EVALUATION OF THE CAUSES OF SOIL DEGRADATION AROUND A TOWNSHIP WATER TREATMENT PLANT AT AJIWA IN KATSINA STATE, NIGERIA

BY

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DECLARATION

I declare that the work in the thesis entitled: **"Evaluation of the Causes of Soil Degradation Around a Township Water Treatment Plant at Ajiwa in Katsina State, Nigeria"** has been performed by me in the Department of Soil Science under the supervision of Professor E.O. Uyovbisere and Professor T. Kparmwang. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any University.

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CERTIFICATION

This thesis entitled: **"EVALUATION OF THE CAUSES OF SOIL DEGRADATION AROUND A TOWNSHIP WATER TREATMENT PLANT AT AJIWA IN KATSINA STATE, NIGERIA"** by Aliyu, Jabiru Ahmed meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, Zaria, and is approved for its contribution to knowledge and literary presentation.

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To my late father Alhaji Ali, my late mother Halima, my guardian Alhaji Ahmadu Sa'in Katsina and my children: Khadija, Aliyu and Ahmadu.

ABSTRACT

A study was initiated to determine the causes of soil degradation of the Ajiwa downstream irrigated lands, resulting from the use of contaminated water of River Tagwai for irrigation, to which was discharged effluent waste sludge from the Ajiwa township water treatment plant in Katsina State, and to proffer possible strategies for good soil and water management of the degraded soils. Soil and water samples were taken at predetermined points along a 5 km stretch of River Tagwai, from Ajiwa dam towards Makurda village, for the determination of relevant parameters in the laboratory. Data were analysed using the SAS statistical package. Mean separation was by LSD and DMRT. Results of the study showed that clay deposition was higher at the point of effluent discharge and decreased with distance, indicating the high impact of the deposits on soil texture and on the soil reaction. The soil pH varied from 4.8 at the point of discharge to 6.4 at distances away, implying that the effluent was acidic, with the attendant effects of acidity on soil processes. Phosphorus fixation was higher at the more acidic proximal sections of the river course. Soil fertility was rated low, and was substantially enriched by the effluent waste deposits up to 2 km, with 70% resulting from this modification, and only 30% of fertility ascribed to the native fertility. However, the chemicals used in the treatments for water purification, (allum ($Al(SO_4)_3.14H_20$); superfloc; hydrated lime, high test hypochloride and chlorine) influenced the soil conditions significantly resulting in the salinity and sodicity of the soils. White salt deposits on the soil surface as a result of capillary movement of soluble salts at periods of dry spell, were derived from the effluent sludge and comprised essentially of $MgSO_4$, Na_2SO_4, Na_2CO_3 and NaCl. These salts are the principal causes of salinity of irrigated lands. Soil and water quality of the study site were poor and could result in the development of sodium hazard when the water is used continuously for irrigation. The values and effects of EC (0.20 dSm^{-1}), SAR (39.35) and ESP (18.15% as well as TDS (20,000 mg L^{-1}) were discussed. It was inferred from the study that the cause of soil degradation was high salinity and sodicity, and the soils should therefore be treated as a case of salt-affected soils. Three strategies were suggested for good soil and water management of these degraded soils: filtration and cationic resin

treatment of the effluent for anion exclusion before effluent sludge is discharged, tube well technology and the use of cultural practices for the reclamation of salt-affected soils.

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CHAPTER ONE

1.0 INTRODUCTION

As agricultural sustainability is of crucial importance in the dry lands of Northern Nigeria due to a variable rainfall regime, the occasional occurrence of drought, increase in population and widespread soil degradation (Essiet, 2001), the water needs for crop production in Katsina State has increased and crop yield is becoming increasingly dependent on irrigation. The hot and dry climate of this region require that irrigation water does not contain soluble salts in amounts that are harmful to the plants, or which can have certain adverse effects on the soil. Water of such quality is often not available in sufficient quantities to satisfy the water requirements of all or some of the different crops grown. Under these conditions the farmers at Ajiwa irrigation area (downstream), are inclined and obliged to use the river water contaminated by the waste water discharged from the water works plant as their main water source for irrigation purposes. Consequently, degradation of the fertility of these soils and other adverse effects such as very shallow water table, impeded drainage, accumulation of salts at the surface soil (salt efflorescent) and decrease in crop yield are suspected as emerging problems being experienced. The problem have forced the people to abandon their farmlands.

