A STUDY OF SOME SALT AFFECTED SOILS IN THE SOKOTO RIMA BASIN

BY

INAKWU OMINYI AKOTS ODEH

B. Sc. (Aqric) in Soil Science, Ibadan

A thesis submitted to the Postgraduate School, Ahmadu Bello University, in partial fulfillment of the requirements for the degree of Master of Science (Soil Science)

Department of Soil Science
Faculty of Agriculture
Ahmadu Bello University
Zaria.

November, 1983

Approved by:

Dr. I. J. Ibanga
Chairman, Supervisory Committee

Mr. W. A. Hope
Member, Supervisory Committee

Dr. L. A. Nnadi
Member, Supervisory Committee

DEDICATION

For Mother:

Mother with each new success

I miss you more.

D E C L A R A T I O N

I hereby declare that the whole of the work now submitted as a Thesis for the Master of Science degree (in Soil Science) of Ahmadu Bello University is the result of my investigation (except where reference is made to published literature and where assistance is acknowledged) and has not been part of any presentation for any other qualification.

November, 1983.

I. O. A. ODEH

M.Sc. Candidate.

ACKNOWLEDGEMENT

I am highly grateful to Dr. A.G. Ojanuga (formerly Head, Soil Science Department) with whom this work was initiated. I gratefully acknowledge the encouragement and advice of, and wish to express my sincere appreciation to, my major advisor, Dr. I.J. Ibanga for his suggestions and constructive criticism in the preparation of this thesis.

My sincere thanks are due to Messrs W.A. Hope and J. Valette for their valuable suggestions during various stages of the project. My acknowledgements are also due to V. Odigie, C. Timbuack, K. Mafe and B. Benti all of the Soil Chemistry laboratory of the Department of Soil Science for their immense co-operation in the laboratory. My thanks go to J.H. Addai, J.O. Eka and A. Fagbemi who draughted the figures and the maps, and to Mrs. R.O. Otenaike who typed the manuscript.

Finally, I express my profound gratitude to God Almighty for making it possible for me to contribute, however minute, my own part to the development of world agriculture.

A B S T R A C T

Twelve pedons in the Wurno Irrigation Scheme area were studied with the objectives of characterizing, classifying and assessing the salinity status of the soils and in addition postulating their genesis. The soils are formed from various recent and sub-recent alluvio-lacustrine sediments which are strongly stratified. The soils are imperfectly to very poorly drained. All the soils lack gravel or coarser material, and have relatively high silt content.

Organic matter content is low in all the soils and decreases either sharply or irregularly with depth. Soil reaction varies from strongly acid to strongly alkaline. Calcium and magnesium dominate the exchange complex although exchangeable Na content is high in the saline - sodic soils. Both the exchangeable bases and CEC are highly dependent on texture. The soils have high base saturation.

The study highlights the amount and type of salt in the soils, profile characteristics, classification, genesis, and management of soils in the area. The commonest salt affected soils are the saline-sodic soils with some pseudo-sodic soils. The soils classify in the "Soil Taxonomy" as Typic Ustifluvents. Vertic Ustifluvents, Typic Haplaquents and Typic Halaquepts. In the FAO/ UNESCO soil legend, the soils are classified as Eutric

Fluvisols, Gleyic Fluvisols and Gleyic Solonchak. The saline-sodic soils are named as Solonchak - Solonetzs, and the sodic soils as pseudo-Solonetzs in the pedological classification.

TABLE OF CONTENT

		Page
DECLARATION	-	i
ACKNOWLEDGEMENTS	-	ii
ABSTRACT	-	iii
LIST OF TABLES	-	viii
LIST OF FIGURES	-	ix
1. INTRODUCTION	-	1
2. LITERATURE REVIEW	-	4
2.1 The Concept of Soil	-	4
2.2 Soil Genesis, Pedology and Soil Survey		7
2.3 Soil Salinity and Alkalinity	-	10
2.4 Genesis of Salt Affected Soils	-	12
2.5 Secondary Salinization and Alkalization of Soils	-	14
2.6 Amelioration of Saline and Sodic Soils	-	17
2.7 Classification of Salt Affected Soils		20
2.8 Previous Soil Studies	-	23
3 ENVIRONMENTAL INFORMATION	-	26
3.1 Location	-	26
3.2 Geology	-	26
3.3 Geomorphology	-	35
3.4 Hydrology	-	37
3.5 Vegetation	-	39

		Page
3.6 Climate	-	41
3.7 Population	-	45
3.8 Present Land Use	-	46
4. MATERIALS AND METHODS	-	48
4.1 Field Studies	-	48
4.2 Laboratory Analyses	-	50
4.2.1 Preparation of samples	-	50
4.2.2 Particle size distribution analyses		50
4.2.3 Water saturation percentage	-	50
4.2.4 Soil reaction	-	51
4.2.5 Organic matter	-	51
4.2.6 Cation exchange capacity	-	52
4.2.7 Exchangeable cations	-	52
4.2.8 Soluble cations and anions	-	53
4.2.9 Electrical conductivity measurement		53
4.2.10 Exchangeable sodium percentage (ESP)		53
5. RESULTS AND DISCUSSION	-	54
5.1 Soil Morphological Characteristics	-	54
5.1.1 Soil description	-	54
Pedon One	-	55
Pedon Two	-	58
Pedon Three	-	61
Pedon Four	-	64
Pedon Five	-	67
Pedon Six	-	70

		Page
Pedon Seven	-	72
Pedon Eight	-	75
Pedon Nine	-	78
Pedon Ten	-	81
Pedon Eleven	-	83
Pedon Twelve	-	86
5.2 Physical Characteristics	-	89
5.2.1 Particle size distribution	-	89
5.3 Chemical Characteristics	-	99
5.3.1 Organic matter	-	99
5.3.2 Soil reaction	-	104
5.3.3 Exchangeable bases	-	105
5.3.4 Cation exchange capacity	-	107
5.3.5 Base saturation	-	108
5.3.6 Soil salinity and alkalinity	-	109
5.4 Soil Genesis	-	110
5.5 Soil Classification	-	113
6. SUMMARY AND CONCLUSION	-	119
REFERENCES	-	125
Appendix	-	131

LIST OF TABLES

TABLE			PAGE
1	Tentative correlation of the FAO/ UNESCO system of classification and the USDA system	-	22
2	Stratigraphic sequence in Sokoto Rima Basin	-	29
3	Evaporation from storage reservoir at Wurno	-	45
4	Some physical characteristics of the soils	-	90
5	Some chemical characteristics of the soils	-	101
6	Classification of the soils	-	113

LIST OF FIGURES

FIGURE		PAGE
1A	LOCATION MAP OF WURNO AREA -	27
1B	MAP OF WURNO AREA -	28
2A	GEOLOGY OF WURNO AREA	30
2B	A SECTION SHOWING GEOLOGICAL FORMATIONS IN WURNO AREA -	31
3	WATER BUDGET HISTOGRAM WITH AVERAGE MAXIMUM T (max.) AND AVERAGE MINIMUM T(min.) SCREEN TEMPERATURES IN TEN DAY PERIODS FOR SOKOTO OVER 20 YEARS -	42
4	MEAN RELATIVE HUMIDITY AT SOKOTO FOR THE YEARS 1943-47 -	43
5	THE TRAVERSES AND POINTS OF PEDONS SAMPLED -	49

CHAPTER ONE

INTRODUCTION

There has been increasing need to expand our knowledge of the complex of natural and artificial resources which together are called "land". The concept of land according to Christian and Stewart (1968), Brinkman and Smyth (1973), Vink (1975) and F A O (1976) envisages land geographically as "a specific area of the earth's surface, its characteristics embrace all reasonably stable or predictably cyclic attributes of the biosphere, the soil and the underlying geology, the topography, the water, the plant and animal populations and the results of the past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of land by man". This definition obviously implies that land constitutes both the natural resources including the soil and man-made resources. It therefore implies that planning decisions ought to be made only after a comprehensive analysis of all relevant factors including the nature of the soil, since soil is an important integral attribute of land, in order to ensure the efficient utilization and preservation of the land resources to produce more food and other needs of the present and future generations of the human population.

Land use planning is the result of a scarcity of land (Vink, 1975). One response to such scarcity is to find

new land which still provides sufficient natural sustenance; the other is to put some effort into primeval land management to increase production at the same locality. This latter response is necessitated by the nature of the land which contains many natural limitations, and by the increasing world population which has brought pressure on land. Both responses call for carefully laid land management practices which require relevant data and other scientific information which are needed for agricultural planning.

The existing knowledge of the land resources including soil for ultimate resource planning is often lacking especially in the developing nations. In Nigeria, the scarce data and lack of other relevant information on the country's environment, particularly the soil resources, are reflected on the poor managerial performance in the agricultural sector as a result of improper pre-implementation planning. Several River Basin Development Authorities have been established to cover all the major rivers throughout Nigeria. Many of these Development Authorities are developing various irrigation schemes to sustain the rapidly growing population. Improper management of these irrigation projects will not only lead to decrease in food production but also may lead to salinity hazard and drainage problems. The objectives of this study are to assess the

salinity status of soils of the Wurno irrigation scheme and to characterize, classify and postulate the genesis of the salt affected soils and give recommendation on their reclamation and management.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Concept of Soil

There are several concepts of soil which have evolved through two centuries of scientific study. The first which was proposed nearly a century ago conceives of soil as disintegrated rock mixed with some decaying organic matter as evident from published reports of Fallou (1862) and Merril (1906). If this concept of soil is accepted as authentic, then weathering alone could have provided adequate explanation for its formation (Simonson, 1959).

In Russia, this concept was replaced much earlier than in other countries. Dokuchaev (1883) published a report of a field study of chernozems in which the idea that soils were more than weathering rock and that they have profiles consisting of genetically related horizons was adduced. The soil was defined as an independent natural evolutionary body formed under the influence of a number of factors of which much stress was placed on climate and vegetation though parent material, relief and time were also considered.

Marbut (1935) while director of the United States Soil Survey read Glinka's (1927) work in German translation and brought Dokuchaev's ideas of soil to the attention of soil scientists in the United States.

Kellogg (1936) who succeeded Marbut related processes of soil formation to prominent great soil groups by names such as podzolization, laterization and solonization. These processes differ from one another in a number of essentials. In fact some pairs of processes such as podzolization and laterization have been considered to be opposite in no small measure. However, a change from this point of view seems necessary when soils of the world are considered as a continuum with a number of properties in common (Simonson, 1959).

According to the Russian school of thought (Neustruyev, 1927; Nikiforoff, 1942), soil evolution is viewed to be a continuous process. It was also proposed that all kinds of soils existing on the earth at any given time are temporary stages. Each stage is succeeded by some other stage in the process of continuing evolution.

The modern concept of soil widely held is the broadened type of the earlier ones. This concept has been modified and extended for soil mapping purposes from the early thirties to the present in which soils are considered as dynamic natural three-dimensional bodies or landscapes each having a lateral dimension on the earth's surface and depth delimited by that material beneath the soil per se which can be considered parent material or not soil (Soil Survey Staff, 1960).

This new concept gave rise to the concept of the pedon which is "the smallest volume that can be considered 'a soil'". It is a three dimensional body with a lateral dimension varying from 1 to 10 m^2 depending on whether the natural genetic layers in soil or the soil horizons are continuous, intermittent or cyclic (Soil Survey Staff, 1960). It's lower limit is the maximum depth of penetration of the roots of native plants (Buol et al, 1973).

The soil individual is represented on the landscape by the collection of its similar contiguous pedons or "polypedon". It is a mappable unit of soil on the landscape characterized by position, size, slope, depth and other features.

On the basis of this new concept, the soil is defined as "the collection of natural bodies occupying portions of the earth's surface that support plants and that have properties due to integrated effects of climate and living matter, acting upon parent material, as conditioned by relief over periods of time" (Soil Survey Staff, 1960). The definition presents soils or soil individuals as natural bodies which are seldom set apart from their neighbours by sharp boundaries. Adjacent bodies grade into one another (Simonson, 1959). They form a continuum over the earth's surface broken only in places by non-soil. The soil continuum is a heterogenous cover (D' Hoore, 1968) over the earth's surface or within a particular region or country because each of the soil individuals composing it has its unique morphological, physical, chemical and mineralogical properties.

2.2 Soil Genesis, Pedology and Soil Survey

Soil genesis is that phase of soil science that deals with factors and processes of soil formation. It includes description and interpretation of soil profiles, soil bodies, and pattern of soil on the earths surface (Buol et al, 1973). Some authors refer to soil genesis as the science of the evolution of soils which are conceived of as natural units (Pomerening and Knox, 1962) and somewhat arbitrary units (Taylor and Pohlen, 1962) in the mosaic of the landscape. It is sometimes referred to as pedology when combined with soil classification activity (Buol et al, 1973).

Pedology (Editorial Staff, 1940; Northcote, 1954; and Gibbs 1955) as a science of its own has been used both as a synonym for soil science (De Sigmond, 1938) and as another name for soil genesis (Vilenskii, 1957). The central theme of pedology, a science owing much to the pioneering work of Dokuchaev up to a century ago is that which is concerned with the natural occurrence, classification and development of soils. Soil in its natural state results from the weathering of minerals by physical, chemical and biochemical processes (Smith and Atkinson, 1975). It represents the theatre of activity between atmospheric processes on the one hand and the imperceptibly slow process of landform development on the other. Soil, is therefore, geologically ephemeral

and is only ever preserved into future age by exceptional circumstance of burial, a phenomenon which leads to the formation of paleosols.

Simonson (1959) viewed soil genesis as consisting of two steps; the accumulation of parent materials, and the differentiation of horizons in the profile. The latter which is of more interest to the soil scientist is considered due to four basic kinds of changes, grossly as additions, removals, transfers and transformations in the soil system. These four kinds of changes cover a wide range of processes. Examples of the four basic changes that result in horizon differentiation are addition of organic matter to the soil in the form of fresh residues, which is subsequently transformed into humus and lost through decay or it may be transferred from one horizon to another. Simonson further postulated that these changes as well as others proceed simultaneously in all soils. It is the balance within the combination of change that governs the ultimate nature of the soil profile. This accounts for the heterogeneity of the soil continuum, and which has necessitated the study of the soil in the field for its practical application in the society. This is the soil survey.

Soil Survey Staff (1960), and Smith and Atkinson (1975) define soil survey as comprising mainly the examination, description, classification and mapping of soils in an area. Soil mapping is often used as a synonym for soil survey or soil cartography though in the other sense of its meaning, it refers to the practical aspects of producing soil maps from the results of soil investigation or soil survey. Soil survey has played and is playing a significant role in our understanding of how soil properties relate to the earth's physical features and of how those properties affect agriculture. No matter the scale of a soil survey, the object of producing a soil map is generally to enable predictions to be made about rational use of land. Usually this has entailed the application of pedology to the requirements of a stable and sustained agricultural system, although soil maps, the products of soil surveys, are increasingly being used for other purposes such as in forestry, engineering and watershed management.

Conventionally, soil survey has depended on the field work, with laboratory analyses merely providing confirmation of field observations. However, the increasingly detailed definition of diagnostic horizons in classification systems (Soil Survey Staff, 1975)

means that in many cases the mapping units or classes are themselves dependent upon laboratory analyses.

2.3. Soil Salinity and Alkalinity

Salinity and alkalinity of soils are a major and ever-present threat to the full exploitation of soils particularly in the arid and semi-arid regions of the world. During the history of agriculture, the importance of this problem has constantly increased, due to the rapid extension of the salinization and alkalization of soils and waters, which in many places, have caused a drastic reduction in agricultural production (Kovda and Szabolcs, 1979). In arid and semi-arid areas of the world, where irrigation is an indispensable precondition for crop growth, soil salinity and alkalinity have particular significance. In these areas, both soils and waters contain a considerable amount of electrolytes causing salinity and alkalinity.

Saline soils are soils for which the conductivity of the saturation extract is more than 4 mmhos cm^{-1} at $25^{o}C$ and exchangeable sodium percentage is less than 15 (USDA Salinity Laboratory Staff, 1969) or soils affected by neutral salts (usually of sodium), mainly chloride and sulphate (Kovda and Szabolcs, 1979). Ordinarily the pH is less than 8.5. Sodic soils on the other hand are soils for which the exchangeable

sodium-percentage (ESP) is greater than 15 and the conductivity is less than 4 mmhos cm^{-1} at 25°C with pH values usually ranging between 8.5 and 10 (USDA Salinity Laboratory Staff, 1969) or simply as soils affected by sodium salts (bicarbonate, carbonate and sulphite) capable of alkaline hydrolysis (Kovda and Szabolcs, 1979).

The third group of salt-affected soils are the saline-sodic soils for which the conductivity of the saturation extract is greater than 4 mmhos cm^{-1} at 25°C and ESP is greater than 15. These soils form as a result of combined processes of salinization and alkalization. However, under conditions of excess salts, the pH values are seldom higher than 8.5 and the particles remain flocculated (USDA Salinity Laboratory Staff, 1969).

Evidence has, however, shown that sodic soils in some areas may have an ESP considerably above 15, and yet pH value especially in the surface horizons, is as low as 6.0. De Sigmond (1938) referred to these soils as degraded soils in which the low pH value is the result of the exchangeable hydrogen.

2.4 Genesis of Salt Affected Soils

Kovda (1947) categorised genesis of salt affected soils in arid and semi-arid regions into three types which may occur in combinations of two or more. The first is the effect of climate. The sparse rainfall leads to insufficient and irregular humidity, and consequently, the soil forming processes are only intensive in certain periods. The weathering processes are sometimes limited by shortage of water which also prevents the leaching and transport of the weathering products. In dry periods, the soluble substances form efflorescence in patches on the soil surface. The dry climate also leads to certain geochemical and hydrological processes which affect the accumulation of soluble products in the soils of these regions.

The second mode of genesis of salt affected soils of which Polynov (1930) and Szabolcs (1961) reported is the effect of the groundwater. Groundwater is always mineralized to some degree (Kovda and Szabolcs, 1979) and the dry climatic condition caused the soluble elements it contains to rise upwards through the soil as a result of capillary action and enrich the soil surface, forming white or grey efflorescences when there is accumulation of sodium salts. These efflorescences may also appear in the upper part of the soil or lower down the profile in root channels and other fissures.

This phenomenon operates whenever a deep horizon rich in salts becomes waterlogged, even if only temporarily. It is greatly accentuated when it is due to a real water-table. However, it is only after a certain "critical depth", varying according to the texture, structure and other factors of the soil, that efflorescences may, subject to the salt content of the groundwater, make their appearance (Kovda and Szabolcs, 1979).

The third category is the naturally occurring salts in soils of these regions. The origin of these salts varies widely. They either originate from parent rock or weathering products of these rocks or from sea spray or efflorescences on denuded surface blown by wind or again they are contained in irrigation or flood waters which have been leached far away from the surface. Due to a climate with a strong power of evaporation, the salts rise up through the profile by capillary action, from mineralized groundwaters.

These salts may simply accumulate in the soil, affecting the flocculation of the clay-humus complex and the development of crop/vegetation and microflora in the soil. More frequently the presence of sodium salts leads to the dispersion of soil colloids and creates a very compact and coherent structure.

When the salts simply accumulate in the soil, the phenomenon is closely associated with saline soil formation, while the dispersive and colloid-chemical effects of the salts are closely related to the formation of sodic soils (Kovda and Szabolcs, 1979). In this case the dispersed clay is easily carried away either laterally or vertically. In the case of vertical transfer, the sodic clay carried away is deposited at some depth of the soil profile where it accumulates as a result of either the effect of an extremely impermeable horizon or because of limited penetration of the sparse rainfall.

2.5 Secondary Salinization and Alkalization of Soils

Secondary saline and sodic soils are those which have not been affected or only slightly destroyed by salinity or alkalinity before human management, and after a certain period of irrigation they become salinized or alkalized (Kovda and Szabolcs, 1979). It is a known fact that the majority of the irrigated zones existing in the world are exposed to the hazard of secondary salinization, alkalization and water-logging.

