and guidelines.

Some evaluation systems group the classes into series or levels of importance (order, class, subclass, type etc.), and are thus hierarchical systems. Other systems have one category, and these are frequently parametric (Hussaini, 2011). In the parametric system, mathematical formulae are applied so that the final result is expressed in numerical terms. These include Model of Storie (1978), and the Square Root Model of (Ogunkule, 1993; Udoh and Ogunkule, 2012; Udoh *et al*., 2011). These can be additive (Index= A+B+C+D+….) or with a multiplicative scheme (Index= AxBxCxDx….) and square root scheme (Index= SQRT (B/100xS/100xC/100x…F/100)). Where SQRT is square root, A the overall least characteristic rating and B, C… are the least rating characteristic for each land quality. It is generally accepted that the parametric methods are, according to Mc Rae and Burnham (1981), simple, objective, quantitative, reliable, easy to understand and apply, even by the non-specialist, and easy to modify and adapt to new uses.

With all these advantages, Hussaini (2011) highlighted the disadvantage of the parametric system to be, difficulty in formulation which if not well applied the results may be erroneous. The parametric scheme is regarded as too artificial, with the relationship between the soil properties and the result of evaluation being poorly defined. In essence, land use evaluation is a dynamic rather than a static process.

2.3.1 Land capability classification

Land capability is the potential of land for use in either specified ways or with specified management practices (Dent and Young, 1981). It has been used in a number of land

classification systems notably that of the Soil Conservation Service of United State Department of Agriculture (USDA) (Killingerbeil and Montgomery, 1961). In the USDA system, soil mapping units are grouped primarily on the basis of their capability to produce common cultivated crops and pasture plants without deterioration over a long period of time (FAO, 1976). The system does not intend to create detailed management plans, only the conservation part of these plans (Rossiter, 1994).

Capability classification refers to general kinds of land use (similar to FAO frame work), rather than specific land use systems (FAO, land utilization types), for which suitability of land areas refers to. Thus detailed explanations about land use and management are not captured in capability classification (Rossiter, 1994). In capability evaluation, rating is based on permanent soil characteristics (limitations) with regard to risks of soil damage (FDLAR, 2013). Limitations are land characteristics which have an adverse effect on capability. Most of the factors considered for capability evaluation are those that relates to soil physical conditions; like effective rooting depth, coarse fragments, drainage conditions, topography (which can predispose the soil to erosion and or flooding), and climatic condition of rainfall (Dent and Young, 1981, Rossiter, 1995). These limitations are called permanent because they cannot easily be changed, at least by minor land improvements. On the other hand temporary limitations can be removed or corrected/ameliorated by minor land improvements. Examples include soil nutrient content and at least a minor degree of drainage. Other chemical conditions apart from physical conditions include the ability of soil to hold nutrients (CEC), soluble salt concentrations (sodicity and salinity), soil texture, soil permeability, and available water

holding capacity (FDALR, 2013; Ali and Kotb, 2010; Raji ,2004; Malgwi, 2001;and Dent and Young,1981.).

Killingebeil and Montgomery (1961), defined capability classes into I—VIII. The capability class describes general "goodness" in the sense of possible intensity of use. Class I = Best, while class VIII = worst. The capability class does not necessarily indicate what is best use for land, nor the most profitable (Dent and Young, 1981, Rossiter 1994). Land defined as suitable for arable might be more profitably put to grass or tree crops. It only indicates the range of uses to which each area could be put. A capability class is a group of capability sub classes that have the same relative degree of limitations or hazards. The classes fall into two groups. Class I-IV can be used for cultivation, while class IV-VIII cannot (Rossiter, 1994).

Capability sub class indicates the major limitations by the use of one or more letters (Dent and Young, 1981). The USDA subclasses like e= erosion hazard, w=excess water (wetness), s = soil limitation within the rooting zone (includes shallowness, stones, low nutrient fertility, difficult to correct salinity), c = climatic limitation (temperature or rainfall). Class I has no subclass. However, the risk of land damage or limitation in use becomes progressively greater from class I-VIII (Mohana *et al*., 2009).

Many researchers have demonstrated the relevance of land capability classification in allocating land uses that aid sustainability using GIS and remote sensing. This includes the work of Ali et al.,(2009) in El Hamman District in Egypt, using remote sensing and GIS as a tool, considered slope, effective depth, drainage, texture, clay, permeability, CEC, EC, ESP, and $CaCo_3$ content as limitations and classified the soils into capability

class IV and V. Similaarly, Ali and Kotb (2010), used satellite data and GIS adjacent to El Manzala in Egypt and classified the soils into classI (highly capable), class II (modearately capable), class III (low capable) and class IV (very low capable). Attribute land characteristics used as limitations include; $CaCo_3$ content, textural class, soil depth, salinity, alkalinity, CEC and drainage conditions. However, Raji (2004), in Kano River Project; considered slope, soil depth, drainage, topography, texture and climatic condition as limitations. He classified the soils in to capability class I, II and III as good, moderate and marginal respectively. The FDALR (2013) in a semi detailed soil survey of some selected states in south western Nigeria reported a capability class of III with major limitations of low subsurface CEC, coarse fragments (gravels), as well as susceptibility to erosion in some areas. In a similar report, some soils were classified as capability class IIIsw with limitations of soil texture and wetness in some selected states of North Central Nigeria.

Since land capability is centered on capability of land use based on management and conservation, measures employed in correcting these limitations include; deep ploughing to improve soil permeability and moisture availability, organic and inorganic fertilization to improve permeability and nutrient availability, ridges as means of enhancing drainage, the use of modern irrigation systems to supply the needed uniform water and avoidance of soil crust formation (FDALR, 2013; Ali and Kotb 2010 Ali *et al*. 2009;Raji, 2004).

2.3.2 Land suitability evaluation

Land evaluation as defined by Van Diepen *et al*. (1991) and Rossiter (1996), is the process of making predictions of land performance over time based on specific types of uses. Land suitability evaluation can be defined as assessment or predictions of land

quality for specific use, these predictions are then used as a guide in strategic land use decision making. The process of land suitability evaluation includes , identification, selection and description of land use types relevant to the area under consideration, mapping and description of different types of land that occur in the area and the assessment of the suitability of the different types of land for selected land use types (FAO, 1976). Rossiter (1995) stated that the modern era of land evaluation began with the publication of FAO frame work for land evaluation (1976) and subsequent guidelines for land evaluation of general kinds of land uses (FAO, 1983, 1984, 1985 and 1991).

Prakash (2003) viewed land suitability evaluation as the pre-requisite for sustainable agricultural production. It involves evaluation of the criteria ranging from soil terrain to socio economic, market and infrastructure. Austin (1978), defined it as the assessment and prediction of land quality in terms of a specific use, in terms of its productivity, degradation hazards and management requirements. The degree of suitability for land use, regardless of the economic conditions is indicated by a physical suitability evaluation (Rossiter and Van Wambeke, 1997).

Land Suitability assessment or evaluation is similar to choosing an appropriate location, except that, the goal is not to isolate best alternative, but to map a suitability index of the entire study area (Joerin and Theriault, 2001). Due to large number of attributes and various criteria involved in decision making, land evaluation has been identified as multi criteria evaluation exercise (Rashmidevi *et al.*, 2009). Land suitability evaluation therefore, requires specialists of different disciplines like soil scientists, agro ecologists, socio economists and planners.

Suitability assessment is based on description of land characteristic and land qualities. Land characteristics are attributes of land that can be measured or estimated (Dent and Young, 1981). Examples include soil texture, slope, annual rainfall and distance to markets. Land characteristics are important; but if they are employed directly in the evaluation, it is often noticed that they are highly correlated to other characteristics. In addition, they may have different effects on land use (De Ridder, 2007). On the other hand, a land quality is a complex attribute of land that acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities can be expressed in a positive (e.g. water availability, erosion resistance), or negative way (e.g. erosion risks). Only those land qualities relevant to land use alternatives under consideration needs to be determined. Land qualities can sometimes be measured or estimated directly. In most cases however, they are based on a combination of land characteristics. For example, we can measure land characteristics that determine the land quality "water availability". Relevant land characteristics include soil texture and structure, organic matter content and rainfall. On the basis of these land characteristics, we can assess the "water availability" (Young, 1976). Beside land, we have to describe management options. These management options are referred to as land utilization types. They are general descriptions of land management that can be carried out on land. Each land utilization type (LUT), has a number of land use requirements (LURs). The LUR should correspond to the land qualities as defined.

According to FAO (1976), general framework for land suitability evaluation, land suitability classification consists of assessing and grouping land types in suitability orders, suitability classes, subclasses and units according to their capacity and major

limitations. There are two orders represented by symbols “S” and “N”. The suitability orders “S” represent a suitable land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources. The suitability order” N” (not suitable land) indicates land which has qualities that preclude sustained use of the kind under consideration (FAO, 1976). The order S can have suitability classes 1= suitable, 2= modearately suitable and 3= marginal, N1= currently not suitable subject to improvement and N2= permanently not suitable, which expresses the degrees of suitability or unsuitability, as presented below:

Table 2. 1:Land Suitability Classes and Subclasses

ORDER	CLASS	DESCRIPTION
"S" Suitable	S1 (highly suitable)	Land having no or significant limitations
	S2 (moderately suitable)	Land having minor limitations to the given type of use.
	S3 (marginally suitable)	Land having moderate limitation to the given type of use.
"N" not suitable	N1(currently not suitable)	Land having severe limitations that preclude the given type of use, but can be improved by specific management.
	N2 (permanently not suitable	Unsurmuontable limitations

Source: FAO, 1976

Land suitability classes reflect degrees of suitability. These are numbered consecutively, using Arabic numbers, in sequence of decreasing degrees of suitability within the order.

Within the order suitable the number of classes is not specified. There might be for example, only two, S1 and S2. Number of classes recognized should be kept to the minimum necessary to meet interpretive aims; five should probably be the most ever used.

Land suitability subclasses reflect kinds of limitations such as moisture deficiency, erosion hazard, etc. Subclasses are indicated by lower case letters with mnemonic significance, e.g. S_2m, S_2e and S_2me. There are no subclasses in class S1. The number of subclasses recognized and the limitation choosen to distinguish them will differ in classifications for different purposes. Limitation factors as indicated in FAO (1976),

have been used by several authors like Choung (2007), Nguyen (2004). Such limitation factors are indicated by small alphabets as follows:

1. d = rootable soil depth
2. f = flooding
1. g = inappropriate soil conditions
2. p = fertility conditions
3. t = soil texture
4. sl = land slope

Land suitability units are subdivisions of a subclass. All the units within a subclass have the same degree of suitability at the class level and similar kinds of limitations at the subclass level (Table 2.1). The units differ from each other in their production characteristics or in minor aspects of their management requirement. Their recognition permits detailed interpretation at the farm planning level. Suitability units are distinguished by Arabic numbers following a hyphen, e.g. S_2e-1, S_2e-2. On the basis of scope of suitability for the order "S" suitable, two types of classifications are proposed by FAO (1979) frame work:

1. Current suitability: The suitability for a defined use of land in its present condition without any major improvement on it.
2. Potential suitability: For a defined use of land units in their condition at some future date, after specified major improvements have been completed, where necessary. Land suitability evaluation used to be done with consideration of the local need, land availability and use.

Many studies related to various aspects of land suitability for crop production have been conducted on the basis of FAO frame work in different areas (Hassan *et al.*, 2004; Friede and Stahr 1999; Alcatara *et al*., 1997; Young and Goldsmith, 1997; Mujica *et al*., 1995; Donnolian *et al*., 1990). In Nigeria, Osie (1993) used FAO (1979) guidelines for evaluation of land suitability for dryland farming in South Western Nigeria. Hussaini, (2011) evaluated the land suitability for cotton, maize, cowpea and sorghum in IAR farm, Samaru, Zaria, Northern Nigeria and found the major limitations to be that of nutrients availability and poor drainage. He classified the land units (LU1 and LU2) into moderately suitable for cotton and maize (S2), and highly suitable for cowpea and sorghum (S1), while LU3 was marginally suitable (S3) for cowpea and sorghum and not suitable (N) for cotton and maize. Ya'u (2000), carried out a suitability evaluation for irrigated rice in Watari irrigation scheme, Kano State and found that, the major limiting factors in the area were: nutrient deficiency, drainage, slope and texture. He classified the soils into moderately suitable (S2). Udoh and Ogunkule (2012) conducted land suitability evaluation for maize in south eastern Nigeria, where they identified climate (excessive annual rainfall) and soil fertility (low exchangeable K) to be the major limiting conditions, and classified the soils into moderately (S2) to marginally (S3) suitable for maize. To determine suitability of Odeda soils for rice production, Ajiboye *et al*. (2011) identified the major limiting conditions to be low levels of available macro and micro nutrients, low organic matter and low cation exchange capacity (CEC). They classified the potential suitability using Square Root Model.

2.4 Land Evaluation and Geographic Information Systems

Land evaluation is concerned with the assessment of land performance when used for specified purposes. This could only be achieved through systematic survey of the soils, evaluating their potentials for wide range of land use options, and formulating land use policies which are economically viable, socially acceptable and environmentally sound (Satisha and Niranjana, 2010). Hence, soil survey data are indispensible for generating soil map of the given area, which helps in deriving crop suitability and cropping system analysis.

Remote sensing data coupled with soil survey information can be integrated in Geographical information system (GIS) to assess crop suitability for various soil and biophysical conditions (Singh, 2012). Thus, generated data is integrated in GIS to obtain different thematic information for use in land evaluation. GIS as a powerful tool to process data in conjunction with information collected using traditional field techniques, helps to overcome data volumes constraints (Burrough, 2005). According to Lillesand and Keifer (2006), remotely sensed data as well as traditional techniques permit the preparation of base maps, including terrain evaluation, land use classification, land degradation maps and a host of other aspects. Quick and efficient access to large amount of information is possible by GIS, exhibiting relationship, patterns and trends (ESRI,1999) which are used in combining soil survey information to monitor land use changes (Stout and Lee, 2004; Wu *et al*., 2004). Application of GIS in land use planning is well documented (Salem *et al*., 2008; Maji *et al*., 1998; Kushwaha *et al*., 1996; Maji *et al*. 1996).

Use of GIS allows the construction of models from which a new thematic map (e.g. land suitability map) can be produced from a set of thematic maps (Harasheh, 1994). Other uses of GIS include efficient storage, management, and analysis of spatial and non-spatial data (Rajitha *et al*., 2007; Giap *et al*., 2005; Kapetsky *et al*., 1987). In addition, GIS functions help to manage spatial data and visualize evaluation results (Liu *et al*. 2005; Wu *et al*. 2004; Chen *et al*., 2003). Thus generated data is integrated in GIS to obtain different thematic information for use in land evaluation techniques. The combined use of remote sensing and GIS provides better prospects of environmental monitoring and forecasting over wider areas within a limited time span (Singh, 2000).

Because of the urgent need to use land in the most rational possible way, use of GIS and RS technology offers a dynamic tool for multidimensional process of land use. The most suitable areas for agricultural use are determined by an evaluation of climate, soil and topographical environmental components and understanding of local biophysical restraints. In this kind of situation, many variables are involved, and each one should be weighted according to their relative importance on the optimal growth conditions for crops through land evaluation and GIS (Perveen *et al*., 2007). In the land evaluation process, GIS has become an important tool, because it integrates complex decisions to be taken under multi-variant situations of the resource base and their dynamics.

2.5 Land Use and Land Cover Classification

Though the terms “land cover” (LC) and “land use” (LU) are sometimes used interchangeably, they are actually different. Simply put, land cover is what covers the surface of the earth, e.g. water, snow, grassland, deciduous forest, bare soil, and land use describes how the land is used, such as wildlife management, agricultural land, irrigated

land urban recreation, etc. (Sesha Sai *et al*., 2007). Land cover can also be defined as layer of the soils and biomass, including natural vegetation, crops and human structures that cover the land surface. While land use refers to the purposes for which human exploits the land cover (Fresco, 1994). A given land use may take place on one, or more than one pieces of land and several land uses may occur on the same piece of land (Kebede, 2010). Land cover change is the complete replacement of one cover type by another, while land use changes also include the modification of land cover types, such as intensification of agricultural use; like irrigation, without changing its overall classification (Turner *et al*. 1993).

The use of remotely sensed data in form of satellites as a source of authentic information for surveying, classification, mapping and monitoring has been emphasized. Land use/cover mapping is one of the most important and typical application of remotely sensed data (Lillesand, 2006). It has been extensively used in supervised image classification where a priori knowledge of all cover types to be mapped within the classified scene is assumed (Sesha Sai *et al*., 2007). The knowledge is used to define signatures of the classes of interest to be applied to the entire scene. Other variants of supervised classification developed in recent years include the decision trees (Hansen *et al*., 2000), fuzzy classification (Foody, 1998; Mannan *et al*., 1998) and mixture modeling (Vander meer, 1995). It seems evident that when one knows what classes are desired and where they occur (at least a sample), supervised classification strategies are preferable. During classification, crop identification and discrimination is centered on the concept that: each crop has a unique spectral signature due to its own architecture, growing period, planting date, plant density, etc. (Raji 2004; Sesha *et al*. 2007).

In areas where land is scarce, the need to maintain food production with growing demand is achieved via technological changes in land use accomplishing higher returns per area of land. Where land is abundant, land conservation remains the main strategy. A better understanding of land use changes is essential to asses and predicts its effects on ecosystem and society (Dolman, *et al*., 2002). The rates and patterns of land use changes need to be understood to design appropriate management. Areas of rapid land use change needs to be identified to focus on land use planning appropriately.

In defining aim of planning new land use systems, the concept of sustainability is very important. New land use systems should provide and save resources for people for a long time without undermining the natural resource base. This implies that productive capacity of the resources base has to be maintained to guarantee stable (or increase) levels of future production. Both wealth and poverty threatens sustainable development (WRR, 1995). The FAO (1989), as cited in De Wit *et al.* (1995), defined sustainability as the management and conservation of the natural resource base, and orientation of technological change in such a manner as to ensure attainment and continued satisfaction of human needs for present and future generations. Such sustainability conserves land, water, plant and animal genetic resources, are environmentally none degrading, technologically appropriate, economically viable and socially acceptable.

2.6 Land Evaluation and Land Use Planning

In industrialized countries, intensive agriculture has been identified as a major problem resulting in declining soil fertility, stagnant yield levels and unfettered soil erosion. Over exploitation of natural resources and scarcity of inputs like chemical fertilizer is associated with intensive agriculture in developed countries (Lanen Van *et al*., 1992).

This will lead us to the question of where to do what and how. This also leads us to a role of land use planning activities; which is defined as a means of supporting decision processes about how to use land, by systematically evaluating land and alternative patterns of land use, choosing the use that meets specified objectives, and drawing up of policies and development programme for the use of that land (Dent, 1980). Omakupt and Huizing (1992), viewed land use planning as a tool to help policy makers, and land users, to use land in a way: that current land use problems are reduced, and that specified social, economic or environmental goals (e.g. sustainability, food self-sufficiency, income, environmental conservation) are achieved.

Land use planning is directed to best models of land use in the face of objectives accepted by stake holders and environmental, economic and social opportunities and constraints. De Ridder *et al*., (2007), clarified the difference between land use planning and land evaluation. While land use planning comprises the decision making process of allocation of land for different uses, land evaluation assesses suitability of land for certain uses. Land evaluation is part of the process of land use planning and the result should be useful for rational land use planning (FAO, 1993). Land use plans provide identification of what is possible concerning land and indicate how to proceed from present land use to the future. The best model of land use is defined by specific objectives of the society. (De Ridder, 2007). Several researches on land evaluation and land use planning using remote sensing and GIS were well documented (Kenneth and Gajere, 2011; Mohammd *et al*., 2011; Ali Mahoud *et al*., 2009; Mohana *et al*., 2009; Raji 2004; Manchanda *et al*.. 2002).

2.7 Rice Culture

2.7.1 Varieties

The production of rice in Nigeria has never been able to meet the demand, and this has led to considerable importation. The country is second largest importer of rice in the world after China with annual imports of 2.1M metric tons (Punch: 14 March, 2014). Rice has moved from a ceremonial to a staple food in Nigerian homes.

In recent years, WARDA (2010), introduced several rice varieties; together with efficient natural resource/crop management and pest and disease management techniques. Typical examples are the high yielding rice varieties: FARO 44(SIPI), FARO 51 (CISADANE), FARO 52 (WITA 4), FARO 57(TOX 40043-1-2-1), FARO 27, FARO 29, FARO 37 and lowland varieties of New Rice for Africa (NERICA) that are currently being evaluated in several parts of Nigeria, prior to full release (WARDA 2006).

2.7.2 Climate

Rice is grown in areas with high temperatures, which range from 24 to 26^{o}C. Low temperatures can be a problem in some areas (IRRI, 1980). However, for solar radiation, little data is available on intensity of solar radiation. But a strong relationship was established between solar radiation and moisture supply. Trials conducted at IRRI farm in 1976 at different dates reveals that some varieties responded positively to increased solar radiation during their reproductive periods, while others did not. However, higher grain yields were obtained for early planting, probably because of higher solar radiation and better rainfall distribution (Jana and De Datta, 1971; De Datta and Beachel, 1972). Daylength has been found to affect performance of some rice varieties.

2.7.3 Land or soil requirement for rice

In Nigeria, intensive irrigated rice based cropping systems are found on alluvial flood plains, valleys and terraces. The main source of water in the dry season is irrigation and the same is used to supplement rainfall in the wet season (IRRI, 2010). A fertile land with good water retention capacity (contains some clay and or/ organic matter i.e. loamy soils); and clay soils are desirable, and heavy soils of valleys and fadamas are preferred (WARDA, 2010). The FAO (1979) has established that, the crop can be grown practically on all types of soils from sandy loam and shallow lateritic soils to heavy clays. The only limiting factor being water supply either in form of rainfall or irrigation. It is however certain that, heavy soils characteristics of river valleys and deltas are better suited to rice growing than lighter soils. The practice of irrigation has however extended rice cultivation to soil taxa with a deficient soil moisture regime in semi-arid and arid areas.

2.7.4 Nutrient requirement

In Nigeria, rice generally shows greater yield response to nitrogen than either phosphorous or potassium. Grain yields are often proportional to amount of nitrogen assimilated by the rice plant (Davide, 1964). But studies carried out at the Federal Rice Research Institute Badeggi (1968-1971), showed that, response of paddy to nitrogen fertilization is low when compared with responses obtained from USA and Japan. This may be partly due to excessive losses through oxidation and reduction processes in the flooded soils. The general fertilizer recommendation based on agro ecology by WARDA (2010) is as follows:

Humid forest: 60kgN, 30-60kg P_2O_5 and 30 kg of K_2O per hectare.

Savannah: 60-80 kg N, 30-60kg P_2O_5, and 30 kg K_2O per hectare.

Sudan/Sahel (under irrigation): 100-120kgN, 60kg P_2O_5 and 30 kg K_2O per hectare.

In intensive rice systems, indigenous N supply is never sufficient, and mineral N fertilizer input represent the largest part of N cycle. Depletion of soil K reserve appears to be a problem in many intensive rice farms, and if left uncorrected, will limit future yield increase and result in poor N use efficiency (Grist, 1986). The requirement for mineral fertilizer may be reduced when organic nutrient sources such as farm yard manure, legume, green manure and azolla are used. WARDA (2010), has recommended the application of fertilizer for small areas in irrigated fields, by closing the irrigation inlet and drainage outlet. Applying the fertilizer between rows, while irrigating and closing the canals for about 10 days to facilitate nutrient absorption, and by draining the field and applying the fertilizer by broadcasting, the fertilizer should be flooded immediately to prevent denitrification.

2.7.5 Micro-nutrient and rice

When the redox potential of a soil decreases such as in rice soils upon flooding, availability of Mn and Fe oxides initially increases because of the reduction and solubility of Mn and Fe oxides in soil (Grist, 1986). If the redox potential decreases to very low values, insoluble sulfides of Cu, Mo, Fe and possibly Mn and Zn may be formed which may make these elements unavailable to the crop.

Rice is highly sensitive to Zn, Fe and Mn deficiency, and Zn is the most important micro nutrient limiting rice growth and yield (Dung *et al*., 2006; Neue *et al*., 1998). Zn deficiency has been identified by IRRI as the most important nutritional factor after

nitrogen and phosphorous in limiting rice yields (Castro, 1997). Giordano and Mortvedt (1972) compared 12 varieties of rice, some of which were developed in the tropics and United States. A marked difference in their response to low Zn availability was observed with shortest duration varieties, having the least tolerance to Zn deficiency. Recent IRRI varieties such as IR42 have proven very tolerant to Zn deficiency as well as many other stresses (IRRI, 1980). Chude *et al*., (2004) set a value of <1.0, <2.5, <1.0 and <0.5 to be low (deficient) for Zn, Fe, Mn and B, while values of >5.0,>5.0>5.0 and >2.0 to be high for Zn, Fe, Mn and B. Obigbesan (2009), was of the view that: values of 1.0 and 1.0-2.0 are critical for Fe and Zn respectively in rice fields. Generally, Zn, Fe and Mn deficiency is common on neutral and calcareous soils, intensively cropped soils, paddy soils and poorly drained soils (Ajiboye, 2011).

The FDLAR (2013) reports indicate that, Fe deficiency is often associated with soils high in pH (e.g. saline-sodic, sodic soils and vertisols). Fe toxicity occurs in strongly acid Ultisols and Oxisols, Deltaic and Estuarine acid sulphate soils and in Histosols, and often associated with other stresses; such as salinity, phosphorous and zinc deficiencies and low base status. Where Fe and Zn deficiencies are noticed, foliar spray of ferrous sulphate or zinc sulphate as a corrective measure is recommended.

2.8 Irrigation Water Quality

As water resource becomes more limiting, increased use is made of inferior irrigation water with high sodium or total salt content or both (Sheinberg *et al.*, 1982). This constitutes a universal threat, because irrigation and underground water normally contains higher salt content than rain water (Malgwi, 2001). FAO (1979), indicated that, most ground and surface waters contain some natural dissolved salts which most often

originate from contact of water (moving in hydrological cycle) with various salts and rock minerals. The quality of irrigation water is of particular importance in arid and semi arid climates. The impact of quality of irrigation water and underground water on soil properties and plant growth determine success and sustainability of any irrigation project. Good and productive soils can be rendered unproductive within a short time with poor irrigation water quality. This necessitates studies to find out safety limits of salt contents in the use of irrigation water (Richards, 1954; Wilcox and Durum, 1967; Malgwi, 2001).

Quality of irrigation water is determined by the following:

Total concentration of soluble salts, or salinity: the effect of salt on crop growth is believed to be largely osmotic in nature. Soluble salts increases the osmotic pressure of water when in excess (Malgwi, 2001). This is determined using electrical conductivity (EC) and total dissolved salt (TDS). Water with electrical conductivity of 7.5 dS m^{-1} is considered safe for most irrigation. Richards, (1954) has stated a limit of 4dS m^{-1} as electrical conductivity of saline soils and irrigation water of > 4d Sm^{-1} leading to salinity. Shahanasi and Kashuta (2008), proposed a limits of EC 0-3dS m^{-1} and TDS of 0-2000mgl^{-1} as safe for irrigation water.

Concentration of sodium relative to other cations or sodicity: The sodicity hazard of irrigation water is measured using its sodium adsorption ratio (SAR). Aggregation of soil particles is determined by the concentration and composition of salts in the soil. But if irrigation water has an excess concentration of sodium over other salts, then clay particles of the soil will disperse instead of aggregating, thereby deflocculating the soil. This will consequently reduce the porosity, permeability and aeration capacity of the soils. These conditions will encourage waterlogging and soil alkalinity and ultimately, limits plant

growth (Abdulqadir, 1998). Malgwi, (2001) proposed a critical limit of SAR value of 10 to be safe for use in irrigation.

Anionic composition of water (carbonate and bicarbonate): In irrigation waters containing high concentration of bicarbonates ions, there is the tendency for calcium, and to a less extent, magnesium to precipitate in the form of carbonate, as soil solution becomes more concentrated, leading to increase in SAR of soil solution and consequently to increase in ESP of the soil (Sheinberg and Oster, 1978). Eaton (1950) assumed that, all calcium and magnesium would precipitate as carbonates and proposed the concept of residual sodium carbonate (RSC) for evaluating high carbonate water. He concluded that water with RSC higher than 2.5meql^{-1} is not suitable for irrigation. Between 1.25 and 2.5 meql^{-1} is marginal while anything less than1.25meq/ l^{-1} is considered safe. Landon (1991), and Ayers (1975), reported that, irrigation water with less than 3mgl^{-1} carbonates and 5 mgl^{-1} bicarbonate ions were considered safe for irrigation. Lakotoro and Singh (2000), affirmed that, the negative residual carbonates (RSC) were associated with negligible amounts of carbonates and bicarbonates in the water. However, Bower *et al*. (1965), proposed the use of saturation index (SI) to be more useful than RSC. They said it is a better estimate of precipitation tendency of carbonates.

Concentration of toxic/hazard elements: The mere occurrence of toxic levels of trace elements in a water resource does not necessarily render the water unfit for agriculture. Evidence does exist from works of Sidle *et al*., (1977), which showed that irrigation water does not pose serious threat to soils.

However, a critical level of 0-2mgl^{-1}, was proposed by Shahinasi and Kahuta (2008) for Boron and 0-10mgl^{-1} for Nitrate. On the other hand, Landon (1991) proposed a limit of 960mgl^{-1} for sulphate and 4mgl^{-1} for chloride as safe for irrigation water.

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Loction

The study area is located within old Dambatta and new Makoda Local Government Areas, in the western part of Kano State, east of Kano-Daura road. It is situated approximately between latitudes 12^{o} 18` and $12^{o}$ 25`N, longitude 8^{o} 32` and $8^{o}$ 38`E. (Figure 3.1). The Babbaruga Dam across Tomas River is just upstream of the existing road and bridge, while potential area for irrigation stretches on either bank of Tomas River (MANR, 1978). River Tomas is one of the three rivers, the other two being Gari and Jakara Rivers, which drain the upland areas north and east of the city of Kano. Lower reaches of the stream; which include some of the project areas, are wider and characterized by many ponds and flood plain areas. Tomas River joins Gari River near Takwasa, some 40km east of Dambatta. These two rivers dissipate themselves by wide spread flooding and infiltration into sandy areas and contribute little or no inflow into river Hadejia system; except perhaps, in times of exceptional precipitation. The scheme covers an area of 12,441ha. (MANR, 1978).

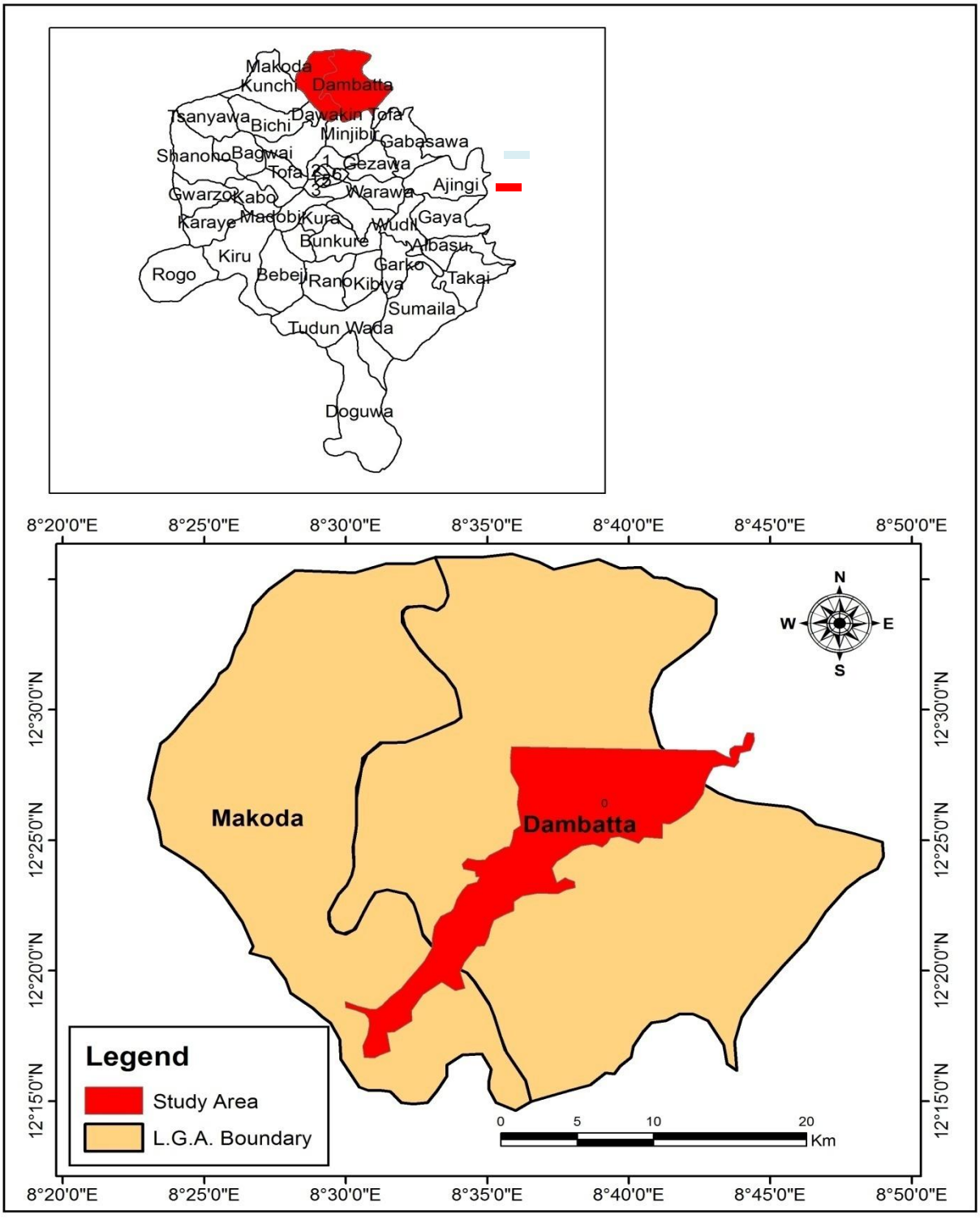


Figure 3. 1:Map of Kano State showing the location of Tomas irrigation scheme

3.2 Climate

The study area is located in sub humid tropical zone with a distinct rainy season lasting from May to September. Rainfall of the area is characterized by heavy storms with a mean yearly precipitation of 833m between 1950 and 1965 (Daniels, 1985). The area has a seasonal climate which is largely determined by inter tropical discontinuity zone (IDZ). The IDZ is a meeting point of maritime from the south west and dry tropical continental air mass or the north easterly winds -harmattan (Malgwi, 2001), during which there is no rain.