This situation at Ajiwa (downstream) irrigation fields may be a case of salt-affected soils. It is usually formed under influence of different electrolytes which alter the physical, chemical and biological properties and eventually the fertility of the soils (Szabolcs, 1989). The total area of salt-affected soils in the world has been estimated to be about 952 million hectares (FAO, 1977). Australia has been reported to have the highest ratio of salt-affected soils in relation to total surface area of any continent in the world, with approximately one third of the land mass being covered by sodic soils and 5% affected by soil salinity (Fitzpatrick *et al*., 1994). In Nigeria, these problems of salinity/sodicity and drainage were also reported in some irrigation projects in the savanna (Allison, 1962; Igbal, 1975; Nwa, 1982 and Maurya, 1982). In salt affected soils, salinity and alkalinity are the main problems that lead to soil degradation, usually as a result of use of poor quality irrigation water and poor drainage or high water table condition as experienced by Sanda (2006), due to hard pan at lower depth. A soil is considered to be saline when the electrical conductivity (EC) of the saturated soil extract is more than 4 dSm^{-1} and sodic (alkaline) when exchangeable sodium percentage (ESP) is more than 15% (Richard, 1954). Szabolcs (1989) observed secondary salinization and sodification in areas prone to salt accumulation due to long term use of poor quality irrigation water, a rise in the ground water table and the appearance of deep saline material at the surface or around the irrigation lands.

Good water for irrigation is fast becoming a scarce commodity in most parts of the world, especially in arid and semi arid regions. Consequent to this, it has become imperative to extend the cropping season by irrigating with waste water (marginal waters) Day et *al*. 1979; Michael *et. al*., 1979; Bole *et al*. 1981; Bangboye, 1986 and Okereke, 1998. The quality and quantity of these salts depend on the origin and course of the water. Due to excess of inorganic compounds, the natural waters of the earth are regarded as electrolytes (Szabolcs, 1989), of which the common dissolved constituents are chlorides, sulphates, carbonates and bicarbonates of calcium, magnesium and sodium, and it is the concentration and proportion of these salts that determine the suitability of water for irrigation use. Other constituents such as boron, which have toxic effect on plants may occur in lesser amounts in irrigation water. Irrigation water quality determines the growth and quality of agricultural crops (Russell, 1973; Michael, 1978). It is therefore necessary to have a good knowledge of its contents while judging its suitability for irrigation. The water quality is expected to vary from source to source due to inherent and external factors, which in turn will affect the irrigated soil quality.

A number of soil properties are adversely affected consequent to salinity/sodicity development. These include structural destruction of soil aggregates leading to decrease in infiltration, permeability and aeration, soil fertility deterioration and reduction in overall productivity. The land becomes marginal from the agricultural point of view. Nevertheless the possible hazards of salinity and or alkalinity in irrigated areas, or areas to be irrigated may be determined by factors such as knowledge of the main source and amount, salt content and composition of irrigation water and drainage.

Based on the concepts discussed, the problem in the Ajiwa downstream irrigation terrain can best be evaluated by employing the methods of salt affected soils.

The objectives of the study therefore were:-

1. To determine the quality of the dam water (input) the waste waters (effluent) and purified water (output);
2. To determine water quality in the observational tube wells at distances from water works plant within the irrigated land area.
3. To determine the effect of the waste water (effluent) on soil properties, general soil fertility of the study area (Ajiwa irrigated lands) at distances from the water treatment plant;

4. To suggest possible strategies of soil and water management for proper utilization of these resources.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soil Degradation

Soil degradation is a result of one or more processes which lessen current and/or potential capability of soil to produce. It is usually a complex process in which several factors can be recognized as contributing to loss of soil productive capacity (FAO, 1977). The concentration of salts in the surface and near-surface zones of soils is a major process of land degradation (O'hara, 1997).

There are two types of soil degradation: firstly, due to erosion by wind or water (Noma *et al*., 2006). For instance in the Mojave desert of South Eastern California, wind erosion was described as the principal mechanism of land degradation, killing plants by burial and abrasion, interrupting natural processes of nutrients accumulation and allowing the loss of soil resources by abiotic transport (Okin *et al*. 2001). In Nigeria, the southern front of the encroaching desert in Northern part of the country was observed to be moving steadily over the years, rendering farmlands unproductive and dwindling the prospects of livelihood of peasant farmers in these areas (Uyovbisere, *et al*., 2006). During rainfall events, the raindrops detach soil particles consequent to which tones of soil are lost by water erosion (Tematio and Olson, 1997; Dumanski and Pieri, 2000). Secondly, defines the condition of loss of fertility due to physical, chemical or biological changes in the soil. For instance, lack of soil cover results in erosion and siltation of reservoir; loss of soil organic matter through land degradation contributes significantly to

Co_2 emission into the atmosphere; and mismanagement of irrigated land results in salinization and waterlogging (Dumanski and Pieri, 2000).