The purpose of irrigation is to optimise the moisture content of the crop - root zone, and this

has the strongest influence on the groundwater regime (Kovacs, 1977). Although infiltration through the surface is smaller than otherwise due to the decreased tension differences, the positive accretion (groundwater recharge) is greater than the negative accretion (evaporation loss) because the storage capacity is filled by irrigation water and, therefore, almost the total amount of irrigation water reaches the water table (Kovacs, 1977). Only few irrigation methods such as trickle irrigation can distribute water in the form of a continuous supply with relatively small quantity per unit time as it is required by plants. Over-irrigation is therefore almost unavoidable, and its effect is to increase positive accretion.

The majority of irrigation schemes today consist of a distribution system generally composed of earth canals which incur seepage losses between the intake works and the irrigated fields, and so the recharge of groundwater is further increased. The excess recharge and the considerable decrease in vertical drainage disturb the natural balance of the groundwater, so irrigation results in continuous rise of the water table within the area of the system.

It is well known that there is a close interrelation between the hydrological processes occurring in the soil-moisture zone and the movement, leaching and accumulation of dissolved salts in the water or bound to the soil particles.

According to Kovda and Szabolcs (1979), secondary salinization and alkalization of soil may take place (due to irrigation) when there is accumulation of salts from irrigation water of poor quality, or when the salt content of the groundwater accumulates in the affected layers or the rising groundwater transports the salts from the deeper soil layers to the surface layers or again when the rising water table limits natural drainage and hinders leaching of salts.

Szabolcs et al (1976) considered several factors that determine the possible hazard of salinization and/or alkalization in irrigated areas. They include climatic factors such as temperature, rainfall, humidity, vapour pressure, evaporation and their fluctuation and dynamics; geologic, geomorphological, geochemical and hydrochemical factors such as natural drainage, the depth and fluctuation of the water table, the direction and velocity of horizontal groundwater flow, salt content and composition of groundwater. Other factors

include those of the soil such as soil profile, texture, structure, saturated and unsaturated water conductivity, soluble salt content, salt composition and salt profiles, exchangeable cations and pH; agrotechnics such as land use, crops, cultivation methods and other crop management practices; irrigation practices which include amount of irrigation water, method, frequency and intensity of irrigation; salt content and composition of irrigation water and profiles; and natural and artificial drainage.

In semi-humid and humid climates, the problems of potential salt affected soils are not the same as those encountered in arid zones, due to the different climatic, geochemical and farming conditions (Szabolcs, 1971 a,b). In such areas, the basic aims of the survey and study of potentially saline or sodic soils are to predict the harmful processes and to elaborate, whenever possible, on methods suitable for preventing the occurrence of secondary salinization and/or alkalization.

2.6 Amelioration of Saline and Sodic Soils

Scofield (1940) stated that if irrigation agriculture is to remain successful, soil salinity and alkalinity must be controlled. Adsorption of excessive amounts

of sodium is detrimental to the physical status of the soil and may be injurious to plants. When the exchangeable-sodium content of soil is excessive or tends to become so, special amendment, leaching and management practices are required to improve and maintain favourable soil conditions for plant growth.

Soluble salts in soil are transported by water. This is the basic principle pertaining to control of salinity. Thus the soil salinity can be controlled if the quality of the irrigation water is satisfactory and if the flow of water through the soil can be controlled (USDA Salinity Laboratory Staff, 1969).

The concentration of soluble salts in the soil solution is increased as water is removed from the soil by evapotranspiration. Dessication of surface soil by transpiration and evaporation creates a function gradient that will produce an appreciable upward movement of water and salt. This upward capillary movement, as earlier indicated, is a process by which many soils become salinized especially if the water table is near the soil surface. Thus the soluble salt content in the soil depends on whether the net downward movement of salt is greater than the net addition from irrigation water and other sources. The salt balance in the soil is therefore, affected by

the quantity and quality of irrigation water and the effectiveness of leaching and drainage (USDA Salinity Laboratory Staff, 1969).

Surface drainage, if practicable and economical, is very valuable particularly where the hazard of water logging is significant. If water is not drained from the surface, it tends to evaporate where it lies, leaving a residue of salt. The removal of subsurface water by ditch and tiles is often recommended but not generally practised in the developing countries.

The use of some special amendments has proven beneficial to some salt affected soils, especially the sodic soils, in improving both productivity and physical properties. Chemical amendments that can be applied to sodic soils include the soluble calcium salts such as calcium chloride and calcium sulphate (gypsum); acid or acid formers such as sulphuric acid, iron sulphate, aluminium sulphate and lime-sulphur; and calcium salts of low solubility like ground limestone. Each type of amendment has a place in reclamation, and effectiveness under different soils conditions is influenced by the alkaline-earth carbonate content and the pH reading (USDA Salinity Laboratory Staff, 1969). Carter et al (1977) reported that a combined application of ammonium nitrate and calcium sulphate (gypsum) is

more beneficial than either ammonium nitrate alone or gypsum alone.

Deep ploughing which is best described as mixing the soil horizons when the soil isploughed to a depth of more than 40 cm has been shown by Bowser and Cains (1967), Cains (1971) to have decreased the soluble salt content and increased the exchangeable Ca to Na ratio in some Solonetz soils and, is also reported to increase the yield and root penetration of subsequent crops (Rasmussen et al, 1972).

When and where it is not economically feasible to maintain low salinity because of saline irrigation water, high water table, or low permeability of the soil, the judicious selection of crops such as sugar beet, alfalfa, onion, spinach, carrot, wheat and cotton which have been found to produce satisfactory yields under irrigation and use of special management practices to minimise salinity may make the difference between success and failure (U.S.D.A.Salinity Laboratory Staff, 1969).

2.7 Classification of Salt Affected Soils

There are some difficulties in the systematization of saline and sodic soils due to the high variation of

kind and sources of salinization (Husz, 1969) and also the effect of these soil types on plant growth varies significantly. The morphology of saline soils varies very greatly and is connected directly with their genesis.

In the proposal of the "Sub-Commission on salt affected soils" of the International Soil Science Society (I.S.S.S.), which has the inventory and cartography of these soils as its primary target, genesis is expressed in the differentiation of the group of sodic soils into

a) Sub-group without structural B-horizon,

b) Sub-group with structural B-horizon. The world map of salt affected soils presented at the 9th International Congress of Soil Science (1968) indicates the following groups:

i) Saline soils

ii) Sodic soils a) with structural B-horizon

b) without structural B-horizon.

iii) Potential saline and sodic soils.

Kovda and Szabolcs (1979) attempted correlating these groupings with other widely used classification systems (Table 1).

As mentioned above, it does not seem acceptable to ignore genesis and morphology in establishing a classification for salt affected soils. This is because in saline areas there are frequently soils whose horizons are not built up as a consequence of soil processes such as illuviation, but whose differentiation

Table 1: Tentative correlation of the FAO/UNESCO system of classification and USDA system.

Source: (Kovda and Szabolcs 1979)

Basic Grouping (1967) of the Subcommission on Salt affected Soils	Soil Map of the World FAO/UNESCO Project	U S D A Classification 1967.
Saline Soils	Solonchak	Salorthids
	Orthic Solonchak	Salorthidic Calciustolls
----------	Mollic Solonchak	Salorthidic Haplustolls
Alkali-Soils without structural B-horizon	Takryic Solonchak	Halaquepts (pp)
	Gleyic Solonchak	
Alkali-Soils with structural B-horizon	Solonetz	Nadurargids Natrargids Natriboralfs Natrudalfs Natrustalfs Natrixeralfs
	Orthic Solonetz	Natralbolls Natriborolls Natrustolls
	Mollic Solonetz	Natraquolls Natraqualfs
	Gleyic Solonetz	Argiabills (pp)
	Solodic Planosols	

PP = in parts.

was caused by the sedimentation of geological materials (strata) of different structure and age (Husz, 1965). These soils do not have "real horizons" but "psuedo-horizons". There is interaction between the strata and the soil processes which results in a morphological phenomenon typical for each soil profile. An example would explain this; an alkali soil with structural B-horizon could be called a classical "Solonetz", but a profile whose B horizon was not built up by these dynamics (Illuviation), but by the sedimentation of a clay material secondarily covered by a fine sandy sediment, should be called "pseudo-Solonetz" or "Strato-Solonetz".

Secondary saline soils have world wide distribution. They are soils which first developed to a certain nonsaline soil type but due to a change in the ecosystem, they became salinized. To clearly show this history, such soils could be called by their original type name with the prefix "Saline" (Husz, 1966), for instance "Saline Tropaquent".

2.8 Previous Soil Studies

Allison (1962) on the request of the then Northern Region Ministry of Agriculture carried out a survey on the salinity status of existing and the then proposed wheat schemes in Northern Nigeria. It was reported that some of the northern irrigated soils (Yau, Daye, Goronyo,

Wurno, Kwarre, etc) are non-saline to moderately saline. Slight evidence of salt inflorescence was noted at some Sokoto-Rima irrigation schemes. These findings were later supported by the works of Singh and Maurya (1979), Maurya (1982) and Ojanuga and Awotundun (1982). Maurya and Singh (1979) noted that Sahel Savanna Zone soils are very much susceptible to salinity and alkalinity under irrigation conditions and that secondary salinization and alkalization started in Sudan Savanna Zone due to water-logging and poor drainage in various irrigation schemes. However salinity and alkalinity are not a common phenomenon in the Guinea Savanna Zone and areas south of it.

The recent survey involving the Soils and Water Resources of the Sokoto valley carried out by the FAO (1969) revealed that with the exception of the Solonetz-like soils, the soil alkalinity was quite low, with the exchangeable sodium percentages well below 15. It was also noted that salinity is not at the time a limiting factor in crop growth except in some irrigation schemes, in which sodium chloride crusts were common and often associated with harmful salinity in the soil profile. However, frequent irrigation without adequate drainage will cause a rapid increase in salinity (Maurya, 1982) particularly in the silt rich floodplain sediments.

Using a modified FAO/UNESCO classification system, the FAO study revealed the following soil types in the study area:

(i) Typic Juvenile soil or slightly matured Juvenile soil on micaceous clay loam to clay of riverine sediments and moderately matured Juvenile soil on micaceous very fine loamy sands to loams of riverine sediments.

(ii) Weakly hydromorphic soils on sand or loamy sand of riverine sediments or weakly bleached hydromorphic soils on sandy loams of riverine sediments.

(iii) Topomorphic vertisols of heavy clays of lacustrine sediments.

(iv) Hydromorphic soils on sandy clays to clays of lacustrine sediments.

No saline or Solonetz-like soils were revealed within the study area at the time (FAO, 1969). However, Ojanuga and Awotundun (1982) mapped some salt affected soils in Kalmalo and Wurno irrigation area and revealed that the commonest salt affected soils in the study area are the saline-sodic soils named in pedological classification as Solonchak-Solonetzs.

CHAPTER THREE

ENVIRONMENTAL INFORMATION

3.1 Location

The project area is located in Sokoto State of Nigeria, and situated between latitude 13° 17' and 13° 21' north, and longitudes 5° 25' and 5° 30' east. The project site is about 48 kilometres by road from Sokoto city and has a total land area of about 800 hectares extending along Rima floodplain, between "Wushi-Wurno" line to the west and "Dinbisu-Lugu" line to the east. The "Lugu Dam", created by damming an abandoned channel of River Rima, and which is the source of water for irrigation, is situated to the east of the irrigated floodplain (Figs 1A and 1B).

3.2 Geology

The sediments of Sokoto-Rima Basin known as 'Sokoto embayment' (Reyment, 1966) constitute about one tenth of a more extensive elongated sedimentary and structural basin - the Iullemmeden basin (Kogbe, 1970; Kogbe, 1979). This larger basin trends in north-west direction from Nigeria into Niger Republic.

Falconer (1911) first recognized the major geological divisions found in Sokoto-Rima basin in his pioneering study of the geology and geomorphology of northern Nigeria. However, the first important stratigraphic study of the Sokoto-Rima basin was

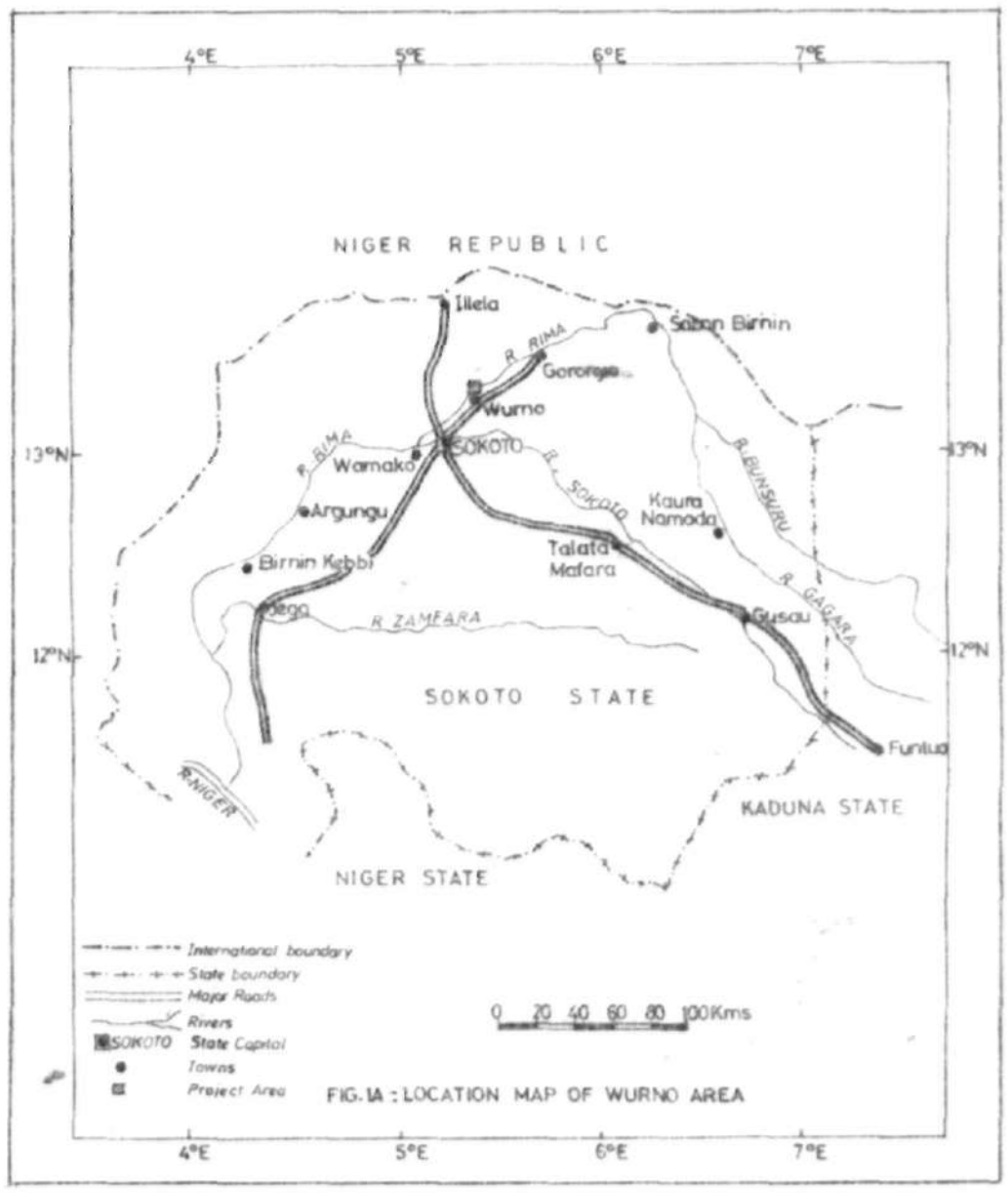


FIG. 1A : LOCATION MAP OF WURNO AREA

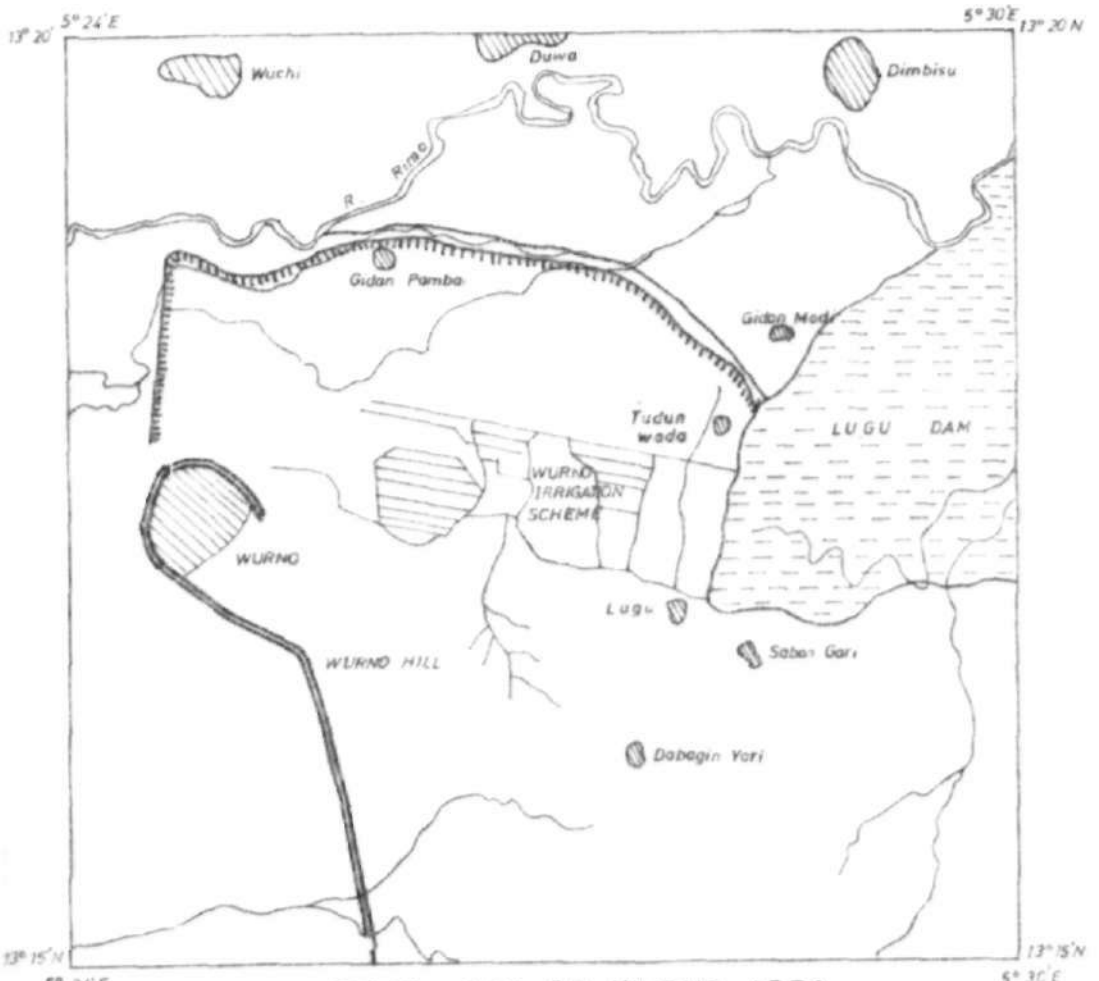


FIG 1B: MAP OF WURNO AREA

Tab

Quat

Eoce

Uppe

Mae:

Low
Cre
Old

Pre

FIG. 2A : GEOLOGY OF WURNO AREA

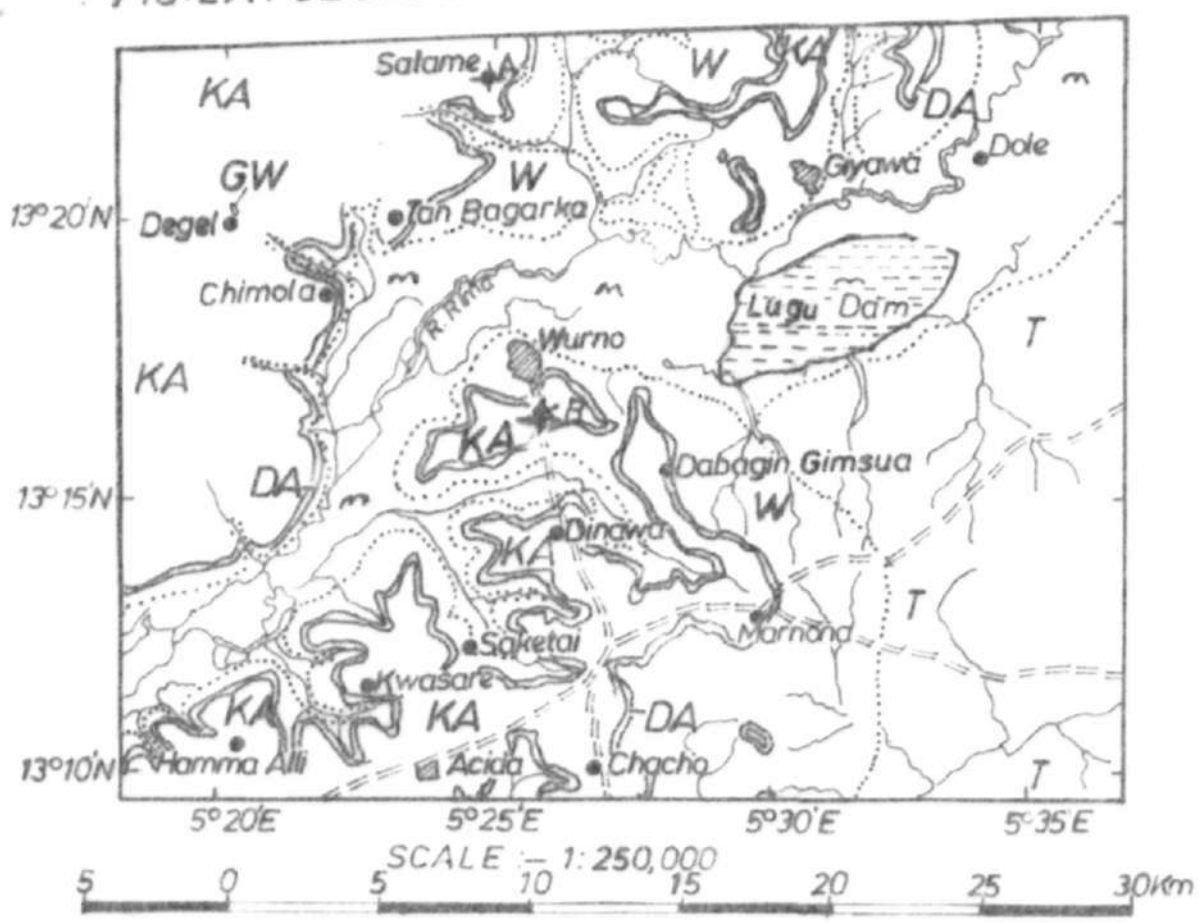


Fig. 2 a

LEGEND

~	Alluvium
G	Gwandu Formation
KA	Kalambaina Formation
DA	Dange Formation
W	Wurno Formation
T	Taloka Formation

From Geological Survey of Nigeria Sokoto, Sheet 2

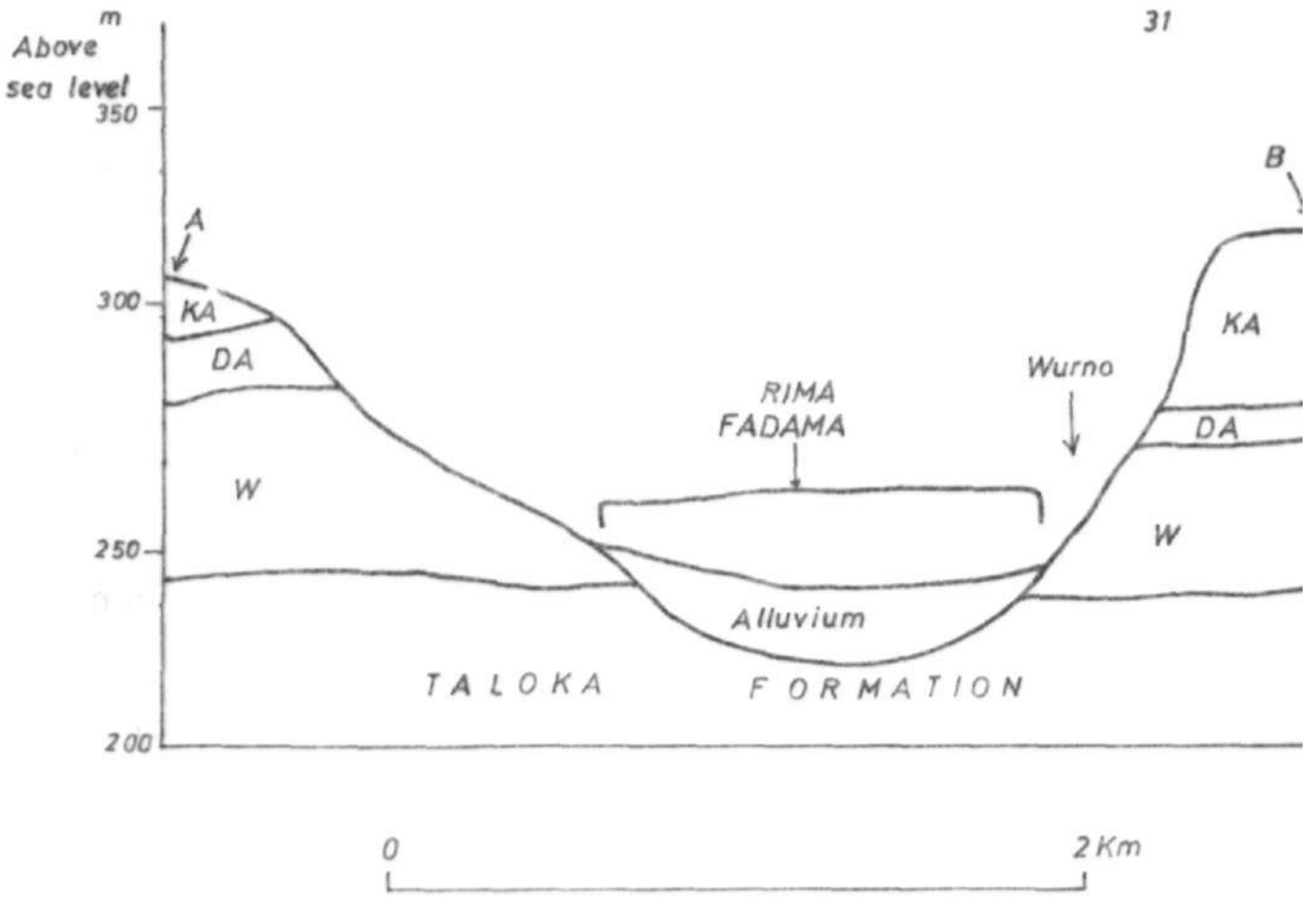


FIG. 2B : A SECTION SHOWING GEOLOGICAL FORMATIONS IN WURNO ARE

carried out by Jones (1948). Later investigations by Kogbe (1976, 1979) have validated much of the findings by earlier workers, though the pre-Maetrichtian deposits which were dated as Cretaceous or Tertiary (Falconer, 1911; Jones, 1948) are confirmed as Cretaceous and not Tertiary.

Kogbe (1979) in his comprehensive study of the geology of Sokoto basin noted that the sediments of this basin were deposited during three main phases of deposition namely the continental Mesozoic and Tertiary phases with an intervening marine Maestrichtian to Palcocene phase (Table 2). Overlying the Pre-Cambrian basement unconformably, the Illo and Gundumi Formations made up of grits and clays, form part of the "Continental Intercalaire" of West African (Furon, 1963). They are overlain unconformably by the Maestrichtian Rima group, consisting of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the shaly Dukamaje Formation. The Paleocene Dange and Gamba Formations (mainly shales) are separated by the calcareous Kalambaina Formation. The overlying continental Gwandu Formation known as Continental Terminal (Furon, 1963 and Killian 1931) is of Tertiary age.

These sediments occupy an area lying between latitude 10^{o}N and 14^{0}N and between longitude $3^{o}30'$ and $7^{o}15'$ E. They dip gently and gradually towards the northwest, with

maximum thickness of over 1000 metres near the frontier of Niger Republic.

In Wurno area, the main geological outcrops are the Wurno, Dange and Kalambaina Formations (Figs 2A and 2B).

The Dukamaje Formation consists predominantly of shales with some limestones and mudstone. The Wurno Formation consists of pale coloured, friable, fine-grained marine sandstones, siltstones and intercalated mudstones (Kogbe, 1972; 1979). In boreholes, the sediments of the Wurno Formation are dark in colour. This is due to the presence of carbonaceous material and finely divided iron sulphides. The friable nature of the sediments make them very easily susceptible to weathering. At Wurno, the formation occupies the lower half of the "Dange Escarpment" and the upper half is made up of Dange Formation sediments. The formation attains a maximum thickness of about 25 metres.

The Dange Formation forms the base of "Sokoto group" of sediments of upper Paleocene age. It consists of semi-consolidated bluish grey shales with thin bands in limestone. Generally, the outcrops are restricted to the slopes of "Dange Scarp". Fibrous bands of gypsum with a large number of irregularly shaped nodules derived from vertebrate remains (Reyment, 1966; Kogbe, 1972) are the major inclusions in the shales.

The Kalambaina Formation consists of white marine, clayey limestones and shales. An outcrop of this formation occurs along Sokoto-Wurno road at about 0.4 km. to Wurno. In Wurno area, the Kalambaina Formation is covered by a mantle of loose sand and laterite. The laterite, usually 1.5 to 3 metres thick, merges down into oolitic ironstones 3 to 5 metres thick (Kogbe, 1979).

Sedimentary deposits of recent geologic origin (Quarternary phase) are found on the bottoms of the wide valleys. The flat floodplain is sometimes up to 5 km wide or more. The middle section of the floodplain consists mostly of medium to coarse sandy material which is covered by a more or less continuous, usually a metre thick, top layer of clayey and silty material (FAO, 1969). Old terrace and levees of earlier river courses which are up to one to three metres in elevation are found along the floodplain. The tops of these old levees consist of fine sand and silt, poorly graded with a minor clay content.

Below the floodplain level, the depth of incision is estimated to reach 30 metres and it is probable that deeper strata contain somewhat more coarse material suspected to be ironstone remains which is now covered by the sand deposits (FAO, 1969).

3.3 Geomorphology

Pugh and King (1952) have described the planation surfaces of the central basement area of Northern Nigeria. The planation surfaces are regarded as part of King's (1967) widely developed "African" surface. Two facets of the "African" surface are recognized (Pullan, 1961). De Swardt (1956) called part of the northern high plain at around 800m above sea level as the Kaduna - Zaria plain, and pointed out that close to Iullemmeden basin, it represents an exhumed pre-Cretaceous surface. It is reasonable to suppose that the pre-Cretaceous surface is the Jurassic "Gondwana" land surface which was covered by the continental Illo-Gundumi Formations, the marine Sokoto and Rima group of sediments, and the continental Gwandu Formation during an intermittent subsidence from late Cretaceous to mid-Cainozoic. The source of these sediments is undoubtedly (either partly or wholly) the basement area of the northern high plain (Pullan, 1961), which is King's "African" surface. Thus the Basement Complex area of the Sokoto-Rima basin is part of the African buried shield of Young (1976), which carries a cover of gently tilted sedimentary beddings.

Pullan (1961) attempted correlating the planation surface in the Birnin Kebbi area with the lower "African" surface which Clayton (1958) described as the "Niger" surface.

The gently tilted sedimentary beddings of the Sokoto-Rima basin result in the formation of the cuesta topography with the "Dange" scarp (Jones, 1948) as the most prominent feature. The "Dange" scarp is closely related to the geology and it retains a marked north-northeast to south-southwest trend which approximately parallels the regional strike (Kogbe, 1979). The escarpment itself has undergone intensive erosion, and the edge has been intensively dissected. The area to the east of this escarpment consists predominantly of a gentle undulating, sandy plain, which extends southwestwards to the Basement Complex boundary. Further to the west, another escarpment occurs marking the eastward limit of a series of younger rocks with a more varied topography.

In general, the land consists predominantly of a gentle undulating plain with an average elevation varying from 250 to 400 metres above sea-level (Kogbe, 1979). This monotonous plain is occasionally interrupted by steep sides flat-topped hills or mesas.

The present river valleys were formed during the late Tertiary or early Pleistocene, and were deeply incised under moist climatic conditions (FAO, 1969). During the Pleistocene the arid climate with short lasting humid oscillations gave rise to oolitic sedimentation of the broad valleys or the fadamas.

The main physiographic feature of the project area is the wide, very flat Rima floodplain, with no macro-relief, and with highly varied and complex detailed micro-relief of the order 2 to 3 metres. The micro-depressions and old levees of former channels are the major impedance to free flow of water. The floodplain which varies from 4 to 8 kilometres wide in the project area is bounded on the southern flank by a cliff which is about 60 metres high. The northern flank is a variable, but more gentle cliff. It is pertinent to indicate here that the micro-reliefs (micro-depressions) within the Wurno-Irrigation land have been levelled to some extent, though not to an acceptable degree to eliminate the problems of water-logging and salinity in the area.

3.4 Hydrology

The Sokoto-Rima Basin lies in the western part of the high plains of Hausaland with its major tributaries rising on the undulating surface of the main Niger-Chad watershed in the neighbourhood of Funtua (Fig.1A). Three of these tributaries - the Gagara, Bunsuru and Maradi flow in a north northwest direction for a considerable part on the Basement Complex, and then uniting in the extreme northeast of Sokoto State to form the Rima River. The Rima River meanders in a huge arc before joining the River Sokoto

near Wamako, and then flows southwards to join the River Niger (Fig 1A).

The tributaries of River Rima, on leaving the pre-Cambrian rocks, flow on to the broad flat plain developed on the soft rocks of the Rima group of sediments, where, no longer restricted in the narrow valleys by resistant rocks, they have developed wide flood-plains or "fadamas". The main floodplains are along the Sokoto-Rima valleys. Due to a sudden change of gradient, there is a reduction of velocity of flow, and the resultant loss of energy has led to the deposition of large quantities of sediments in the wide valleys (Ledger, 1961). The resulting excessive aggradation is causing a progressive downstream reduction in the volume of water flow through the lower reaches due to evaporation and seepage losses. These losses are not off-set by local inflow due to low run-off coefficient of the sedimentary rocks.

Floods in the rivers vary considerably in their peak discharges and duration. The peaks are moderated particularly in the middle and lower reaches by the wide nature of the valleys, while the duration is increased (FAO, 1969).

Groundwater is present in the sedimentary rock formations, but the yields of wells are only moderate as the sediments are fine to medium-grained. The water table varies from 1 to 15 metres (FAO, 1969) and may be less in the fadamas even at the peak of dry season.

For all practical purposes, the quality of surface and groundwater is excellent to good (du Preez and Barber, 1965), but Singh and Maurya (1979), based on the analysis carried out on the Lugu Dam waters, rated the waters as of medium salinity and of medium sodium hazards (sampling was in January 1979). It was further stated that the water could only be used successfully with a moderate amount of leaching to curb these hazards. More than 80 percent of the total run-off comes from the Basement Complex which covers 45 percent of the total catchment area of the Sokoto-Rima basin.

3.5 Vegetation

The natural vegetation on the deep upland soils is typical of the Sudan Savanna Zone which consists of almost continuous grass and scattered tree cover. Tree and shrub savanna develops on shallow soils. However, there is little or no truly representative savanna woodland left since most areas where trees can grow are either permanently or spasmodically cultivated. In this area, only the economically important trees such as dum palm (Hyphaeme thebaica), the baobab (Adansonia digitata),

shea butter tree (Butyrospernum parkii), acacia (Acacia albida) and kapok (Bomba costatum) are preserved (Pullan 1961; Kogbe 1979).

Other trees which may be found are Combretum micranthum and the Guiera senegalensis. Azadirachta indica (neem) has been planted as shade trees in the villages, especially along new avenues cut at right angle to each other in many villages.

The grasses that predominate are Tripogon minimus, Zornia diphylia, Sporobolus festivus, Brachiavia stigmatisata, Loudetia togoensis and Andropogon pseudapricus.

On the higher sandy banks Borassus aethiopun is a common tree. The extensive cultivation of local (red) variety of rice has led to the establishment of volunteer rice (Oryza glaberrima) in the floodplain. Other wild rice varieties which have invaded the cultivated rice are Oryza barthii and O. stampfi.

3.6 Climate

The project area lies in the Sudan Zone which experiences type A_w in the Koppen's classification of climatic types. This zone is characterized by a convectional rainfall within the Inter-Tropical Convergence Zone (I.T.C.Z.) during the short wet season which extends rrom midMay to midSeptember (Udo, 1973; Kogbe, 1979) but during the dry season, is under the influence of a continental air mass or the north-east trades which blow from the Sahara and are known as the "Harmattan" in West Africa.

As the area is far removed from the sea, both the total rainfall and the length of the wet season are minimal. Thus Sokoto, the nearest meteorological station to the project site, has a mean annual rainfall of 74.0 cm over a period of 62 years (FAO, 1969).

The rainfall regime is predominantly single peaked (Pullan 1961; Kowal and Knabe, 1972). The wettest months are June (110mm), July (190mm), August (250mm) and September (130mm). There is hardly any rainfall in November, December, January, February and March (Fig. 3).