The rainy season normally begins in June and ends in September. Seasonal distribution of mean monthly rainfall and the annual rainfall for 11 years (2003- 2013) was 1,260.33mm (Table 3.1). The data shows that, peak rainfall months in the area were July and August. The seasonal variation in temperatures show increase from January (29.5^{O}C) to May (38.22^{O}C). As a result of rains, there is a decrease in temperature to (30.28^{O}C) in August, because of cloud effect. And then there is slight increase after the rains in November (33.15^{O}C). This decrease in temperature continues till January (Table 3.1) due to the effect of the cool, dry and dusty harmattan winds.

Table 3. 1:A long term average summary of climatic data of Kano area (2003-2013)

Month	Temperature (^{o}C)		Mean rainfall	Relative humidity	Evaporation (mm)	Sunshine hours
	Max	Min	(mm)	(%)		
Jan	29.5	13.63	0.00	27.82	9.3	6.72
Feb	34.09	17.62	0.00	23.45	11.24	7.6
March	36.87	20.38	0.00	20.89	13.12	7.28
Apr	39.57	24.64	26.44	35.96	12.74	7.44
May	38.22	25.48	84.11	53.07	9.94	7.29
June	34.79	23.72	195.41	64.78	6.37	5.54
July	31.61	22.2	335.4	74.55	3.79	6.14
Aug	30.28	21.78	379.63	80.25	2.6	5.79
Sept	32.3	22.33	195.15	73.74	3.65	7.18
Oct	33.85	21.16	24.19	52.21	6.41	8.34
Nov	33.15	16.69	0.00	31.1	9.02	8.41
Dec	28.88	13.55	0.00	32.34	8.57	8.05
Total			1,240.33			

Source: Nimet Forecast office, Malam Aminu Kano International Airport (MAKIA), Kano 2013.

3.3 Geology/Parent material

The project area lies within the basement complex formation, which consists of Precambrian igneous and metamorphic rocks, overlain by a mantle of Aeolian deposits varying in thickness from 3.048m to 15.24m. Though at certain places much deeper thickness is encountered, at other places, the rock outcrops are at the surface (MANR, 1978). The upland soils were derived mostly from weathering of the basement complex rocks, overlying aeolian deposits, which in the project area are mainly aeolian, alluvial and colluvial or mixture of these. Outcrop of granites are visible at a number of locations in the area, the most prominent being the ones near the dam site on the left bank of the river. Physiographically, the project area can be described as consisting of gentle plain of low relief, with the ground on either side of the river gently sloping towards the flood plain. The weathered basement complex rocks are overlain by thick deposits of colluvial, alluvial and aeolian materials or a combination of these, just like that of Jakara River (Malgwi 2001).

3.4 Soils

Soils of the project area have developed under tropical climatic conditions, with yearly cycles of a short wet season followed by a long dry season. In general, the soils are weakly developed with little horizon differentiation (MANR 1978).

The soils were classified into:

3.4.1 Lower terrace (flood plains)

Soils on either side of Tomas River existing on the lower terraces, and they are young in origin, because they have developed on recent deposits of the river alluvium/colluviums (Bennet *et al*., 1979). Due to permanent seepage and poor surface runoff in the flood

plains, swampy and wet conditions have existed, and hydromorphic (low humic gley) soils can be found in this part of the area.

3.4.2 Higher terraces

Soils that fall within the project area as weakly developed, extending from the lower terrace area to highest project area levels. They were classified as Regosols which are soils that have developed on loose sandy material and show little profile development. Weathering of the ancient bedrock produces reddish residual material whose end product was laterite. Regosols being the soils of the higher terraces are extensively distributed in the project area (MANR, 1978).

3.4.3 Transitional belt

Soils between the lower terraces and the higher terraces which were coarse to moderately coarse textured, but moderately well drained with white to whitish pink, pale brown to grayish brown and yellow to brownish yellow colours and faint to distinct iron mottles in sub soils and the substrata.

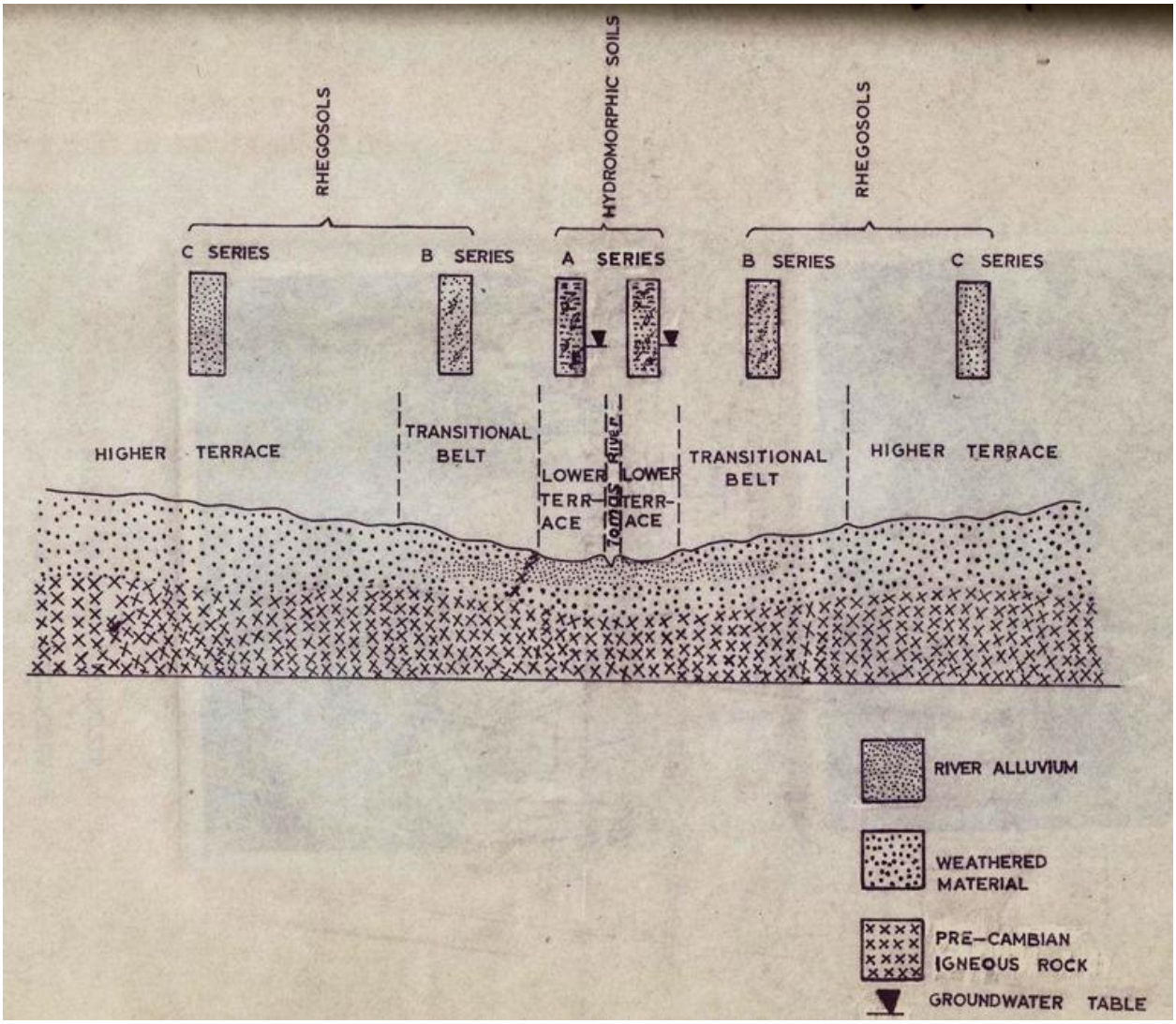
3.5 Vegetation

Vegetation of the study area has been described as Sudan savannah (Daniel, 1985), made up of grasses and shrubs which thrive during the short rainy season, withering away in the dry season, and of trees adapted to the prevailing climatic conditions. The natural vegetation was of Sudan sub humid (FDLAR, 2013). The vegetation was modified by cultivation, bush burning, and animal grazing. Cultivated areas are made up of few trees, shrubs, grasses and herbs. The trees and shrubs include *Parkia biglobosa*, *Adansonia*

digitata, *Acacia albida*, *Combretum glutinosum* and *Diliostigma reticulate*. Common herbs and grasses include among others *Andropogan gayanus* and *Cynodon dactylon*.

3.6 Land use

There are two types of farming in the study area, rain fed and irrigated. Sometimes, irrigation is used to supplement rainfed farming. Major type of land use in the study area includes arable farming, livestock farming, and fire wood and timber exploitation. Arable farming consists of subsistence and irrigation farming which are characterized by intensive and continuous cultivation (Yaro, 2005), with no case of land tenure conflict reported. The main crops grown under rain fed are sorghum, millet, groundnut, cassava, cowpea, and sometimes rice, maize and water melon. Rice and maize are often supplemented with irrigation. The main crops grown under irrigation are rice, maize, vegetable and water melon. Vegetables grown include tomatoes, onion, pepper, lettuce, cabbage and carrots. Livestock farming is practiced mainly by the Fulani's, who rear stocks either for milk production or fattening for slaughter. Sometimes they rear livestock also as draught animals. Grazing is one of the major activities in the area. Sugarcane and mango plantations are also found in the flood plain areas.



Source: MANR Kano State, 1978

Figure 3. 2:The soil catena of the project area in relation to physiography and geomorphology.

3.7 Materials

3.7.1 Ancillary data

The published soil map at scale of 1:25,000 produced in 1978, obtained from Kano State Ministry of Agriculture and Natural Resources (1978), was considered ancillary data. The soil map was digitized and georeferenced (Figure 3.3) for further analysis and served as a base map for this study.

3.7.2 Satellite image

SPOT 5 (2005) satellite image with 3 bands (1, 2 and 3) and spatial resolution of 5.0m multispectral and 2.5m panchromatic were used for land cover and land use classification of the Tomas irrigation scheme.

3.7.3 Digital elevation model (DEM)

Digital elevation model was used as an input data in ArcGIS to derive landforms, slope and contour maps.

3.7.4 Software

The softwares used for data preparation and analysis include: Integrated Land and Water Management Systems (ILWIS) for digitization of land use and land cover, and most of GIS analysis. Arc VIEW and Arc GIS 9 were used for map creation; layout and finalization, while ERDAS IMAGINE 9.1 was used for land use and land cover classification.

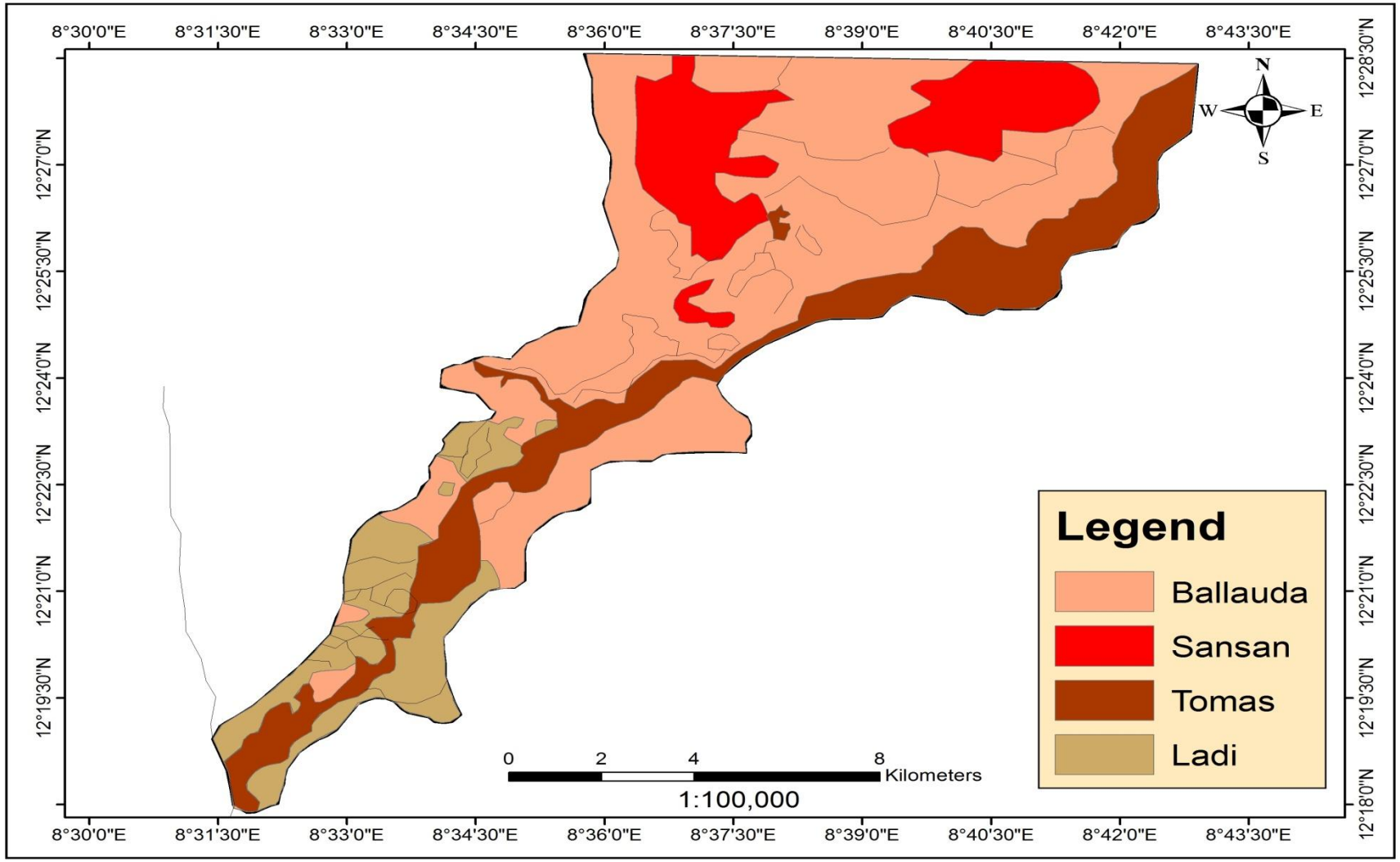


Figure 3. 3:Digitized map of Tomas irrigation scheme showing soil mapping units

3.7.5 Global Positioning System (GPS)

GPS was used in collecting geographic coordinate values in UTM, latitude-longitude. The GPS reading was used in locating positions of different land uses and land covers for image classifications.

3.8 Methodology

3.8.1 Data acquisition

Data acquisition involves acquisition of ancillary data on climate, soil, vegetation, soil maps, satellite images of SPOT 5, and contact with relevant organisations like: National Space Research and Development Agency (NASRDA), as well as contact with Remote Sensing (RS) and Geographic Information System (GIS) experts and gathering of relevant information on the study area.

3.8.2 Image classification

Land cover and land use classification was carried out using SPOT 5 satellite images for identifying land cover and land use types. For the study of current land use, supervised signature extraction classification method was used in classifying the image. The land use and land cover themes were generated through manual interaction and field experience. Based on literature, initial classification was erected as irrigated crops, non irrigated crops, fallow, settlement, bare soil and rock out crop, forest reserve and water bodies. The acquired images were processed using ERDAS IMAGINE 9.1 and ArcGIS 9 software. On the acquired images, water bodies appeared deep blue, vegetation (plantations and cropped areas) were red, while settlements and roads showed up in shades of cyan. The classification system used by Raji (2004) in Kadawa irrigation scheme using Nig.Sat 1 was employed in this study.

3.9 Detailed Field Work

The field work was carried out to identify major land use and land cover types especially for the various crop types within the irrigated crop class and to confirm for areas of uncertainty. This was made possible with the aid of GARMIN GPS (hand held), software version 4.52(GARMIN, 1999). Coordinates of one hundred and ten (110) points were identified and their land use noted. Information at each location on crop type, both growing and harvested, farm size, type of fertilizer applied, soil management practice, socio-economic characteristic of farmers, agricultural land use system, land tenure system, various constraint to sustained agricultural land were collected using questionnaires.

3.9.1 Exploratory soil and socio-economic survey

Exploratory survey was carried out in identifying and confirming the different mapping units produced by the Ministry of Agriculture and Natural Resources (MANR, 1978), Kano. The soil mapping units were produced at the scale of 1:25,000. Four different soil mapping units Ballauda (Ba), Sansan (Sn), Tomas (To) and Ladi (La) were identified and confirmed. The soil map was digitized using GIS for further manipulation and analysis. Detailed field work was later carried out by digging two profile pits in each soil mapping unit. Socio-economic data were collected in three villages (Sansan, Shiddar and Kulfare) with moderate adoption of irrigated rice production on a purposive basis. A random selection of farmers interviewed was made in each of the three villages. A total of 112 respondents made of 80 producers, 10 traders, 15 consumers and 7 local and modern processors were interviewed. Data was analysed appropriately using means, percentages and tables.

3.9.2 Soil sampling

Two profile pits each were dug on each mapping unit (Ba, To, La, and Sn) as in Figure 3.4. Their morphological properties were described in accordance with soil survey manual procedure (Soil Survey Staff: 1993). Soil depth, colour, structure, texture, consistency, mottling, concretions, roots, horizon boundary and pores were determined. Undisturbed core samples were taken using $100cm^3$ core ring sampler from pedogenic horizons for laboratory determination of bulk density, hydraulic conductivity and available water holding capacity. Bulk soil samples from pedogenic horizons were collected in polythene bags for physical and chemical analysis.

3.9.3 Water sampling

Water from the tube wells and surface was sampled in plastic bottle for laboratory analysis. The following parameters were determine pH, electrical conductivity (EC), dissolved cations (Ca, Mg, K, Na), Sodium adsorption ratio (SAR) and Adj. SAR, carbonate and bicarbonate, residual sodium carbonate (RSC), boron, sulphate, chloride and nitrate.

3.9.4 Infiltration measurements

Infiltration measurements were carried out on each profile using double ring infiltrometers as described by Anderson and Ingram (1993). Readings were taken at intervals until equilibrium infiltration was reached.

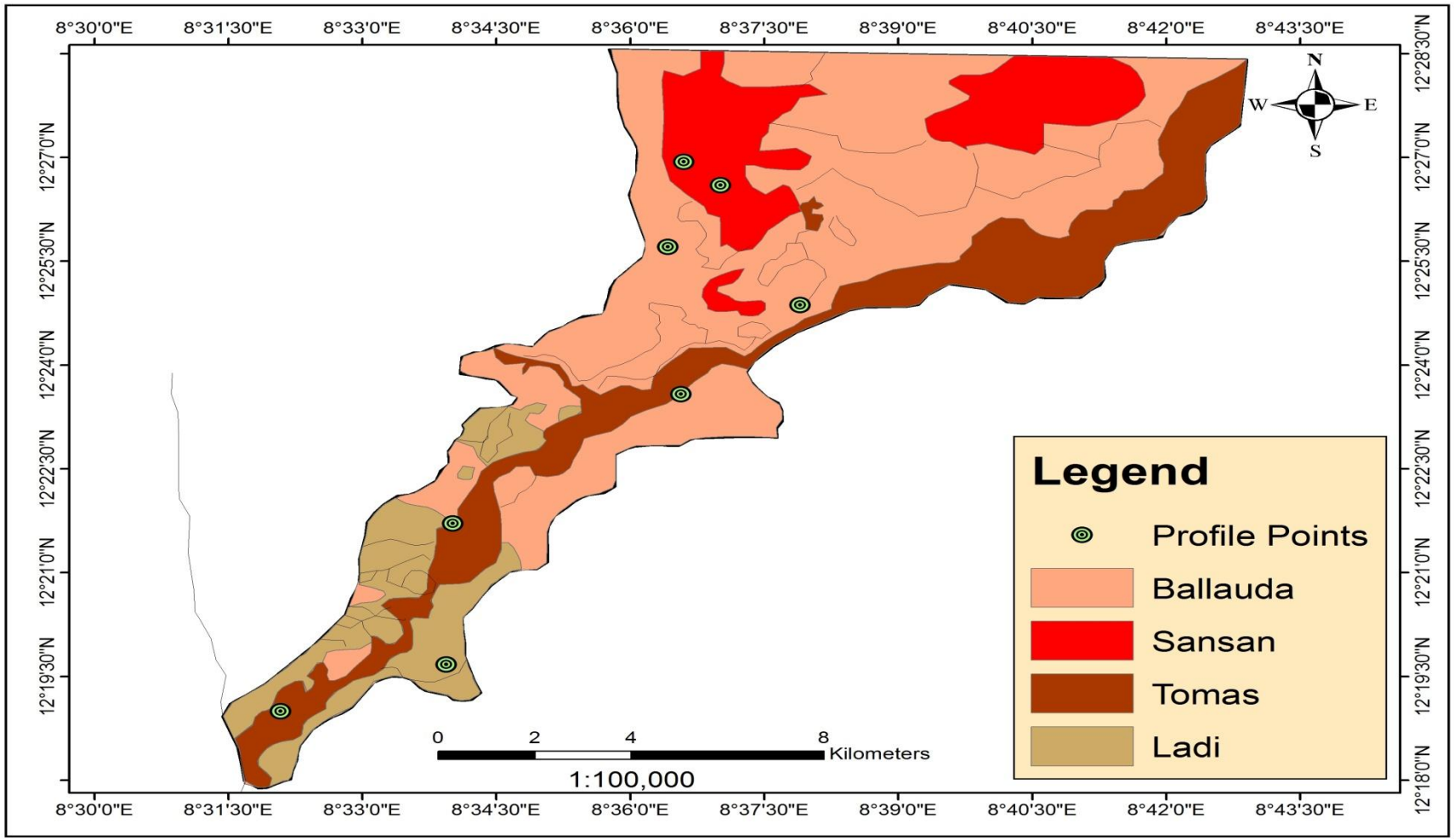


Figure 3. 4:Map of Tomas irrigation scheme showing mapping units and location of profile pits

3.10 Laboratory studies

3.10.1 Sample preparation

The disturbed soil samples collected from pedogenic horizons were air dried, crushed and passed through 2mm sieve. These were stored in plastic containers for laboratory analysis.

3.10.2 Particle size distribution analysis

This was determined by hydrometer method (Day, 1965); using water and 5% calgon (Sodium hexametaphosphate) as a dispersing agent after shaking on a reciprocating shaker for 24 hours for proper or complete dispersion of the particles.

3.10.3 Bulk density

Bulk density was determined by oven-drying the undisturbed samples collected in $100cm^3$ core ring sampler to constant weight at 105^0C, and dividing the oven dried weight by the total volume of the soil as described by Blake and Hartge (1986).

$$\text{Bulk density } (gcm^{-3}) = \frac{\text{Weight of oven dry soil (g)}}{\text{Volume of soil } (cm^3)}$$

3.10.4 Particle density

This was determined after the removal of entrapped air in soils using the pycnometer method as described by Blake and Hartge (1986).

3.10.5 Available water holding capacity (AWC)

Available water capacity was calculated mathematically from the differences between moisture held at field capacity (10 and 30kpa) and at the permanent wilting point

(1500kpa) pressure using pressure plate methods as described by Klute (1986), from the formular proposed by FAO (1979) as follows:

$$Aw = (WFC - Wpwp/100) \times \rho b/\rho w) \times d$$

Aw = available water in cm

WFC = Water at field Capacity on % dry weight basis.

Wpwp = Water at Permanent Wilting point on % dry weight basis.

ρb =Soil bulk density in gcm^{-3}

ρw = density of water in gm^{-3}

d= depth of soil in cm

3.10.6 Total porosity

Total porosity was calculated mathematically from the results of bulk density and particle density (Vomocil, 1965) using the formular:

$$F = 100\ [1 - \rho b/\rho p]$$

Where:

F = total Porosity (%)

ρb = bulk density gcm^{-3}

ρp = particle density gcm^{-3}

3.10.7 Hydraulic conductivity

This was determined with undisturbed core samples by constant head method (Anderson and Ingram, 1993).

3.10.8 Soil pH

Soil pH was determined in both water and 1M $CaCl_2$ Solution in a 1:2.0 soil/ solution ratio using a pye Unicam model 290mk pH meter.

3.10.9 Exchangeable acidity (Al+H)

The soil sample was leached with 1M KCl solution. Exchangeable acidity (H+Al) was determined by titrating the leachate with standard sodium hydroxide (NaOH) solution (Anderson and Ingram, 1993).

3.10.10 Exchangeable bases

The exchangeable bases from soil samples were extracted using ammonium acetate (1N NH_4OAc) solution at pH 7.0 by repeated extraction method (Anderson and Ingram, 1993). Potassium and sodium was read on a Galen Kamp flame photometer. Calcium and magnesium was read on Atomic Absorption Spectrophotometer (AAS), a pye Unicam model Sp 192 at 423 and 285nm wavelength respectively.

3.10.11 Cation exchange capacity (CEC)

CEC was determined by neutral (pH 7.0) NH_4OAc saturation method (Anderson and Ingram, 1993). The Cation exchange capacity of clay fraction was calculated using the formular proposed by Sombroek and Zonneveld (1971).

$$\text{CEC clay} = \frac{\text{CEC } (NH_4OAc) - (3.5 \times \%\ OC)}{\%\ \text{Clay}} \times 100$$

3.10.12 Effective CEC

The effective CEC was determined as the sum of total exchangeable bases by NH_4OAc and 1M KCl exchangeable acidity.

3.10.13 Base saturation (BS)

The BS was calculated for both NH_4OAc determined CEC and ECEC from the formular:-

$$\% \text{ Base Saturation } = \frac{Total\ exchangeable\ bases}{CEC\ or\ ECEC} \times 100$$

3.10.14 Exchangeable sodium percentage (ESP)

The ESP was calculated as proportion of the cation exchange capacity occupied by sodium cations as follows:-

$$ESP = \frac{Exchangeable\ sodium}{CEC\ (pH\ 7.0)} \times 100.$$

3.10.15 Electrical conductivity (EC)

Electrical conductivity was determined in a 1:2.5 soil water ratio using a Wheatstone bridge at 25^oC (Udo *et al*., 2009).

3.10.16 Total salt concentration

Electrical conductivity reading obtained was multiplied by the factor of 640 to give the total salt in $mgkg^{-1}$ (Dregne, 1976)

3.10.17 Sodium adsorption ratio (SAR)

SAR was calculated using the formular:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

3.10.18 Adjusted SAR (Adj. SAR)

Adjusted SAR was calculated from the following relationship

$$Adj.SAR = \left(\frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}\right)\left(1 + 8.4 - PH_c\right)$$

Where; Adj. SAR = Adjusted SAR.

$PH_c = PK_2^1 - PK_c^1 - P(Ca + Mg) + P(HCO_3)$

$PK_2^1 - PK_c^1 = P(Ca + Mg + Na)$

$P(HCO_3) = P(CO_3 + HCO_3)$

Where;

Adj. SAR= Adjusted SAR

pHc= pK^1_2

3.10.19 Organic carbon

The acid-dichromate wet oxidation method of Walkey and Black as described by Nelson and Sommers (1982) was used in organic carbon determination. The heat of dilution of added concentrated suphuric acid (H_2SO_4) hastens the reaction.

3.10.20 Available phosphorous

Available phosphorous was extracted by Bray No-1. Method (Bray and Kurtz, 1965). Phosphorous in solution was determined by the ascorbic acid blue colour method of Murphy and Riley (1962).

3.10.21 Total nitrogen

Total nitrogen was determined by the micro-Kjeldahl technique (Bremner, 1965). Potassium sulphate was used as a catalyst.

3.10.22 Sulphate

Sulphate was extracted with P-solution from calcium hydrogen phosphate $(CaH_2SO_4)_2$ method (Fox *et al*., 1964). Sulphate in solution was determined turbidmetrically in dilute hydrochloric acid. (Hortwitz, 1975)

3.10.23 Carbonate and bicarbonate

These were determined by the rapid acid neutralization method. The soil extract was titrated with dilute 0.02N H_2SO_4 using phenolphthalein as an indicator to a colourless solution for carbonate end point and on further addition of dilute 0.02N H_2SO_4 the colour turned methyl orange for bicarbonate end point.

3.10.24 Residual sodium carbonate

Donahue *et al*., (1990) provided an equation for calculating RSC. This was employed for this study. The equation is as follows:

$RSC= (CO_3+HCO_3)- (Ca+ Mg)$

3.10.25 DTPA extractable micro-nutrients (CU, Zn, Mn and Fe)

The diethylene triamine pentacetic acid (DTPA) method of Lindsay and Norvell (1978) was employed. Atomic Absorption Spectrophotometer (AAS) was used to read the concentrations of Cu, Zn, Mn and Fe).

3.10.26 0.1M Hcl extractable cationic micro-nutrients (Cu, Zn, Mn and Fe)

Available cationic micro-nutrients were extracted with 0.1M HCl solution by shaking soil paste for 4 hours and then centrifuged at 10,000 rpm. The Cu, Fe, Mn and Zn contents in extract were determined using AAS at 325,373.9, 280 and 214 wavelengths respectively.

3.10.27 Boron

Boron was determined using Morgan's solution. Boron was extracted using 1N sodium acetate and colour development to yellowish orange and Azomethine – H. The concentration was read using spectronic 20.

3.11 Water Analysis

3.11.1 pH

The pH of irrigation water was determined directly with a glass electrode on a pye unicam model 290 MK pH meter.

3.11.2 Sodium adsorption ratio (SAR) and Adj. SAR

These were determined using the equations in sections 4.4.17 and 4.4.18

3.11.3 Electrical conductivity

The electrical conductivity was read directly using conductivity meter

3.11.4 Dissolved base cations (Ca, Mg, Na and K)

Flame photometer was used to read Na and K, while Atomic Absorption Spectrometer (AAS) was used to determine Ca nd Mg in the irrigation water

3.11.5 Carbonate and bicarbonate

The carbonate and bicarbonate were determined by the rapid titration method

3.11.6 Chloride

Silver nitrate and potassium chromate were used in determining the chloride content of irrigation water.

3.11.7 Nitrate

The distillation and titration methods of Bremner (1965) were applied for nitrate determination.

3.11.8 Sulphate

The sulphate content of irrigation water was determined turbidimetrically.

3.11.9 Boron

Azomethine-H was used to develop the colour for B determination, and concentration was read using Spectrophotometer 20.

3.11.10 Residual sodium carbonate (RSC)

The RSC was calculated using the same equation in section 4.4.24

3.12 Mineralogical Analysis

3.12.1 Total elemental analysis

Total elemental analyses of soil sample (<2mmk) expressed as oxides were determined by X-ray fluorescent spectroscopy in the multiuser laboratory, A. B. U. Zaria, using energy dispersing X ray fluorescence (EDXRF), a detector and a computer ADC- card, models Canberra and ORTEC (Trump 8k) respectively. Annular 2 mCi^{109} Cd as the excitation source that emits Ag-K X-rays (22.1 Kev) and ^{35}Fe that emits Mn- K X- rays

(5.89 Kev), in which case all the elements with lower characteristic excitation energies were accessible for detection in the soil samples.

3.12.2 Mineralogy of clay fraction

Clay mineralogy was determined by X-ray diffraction (XRD) technique. This was carried out after saturating the clay fraction with magnesium ions. Diffraction patterns were obtained using CuKα radiation using the Shimadzu X-ray diffractometer model XRD-600. The samples were step-scanned between 2 and 45^{o} 2 using scanning speed of $4^{o}min^{-1}$ at sampling pitch of 0.020^{o} and a pre set time of 0.30 seconds. Oriented samples were prepared by air drying on a standard glass slide for the examination. The analysis was carried out at the National Steel and Raw Materials Exploration Agency, Malali, Kaduna.

3.13 Statistical Analysis

Data generated were analyzed using descriptive statistics (Agbenin, 1995), where ranges and means were used. Different mapping units represent the treatments, while pedons were the replications and sampling procedures were completely randomized. Student t-test was used to test significant difference between the different land use types in each mapping unit.

3.14 Soil classification

Data collected from field and laboratory analysis were used to classify the soils based on criteria of the USDA Soil Taxonomy System (Soil Survey Staff, 2010) and the World Reference Base for Soil Resource, (FAO,2006).

3.15 Land capability evaluation

Land capability is the potential of land for use in specified ways, or with specified management practices (Dent, 1980). The capability classification used was based on rating of a set of permanent soil characteristics regarding risks of soil damage. The United State Department of Agriculture (USDA) version by Killingibiel and Montgomery (1961) was adopted for this study. The procedure used involved, digitization of soil map of the study area, to form a homogeneous soil unit in the form of permanent soil limitations of soil depth, drainage, soil texture and nutrient retention capacity. Electrical conductivity (EC) and exchangeable sodium percentage (ESP) were also obtained. These limitations were used to form a simple capability classification with rankings in accordance with the main limiting factor (Table 4.14).

3.16 Extent of land utilization

The current land use was reduced to three legends (i.e. irrigated, rainfed and "others"). These were classified based on land use intensities, with irrigated land use as "highly intensive", rainfed land use as "moderately intensive" and others as "low intensity". The supervised land use map produced was compared with potential land capability map using a cross tabulation algorithm, leading to the production of a new map and a new table, indicating extent of land utilization in the area. This provided an idea about areas that are under utilized, over utilized or well managed.

3.17 Land suitability evaluation

Land suitability evaluation is the prerequisite for sustainable agricultural production. It involves evaluation of the criteria ranging from soil, terrain to socio-economic, market and infrastructure (Prakash, 2003). For the suitability evaluation of the study area for

irrigated rice, the land use requirements used by FAO, 1953; Sys *et al*., 1991; 1993; De Datta (1989) and Udoh *et al*. (2011), were employed. The soil characteristics known as land qualities were matched with the land requirement for irrigated rice production (FAO, 1976). This is also referred to as reconciliation of information about land qualities with the information on crop requirement, which takes place through a medium of chosen criteria usually land characteristics or diagnostic criteria (FAO, 1979).

The suitability of individual mapping units for irrigated rice production was evaluated both by the conventional (non-parametric) (FAO, 1976) and parametric method (Storie, 1954, Ajiboye *et al*., 2011). For the non-parametric evaluation, matching activities were carried out with respect to each soil mapping unit Ballauda, (Ba), Sansan (Sn), Tomas (To) and Ladi (La), to determine which mapping unit would support economic rice production under irrigation management. The overall suitability class was obtained from the most limiting suitability class.

For the parametric method, the current suitability was computed linearly using index of current (actual) productivity. IPC= A X B/100 X C/100 X…F/100, where, IPC is index of current (actual) productivity, A the overall least rating characteristics, and B and C ….are the least rating characteristics for each land quality group. In each pedon, only one member of each of the six land qualities was used in the calculation because there was usually a strong correlation among members of the same group (Ogunkule, 1993). So it was substituted into the index of productivity equation above. However, for the potential productivity (IPP), soil fertility (F) constraints were assumed to be corrected, so not considered as part of the F group, on the other hand, those F group members which are not easily altered e.g. CEC, BSP and PH were considered (Ajiboye *et al*., 2011). The

relevant land qualities and characteristics employed in this study were presented in (Table 4.16). Data obtained on these, were compared with those already in Table 4.16, to rate the soil mapping units into different suitability classes.

CHAPTER FOUR

4.0 RESULTS

4.1 Current Land Use and Land Cover

From SPOT 5 image classification, three major land use and cover types were identified. These classes include; irrigated land use type 1,544.4 ha (12.6%), rainfed 8,605ha (70.42%) and others 2,069.5 ha (16.94%) (Table 4.1 and Figure 4.1)

4.2 Description of Soil Mapping Units

4.2.1 Morphological properties

The soils in Ballauda (Ba), Sansan (Sn), Tomas (To) and Ladi (La) mapping units were well drained and deep, except for pedon Ba1 in Ballauda series which was imperfectly to well drained and water table was encountered at depth 114cm. The parent material was colluvial, loessial and alluvial or a mixture of these, over basement complex. These soils were located on a gently sloping plain of level or nearly level plain of 0-2% slope. The surface thickness of soils in mapping unit Ba and Sn ranged from 10-35cm, with reddish brown to strong brown colours (7.5YR4/6, moist) and of sandy loam to loamy sand texture. For mapping unit To, the surface soil was of yellowish brown (10YR3/4 moist) colours and mostly of sandy loam textures, while the subsurface colours ranged from yellowish red (5YR5/8 moist) to very pale brown (10 YR8/4 moist). Few faint mottles were observed at the subsurface of pedon Ba1 (2.5Y4/2). Structurally, all soils of mapping units Ba, To and La were either single grained or weakly structured at the subsurface horizons. Mapping unit Sn varied in structure from fine subangular blocky and structureless material (single grained) (Table 4.2).

Table 4. 1:Area and extent of the different land use and land covers in the Irrigation scheme.

Before			**After**	
Description	**Area (Ha)**	**(%)**	**Area (Ha)**	**(%)**
Irrigated	1,356.25	10.90	1,544.40	12.64
Rainfed	8,793.71	70.68	8,605.50	70.42
Others	2,291.51	18.42	2,069.50	16.94
Total	12,291.51	100.00	12,219.4	100.00

The difference in areas (Table 4.1) was due to the field check with the classified image for adoption and refining of the training samples.

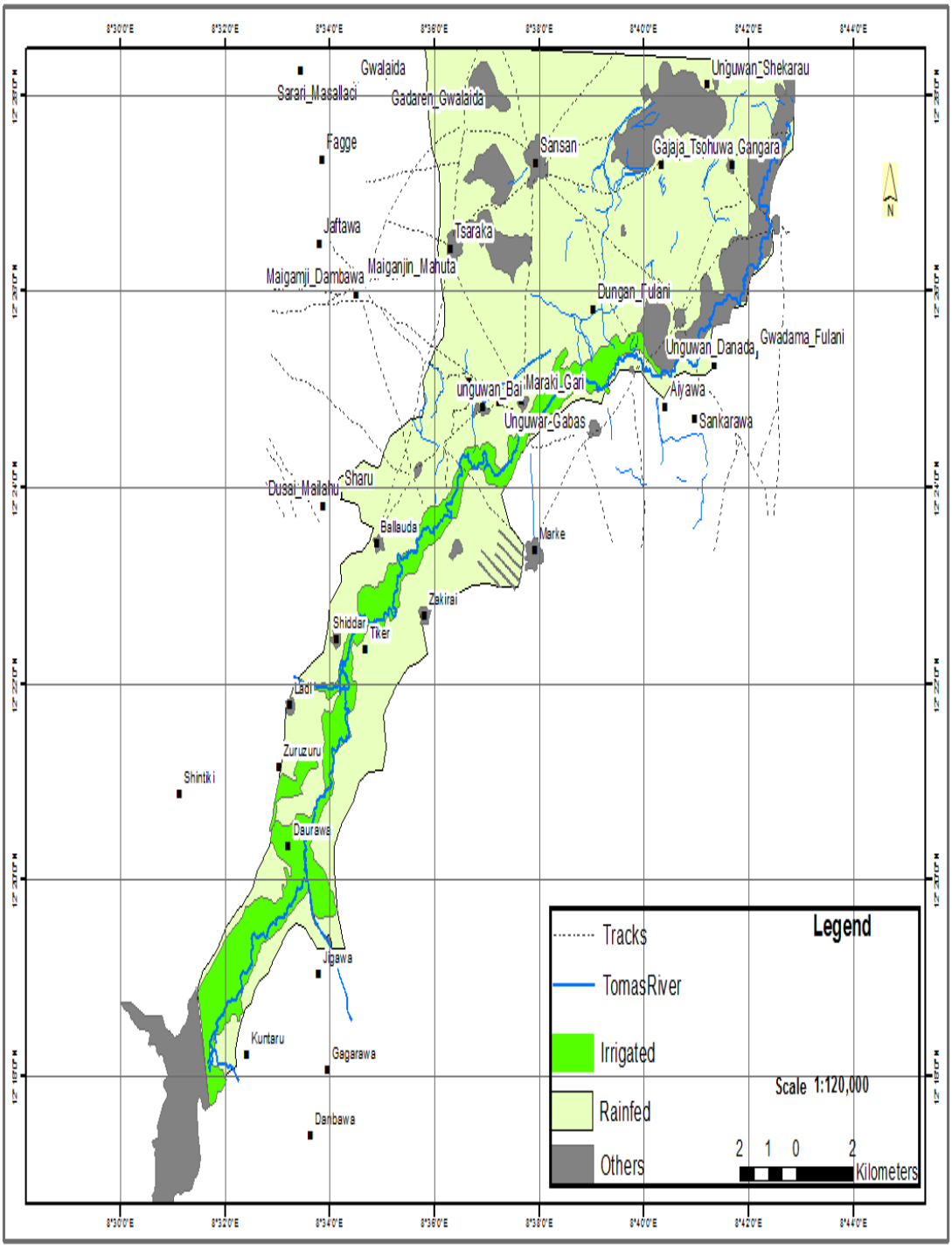


Figure 4. 1:Map of Tomas irrigation scheme showing landuse types

Consistency of soils in the mapping units was mostly non sticky and non plastic when wet. The boundary in surface horizon of pedon Ba1 was clear and wavy (cw), To1, To2 and La1 clear and smooth (Cs). Gradual boundary was observed in pedon Ba2 and Sn2. There were few fine roots in surface horizons of all the mapping units. Few fine to medium pores were also observed, especially in pedons To1, Ba2 and Sn2. Many fine to few medium tubular and vesicular pores were found in pedons Ba1, To2, La1, Sn1 and Sn2 respectively (Table 4.2)

4.2.2 Soil physical properties

The physical properties of mapping units were presented in Table 4.3. Gravel content of the pedons in all mapping units was negligible or none at all. Sand was the dorminant particle size fraction in both surface and subsurface horizons in all mapping units. There was a decrease in sand content with depth in mapping unit Ba and To, while in mapping unit Sn, there was an increase in sand content with an increase in depth. Clay was the next dorminant fraction after sand, while silt was the least of fine earth separates in all mapping units. Bulk density for all the mapping units were rated low to moderate, but the soil strength was suitable for root penetration. Higher bulk density values were observed in the surface horizons compared to subsurface horizons. Total total porosity values and data for available water capacity were presented in Table 4.3.

4.2.3 Effect of irrigation on soil physical properties

There was a significant difference in mean values of sand content (Table 4.4), between irrigated and rainfed land use ($P< 0.05$) in mapping unit Ba, and Prb ($P< 0.01$) in mapping unit La. Mean values of clay content shows that, there was a significant difference ($P<0.05$) in mapping unit La, between irrigated (La1) and rainfed (La2). The

land use indicated a highly significant difference (P<0.01) in silt content (Table 4.4) in mapping unit Ba and La. There was also a significant difference in moisture content at field capacity and permanent wilting point (P<0.05) between irrigated and rainfed land use in mapping unit Ba. On the other hand, a highly significant difference (Prb <0.01) was also observed in mapping unit La between water retention at FC and PWP in irrigated (La1) and rainfed (La2) land use

Table 4. 2:Summary of morphological properties of soil mapping unit Tomas (TO)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon TO1			Soil mapping unit To		Lat. N12.35926	Long. E008.56892		Alt. 419m			
Ap	0-30	10YR5/3	10YR7/2	----------	LS	Om	sopo	vfr	H	Cs	Few fine roots
AC	30-80	10YR2/6	10YR8/3	----------	SL	Om	sopo	vfr	S	Gs	Few fine roots
C1	80-138	10YR7/6	----------	10YR5/8	LS	Om	sopo	vfr	S	Cs	Few fine roots
C2	138-230	10YR8/4	----------	7.5YR6/2	LS	Om	sopo	vfr	S		Few ant holes

Symbols derived from soil survey manual (Soil Survey Staff, 2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
TO1: Tomas irrigated

Table 4.2 continued: Summary of morphological properties of soil mapping unit Tomas (TO2)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon TO2			Soil mapping unit To		Lat. N12.32793	Long. E008.56601		Alt. 432m			
Ap	0-20	10YR3/4	10YR5/4	----------	LS	1fsbk	sopo	vfr	H	Cs	Few fine roots and fine tubular pores
AB	20-55	10YR5/8	10YR6/6	----------	LS	1fsbk	sopo	vfr	S	Cs	Few coarse roots and many tubular pores
BW	55-140	5YR5/8	5YR6/8	----------	LS	1fsbk	sopo	vfr	S	Gs	Many fine tubular pores
C	140-210	7.5YR5/8	7.5YR6/8	----------	LS	Om	sopo	vfr	H		Few fine pores

Symbols derived from soil survey manual (Soil Survey Staff, 2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
TO2: Tomas rainfed

Table 4.2 continued: Summary of morphological properties of soil mapping unit Ballauda (Ba)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon Ba1				Soil mapping unit Ba	Lat. N12.4134	Long. E008.63240	Alt. 407m				
Ap	0-10	10YR3/2	10YR5/4	----------	SL	2msbk	Ssps	fr	H	Cw	Few fine roots
AC	10-35	10YR4/1	10YR5/4	----------	SL	1msbk	Ssps	vfr	Lo	Cs	Many fine tubular pores
C1	35-60	2.5Y5/2		2.5Y4/2	LS	om	sopo	Vfr	S	Cs	Few medium vesicular pores
Cg	60-114	2.57/2		2.5Y7/2	LS	om	sopo	Vfr	Lo		Gleyed condition

Symbols derived from soil survey manual (Soil Survey Staff, 2010)

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
Ba1: Ballauda irrigated

Table 4.2 continued: Summary of morphological properties of soil mapping unit Ballauda (BA)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon Ba2				Soil mapping unit Ba	Lat. N12.42792	Long. E008.60704		Alt. 429m			
Ap	0-26	7.5YR4/6	7.5YR6/6	----------	LS	1fabk	Sopo	vfr	S	Gs	Few fine roots and many vesicular pores, fine quartz grains.
BA	26-63	7.5YR4/6	7.5YR5/8	----------	LS	1fabk	Sopo	vfr	Lo	Gs	Many fine tubular pores
BC	63-143	5YR4/6	5YR5/6	…….	SL	1fabk	Sopo	vfr	Lo	Gs	Few medium vesicular pores
C	143-232	5YR4/6	5YR5/8	……..	LS	Om	Sopo	vfr	Lo		Common fine roots, cracks from top down

Symbols derived from soil survey manual (Soil Survey Staff, 2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular blocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
Ba2: Ballauda rainfed

Table 4.2 continued : Summary of morphological properties of soil mapping unit Ladi (La)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon La1				Soil mapping unit La	Lat. N12.31665	Long. E008.53489	Alt. 425m				
Ap	0-12	10YR4/3	10YR5/2	----------	SL	Om	sopo	vfr	Lo	dw	common fine roots and many tubular pores
AC	12-42	7.5YR4/6	7.5YR5/6	----------	SL	Om	sopo	vfr	Lo	gs	Many fine tubular pores
C1	42-185	5YR4/6	5YR5/8	……	SL	Om	sopo	vfr	Lo	gs	Few fine tubular pores
C2	185-232	10YR5/6	……	10YR4/5	SL	Om	sopo	vfr	Lo	……	Common fine vesicular pores

Symbols derived from soil survey manual (Soil Survey Staff,2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
La1: Ladi irrigated

Table 4.2 continued :Summary of morphological properties of soil mapping unit Ladi (La2)

Horizon	Depth(cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	Moist	Dry		
Pedon La2				Soil mapping unit La	Lat N12.39293	Long. E008.60881	Alt. 427m				
Ap	0-48	10YR4/6	10YR6/4	----------	LS	Om	sopo	vfr	H	Cs	Many fine tubular pores
AC	48—128	10YR5/6	10YR7/6	----------	LS	1fsbk	sopo	vfr	S	Gs	Few fine roots
C1	128-164	10YR6/6	10YR8/4	…….	LS	Om	sopo	vfr	Lo	Gs	Few fine roots
C2	164-250	10YR7/6	10YR8/2	……	S	Om	sopo	vfr	Lo	……	Few fine roots

Symbols derived from soil survey manual (Soil Survey Staff,2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
La2: Ladi rainfed

Table 4.2 continued: Summary of morphological properties of soil mapping unit Sansan (Sn)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	moist	Dry		
Pedon Sn1			Soil mapping unit Sn		Lat. N12.44294	Long. E008.61708		Alt. 416m			
Ap	0-18	10YR3/1	10YR5/2	----------	SL	1fabk	Sopo	vfr	S	ds	Few fine roots, with micro and mcro pores
BA	18—53	10YR3/1	10YR4/3	----------	SL	2fsbk	Sopo	vfr	H	gs	Few fine roots, with micro pores
BC	53-153	10YR7/3	10YR8/2	…….	LS	Om	Sopo	vfr	S	gs	Few fine tubular pores, and ant holes
C	153-264	10YR7/2	10YR8/2	…….	LS	Om	Sopo	vfr	Lo		Yellow patches

Symbols derived from soil survey manual (Soil Survey Staff, 2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
Sn1: Sansan irrigated

Table 4.2 continued : Summary of morphological properties of soil mapping unit Sansan (Sn)

Horizon	Depth (cm)	Munsell Colour		Mottle Colour	Texture	Structure	Consistency			Boundary	Other features
		Moist	Dry				Wet	moist	Dry		
Pedon Sn2				Soil mapping unit Sn	Lat. N12.44903	Long. E008.61057	Alt. 426m				
Ap	0-23	10YR4/3	10YR5/4	----------	LS	1msbk	sopo	vfr	s	gw	Few fine roots and tubular with ant holes.
AB	23—72	10YR3/3	10YR5/3	----------	LS	2fsbk	sopo	vfr	s	gw	Few fine vesicular pores and ant holes
BC	72-153	10YR4/6	7.5YR6/6	…….	LS	Om	sopo	vfr	Lo	gs	Few ant holes and vertical cracks.
C1	153-213	10YR5/6	10YR7/6	…….	LS	Om	sopo	vfr	s	gs	Few ant holes, ring form of iron concretions and vertical cracks.
C2	>213	10YR7/2	10YR8/2		LS	Om	Sopo	vfr	s		Vertical cracks.

Symbols derived from soil survey manual (Soil Survey Staff, 2010).

Texture: SL, Sandyloam, LS = Loamy Sand.
Structure: 1fsbk: Weakfine subangular blocky, 1 fabk: weak angular bocky, Om: structurelss, massive, 2fsbk: moderate fine subangular blocky, 1 msbk: weak medium subangular blocky.
Soil consistence: wet: Sopo, Nonsticky nonplastic, **Moist:** vfr – very friable, fr – friable, **Dry**: H – hard, S – soft, LO**:** - loose.
Boundary: CS – clear, smooth, **Gs** – gradual smooth, **CW** – clear, wavy, **Dw** – diffuse, wavy, **Ds** – diffuse, smooth, **Gw** - gradual wavy
Sn2: Sansan rainfed

Table 4. 3:Soil physical properties of Tomas irrigation scheme

Horizon	Depth (cm)	Particle Density	Bulk Density	Ksat (cms^{-1})	Total Porosity	Field Capacity	PWP	AWC	Particle Sizedistribution			Textural Class	Equilibrium infiltration rate (cm/hr)
		← ($Mg\ m^{-3}$) →			← (%) →				Sand	Silt	Clay		
									← ($g\ Kg^{-1}$) →				
Map Unit Ballauda (Ba)													
Pedon Ba1		Location Ballauda fadama			Lat. N12.4134		Long. E008.163240			Alt. 407m			
AP	0-10	2.18	1.34	0.209	38.5	23.9	19.4	4.5	780	90	130	Sandy loam	46.2
AC	10-35	2.65	1.60	0.265	39.6	24.9	18.7	6.1	720	120	160	Sandy loam	
C1	35-60	2.68	1.67	0.48	38.6	18.2	7.7	10.5	820	60	120	Loamy sand	
C2	60-114	2.65	1.47	0.124	51.9	11.1	11.0	0.1	820	80	100	Loamy sand	
Pedon Ba2		Location Fulani Banda maye			Lat. N12.42792		Long. E008.60704			Alt. 429m			
AP	0-26	2.68	1.48	0.069	44.8	7.9	4.9	3.0	860	30	110	Loamy sand	65.5
BA	26-63	2.56	1.31	0.156	48.8	8.3	4.6	3.7	840	30	130	Loamy sand	
BC	63-143	2.65	1.31	0.159	50.6	7.9	7.2	0.7	830	10	160	Sandy loam	
C	143-232	2.35	1.43	0.265	39.1	8.6	5.9	2.7	850	10	140	Loamy sand	
Map Unit Sansan (Sn)													
Pedon Sn1		Location Fadama Tsaraka			Lat. N12.44294		Long. E008.61708			Alt. 416m			
AP	0-18	2.41	1.28	0.221	46.9	19.2	11.0	8.2	810	20	170	Sandy loam	18.5
BA	18-53	2.28	1.42	0.467	37.7	24.3	19.5	4.8	810	50	140	Sandy loam	
BC	53-153	1.92	1.31	0.467	60.4	2.9	1.9	1.0	900	10	90	Loamy sand	
C	153-264	1.48	1.54	0.139	4.05	7.4	4.6	2.8	890	20	90	Loamy sand	
Pedon Sn2		Location Bagare			Lat. N12.44903		Long. E008.61057			Alt. 426m			
AP	0-23	2.63	1.28	0.221	63	31.9	30.4	1.5	880	20	100	Loamy sand	50.5
AB	23-72	2.22	1.28	0.248	42.3	6.5	5.3	1.2	860	20	120	Loamy sand	
BC	72-153	2.27	1.41	0.467	37.9	7.9	4.1	3.8	880	10	110	Loamy sand	
C1	153-213	2.17	1.24	0.441	42.9	5.1	2.2	2.9	890	10	100	Loamy sand	
C2	>213	2.15	1.20	0.38	40.3	6.2	1.9	4.3	880	20	100	Loamy sand	

Key: Ba1: Ballauda irrigated, Ba2: Ballauda rainfed, Sn1: Sansan irrigated Sn2: Sansan rainfed

Table 4.3 continued: Soil physical properties of Tomas irrigation scheme

Horizon	Depth (cm)	Particle Density	Bulk Density	Ksat (c ms^{-1})	Total Porosity	Field Capacity	PWP	AWC	Particle Size distribution			Textural Class	Equilibrium infiltration rate (cm/hr)
		← (Mg m^{-3}) →			← (%) →				Sand ←	Silt ($g\ kg^{-1}$)	Clay →		
					Map Unit Tomas(To)								
Pedon To1		Location Fadama Shiddar		Lat. N12.35936		Long. E008.56892			Alt. 419m				
AP	0-30	2.43	1.39	0.418	46.1	8.6	7.5	1.1	840	40	120	Loamy sand	2.45
AC	30-80	2.29	1.39	0.076	38.8	6.9	5.0	1.9	830	70	100	Sandy loam	
C1	80-138	2.23	1.41	0.234	36.8	6.2	4.1	2.1	860	40	100	Loamy sand	
C2	138-236	2.2	1.00	0.441	54.5	50.2	49.9	0.1	900	10	90	Loamy sand	
Pedon To2		Location Tsallewa		Lat. N12.32793		Long. E008.56601			Alt. 432m				
AP	0-20	2.33	1.27	0.234	45.5	9.0	6.7	2.3	880	20	100	Loamy sand	50.00
AB	20-55	2.63	1.39	0.139	47.1	10.0	5.6	4.4	850	10	140	Loamy sand	
BW	55-140	2.13	1.54	0.441	28.4	9.4	6.8	2.6	870	30	140	Loamy sand	
C	140-210	2.37	1.44	0.441	39.2	6.3	4.8	1.5	850	20	130	Loamy sand	
					Map Unit Ladi (La)								
Pedon La1		Location Kulfare		Lat. N12.31665		Long. E008.53489			Alt. 425m				
AP	0-12	2.29	1.32	0.216	42.4	13.2	10.3	2.9	780	80	140	Sandy loam	18.12
AC	12-42	2.28	1.67	0.209	26.8	11.7	10.2	1.5	780	60	160	Sandy loam	
C1	42-185	2.27	1.69	0.467	25.6	19.6	15	4.6	740	80	180	Sandy loam	
C2	185-232	2.44	1.53	0.234	37.3	15.5	11.8	3.7	780	60	160	Sandy loam	
Pedon La2		Location Zakiran kauye		Lat. N12.39293		Long. E008.60881			Alt. 427m				
AP	0-48	2.41	1.48	0.132	38.6	6.8	3.4	3.4	870	20	110	Loamy sand	45.00
AC	48-128	2.35	1.47	0.221	37.4	10.1	4.6	5.5	830	10	160	Loamy sand	
C1	128-164	2.5	1.33	0.199	46.8	4.7	4.1	8.6	880	10	110	Loamy sand	
C2	164-250	2.4	1.14	0.221	52.5	4.6	1.4	3.2	890	20	90	Loamy sand	

Key: TO1: Tomas irrigated, TO2: Tomas rainfed , La1: Ladi irrigated, La2: Ladi rainfed

Table 4. 4:Effect of irrigation on soil physical properties

Mapping unit Ballauda (Ba)

	Physical properties									
Land use	PD	BD	Ksat	TP	FC	PWP	AWC	SAND	SILT	CLAY
	← $Mg\ m^{-3}$ →		cms^{-1}	← % →				← $g\ Kg^{-1}$ →		
Irrigation	2.65	1.52	0.2115	42.15	19.5	14.2	5.3	785	87.5	127.5
Rainfed	2.56	1.3825	0.1623	45.825	8.175	5.65	2.525	845	20	135
Difference	0.0925	0.1375	0.0492	-3.675	11.325	8.55	2.775	-60	67.5	-7.5
t-value	0.47	1.62	0.97	0.89	3.58	2.91	1.24	2.45	4.9	0.46
Significance	NS	NS	NS	NS	*	*	NS	*	**	NS

Mapping unit Sansan (Sn)

Irrigation	2.02	1.25	0.3235	37.26	13.45	9.25	4.2	852.5	25	122.5
Rainfed	2.59	1.33	0.3443	46.53	12.85	10.5	2.35	878	16	106
Difference	-0.575	-0.077	-0.021	-9.262	0.6	-1.25	1.85	25.5	9	16.5
t-value	1.33	0.44	0.20	0.70	0.07	0.16	1.12	1.14	1.11	0.92
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Mapping unit Tomas (To)

Irrigation	2.29	1.297	0.292	44.05	17.93	16.63	1.53	857.5	40	102.5
Rainfed	2.37	1.41	0.314	39.3	8.68	5.98	2.7	862.5	20	127.5
Difference	-0.078	-0.113	-0.021	4.75	9.25	10.65	-1.175	-5	20	-25
t-value	0.68	0.99	0.19	0.75	0.86	0.96	1.75	0.29	1.55	2.20
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Mapping unit Ladi (La)

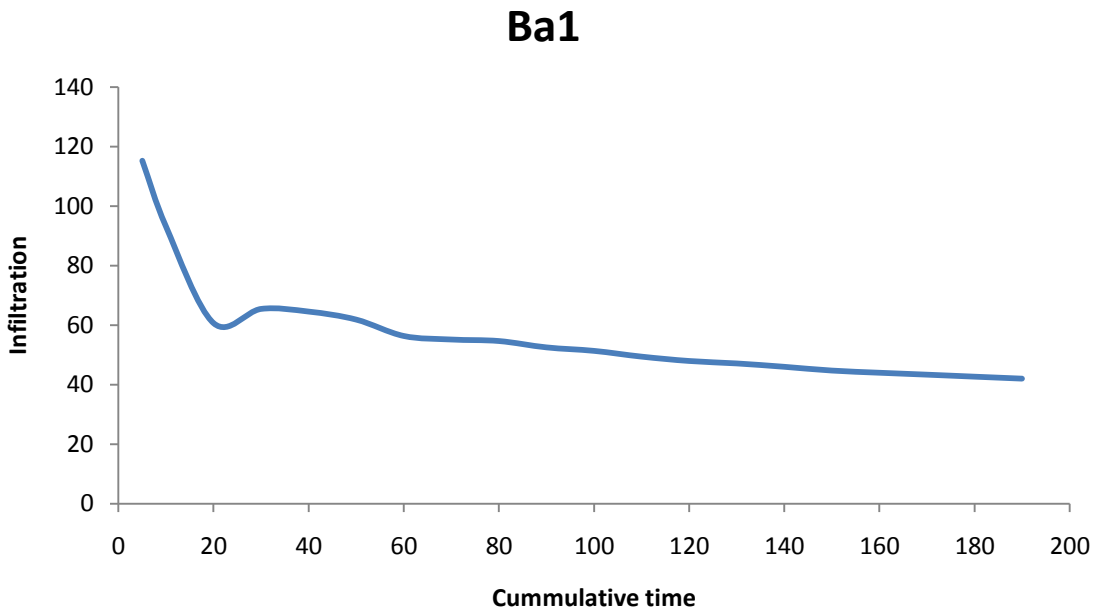
Irrigation	2.32	1.55	0.282	33.03	15	11.83	2.93	770	70	160
Rainfed	2.42	1.36	0.193	43.83	6.55	3.38	3.18	867.5	15	117.5
Difference	-0.095	0.1975	0.088	-10.8	8.45	8.45	-0.25	-97.5	55	42.5
t-value	1.87	1.69	1.35	1.99	3.93	6.39	0.20	5.90	8.52	2.5
Significance	NS	NS	NS	NS	**	**	NS	**	**	*

4.2.4 Soil infiltration

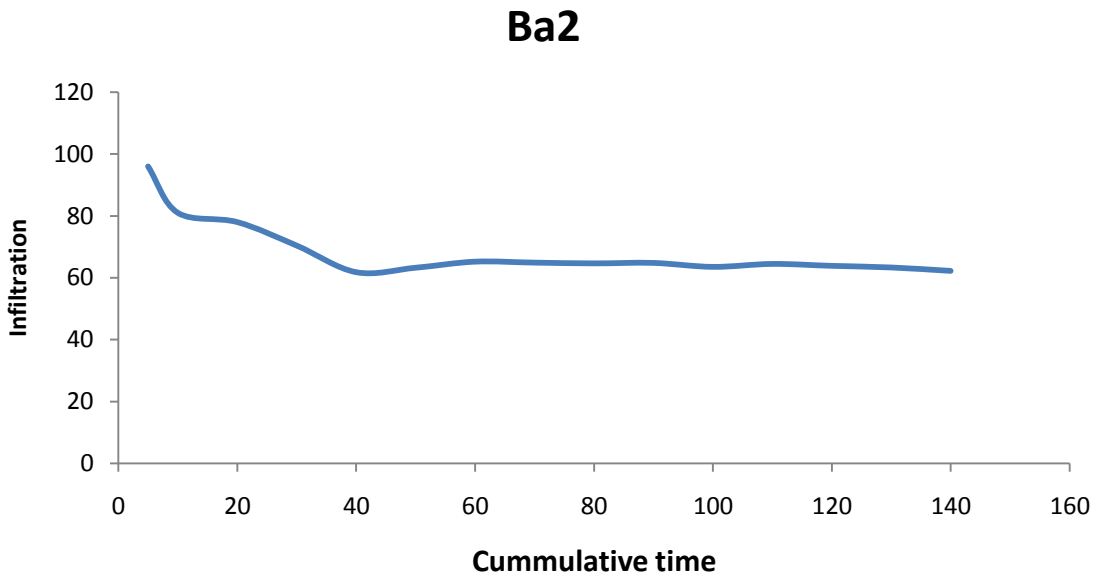
Infiltration curves of the study area in figures 4.2 to 4.5 shows a general trend which starts from low value; which increases rapidly, then followed by a gradual increase towards equilibrium. Pedons To1, La1 and Sn1 were said to have low infiltration rates, while Ba1, Ba2, La2 and Sn2 were considered high (Table 4.3).

4.2.5 Soil chemical properties

Soil chemical properties of mapping units were presented in Table 4.5. Soil pH (water) of all mapping units ranged from 5.4 to 6.6. In pedons Ba1 and Sn1 lower values were observed in the surface horizon. In the surface of pedons Ba2 and Sn2 higher pH values were obtained. In irrigated pedons (Ba1 and Sn1), there was an increase in soil pH with increase in soil depth, while in pedon (Ba2), which was non irrigated, there was a decrease in soil pH with an increase in soil depth. The pH measured in $CaCl_2$ solution was lower than pH in water in all the mapping units, giving a negative delta pH values. The organic carbon content was rated very low to moderate. Pedons Ba1and Sn1 (irrigated), showed a higher value of OC than pedon Ba2 and Sn2 (non irrigated). Total N values were rated low to medium (Chude *et al*., 2004), Total N values tend to decrease from surface to sub surface horizons. Available P values for the mapping units were rated low to medium (Chude *et al*., 2004). From the results (Table 4.5), it can be seen that, higher values of available P were found in the non irrigated pedon (To2) compared to irrigated pedon (To1). Calcium was found to be the principal saturating cation among exchangeable basic cations in the mapping units.