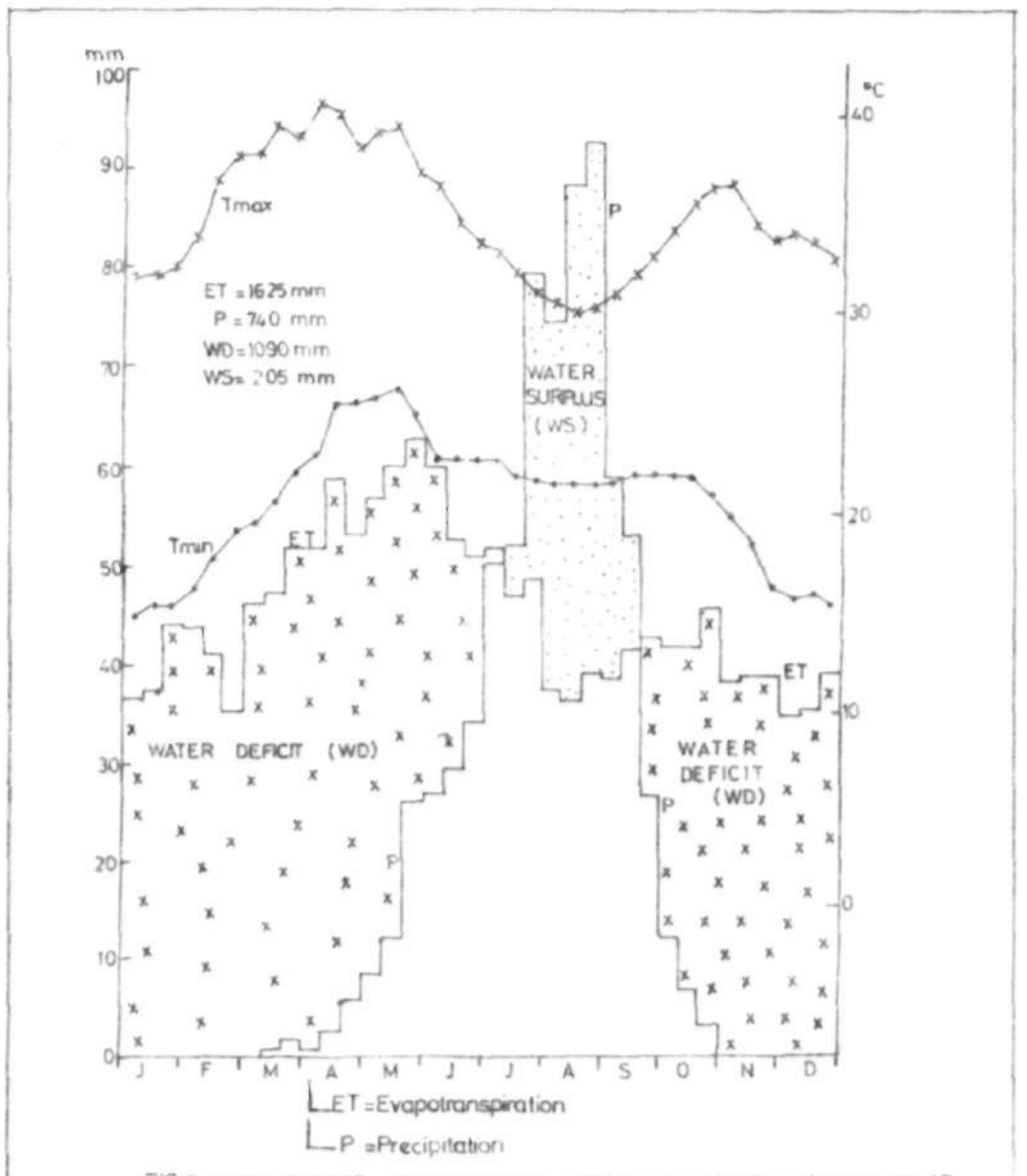


FIG. 3 WATER BUDGET HISTOGRAM WITH AVERAGE MAXIMUM (Tmax) AND AVERAGE MINIMUM (Tmin) SCREEN TEMPERATURES IN TEN DAYS PERIOD FOR SOKOTO OVER 20 YEARS PERIOD (KOWAL AND KNABE, 1972)

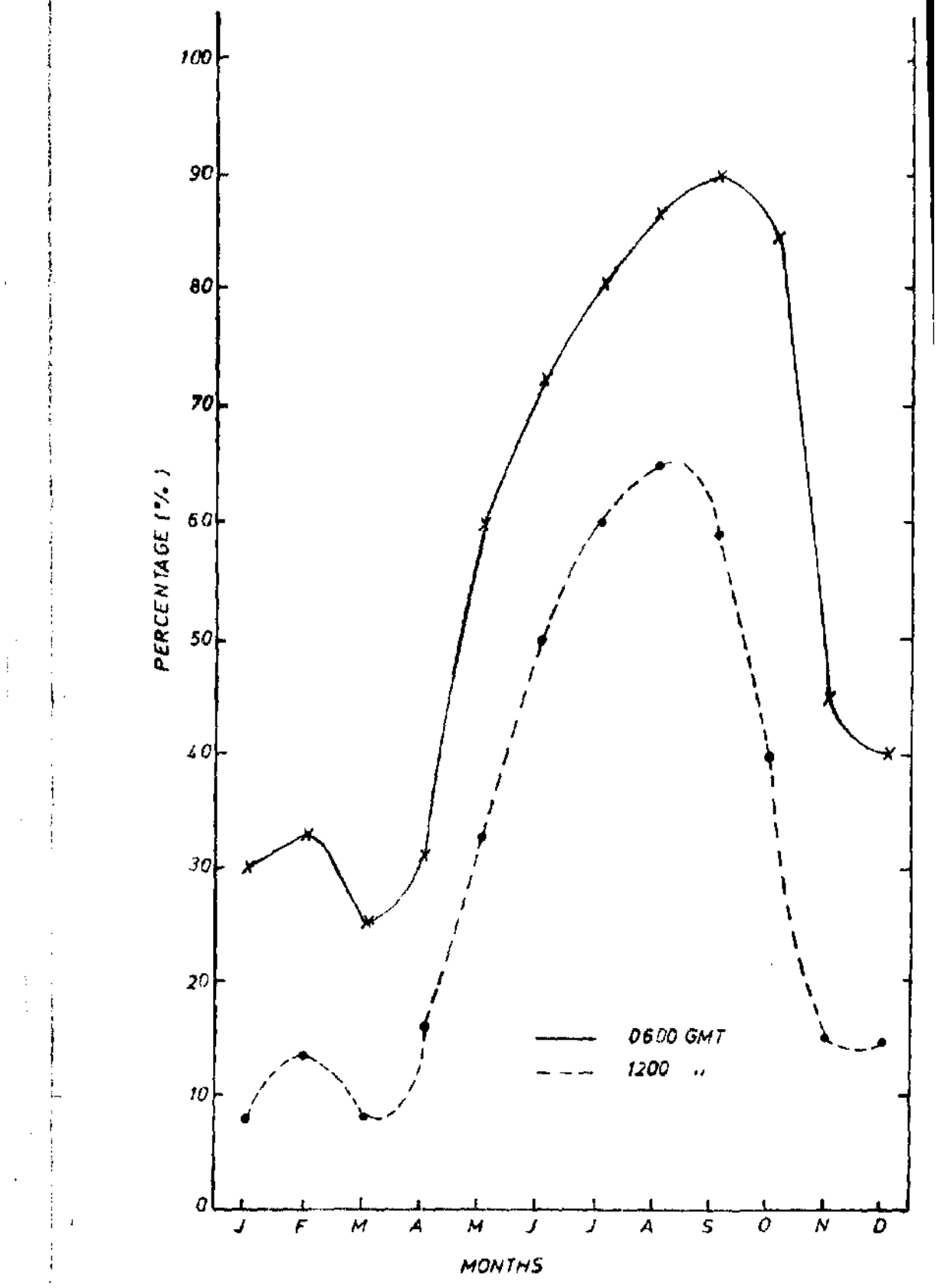


FIG.4: MEAN RELATIVE HUMIDITY AT SOKOTO FOR T
YEARS 1943–47

The seasonal range of temperature is usually high as the difference between dry and wet season insolation is very pronounced. Maximum temperatures are attained before the onset or the rains more frequently in March and April (Fig.3). Monthly mean maxima are usually up to 40°C in April and fall to 30°C in August (Kowal and Knabe, 1972). Monthly mean minima rise to 25°C in May and fall to 15°C in December. The diurnal range of temperature is marked since the clear skies which promote day time heating allow night-time radiation.

The relative humidity in the project area changes abruptly with the movement of harmattan or maritime air (FAO, 1969). The highest recorded relative humidity is associated with maritime air mass while the lowest recorded relative humidity is associated with the harmattan.

Towards the beginning of the wet season starting in May, the number of humid days increases gradually with general northward movement of the southern monsoon air, thus showing a moderate increase in the relative humidity reaching a maximum of over 90 percent in August (Fig. 4). After the wet season, the northern continental air mass moves faster towards the south, resulting in an abrupt drop in relative humidity.

Mean daily variations of relative humidity are closely associated with daily temperature. The lowest temperature at about 0600 hours is accompanied by the highest relative humidity, and the highest temperature at about 1200 hours corresponds to the lowest relative humidity (Fig. 4).

Table 3: Evaporation from storage reservoir at Wurno (cm/month). (FAO 1969).

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1965	11.9	17.5	23.7	17.8	nr.	nr.	nr.	nr.	nr.	nr.	nr.	17.5
1966	16.6	21.0	20.3	12.6	nr.	nr.	nr.	nr.	nr.	nr.	nr.	nr.

nr = not recorded.

3.7 Population

The two ethnic groups that inhabit the area are the Fulani and the Hausa. Although farming and trading predominate amongst the latter, and cattle rearing amongst the Fulani tribe, many Hausa peasant farmers now own cattle, and many Fulani have abandoned cattle rearing and become cultivators (Kogbe, 1979).

The project area is situated within the sparsely populated districts of Sokoto State with the highest densities occurring in Wurno town. There are smaller

settlements scattered within and around the Wurno Irrigation scheme, which include Lugu, Dimbisu, Duwa, Wuchi and Gidan Modi (Fig. 1B).

This confirms the fact that the areas bordering the rivers are the most densely settled due to the need to establish settlements near a water source which is needed for domestic comsumption and dry season farming on floodplain.

3.8 Present Land Use

Two major types of agricultural land identified by FAO (1969) are the floodplain and the upland. The soils in the floodplain, which are somewhat heavy because of high silt and clay content washed from the upper reaches of the rivers, are rather productive. During the dry season irrigation from wells is practised where the water table is high. The crops mainly grown are maize, wheat, sweet potatoes, vegetables, onions, tobacco and sugar cane. Rice is the only crop grown in the floodplain during the rainy season and the variety chosen is the one that tolerates high floods. The cattle belonging to the resident population graze during the dry season on the floodplain while during the wet season, they depend for their forage on the fallow grassland and reserved forests.

The project area is a partial polder scheme of which the source of water is an artificial lake known as Lugu Dam created by damming an abandoned channel of River Rima. Wheat was the main crop but now replaced by rice in the rainy season and vegetables and onion in the dry season. The Sokoto State Ministry of Agriculture has been carrying out research in irrigated agriculture on a small scale, in which the local farmers are highly involved. Land is rented to farmers in 0.4 hectare plots to grow rice while the Government levels the land with heavy machinery and ploughs with tractors. The farmers make the channels on their own land while the main canals are constructed and maintained by the Government. The irrigation water is controlled to a considerable extent.

In the uplands the main crops grown are guinea corn, millet and cowpeas. Millet and guinea corn are the staple food of the local population. The traditional practice of bush fallow is still followed in the uplands but with increasing pressure of population, the fallow period is being shortened, and the need for more in intensive methods of production is apparent. The nomadic cattle also graze in both the reserved and unreserved forest areas during the wet season.

CHAPTER FOUR

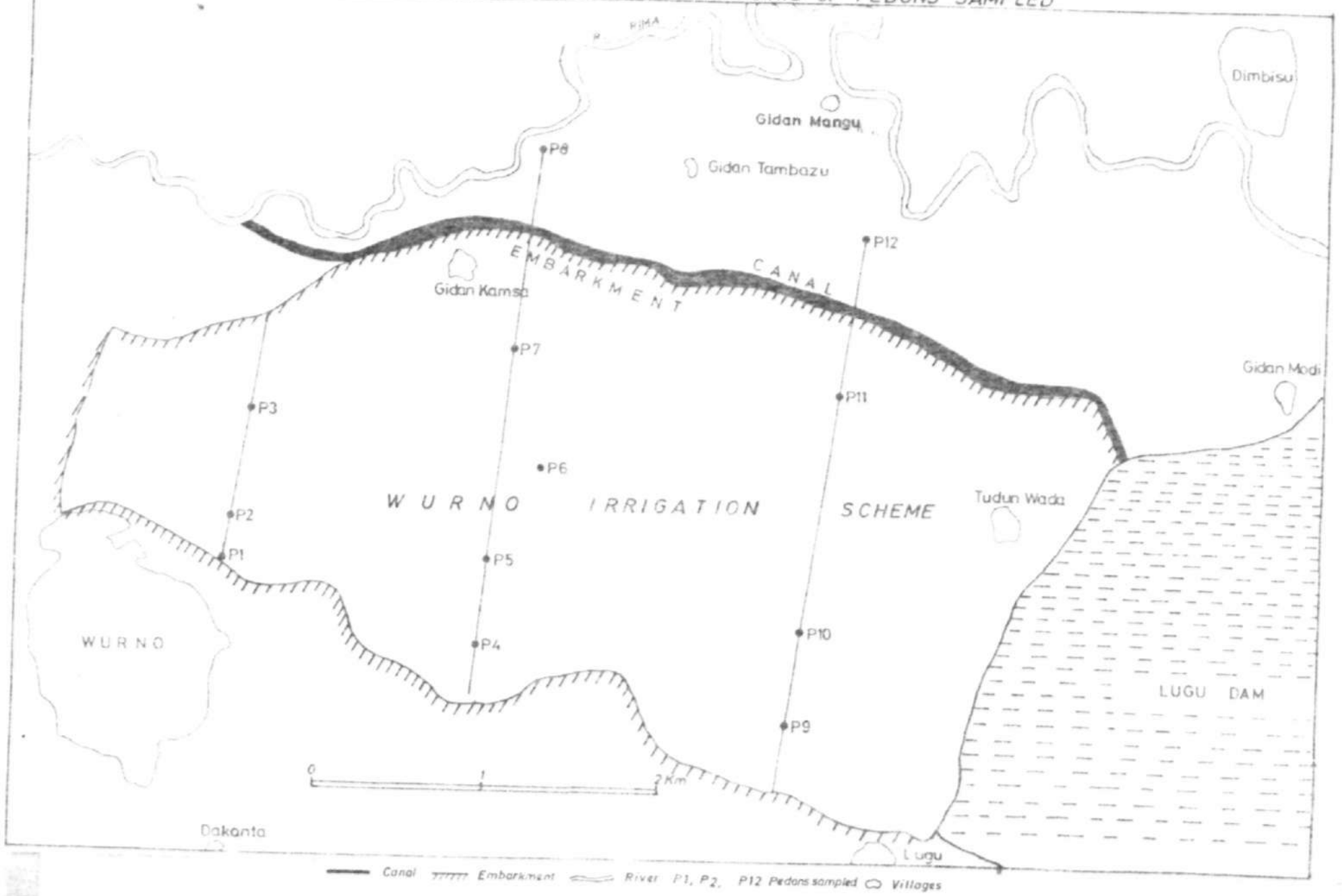
MATERIALS AND METHODS

4.1 Field Studies

A preliminary investigation of the area under Wurno Irrigation Scheme was first undertaken to generally assess the possibility of occurrence of salt affected soils. Also since the occurrence of the salt on the surface is a seasonal phenomenon in this part of Sudan Zone, the investigation was carried out at the peak of the dry season (21 and 23 February, 1982) when the surface efflorescences became more conspicuous.

Three traverses spaced at intervals of about 1.5 km apart were laid across the area. The traverses were such that they cut across the irrigated plots as well as the non-irrigated plots within and outside the Wurno Irrigation Scheme. By this procedure the loci of salt affected soils in relation to other soils that are non-salt affected were revealed. Profile pits were dug at sites along the traverses where evidence of surface efflorescences were observed particularly within the irrigated plots, and for comparison purpose, at sites outside the irrigated plots. The pedons were assigned pedon No. 1, 2, 3, ... and 12 respectively (Fig.5).

FIG. 5 : THE TRAVERSES AND POINTS OF PEDONS SAMPLED



The morphological characteristics of each pedon were described according to the U.S.D.A. system (Soil Survey Staff, 1962) and bulk samples from each of the horizons were taken for laboratory analyses.

4.2 Laboratory Analyses

4.2.1 Preparation of samples

The bulk samples were air-dried, ground and passed through a 2 mm sieve for subsequent analyses.

4.2.2 Particle size distribution analysis

The method used is essentially the hydrometer procedure of Bouyoucous as described by Day (1956). The fine earth samples ($\leq$ 2 mm diameter) were treated with sodium hexametaphosphate as a dispersing agent and sufficiently shaken on a horizontal reciprocating shaker. Each sample was transferred to a 1000 cm^3 cylinder, and the volume made to mark. The proportion of each separate (sand, silt and clay) was derived from the hydrometer measurements. The sand fraction was separated into coarse and fine sub-fractions by sieving with a 72-mesh sieve (0.21 mm).

4.2.3 Water saturation percentage

A sufficient amount of saturated soil paste was made by adding distilled water to a sample of soil while stirring. The criteria for saturation is when

the soil paste glistens as it reflects light, and flows slightly when the container is tipped (U. S. D. A, Salinity Laboratory Staff, 1969).

A weighed portion of the saturated soil paste was then transferred into an aluminium dish (of known weight) and placed in an oven kept at 105°C overnight. The remaining portion was kept for later use.

Calculation:

Saturation percentage (Sp) =

Loss in weight on drying X100/weight of oven dry soil.

4.2.4 Soil reaction

The pH readings were determined in 1:1 and 1:2 soil: water suspensions for each of the samples. The suspensions were prepared using distilled water, and shaken intermittently for an hour before pH readings were taken by pH meter method (U.S.D.A.Salinity Laboratory Staff, 1969).

4.2.5 Organic matter

The method of Walkley and Black (1934) was used for the determination of organic carbon. The samples were ground to pass through a 500/u screem. A weighed amount (1 gm) of each of the samples was oxidized

with standard potassium dichromate solution and sulphuric acid which provides the heat for the reaction. This was followed by titration of the excess dichromate with a standard ferrous ammonium sulphate solution, using orthophenanthroline as indicator. The percent organic matter was derived by multiplying the percent carbon by factor of 1.72.

4.2.6 Cation exchange capacity

Soil cation exchange capacity usually defined as the sum of exchangeable cations of a soil was determined by NaOAc/NH_4OAc method. This method was preferred to the NH_4OAc method because the ammonium ion is subject to fixation in saline and alkaline soils (Bower et al, 1952). The soil samples were saturated with sodium acetate at pH 8.2. The adsorped sodium displaced by ammonium after repeated treatment with ammonium acetate was then determined by flame photometry.

4.2.7 Exchangeable cations

The samples were leached with ammonium acetate (NH_4OAc) solution at pH 7.0 (Bower et al, 1952). Sodium and potassium in the leachate were determined by means of flame emission, using a standard flame photometer while calcium and magnesium were determined by atomic absorption spectrophotometry.

4.2.8 Soluble cations and anions

Saturated soil extract was obtained by the use of a vacuum pump on the paste saved from the water saturation determination. Soluble cations and anions determinations were carried out on the soil saturation extract. Soluble sodium and potassium were determined on the flame photometer while soluble calcium and magnesium were determined using the atomic absorption spectrophotometer.

Soluble carbonates and bicarbonates in the saturation extract were titrated against sulphuric acid using phenophthalein and methyl orange as indicator respectively while soluble chloride was determined by titrating with standard silver nitrate reagent (Reitemeier, 1943). Sulphate in the saturation extract was estimated from the difference between soluble cations minus measured soluble anions.

4.2.9 Electrical conductivity measurement

Part of the saturation extract obtained was used for the determination of the electrical conductivity at full saturation using a bridge scale and the conductivity cell (U. S. D. A. Salinity Laboratory Staff, 1969).

4.2.10 Exchangeable sodium percentage (ESP)

The exchangeable sodium percentage (ESP) was got by derivation using the equation:

ESP = Exchangeable Na in meq/100g x 100/cation exchange capacity.

CHAPTER FIVE

RESULTS AND DISCUSSION

The characterization of soils which is very pertinent to the understanding of the soils when considering their management and reclamation is assessed in terms of their morphological, physical and chemical properties.

5.1 Soil Morphological Characteristics

5.1.1 Soil descriptions

The soils in the study area occur on almost flat or nearly level floodplain termed "Fadama" in Hausa. The floodplain is subjected to floods in the rainy season, and is characterized by a high water table which recedes to between 1 metre and 1.5 metres of the surface at the peak of the dry season. Due to this factor, the soils are imperfectly to very poorly drained.

Depositional beddings or strata evidenced by very strong stratification are common to all the soils. Most of the soils (pedons 1, 2, 4, 6, 8, 10, 11 and 12) are characterized by (A) C profiles which are relatively little modified by pedogenic processes other than humus formation.

All the pedons are characterized by an ochric epipedon. The profile morphology of each of the pedons is typical of alluvial soils, as described below.

Pedon one

This soil occurs on fluviatile fine loamy sand to clay loam of "Kurukuru" micaceous deposits. The landform is an old levee of a recent meandering river system characterized by a gentle relief. Rice is grown in the surroundings but the pedon was left bare due to incipient salinity.

Location:	At the one kilometre point along Wurno - Lugu road and about 200 metres north east of Wurno.
Physiographic position:	Rima floodplain
Topography:	Nearly level
Drainage:	Somewhat poorly drained
Depth to water table:	1.8 metres
Vegetation and landuse:	Uncultivated but surroundings cultivated with rice.
Parent material:	Micaceous fluviatile deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
A1	0-25	Dark yellowish brown (10 YR 4/4. moist) loam; few, medium distinct brownish yellow (10 YR 6/8) mottles; moderate medium subangular blocky structure; hard dry, firm moist, slightly sticky and slightly plastic wet; common, fine and medium roots; few fine and medium iron concretions (of secondary origin); common fine interstitial open pores; mildly alkaline (pH 7.6); light grey surface efflorescences; abrupt, smooth boundary:
AC	25-67	Yellowish brown (10YR 5/6, moist) loam; very few dark reddish brown (5 YR 3/3) mottles; weak (almost massive) medium subangular blocky structure; friable moist, slightly sticky and slightly plastic wet; common micas; few fine and medium interstitial open pores; mildly alkaline (pH 7.8); abrupt, smooth boundary.