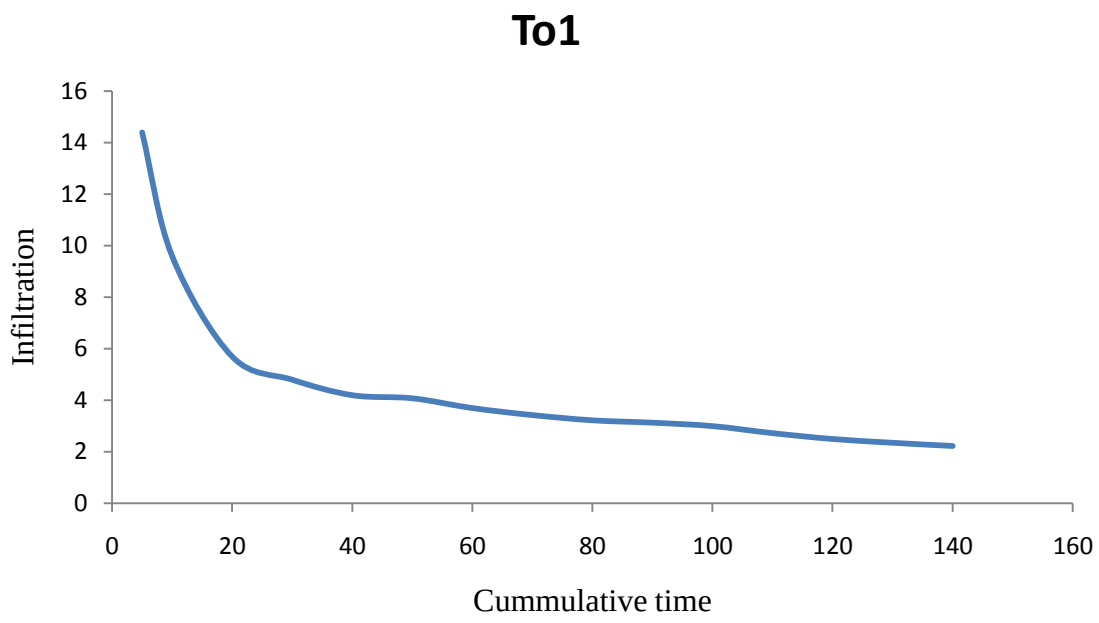


Ba1: Ballauda irrigated

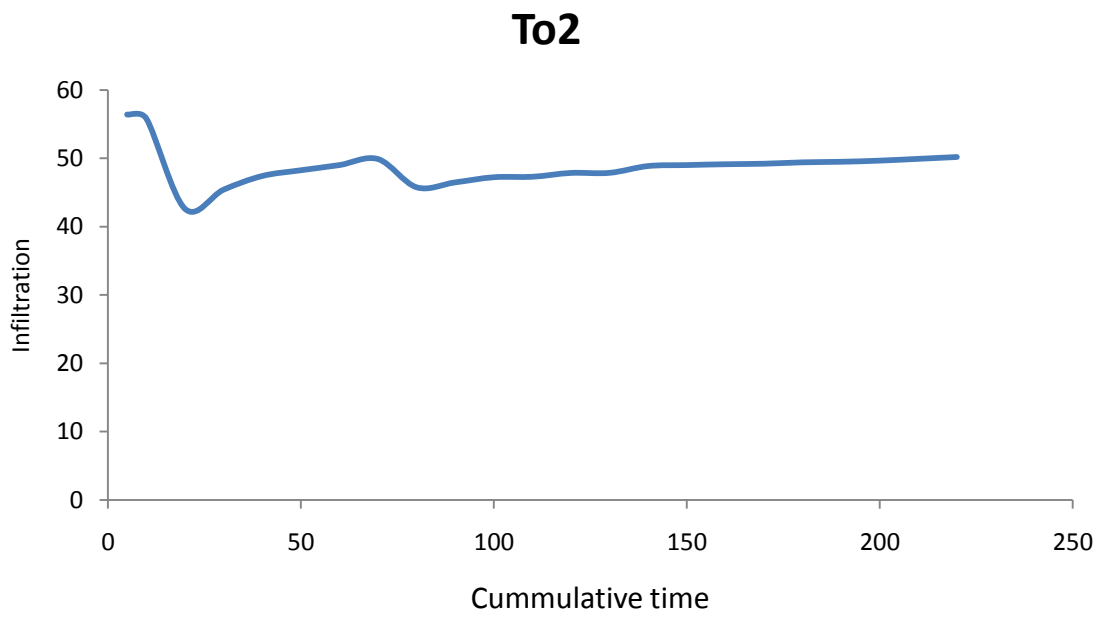


Ba2: Ballauda rainfed

Figure 4. 2:Soil infiltration curve for Ballauda series (Ba)

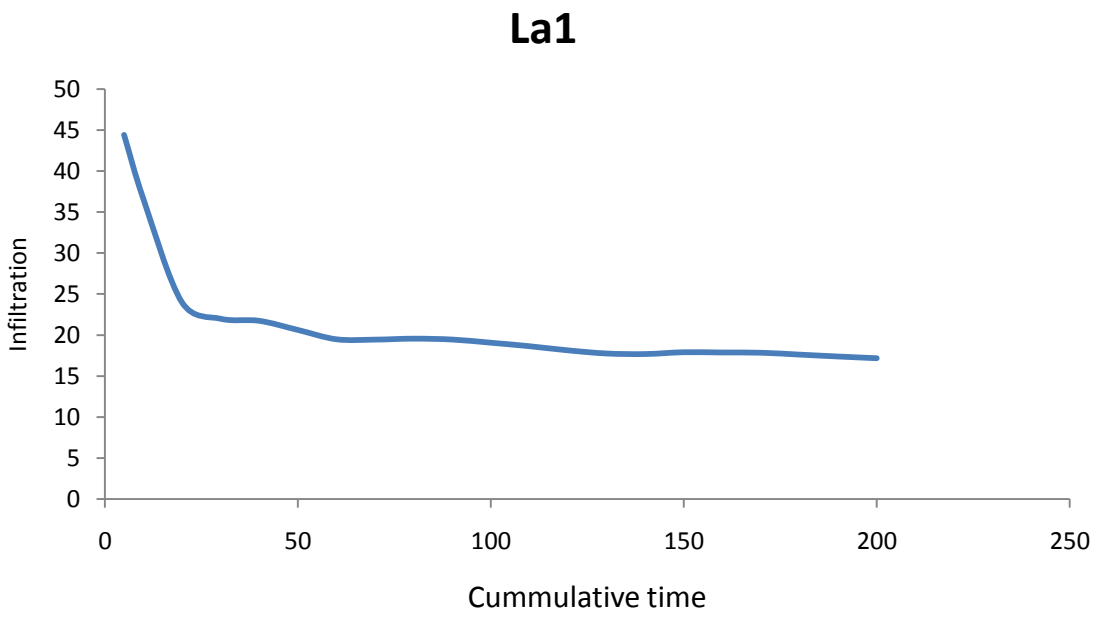


TO1: Tomas irrigated

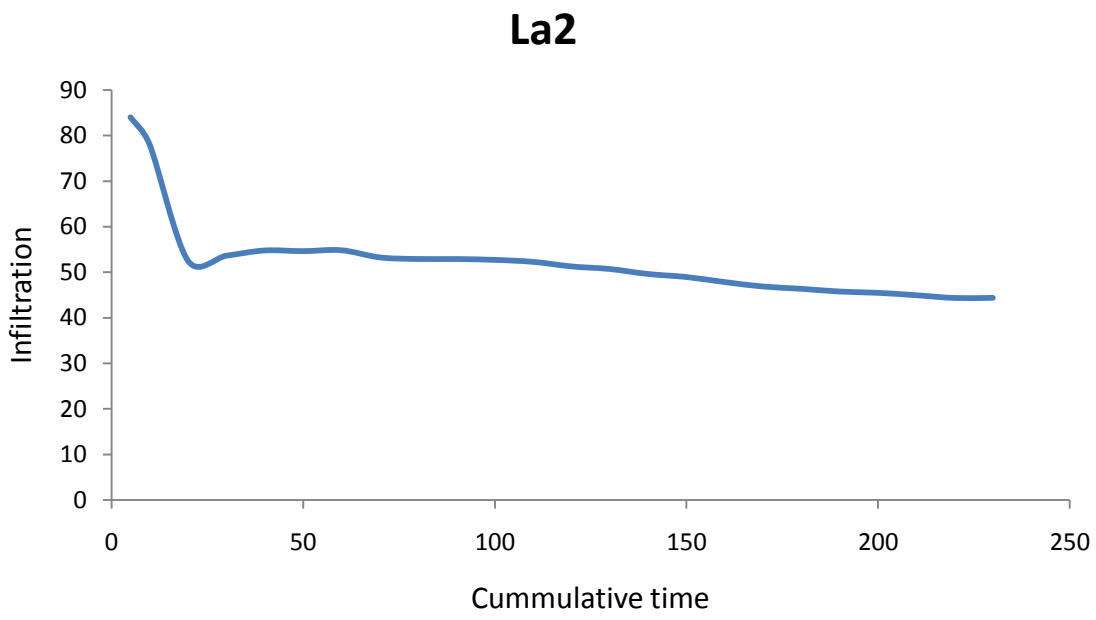


TO2: Tomas rainfed

Figure 4. 3:Soil infiltration curve for Tomas series (To)

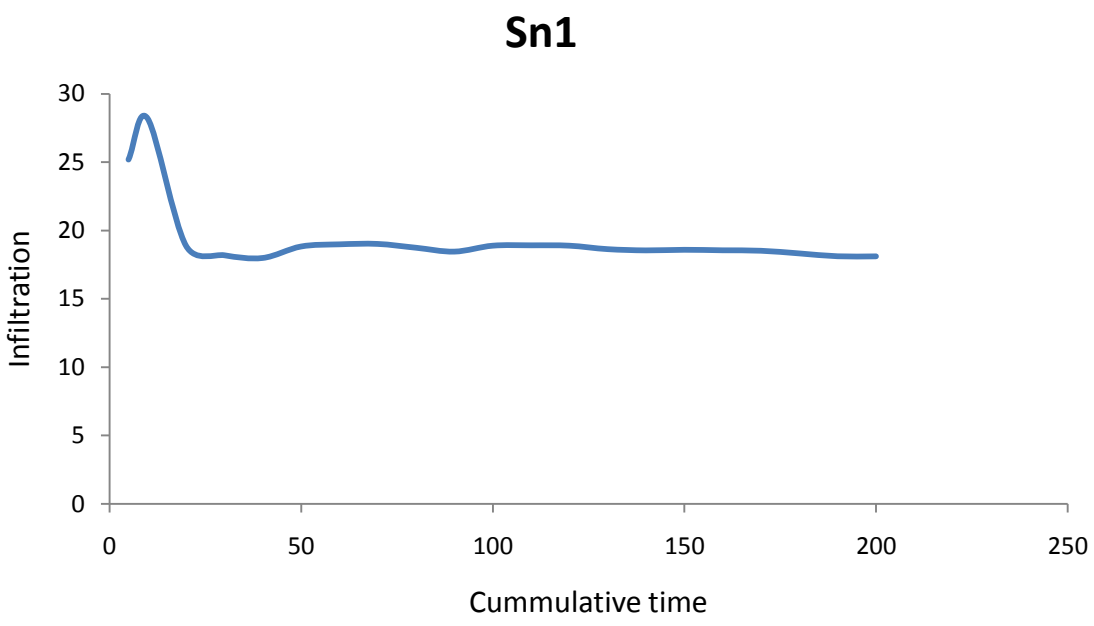


La1: Ladi irrigated

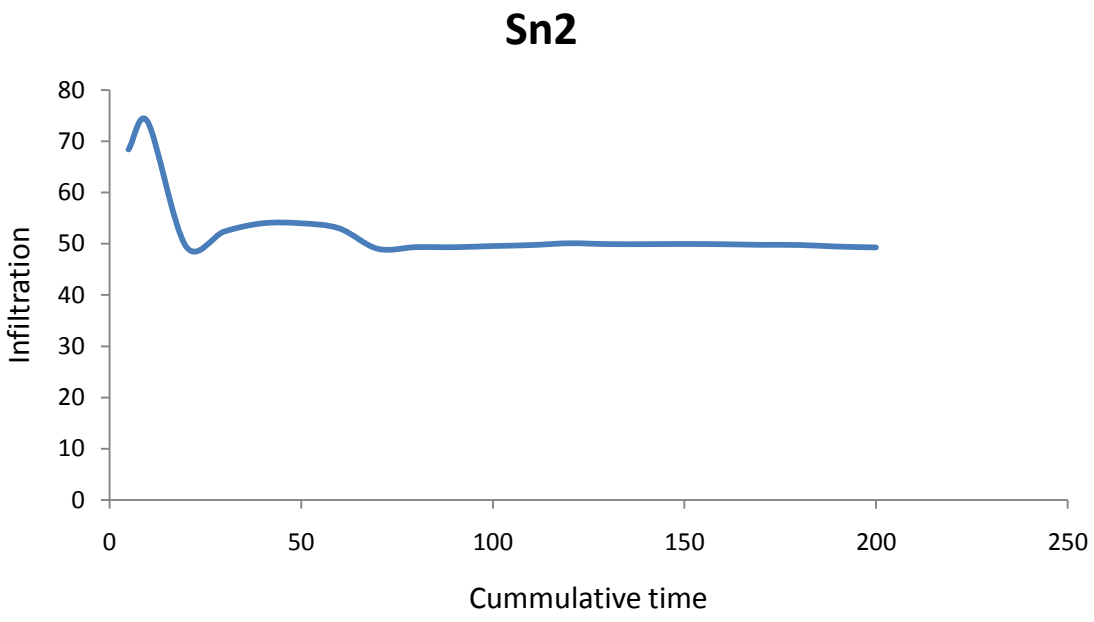


La2: Ladi rainfed

Figure 4. 4:Soil infiltration curve for Ladi series (La)



Sn1: Sansan irrigated



Sn2: Sansan rainfed

Figure 4. 5:Soil infiltration curve for Sansan series (Sn)

The values of exchangeable Ca^{2+} were rated as very low to low (Awotundun, 1973; Enwezor *et al*., 1989). After Ca^{2+}, the next dorminant cation was magnesium (Mg^{2+}). Lower values on the surface horizons that increase with depth were found in pedon To2, while in pedon To1 higher values of exchangeable Mg were noticed which decreased with depth (Table 4.5). Sodium ranked third among the cations (Table 4.5). Its contents in the soil mapping units (Ba, Sn, To and La) ranged from low to very low (Enwezor *et al*., 1989). Exchangeable K values were rated very low (Enwezor *et al*., 1989). The values of exchangeable K were found to decrease with increase in soil depth in mapping unit To and Sn.

Exchangeable acidity values for all the mapping units were generally low (Table 4.5); less than 1cmol (+) kg^{-1}. The CEC values were rated very low to moderate. Higher values were obtained at sub surface horizons. The ECEC values were rated low to medium. The effective CEC values were lower than the CEC values. The range and mean values for base saturation percentage (BSP) in these mapping units were rated low to high (Table 4.5). The value of EC for the mapping units were rated low. The SAR values were rated very low in all the mapping units (Richard, 1954). The values ranged from 0.11 to 0.19. Higher values of ESP were recorded on the surface horizons with an inconsistent decrease in sub surface horizons, with an increase in soil depth especially in pedons Ba1, Ba2 and To2 (Table 4.5).

Table 4. 5:Soil chemical properties of Tomas irrigation scheme

Horizon	Depth (Cm)	pH		ΔpH	EXCH. BASES				TEB	EXCH ACID	CEC	ECEC	CEC Clay	OC	Total N	Avail P	BSP	ESP	SAR	Adj. SAR	EC	CO_3	HCO_3^{-1}	RSC
		H_2o	$CaCl_2$		Ca	Mg	Na	K	cmol(+) kg^{-1}					g kg^{-1}		mg kg^{-1}	%				dS m^{-1}	cmol(+) kg^{-1}		
Map Unit Ballauda (Ba)																								
Pedon Ba1	Location Ballauda fadama				Lat. N12.4134						Long. E008.163240						Alt. 407m							
AP	0-10	5.8	4.3	-1.5	3.91	1.22	0.74	0.16	6.03	0.6	7.9	6.63	37.9	8.5	1.8	8.75	76.4	9.4	0.16	0.38	0.23	0	2	-3.13
AC	10-35	5.9	3.8	-2.1	2.26	0.44	0.37	0.06	3.12	0.5	10.6	3.62	57.1	4.2	2.8	1.75	29.5	3.5	0.11	0.13	0.03	0	0.4	-2.29
C1	35-60	6.4	3.9	-2.5	0.72	0.26	0.29	0.03	1.30	0.6	5.3	1.90	43.0	0.4	1.1	1.75	24.6	5.5	0.15	0.18	0.02	0	1.0	-0.38
C2	60-114	6.3	5.6	-0.7	0.19	0.14	0.22	0.02	0.57	0.2	2.0	0.77	1.45	5.3	1.8	4.38	28.7	11.0	0.19	0.24	0.02	0	0.6	0.26
Pedon Ba2	Location Fulani Banda maye				Lat. N12.42792						Long. E008.60704						Alt. 429m							
AP	0-26	6.1	5.3	-0.8	0.66	0.33	0.22	0.04	1.25	0.2	2.5	1.45	14.8	2.5	1.4	1.75	49.9	8.8	0.11	0.15	0.02	0	0.4	-0.59
BA	26-63	5.9	5.3	-0.6	0.59	0.27	0.22	0.03	1.11	0.2	4.1	1.31	25.9	2.1	1.8	1.75	27.1	5.37	0.12	0.15	0.01	0	0.4	-0.46
BC	63-143	6.1	5.4	-0.7	0.85	0.29	0.25	0.03	1.43	0.2	2.8	1.63	15.1	1.1	2.1	2.63	50.9	8.93	0.12	0.14	0.01	0	0.2	-0.95
C	143-232	6.1	5.6	-0.5	0.77	0.35	0.24	0.03	1.38	0.2	3.2	1.58	20.9	0.8	1.8	1.75	43.2	7.5	0.11	0.16	0.01	0	0.6	-0.51
Map Unit Sansan (Sn)																								
Pedon Sn1	Location Fadama Tsaraka				Lat. N12.44294						Long. E008.61708						Alt. 416m							
AP	0-18	4.7	4.3	-0.4	1.25	0.26	0.21	0.07	1.79	0.5	7.9	2.29	23	11.4	3.2	12.3	22.7	2.66	0.09	0.10	0.04	0	0.2	-1.31
BA	18-53	4.9	4.3	-0.6	3.09	0.51	0.23	0.06	3.89	0.8	13.5	4.69	76.9	7.8	1.8	5.25	22.8	1.7	0.06	0.07	0.04	0	0.4	-3.2
BC	53-153	5.5	5.3	-0.2	0.24	0.25	0.21	0.02	0.72	0.4	2.5	1.12	10.5	7.3	1.8	5.2	28.9	8.4	0.15	0.18	0.01	0	0.4	-0.09
C	153-264	5.3	5.2	-0.1	0.26	0.24	0.23	0.03	0.76	0.2	2.5	0.96	20.4	1.9	1.1	1.75	30.4	9.2	0.16	0.19	0.01	0	0.2	-0.29
Pedon Sn2	Location Bagare				Lat. N12.44903						Long. E008.61057						Alt. 426m							
AP	0-23	5.5	5.4	-0.1	1.39	0.42	0.21	0.03	2.04	0.2	3.1	2.24	24.4	1.9	1.4	7.0	65.9	6.77	0.08	0.09	0.02	0	0.2	-1.6
AB	23-72	5.7	5.3	-0.4	1.54	0.34	0.2	0.03	2.11	0.2	3.9	2.31	25.2	2.5	1.1	1.75	54.1	5.13	0.07	0.08	0.01	0	0.2	-1.68
BC	72-153	5.5	5.7	0.2	1.00	0.41	0.25	0.04	1.7	0.2	4.0	1.9	33.8	0.8	1.8	12.3	42.5	6.25	0.11	0.13	0.01	0	0.2	-1.01
C1	153-213	5.7	5.7	0	0.46	0.29	0.21	0.02	0.98	0.2	2.7	1.18	23.2	1.1	1.4	8.75	36.2	7.78	0.12	0.15	0.01	0	0.2	0.55
C2	>213	5.8	5.7	-0.1	0.42	0.32	0.23	0.02	0-99	0.2	3.3	1.19	29.2	1.1	1.4	2.63	30.1	6.97	0.13	0.17	0.01	0	0.4	-0.34

Key: Ba1: Ballauda irrigated, Ba2: Ballauda rainfed, Sn1: Sansan irrigated and Sn2: Sansan rainfed.

Table 4.5 continued: Soil Chemical Properties of Tomas Irrigation Scheme

Horizon	Depth (Cm)	pH		ΔpH	EXCH. BASES				TEB	EXCH ACID	CEC	ECEC	CEC Clay	OC	Total N	Avail P	BSP	ESP	SAR	Adj. SAR	EC	CO_3	HCO_3^{-1}	RSC
		H_2o	$CaCl_2$		Ca	Mg	Na	K						g kg^{-1}		mg kg^{-1}	%				dS m^{-1}	cmol(+) kg^{-1}		
					cmol(+) kg^{-1}																			
Map Unit Tomas (To)																								
Pedon To1	Location Fadama Shiddar				Lat. N12.35936						Long. E008.56892					Alt. 419m								
AP	0-30	5.2	5.5	0.3	1.05	0.31	0.24	0.09	1.69	0.4	4.6	2.09	26.7	4.0	1.8	8.75	36.7	5.22	0.1	0.12	0.05	0	0.4	-0.96
AC	30-80	6.0	5.8	-0.2	0.35	0.12	0.23	0.03	0.73	0.4	2.4	1.13	12.8	3.2	1.8	1.75	30.4	9.58	0.17	0.19	0.02	0	0.2	-0.27
C1	80-138	6.6	5.9	-0.7	0.54	0.12	0.23	0.02	0.91	0.2	1.8	1.11	5.4	3.6	1.4	1.75	50.6	12.8	0.14	0.15	0.02	0	0.2	-0.46
C2	138-236	6.4	6.0	-0.4	0.11	0.09	0.23	0.01	0.43	0.2	1.5	0.63	6.56	2.6	2.1	1.75	28.7	15.3	0.26	0.28	0.01	0	0.4	0.21
Pedon To2	Location Tsallewa				Lat. N12.32793						Long. E008.56601					Alt. 432m								
AP	0-20	6.1	5.9	-0.2	0.33	0.34	0.23	0.1	1.0	0.6	4.0	1.6	24.9	4.3	1.8	3.5	25.0	5.75	0.14	0.17	0.02	0	0.2	-0.47
AB	20-55	6.1	5.8	-0.3	0.63	0.40	0.25	0.05	1.34	0.2	5.0	1.54	33.7	0.8	1.4	10.5	26.7	5.00	0.12	0.18	0.01	0	0/2	-0.84
BW	55-140	5.9	5.6	-0.3	0.55	0.39	0.24	0.05	1.23	0.2	3.9	1.43	25.9	0.8	2.1	3.5	31.4	6.15	0.12	0.16	0.01	0	0/2	-0.74
C	140-210	6.0	5.8	-0.2	0.85	0.33	0.24	0.05	1.46	0.4	0.5	1.87	1.15	1.0	1.8	4.38	292	48	0.11	0.18	0.01	0	0.4	-0.77
Map Unit Ladi (La)																								
Pedon La1	Location Kulfare				Lat. N12.31665						Long. E008.53489					Alt. 425m								
AP	0-12	5.6	5.8	0.2	3.46	0.59	0.3	0.13	4.48	0.2	2.5	4.68	1.86	6.4	4.2	47.3	179	12.0	0.07	0.11	0.01	0	0.2	-3.85
AC	12-42	6.1	5.9	-0.2	3.15	0.57	0.25	0.11	4.08	0.4	1.2	4.48	5.31	1.0	2.1	3.5	340	20.8	0.06	0.09	0.01	0	0.4	-3.32
C1	42-185	6.6	5.9	-0.7	3.47	0.69	0.29	0.17	4.61	0.4	1.0	5.01	3.61	1.0	2.5	8.75	461	29.0	0.07	0.11	0.01	0	0.2	-3.95
C2	185-232	6.3	6.0	-0.3	3.14	0.83	0.30	0.10	4.37	0.2	5.0	4.57	29.9	0.6	2.5	1.75	87.3	6.00	0.08	0.10	0.01	0	0.2	-3.78
Pedon La2	Location Zakiran kauye				Lat. N12.39293						Long. E008.60881					Alt. 427m								
AP	0-48	6.1	5.9	-0.2	0.59	0.32	0.29	0.04	1.24	0.4	2.3	1.64	16.14	1.5	1.8	5.27	53.9	12.6	0.15	0.19	0.01	0	0.2	-0.71
AC	48-128	6.0	5.5	-0.5	1.19	0.29	0.27	0.03	1.78	0.2	2.3	1.98	11.09	1.5	2.1	3.5	77.5	11.7	0.11	0.17	0.01	0	0.4	-1.08
C1	128-164	5.9	5.5	-0.4	0.47	0.21	0.29	0.03	0.99	0.4	2.2	1.39	7.59	3.9	1.8	12.3	45.4	13.2	0.18	0.2	0.01	0	0.2	-0.48
C2	164-250	5.9	5.7	-0.2	0.18	0.17	0.26	0.03	0.64	0.4	2.1	1.04	0.94	8.9	1.4	4.38	30.4	12.4	0.22	0.24	0.01	0	0.4	0.05

Key: To1: Tomas irrigated, To2: Tomas rainfed, La1: Ladi irrigated and La2: Ladi rainfed

The carbonate content of all the pedons were almost zero (0.00) and Low values of bicarbonates were observed in all the pedons (Table 4.5). The extractable available micro-nutrients contents of all mapping units were presented in (Table 4.7). All the mean values using 0.1M HCl and DTPA for Cu, Fe, Zn and Mn, indicated higher values above the critical limits set by Lindsday and Norvel (1978), Sims and Johnson (1991) and Chude *et al.* (2004), However, extractable mean values of Zn, using 0.1M HCl in mapping unit To indicates a higher value.

4.2.6 Effect of irrigation on soil chemical properties

A significant difference ($P<0.05$) was observed between these soils on irrigated (Ba1and Sn1) and rainfed (Ba2 and Sn2). Irrigation has been found to significantly ($P< 0.01$) influenced exchangeable calcium in mapping unit La. Pedon La1 was found to contain higher values of exchangeable Ca than pedon La2. A significant difference ($P <0.01$) was noticed between mean values of the irrigated pedon (To1) and rainfed (To2) pedon, where the irrigated recorded a much lower value than the rainfed. Total exchangeable bases (TEB) were also significantly influenced by irrigation ($P<0.01$), where the mean values of rainfed (La2) was found to be lower than irrigated (La1) (Table 4.6),. There was a significant ($P<0.05$) difference between soils on different land use types, on comparing means. Soils on irrigated pedons (Ba1 and Sn1) were significantly higher than the rainfed (Ba2 and Sn2) (Table 4.6). Irrigation influenced mean values of BSP significantly ($P <0.05$) in mapping units La and Sn, where irrigated pedons (La1 and Sn1) recorded higher value than the rainfed pedons (La2 and Sn2).

4.2.7 Effect of irrigation on soil micro nutrients

The results showed a significant difference ($P<0.05$) between pedon Ba1 and pedon Ba2 using 0.1 M Hcl in Fe, Cu and Zn. Using DTPA, a highly significant difference ($P<0.01$) was observed in mapping unit To, between the land uses in Zn mean values (Table 4.8) and a significant difference ($P<0.05$) in mapping units Sn and La also between the irrigated (Sn1 and La1) and rainfed (Sn2 and La2) in Cu and Mn mean values.

4.3 Irrigation water quality

The salinity hazards using EC and TDS of the irrigation water (IW) and drainage water (DW) were rated very low to low (Table 4.9). The pH of the irrigation and drainage waters were rated moderate. Low levels of carbonates and bicarbonates were recorded in all the pedons (Table 4.9). The residual sodium carbonate (RSC) was found to be negative in all the water samples studied. The SAR for the water was low, likewise the Adj. SAR. Moderate levels of Ca were recorded in all the water samples, while values for Mg, Na and K were all rated low in the water samples. No nitrate was detected in the Tomas irrigation water. The ranges for sulphate and chloride were 0.5 to 2.4 mgl^{-1} and 0.09 to 0.95 mgl^{-1} respectively, indicating low levels (Table 4.9).

4.4 Total Elemental Analysis

SiO_2 was found to be the most dorminant element from the result of X-ray fluorescence spectroscopy (XRF) (Table 4.10), while Fe_2O_3 and Na_2O were low. The trend of distribution within each pedon indicates increase of SiO_2 value with increase in depth for mapping unit Ba, and irregular distribution in depth for mapping units To, Sn and La. Na_2O values showed a decrease with soil depth from the surface horizons for pedons To and La. In pedon Ba, there was increase in value with increase in soil depth, indicating some presence of sodicity

at the lower sub surface horizon. For pedon La, the distribution was irregular. Other elements identified but in smaller or minute quantities (%), include MgO, CaO, K_2O, TiO_2, Cr_2O_3 ,MnO_2, SO_3 and SrO.

Table 4. 6:Effect of irrigation on soil chemical properties

Land use	EXCH. BASES				TEB	CEC	ECEC	PBS	SAR	OC	Avail p	Toatal N	EC	EA	PH water	pH Cacl2	ESP
	Ca	Mg	Na	K													
	← cmol(+)kg^{-1} →							%		gkg^{-1}	mg kg^{-1}	g kg^{-1}	dS m^{-1}				%
Mapping unit Ballauda (Ba)																	
Irrigation	1.77	0.52	0.405	0.068	2.758	6.45	3.233	39.76	0.153	5.5	4.158	1.875	0.075	0.48	6.12	4.4	7.33
Rainfed	0.72	0.31	0.232	0.033	1.292	3.15	1.492	42.78	0.115	1.63	1.97	1.775	0.013	0.2	6.1	5.4	7.65
Difference	1.05	0.21	0.173	0.035	1.466	3.3	1.741	3.02	0.038	3.88	2.188	0.1	0.063	0.28	0.1	1.0	0.32
t-value	1.26	0.84	1.49	1.09	1.2	1.77	1.36	0.22	2.34	3.47	1.31	0.26	1.21	2.91	0.41	2.38	0.17
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	*	NS	*	NS
Mapping unit Sansan (Sn)																	
Irrigation	1.212	0.313	0.22	0.045	1.790	6.85	2.265	25.61	0.115	7.1	6.113	1.975	0.025	0.475	5.1	4.8	4.89
Rainfed	0.961	0.355	0.22	0.028	1.564	3.4	1.764	45.74	0.102	1.48	6.476	1.42	0.012	0.2	5.6	5.6	6.58
Difference	0.251	0.042	0.00	0.017	0.226	3.45	0.501	20.13	0.012	5.62	0.364	0.555	0.013	0.275	0.5	0.8	1.69
t-value	0.35	0.6	0.00	1.36	0.29	1.37	0.56	2.95	0.45	2.83	0.12	1.22	1.46	2.20	2.81	2.72	0.96
Significance	NS	NS	NS	NS	NS	NS	NS	*	NS	*	NS	NS	NS	*	*	*	NS
Mapping unit Tomas (To)																	
Irrigation	0.512	0.158	0.233	0.038	0.939	2.575	1.239	36.59	0.168	3.35	3.5	1.775	0.025	0.3	6.05	5.8	10.73
Rainfed	0.59	0.364	0.24	0.063	1.256	3.35	1.606	93.95	0.125	1.73	5.47	1.775	0.012	0.35	6.025	5.8	16.22
Difference	0.079	0.206	0.01	0.025	0.317	0.775	0.367	57.35	0.044	1.625	1.97	0.00	0.013	0.05	0.025	0.0	5.49
t-value	0.35	3.87	1.57	1.14	1.11	0.64	1.15	0.85	1.28	1.79	0.81	0.00	1.39	0.45	0.08	0.2	0.51
Significance	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Mapping unit Ladi (La)																	
Irrigation	3.305	0.668	0.285	0.128	4.385	2.425	4.685	267	0.071	3.6	15.31	2.825	0.01	0.3	6.2	5.9	16.96
Rainfed	0.607	0.248	0.278	0.033	1.165	2.225	1.515	51.81	0.165	3.95	6.35	1.775	0.01	0.35	5.9	5.7	12.48
Difference	2.698	0.420	0.008	0.095	3.221	0.2	3.171	215.19	0.093	0.35	8.96	1.05	0.00	0.05	0.2	0.2	4.48
t-value	11.72	6.06	0.53	6.06	12.12	0.22	13.74	2.57	4.07	0.15	0.82	2.15		0.65	0.81	2.40	0.89
Significance	**	**	NS	**	**	NS	**	*	**	NS	NS	NS		NS	NS	NS	NS

Table 4. 7: Micro nutrient levels in Tomas irrigation soils

HORIZON	DEPTH	IRON		ZINC		MANGANESE		COPPER	
		DTPA	Hcl	DTPA	Hcl	DTPA	Hcl	DTPA	Hcl
		← mg kg^{-1} →							
MAP UNIT Ballauda (Ba)									
Pedon Ba1									
AP	0-10	159.7	470.4	3.14	24.66	32.87	24.66	2.5	4.2
AC	10-35	276.2	600	2.77	37.21	5.15	37.21	2.8	3.5
C1	35-60	58.88	200	3.00	63.78	69.52	63.78	2.1	2.5
C2	60-114	0.98	60.5	1.68	11.84	1.32	11.84	0.31	1.3
Pedon Ba2									
AP	0-26	5.42	0.3	1.44	4.82	2.51	25.18	0.33	0.7
BA	26-63	13.49	10.4	5.2	4.62	17.72	27.18	0.39	0.7
BC	63-143	6.84	2.11	1.6	4.07	12.82	8.36	0.29	0.9
C	143-232	2.65	19.94	9.29	3.6	2.25	3.10	0.36	0.6
MAP UNIT Sansan (Sn)									
Pedon Sn1									
AP	0-18	124.85	220.8	4.39	4.49	8.73	12.25	1.71	1.5
BA	18-53	103.79	120.92	2.58	41.95	8.71	11.33	3.52	4.3
BC	53-153	9.25	19.76	1.51	18.62	0.3	1.01	0.84	1.4
C	153-264	2.88	11.09	1.43	5.43	1.13	0.98	1.35	1.7
Pedon Sn2									
AP	0-23	26.29	9.76	2.64	3.15	16.24	13.17	0.4	0.7
AB	23-72	26.66	140.4	1.47	31.99	17.08	25.91	0.6	3.3
BC	72-153	17.41	34.65	1.58	7.83	14.48	16.64	0.62	1.2
C1	153-213	10.13	16.12	1.13	5.35	3.72	4.53	0.29	0.7
C2	>213	6.95	21.3	1.45	21.29	5.81	7.61	0.37	0.9
MAP UNIT Tomas (To)									
Pedon To1									
AP	0-30	105.89	306	2.71	15.01	7.63	13.22	0.86	1.6
AC	30-80	9.36	87.49	2.46	20.27	3.22	5.18	0.21	1.4
C1	80-138	8.83	51.1	2.52	20.95	2.26	3.68	0.31	0.9
C2	138-236	5.51	25.06	2.63	5.95	0.23	0.55	0.53	1.0
Pedon To2									
AP	0-20	0.66	44.37	1.62	9.33	2.05	3.96	0.25	0.9
AB	20-55	3.58	22	2.19	17.71	11.58	18.9	0.42	0.9
BW	55-140	7.15	40.46	1.51	6.99	16.48	25.57	0.41	1.2
C	140-210	4.98	20.76	1.81	5.08	10.84	23.48	0.47	0.9
MAP UNIT Ladi (La)									
Pedon La1									
AP	0-12	131.13	413.58	2.65	4.99	29.86	9.79	0.88	1.4
AC	12-42	26.53	10.22	1.95	6.18	62.64	17.65	0.79	1.4
C1	42-185	9.8	36.06	1.72	13.29	22.45	39.47	1.04	1.6
C2	185-232	4.69	24.06	3.11	5.91	18.3	22.66	5.25	5.1
Pedon La2									
AP	0-48	37.36	19.26	1.43	6.38	6.81	9.6	0.37	1.0
AC	48-128	6.77	24.49	2.81	3.61	7.97	9.41	0.38	0.7
C1	128-164	1.68	11.33	1.46	5.43	1.43	2.26	0.31	0.9
C2	164-250	5.14	8.31	2.66	7.89	0.34	1.3	0.32	0.9

Key: Ba1: Ballauda irrigated, Ba2: Ballauda rainfed, Sn1: Sansan irrigated, Sn2: Sansan rainfed, To1: Tomas irrigated, To2: Tomas rainfed, La1: Ladi irrigated and La2: Ladi rainfed.

Table 4. 8:Effect of irrigation on extractable (Hcl) and (DTPA) soil micro nutrients

Mapping unit Ballauda (Ba)

Land use	Cu Hcl	Fe Hcl	Mn Hcl	Zn Hcl
	←	mg kg^{-1}	→	
Irrigation	2.875	332.73	14.188	34.374
Rainfed	0.725	8.187	15.955	4.2775
Difference	2.15	324.54	1.768	30..095
t-value	3.39	2.6663	0.14	2.71
Significance	**	*	NS	*

Mapping unit Ballauda (Ba)

Land use	Cu DTPA	Fe DTPA	Mn DTPA	Zn DTPA
	←	mg kg^{-1}	→	
Irrigation	1.928	123.94	27.215	2.647
Rainfed	0.343	7.1	8.825	4.382
Difference	1.585	116.84	18.39	1.735
t-value	2.84	1.93	1.13	0.92
Significance	*	NS	NS	NS

Mapping unit Sansan (Sn)

Land use	Cu Hcl	Fe Hcl	Mn Hcl	Zn Hcl
	←	mg kg^{-1}	→	
Irrigation	2.225	93.143	6.393	17.623
Rainfed	1.36	44.446	13.572	13.922
Difference	0.865	48.697	7.18	3.701
t-value	1.02	0.89	1.47	0.36
Significance	NS	NS	NS	NS

Mapping unit Sansan (Sn)

Land use	Cu DTPA	Fe DTPA	Mn DTPA	Zn DTPA
	←	mg kg^{-1}	→	
Irrigation	1.844	60.193	4.718	2.478
Rainfed	0.456	17.488	11.466	1.654
Difference	1.399	42.705	6.749	0.824
t-value	2.38	1.34	1.86	1.12
Significance	*	NS	NS	NS

Table 4.8: Continued: Effect of irrigation on extractable (Hcl) and (DTPA) soil micro nutrients

Mapping unit Tomas (To)

Land use	Cu Hcl	Fe Hcl	Mn Hcl	Zn Hcl
	←		mg kg^{-1}	→
Irrigation	1.225	117.41	5.658	15.54
Rainfed	0.975	31.898	17.978	9.778
Difference	0.25	85.515	12.32	5.76
t-value	1.38	1.33	2.21	1.29
Significance	NS	NS	NS	NS

Mapping unit Tomas (To)

Land use	Cu DTPA	Fe DTPA	Mn DTPA	Zn DTPA
	←		mg kg^{-1}	→
Irrigation	0.478	32.398	3.335	2.58
Rainfed	0.388	4.093	10.238	1.783
Difference	0.09	28.305	6.903	0.798
t-value	0.59	1.15	2.04	5.0
Significance	NS	NS	NS	**

Mapping unit Ladi (La)

Land use	Cu Hcl	Fe Hcl	Mn Hcl	Zn Hcl
	←		mg kg^{-1}	→
Irrigation	2.375	120.98	22.393	7.593
Rainfed	0.875	15.848	5.643	5.828
Difference	1.5	105.13	16.75	1.765
t-value	1.65	1.08	2.51	0.83
Significance	NS	NS	NS	NS

Mapping unit Ladi (La)

Land use	Cu DTPA	Fe DTPA	Mn DTPA	Zn DTPA
	←		mg kg^{-1}	→
Irrigation	1.99	43.038	33.213	2.358
Rainfed	0.345	12.738	4.138	2.09
Difference	1.645	30.3	29.075	0.268
t-value	1.51	0.98	2.84	0.54
Significance	NS	NS	*	NS

Table 4. 9:Irrigation water quality indicators in Tomas irrigation scheme

MAPPING UNITS	PH	EC	Cl^{-1}	Co_3^{-2}	RSC	Hco_3^{-1}	SO_4^{-2}	BORON	TDS	K	Na	Ca	Mg	NO_3^{-1}	SAR	Adj. SAR
		dS m^{-1}	←					mg l^{-1}	→							
Ba(IW)	5.8	0.09	2.6	0.4	-6.39	2	420.000	1.9	420.000	0.02	0.08	6.23	2.56	0	0.038	0.093
Ba(DW)	6.90	0.5	2.7	0.35	-5.68	3.5	0.7	1.9	200.000	0.02	0.08	7.12	2.41	0	0.037	0.037
TO(IW)	7.2	0.09	1.7	0.25	-7.96	1.8	0.7	1.9	50.000	0.05	0.02	5.81	4.2	0	0.09	0.246
TO(DW)	7.2	0.85	2	0.37	-7.04	1	2.4	2	30.000	0.01	0.01	4.65	3.76	0	0.05	0.123
La(IW)	6.5	0.1	1.8	0.2	-7.03	1.2	0.5	1.9	50.00	0.07	0.02	5.43	2.8	0	0.09	0.221
La(DW)	6.6	0.95	1.7	0.23	-2.59	0.7	0.6	1.8	30.000	0.05	0.02	2.65	1.87	0	0.013	0.023

Key: Ba (IW) and Ba (DW) : Ballauda (IW) irrigation water and(DW) drainage water

To (IW) and To (DW): Tomas (IW) irrigation water and (DW) drainage water

La (IW) and La (DW): Ladi (IW) irrigation water and (DW) drainage water.

Table 4. 10:Percentage elemental composition in oxide form of soils in Tomas irrigation scheme

HORIZON	DEPTH	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	Cl	K_2O	CaO	TiO_2	Cr_2O_3	Mn_2O_3	Fe_2O_3	ZnO	SrO
MAP UNIT								Ballauda (Ba)								
Pedon Ba1																
AP	0-10	0	0.52	14.77	77.77	0	0.54	0.05	0.99	0.37	1.15	0.07	0.06	3.77	0	0.01
AC	10-35	0	0.47	15.1	77.56	0	0.58	0.03	1.27	0.16	1.41	0.01	0.02	3.38	0	0.01
C1	35-60	0.07	0.26	7.93	87.29	0	0.67	0.05	1.18	0.11	1.35	0	0.01	1.07	0	0.01
C2	60-114	0.08	0.08	3.0`9	93.21	0	0.71	0.07	1.25	0.07	1.15	0	0.01	0.28	0	0.01
MAP UNIT								Sansan (Sa)								
Pedon Sn1																
AP	0-18	0	0.47	13.36	82.4	0	0.57	0.03	0.49	0.12	0.87	0.01	0.03	1.65	0	0.01
BA	18-53	0	0.49	13.9	82.22	0	0.45	0.03	0.52	0.27	0.84	0.01	0.01	1.24	0	0.01
BC	53-153	0.08	0.32	5.34	91.94	0	0.76	0.05	0.42	0.07	0.69	0	0.01	0.33	0	0.01
C	153-264	0	0.33	8.46	88.00	0	0.62	0.06	0.64	0.08	1.28	0.01	0.01	0.52	0	0.01
MAP UNIT								Tomas (To)								
Pedon To1																
AP	0-30	0.15	0.33	9.49	85.63	0	0.7	0.06	1.04	0.12	1.15	0	0.02	1.3	0	0.01
AC	30-80	0	0.13	4.67	91	0	0.68	0.06	1.36	0.08	1.13	0	0.01	0.85	0	0.01
C1	80-138	0	0.15	5.21	89.11	0	0.69	0.06	1.72	0.09	1.7	0.01	0.02	1.25	0	0.01
C2	138-236	0	0.14	3.48	91.54	0	0.74	0.09	1.14	0.07	2.06	0	0.02	0.71	0	0.01
MAP UNIT								Ladi (La)								
Pedon La1																
AP	0-12	0.11	0.4	9.07	85.23	0	0.64	0.05	1.27	0.31	1.06	0	0.04	1.82	0	0.01
AC	12-42	0	0.48	14.05	79.33	0	0.52	0.03	1.24	0.25	1.13	0	0.07	2.9	0	0.01
C1	42-185	0	0.51	14.5	78.42	0	0.56	0.03	1.24	0.23	1.27	0.01	0.05	3.18	0	0.01
C2	185-232	0	0.53	14.26	79.55	0	0.51	0.03	1.25	0.22	1.14	0.01	0.03	2.48	0	0.01

4.5 Clay Mineralogy

The results of X-ray Diffractogram of samples (XRD) (Table 4.11 and figures 4.6 to 4.9) showed that, mapping unit La (figure 4.9) was dominated by feldspars plagioclase (feldspar), hornblende (amphibole) and sanidine (k-feldspar). Muscovite (mica) and other minerals found but in smaller amount include hematite and chlorite. Mapping unit Sn (Figure 4.7) showed the predominance of feldspars over other minerals; plagioclase, sanidine, orthoclase and hornblende. This is followed by chlorite.The other mineral found but in smaller amount is hematite. The horizons in mapping unit Ba (Figure 4.6), indicate a dorminance of kaolinite and plagioclase. Other minerals found in smaller amounts include hornblende and muscovite. Soil mapping unit To (Figure 4.8) shows that, kaolinite, chlorite and hornblende are the major minerals in this unit. Other minerals found include sanidine and plagioclase.

4.6 Soil Classification

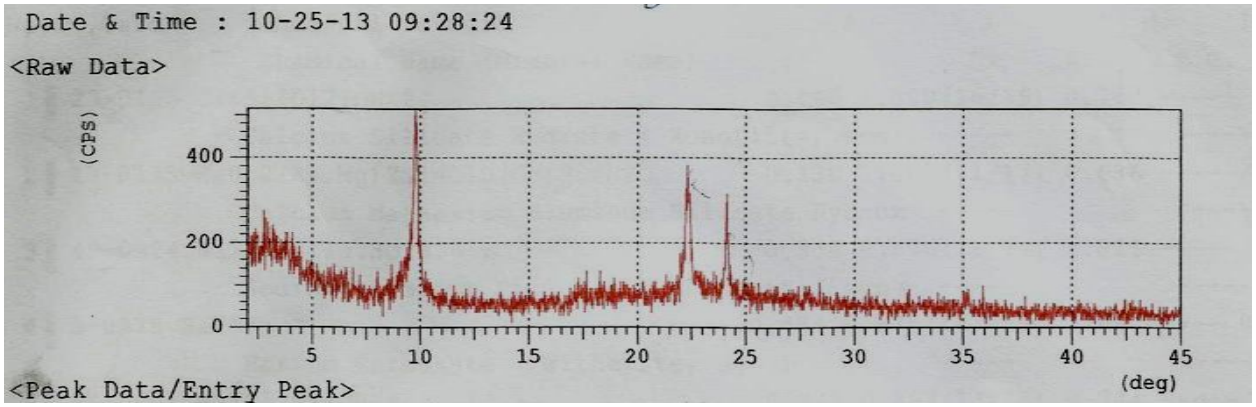
The soil classification in (Table 4.12) was based on the USDA Soil Taxonomy (2010) and World Reference Base for Soil Resource (FAO/UNESCO, 2006). The criteria used for classification was Soil moisture regime, Soil temperature regime, Diagnostic surface horizon (epipedon) and Diagnostic subsurface horizon (endopedon).

4.7 Land Capability Classification

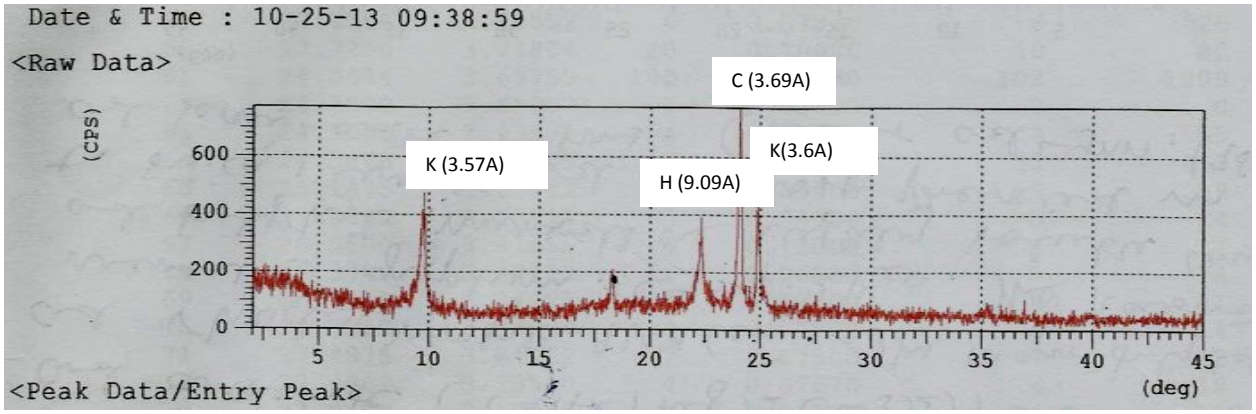
The main soil characteristics considered as limitations were, soil depth, soil texture, drainage condition, slope, CEC, salinity and alkalinity (Table 4.13). They were used for classification.

Table 4. 11:Mineralogical characteristics of Tomas irrigation scheme soils.

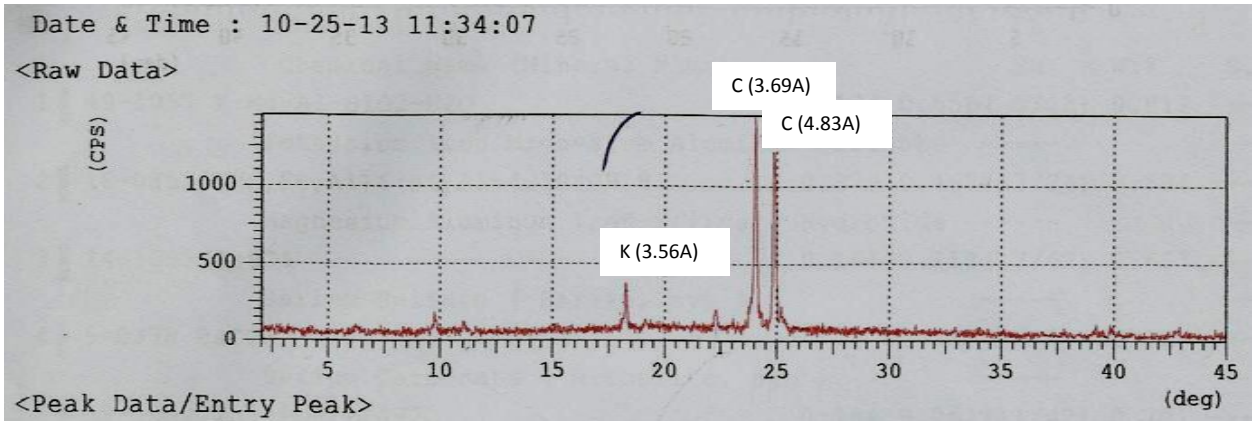
Map unit	HORIZON	PEAK	D(Å)	INTENSITY	MINERAL
La	0-42	9.6983	9.11246	100	Muscovite
		3.99150	3.9915	52	Plagioclase
		9.83968	9.8396	15	Muscovite
	42-185	22.3102	3.9815	100	Plagioclase
		9.7586	9.0562	92	Hornblende
		24.0845	3.6921	46	Hématite
	185-232	24.0291	3.7005	100	Sanidine
		18.2497	4.8572	41	Chlorite
		9.7327	9.0803	36	Hornblende
Sn	0-53	22.2820	3.9865	100	Plagioclase
		9.7416	9.0720	90	Hornblende
		22.5200	3.9449	62	Plagioclase
	53-153	24.1221	3.6864	100	Chlorite
		23.900	3.7202	38	Hématite
		22.4000	3.9658	33	Orthoclase
	153-264	23.9768	3.7084	100	Sanidine
		24.7611	3.5927	45	Chlorite
		9.6800	9.1296	19	Hornblende
Ba	0-35	9.7715	9.0044	100	Muscovite
		22.307	3.9821	65	Plagioclase
		24.104	3.6891	42	Hématite
	35-60	24.0484	3.6975	100	Chlorite
		24.8868	3.5748	57	Kaolinite
		9.7205	9.0917	52	Hornblende
	60-114	24.088	3.6915	100	Chlorite
		24.925	3.5693	87	Kaolinite
		18.334	4.8349	19	Chlorite
To	0-80	24.087	3.6917	100	Chlorite
		24.916	3.5707	52	Kaolinite
		18.3018	4.8435	19	Chlorite
	80-138	23.8732	3.7243	100	Sanidine
		24.6893	3.6030	51	Kaolinite
		9.6324	9.1746	30	Hornblende
	138-236	9.8028	9.0155	100	Hornblende
		22.3490	3.9747	83	Oligoclase
		9.3800	9.4209	19	hornblende.



Ba (0 – 35cm) M= Muscovite, P = Plagioclase, Ha = Hematite

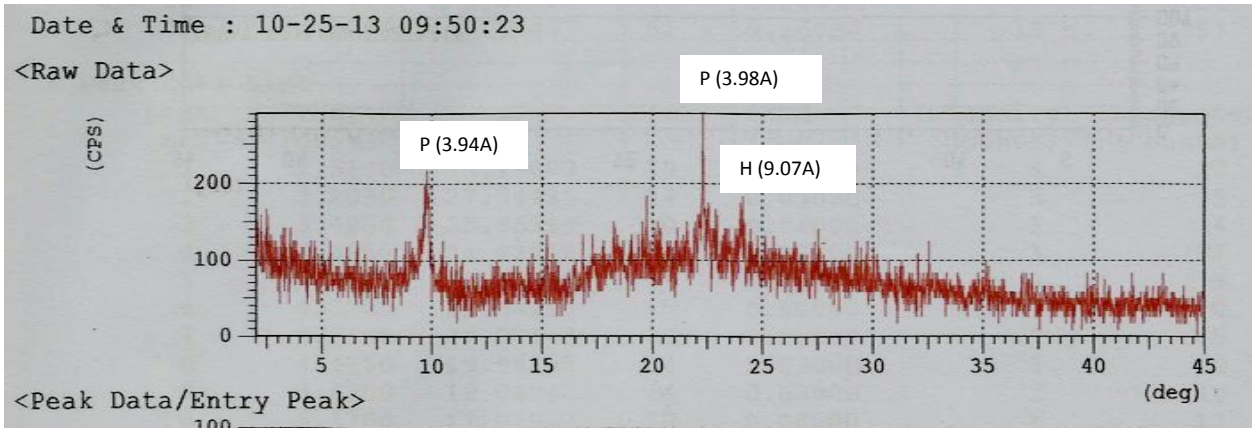


Ba (35– 60cm)C = Chlorite, K = Kaolinite, H = Hornblende

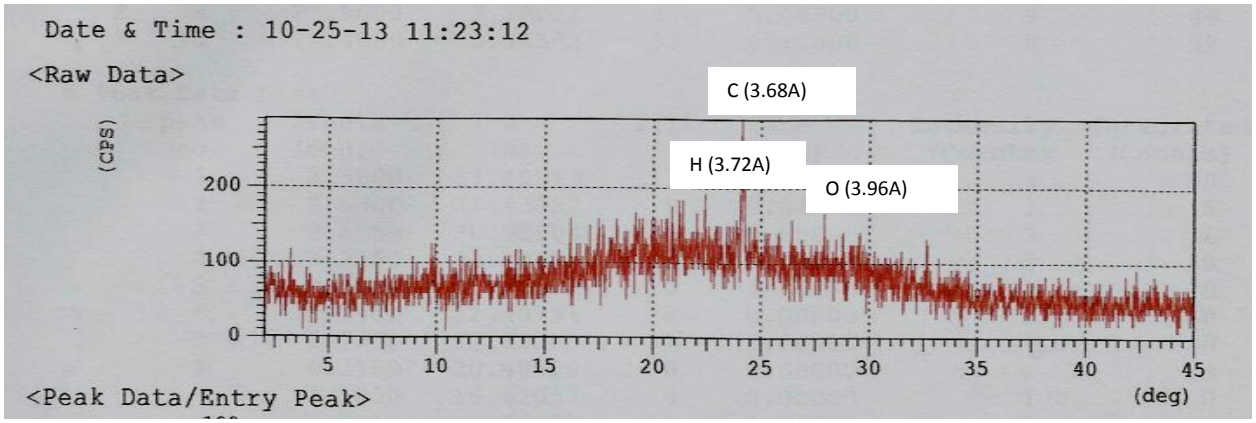


Ba (60 – 114cm) C = Chlorite, K = Kaolinite

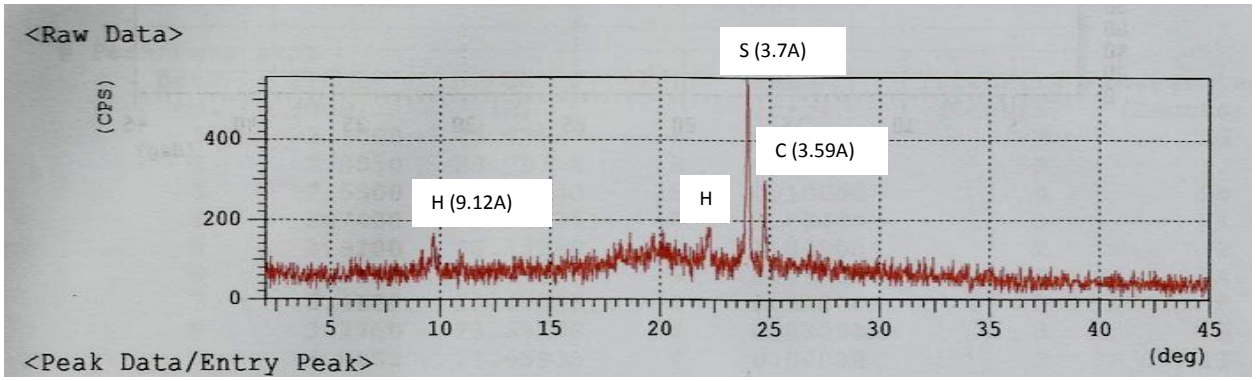
Figure 4. 6:X-ray Diffractogram peaks of Ballauda series (Ba)



Sn (0 – 53cm) P = Plagioclase, H = Hornblende

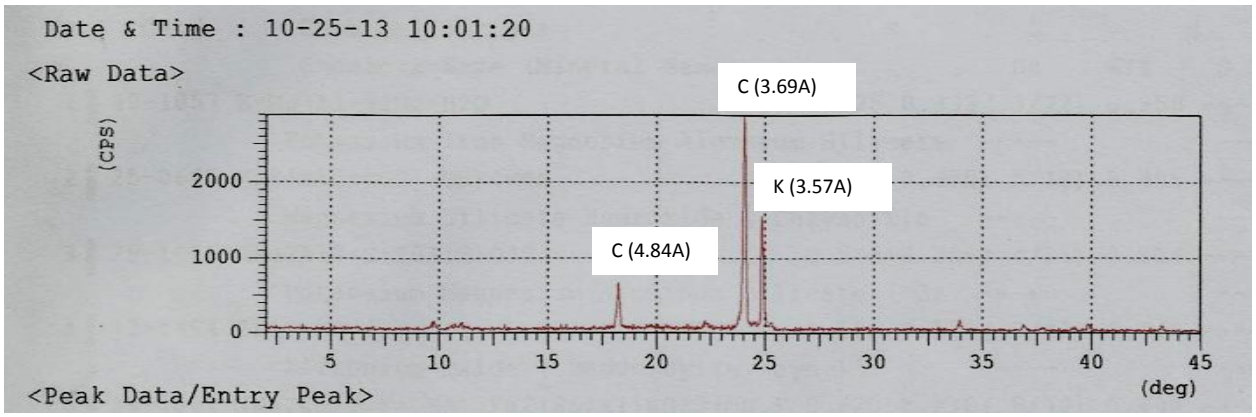


Sn (53 – 153cm) C = Chlorite, H = Hematite, O = Orthoclase

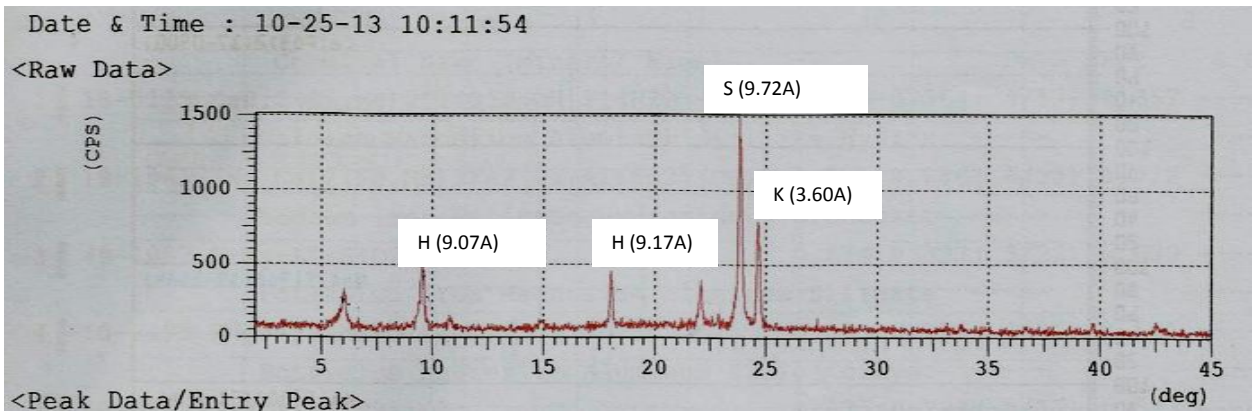


Sn (153 – 264cm) S = Sanidine, C = Chlorite, H = Hornblende

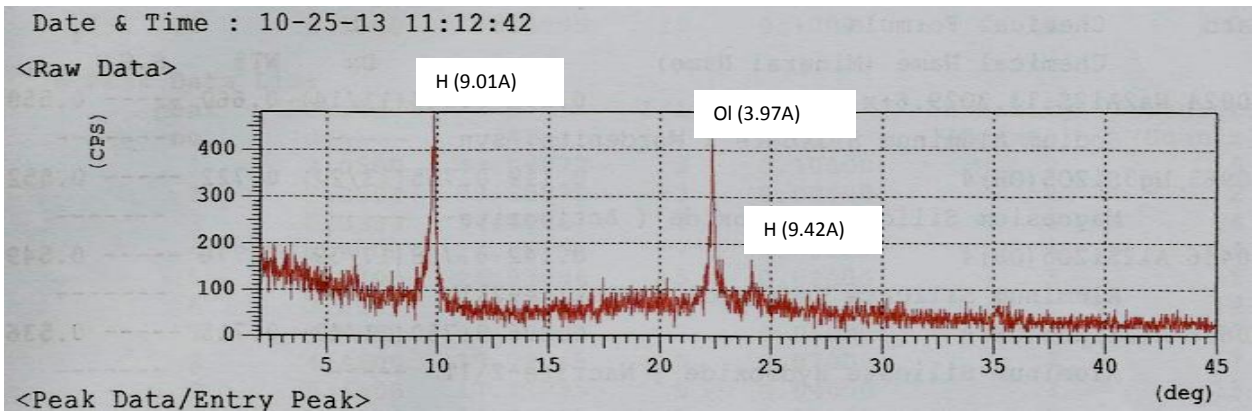
Figure 4. 7:X-ray Diffractogram peaks of Sansan series (Sn)



To (0 – 80cm) C = Chlorite, K = Kaolinite

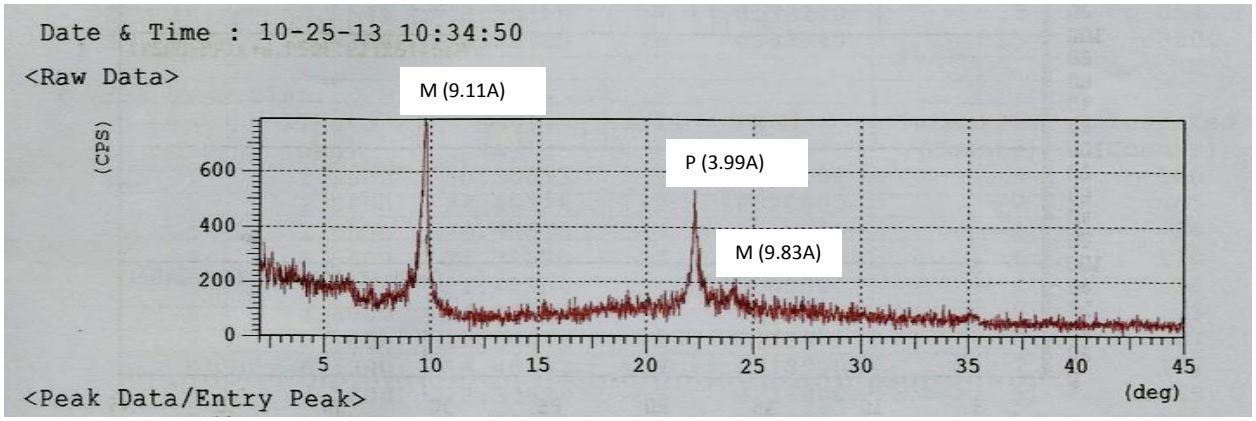


To (80 – 138cm) S = Sanidine, K = Kaolinite, H = Hornblende,

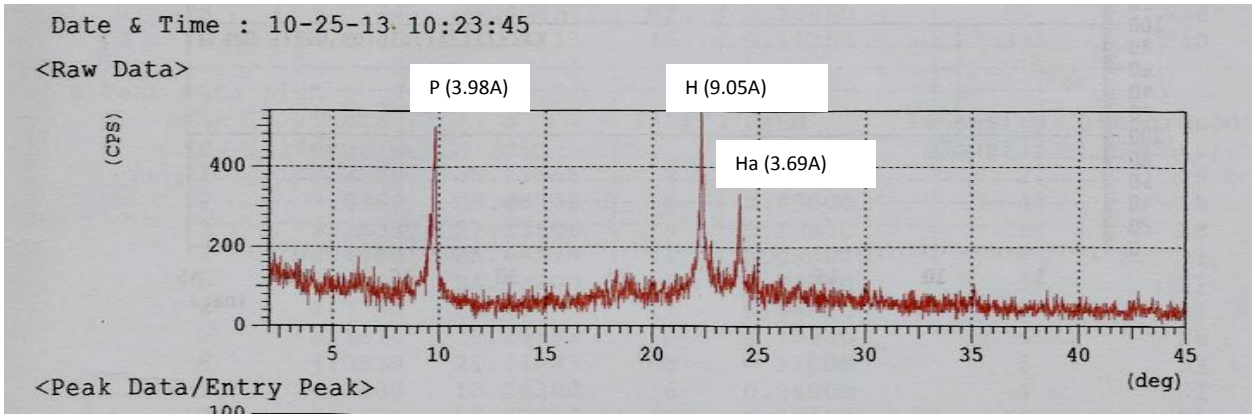


To (138 – 236cm) H = Hornblende, Ol = Oligoclase

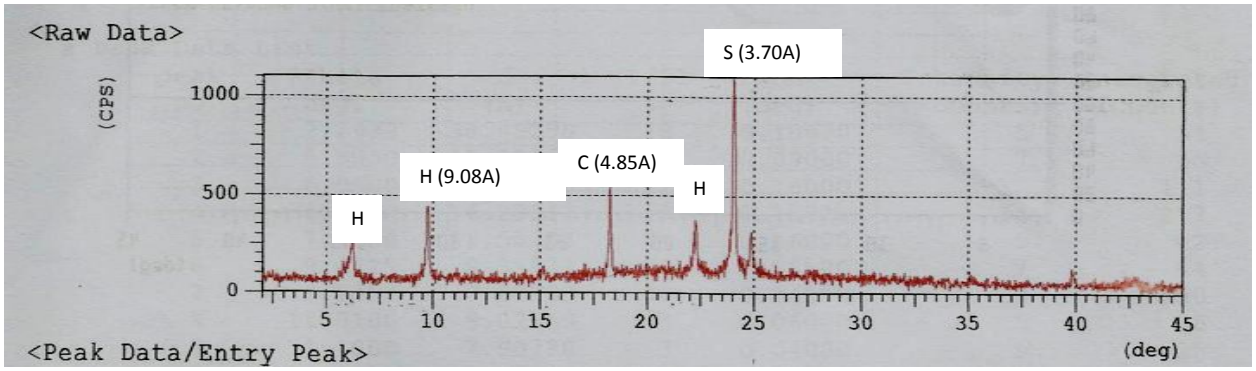
Figure 4. 8:X-ray Diffractogram peaks of Tomas series (To)



La (0 – 42cm) M= Muscovite, P = Plagioclase



La (42 – 185cm) P = Plagioclase, H = Hornblende, Ha = Hematite



La (185 – 232cm) S = Sanidine, C = Chlorite, H = Hornblende

Figure 4. 9:X-ray Diffractogram peaks of Ladi series (La)

Table 4. 12:Soil classification of Tomas Irrigation

MAP UNIT	USDA SOIL TAXONOMY	WRB(FAO UNESCO)
Ba	Arenic Haplustepts, to Aquic Ustifluvents, coarse-loamy, mixed, isohyperthermic	Haplic Arenosols to Gleyic fluvisols.
Sn	Typic Haplustepts, coarse-loamy, mixed, isohyperthermic	Haplic Arenosols
To	Typic Haplustepts to Typic Ustifluvents coarse-loamy, mixed, isohyperthermic	Haplic Arenosols to Haplic fluvisol
La	Typic Ustifluvent coarse-loamy, mixed, isohyperthermic	Haplic fluvisols

Table 4. 13:Legend for land capability classification.

Soil characteristics	Class I	Class II	Class III
	Good	Moderate	Marginal
Soil depth (cm)	>120	50-120	<50
Drainage	Well drained	Moderately imperfectly drained	Poorly drained
Slope (%)	0-2	2-4	>4
Texture	Loam	Sandy loam to silty clay loam	Loamy sand to clay, clay loam
EC ($dS\ m^{-1}$)	<4	4-8	8-16
CEC ($cmolkg^{-1}$)	>30	15-30	<15
ESP (%)	<15	15-20	>20

Source: Ali Mahmoud *e al.*, 2009 ; Raji, 2004; FAO, 1985

4.7.1 Current capability

All the soil mapping units of Tomas irrigation scheme (Ballauda, Sansan, Ladi and Tomas series) were classified as marginal (IIIfs), with major limitations of inherent low soil fertility (Low CEC, OC, total N and available P) and coarse texture in addition to climatic limitation.(Table 4.14)

4.7.2 Potential capability.

Majority of these limitations (IIIfs), would be corrected with little management or conservation measures. Climatic limitation and low inherent soil fertility were all found to be correctable limitations. ESP, EC, Salinity and alkalinity were found to pose no threat in the irrigation scheme.

4.8 Extent of land utilization

From the result of this study (Table 4.15), marginally capable land subjected to intensive cultivation (irrigation), accounted for 1,538.4ha (13.25%), and also marginal lands subjected to moderately intensive use (rainfed), accounted for 8,587.51ha (73.95%). The remaining 1, 487.3ha (12.81%), are areas of marginal capability class been subjected to low intensive use (others).