Horizon	Depth (cm)	Description
C1	67-86	Light brownish gray (10 YR 6/2, moist) sandy loam; common, fine and medium distinct dark brown (7.5 YR 4/4) mottles; structureless, massive; friable moist, slightly sticky and slightly plastic wet; common micas; moderately alkaline (pH 7.9); abrupt, smooth boundary.
C2	86-115	Yellowish brown (10 YR 5/4, moist) silt loam; common medium distinct yellowish brown (10 YR 5/8) mottles; structureless, massive; horizontal cleavages associated with macro-stratification; firm moist, slightly sticky and slightly plastic wet; common micas; very few fine iron concretions; mildly alkaline (pH 7.7); clear, smooth boundary.
II C3	115-130	Grayish brown (10 YR 5/2, moist) loam; common fine and medium prominent brownish yellow (10 YR 6/8) mottles; weak (almost massive) medium and coarse subangular blocky structure; friable moist, slightly

Horizon	Depth (cm)	Description
		sticky and slightly plastic wet; common micas; very few interstitial pores; mildly alkaline (pH 7.5); abrupt, smooth boundary.
III C4	130-180	Light brownish gray (10 YR 6/2, moist) clay loam; many, medium and coarse distinct yellowish brown (10 YR 5/6) mottles; structureless, massive; firm moist; sticky and plastic wet; mildly alkaline (pH 7.6).

Pedon Two

Pedon two is developed on lacustrine clay of "Ambursa Central" sediments. The landform is a relatively high part of a former lacustrine flood basin which has nearly level relief. The soil is very poorly drained due to the heavy textured horizons which impede downward percolation of water. Rice is grown on supplemental irrigation basis in the wet season. Onion is grown during the dry season.

Location: About 500 metres north east of Wurno town and 300 metres north of the one kilometre point along Wurno-Lugu road.

Physiographic position: Flood plain of River Rima.

Topography: Nearly level, shallow mini-basin.

Drainage: Very poorly drained.

Depth to water table: 1.2 metres.

Vegetation and land use: Cultivated with rice (wet season) and onion (dry season).

Parent material: Lacustrine deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-18	Light brownish gray (10 YR 6/2, moist) clay; few, fine and medium distinct red (2.5 YR 5/8) mottles; strong coarse angular blocky structure; very firm moist, very sticky and very plastic wet; common fine roots; common medium interstitial pores; many cracks along line of weakness between macropeds; common, fine and very fine roots; medium acid (pH 5.6); gradual, smooth boundary.

Horizon	Depth (cm)	Description
AC	18-32	Light brownish gray (10 YR 6/2, moist) clay; few fine faint dark reddish brown (10 YR 3/4) mottles; structureless to weak coarse angular blocky structure; firm moist, very sticky and very plastic wet; few cracks; slicken-sides 1 cm across; few very fine roots; strongly acid (pH 5.4); gradual, smooth boundary.
C1	32-69	Light brownish gray (10 YR 6/2, moist) clay; few, fine and medium faint dark reddish brown (10 YR 3/4) mottles; structureless, massive; firm moist, very sticky and very plstic wet; slickensides up to 1 cm across; medium acid (pH 5.6); clear smooth boundary.

Horizon	Depth (cm)	Description
C2	69-90	Pinkish gray (7.5 YR 7/2, moist) clay; few fine faint strong brown (7.5 YR 5/6) mottles; structureless, massive; very firm moist, very sticky and very plastic wet; weak slickensides; slightly acid (pH 6.5); gradual, smooth boundary.
C3g	90-120	Light gray (10 YR 6/1, moist) clay; common, fine and medium faint dark brown (10 YR 3/3) and dark yellowish brown (10 YR 4/4) mottles; structureless, massive; very firm moist, very sticky and very plastic wet; slightly acid (pH 6.4).

Pedon Three

This soil occurs on a relatively high patch of flooded floe terrace. The parent material is the fluviatile sands to sandy loams of "Argungu Floe" sediments with an admixture of clayey sediments. The local relief is nearly level.

Location: One kilometre north of the one kilometre point along Wurno-Lugu road.

Physiographic position: River Rima floodplain.

Topography: Nearly level; less than two percent slope.

Drainage: Imperfectly drained

Depth to water table: 2.4 metres.

Vegetation and landuse: Cultivated with sorghum (wet-season).

Parent material: Fluviatile deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0–10	Dark yellowish brown (19 YR 4/4, moist) fine sandy loam; weak medium subangular blocky structure; hard dry, friable moist, slightly sticky and non-plastic wet; common fine roots; common fine and medium interstitial pores; medium acid (pH 5.9), diffuse, smooth boundary.
A12	10–25	Yellowish brown (10 YR 5/6, moist) fine sandy loam; weak, fine and medium subangular blocky structure; slightly hard dry, friable moist, slightly sticky

Horizon	Depth (cm)	Description
		and slightly plastic wet; few fine roots; few fine interstitial pores; patchy thin coatings of fine sand on ped faces; neutral (pH 6.7); gradual, smooth boundary.
B1	25-50	Pinkish white (7.5 YR 8/2, moist) silt loam; few, fine and medium faint yellow (10 YR 8/6) mottles; weak medium subangular blocky structure; very friable moist, slightly sticky and slightly plastic wet; few fine roots; few fine interstitial pores; faint clay skins; mildy alkaline (pH 7.4); gradual, smooth boundary.
C1	50-80	Pink (7.5 YR 8/4, moist) sandy loam; few medium faint reddish yellow (7.5 YR 7/6) mottles; porous massive structure; loose moist, non sticky wet; very few fine roots; mildly alkaline (pH 7.8) gradual, smooth boundary.

Horizon	Depth (cm)	Description
II C2	80-125	Dark brown (7.5 YR 4/4, moist) clay; common medium faint strong brown (7.5 YR 5/8) mottles; weak (almost massive), medium and coarse subangular structure; firm moist, very sticky and very plastic wet; very few, fine and medium tubular and interstitial pores; thin complete clay skins; slightly acid (pH 6.5); gradual, smooth boundary.
III C3	125-180	Very pale brown (10 YR 7/3, moist) coarse sand; very few faint yellow (10 YR 7/6) mottles; structureless, single grain; loose moist, non-sticky wet; mildly alkaline (pH 7.5).

Pedon Four

This soil is characterized by fine textured horizons which developed from the lacustrine heavy clays of "Ambursa Central" deposits. The landform is an elongated extensive former lacustrine shallow

flood basin which is almost flat. The soil is very poorly drained due to high water table and seasonal flooding during the wet season.

Location: About 2.3 kilometres north west of Lugu town.

Physiographic position: River Rima floodplain.

Topography: Nearly level; less than two percent slope.

Drainage: Very poorly drained.

Depth to water table: 1.2 metres.

Vegetation and landuse: Cultivated with rice by irrigation.

Parent material: Lacustrine deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-14	Dark brown (7.5 YR 4/4, moist) clay; few fine and medium faint strong brown (7.5 YR 5/6) mottles; strong coarse angular blocky structure; very hard dry, firm moist, very sticky and very plastic wet; many fine roots; many open cracks 3cm across; many, fine and medium interstitial pores; slightly acid (pH 6.4); abrupt, smooth boundary.

Horizon	Depth (cm)	Description
AC	14-38	Dark brown (7.5 YR 4/2, moist) clay; few fine faint yellowish red (5 YR 5/6) mottles; structureless massive; firm moist, very sticky and very plastic wet; few fine roots; weak and broken slickensides; mildly alkaline (pH 7.7); abrupt, smooth boundary.
C1	38-78	Brown (10 YR 4/3, moist) clay; few fine and medium faint yellowish red (5 YR 5/6) mottles; structureless, massive; some horizontal cleavages; firm moist, very sticky and very plastic wet; faint and broken slickensides; mildly alkaline (pH 7.6; gradual, smooth boundary.
C2	78-110	Light gray (10 YR 6/1, moist) clay; common medium distinct red (2.5 YR 5/6) mottles; weak almost massive) medium

Horizon	Depth (cm)	Description
		angular blocky structure; firm moist, very sticky and very plastic wet; few fine vesicular pores; faint broken clay skins; mildly alkaline (pH 7.4); gradual, smooth boundary.
II C3g	110-130	Gray (10 YR 5/1, moist) sandy loam; common, fine and medium distinct yellowish brown (10 YR 5/6 and reddish brown (5 YR 4/6) mottles; structureless, massive; friable moist; slightly sticky and non-plastic wet; mildly alkaline (pH 7/4).

Pedon Five

Pedon five developed on fluviatile loamy sand to loams of "Kurukuru" micaceous sediments of the terracelike old levees of a recent meandering river system.

Location: About two kilometres south of Gidan Mangu.

Physiographic position: River Rima floodplain

Topography: Nearly level

Drainage: Poorly drained

Depth to water table: 0.85 metre

Vegetation and landuse: Under irrigated rice

Parent material: Fluviatile sediments

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-10	Dark yellowish brown (10 YR 4/4, moist) sandy clay loam; few fine faint yellowish brown (10 YR 5/6) mottles; strong, medium and coarse angular blocky structure; hard dry, firm moist, slightly sticky and slightly plastic wet; common fine roots; many, fine and medium interstitial pores; many open cracks; mildly alkaline (pH 7.6); grey saline crust on surface; smooth, gradual boundary.

Horizon	Depth (cm)	Description
AC	10-35	Light brownish gray (10 YR 6/2, moist) sandy clay loam; common medium distinct yellowish brown (10 YR 5/8) mottles; weak, fine and medium subangular blocky structure; friable moist, sticky and plastic wet; few fine roots; few micas; weak macro-stratification; few, fine and dedium interstitial pores; moderately alkaline (pH 7.9); smooth, abrupt boundary.
C1	35-77	Light brownish gray (10 YR 6/2, moist) sandy loam; common medium distinct brownish yellow (10 YR 6/6) mottles; structureless, single grain; loose moist, non - sticky wet; moderately alkaline (pH 7.9); gradual, smooth boundary.
II C2	77-100	Light brownish gray (10 YR 6/2, moist) loamy sand; many, medium and coarse prominent brownish

Horizon	Depth (cm)	Description
		yellow (10 YR 6/6) mottles; structureless, single grain; loose moist, non sticky wet; moderately alkaline (pH 7.9).

Pedon Six

Pedon six developed from fine sandy loam to clay loam of "Kurukuru" micaceous deposits which have been resorted to a considerable extent. The landform is an old levee of a recent meandering river system. The levee has been partially levelled for irrigation purpose. The soil is very poorly drained.

Location: About 1.5 kilometres south south east of Gidan Mangu

Physiographic position: River Rima floodplain

Topography: Level or flatland

Drainage: Very poorly drained

Depth to water table: 1.6 metres

Vegetation and landuse: Uncultivated; surroundings cultivated with rice. Probably avoided due to soluble salts effect.

Parent material: Fluviatile sediments sediments (micaceous)

Typical Profile Description

Horizon	Depth (cm)	Description
A1	0-21	Grayish brown (10 YR 5/2, moist) fine sandy loam; common fine faint brownish yellow (10 YR 6/8) mottles; moderate medium subangular blocky structure; soft dry, friable moist, slightly sticky and non-plastic wet; few fine roots; common fine and medium interstitial pores; neutral (pH 6.9); grey crust on surface; gradual, smooth boundary.
AC	21-50	Dark grayish brown (10 YR 4/2) moist) fine sandy loam; common fine faint brown (10 YR 5/3) mottles; weak medium and coarse angular blocky structure tending towards columnar; friable moist, slightly sticky and non-plastic wet; very few micas; few fine, and common me medium interstitial pores; neutral (pH 7.0); abrupt, smooth boundary.
C1	50-90	Grayish brown (10 YR 5/2, moist) loam; common fine faint dark brown (7.5 YR 4/4) mottles; structureless,

Horizon	Depth (cm)	Description
		massive; firm moist, slightly sticky and slightly plastic wet; medium a acid (pH 6.0); clear, smooth boundary.
C2g	90-133	Gray (5 Y 5/1, moist) clay loam; common, fine and medium yellowish red (5 YR 4/8) mottles; structureless, massive; very firm moist, very sticky and slightly plastic wet; few horizontal cleavages; faint discontinuous clay skins; strongly acid (pH 5.5); abrupt, smooth boundary.
C3g	133-160	Light brownish gray (2.5 Y 6/2, moist) fine sandy loam; common, medium and coarse distinct yellowish brown (10 YR 5/6) mottles; structureless, massive; very friable moist, slightly sticky and non-plastic wet; neutral (pH 7.3).

Pedon Seven

This soil occurs just at the boundary between an abandoned backswamp and a recent meandering river and raised levees of the same river channel. The parent material is the fluviatile sandy loam to clay of "Kurukuru"

micaceous deposits. The soil is imperfectly drained due to its physiographic position on the floodplain, being relatively raised above the abandoned river channel.

Location: About 400 metres south of Gidan Mangu.

Physiographic position: River Rima floodplain

Topography: Nearly level; about two percent slope.

Drainage: Imperfectly drained

Depth to water table: 3.0 metres

Vegetation and landuse: Cultivated with sorghum

Parent material: Fluviatile deposits

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-20	Yellowish brown (10 YR 5/4, moist) coarse sandy loam; strong, medium and coarse subangular blocky structure; hard dry, firm moist, slightly sticky and non-plastic wet; common fine roots; common, medium and fine interstitial pores; few open cracks; slightly acid (pH 6.4); gradual, smooth boundary.

Horizon	Depth (cm)	Description
B1	20-45	Dark yellowish brown (10 YR 3/4, moist) loam; moderate, medium and coarse subangular blocky structure; firm moist, sticky and slightly plastic wet; few fine roots; few micas; common, fine and medium interstitial pores; some horizontal cleavages associated with macro-stratification; slightly acid (pH 6.5); abrupt wavy boundary.
II B2	45-59	Yellowish brown (10 YR 5/4 moist) silt loam; few fine faint yellowish brown (10 YR 5/8) mottles; weak (almost massive) medium subangular blocky structure; slightly friable moist, slightly sticky and non-plastic wet; common micas; very few fine interstitial and vesicular pores; slightly acid (pH 6.1); abrupt, smooth boundary.
III C1	59-90	Very pale brown (10 YR 7/4, moist) fine sandy loam; few fine faint bright brownish yellow (10 YR 6/6) mottles; structureless, single

Horizon	Depth (cm)	Description
III C1		grain; loose moist, non-sticky wet; neutral (pH 7.0); abrupt, smooth boundary.
IV C2g	90-160	Light brownish gray (10 YR 6/2, moist) clay; few medium faint brown (10 YR 4/6) mottles; structureless, massive; very firm moist, very sticky and plastic wet; slightly acid (pH 6.2); clear, smooth boundary.
V C3g	160-200	Light brownish gray (2.5 Y 6/2, moist) loam; many, fine and medium distinct strong brown (7.5 YR 5/8) and yellowish brown (10 YR 5/8) mottles; structureless, massive; very firm moist, very sticky and plastic wet; medium acid (pH 6.0).

Pedon Eight

Pedon eight occurs on the levees of a recent meandering river, which has been considerably altered by ploughing and other cultivation activities. Sorghum is the major crop grown while the surrounding land is left fallow but under intensive grazing. It is not within the Wurno Irrigation Scheme.

Location: About 500 metres north of Gidan Mangu.

Physiographic position: River Rima floodplain

Topography: Nearly level

Drainage: Poorly drained

Depth to water table: 2.6 metres

Vegetation and landuse: Cultivated with sorghum.

Parent material: Micaceous fluviatile sediments.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-15	Dark yellowish brown (10 YR 4/4, moist) clay loam; few fine and medium faint strong brown (7.5 YR 5/6) mottles; strong, fine and medium granular structure; hard dry, firm moist, sticky and plastic wet; many, fine and coarse roots; many medium interstitial pores; medium acid (pH 5.8); gradual, smooth boundary.
AC	15-34	Light brownish gray (10 YR 6/2, moist) clay loam; common, fine and medium distinct reddish yellow (7.5 YR 6/8) mottles; moderate coarse, few medium subangular

Horizon	Depth (cm)	Description
		blocky structure; very friable moist, sticky and plastic wet; common fine roots; few micas; common, fine and medium interstitial and tubular pores; medium acid (pH 5.8); gradual, smooth boundary.
C1	34-47	Grayish brown (10 YR 5/2, moist) sandy clay loam; common, fine and medium prominent brownish yellow (10 YR 6/8) mottles; structureless, massive; very friable moist, sticky and plastic wet; few fine roots; common micas slightly acid (pH 6.3); gradual, wavy boundary.
C2	47-63	Grayish brown (10 YR 5/2, moist) loam; common fine distinct yellowish brown (10 YR 5/6), strong brown (7.5 YR 5/8) mottles; structureless, massive; friable moist, slightly sticky and slightly plastic wet; very few fine roots; many micas; slightly acid (pH 6.5); gradual, wavy boundary.

Horizon	Depth (cm)	Description
II C3	63-104	Brown (10 YR 4/3, moist) sandy loam; few fine faint bright yellowish and dark reddish brown (2.5 YR 3/4) mottles; grayish streaks of quartz material; structureless, single grain; loose moist, non-sticky wet; neutral (pH 7.2); abrupt, wavy boundary.
III C1	104-184	Very dark grayish brown (10 YR 3/2, moist) clay; very few fine, very faint brown (10 YR 5/3) mottles; structureless, massive; very firm moist, very sticky and very plastic wet; slightly acid (pH 6.1).

Pedon Nine

Pedon nine developed on a shallow concave depression within the spill area of a recent meandering river system. The parent material is the fluviatile clay loams and clays of the "Gande" micaceous deposits which are calcareous and have white lime concretions in voids in the subsoil. The depression had been modified for irrigation purposes with bunds built to enclose the depression. The profile pit was situated close to the bund where greyish efflorescences were observed, indicating precipitation of soluble salts.

Location: About 600 metres north west of Lugu town.

Physiographic Position: River Rima floodplain.

Topography: Nearly level.

Drainage: Very poorly drained

Depth to water table: 0.86 metre

Vegetation and landuse: Bare but surroundings are cultivated with rice.

Parent material: Micaceous fluviatile sediments.

Typical Profile Description

Horizon	Depth (cm)	Description
A1	0-10	Pale brown (10 YR 6/3, moist) clay loam; common medium distinct strong brown (7.5 YR 5/6) mottles; moderate medium subangular blocky structure; firm moist, sticky and plastic wet; common fine roots; common, fine and medium interstitial pores; strongly acid (pH 5.5); gradual, smooth boundary.
A12	10-24	Grayish brown (10 YR 5/2, moist) clay loam; common dedium prominent brownish yellow (10 YR 6/8) mottles; weak coarse subangular

Horizon	Depth (cm)	Description
		blocky structure; firm moist, slightly sticky and slightly plastic wet; very few micas; few fine roots; few and medium interstitial pores; neutral (pH 7.1); abrupt, smooth boundary.
AC	24-42	Light brownish gray (10 YR 6/2, moist) loam; common medium and coarse prominent yellowish brown (10 YR 5/6) mottles; moderate coarse angular blocky structure; very friable moist, slightly sticky and slightly plastic wet; few very sticky lime concretions; common micas; common, fine and medium interstitial and vesicular pores; neutral (pH 7.2); clear, irregular boundary.
Cca	42-90	Very dark brown (10 YR 3/2, moist) gray (5 Y 5/1, moist) clay; common medium, faint and distinct brown (10 YR 5/3) light olive brown (2.5 Y 5/4) mottles; structureless, massive; few horizontal cleavages; very firm moist, very sticky and very plastic wet; few very sticky lime concretions; mildly alkaline (pH 7.4).