Table 4. 14:Current land capability classification

Map unit	Pedon	Soil depth	Drainage	Texture	Slope	EC	CEC	ESP	Class	Sub class
To	To1	I	I	III	I	I	III	I	III	III_{fs}
	To2	I	II	II	I	I	III	I	III	III_{fs}
La	La1	I	I	III	I	I	III	I	III	III_{fs}
	La2	I	I	III	I	I	III	I	III	III_{fs}
Ba	Ba1	I	II	II	I	I	III	I	III	III_{fs}
	Ba2	I	I	II	I	I	III	I	III	III_{fs}
Sn	Sn1	I	I	II	I	I	III	I	III	III_{fs}
	Sn2	I	1	III	I	I	III	I	III	III_{fs}

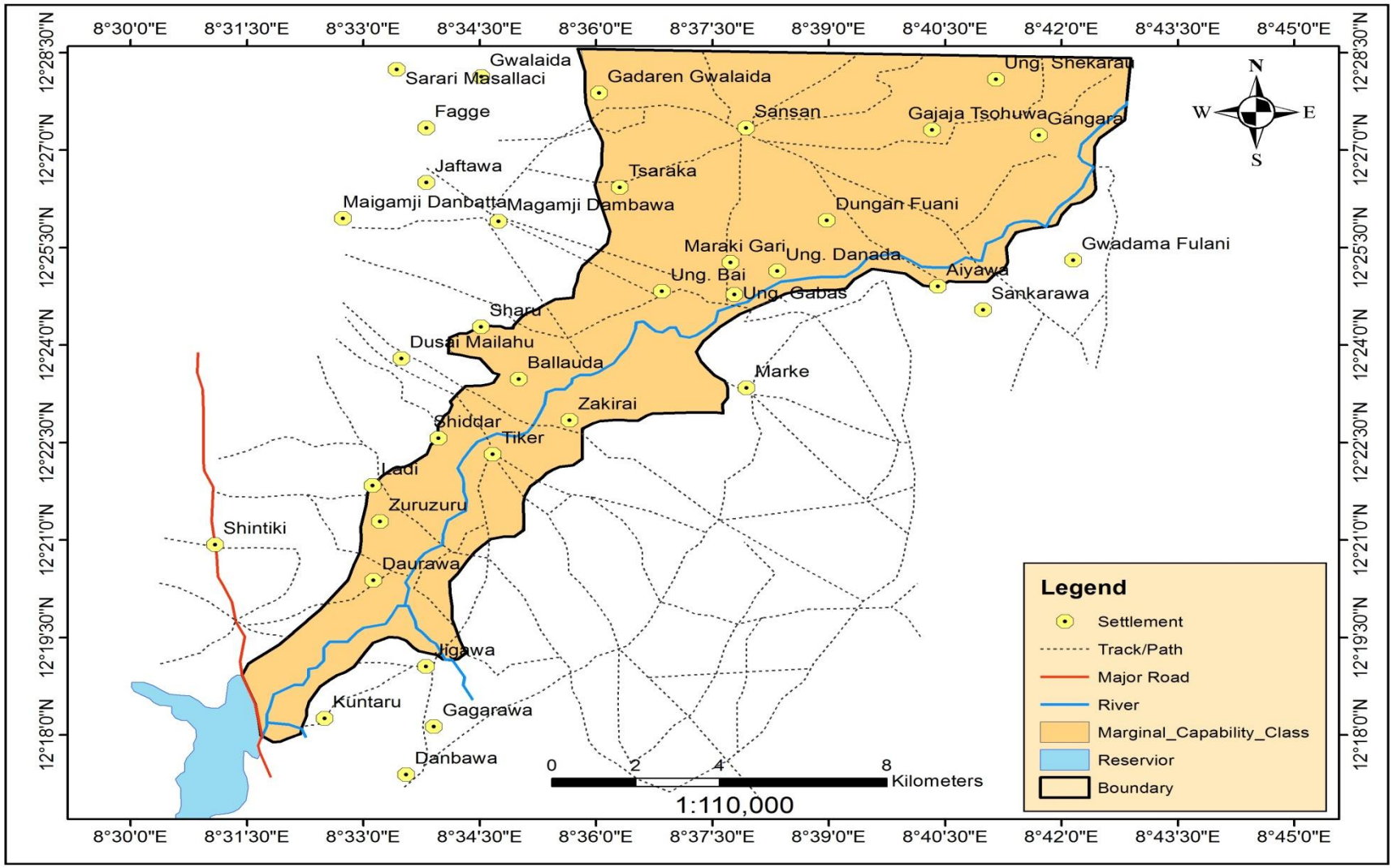


Figure 4. 10:Soil capability map of Tomas irrigation scheme

Table 4. 15:Actual vs potential land use (in ha)

Capability class	high intensity	moderate intensity	low intensity
marginal	1,538.4ha	8,587.38ha	1,487.3ha

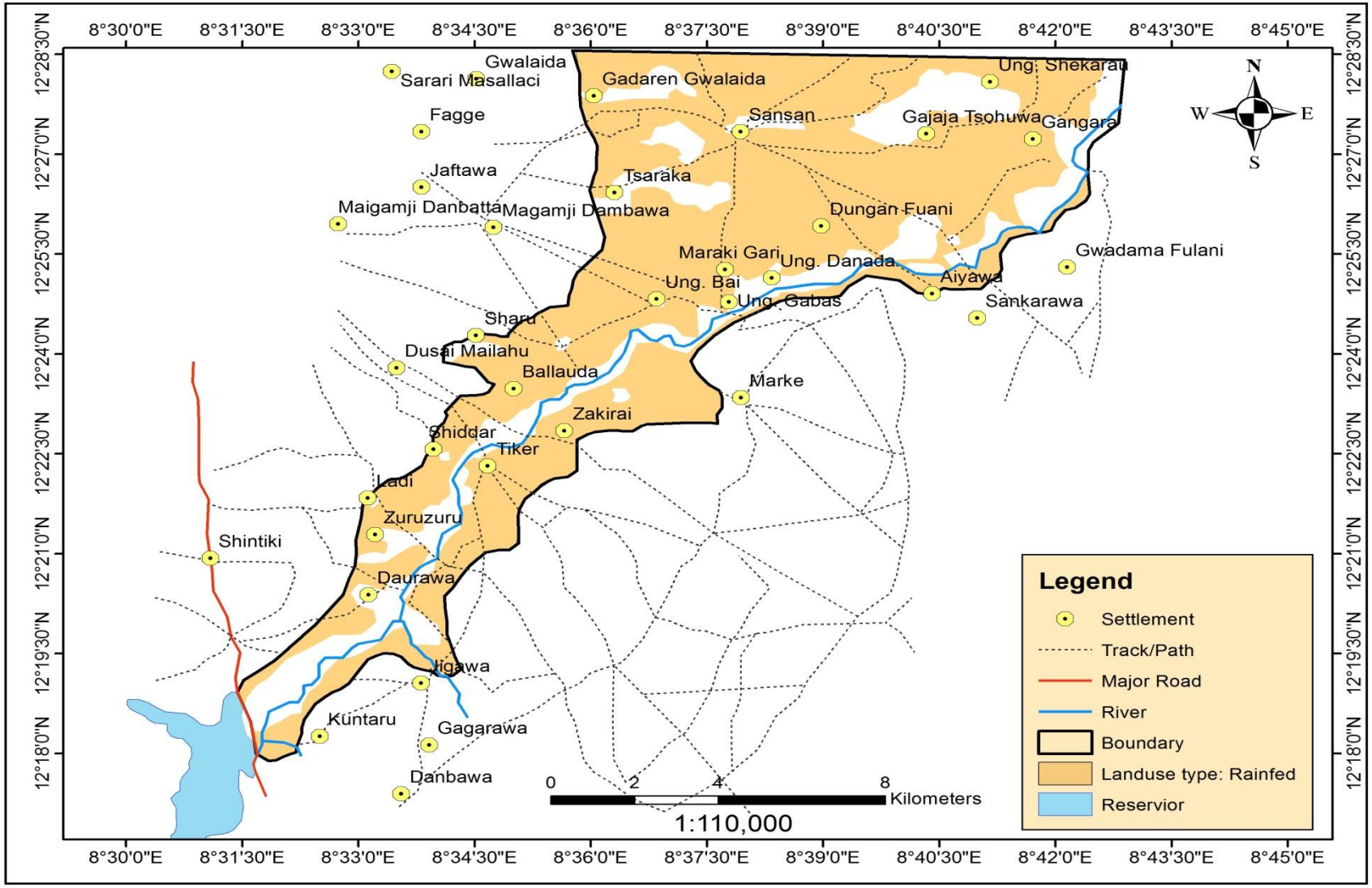


Figure 4. 11:Map of Tomas irrigation scheme showing extent of rainfed land use type on marginal capability class

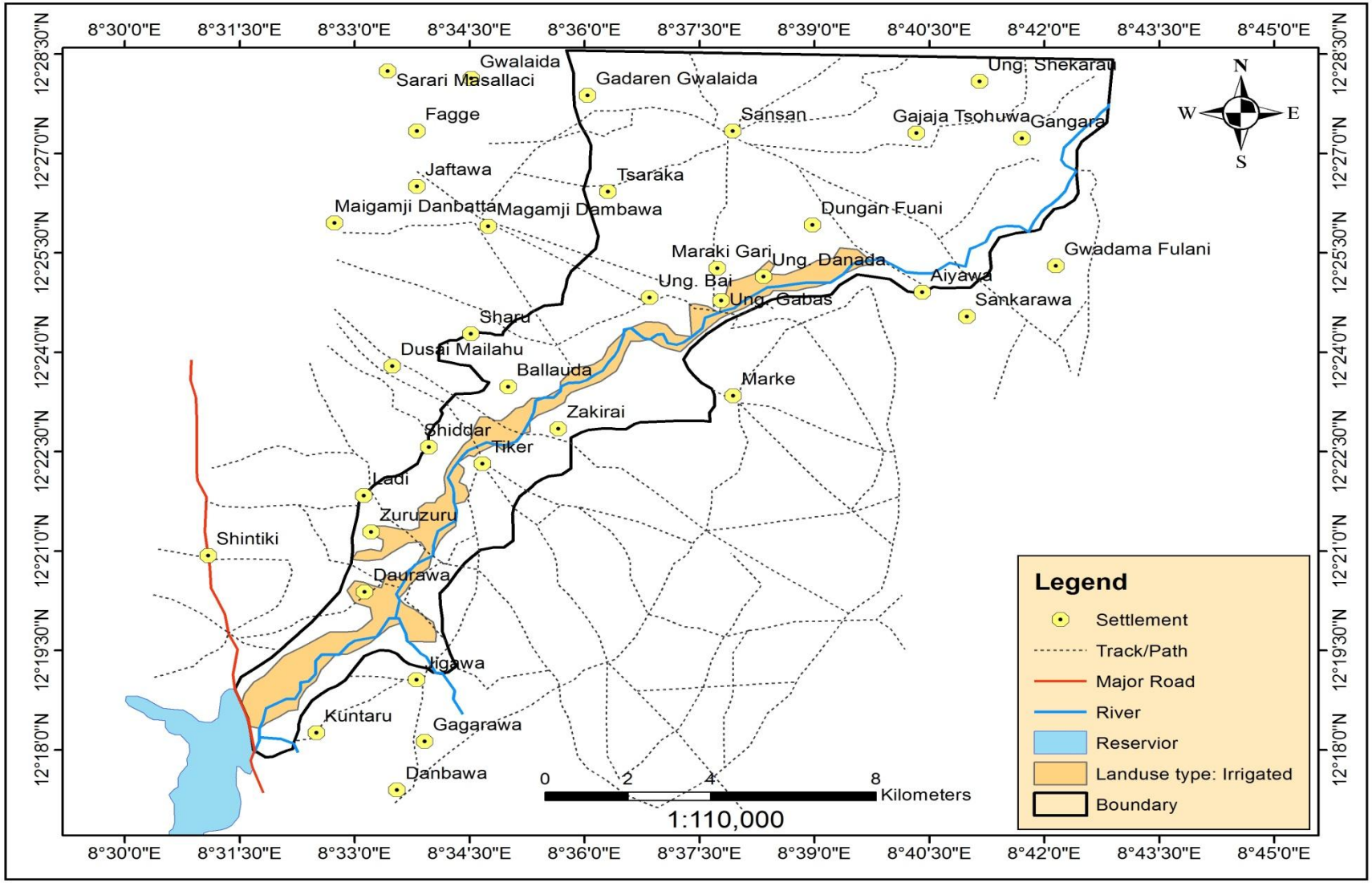


Figure 4. 12:Map of Tomas irrigation scheme showing extent of irrigated land use type on marginal capability class

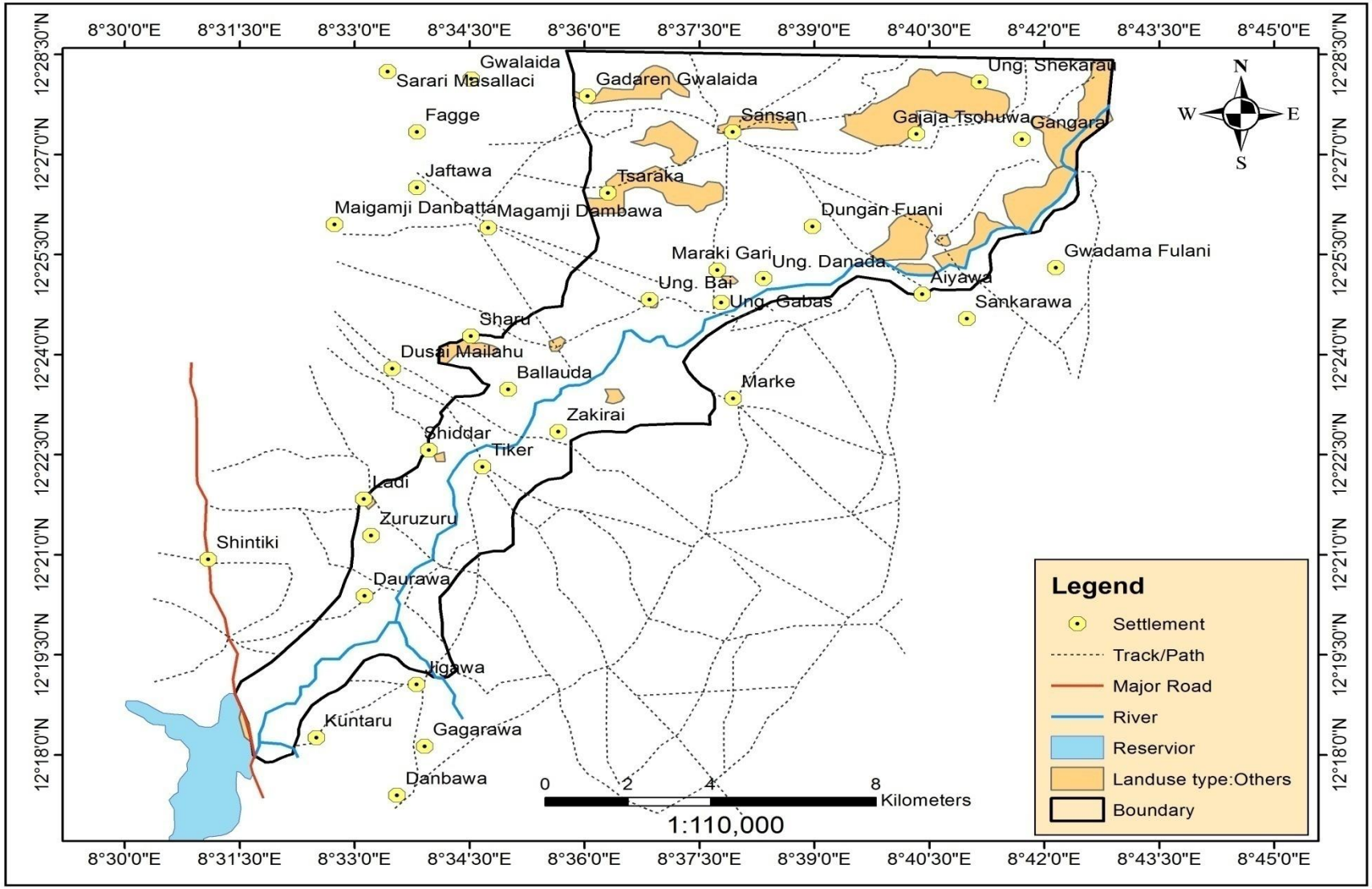


Figure 4. 13:Map of Tomas irrigation scheme showing extent of "others" land use type on marginal capability class

4.9 Soil Suitability classification

Six chosen land qualities with their associated characteristics were considered in this study (Table 4.16).

4.9.1 Soil suitability class S3 (actual)

Soils of Ballauda (Ba), Sansan (Sn), Ladi (La) and Tomas (To) mapping units all belong to this suitability class. They have major limitations in terms of soil fertility (f) which was inherently low and soil texture (s) which ranged from sandy loam to loamy sand. This rated all the mapping units in to S3 ‘ marginally’ suitable for irrigated rice production with the same limitations to give the suitability subclass (S3fs) (Tables 4.17 and 4.18).

4.9.2 Soil suitability class S2 (potential)

The results in (Table 4.18) show the suitability classification, actual (fig.4.14) and potential (fig.4.15) for irrigated rice in Tomas irrigation scheme after the limitations were eliminated from the evaluation procedure. Table 4.19 present the suitability classification using the parametric system.

Table 4. 16:Land use requirement for suitability classification for irrigated rice

Land qualities/ characteristics	Unit	S1	S2	S3	N1	N2
Climate (c)						
Solar radiation	Sunshine hrs/day	> 478	478-358	358-239	239-120	Any
Mean annual temperature	^{o}C	22-25	20-22	18-20	16-18	< 16
Relative humidity	%	70-75	65-70	60-65	<60	
Soil physical properties (s)						
Texture (clay)	%	LC	SCL	SL	S	S
Drainage (d)						
Wetness		WD-MD	PD	VPD	ED	__
Workability (w)						
Soil depth	(cm)	65-70	50-65	35-50	30-35	< 30
Slope	%	0 -2	2-4	4-6	6-10	> 10
Surface stoniness		None	None to slightly gravel	Slightly stony	Stony	___
Erosion (e)		None	None to slight	Eroded	Well eroded	___
PH		5.5-7.5	5.2-5.5	<5.2	>7.5	Any
Fertility status (f)						
Total N	gkg^{-1}	>2.0	1.5-2.0	1.0-1.5	0.5-1.0	<0.5
CEC ($Cmol/kg^{-1}$)	($Cmol/kg^{-1}$)	12.0-16.0	8.0-12.0	5.0-8.0	<5.0	
Organic C	gkg^{-1}	>2.0	2.0-1.5	1.2-1.5	1.0-1.2	<1.0
Available P	$Mgkg^{-1}$	15-20	8-15	5-8	3-5	< 3
Exchangeable K	($Cmol/kg^{-1}$)	0.3-0.5	0.2-0.3	0.1-0.2	< 0.1	__
Micro nutrient						
Fe	$Mgkg^{-1}$	3.5-4.5	2.5-3.5	1.5-2.5	1.0-1.5	< 1.0
Zn	$Mgkg^{-1}$	1.5-2.0	1.0-1.5	0.8-1.0	0.6-0.8	< 0.6
Mn	$Mgkg^{-1}$	1.0-1.5	0.8-1.0	0.6-0.8	0.5-0.6	< 0.5

SOURCES: Udoh *et al*., (2011), Sys *et al*., (1991, 1993), De Datta (1989) and FAO (1953)

KEYS: LC = loamy clay, SCL = Sandy clay loam, SL = sandy loam, S = sand, MD = moderately drained, WD=well drained, PD = poorly drained, VPD = very poorly drained, ED = excessively drained

Table 4. 17:Land suitability classification and ratings for the different soil mpping units

Mapping unit	Representative soil pedons	Climate (c) a) Solar radiation b) mean temperature c) Relative humidity	Soil physical properties (s) Texture	Drainage wetness	Workability a). slope b). soil depth c) stoniness	Erosion	PH	Fertility status (f) macro-nutrients. a). Total (N) b). CEC c). Organic C d). Available P	Fertility status (f) micro-nutrients. a). Fe b). Mn c). Zn d). Cu	Class	Sub-class
Ba	Ba_1, Ba_2	S_1	S_3	S_2	S_1	S_1	S_1	S_3	S_1	S_3	S_3 fs
Sn	Sn_1, Sn_2	S_1	S_3	S_1	S_1	S_1	S_1	S_3	S_1	S_3	S_3 fs
To	To_1, To_2	S_1	S_3	S_1	S_1	S_1	S_1	S_3	S_1	S_3	S_3 fs
La	La_1, La_2	S_1	S_3	S_2	S_1	S_1	S_1	S_3	S_1	S_3	S_3 fs

Key: Ba1: Ballauda irrigated, Ba2: Ballauda rainfed, Sn1: Sansan irrigated, Sn2: Sansan rainfed, To1: Tomas irrigated, To2: Tomas rainfed, La1: Ladi irrigated, La2: Ladi rainfed. S1: Highly suitable class, S2 : moderately suitable class, S3 : marginally suitable class and S3fs= Marginally suitable with fertility and texture as limitations.

Table 4. 18:Actual and potential suitability ratings of soil mapping units

Soil and Climatic characteristics	Ballauda (Ba)	Sansan (Sn)	Tomas (To)	Ladi (La)
Climate (C)				
Mean annual temperature (^{o}C)	S1	S1	S1	S1
Solar radiation	S1	S1	S1	S1
Relative humidity	S1	S1	S1	S1
Soil physical properties(S)				
Texture	S3	S3	S3	S3
Drainage (d)				
Wetness	S2	S1	S1	S2
Workability(W)				
Slope(%)	S1	S1	S1	S1
Soil depth(cm)	S1	S1	S1	S1
Stoniness	S1	S1	S1	S1
Erosional hazards(e)	S1	S1	S1	S1
Fertility status(F)				
Macro-nutrients, CEC And PH.	S3	S3	S3	S3
Micro-nutrients (Fe,Mn,Zn and Cu)	S1	S1	S1	S1
Aggregate Suitability(Actual)	**S3**	**S3**	**S3**	**S3**
Aggregate Suitability(potential)	**S2**	**S2**	**S2**	**S2**

Key: S1: Highly suitable class, S2: moderately suitable class, S3: marginally suitable class

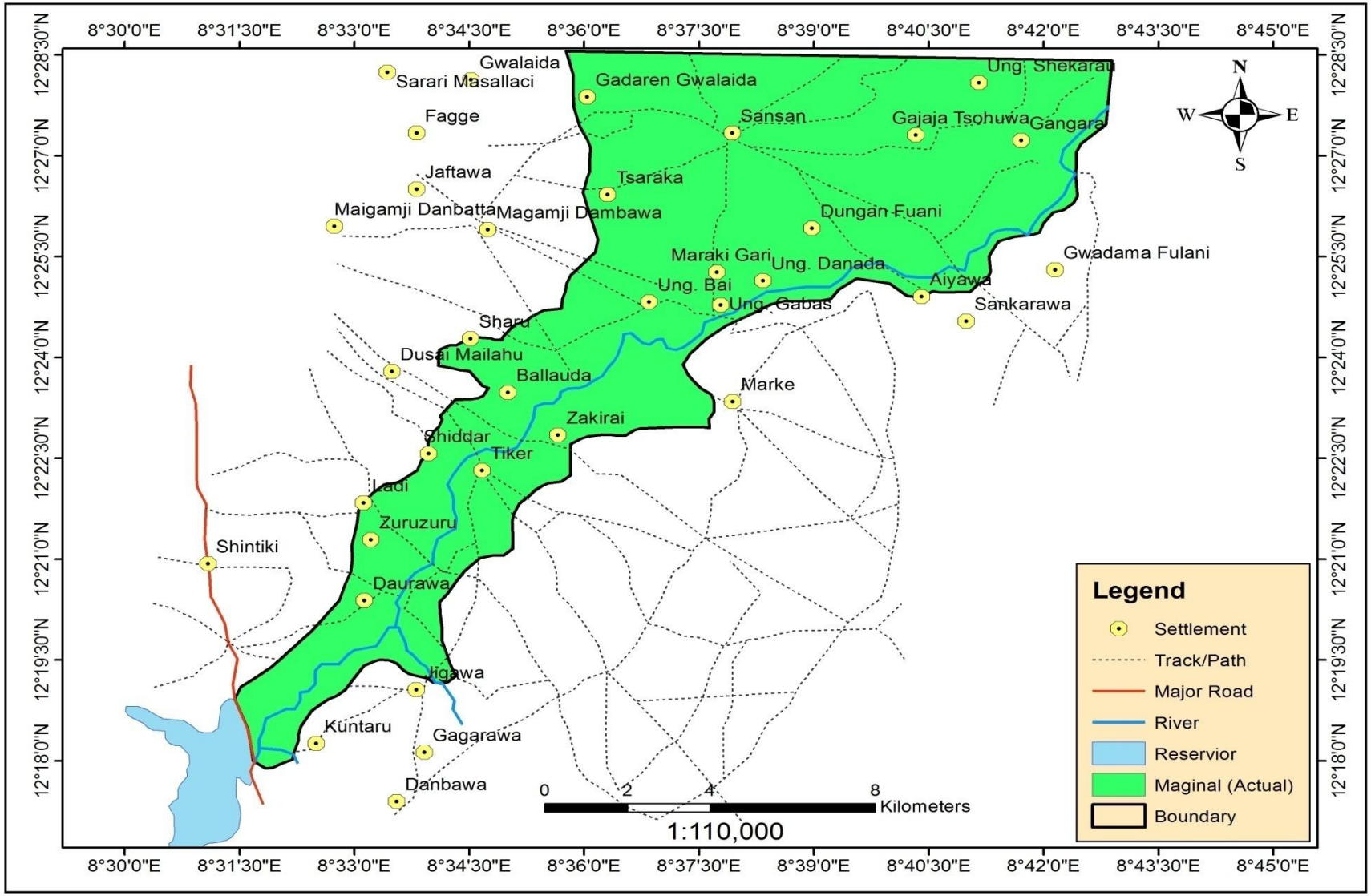


Figure 4. 14:Soil suitability map of Tomas irrigation scheme

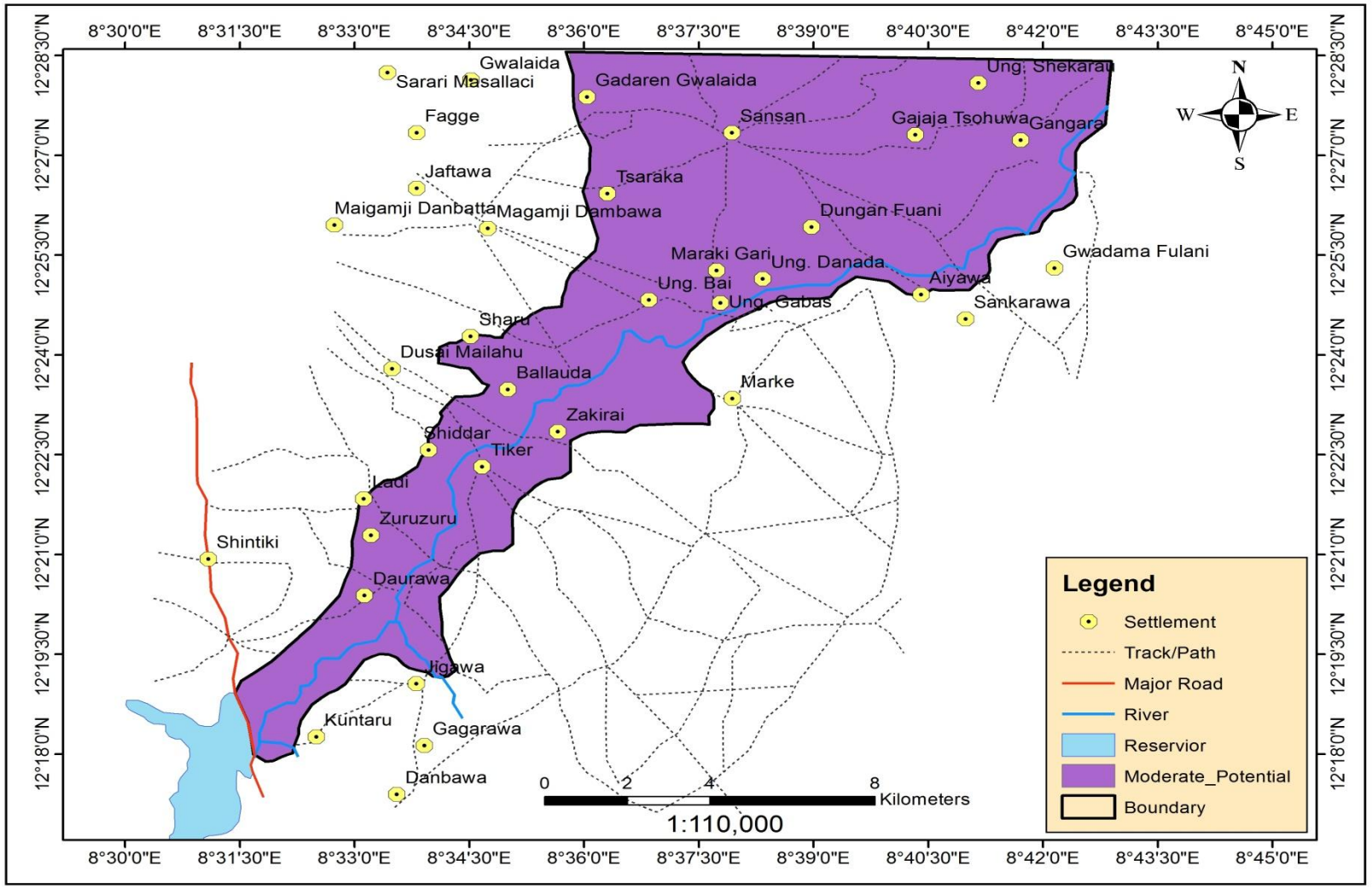


Figure 4. 15:Soil suitability map of Tomas irrigation scheme

Table 4. 19:Land suitability class scores and ratings of the soil pedons according to severity of limitations

Land quality/characteristics	Ba1	Ba2	Sn1	Sn2	To1	To2	La1	La2
Climate (C)								
Solar radiation	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Mean annual temp.	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Relative humidity	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Soil physical properties(S)								
soil texture	45(S3)	45(S3)	45(S3)	45(S3)	45(S3)	45(S3)	45(S3)	45(S3)
Drainage								
Wetness	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Workability (W)								
Slope	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Soil depth	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Surface stoniness	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Erosion (e)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Fertility status (F)								
Ph	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Base Saturation Percentage	45(S3)	45(S3)	25(S3)	45(S3)	35(S3)	90(S1)	100(S1)	50(S2)
Micro-nutrients								
Total N	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)
CEC	45(S3)	20(N1)	45(S3)	20(N1)	20(N1)	20(N1)	20(N1)	20(N1)
Organic C	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)	12.5(N2)
Available P	20(N1)	12.5(N2)	45(S3)	45(S3)	20(N1)	45(S3)	70(S2)	45(S3)
K	20(N1)	20(N1)	20(N1)	20(N1)	20(N1)	20(N1)	45(S3)	20(N1)
Micro-nutrients								
Fe	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Mn	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Zn	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)	100(S1)
Actual suitability	5.63(N2)	5.63(N2)	5.63(N2)	5.63(N2)	5.63(N2)	5.63(N2)	5.63(N2)	5.63(N2)
Potential suitability	20.25(N1)	9.0(N2)	11.25(N2)	9.0(N2)	9.0(N2)	9.0(N2)	9.0(N2)	9.0(N2)

Key: ratings S1= (100-75) ,S2= (74-50),S3=(49-12.5), N1= (24-12.5) and N2=(12.5-0)

4.10 Socio-economic Evaluation for Irrigation Rice Production in Tomas Irrigation Scheme

Table (4.20) shows Gender, Age, marital status and educational qualification of rice farmers interviewed using questionnaire in Tomas irrigation scheme. Majority of the farmers were male, married, literate and over 50 years of age. Table (4.21) shows the various sizes of land occupied by farmers for irrigated rice production, with majority of them cultivating less than 2ha.

4.10.1 Rice varieties

Three common varieties of rice FARO 44, FARO52 and FARO 57 were recommended by USAID MAARKET in the area. The varieties and their sources were presented in (Table 4.22).

4.10.2 Farmer participation in co-operatives/associations

Six different farmer associations exist in Tomas irrigation scheme. Majority of the rice farmers in the area (96%), belong to one association or another with 40% of them belonging to Babbar ruga rice farmers association, while about 4% of them were none members in any of the associations (Table 4.23)

4.10.3 Land tenure, land use and fertility status

Majority of the rice farmers in the area got their land through rent. About 21% of the rice farmers owned their lands, which may be through inheritance or direct purchase. The remaining 4% of the farmers were cultivating their land for irrigated rice production on a lease hold title (Table 4.24). Majority of the farmers in the area (71%) reported a decrease in the fertility status of their soil which was reflected in their realized yield after

harvest and none of the farmers reported an increase in fertility in his rice farm. The results revealed majority of the farmers were using inorganic fertilizer (Table 4.25).

Table 4. 20:Socio- economic characteristics of irrigated rice farmers in Tomas irrigation scheme.

Variables	Frequency	Percentage
Gender		
Male	108	96.43
Female	4	3.57
Age (years)		
25-30	10	8.93
30-49	22	19.64
50-70	73	65.18
>70	7	6.25
Marital status		
Single	5	4.46
Married	95	84.82
Divorced/widow	12	10.71
Educational qualification		
Quaranic educ.	25	22.32
Primary	30	26.79
Secondary	27	24.11
Tertiary	30	26.79

Table 4. 21:Farm size used for irrigated rice

Size (Ha)	Frequency	Percentage (%)
4	20	17.85
2	60	53.57
3	28	25
18	4	3.57

Table 4. 22:Rice varieties cultivated in the area and their sources

Local	Improved	Both	%	Source
16	-	Nil	14.28	Fellow farmer
-	20 FARO44	Nil	17.85	Bakker Bros.
-	32 FARO44	Nil	28.57	USAID MKT
-	24 FARO44	Nil	21.43	WACOT
-	16FARO44	Nil	14.28	Seed company
-	4FARO44	Nil	3.57	KNARDA

Table 4. 23:Farmer participation in cooperatives/association

Name of Association	frequency	Percentage (%)
Dambatta B rice producers association	40	35.7
k/kudu multipurpose	4	3.57
Babbar Riga rice producers	44	39.29
Kurna young farmers	12	10.71
Shiddar Dorayi farmers	8	7.14
No association/cooperative	4	3.57

Table 4. 24:Land tenure

Acquisition	Respondents(frequency)	Percentage %
Leased	4	3.57
Rented	84	75
Owned	24	21.43

Table 4. 25:Fertility status

Fertility status	**Frequency**	**Percentage (%)**
Increasing	Nil	00
Decreasing	80	71.43
Stable	32	28.57
Improving fertility	**Frequency**	**Percentage (%)**
Inorganic fertilizer	52	46.43
Green manure	20	17.85
Others	8	7.14

4.10.4 Source of water for irrigation

About 64% of the rice farmers use water for irrigating their rice farm from the dam, while 35% of the rice farmers, whose farms were located at a distance from the dam to device the use of tube wells as their source of water for irrigating their rice field (Table 4.26).

4.10.5 Rice marketing channels

Three rice marketing channels were identified (Table 4.27). They include; individuals, local markets aand UMZA processing mill. The largest percentage (57%) of the rice produced in the scheme goes to UMZA.

4.10.6 Problems of irrigated rice production in Tomas area

About 53% of the farmers complained about high cost of labor and 46% responded by saying unreliable and inadequate water supply was their major problem in addition to poor access to inorganic fertilizer and borrowed capital/ credits (Table 4.28).

4.10.7 Profitability of irrigated rice production

The data in (Table 4.29) shows the Input costs and revenue for irrigated rice production obtained from farmers and USAID MARKETS.

Table 4. 26:Source of water for irrigation

Source	Respondents	Percentage (%)
Dam	72	64.29
Tube wells	40	35.7
Bore holes	Nil	Nil

Table 4. 27:Rice marketing channels

Form of sale	Respondents	(%)
Unprocessed to local markets	44	39.29
Processed to individuals	4	3.57
Unprocessed to Umza	64	57.14

Table 4. 28:Problems of irrigated rice production in Tomas area

Problem	Poor access to borrowed capital	Poor access to inorganic fertilizer	Inadequate water supply	High cost of labor
Frequency	112	112	52	60
Percentage (%)	100	100	46.42	53.57

Table 4. 29:Profitability of irrigated rice production

Items	**cost (N/Ha)**
Labor	
Nursery establishment	5,000
Land preparation	5,000
Planting	2,000
Weeding (1^{st} and 2^{nd})	4,500
Fertilizer application	2,000
Pesticide application	2,000
Harvesting/threshing/winnowing	7,500
Materials	**cost (N/Ha)**
Seeds	10,000
Fertilizer (6 bagsx5, 500)	33,000
Water charges	5000
Bags/bagging/transportation	7,200
Total cost	83,200
Total revenue (60bagsx5000)	300,000
Net farm income	216,800
Rate of return on investment (RRI)	3.60

CHAPTER FIVE

5.0 DISCUSSION

5.1 Current Land Use and Land Cover

Land use and cover types identified were based on differences of spectral characteristics of the landscape for separation into land use and land cover classes.

5.1.1 Irrigated land use type

These areas were mostly around the river banks and tributaries within the scheme. The low percentage of irrigation activity in the area was due to lack of irrigation channels for water conveyance from the dam to farmer's fields, and/ or poor maintenance of existing ones. This may have necessitated farmers to use tube wells in their farms for irrigation activity. Crops grown for irrigation purposes include; maize, rice and water melon. About 70% of irrigated fields were cultivated for vegetables which include; tomatoes, onion, pepper and water melon.

5.1.2 Rainfed land use type

This was identified as the most dorminant land use type in the area, accounting for about 70 percent of total area. Sorghum-millet-cowpea and maize-millet-cowpea were the major crop rotation types in the area. Maize and water melon were also cultivated under rainfed on monocropping basis, likewise rice with supplementary irrigation.

5.1.3 "Others" land use and land cover types

The third land use and land cover type was classified as "others" and includes water body, forests, plantations, settlements, bare soil, sugar cane and mango plantations located along river banks.

5.2 Description of Soil Mapping Units

5.2.1 Morphological properties

Brown colour obtained for the surface horizons may be due to oxidation of iron II to iron III in sand sized fractions (Hassan, 2010). Strong brown to yellowish red (7.5 YR 4/6 moist) colours observed in the subsurface horizons indicate the presence of oxidized iron in well drained uplands especially in the tropics (Brady and Weil, 2005). The dark grayish brown colour of subsurface horizon especially in pedon Ba1 was an indication of anaerobic condition showing gleization (Raji, 1995; Hassan, 2010). Generally, braunification process in these mapping units was a clear indication that, soils of these mapping units might be the least weathered (Raji, 1995). The single grained or weakly structure of soils of the mapping units indicates dorminance of sand fraction in all mapping units, and confirms the poor or less pedogenic development leading to little or no horizonation (Yaro, 2005). Horizonation in all mapping units was not quite pronounced, and this may be due to the sandy nature of parent material which favours addition than removal, translocation and transformation as pedogenic processes (Dregne, 1976; Steila, 1987; Raji, 1995; Malgwi, 2001). The non sticky and non plastic consistency of the soils indicates the predorminance of sand fraction and low clay content of the soils. Where consistency was slightly sticky and slightly plastic as in the surface horizons of pedon Ba1, it may be due to imperfectly drained condition of this pedon. All the soils were friable to very friable when moist, which made them suitable for cultivation at a wide range of moisture content (Malgwi, 2001). The clear nature of the boundary was due to melanization by organic matter in the surface horizons, while gradual boundary was attributed to sedimentation pattern within the pedons, reflecting

lithologic discontinuity of the parent material. The wavy appearance was attributed to cultivated ridges (Maniyunda, 2012). Vertical cracks indicates faunal pedoturbation and root activity of higher plants, while fine quartz grains confirmed the sandy nature of parent material and low level of weathering. Better moisture condition in pedon Ba1 than Ba2 may be due to irrigation, which resulted in moderate horizonation that favours increase in colour, texture and structural development compared to Ba2.

5.2.2 Soil physical properties

The gravel contents of the soils were negligible, which suggests the aeolian and or fine colluvial origin of the parent material (Esu, 1982). The dorminance of sand particle in both surface and subsurface horizons in all mapping units is in agreement with the other works carried out on basement complex in Nigeria (Malgwi, 2001; Fasina *et al*., 2007; Voncir *et al*., 2008; Obi and Akinbola, 2009; Ande, 2010; Maniyunda,2012). Sand fraction was found to be higher in the surface horizon (AP), indicating aeolian source of parent material of the upper horizon and possible occurrence of soil erosion which carried away the finer fractions in the surface horizon.

The decrease in sand content with depth in mapping unit Ba and To, may be attributed to the degree of weathering of parent rock (Maniyunda, 2012). In mapping unit Sn, there was an increase in sand content with an increase in depth which supports the colluvial or saprolitic origin of the lower sub soil. The clay fraction content increased from AP horizons to B horizons. The increase in clay content with soil depth in Ba and La was attributed to depletion of clay in the surface, and illuviation into subsurface horizons (Maniyunda, 2012), while in mapping unit Sn, clay values remained constant with depth. Higher bulk density values were observed in the surface horizons, but where lower values

were found generally below 1.3 Mg m-3, this indicates a porous soil condition (FAO, 2006). Bulk density values varied between pedons Ba1, La1 and Ba2, La2. The variation may have been due to the nature and type of land use practiced on the pedons. In this case, pedons Ba1, La1 being in an irrigated area subjected to intensive cultivation may lead to high compaction and poor structural development. Donahue *et al*. (1990) set a limit of 1.4 Mg m^{-3} and 1.6 Mg m^{-3}, for clay and sandy soils to be the best for plant performance. However, Veighmiyer and Hendricson (1948) observed a range of 1.7and 1.8 Mg m^{-3}, and 1.45 and 1.65 Mg m^{-3} for sandy and clayey soils respectively to inhibit root growth.

The low to moderate total porosity values were indicative of low to moderate adequate pore spaces. These levels of soil porosity would be adequate for the movement of water and plant nutrients in the soil. The lower total porosity values observed in the surface horizons were mainly due to mechanical or animal traction which leads to soil compaction especially in intensively cultivated areas like in pedon To1. It may also be associated with crust formation in cultivated soils of savannah environments as reported by (Kowal and Knabe, 1972; Jones and Wild, 1975; Adeoye, 1985; Brady and Weil, 2005), in savannah soils of Nigeria. The available water capacity indicates that, almost all the soils have low capacity to retain enough moisture for plant growth, with the exception of some horizons in mapping unit Ba1, which was within the range of 9.5 to 12.5%, considered adequate for plant growth by FAO, (1979).

5.2.3 Effect of irrigation on soil physical properties

There was a significant difference in mean values of sand content (Table 6), between irrigated and rainfed land use ($P< 0.05$) in mapping unit Ba and Prb ($P< 0.01$) in mapping unit La. Higher mean values of sand in the rainfed pedon Ba2 and La2 were due to continuous deposition of harmattan dust and aeolian material, while in pedon Ba1and La1 there was an increase of organic matter content as a result of increase in soil microbial activity due to irrigation. The mean values of clay content shows that, there was a significant difference ($P<0.05$) in mapping unit La, between the irrigated (La1) and rainfed (La2). This confirms the influence of particle size distribution and the higher amount of clay in irrigated pedon (La1). The land use indicated a highly significant difference ($P<0.01$) in silt content in mapping unit Ba and La. This implied that, land use influenced silt content of soils on irrigated Ba1, La1 than rainfed Ba2, and La2 pedons. The silt content of irrigated pedons was higher than that of rainfed. This was due to location of pedons Ba1 and Sn1 in a low lying area and deposition of fine colluvial and alluvial sediments from Tomas River. There was a significant difference in moisture content at field capacity and permanent wilting point ($P<0.05$) between the irrigated and rainfed land use in mapping unit Ba. A highly significant difference (Prb <0.01) was also observed in mapping unit La between water retention at FC and PWP in irrigated (La1) and rainfed (La2) land use. This was attributed to initial moisture in the irrigated pedons, distributive pattern of soil particles between the pedon and pore spaces between soil particles, leading to improved moisture content at FC and PWP. However, there was no significant difference between mapping units To and Sn, between pedons To1,Sn1 and

To2, Sn2, indicating that, coarse texture of the soil fraction in both pedons were the same statistically, there by retaining almost the same moisture content at this level.

5.2.4 Soil infiltration

The low infiltration rates of pedons To1, La1 and Sn1, may be related to soil compaction and surface crusting due to intensive cultivation (irrigation), which are responsible for changing the pore size towards successively smaller pores (Hassan, 1998). The resultant effect is a net decrease in infiltration rate and capacity. The low infiltration rates in pedons To1, La1 and Sn1, may also be related to the presence of clay layer which may impede flow because of its low hydraulic conductivity (Hassan, 1998). Since these pedons (To1, La1 and Sn1) were sited on irrigated fields, they show low infiltration rates because water moves slowly into the soil when moisture conditions are high (Ghosh and Maity, 1976; Babaji, 1982; Babalola, 1986). Soils in pedon Ba1, Ba2, Sn2, To2 and La2 had high infiltration rates as opposed to To1, Sn1 and La1, because they were initially dry.

5.2.5 Soil chemical properties

The soil pH (water) of all mapping units ranged from 5.4 to 6.6, indicating strongly acidic to near neutral soil reaction. These values are within the limits of (pH 5.5 to 6.5) set for optimum crop production in the tropics (Esu, 2010). There was a little variation in pedons Ba1 and Ba2 in this mapping unit. In pedon Ba1 and Sn1 lower values were observed in the surface horizon. This might be associated with accumulation of reduction products and dissociation of strongly acid functional groups in organic matter derived from plant residues and animal excreta (Esu, 1982). In the surface of pedon Ba2 and Sn2 higher pH values were obtained. This was attributed to the accumulation of exchangeable Ca and

Mg derived from biogenetic cycling of bases, and also addition of basic cations to the surface soil layer as loess during harmattan (Esu, 1982; Malgwi, 2001) . In irrigated pedons (Ba1 and Sn1), there was an increase in soil pH with increase in soil depth, reflecting basic nature of the parent material and irrigation water used, while in pedon (Ba2); which was non irrigated, there was a decrease in soil pH with an increase in soil depth. This can be attributed to aeolian dust deposits and less intensive leaching of bases to the lower horizons (Raji, 1995). The pH measured in $CaCl_2$ solution was lower than pH in water in all the mapping units, giving a negative delta pH values. The pH in $CaCl_2$ suspension, gives a closer approximation to the pH of the soil solution (Schofield and Taylor, 1955). Difference between the values of pH measured in water and calcium chloride was generally small; majority less than 1 pH unit implying a small amount of surface available for cation adsorption sites. This could be due to low organic matter and nature of clay/ low clay content of soils in Tomas irrigation scheme.

The low to moderate value of OC in all the mapping units indicates low to moderate buffering capacity of the soils, poor nutrient retention and availability status of the soils, hence their low inherent fertility status. Therefore, the soils will require more attention in adopting farming practices that encourages soil conservation of organic matter. This includes, return of crop residues and incorporation of the same after harvest, legume based rotation, minimum or zero tillage to mention but a few. The low to moderate values of total N may be due to the low organic carbon, because it is a major source of nitrogen in the soil. This is similar to the findings of Malgwi (2011) for Sudan Savannah soils, and Maniyunda (2012) in Northern Guinea Savannah soils. Total N values tend to decrease from surface to sub surface horizons, thus reflecting the organic matter distribution in the

soils. The low to medium levels of N in these mapping units would indicate that, the soils will require very liberal doses of nitrogen for optimum crop growth (Esu, 2010). Therefore, management practices that are adopted to increase the soil organic carbon will invariably increase the soil total N. Also, the low soil organic carbon implies negligible or very low N contribution is expected from organic matter and virtually almost all the N requirements of crops must come from inorganic nitrogenous fertilizers, such as urea and high quality organic residues; such as leguminous crops haulms. This will build up the organic matter content to maintain soil quality and improve the sustainable use of the soils. Similar to N, organic matter is the major reservoir of soil P, consequently also, management practices that increase soil organic matter content will increase and enhance P availability. Therefore, these soils have low to moderate P deficiency problem that will require adequate P fertilization and increasing the soil organic matter content, for optimum yield of crops. This is supported by the pH range of these soils and low aluminium ions concentrations which suggests moderate limitations to P availability and low P fixation in these soils (FDALR, 2013).

The values of Ca^{2+} were generally very low to low (Enwezor *et al*., 1989). Low Ca^{2+} rating was also observed in Northern Guinea Savannah soils by Olowolafe and Dung, (2000), and Hassan, (2010). The low level of Ca^{2+} in these mapping units can be improved through organic matter addition or the use of Ca based fertilizer formulations. The values of Mg^{2+} were generally very low to low (Enwezor *et al*., 1989). Lower values of Mg^{2+} were characteristics of the savannah soils (Ogunwale, 1973; Maniyunda, 2012). The lower values of exchangeable Na observed in the mapping units indicate that the percentage of Na on the cation exchange sites was low. This was in contrast with the high

exchangeable Na values recorded in Kadawa and Minjibir with means of 2.90 and 2.80 cmol (+) kg^{-1}, where intensive irrigation activity was taking place, resulting in rise in water table, poor drainage and sodicity build up (Malgwi, 2001).

The values of exchangeable K were found to decrease with increase in soil depth in mapping unit To and Sn. The mean values were below the critical limit of > 0.15cmol (+) kg^{-1}, set for Nigeria (Obigbesan, 2009). To counteract these, rich potassium based fertilizer formulations should be used to meet individual crop requirement. At certain horizons, there was an increase in value of Total exchangeable bases (TEB) with an increase in soil depth, especially in B or gleyed horizon which may be due to the saturation of the horizons with base enriched ground water (Esu, 1982). Where, low TEB were observed in the well drained pedons, this may be attributed to the sandy texture of the soils coupled with their low organic matter content which allow for leaching losses of these bases or their eluviations in to the underlying lower B and C horizons. The exchangeable bases occurred in the order Ca>Mg>Na>K, which was contrary to the earlier findings in the Nigerian savannah soils by (Ogunwale 1973; Ojanuga and Awujoola, 1979; Esu, 1982; Raji, 1995; Yaro, 2005) which indicated that, the exchangeable bases occur in the order Ca>Mg>K>Na. On the other hand, it was in agreement with the works of (Hassan *et al*., 2004; Odunze, 2006; Fasina, 2007 and Maniyunda, 2012) for soils on Basement Complex.

The low values of CEC of the pedons may be attributed to some of the exchange sites being occupied by ferric ions (Coleman and Thomas, 1964). Higher values were obtained at sub surface horizons. This may be due to an increase in clay content (Jones and Wild, 1975). In some horizons with low clay content, higher CEC values were observed, and

this is because the exchange sites of the soil at that horizon may likely reside with the silt size kaolinite fraction (Martini, 1970; Ojanuga, 1971; 1975). The low CEC values in these soils indicate that the soils were low in their nutrient holding capacities thus resulting in significant nutrient loss by leaching. Strategic management of the CEC of these soils requires increasing the soil organic matter content by application of organic manure and increasing the length of fallow period where possible. The effective CEC values were lower than the CEC values; this reflects a moderate degree of base saturation (Raji, 1995). It also indicates the presence of soil minerals with variable charge surfaces (Osher and Buol, 1998). There was a significant relationship between PH of the soil and ECEC, because ECEC measures charge at the soil pH, whereas the CEC- NH4OAC measures on the soil colloids at pH 7.

The low value of Electrical conductivity (EC), indicates that salinization was not a significant pedogenic process in the soils as a result of good drainage and Ustic moisture regime (Raji, 1995). The soils were therefore non saline. The very low values SAR of these soils were similar to those reported by Malgwi (2001), in Kadawa irrigation scheme, Kano and Omar (2012), in South Western Bauchi State. The values were below the critical limit of 13 indicative of Sodic soils. Adj. SAR values indicate the high possibility of precipitating Ca and Mg as carbonates (Malgwi, 2001). These were also low in these soils.

Higher values of ESP in surface horizons with an inconsistent decrease in sub surface horizons, with an increase in soil depth especially in pedons Ba1, Ba2 and To2 may be related to capillary movement of the soluble sodium salts and subsequent deposition in the surface horizons. Malgwi (2001), observed that, ESP and salinity are generally lowest

at the surface and increase with depth in irrigated soils. The mean values of all the mapping units indicate that, the soil was non-sodic, because mean less than the critical limit of 15% ESP. However, some horizons at the substratum in pedon La1 indicate some signs of sodicity development. None availability of carbonate content in all the pedons may be due to the presence of of calcium silicate that is more soluble than $CaCo_3$, resulting into higher bicarbonate content. Low values of bicarbonates was due to source of Co_3 and HCo_3 from Aeolian deposits, irrigation water, underground water, ion exchange phenomenon, to biological reduction of sulphates and decay of Na containing plants.. The extractable available micro-nutrients contents mean values using 0.1M HCl and DTPA for Cu, Fe, Zn and Mn, indicated higher values above the critical limits set by Lindsday and Norvel (1978), Sims and Johnson (1991) and Chude *et al*. (2004), suggesting that, there will be no threat to their deficiencies in the nearest future. However, extractable mean values of Zn, using 0.1M HCl in mapping unit To indicates a higher value, which may lead to zinc toxicity.

5.2.6 Effect of irrigation on soil chemical properties

A significant difference ($P<0.05$) was observed between soils on irrigated (Ba1and Sn1) and rainfed (Ba2 and Sn2), where higher mean values of OC were observed in irrigated pedons compared to non irrigated pedons. This was attributed to the high amount of organic matter accumulation and microbial activity due to additional moisture supplied by irrigation. Irrigation has been found to significantly ($P< 0.01$) influenced exchangeable calcium in mapping unit La. Pedon La1 was found to contain higher values of exchangeable Ca than pedon La2, this may be attributed to the high calcium content of harmattan dust material added annually or to the initial content in the parent material

which was high in Ca (Lawes, 1962; Malgwi,2001; Maniyunda 2012). It also shows an irregular distribution in Ca with soil depth. A significant difference ($P < 0.01$) was noticed between mean values of the irrigated pedon (To1) and rainfed (To2) pedon, where the irrigated recorded a much lower value than the rainfed. This confirms the ease with which exchangeable Mg may be removed from exchange site complex (Karbo and Folorunsho, 1986). In mapping unit La, irrigation significantly influenced ($P<0.01$) the level of exchangeable Mg. Lower values were observed in pedon La2 compared with La1. This may be due to coarse nature of the soils leading to reduced Mg through leaching since they were known to have less charge surfaces.

Total exchangeable bases (TEB) were also significantly influenced by irrigation ($P<0.01$), where the mean values of rainfed (La2) was found to be lower, than irrigated (La1). This was attributed to the sandy nature of the pedon coupled with their low organic matter content which allow for leaching losses of these bases. Therefore, application of organic manure is highly recommended to increase the CEC, thereby reducing leaching of these bases from the soil. There was a significant ($P<0.05$) difference between soils on different land use types, on comparing means. Soils on irrigated pedons (Ba1 and Sn1) were significantly higher than the rainfed (Ba2 and Sn2). This may be linked to the high amount of leaching of exchangeable bases taking place in soils on rainfed pedon. The pH and exchangeable acidity follow the same trend. However, where the pH was found to be high, lower values of exchangeable acidity were realized. This may be linked to the precipitation of exchangeable aluminium in tropical soils out of the solution as insoluble gibbsite especially at PH 5.5 to 6.0 (Sanchez, 1976). Soluble aluminium is not likely to

be found in soils with a pH greater than 4.7, and likewise exchangeable aluminium is generally absent if the pH is greater than 5.0 (FDALR, 2010).

Irrigation influenced mean values of BSP significantly (P <0.05) in mapping units La and Sn, where irrigated pedons (La1 and Sn1) recorded higher value than the rainfed pedons (La2 and Sn2). The lower mean values implicated increase in fine sand content which could lead decrease base saturation percentage as it did not significantly contribute to exchange sites. Higher mean values indicated that, the soils were not excessively leached or because of the parent material which significantly influenced the base saturation (Jaiyeoba, 2006; Maniyunda, 2012). The significant difference (P<0.05) in mean values of ESP due to irrigation was as a result of leaching of exchangeable Na in the exchange sites due to irrigation in pedon La1 compared to La2, in which the mean value was higher.

5.2.7 Effect of irrigation on soil micro nutrients

Statistically, the results showed a significant difference(P<0.05) between pedon Ba1 and pedon Ba2 using 0.1 M Hcl in Fe, Cu and Zn.This may be linked to the high amount of organic matter content in pedon Ba1 compared to Ba2 due to irrigation. Using DTPA, a highly significant difference (P<0.01) was observed in mapping unit To, between the land uses in Zn mean values, and a significant difference (P<0.05) in mapping units Sn and La also between the irrigated (Sn1 and La1) and rainfed (Sn2 and La2) in Cu and Mn mean values. Higher mean values of Fe, Zn, Cu and Mn in irrigated pedons (Ba1,To1, Sn1 and La1) may be linked to higher organic matter content due to irrigation and the presence of Cu- bearing minerals in Ba1 and Sn1, zinc bearing minerals in Ba1 and To1 and manganese bearing minerals in La1.

5.3 Irrigation water quality

The parameters analyzed were that of salinity hazards, sodicity hazards (permeability), anionic composition, pH, basic cations, and heavy/toxic metals.

5.3.1 Salinity hazard

The EC was rated low, because irrigation water with EC of 7.5 dS m^{-1} was considered safe for irrigation. However, The values indicated no potential threat from salinity in all the soils, as their EC values fell below the critical level of 0 to 3dS m^{-1} for irrigation water (Shahinasa and Kashuta, 2008). Therefore, the water was considered safe and suitable for irrigation. The Total Dissolved Salts (TDS) values were also considered low, as they did not reach the critical limits of 0 to 2000 mgl^{-1} proposed by Shahanasi and Kashuta (2008). The higher values of soluble salts obtained in pedon Ba1 compared with other pedons, might not be unconnected with the location of this pedon at the low lying fadama area (Malgwi, 2001). Therefore, the irrigation water do not pose any danger to the soils and crops and it is considered suitable for irrigation.

5.3.2 pH

The pH of the irrigation and drainage waters ranged from 5.8 to 7.2. This indicates an acidic to neutral condition. Safe pH range for irrigation water was between 6.0 and 8.5 (Omar, 2012).

5.3.3 Carbonates and bicarbonates

The residual sodium carbonate (RSC) was found to be negative in all the water samples studied. This indicates negligible mount of carbonates and bicarbonates in the water (Lakotoro and Singh, 2000), which ultimately confirms the suitability of the water for

irrigation, as the carbonates and the bicarbonates levels in the irrigation water did not reach the limit proposed by Landon (1991).

5.3.4 Basic cations and sodicity hazard

Moderate levels of Ca helps to stabilize soil structure apart from plant nutrition. Low values of Mg, Na and K were observed in water samples (Table 4.9). The low Na concentration in the water was an indication that, the water is free from problems associated with high Na concentration (Omar, 2012). This confirms the Tomas irrigation water to be non- sodic. With an SAR of 0.013 to 0.09, the water samples fell below the critical value of 10.0 (Malgwi, 2001). They are therefore non sodic and suitable for irrigation purposes.

5.3.6 Nitrate, sulphate, chloride and Boron content

No nitrate was detected in the Tomas irrigation water. The values for sulphate and chloride were not up to the critical limits of 960 mgl^{-1}, proposed by Landon (1991). So the water samples were good, suitable and safe for irrigation purposes with regards to their nitrate, chloride and sulphate contents. For Boron, values which ranged from 1.8 to 2.0 mgl^{-1} are considered adequate when compared to the critical value of 0 to 2.0 mgl^{-1} proposed by Landon (1991).

5.4 Total Elemental Analysis

The predorminance of SiO_2 content in all mapping units may be related to the sandy nature of the parent material. Quartz content is generally concentrated in sand and silt fractions with secondary quantities in the clay fraction. Both sand and silt fractions of most soils are dorminantly quartz (Sparnger, 1948; Yaalon, 1955; Hill and Shearin,

1962). The SiO_2 depth distribution in soils was a function of parent material and degree of weathering, which resulted in little pedogenetic change in quartz content with depth. The low values of Fe_2O_3, indicates non existence of the plinthic horizons in all the mapping units. This is in contrast with the work of Yaro (2005), where he confirmed the presence of higher content of iron in plinthitic horizon with mean value of 9%, 7.25% and 8.31%, as against the non plinthitic horizons with iron contents of 3.22%. This is also in line with the works of (Woods and Perkins, 1996; Daniels *et al*., 1979; Dos Anjos *et al*., 1995). Generally, low value of Na_2O was realized in all the mapping units indicating less threat to sodicity problem.

ORDER OF ARRANGEMENT OF THE ELEMENTS IN EACH SOIL MAPPING UNIT;

To:SiO_2>Al_2O_3>TiO_2>K_2O>Fe_2O_3>SO_3>CaO>MgO>Cl>Na_2O=SrO>MnO_2>Cr_2O_3> P_2O_5=ZnO

La: SiO_2> Al_2O_3> Fe_2O_3> K_2O >TiO_2> SO_3>MgO>CaO> MnO_2>Cl>Na_2O>SrO> Cr_2O_3> ZnO= P_2O_5

Ba: SiO_2 > Al_2O_3> Fe_2O_3> TiO_2> K_2O >SO_3>MgO>CaO> Na_2O > MnO_2>SrO> Cr_2O_3> P_2O_5 =ZnO

Sn: SiO_2 > Al_2O_3> Fe_2O_3> TiO_2>SO_3> K_2O >MgO>CaO>Cl> Na_2O > MnO_2>Sro> Cr_2O_3> P_2O_5

=ZnO.

5.5 Clay Mineralogy

The prominent presence of feldspars in mapping unit La is a clear indication that, the soils are young in origin, which also is an indication that the soils have not been subjected to intensive weathering (Jackson, 1964). The presence of muscovite in mapping unit La also shows that the soils are less weathered, younger in origin and contain some reserve of weatherable minerals (Jackson *et al*. 1948, 1952; Hue sang Jackson, 1952 and Jackson, 1959, 1964 and Malgwi, 2001). Because of its resistance to weathering, it releases K at much slower rate. Feldspar was also the dorminant mineral in mapping unit Sn. Other mineral found but in smaller amount is hematite (3.72 Å). The presence of hematite in some horizons is an indication that advanced weathering stage has been reached (Jackson, 1964), since it is a product of pedogenesis. Kaolinite and feldspar were the most dorminant in horizons of mapping unit Ba. Other minerals found in smaller amounts include hornblende (9.09 Å) and muscovite (9.77 Å). The preponderance of Kaolinite in this mapping unit may be related to the parent materials of which most of it have undergone a complete cycle of weathering (Malgwi, 2001).

Soil mapping unit To shows that, kaolinite, (3.57 Å and 3.60 Å), chlorite (3.69 Å and 4.84 Å) and hornblende (9.80 Å and 9.38 Å) are the major minerals in this unit. Other minerals found include sanidine (3.7 Å) and plagioclase (3.97 Å). The prodorminance of kaolinite has confirmed its abundance as a mineral that is inherited in Nigerian soils (Jungerius and Levelt, 1964). Garrels and Christ (1965) showed that, stability field of kaolinite is bounded by the stability field of gibbsite, k-mica, k-feldspar and amorphous silica as derived from suggested mineral equilibrium. The presence of hornblende is an indication that, the soils in this unit were rejuvenated by the deposition of fresh materials

brought in either by wind or water or both. For chlorite, it was found that, it weathers to hydroxyl-interlayer vermiculite (HIV), then to vermiculite or kaolinite or halloysite. There is a good relationship in terms of weathering sequence between hornblende and chlorite, which indicates the extent of weathering of hornblende and the intensity of chemical weathering. In Britain, hornblende initially alters to chlorite, with some sphene, hematite and epidote. Upon further leaching (weathering), the chlorite weather to chlorite-vermiculite mixed layer and then to vermiculite (Stephen, 1952).

With kaolinite and feldspars in abundance in most of the soils, it indicates the stage of weathering of the soils; where mineral feldspar weathers to mica, kaolinite and then Gibbsite. It also confirms the abundance of silica (Quartz) from X-ray flouresecence results of the mapping units. Warm and humid conditions in the tropics facilitate rapid removal of potassium and dissolved silica so that feldspar and mica quickly weather into kaolinite and gibbsite (Goro and Garvin, 1981). It also causes marked dissociation of soil water leading to a buildup of hydrogen ions; which favours hydrolytic weathering of silicates to kaolinite (Ojanuga, 1979).

The predorminance of feldspar in all the mapping units indicate that the soils are immature, because feldspar is weathered to Kaolinite and Gabbsite in more matured soils. However, mapping unit Ba and To were considered as a bit more weathered and matured, while mapping unit Sn and La were considered younger and less intensively weathered.

5.6 Soil Classification

a) Soil moisture regime

There was limited moisture condition in the soil. The soils were dry for more than 90 cumulative days. But moisture was present for more than 180 cumulative days when conditions were suitable for plant growth (Soil survey staff, 1998, 1999, 2010). All the pedons were well drained, except pedon Ba1. Therefore, they predominantly had ustic moisture regime. Some pedons were located in the flood plains which may be saturated with water after the end of the rainy season, with a low redox potential with little or no oxygen. This resulted in aquic moisture regime in pedon Ba1

b) Soil temperature regime

The mean air annual temperature of the study area was generally high. The mean annual soil temperature was inferred to be >22^{o}C. This results in isohyperthermic soil temperature regime to the soil (Soil Survey Staff, 1998, 1999).

c) Diagnostic surface horizon (epipedons)

The surface epipedons of all the pedons were too light in colour, too low in organic C, low in P, poor in humus and too thin to be either mollic, umbric or histic, melanic or plaggen epipedons. Hence, they were ochric.

d) Diagnostic sub surface horizons (endopedons)

Pedons Ba2, To2, Sn1 and Sn2 had a cambic horizon. The cambic horizon is an altered horizon > 15cm thick, which results from physical alteration, chemical transformation, or removals or a combination of two or more of these processes. Pedons To1, Ba1, La1 and

La2 had no evidence of soil development from their perceived parent materials. They had no discernable subsurface B horizon.

5.6.1 USDA Soil Taxonomy System

At the order level, pedons Ba2, To2, Sn1 and Sn2 were classified as Inceptisols (Soil survey staff, 2010), because of their weakly developed (altered) cambic horizons, while pedons To1, Ba1, La1 and La2 were classified as Entisols at the order level due to the absence of diagnostic B horizon, but they had an ochric epipedons.

At the Sub Order level, pedons Ba2,,To2, Sn1 and Sn2 were classified as Ustepts because of their Ustic moisture regime, while To1, Ba1, La1 and La2 classified as Fluvents, due to sand materials transported and deposited by the river, with irregular decrease in the content of organic carbon and occurred on landscape of less than 2% slope.

At the Great Group level, pedons Ba2, To2, Sn1 and Sn2 were classified as Haplustepts, due to the presence of simple profile and absence of duripan or calcic horizon within 100cm in the mineral soil, while To1, Ba1, La1 and La2 were classified as ustifluvents since the prevailing moisture regime in Kano State is ustic (Soil Survey Staff, 1999).

At the Sub group level, pedons To2, Sn1 and Sn2 were classified as Typic Haplustepts because they have no other special feature that differentiates them from other Haplustepts in the subgroup. Pedon Ba2 had a chroma too high (>3), for typic subgroup in the subsurface horizons between the depth of 25cm and 75cm below the surface which is attributed to better aeration, and was therefore classified as Arenic Haplustepts. According to Soil survey staff (2010), pedon Ba1, was classified as Aquic Ustifluvents at the subgroup level; since it experienced fluctuating water table condition in normal years.

Pedons To1, La1 and La2 were classified as Typic Ustifluvents due to the absence of any special feature that differentiates them from other Ustifluvents.

At the family level, particle size and mineralogy were used for classification. All the pedons are coarse loamy particle size by weight, and they contained more than 15% fine sand and less than18% clay. They are therefore classified as coarse-loamy, mixed, isohyperthermic.

5.6.2 FAO/UNESCO/ World Reference Base

Using the World reference Base for Soil Resource (2006) (FAO/UNESCO, 2006), pedons Ba2, Sn1, Sn2, and To2 were classified as Arenosols. These are soils which are coarser than sandy loam to a depth of at least 100cm of the surface, and have no fluvic or andic properties except ochric A horizon. They are weakly developed, coarse textured (sandy) soils which have good root permeability and water volume, but also dry out quickly.

At the sub unit level, they were placed as Haplic Arenosols (FAO/UNESCO,WRBS, 2006), because they had a simple profile arrangement, and lacked humic, ferric, plinthic, gleyic and stagnic properties within 125cm at the surface. Pedons To1, La1 and La2 were classified as Fluvisols. These are soils that are young, alluvial deposits in river valleys, estuaries and coastal regions. They have no diagnostic horizon other than histic, mollic, ochric, salic or sulfuric horizon. At the sub unit level, they were classified as Haplic, because their profile were simple, and lacked humic, ferric, plinthic and gleying properties within 125cm of the surface. In addition, pedon La1 has the properties of Eutric, because it has a base saturation percentage by (NH_4AO_C) method of more than

50% throughout the profile. Pedon Ba1 has properties which qualifies it to be classified as Gleysol. This is by virtue of its alluvial and fluvic properties and having no diagnostic horizon other than an ochric epipedons. At the sub unit level, it was classified as Haplic gleysol, because its profile was simple, and it has within 100cm of soil surface in some part reducing condition and 25% or more of soil with gleyic colour pattern.

5.7 Land Capability Classification

The land capability classification system does not intend to create detailed management plans, but only the conservation part of these plans (Rossiter, 1994). The main soil characteristics considered as limitations were, soil depth, soil texture, drainage condition, slope, CEC, salinity and alkalinity. These were linked with the digitized soil mapping units in a GIS environment. The Tomas soils were generally associated with climatic limitations, because of the critically low and poorly distributed rainfall, which is inadequate for some crops such as rice.

5.7.1 Current capability

These are soils that are deep, well drained with good condition for easy root development and mechanization, which could rate the soil as class I. However, due to inherent low soil fertility (Low CEC, OC, total N and available P), coarse texture in addition to climatic limitation, these soils are classified as class IIIfs. The coarse sandy texture and high infiltration rate facilitates poor moisture retention ability, and leaching in the soils, while low inherent fertility makes the soils to have poor nutrient holding capacity. Current land capability class of these soils is rated as class IIIfs (marginal) based on the ratings. This indicates that, these soils (Ballauda, Sansan, Ladi and Tomas) have severe limitations that

reduce the choice of crop; they require very intensive conservation measures or both (Killingebiel and Montgomery, 1961).