Pedon Ten

This soil is developed on the fluviatile sandy loam to clay of "Gande" micaceous sediments of levees formed by recently deserted river channels. The soil is characterized by poor horizon development with only few horizons present.

Location: About 1.2 kilometres south west of Tudun Wada.

Physiographic position: Within River Rima floodplain

Topography: Nearly level

Drainage: Poorly drained

Depth to water table: 2.0 metres

Vegetation and landuse: Uncultivated.

Parent material: Micaceous fluviatile deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
A1	0-25	Light yellowish brown (10 YR 6/4, moist) sandy loam; few fine faint yellowish brown (10 YR 5/8) mottles; moderate medium subangular blocky structure; soft dry, friable moist, slightly sticky and non-plastic wet; common fine roots; common,

Horizon	Depth (cm)	Description
		fine and medium interstitial pores; slightly acid (pH 6.2); gray surface crust; abrupt, wavy boundary.
AC	25-65	Yellow (10 YR 7/6, moist) sandy loam; few fine very faint dark brown (10 YR 5/3) mottles; weak subangular blocky structure; loose moist, non-sticky wet; neutral (pH 7.1); abrupt, wavy boundary.
II C1g	65-119	Light gray (10 YR 6/1, moist) silty clay loam; few fine faint yellowish brown (10 YR 5/4) mottles; structureless, massive; firm moist, slightly sticky and slightly plastic wet; common micas; few fine, interstitial and vesicular pores; neutral (pH 6.9); gradual, smooth boundary.
III C2g	119-150	Grayish brown (2.5 Y 5/2, moist) clay; few fine faint yellowish brown (10 YR 5/4) mottles; structureless, massive; very firm

Horizon	Depth (cm)	Description
		moist, very sticky and very plastic wet; few micas; slightly acid (pH 6.1); gradual, smooth boundary.
IV C3g	150-200	Light brownish gray (2.5 Y 6/2, moist) sandy loam; common medium distinct yellowish brown (10 YR 5/6) mottles; weak subangular blocky structure; friable moist, slightly sticky and slightly plastic wet; common micas; very few interstitial pores; moderately alkaline (pH 8.0).

Pedon Eleven

This pedon occurs on former lacustrine flood basin which is relatively flat. The basin is subject to flooding to about 60 centimetres annually. The soil is used for cultivation of rice by irrigation.

Location: About 1.2 kilometres north west of Tudun Wada.

Physiographic position: River Rima floodplain

Topography: Nearly level; less than one percent slope.

Drainage: Very poorly drained

Depth to water table: 1.7 metres

Vegetation and landuse: Used for rice cultivation

Parent material: Lacustrine sediments.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-15	Grayish brown (10 YR 5/2, moist) clay loam; common fine distinct strong brown (7.5 YR 5/8) mottles; strong, medium and coarse angular blocky structure; very hard dry, very firm moist, very sticky and very plastic wet; common fine roots; common, fine and medium interstitial pores; many cracks; medium acid (pH 5.6); clear, smooth boundary.
Bg	15-30	Very dark brown (10 YR 2/2, moist) clay; few fine faint yellowish brown (10 YR 5/6) mottles; moderate coarse angular blocky structure; very firm moist, very sticky and very plastic wet; few fine roots; few fine interstitial and vesicular

Horizon	Depth (cm)	Description
		pores; weak slickensides; faint clay skins; medium acid (pH 5.6); clear, wavy boundary.
II C1g	30-65	Light brownish gray (10 YR 6/2, moist) fine sandy loam; common, fine and medium distinct yellowish brown (10 YR 5/6) mottles; structureless, single grain; very friable moist, non-sticky wet; neutral (pH 6.8); abrupt, irregular boundary.
III C2g	65-124	Light brownish gray (2.5 Y 6/2, moist) clay; common fine distinct strong brown (7.5 YR 5/6) mottles; structureless, massive; few horizontal cleavages; very firm moist, very sticky and very plastic wet; moderately alkaline (pH 7.9); clear, wavy boundary.
IV C3g	124-170	Grayish brown (10 YR 5/2, moist) silty clay; few fine faint yellowish brown (10 YR 5/6) mottles; structureless, massive; some horizontal

Horizon	Depth (cm)	Description
		cleavages; very firm moist, very sticky and very plastic wet; moderately alkaline (pH 8.0).

Pedon Twelve

Pedon 12 which occurs on fluviatile fine sandy loam to loam of "Kurukuru" micaceous deposits of an abandoned levee of an old river is characterized by flattish relief. As the site is slightly raised above the general topography, the soil is used for cultivation of sorghum under rainfed agriculture.

Location: 1.0 kilometre south south east of Gidan Mangu.

Physiographic position: River Rima floodplain

Topography: Flattish; less than two percent slope.

Drainage: Very poorly drained.

Depth to water table: 3.5 metres.

Vegetation and landuse: Low trees, sorghum.

Parent material: Micaceous fluviatile deposits.

Typical Profile Description

Horizon	Depth (cm)	Description
Ap	0-15	Dark brown (7.5 YR 4/4, moist) loam; few fine distinct yellowish red (5 YR 5/8) mottles; moderate fine subangular blocky structure; hard dry, very friable moist, slightly sticky and slightly plastic wet, common fine roots; common, fine and medium interstitial pores; common antholes; strongly acid (pH 5.3); gradual, wavy boundary.
B1	15-29	Strong brown (7.5 YR 5/6, moist) fine sandy loam; common fine distinct yellowish red (5 YR 5/8) mottles; weak fine subangular blocky structure; hard dry, very friable moist, slightly sticky and slightly plastic wet; few fine roots; common fine interstitial pores; few antholes; slightly acid (pH 6.4); clear, wavy boundary.
C1	29-40	Light brownish gray (10 YR 6/2, moist) fine sandy loam; common medium distinct yellowish brown

Horizon	Depth (cm)	Description
		(10 YR 5/6) mottles; compact structure (traffic pan); very hard dry, very friable moist, non-sticky wet; few micas; few antholes; neutral (pH 7.3); clear, smooth boundary.
C2	40-52	Grayish brown (10 YR 5/2, moist) silt loam; common medium distinct yellow (10 YR 7/6) mottles; compact structure as above; very hard dry, very friable moist, slightly sticky and non-plastic wet; few micas; few antholes; mildly alkaline (pH 7.7); abrupt, smooth boundary.
C3	52-95	Dark grayish brown (10 YR 4/2, moist) fine sandy loam; common fine faint yellowish brown (10 YR 5/4) mottles; compact structure; very hard dry, friable moist, slightly sticky and non-plastic wet; common micas; moderately alkaline (pH 8.1); abrupt, smooth boundary.

Horizon	Depth (cm)	Description
II C4	95-130	Brown (10 YR 4/3, moist) clay; few fine distinct yellowish red (5 YR 5/8) mottles; structureless, massive; very firm moist, very sticky and very plastic wet; mildly alkaline (pH 7.8); diffuse, smooth boundary.
III C5	130-190	Grayish brown (10 YR 5/2, moist) loam; many, fine and medium faint yellowish brown (10 YR 5/6) mottles; weak, fine and medium subangular blocky structure; firm moist, slightly sticky and slightly plastic wet; common micas; few very sticky lime concretions; few, fine and medium interstitial pores; very strongly alkaline (pH 9.4).

5.2 Physical Characteristics

5.2.1 Particle size distribution.

The particle size distribution data are shown in Table 4. From the results, coarse fragments (greater than 2 mm in diameter) are negligible in all the pedons. The absence of gravel is likely connected with the origin of the parent materials which were well sorted by past

Table 4: Some Physical characteristics of the soils

Soil	Horizon	Depth	Particle size dust (< 2mm)				
			Sand			Silt	Clay
		cm	Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05mm	0.05-0.002mm	<0.002mm
			%				
Pedon 1	A_1	0-25	18	26	44	34	22
	AC	25-67	18	24	42	36	22
	C_1	67-86	19	36	54	30	16
	C_2	86-115	15	17	32	44	24
II	C_3	115-130	21	23	44	32	24
III	C_4	130-180	12	11	23	47	30
Pedon 2	Ap	0-18	14	4	18	26	56
	AC	18-32	12	2	14	24	62
	C_2	32-69	12	2	14	26	60
	C_3	69-90	22	8	30	22	48
	C_{4g}	90-120	24	8	32	18	50

Soil	Horizon	Depth	Particle size dust (< 2mm)				
			Sand			Silt	Clay
		cm	Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05mm	0.05-0.002mm	<0.002mm
			%				
Pedon 3	Ap	0-10	16	42	58	32	10
	A_{12}	10-25	13	43	56	34	10
	B_1	25-50	11	15	26	56	18
	C_1	50-80	7	47	54	38	8
	II C_2	80-125	10	2	12	32	56
	III C_3	125-180	59	27	86	2	12
Pedon 4	Ap	0-14	2	-	2	34	64
	AC	14-38	9	1	10	24	66
	C_2	38-78	13	1	14	18	68
	C_{3g}	78-110	24	10	34	24	42
	II C_{4g}	110-130	34	26	60	12	28

Soil	Horizon	Depth	Particle size dust (<2mm)				
			Sand			Silt	Clay
			Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05mm	0.05-0.002mm	<0.002mm
			%				
Pedon 5	Ap	0-10	34	16	50	20	30
	AC	10-35	31	27	58	24	18
	C_1	35-77	41	27	68	20	12
	II C_2	77-100	43	35	78	10	12
Pedon 6	A_1	0-21	13	39	52	38	10
	AC	21-50	28	32	60	38	2
	C_1	50-90	16	34	50	38	12
	C_{2g}	90-133	19	13	32	32	36
	C_{3g}	133-160	20	31	51	35	14

Soil	Horizon	Depth	Particle size dust (<2mm)				
			Sand			Silt	Clay
			Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05mm	0.05-0.002mm	<0.002mm
			%				
Pedon 7	Ap	0-20	43	10	53	28	19
	B_1	20-45	21	21	42	36	22
II	B_2	45-59	14	2	16	76	8
III	C_1	59-90	32	36	68	22	10
IV	C_{2g}	90-160	12	2	14	28	58
V	C_{3g}	160-200	28	10	38	24	38
Pedon 8	Ap	0-15	23	15	38	32	30
	AC	15-34	24	13	36	32	32
	C_1	34-47	23	23	46	34	20
	C_2	47-63	21	23	44	36	20
II	C_3	63-104	13	45	58	34	8
III	C_4	104-184	21	40	61	30	9

Soil	Horizon	Depth	Particle size dust (<2mm)				
			Sand			Silt	Clay
			Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05	0.05-0.002	<0.002mm
			%				
Pedon 9	A_1	0-10	20	16	36	32	32
	A_{12}	10-24	20	16	36	34	30
	B_2	24-42	17	23	40	44	16
	C	42-90	9	2	11	33	56
Pedon 10	A	0-25	25	26	51	36	13
	AC	25-65	17	53	70	24	6
	II C_{1g}	65-119	13	5	18	46	36
	III C_{2g}	119-150	25	7	32	14	54
	IV C_{3g}	150-200	36	24	60	16	24

Soil	Horizon	Depth	Particle size dust (<2mm)				
			Sand			Silt	Clay
			Coarse 2.0-0.2mm	Fine 0.2-0.05mm	Total 2.0-0.05mm	0.05-0.002mm	<0.002mm
			%				
Pedon 11	Ap	0-15	16	8	24	48	28
	AC	15-30	14	2	16	24	60
	II C_{1g}	30-65	14	44	58	30	12
	III C_{2g}	65-124	13	3	16	26	58
	IV C_{3g}	124-170	13	5	18	42	40
Pedon 12	Ap	0-15	15	25	40	42	18
	AC	15-29	14	44	58	30	12
	C_1	29-40	9	49	58	28	14
	C_2	40-52	5	27	32	64	4
	C_3	52-95	22	27	49	36	15
	II C_4	95-130	12	12	14	28	58
	III C_5	130-190	14	34	48	38	14

river systems before settling in the present sites. Thus the bulk of deposition of materials from the upper reaches of the river systems is the fine earth (less than 2mm diameter) fractions which were transported through a greater distance due to their relatively smaller sizes compared with gravel and larger particles.

Reflecting a strong stratification of material, the texture sequence of most of the pedons is complicated showing no defnite order down their profiles. Pedons 2 and 4, however, show homogeneous clay profiles while pedon 10 has a profile showing gradual increase in clay content with increasing depth, and pedon 5 shows a gradual decrease in clay content down the profile, all within 150 centimetres of the surface.

Total sand content ranges from 2 to 86 percent. This shows a very high variation in sand contents of the soils as predominantly influenced by sedimentation of material rather than pedogenic changes. In pedons 1, 3, 6 and 12, the fine sand fraction (0.2 - 0.05 mm) predominates over the coarse sand fraction. However, while pedon 10 shows an undefined variation in sand content in its horizons, all the remaining pedons are characterized by higher coarse sand fraction than fine sand fraction.

One of the outstanding features in most of the pedons is the high silt content (Table 4). With the exceptions of pedons 2, 4, 5 and 10, all the pedons contain not less than 25 percent silt in all the horizons within 125 centimetres of the surface. Silt content ranges from 2 percent in pedon 3 to 76 percent in pedon 7 which, like the sand fraction, reflects the wide variation in texture of these alluvial soils. Pedon 7 particularly has the highest silt content (a mean value of 36 percent with a range of 14 - 76 percent). Pedon 5 has the lowest mean silt content of 18 percent (a range of 10-24 percent). All the other pedons have silt contents intermediate between the values for the two pedons in an increasing order of pedons 2, 4, 10, 8, 9, 11, 6, 1 and 12. The relatively high silt content of these soils is related to their parent material which is alluvial in nature as explained earlier. This inherited property, including the high clay content in some pedons (discussed later) does not only control the physical properties of the soil, but also the chemical properties including the availability of plant nutrients.

Clay content also varies in similar fashion as the sand and silt contents. However, with the exception of pedons 2, 4, 7 and 9, the clay fraction is usually less than either the total sand content or the silt fraction in most of the horizons. This is consonant with the initial sedimentation by the river systems.

Generally, the clay content ranges between 2 percent (pedon 6) and 70 percent (pedon 7). However, the mean values for the heavy textured pedons (2 and 4) are 55 and 54 respectively.

A basic distinction between the pedons, however, is the relatively sandy sediments of the levees and braided channels (pedons 5, 6 and 10), fine sandy and silty loams of normal flatland of the floodplain (pedons 1, 7, 8 and 12) and the clays of backswamps and lacustrine basins (pedon 2, 4 and 9). Such patterns are complicated by intermittent changes of course of the main channels and, in the longer term, lowering of the active floodplain to leave terraces (Young, 1976) just as in the case of pedons 3 and 11.

Texture of the surface horizons varies considerably from sandy loams for pedons 3, 6 and 10, loams for pedons 1, and 12, clay loams for pedons 5, 8, 9 and 11 to clays for pedons 2 and 4.

In general, the particle size distribution data validate the alluvial nature of the parent materials of all the soils and their sedimentational sequence associated with megastratification. Homogenization which is the elimination of features of depositional

layering, mainly the textural feature, is still at the initial stage with minor clay translocation evidenced by some weak, faint clay skins in the sub-strata of some of the pedons.

5.3 Soil Chemical Characteristics

5.3.1 Organic matter

There is generally a low level of organic matter content in all the soils studied (Table 5 and Appendix). The values range between zero in deep pseudo - horizons of pedons 11 and 12 to 1.38 percent in the surface horizon of pedon 4. In most cases, the organic matter values are less than one percent in the surface horizons and less than 0.5 percent (in some cases less than 0.1 percent) in the subsoil or pseudo-horizons. In pedon 1, the range is 0.17 - 0.34 percent; pedon 11, 0.00-0.95 percent; and in pedon 4, the range is 0.17 - 1.38 percent. The values for the other pedons are within the limits of the ones mentioned above.

The organic matter content which is highest in the surface horizon decreases either sharply or irregularly with depth. In pedons 1, 7, 8, 9 and 12 (Table 5 and Appendix) the strata of clayey materials contain more organic matter than in the overlying coarser strata which is a characteristic of soils of

alluvial parent materials. In pedons 6 and 10, organic matter content does not decrease appredíably below the surface horizons. This is because most of the alluvial parent materials of the soils came from eroding soils or streambanks which had contained considerable amount of organic matter that is mainly in the clay fraction (Soil Survey Staff, 1975). This explains why the heavy textured soils (pedons 2, 4 and to some extent 9) contain comparatively higher organic matter, even in the deep layers, than the coarser-textured soils.

The general low content of organic matter in the soils of the study area is attributable to several factors. Firstly, the semi-arid tropical climate of the area is inimical to the formation and accumulation of humus. Secondly the sparse vegetation cover which results in direct insolation of the soil surface causes rapid oxidation of the soil organic matter. Also the frequent bush fires, intensive cultivation of the soils coupled with dry season grazing of the floodplains result in rapid destruction of the potential humus material in the form of crop residues.

Because of the consistently low organic matter in the soils of the study area, a deficiency of nitrogen and phosphorus is likely to occur, particularly in the

Table 5: Some chemical characteristics of the soils

Soil	Horizon	Depth cm	pH (H_2O)	OM (%)	Exchange cations meq/100g Ca	Mg	K	Na	TEB	CES	CEC*	BS %	ESP	ECe mmhos/cm	WS %	Water soluble ions meq/100g Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4
Pedon 1	A_1	0-25	7.6	0.34	5.93	.54	.77	2.39	9.6	10.6	48.3	91	23	4.8	24	6.9	.9	2.5	6.0	-	2.7	5.2	8.4
	AC	25-67	7.8	0.17	5.10	.60	.87	1.22	7.8	10.5	47.5	74	12	4.7	20	1.4	.2	.5	2.0	-	1.3	2.5	.2
	C_1	67-86	7.9	0.17	5.13	.70	.37	1.09	7.3	9.3	56.4	79	12	2.2	18	1.1	.3	..4	1.3	.3	1.3	1.2	.3
	C_2	86-115	7.7	0.26	7.11	.78	1.13	1.69	10.7	12.2	50.9	88	14	1.4	22	1.0	.6	.5	1.0	.1	1.5	1.3	.3
II	C_3	115-130	7.5	0.17	6.75	1.97	.92	1.30	10.9	11.5	47.7	96	11	1.5	24	1.0	.3	.1	1.2	-	.7	1.8	.2
III	C_4	130-180	7.6	0.17	8.20	1.71	.44	1.00	11.4	11.7	38.8	97	9	2.1	24	1.2	1.0	.2	2.0	-	.5	2.0	1.9

CEC = CEC by NaOAc method.

CEC* = CEC by NaOAc method per 100g of clay.

BS = Base saturation from CEC by NaOAc method.

TEB = Total exchangeable bases.

WS = saturation.

Table 5: Continued Some chemical characteristics of the soils

Soil	Horizon	Depth cm	pH (H_2O)	OM (%)	Exchange cations meq/100g Ca	Mg	K	Na	TEB	CES	CEC*	BS %	ESP	ECe mmhos/cm	WS %	Water soluble ions meq/100g Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4
Pedon 9	A_1	0-10	5.5	.95	6.50	3.44	.53	1.69	12.2	11.2	35.0	100	15	6.5	28	14.5	8.9	.2	24.7	6.11	3.8	12.1	26.4
	A_{12}	10-24	7.1	.43	8.12	3.73	1.54	2.56	16.0	15.7	52.2	100	16	4.5	33	7.4	3.9	.5	7.4	3.2	2.5	6.6	6.7
	B_2	24-42	7.4	.26	4.25	2.00	.92	1.52	8.7	8.7	54.4	100	17	4.2	28	5.0	2.5	.2	5.2	2.2	2.5	3.8	3.9
	C	42-90	6.7	.43	12.50	4.10	1.80	3.24	21.6	24.1	42.5	90	14	3.6	43	3.1	1.2	.2	5.4	.4	2.2	4.4	2.1
Pedon 10	A	0-25	6.2	.52	2.15	.75	.55	1.82	4.3	4.0	33.3	100	19	4.8	27	.7	.4	.1	2.6	-	.8	1.8	1.3
	AC	25-65	7.1	.43	1.50	.50	.27	.22	2.5	3.1	51.8	76	7	1.8	23	.4	.3	.2	.8	-	.6	.5	.6
	II C_{1g}	65-119	6.9	.34	5.42	2.70	.53	1.04	9.7	12.2	33.9	79	9	.9	23	.5	.7	.2	1.1	-	.9	.8	.8
	III C_{2g}	119-150	6.1	.34	5.45	2.52	1.74	1.61	11.3	13.2	24.4	86	12	.8	30	.6	.3	.1	1.1	-	.2	.5	2.4
	IV C_{3g}	150-200	8.0	.17	3.10	1.11	.92	.61	5.7	6.7	27.7	86	9	1.2	21	1.0	1.5	.5	1.4	.3	2.1	1.4	.6
Pedon 12	Ap	0-15	5.3	.77	2.20	.98	.41	.15	3.7	3.6	20.0	100	4	.6	28	.3	.1	.2	.3	-	.3	.1	.5
	AC	15-29	6.4	.26	2.03	.76	.21	.15	3.2	3.4	28.3	93	4	.3	29	.3	.6	.1	.4	-	.6	.5	.3
	C_1	29-40	7.3	.17	2.3	.50	.25	.20	3.3	3.5	25.0	93	6	.5	26	.4	.2	.2	.2	-	.1	.5	.4
	C_2	40-52	7.7	.08	1.60	.25	.24	.27	2.4	2.8	68.8	86	10	.4	29	.1	.1	.1	.4	-	.1	.3	.2
	C_3	52-95	8.1	.08	2.65	.75	1.69	2.24	7.3	7.5	49.8	97	30	.5	27	3.2	1.2	.2	2.3	2.0	2.5	1.2	1.2
	II C_4	95-130	7.8	.26	5.45	2.41	1.30	3.16	12.3	14.1	24.3	87	22	.6	42	.9	1.8	.3	1.5	1.2	1.5	1.0	.8
	III C_5	130-190	9.4	.00	1.65	.91	.36	1.14	4.1	4.3	30.4	96	27	1.2	23	5.2	1.2	.4	3.8	3.5	2.8	3.6	.8

soils subjected to more intensive cultivation and more frequent cropping.

5.3.2 Soil reaction

There is a wide variation in the reaction of the soils in the study area (Table 5 and Appendix). While there are pedons which are strongly acid to neutral in their profiles, the other soils are mildly alkaline to even strongly alkaline.

The first group of soils which are strongly acid to neutral in soil reaction includes pedons 2, 7 and 8 which have soil pH ranging between 5.4 and 7.2. Pedon 2, particularly, has pH range of 5.4 - 6.5. In the second group of soils which includes pedons 3, 4, 6, 9, 10, 11 and 12 the pH varies between 5.5 and 9.4. While pedon 6 has pH range of 5.5 - 7.3 and pedon 10, 6.1 - 8.0, pedon 12, has a range of 6.4 - 9.4. There is still a third group of pedons, 1 and 5, which have pH values in the alkaline range, that is 7.5 - 7.9 and as such are mildly to moderately alkaline in reaction.

In general, the pH values increase with increase in depth of the soil probably due to the alkaline nature of the groundwater which is close to the surface. The

surface horizons of pedons 9, 10 and 12 are acid in reaction. The low pH values, inspite of electrical conductivity values greater than 4 mmhos cm^{-1} at $25^{o}C$, may be due to an excess of exchangeable hydrogen (De Sigmond, 1938) and a high concentration of soluble sulphate (pedon 9) in the soil solution (Table 5). The low pH recorded for the surface horizon of pedon 12 is attributable to, in addition to the factors given above, a low amount of soluble carbonates and bicarbonates. However in some deep strata of pedons 1, 9, 10, 11 and 12 the pH values range between 7.9 - 9.4. This may be due to the calcareous nature of the soil parent materials and the presence of appreciable amounts of soluble carbonates and bicarbonates in the soil. The relatively high pH values reflect the extent of alkalization and/or salinization processes which have taken place in the soils of the area.

5.2.3 Exchangeable bases

Calcium and magnesium are the principal cations found on the exchange complex of the soils in the study area (Table 5), though exchangeable sodium is considerable in some of the soils (pedons 1, 3, 5, 6, 9, 10 and 12). Exchangeable K is comparatively low in all the soils.

Generally, the Ca content is higher than Mg Thus while exchangeable Ca ranges between 20.1 meq/100g and 1.1 meq/100g exchangeable Mg ranges between 6.6 meq/100g and 0.2 meq/100g.

Sodium content which is relatively high in some of the pedons varies between 3.4 meq/100g in pedon 9 and 0.1 meq/100g in pedon 7. In general, the high Na content is associated with alkalization/ salinization processes which have taken place in the soils of the area. Since Na is considerably high in amount in the soil solution (Table 5), Ca and Mg are being precipitated as sulphates and/or carbonates. Under such conditions, part of the original exchangeable Ca and Mg is being replaced by Na.

Soil texture is the dominant feature of the soil that influences the amount of the exchangeable bases. The more heavily textured soils (pedons 2, 4, 7 and 9 contain more of the exchangeable bases than the light - textured soils. Conversely, there is no definite order down the various soil profiles of most of the pedons in which the exchangeable bases increase or decrease in amount due to the high variation in the textural sequence. An exception is pedon 5 in which exchangeable bases decrease with increase in depth in consonance with texture.

5.3.4 Cation exchange capacity

The cation exchange capacity (CEC) which was determined by sodium acetate (NaOAc) method at pH 8.2 is as highly variable as was the case with the exchangeable bases. The values vary between 2.0 meg/100g in pedon 3 and 28.3 meg/100g in pedon 4 (Table 5).

Since soil texture appears to exert a dominant influence on the CEC, and since there is a generally low content of organic matter CEC,values are in conformity with the textural sequence in the profiles of all the pedons. Soils of medium to heavy textures (pedons 2, 4, 7 and 9) usually have CEC (NaOAc method) of not less than 15 meg/100g, and they do not show appreciable difference in CEC values between the topsoil and subsoil. On the other hand, the light - textured pedons have CEC values (NaOAc method) which either increase or decrease in harmony with clay content. For example, in pedon 5, the CEC values (NaOAc method) decrease with increase in depth in close association with a change in texture.

The CEC/100g of clay which gives an approximate indication of the nature of clay minerals is marred by the relatively high silt content in most of the soils, since an appreciable proportion of CEC resides with the

fine silt. Values, however, are generally low for many of the soils (pedons 2, 3, 4, 6, 8 and 10) which show values between 14.7 meq/100g of clay in pedon 8 and about 40 meq/100g of clay in pedon 4 except the surface horizons of pedon 3 and 6 which have values of 49.4 meq/100g of clay and 63.0 meq/100g of clay respectively, and a sub-horizon of pedon 10 with 51.8 meq/100g of clay. A very high value of 210 meq/100g of clay is recorded for one horizon in pedon 6 due to an extremely low clay content, and this trend is depicted in all horizons low in clay.

5.3.5 Base saturation

Characteristically, the percentage base saturation is high. Values generally range between 70 and 100 percent, the only exception being pedon 7 which has a lower value of 61 in one horizon (Table 5 and Appendix). Since saturation values are primarily dependent on intensity of leaching which is influenced by rainfall, site drainage and permeability, the high values of base saturation obtained for the soils of the study area are normal.

5.3.6 Soil salinity and alkalinity

From previous studies (Singh and Maurya, 1979; Maurya, 1982; Ojanuga and Awotundun, 1982) and the results of the present study, the soils of the area show incipient salinity and alkalinity. With the exceptions of pedons 2, 4, 7, 8 and 11, the soils are either saline sodic or non-saline sodic in their profiles.

Soils that are saline-sodic include pedons 1, 5, 6, 9 and 10. The electrical conductivity of the saturation extract (EC_e) exceeds 4 mmhos cm^{-1} at 25°C in the surface horizons of these soils, and throughout the solum of pedon 9. Also the ESP is equal or greater than 15 in some of their horizons (Table 5). However, the pH ranges between 5.5 in the surface horizon of pedon 9 and 8.0 at some depth in pedon 10. The low pH value recorded for the topsoil of pedons 9 and 10 is due to excess exchangeable acidity and, in the case of pedon 9, high concentration of sulphate (Table 5).

There is a high concentration of soluble salts in the surface horizons of these soils and this justifies the high ECe values which exceed the minimum that many crops can tolerate. The higher proportion of soluble cations consists of Na, while the dominant anions are the sulphates and the chlorides. Judging from these results, the greater proportion of the soluble salts

in these soils is likely to be sulphates and chlorides, although bicarbonates and carbonates are present in appreciable amounts in the subsoil of pedon 9. This condition promotes alkalization and salinization processes in the soils.

Pedons 3 and 12 are non-saline sodic soils because the ESP values exceed 15 at some depths, but the soluble salts are low (Table 5). The pH readings are, however, lower than 8.5 due to the fact that the ESP values do not exceed 15 appreciably, and there is a low amount of alkali earth carbonates. The high pH (9.4) recorded for the deepest pseudo-horizon of pedon 12 is due to the calcareous nature of the parent material and the considerable amount of soluble Ca and Na.

The farmers cultivating the land in the irrigation project area currently avoid the potentially saline - sodic soils (pedons 1, 6, 9 and 10) because the present salt level in the soils is sufficient to limit crop growth.

5.4 Soil Genesis

The factors that have strong influence on the formation of soils in the study area include climate - both past and present, parent material, the topography

and drainage. Their effects have been most profound on the soil morphology and the physical and chemical properties.

The soils which were derived from various unconsolidated alluvial cum lacustrine deposits show multicoloured mottlings and gleying within one metre of the surface. This is a reflection of their having developed under seasonally impeded drainage conditions. The low topographic position associated with poor drainage resulted in partial reduction and hydration of the iron oxides contained in the soils.

Inspite of the powerful influence of climate, the nature of the parent material is clearly shown in these soils in terms of texture and stratification. The texturally stratified soils show some weak and faint clay skins within their subsoils and pseudo-horizons indicating some clay translocation by percolating flood and irrigation water. It is pertinent to adduce here that the inherited clay and silt contents control not only the internal drainage conditions but also the CEC, the availability of plant nutrients, and foremost the accumulation of harmful salts in the soils.

The main apparent factor promoting the salt accumulation in the soils and, hence, salinization and alkalization

processes, is the high water table which rises to the soil surface in the rainy season. Under this condition, the soils become charged with salts in the groundwater. In the following prolonged dry season the water table recedes owing to the marked evaporation of the surface water and transpiration (Table 3). As a result, dissolved salts particularly sulphates and carbonates of Ca and Mg precipitate and accumulate in the soils during the recession of the water table. Under such situations, alkalization processes are enhanced. The salts in the groundwater within the study area are believed to have been derived from fertilizer application and the application of irrigation of poor quality classified as C_2S_2, moderately saline with moderate sodium content (Singh and Maurya, 1979).

The role of the soil parent material in the salting of the groundwater, and subsequently the salinization and alkalization of the soils need a more detailed study of the micro-geomorphology of the area as well as the mineralogy of the soils and the parent materials. However, the present study shows that all the saline-sodic soils are derived from "Kurukuru - Gande" micaceous deposits which are characterized by the presence of platy micas which impede downward percolation of water, and thus promote salinization and alkalization processes. Most of the saline-sodic

soils (pedons 1, 5, 6 and 10) are situated on slightly raised grounds which are subject to more prolonged evaporation and evapotranspiration.

5.5 Soil Classification

As mentioned earlier in the literature review, it is somewhat difficult to systematize salt affected soils due to their high variations in kind and sources of salinization. Therefore pedogenic considerations and morphology are pertinent in establishing a classification for saline and sodic soils. The formation of soils in the study area is largely influenced by the sedimentation of geological and non-geological materials of different textures and age which has brought about some stratification. Also the soils became salinized and are still being salinized due to changes brought about by irrigation. It is therefore important to adopt the proposals of Husz (1969) which consider genesis, stratification of geologic materials as well as the history of the secondary saline soils in the classification of salt affected soils. Bearing this in mind, an attempt is made below to classify the soils into higher categories of "Soil Taxonomy" (Soil Survey Staff, 1975), as well as of the FAO/UNESCO system (FAO, 1974). Also a pedological classification of the salt affected pedons is proposed (Table 6).

soils (pedons 1, 5, 6 and 10) are situated on slightly raised grounds which are subject to more prolonged evaporation and evapotranspiration.

5.5 Soil Classification

As mentioned earlier in the literature review, it is somewhat difficult to systematize salt affected soils due to their high variations in kind and sources of salinization. Therefore pedogenetic considerations and morphology are pertinent in establishing a classification for saline and sodic soils. The formation of soils in the study area is largely influenced by the sedimentation of geological and non-geological materials of different textures and age which has brought about some stratification. Also the soils became salinized and are still being salinized due to changes brought about by irrigation. It is therefore important to adopt the proposals of Husz (1969) which consider genesis, stratification of geologic materials as well as the history of the secondary saline soils in the classification of salt affected soils. Bearing this in mind, an attempt is made below to classify the soils into higher categories of "Soil Taxonomy" (Soil Survey Staff, 1975), as well as of the FAO/UNESCO system (FAO, 1974). Also a pedological classification of the salt affected pedons is also proposed (Table 6).

The soil moisture regime as indicated by the climatic data discussed in the literature is Ustic because the soil moisture control section at 50 centimetres is dry in some or all parts for 90 or more cummulative days. Also the temperature regime is hyperthermic because the mean annual temperature is higher than 22°C and the difference between mean wet season (June - August) and mean dry season (December - February) temperatures is more than 5°C at a depth of 50 centimetres.

In the "Soil Taxonomy" all the pedons except pedon 9 are classified as Entisols because they show little evidence of development of pedogenic horizons. However, pedons 1, 3, 5, 9 and 10 are further classified as Typic Ustifluvents (Table 6) because they are formed in recent water- deposited sediments which do not have a diagnostic horizon other than an ochric epipedon, have organic matter content that decreases irregularly with increasing depth or remains at about or greater than 0.2 percent at a depth of 1.25 metres, and they have an ustic moisture regime. Pedons 2 and 4 are best placed as Vertic Ustifluvents because they have, in addition to properties of the Typic Ustifluvents, fine texture and sufficiently wide cracks that are characteristics of Vertisols.

Table 6: Cl

Soil	U Soi
Pedon 1	Typ
Pedon 2	Ver
Pedon 3	Typ
Pedon 4	Ver
Pedon 5	Typ
Pedon 6	Typ
Pedon 7	Typ
Pedon 8	Typ
Pedon 9	Typ
Pedon 10	Typ
Pedon 11	Typ
Pedon 12	Typ

Pedons 6, 11 and 12 are placed in the Typic Haplaquents because they are saturated with water at some time of the year within 50 cm of the surface, mottled and have dominant matrix colours that have value, moist, of 2 or less.

Pedon 9 which shows more advanced stage of salinization/alkalization can best be classified as Typic Halaquept in the "Soil Taxonomy". The soil has an ESP of 15 or more in more than half of the upper 50 centimetres, has chroma of 2 or less in more than 60 percent of the matrix in the subsoil between 15 and 75 centimetres and has an ochric epipedon. The soils do not have plinthite within 1.25 metres of the soil surface, do not have a sulphuric horizon within 50 centimetres of the surface and do not have vertic properties.

In the FAO/UNESCO system of classification, all the soils qualify as Fluvisols (Table 6) because they developed from recent alluvial deposits with more or less depositional rather than pedogenic horizons other than an ochric epipedon. All the pedons except 6,9, 11 and 12 are placed in the lower category of Eutric Fluvisols because they have a base saturation of more than 50 percent between 20 and 50 centimetres from the surface but are not calcareous at this depth. However, pedons 6, 11 and 12 are further classified as Gleyic

Fluvisols because they show, in addition, hydromorphic properties within 50 centimetres of the surface. Pedon 9 is best placed in the Gleyic Solonchaks because it is characterized by ECe greater than 4 mmhos cm^{-1} at $25^{o}C$ within 125 cm of the surface, though the ESP is equal or greater than 15 in some of the horizons.

Since pedons 1, 5, 6 and 10 are slightly saline-sodic partially due to irrigation, the prefix "slightly saline-sodic" could be used to qualify these soils as classified in the two systems above (Husz, 1969). For example, pedon 6 could be described as slightly saline-sodic Typic Haplaquent in the "Soil Taxonomy" or slightly saline-sodic Gleyic Fluvisol in the FAO/UNESCO system.

A pedological classification (Ojanuga and Awotundun, 1982) for the salt affected soils is hereby proposed. In this classification, consideration is given to the nature of the salts that accumulate in the soils, and which may influence the morphological, physical and chemical properties of the soils. As such, pedons 1,5,6,9 and 10 are termed Solonchak - Solonetzs (Table 6) because they are relatively saline particularly in their surface horizons which have an electrical conductivity of more than 4 mmhos cm^{-1} at $25^{o}C$, and at the same time are sodic having ESP of 15

or more in their profiles (Table 5). However pedons 3 and 12 are classified as pseudo-Solonetzs because only pseudo-horizons exclusively formed as a result of sedimentation processes are sodic.

CHAPTER SIX

SUMMARY AND CONCLUSION

A study was carried out to assess the salinity status of soils of the Wurno Irrigation Scheme area, with the objectives of characterizing and classifying the soils and postulating their genesis. Twelve pedons were selected for the study purpose.

The soil parent material consists of various Pleistocene, Holocene and later sediments which include the "Argungu Floe" deposits, "Ambursa Central" deposits and the "Kurukuru-Gande" micaceous deposits. While only pedon 3 was found to have developed from "Argungu Floe" sediments, pedons 1,5,6,8 and 11 developed on the "Kurukuru" micaceous deposits, and pedons 9 and 10 on the "Gande" micaceous deposits. Pedons 2, 4 and 12 formed on the "Ambursa Central" deposits.

In terms of their morphology, the soils are characterized mostly by strong brown (7.5 YR 5/8) to gray (5 Y 5/1) colour and structureless to subangular blocky structure. They are generally imperfectly to very poorly drained because of their relatively flat topographic position in the Rima River floodplain. Most of the soils studied showed hydromorphic properties within one metre of the surface implying that the water table is rather high. The water table recedes to between 1.0 to 1.5 metres at the peak of the dry season. Most of the soils (Pedons 1, 2, 4, 6, 8, 10, 11 and 12) are characterized by (A) C profiles with an ochric epipedon.

The soils contain very few or no gravels. The Textural sequence of most of the pedons is highly variable and shows no definite order down their profiles. The sand, silt and clay fractions are also highly variable in all the soils. One of the outstanding features in many of the pedons, however, is the relatively high silt content which commonly ranges from 25 to about 70 percent. In most horizons the clay content is usually the least when compared to the sand or silt contents. Pedons 2, 4, 7 and 9 are, however, the only exceptions.

The organic matter content is generally low (less than 1 percent) in all the soils. It is always highest in the surface horizon and decreases either sharply or irregularly with depth. The semi-arid tropical climate which results in sparse vegetation cover coupled with frequent bush fires and intensive cultivation and grazing account for the destruction and rapid mineralization of the potential humus materials.

There is a wide variation in the reaction of the soils in the study area. The pH values in these soils range from 5.4 to 9.4, and generally increase with increase in depth probably due to the alkaline nature of the ground-water. The relatively high pH values in some pedons reflect the alkalization and/or salinization processes which have taken place in the soils of the area.

Calcium and magnesium dominate the soil exchange complex with Mg in lesser amounts than Ca. Exchangeable Na is considerable in the sodic soils, while exchangeable K is comparatively low in all the soils. Since soil texture is the dominant feature of the soils that influences the amount of the exchangeable cations, the more heavily textured soils (2, 4, 7 and 9) contain exchangeable bases than the light-textured soils. Also the textural sequence which is highly variable in most of the soils is reflected in the zig-zag order in which the total exchangeable bases increase or decreases with depth.