5.7.2 Potential capability.

Climatic limitation and low inherent soil fertility were all found to be correctable limitations. Climatic limitation may be corrected with irrigation, while nutrient availability and CEC should be corrected by incorporation of crop residues, cover cropping in a good rotation farming system and inorganic fertilizer application. These measures would upgrade the capability class of these soils from marginally capable class (IIIfs) to moderately capable class (IIs) (Ali *et al.*, 2009). ESP, EC, salinity and alkalinity were found to pose no threat in the scheme.

5.8 Extent of Land Utilization

Identification and description of current and potential production areas would help in knowing the extent of land utilization in an area. This was achieved by comparing differences and similarities between present/current land use in the area and the potential land use (Perveen *et al*., 2007), which will finally give insight into areas affected by under or over utilization for proper assessment, in order to avoid land degradation, and improve on crop yields (Raji, 2004).

It was found that, marginally capable land subjected to intensive cultivation (irrigation), accounted for 1,538.4ha (13.25%), and also marginal lands subjected to moderately intensive use (rainfed), accounted for 8,587.51ha (73.95%). These were areas identified with over utilization, which may lead to land degradation. The remaining 1, 487.3ha (12.81%), are areas of marginal capability class being subjected to low intensive use

(others). This is an area that is properly managed; where current use fits the potential capability or suitability (Raji, 2004). Therefore, there is no threat to sustainability in terms of land degradation or otherwise in this area.

5.9 Soil Suitability Classification

Six chosen land qualities with their associated characteristics were considered in this study. They include climate(C), drainage (D), nutrient availability/ fertility status (F), soil physical properties (S), workability (W) and erosional hazards (e).

5.9.1 Soil suitability class S3 (actual)

Soils of Ballauda (Ba), Sansan (Sn), Ladi (La) and Tomas (To) mapping units belong to this suitability class. These soils have no limitation with regards to climate, workability, erosion, soil pH and drainage and were classified as (S1) highly suitable. This indicates that, these soil units were found to be optimum for irrigated rice production. However, these soils present major limitations in terms of soil fertility (f) which was inherently low and led to poor nutrient holding capacity and soil texture (s) which ranged from sandy loam to loamy sand with negligible percentage of clay, which facilitates low moisture retention capacity. This rated all the mapping units into S3 (marginal) and makes them sub optimum for irrigated rice production. Using Liebig's law, the suitability of Ballauda (Ba), Sansan (Sn),Ladi (La) and Tomas mapping units are classified in to (S3) actual suitability, which means the soils are ' marginally' suitable for irrigated rice production with the same limitations to give the suitability subclass (S3fs). They have limitations which are severe for sustained application of irrigated rice production, and so will reduce productivity or benefits or increased required inputs that the expenditure will be marginally justified.

5.9.2 Soil suitability class S2 (potential)

The suitability classification for irrigated rice in Tomas irrigation revealed S3fs marginally suitable class with major limitation of fertility status and texture in all the mapping units.The nutrient limitation is of great importance because of the need rice have for certain elements especially N, for nutrition and proper growth (Grist, 1986). These nutrients were found to be low in all the mapping units.

To ameliorate these limitations, there is need for more attention in adopting farming practices that encourage conservation of organic matter, supplement the soil N level with external sources of N for optimum rice production due to the importance of N (Davide, 1964), annual incorporation of rice residues instead of burning, and application of full doses/rates of P for crops annually at these mapping units to obtain optimum rice yield. This will ultimately help in improving the nutrient holding capacity of these soils, by making them retain more moisture, a condition favourable for irrigated rice production, since rice requires high amount of moisture to survive (IRRI, 2010). If these limitations are eliminated from the evaluation procedure, the potential suitability of all the mapping units could be raised to S2 'moderately suitable' class. This is a class with moderately severe limitation but projected benefits which are subjected to increased inputs above the highly suitable lands for irrigated rice production.

The results of suitability assessment for irrigated rice is shown in (Table 4.18 and 4.19) using the non parametric and parametric methods. By the non parametric method, all the pedons were found to be marginally suitable (S3) for irrigated rice production for actual (current) aggregate suitability. The potential aggregate suitability for all the pedons were

moderately (S2) suitable for irrigated rice production after the major correctable limitations were amended.

The parametric method indicates that, all the mapping units had an index of current productivity (IPc) of 5.63 (N2), and were classified as permanently not suitable for irrigated rice production. The major limitations were mainly nutrient availability or soil fertility (F) like low levels of available macro- nutrients, organic carbon and low cation exchange capacity. However, the evaluation of potential suitability by index of potential productivity (IPp) of Tomas using the parametric linear model (without considering the levels of organic C, macro and micro- nutrients which were regarded as temporary limitations), indicates that all the mapping units were permanently not suitable 9.0(N2) and 11.25(N2), with the exception of pedon Ba1 which was currently not suitable 20.5(N1) (table 23). Using the non parametric method, Tomas irrigation scheme was found to be more favourable to irrigated rice production than the parametric method, and none of the soils was found to be highly suitable (SI) for optimum irrigated rice production.

5.10 Socio-economic Evaluation for Irrigation Rice Production in Tomas Irrigation Scheme

In order to keep pace with population growth, rice yields in both irrigated and low land environments must increase by 25% over the next 20 years (IRRI, 2010). In Nigeria the situation is not different, because rice production has never been able to meet the demand and has led to considerable importation. The country is second largest importer of rice after China with annual imports of 2.1m metric tonnes (Punch, March 14, 2014). Some of the major factors responsible for production not meeting consumption includes low

yielding varieties and use of poor (low fertility) soils for rice production (Adeoye, 1985). This will definitely increase our domestic rice production by cultivating upland, lowland and irrigated rice through effective and planned use of our agricultural lands.

Though irrigated rice production has been practiced in Kano state for long, it became more popular as a result of the flood of 2011 wet season which resulted in short fall in the expected amount of rice to be produced in that season. USAID MARKETS facilitated the idea of dry season (irrigated) rice to augment the said short fall, which became very successful and promising by producing a much higher yield than the wet season rice under the same input and management levels. Farmers in Tomas irrigation scheme were among farmers used by USAID MARKETS for irrigated rice production. The socio-economic characteristics are important human attributes that help to enhance efficiency of farmers and marketers of agricultural produce in their business (Musa, 2003). A total of 112 farmers were used for socio- economic evaluation in the scheme. A greater majority of the farmers were male, and also majority of them ranged from 50 years and above. This was as a result of the rural urban migration of the youth, and the reluctance of the young school leavers to work on the farm (Ibrahim *et al*., 2012). The percentage of irrigated farmers that are married was high (84.82%), with the remaining being single, divorced or widowed. Almost all the farmers are literate, with over 50% having secondary to tertiary education. This was due to the participation of serving and retired civil servants in irrigated rice production in the area, which consequently increase the adoption level of the farmers towards new and improved technological innovations.

Irrigated rice was produced by small scale farmers in the study area, with majority of them cultivating < 2 Ha of the rice farms. Only few farmers were cultivating up to 18Ha.

This shows that, majority of the farms used for irrigated rice production in the area were under small and marginal operations, which means that marginal profits and less income were realized by the farmers.

5.10.1 Rice varieties

The most common varieties of rice used for irrigation as recommended by USAID MARKETS, were FARO 44, FARO52 and FARO 57. These are improved varieties. However, majority of the farmers used improved varieties of irrigated rice in the study area (Sippi FARO 44), while few14% were using local variety called Jamila. Farmers obtain their seeds from different sources and farmers that use local variety, obtain the seeds from their fellow farmers. The adoption of improved seeds was as a result of the presence of USAID MARKETS and Growth Enhancement Scheme (GES) programme introduced by Federal government of Nigeria which assists in providing subsidized and certified seeds and other inputs to farmers.

5.10.2 Farmer participation in co-operatives/associations

Farmer associations/cooperatives were formed by farmers in order to have easy access to inputs, credits, markets and extension services, which may help them in expanding their scale of operation, thereby improving their standard of living. Part of the benefits derived by farmers for being members of one association/cooperative or another includes; free extension services, attending workshops and trainings with full sponsorship by USAID MARKETS, access to certified inputs by linking farmers with suppliers like NOTORE, access to loans and credits by linking farmers with banks like Stanbic, BOA and micro finance banks where USAID MARKETS serve as guarantor, access to markets and

sometimes access to machineries like tractors, planters, rippers etc. In the year 2012, USAID MARKETS donated a tractor to Kadawa irrigated rice farmers.

5.10.3 Land tenure, land use and fertility status

Land tenure is defined as the system of land ownership. This has serious influence on agricultural systems practiced in Nigeria because most of the tenure systems are customary in nature, and lead to land fragmentation. The cost of land rent depends on proximity of land to the dam site. This is because the closer the farm is to the dam, the higher the land rent.Those farms located at a far distance to the dam, their land rent is cheap. The decrease in fertility status of soil which reflected in their yield after harvest was attributed to continuous depletion of the irrigated fields during wet and dry season year in year out, and the inability of the poor farmers to buy recommended quantity of fertilizer. Inorganic fertilizer ingredient increased yield of most improved crop varieties, but were inaccessible to most poor farmers.

5.10.4 Source of water for irrigation

The main reason for introducing irrigation activity in this area was due to the low rainfall which led to the construction of Tomas Dam. Majority of rice farmers use water for irrigating their rice from the dam. This was only possible for those farms located close to the dam, because channels meant for conveying water from the dam to distant farms were dilapidated. This necessitated rice farmers whose farms were located at distances from dam to device the use of tube wells as their source of water for irrigating their rice field. Farmers are not exposed to use of bore holes, so they don’t use it as a source of water for irrigation.

5.10.5 Rice marketing channels

Rice farmers in Tomas disposed their rice through three marketing channels either in processed or unprocessed form (paddy). The first channel was sale of unprocessed rice (paddy) to recommended processors like Umza. Though, there were two recommended processors in Kano; UMZA and POPULAR RICE PROCESSING companies, almost all the farmers that dispose their unprocessed rice do so only to UMZA. This is because of easy market channel and introduction of new technologies in form of extension services through USAID MARKETS.

The second channel was the sale of unprocessed rice to local markets, where unprocessed rice was taken to nearby popular weekly Dambatta market about 2km from the site, and also Dawanau market near Kano metropolis. The last channel was a situation where by farmer's sale their processed rice locally to consumers for directs home usage, especially to those who are not rice farmers in the community.

5.10.6 Problems of irrigated rice production in Tomas area

Almost all the rice farmers in the study area unanimously presented two major problems affecting irrigated rice production. These are the issues lack of subsidy on inorganic fertilizer and inaccessibility to borrowed capital or credits. For inorganic fertilizer, currently there was no subsidized fertilizer for sale to farmers in the state. The only subsidy in fertilizer is through the Growth Enhancement Scheme (GES) progamme of the Federal government of Nigeria, where two bags of the commodity was given to a farmer. This was grossly inadequate. Recently, USAID MARKETS was able to introduce some input production companies to the rice farmers for easy access, but there is no subsidy.

In case of borrowed capital/credits, farmers are faced with the problem of security/ collateral. The lending policies of our commercial banks did not favor the common farmer. The recent introduction of some banks like Stanbic, IBTC and BOA to rice farmers associations by USAID MARKETS, and the creation of micro-finance banks by Kano state government in all the 44 local governments, may help to alleviate this problem by helping the farmers to expand their scale of operation.

5.10.7 Profitability of irrigated rice production

The profitability of irrigated rice crop was determined using Net farm income analysis and rate of return on investment (RRI). This was made possible by having adequate information on inputs costs and revenue in the enterprise. There was an indication that irrigated rice production was labour intensive in Tomas irrigation scheme. The total cost was ₦83, 200/Ha and the total revenue was ₦300, 000, while Net Farm Income (NFI) was ₦216, 800/Ha. Irrigated rice production was therefore a profitable venture with Net Farm Income (NFI) of ₦216, 800/Ha and Rate of Return on Investment (RRI) of ₦3.60 for every naira invested.

CHAPTER SIX

SUMMARY AND CONCLUSION

Land evaluation study was conducted at Tomas Irrigation Scheme with the aim of identifying and mapping the different land uses, assessing the current and potential capabilities and classifying the soils based on their suitability to irrigated rice production. The procedures employed included: digitisation of the Tomas soil map, the use of SPOT5 satellite imagery in classifying the different land uses through supervised image classification, and mapping the same with the aid of ArcGIS, study of the morphological, physical, chemical, mineralogical characteristics. Others were water quality indicators for irrigation, classifying the soils using USDA soil taxonomy and FAO/UNESCO WRB (2010), developing a land capability classification of the soils with extent of land utilization and finally classifying the soils for irrigated rice production (using non parametric and parametric methods) with its associated socio economic parameters.

Three major land use types identified were irrigated, rainfed and "others" land use types. Morphologically, the soils were generally similar, but with little variations within and among the mapping units. The soils were structureless (single grained), indicating their sandy nature and poor or little horizonation. Particle size distribution from all mapping units revealed that, sand was a dorminant particle size with sandy loam texture over loamy sand, which led to high water percolation and resultant low water holding capacity.

The chemical properties of the soils indicated a strongly acidic to near neutral soil reaction. The values of organic C, total N, CEC and exchangeable bases (Ca, Mg, Na and

K) were low. The sandy texture coupled with low organic matter content allow for leaching of these bases, hence their low nutrient status. Electrical conductivity (EC) and Exchangeable sodium percentage (ESP) were all rated low, indicating no threat to salinity and sodicity in the short run.

According to United State Department of Agriculture (USDA) Soil Taxonomy systems of classification, the soils were classified as Arenic Haplustepts, Typic Haplustepts, Typic Ustifluvents and Aquic Ustifluvents at the subgroup level. In the World Reference Base classification systems, the soils were classified as Haplic Arenosols, Haplic fluvisols and Gleyic fluvisol at the sub unit level.

The land capability classification of the scheme revealed "marginal" capability class (IIIs) with major limitations of inherent low fertility due to low CEC, total N, and organic C and coarse soil texture. The extent of land utilization indicated that 86.2% of the land in the study area was over utilized. These are marginal lands subjected to high intensity and moderate intensity use. Only 12.81% of the land was properly managed, where current land use fits potential capability. The suitability evaluation of the mapping units for irrigated rice shows that, all the mapping units were" marginally suitable"(S3), for actual suitability and "moderately suitable" (S2) for potential suitability, after the correctable major limitations were amended. This is for the non parametric method. For the parametric method, all the mapping units had an index of current productivity (IPC) of 5.63(N2), hence classified as "permanently not suitable" for irrigated rice production. However, for the index of potential productivity (IPP), all the mapping units were also "permanently not suitable" 9.0(N2), except pedon Ba1, which was currently not suitable

20.5(N1). None of the mapping units was found to be highly suitable (S1) by both non parametric and the parametric methods.

The socio economic analysis reveals that, high cost of labour, unreliable and inadequate water supply for irrigation and inadequate input supplies were part of the challenges faced by farmers. Net farm income to the farmers was positive with NFI of 216,800, and rate of return on investments (RRI) of 3.60 for every naira invested, indicating that irrigated rice production in the area was profitable.

Though the capability and suitability of these soils were "marginal" (IIIs) and (S3), but still farmers in the area were producing irrigated rice at a profit. This calls for an indigenous capability and suitability classification systems to verify the compatibility of the USDA and FAO capability and suitability systems in our environment.

In conclusion, three major landuses /cover were identified, delineated and mapped.

The morphological properties of the soils were generally similar with little variation.

The physical characteristics revealed sand as the most dorminannt particle size fraction with loamy sand over sandy loam.

The chemical properties of the soils indicated low levels of organic C, total N,CEC and exchangeable bases.

According to Soil Taxonomy systems of classifications, the soils were classified as inceptisols and entisols at order level, while for FAO/UNESCO World reference base for soil resources, they classified as Arenosols at the order level.

The potential capability class of the soils was "marginal" (IIIfs).

The extent of land utilization indicated 86.2% of the land was overutilized, and only 12.8% was properly managed.

The actual suitability classification for irrigated rice was" marginal" (S3fs), and the potential suitability classification was "moderate" (S2fs). But still farmers were producing irrigated rice at a profit.

For furher studies, there is need for a full detailed soil survey of Tomas irrigation scheme using aero- space remote sensing and GIS technology because of the heterogenous nature of flood plain soils.

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APPENDICES

PROFILE DESCRIPTION

Profile NR	Tomas (TO_1)
Location	Fadamar mata(shiddar) N 12.35936, E 008.56892 Elevation 419m
Taxonomic Classification	Typic Ustifluvent/Haplic fluvisols
Soil Parent Material	Alluvial-Loessial
Geology	Alluvial-Loessial over Basement complex
Geomorphology	Nearly flat
Topography	Upper crest, nearly level 0-2%
Vegetation/ Land use	Rice-during rainy season, tomatoes, maize, onions,
sweet	pepper, and water melon in the dry season.
Soil Erosion/Hazard	None
Drainage	Well to imperfectly drained
Depth to Water Table	Not encountered
Depth to Impenetrable Layer	Not encountered
Date Sampled	May 21, 2013
Described By	Dr W B Malgwi and Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-30	Light gray (10YR 7/2 dry), brown (10 YR 5/3 moist); Loamy sand, massive, non sticky non plastic, very friable (moist), hard (dry); few fine roots, clear smooth boundary.
AC	30-80	Very pale brown (10 YR 8/3 dry), brownish yellow (10 YR2/6 moist), sandy loam, massive, non sticky non plastic; gradual smooth boundary; very friable (moist), hard (dry).
C1	80—138	Gray (10 YR 7/6 moist), few fine faint mottles, loamy sand, massive, non sticky non plastic, very friable (moist); clear smooth boundary
C_2	138—230	Very pale brown (10 YR 8/4 moist); few fine faint mottles; loamy sand, massive, non sticky, non plastic; very friable (moist)

PROFILE DESCRIPTION

Profile NR	Tomas (TO_2)
Location	Tsallewa N 12.32793 E 008.56601 Elevation 432m
Taxonomic Classification	Typic Haplustepts/Haplic Arenosols
Soil Parent Material	Alluvial/ aeolian
Geology	Alluvial/ aeolian over Basement complex
Geomorphology	Nearly flat
Topography	Crest, nearly level 0-2%
Vegetation/ Land Use and regrowth.	Open parkland, cultivated to millet, sorghum beans, surrounded by thick shrub
Soil Erosion/Hazard	None encountered.
Drainage	Well drained
Depth to water table	Not encountered
Depth to Impenetrable Layer	Not encountered
Date Sampled	May 21, 2013
Described By	Dr W B Malgwi and Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-20	Yellowish brown (10 YR 5/4 dry), dark yellowish brown (10 YR ¾ moist). loamy sand, weak fine to medium sub angular blocky; non sticky non plastic; few fine roots and tubular pores, clear smooth boundary.
AB	20-55	Brownish yellow (10 YR 6/6 dry), yellowish brown (10 YR 5/8 moist); Loamy sand to loamy sand, weak, fine sub angular; non sticky non plastic (moist), very friable (moist), hard (dry); few coarse roots, many fine tubular pores, clear smooth boundary.
BW	55-140	Reddish yellow (5YR 6/8 dry), yellowish red (5YR 5/8 moist), loamy sand to sandy loam; moderate, fine to medium sub angular blocky; non sticky non plastic; very friable (moist), hard to soft (dry); few coarse roots; many tubular pores; gradual smooth boundary.
C	140-210	Reddish yellow (7.5 YR6/8 dry); grayish brown (7.5 YR5/8 moist); loamy sand; massive, non sticky non Plastic; very friable (moist), soft (dry); few fine tubular Pores.

PROFILE DESCRIPTION

Profile NR	Ballauda ($Ba_{1)}$
Location	Ballauda fadama N 12.4134 E 008.63240 Elevation 407m
Taxonomic Classification	Aquic Ustifluvent/ Gleyic fluvisol
Soil Parent Material	Colluvial-alluvial-loessal
Geology	Colluvial-alluvial over Basement complex
Geomorphology	Nearly flat
Topography	Flood plain, level or nearly level 0-2%
Vegetation/ Land use	Sugar cane and maize in the fadama, Surrounded by mango plantations.
Soil Erosion/Hazard	None encountered.
Drainage	Well drained to imperfectly drained.
Depth to water table	Encountered at 114cm
Depth to impenetrable layer	Not encountered
Date Sampled	May 23, 2013
Described By	Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-10	Yellowish brown (10 YR 5/4 dry), very dark grayish brown 10 YR 5/4 moist); sandy loam; moderate medium Sub angular blocky; slightly sticky, slightly plastic; firm (moist), hard (dry); few fine roots; few fine vesicular Pores; clear and wavy boundary.
AC	10-35	Yellowish brown (10 YR 5/4dry), dark gray (10 YR 4/1moist); sandy loam, weak medium sub angular blocky; Very friable (moist), loose (dry); many fine tubular Pores; clear and smooth boundary.
C_1	35-60	Grayish brown (2.5 YR 5/2 moist); few fine faint mottles (2.5Y4/2) loamy Sand, massive,; non sticky non plastic; very friable (moist); few fine vesicular pores; clear smooth boundary.
C_g	60-114	Light gray (2.5 YR7/2 moist); loamy sand; massive, non sticky non plastic; gleyed condition depth to water table.

PROFILE DESCRIPTION

Profile NR	Ballauda (Ba_2)
Location	Fulani Banda maye N 12.42792, E 008.60704
	Elevation 429m
Taxonomic Classification	Arenic Haplustepts/Haplic Arenosols
Soil Parent Material	Alluvial-aeolian
Geology	Alluvial-aeolian over Basement complex
Geomorphology	Nearly flat
Topography	Flood plain, nearly level 0-2%
Vegetation/ Land use and	Open parkland with some shrubs, sorghum millet cultivated
Soil Erosion/Hazard	None
Drainage	Well drained
Depth to water table	Not encountered
Depth to impenetrable layer	Not encountered
Date Sampled	May 23, 2013
Described By	Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-26	Reddish yellow (7.5 YR 6/6 dry), strong brown (7.5 YR 4/6 moist); loamy sand, weak fine sub angular blocky Structure; non plastic non sticky; very friable (moist) Soft (dry); few fine roots, many fine vesicular pores; gradual smooth boundary.
BA	26-63	Strong brown (7.5YR 5/8 dry), strong brown (7.5YR 4/6 Moist); loamy sand; weak fine angular blocky; non Sticky non plastic; loose (moist), loose dry); few fine roots; many fine vesicular and tubular pores; gradual and smooth boundary.
BC	63-143	Yellowish red (5YR 5/6 dry), yellowish red (5 YR 4/6 moist); sandy loam, weak fine angular blocky structure; non sticky non plastic; few fine roots; common fine vesicular pores; gradual smooth boundary.
C	143-232	Yellowish red (5YR 5/8 dry), yellowish red(5YR 5/8moist) loamy sand, massive; non sticky non plastic; common fine roots, vertical cracks from top down wards.

PROFILE DESCRIPTION

Profile NR	Ladi (La1)
Location	Kulfare N 12.31665, E 008.53489 Elevation 425m
Taxonomic Classification	Typic Ustifluvent/Haplic Fluvisols (Eutric)
Soil Parent Material	Colluvio-alluvial-loessal
Geology	Colluvio-alluvial-loessal over Basement complex
Geomorphology	Nearly flat
Topography	Lower slope, nearly level 0-2%
Vegetation/ Land use	Rice and maize cultivated during wet and dry season, irrigation channels for conveyance and the area divided into basins.
Soil Erosion/Hazard	None
Drainage	Well drained
Depth to water table	Not encountered
Depth to impenetrable layer	Not encountered
Date sampled	May 22, 2013
Described By	Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-12	Grayish brown (10 YR 5/2 dry), brown (10 YR 4/3 moist); Sandy loam, structureless (massive); non sticky non plastic; very friable (moist), loose (dry); common fine roots; many fine tubular pores; diffuse wavy boundary.
AC	12-42	Strong brown (7.5 YR 5/6 dry), strong brown (7.5 YR 4/6 moist); sandy loam, massive; non sticky non plastic; very friable (moist), hard (dry); many fine tubular pores; gradual smooth boundary.
C_1	42-185	Yellowish red (5YR 5/8 dry), yellowish red (5YR 4/6 moist); sandy loam, massive; non sticky non plastic; very friable (moist), hard (dry); few fine tubular pores; gradual smooth boundary.
C_2	185-232	Yellowish brown (10YR 5/6 moist); common fine faint mottles; sandy loam , massive; non sticky non plastic; very friable (moist), loose (dry); common fine vesicular pores

PROFILE DESCRIPTION

Profile NR	Ladi (La2)
Location	Zakiran kauye (Gabas) N 12.39293, E 008.60881 Elevation 427m
Taxonomic Classification	Typic Ustifluvent/Haplic Arenosols
Soil Parent Material	Alluvial-aeolian
Geology	Alluvial-aeolian over Basement complex
Geomorphology	Nearly flat
Topography	Lower slope, nearly level 0-2%
Vegetation/ Land use	Open parkland, cultivated to millet, Sorghum and beans previous season.
Soil Erosion/Hazard	None
Drainage	Well drained
Depth to water table	Not encountered
Depth to impenetrable layer	Not encountered
Date Sampled	May 21, 2013
Described By	Dr W. B. Malgwi and Yau S L

HORIZON DESCRIPTION

HORIZON	DEPTH	DESCRIPTION
AP	0-48	Grayish brown (10 YR 5/2 dry), brown (10 YR 4/3 moist); loamy sand, structureless (massive); non sticky non plastic; very friable (moist), loose (dry); common fine roots; many fine tubular pores; clear smooth boundary.
AC	48-128	Strong brown (7.5 YR 5/6 dry), strong brown (7.5 YR 4/6 moist);loamy sand, massive; non sticky non plastic; very friable (moist), hard (dry); many fine tubular pores; gradual smooth boundary.
C_1	128-164	Yellowish red (5YR 5/8 dry), yellowish red (5YR 4/6 moist);loamy sand, massive; non sticky non plastic; very friable (moist), hard (dry); few fine tubular pores; gradual smooth boundary.
C_2	164-250	Yellowish brown (10YR 5/6 moist); common fine faint mottles; sand , massive; non sticky non plastic; very friable (moist), loose (dry); common fine vesicular pores

PROFILE DESCRIPTION

Profile NR	Sansan (Sn_1)
LOCATION	Fadama Tsaraka N 12.44294, E 008.61708 Elevation 416m
Taxonomic Classification	Typic Haplustepts/Haplic Arenosols
Soil Parent Material	Alluvial-Aeolian
Geology	Alluvial-Aeolian over Basement complex
Geomorphology	Nearly flat
Topography	Middle slope, nearly level 0-2%
Vegetation/ Land use	Open parkland, cultivated to sesame, Sorghum and millet. Surrounded with mango plantation. .
Soil Erosion/Hazard	None
Drainage	Well drained
Depth to water table	Not encountered
Depth to impenetrable layer	Not encountered
Date Sampled	May 16, 2013
Described By	Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-18	Grayish brown (10 YR 5/2 dry), very dark gray (10YR 3/1 moist); sandy loam; weak fine angular blocky structure; slightly sticky (wet), non plastic ; very friable (moist), soft (dry); few fine roots; few macro and micro pores; diffuse smooth boundary.
BA	18-53	Dark grayish brown (10YR 4/3 dry), very dark gray (10 YR 4/3 moist); sandy loam; moderate fine angular blocky structure; non plastic and slightly sticky (wet); very friable (moist), hard (dry); few fine roots; few micro and macro pores; gradual smooth boundary.
BC	53-153	Very pale brown (10YR 8/2 dry), very pale brown (10YR7/3 moist);loamy sand; structureless; non sticky and non plastic; loose (moist), loose (dry); micro and macro pores; few ant holes; gradual smooth boundary.
C	153-264	Very pale brown (10YR 8/2 dry), light gray (10YR 7/2 moist); loamy sand; few fine faint mottles; structureless non sticky and non plastic; loose (moist), soft (dry); few micro pores; few ant holes. The horizon appeared bleached with patches of yellowish colour.

PROFILE DESCRIPTION

Profile NR	Sansan (Sn_2)
Location	Bagare N 12.44903, E 008.61057 Elevation 426m
Taxonomic Classification	Typic Haplustepts/Haplic Arenosols
Soil Parent Material	Alluvil-aeolian
Geology	Alluvial-aeolian over Basement complex
Geomorphology	Nearly flat
Topography	Middle slope, nearly level 0-2%
Vegetation/ Land use	Open parkland, cultivated to wet Season sorghum, millet, beans and Ground nut, surrounded with regrowth of shrubs.
Soil Erosion/Hazard	None encountered
Drainage	Well drained
Depth to water table	None encountered
Depth to impenetrable layer	Not encountered
Date sampled	May 16, 2013
Described By	Yau S L

HORIZON DESCRIPTION

Horizon	Depth	Description
AP	0-23	Yellowish brown (10 YR 5/4 dry), brown (10YR 4/3 moist);loamysand;weak medium subangular angular blocky structure; non sticky and non plastic; very friable (moist) hard (soft); few fine roots; few macro and micro pores; vescicular and ant holes; gradual and wavy boundary.
AB	23-72	Brown (10YR 5/3 dry), dark brown(10 YR3/3 moist); loamy sand; moderate fine sub angular blocky structure; non sticky non plastic; very friable(moist), soft (dry); few fine roots; few micro pores; few ant holes; gradual and wavy boundary; vertical cracks seen.
BC	72-153	Reddish yellow (7.5YR6/6 dry), strong brown, (7.5YR4/6moist); sand; structureless; non sticky and non plastic; loose (moist), soft (dry);Few ant holes; gradual and smooth boundary. Vertical cracks.
C1	153-213	Yellow (10YR7/6 dry), yellowish brown (10YR 5/6moist) loamy sand Structureless (massive); non sticky and non plastic; loose (moist), soft (dry); few ant holes and termite holes; iron concretions/mica flakes in a ring form; Vertical cracks, gradual smooth boundary.
C2	>213	Very pale brown(10YR8/2 dry),light gray (10YR 7/2 moist) loamy sand; structure less; loose (moist),soft(dry); few micro pores.

QUESTIONNAIRE FOR SOCIO-ECONOMIC ASSESSMENT
SOCIO-ECONOMIC DATA FOR IRRIGATED RICE PRODUCTION IN TOMAS IRRIGATION SCHEME KANO SATE

Date of Survey _____
Village/Locality_____

1. Gender of household head Male ☐ Female ☐
2. Age _____
3. Marital status Not married ☐ Married ☐ Divorced ☐
   Widow ☐
4. Number of person in the household _____
5. Educational qualification.

   No formal education ☐

   Primary ☐ Trade/craft school ☐

   Secondary (JSS) ☐ Quranic education ☐

   Secondary (SS) ☐ Diploma (OND/NCE) ☐

   HND (Diploma) ☐

   Adult education ☐

   University degree ☐

6. Total farm size for all crops:_____
7. Farm size devoted to rice:_____
8. How long have you been in rice farming:_____
9. How many bags of rice do you produce annually:_____
10. How much was consumed at home_____
11. How much was sold_____
12. How much was realized from the sale_____
13. Do you belong to any self help/farmer organization group? Yes ☐ No ☐
14. If yes name the organization/association:_____
15. What are the benefits you derive from the association

1. _____
2. _____
3. _____
4. _____

5. How frequent do extension workers visit your farms? Frequent ☐
   Not frequent ☐ Not at all ☐
6. Who are the buyers of your rice_____ Processed ☐ Unprocessed ☐
7. What is the total cost of processing rice:-
   a). _____

b) List the processing steps and their cost
i. Threshing (₦/bag)_____
ii. Packaging (₦ / bag)_____
iii. Parboiling (₦ /bag)_____
iv. Milling (₦/ bag) _____
c). Total cost of processed rice (₦ /bag)_____(i - iv)
d). Total volume / quantity produced per year _____
e). Total income for product per year_____

19. Are you linked to any buying / processing organization? Yes ____ No__
20. If yes, name the organization:_____
21. What benefit do you derive from the organization? _____
22. What is the distance from your community to the nearest rice market? _____
23. How do you transport your rice to the market? Okada ☐ Donkey/cows ☐ Truck/Bus ☐ Bicycles ☐
24. What problems do you encounter in marketing rice? _____
25. Do you cultivate improved rice variety? Yes _____ No_____
26. If, yes, name the variety_____
27. What are your sources for the improved seeds_____?
28. What are your major problems in rice production Tick Yes or No only

1.	No improved rice variety.	Yes	or	No
2.	Lack of poor extension services.	-----		----
3.	No inorganic fertilizer.	-----		----
4.	No access to borrowed capital/credit.	-----		----
5.	No enough land to produce rice.	-----		----
6.	High cost of labour in rice production.	-----		----
7.	Problems of pest and diseases.	-----		-----
8.	Lack of market information.	-----	-----	
9.	Low price of rice.	-----		-----

29. How do you possess your land? Rented ☐ Leased ☐ Owned ☐
30. For how long have you been cultivating the same land _____
31. Is the land holding increasing or decreasing. Increasing ☐ Decreasing ☐
32. Why? _____
33. Do you have enough land for rice production? Yes ☐ No ☐
34. If no? What are the causes? _____
35. What is fertility of you rice farm. Increasing ☐ decreasing ☐ ☐ stable
36. How do you improve the fertility status of your farm? Inorganic fertilizer

Green manure ☐ FYM ☐ others ☐

37. Is the rainfall. ☐ Increasing ☐ decreasing or constant in your area?

38. What is the trend in water supply inform of irrigation for irrigated rice in the last 2 years. Increasing ☐ decreasing ☐ constant ☐ ☐ fluctuating

39. What is your source of water supply for irrigated rice? Tube well, ☐ Dam ☐ Boreholes ☐

40. Is the water from the dam been released for use frequently?

Yes ☐ No ☐

41. If your answer to (40) is No, what are the reasons?

_____

_____

42. Do you practice crop rotation on your irrigated farm? Yes ☐ No ☐

43. What are the major prevalent pests and diseases encountered in rice production in the area?

_____
_____

44. What are the measures used to combat them

_____
_____

45. What is the amount of loss incurred as a result of pest and disease?

_____

_____

46. How much will it cost a farmer to produce irrigated rice from land preparation to harvesting per acre? Use the following information

i. Land preparation _____ ₦

ii. Planting _____

iii. Weeding _____

iv. Fertilizer application_____

v. Weeding_____

vi. Pesticide application

vii. Harvesting

46. What is the quantity and cost of seeds and fertilizer per acre for irrigated rice.

i. Quantity / acre (seed kg)_____

ii. Cost per acre (seed ₦)_____

47. How much do your pay as water charge for irrigating your rice.

(₦/acre)_____

48. What is the total cost involved in fuelling for using tube well/borehole in irrigating your rice field

_____ ₦ / acre