The CEC (by NaOAc method) varies between 2.0 meq/100 g and 28.3 meq/100 g and is influenced by texture in similar fashion as the exchangeable bases. The heavy-textured soils have CEC values of not less than 15 meq/100 g. The CEC/100g of clay is considerably high in some pedons, and if not for the fine silt interference, would have indicated a preponderance of 2:1 lattice clays, and low values accounted for the high proportion of 1:1 lattice clays.

Base saturation values are high in all the soils. The values generally range from about 70 to 100 percent which is a result of poor drainage, low permeability and scarce rain water for leaching.

Incipient saline-sodic soils occur as patches (pedons 1, 5, 6, 9 and 10) with white efflorescences on the soil surface. ECe of such soils is between about 1.0 and 6.5 mmhos cm^{-1} at $25^{o}C$, with high values in the surface horizons. The dominant soluble cation is Na while a greater proportion of the soluble anions consists of chlorides and sulphates. There are also non-saline sodic soils (pedons 3 and 12) that have ESP equal to or greater than 15 at some depths although the pH ranges from 6.0 to 8.0.

The soils which developed from various unconsolidated alluvio-lacustrine deposits under seasonally impeded drainage conditions (associated with low topographic positions) show hydromorphic properties within one metre of the surface. The influence of parent material on the soil is clearly shown in terms of texture and stratification. The high water table which rises to the soil surface in the rainy season is the main factor promoting the salt accumulation in the soils. As the water table recedes in the dry season, the saline ground water leaves behind precipitated salts in the root zone. All the saline-sodic soils are derived from "Kurukuru-Gande" micaceous deposits, and most salt affected soils are situated on slightly raised ground.

The soils of the area are classified using both the "Soil Taxonomy" of the USDA and the FAO/UNESCO soil

legend. Also a pedological classification is proposed for the salt affected soils. Using the "Soil Taxonomy", pedons 1, 3, 5, 7, 8 and 10 belong to the Typic Ustifluvents while pedons 2 and 4 are placed as Vertic Ustifluvents. However, pedons 6, 11 and 12 are classified as the Typic Haplaquents and pedon 9 as the Typic Halaquept. In the FAO/UNESCO system of classification all the pedons except 6, 9, 11 and 12 are classified as Eutric Fluvisols. Pedons 6, 11 and 12 are classified as Gleyic Fluvisols while pedon 9 could best be classified as Gleyic Solonchak. All the saline-sodic soils (pedons 1, 5, 6, 9 and 10) are termed as Solonchak-Solonetzs while the non-saline sodic soils are regarded as Pseudo-Solonetzs in the pedological classification.

In conclusion, it is relevant to give recommendations on how the salt affected soils can be reclaimed, and to prevent potentially saline and/or sodic soils from developing into salt affected soils. First and foremost, adequate artificial drainage should be provided to lower the water table and thus prevent waterlogging and subsequent salinization and/or alkalization. This will promote proper leaching of soluble salts out of the rooting zone of the soil. Secondly, the addition of calcium sulphate (gypsum) which furnishes Ca that could displace harmful amounts of soluble Na in the surface horizons of the salt affected soils is hereby envisaged.

Lastly, if the irrigation plots are adequately levelled, it would ensure an even distribution of irrigation water and so prevent waterlogging and subsequent salinization and alkalization.

R E F E R E N C E S

Allison, H.E. (1962), Preliminary Report. Salinity Status of Irrigation Schemes of Northern Nigeria. Consultant Report No. 44.

Bower, C.A.; Reitemeier, R.F. and Fireman, M. (1952), Exchangeable cations analysis of saline and alkali soils. Soil Science 73: 251-261, Illus.

Bowser, E.W. and Cains, R.R. (1967), Some effect of deep ploughing a Solonetz soil. Canadian Journal of Soil Science Vol. 47: 239-244.

Brinkman, R. and Smyth, A.J. (Ed): (1973). Land evaluation for rural purposes. Publ. 17, Wageningen: International Institute of Land Reclamation and Improvement (ILRI).

Buol, S.W., Hole, F.D. and McCracken, R.J. (1973). Soil Genesis and Classifications Iowa University Press Ames, Iowa U.S.A.

Cains, R.R. (1971), Effect of deep ploughing on the fertility satus of black Solonetz soils. Canadian Journal of Soil Science 51: 411-414.

Carter, M.R.; Cains, R.R. and Webster, G.R. (1977), Amelioration of a Brown Solodized Solonetz Soil by surface application of gypsum plus ammonium nitrate. Can. J. Soil Sci. 57: 139-145.

Christian, C.S. and Stewart, G.A. (1968), Methodology of integrated surveys.Nat. Resources Research UNESCO 6: 233-80.

Clayton, W.D. (1958), Erosion surfaces in Kabba Province, Nigeria. Journal of the West African Science Association Vol. 4: 141-149.

Day, P.R. (1956), Report of the committee on Physical Analyses. 1954-55. Soil Science Society of America Proceedings. 21:662.

De Sigmond, A.A.J. (1938), The Principles of Soil Science. 362pp., Illus London.

De Swardt, A.M.J. (1956), Recent erosion surfaces on the Jos Plateau. Proceedings of the 3rd West African Conference; 180-186.

D'Hoore, J. (1968), 'The classification of tropical soils'. In R.P. Moss (ed.) The Soil Resources of Tropical Africa. Cambridge at the University Press, London, England.

Dokuchaev, V.V. (1883), Russian Chernozem (Russkii Chernozem). (Transl. from Russian by N. Kaner). Israel Prog for Sci Trans., Jerusalem, 1967. Available from U.S. Dept. Commerce Springfield, Va.

Du Preez, J.W. and Barber, W. (1965). The distribution and chemical quality of groundwater in Northern Nigeria. Geological Survey of Nigeria Bull. 36: 38-45.

Editorial Staff. (1940). Obituary notice. Soils and Fertilizers 3: 147-148.

Falconer, J.D. (1911), The geology and geography of Northern Nigeria. MacMillan and Co. London.

Fallou, F.A. (1862), Pedologie Oder allgemeine und
besondere Bodendunde. Dresden, Germany; 180-182.

FAO, (1969), Soil and Water Resources Survey of the Sokoto
Valley. Final Report
Vol. I: General.
Vol. V! Climate and Hydrology
Fol. V: Soil survey and Land Classification.
FAO/SF, Rome.

FAO (1974). FAO-UNESCO Soil map of the World Vol. I.
Legend. Paris.

FAO (1976), A framework for land evaluation. Soil Bull.
32, Food and Agric. Org of the U.N.,
Rome, Italy.

Furon, R. (1963), Geology of Africa (trans. Hallam,
H. and Stevens, L.A.). Oliver and Boyd, London.

Gibbs, H.S. (1955), What is pedology? Soil and Fertilizers
18 : 188-90.

Glinka, K.D. (1927): Dokuchaev's ideas in the development
of pedology and cognate sciences. Russian
Pedological Investi.; Acad. Sci. U.S.S.R. 82p.

Husz, G. (1965) Zur Kenntnis der jugquartaren Sedimente
des Seewinkels im Burgenland. Eisenstadt.
Wiss Arbeitenaus dem Burgenland. Heft. 32.

------- (1966) Zur Systematik der salzboden des
Seewinkelgebietes in Osterreich. Die Bondenkultur
17.295 - 310.

~~------~~ (1969), Contribution to the discussion about the classification and cartography of salt affected soils. Symposium on the reclamation of sodic and sodasaline soils Yerovan. Agrochemistry and soil science 18: 1 - 392.

Jones, B. (1948), The sedimentary rocks of Sokoto Province. Geological Survey of Nigeria, Bull. No. 18.

Kellogg, C.E., (1936), Development and significance of the great soil groups of the United States. USDA Misc. Publ. 229, 40p.

Killian, C.M. (1931), Des principaux complexes continentuxdu sahara C.R. Soc. Geol. Rance Ser.V. p. 109.

King, L.C. (1967), The Morphology of the Earth: A study and Synthesis of World Scenery, 2nd ed. Oliver and Boyd, London.

Kogbe, C.A. (1970), Preliminary notes on the geology of the Nigerian Sector of the Iullemmeden Basin Proc. 1st Conf. on African Geology Ibadan, pp 219. 1972.

------ (1972), Geology of the Upper Cretaceous and Lower Tertiary sedimerts of the Nigerian Sector of the Iullemmeden Basin (West Africa). Geologische Rundschau Vol 62/1, 197 - 211, Stuttgart.

------ (1976) Excursion Guide to the Sokoto Basin. Geological Guide to some Nigerian Cretaceous to Recent localities. 7th African Micropalaeontological Colloquim: 56-74.

------ (1979) Geology of the South-East Sector of Iullemmeden Basin. Bull. Dept. Geol. ABU, 2/1: 420p. Zaria.

Kovacs, G. (1977), Changes in hydrological processes due to influence of Irrigation. In. E.B. Worthington (ed.) Arid Land Irrigation in Developing Countries. Pergamon Press, London.

Kovda, V.A. (1947), Origin and regime of salt affected soils (R) Vols. I. and II. 12d. Akad. Nauk: SSSR Moskva.

Kovda, V.A. and Szabolcs. I. (1979), Modelling of Soil salinization and alkalization. Agrochemistry and Soil Science, 28 (suppl.) 1-208 Budapest.

Kowal, J.M. and Knabe, D.T. (1972), An Agroclimatological Atlas of the Northern States of Nigeria, with Explanatory Notes. Ahmadu Bello Univ. Press, Zaria. Nigeria.

Ledger, D.C. (1961), Recent hydrological changes in the Rima Basin, Northern Nigeria. Geographical Journal Vol. 127: 477-487.

Marbut, C.F. (1935), Soils of the United States. In USDA Atlas of American Agriculture, pt 3 Advance Sheets No. 8: 98p.

Maurya, P.R. (1982), Development of salinity and alkalinity in irrigated soils of Nigeria. 4th Afro-Asian Regional Conference of ICID, Lagos, Nigeria Vol. II (Publ. 01): 1-17.

Merril, G.P. (1906), A treatise of rocks, rock weathering and soils. The Macmillian Co., New York.

Neustruyev, S.S. (1927), Genesis of soils Russian Pedological Investigation, Acad. Sci USSR Moscow 98p.

Nikiforoff, C.C. (1942), Fundamental formula of soil formation Am. J. Sci. 240: 847-866.

Northcote, K.H. (1954), The place and function of pedology in soil science. Soils and Fertilizers 17: 305-10.

Ojanuga, A.G. and Awotundun, E.F. (1982), Mapping and characterization studies of salt affected soils in Northern Nigeria. 4th Afro-Asian Regional Conference of ICID, Lagos, Nigeria, Vol.II (Publ. 02): 19-27.

Polynov, B.B. (1930), Determination of critical depth occurrence of the groundwater level salinizing soils. (R) IZV. Sector Hydrotechnics and Hydrotechnical constr. No. 22. Leningrad.

Pomerening, J.A. and Knox, E.G. (1962), A test for natural soil groups within the Williamette catena population. Soil Sci. Soc. of Am. Proc. 26: 282-87.

Pugh, J.C. and King, R.L. (1952), Outline of the geomorphology of Nigeria. South African Geographical J. XXXIV.

Pullan, R.A. (1961), Report on the reconnaissance and detailed soil surveys of the Birnin Kebbi area. Bulletin No. 17. Regional Res. Station, Samaru, Zaria.

Rasmussen, W.W., Moore, D.P. and Alban, L.A. (1972) Improvement of a Solonetzic soil by deep ploughing, subsoiling and amendments. Soil Sc. Soc. Am. Proc. 36: 137-142.

Reitemeier, R.F. (1943), Semimicroanalysis of saline soil solutions. Indus and Engin. Chem. Analyt. Ed. 15: 393-402 illus.

Reyment, R.A. (1966), Studies on Nigerian Upper Cretaceous and Lower Tertiary Ostracoda Part 3: Stratigraphical Paleoecological and Biochemical conclusions. Stockh Constr. Geol. 14, 151pp.

Scofield, C.S. (1940), Salt balance in irrigated areas. Jour. Agr. Res. 61: 17-39 illus.

Simonson, W. (1958), Outline of a generalized theory of soil genesis. Soil Sc. Soc. Am. Proc. 23: 152-156.

Singh, A. and Maurya, P.R. (1979), Salinity status and waterlogging in irrigated agriculture of Northern Nigeria. 6th. Nigerian Irrig. Sem. Proc. Zaria, Nigeria.

Smith, R. and Atkinson, K. (1975), Techniques in Pedology: and handbook for environmental and resource studies. Printing office, Washington D.C., U.S.A.

Soil Survey Staff (1962). Soil Survey Manual, USDA, Soil Conservation Service, Washington D.C. U.S.A.

Soil Survey Staff (1975), Soil Taxonomy. A basic system of soil classification for making and interpreting soil surveys. USDA, Soil Conservation Service, Washington DC. U.S.A.

Szabolcs, I. (1961), The influences of water regulation and irrigation on soil formation processes in the Trans-Tisza region (H) Akademiai Kiado. Budapest.

------- (1971a) European salt affected soils and their utilization. (H, g) Foldt. Kozl. 19: 145-154.

------- (1971b) European solonetz soils and their reclamation. Akademiai Kiado. Budapest.

Szabolcs, I; Varallyay, G. and Darab, K. (1976), Soil and hydrologic surveys for the prognosis and monitoring of salinity and alkalinity. FAO Soil Bull. 31: 119-129.

Taylor, N.H. and Pohlen, I.J. (1962), Soil survey methods. New Zealand Soil Bur. Bull. 25.

Udo, R.K. (1973), Geographical Regions of Nigeria. Heinemann, London.

USDA, Salinity Laboratory Staff, (1969), Diagnosis and improvement of saline and alkali soils USDA Agric Handbook 60, 160p.

Vilenskii, D.G. (1957), Soil Science (Transl.by Birron, A. Cole, Z.S.) Israel Prog. for Sci. Transl. Jerusalem, 1960. Available U.S. Dept. Commerce, Washington.

Vink, A.P.A.(1975) Land use in advancing agriculture. Springer-Verlag, Berlin. Heidelberg New York, USA.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 37: 29-38.

Young, A. (1976) Tropical soil and soil survey. Cambridge University Press, London.

Appendix

Soil	Horizon	Depth cm	pH (H_2O)	OM (%)	Exchange cations meq/100g Ca	Mg	K	Na	TEB	CEC	CEC*	BS %	ESP	ECe mmhos/cm	WS %	Water soluble ions meq/100 Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4
Pedon 2	Ap	0-18	5.6	.86	7.50	5.18	1.18	0.96	14.8	6.3	29.1	91	6	1.3	37	.8	.3	1.0	1.1	-	0.5	2.0	.9
	AC	18-32	5.4	.52	7.20	6.17	1.44	1.30	16.1	19.1	30.8	84	7	2.3	41	1.4	.68	1.0	2.4	-	.4	1.2	3.9
	C_2	32-69	5.6	.43	6.13	6.02	1.33	1.30	14.8	15.0	25.0	99	9	2.0	43	.9	.4	.4	2.2	-	.8	1.8	1.3
	C_3	69-90	6.5	.17	7.20	4.17	1.18	1.09	13.6	14.6	30.4	93	8	1.7	29	.8	.4	.5	1.3	-	.7	1.1	1.2
	C_{4g}	90-120	6.4	.17	7.35	5.11	1.33	1.00	14.8	14.7	29.4	100	7	1.4	35	.9	.3	.5	1.1	-	.5	1.3	1.0
Pedon 4	Ap	0-14	6.4	1.38	15.00	5.09	.74	2.26	23.1	21.5	33.6	100	11	1.9	44	.8	.2	1.0	1.5	-	1.1	1.6	.8
	AC	14-38	7.7	.69	20.11	5.17	1.79	2.39	29.5	28.3	42.9	100	8	.7	43	4.1	.1	.5	1.3	-	3.2	1.2	1.6
	C_2	38-78	7.6	.52	17.15	4.66	1.69	2.04	25.5	27.4	40.3	93	7	.4	45	.4	.1	.1	.5	-	.3	.3	.6
	C_{3g}	78-110	107.5	.26	7.55	2.78	.87	.87	12.1	10.9	26.0	100	8	.5	32	.8	1.1	.2	.3	-	.6	.4	1.4
II	C_{4g}	110-130	7.4	.17	3.58	1.37	.37	.57	5.9	6.5	23.2	91	9	3.7	25	.6	.2	.3	2.5	-	.2	.7	2.4

CEC = CEC by NaOAc method; CEC* = CEC by NaOAc method/100g of clay; B.S. Base saturation

TEB = Total exchangeable bases; W.S. = Water saturation.

Appendix

Soil	Horizon	Depth cm	pH (H_2O)	OM %	Exchange cations meq/100g Ca	Mg	K	Na	TEB	CEC	CEC*	BS %	ESP	ECe mmhos/cm	WS %	Water soluble ions meq/100g Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4
Pedon 11	Ap	0-15	5.6	.95	5.89	2.74	.92	.74	10.3	11.2	40.0	92	7	.6	29	.4	.1	.2	.8	-	.2	.7	.
	B_g	15-30	5.6	.52	7.25	3.11	.91	2.54	16.0	19.5	32.5	82	13	1.3	46	.4	.1	.1	2.2	-	.3	1.6	.
	II C_{1g}	30-65	6.8	.17	2.00	.80	1.44	.70	4.9	5.1	42.6	97	14	1.1	21	.3	.2	.2	1.1	-	.2	1.3	.
	III C_{2g}	65-124	7.9	.17	7.05	3.89	.44	2.10	13.5	17.3	29.7	78	12	.7	38	1.2	2.7	.1	1.6	.7	2.1	.8	2.
	IV C_{3g}	124-170	8.0	.00	6.25	3.10	2.82	1.96	14.1	14.7	36.6	97	13	.6	35	.6	.9	.2	1.0	.7	.3	.1	1.
Pedon 7	Ap	0-20	6.4	.86	7.25	2.81	1.03	.42	12.5	13,0	65.0	96	3	.4	40	.2	.2	-	.3	-	.2	.3	.
	B_1	20-45	6.5	.26	8.15	2.96	.51	.29	11.9	14.3	64.8	84	2	.5	28	.3	.1	.1	.3	-	.3	.1	.
	II B_2	45-59	6.1	.26	7.45	4.65	.92	.61	13.6	14.3	170.8	95	4	.2	59	.1	.1	.1	.2	-	.3	.1	.
	III C_1	59-90	7.0	.17	11.25	4.68	.26	.14	16.3	3.4	45.0	70	4	.4	25	.2	-	.1	.3	-	.2	.1	.
	IV C_{2g}	90-160	6.3	.26	7.25	4.54	1.16	.98	13.9	22.8	39.9	61	4	.2	48	.2	.1	.5	1.2	-	.5	.5	.
	IV C_{3g}	160-200	6.0	.52	6.66	3.98	.77	.83	12.2	16.7	43.9	73	9	.9	25	.4	.3	.4	.7	-	.6	.5	.
Pedon 8	Ap	0-15	5.8	.77	3.10	1.25	.56	.20	5.1	4.4	14.7	100	5	.5	28	.4	.2	.2	.2	-	.2	.4	.
	AC	15-34	5.8	.43	3.20	1.57	.46	.22	5.5	7.6	23.8	72	3	.4	27	.2	.1	.2	.3	-	.3	.3	.
	C_1	34-47	6.3	.26	3.10	2.17	.38	.22	5.9	6.5	32.5	89	3	,8	24	.3	.2	.2	.8	-	.4	.4	.
	C_2	47-63	6.5	.17	4.00	1.16	.37	.26	5.8	5.4	27.0	100	5	.4	23	.5	.2	.2	.3	-	.3	.5	.
	II C_3	63-104	7.2	.08	1.15	.43	.26	.25	2.1	2.4	29.4	89	11	.5	26	.4	.1	.1	.4	-	.1	.3	.
	III C_4	104-184	7.0	.17	2.00	.68	.25	.17	3.7	3.1	31.1	100	6	.6	20	.6	.3	.3	.4	-	.3	.6	1.