The agricultural activities that lead to soil degradation encompass all aspects of improper agricultural land management such as uneven distribution of irrigation water, high N fertilization (Villo-castorena *et al*. 2003), and poor drainage leading to soil problems such as salinization and alkalization. These processes of salinization and alkalization refer to the surface or near surface accumulation of salts, mainly chlorides, sulphates, carbonates and bicarbonates of calcium, magnesium and sodium. They take place where poor quality irrigation water is used or where the rising water table limits natural drainage and hinders the leaching of salts (Datta and de Jong, 2002). Musto (1977) reported rise in water table due to excessive irrigation and inadequate drainage in Argentina which resulted in salinization and alkalization of soils especially in low lying areas. In other parts of the world also, serious salt and waterlogging that lead to soil degradation have been reported (Qureshi and Barret-Lennard, 1998; Datta and de Jong, 2002; Presely *et al*., 2004 and Brady and Weil, 2004). Mesopotamia, Euphratus valley, Medjerdah valley, Kairovan plain, part of Tunisia, the oases and the irrigated plains of Africa, the Medani in Sudan, the Arabian Peninsula, Jordan valley in Jordan and several alluvial plains in Somalia are few to be mentioned (Gaddas, 1977; Szabolcs 1989). Salinity can be caused by acid, neutral or alkaline water soluble salts (Abrol 1988; Szabolcs 1989). The problem affects both soil and water, which therefore means that salinity and alkalinity directly limit soil fertility. More than half of the existing irrigation systems of the world have been reported to be damaged by salinity, alkalinity or waterlogging (Szabolcs, 1989). Although the ISSS/UNESCO/FAO Maps of salt-affected soil have delineated those areas which were potentially saline or alkaline. The total area of salt affected soils in the world is estimated to about 952 million hectares (FAO, 1977). The distribution depends on climatological and hydrological differences (Noma, 2006). This is because irrigation systems are particularly prone to salinization and it is considered to be one of the main causes of falling crop yields and the loss of land from production. On the global scale, Szabolcs (1987), estimated that about 10 million ha of irrigated land is abandoned every year because of salinization and alkalization (Ohara, 1997).

2.2 Genesis of Salt-Affected Soils

As human activities increase in an attempt to satisfy unlimited demands for food, feed and fuel wood corresponding pressure is exerted on the environment which leads to land degradation of different types and intensities (Noma, et. al, 2006). While Yaro *et al*., (1998) reported that the soils of the semi arid and arid areas often contain soluble salts which are redistributed by the rise and fall of the ground water table.

The developing water table has genesis and effect. For instance, the low-lying areas where the saline ground water emerges are termed saline-seeps (Brady and Weil, 2004). According to them these occur naturally in some locations, but their formation is often greatly increased when the water balance in a semi-arid landscape is disturbed by bringing land under cultivation. Also, if a shallow layer restricts percolation, it will further encourage the flow of the salt-laden ground water across the landscape toward the lowest elevation. Eventually, water table may rise to within 1m or less of the soil surface and capillary rise will begin to contribute to a continuous stream of salt-laden water to replace the water lost at the surface by evaporation. The evaporating water will leave behind the salts which soon accumulate to levels that inhibit plant growth. Year by year the evaporation zone will creep up the slope and the barren, salinized area will become larger and more degraded. When bicarbonate combines with calcium or magnesium in soils, calcium carbonate or magnesium carbonate precipitate out. Consequently, the sodium adsorption ratio (SAR) of the soil increases and permeability to water may become a problem Richard *et al.*, 2004).

2.3 Salinity/Alkalinity in Nigeria

Salinity has posed a serious threat to the permanence of irrigated agriculture, particularly in arid and semiarid parts of the world. Over the years, salinity surveys of irrigation projects in Northern Nigeria revealed that some soils are already salinized while others are gradually deteriorating as a result of a lack of internal drainage facilities. Singh and Maurya (1979) reported that some soils of irrigated sites in northern Nigeria like Kalmalo, Tungan Tudu, Wurno and Bakura in Sokoto State of Nigeria are either saline or alkaline. Soils of Tungan Tudu were slightly salinized at the surface while soils in Wurno, Hadejia (Yamidi Sector) and Tallun showed signs of salt accumulation at the surface. In recent times, soils of the Kadawa area are also gradually salinizing (Okai, 1995). Malgwi, (2003) also reported salinity, watgerlogging and low fertility problems in Kura-Kadawa and Barwa Minjibir in the Chalawa and Jakara plains respectively. However the use of animal manure and crop residues could ameliorate these problems. The organic materials will increase the organic matter content of the soil, thereby enhancing the formation of desirable soil structure which in turn would enhance water penetration and movement in the soils. Mulching to reduce evaporation from the surface and thus reducing the rate of salt build up and increasing infiltration rates is another way to control salinity problem. Examples of irrigation projects seriously salinized can be found in the Hadejia, Kano and Sokoto Rima valley projects and Tungan Tudu and Kalmalo projects all in the North Western part of Nigeria (Ramalan, 1994). In the North East, Yau, Daya and Abada irrigation schemes have similarly been affected by salinity (Allison, 1962).

Sodium affected soils have been observed in Bakura irrigation station and Kadawa irrigation schemes (Singh and Maurya, 1979, Maurya, 1982); while the source of salts in some of these soils are from parent materials. In others, the build-up is as a result of poor water management. Recent salinity/sodicity reports of soils of Wurno Sokoto State) showed that the problem must have arisen from the soils (Danmowa *et al.*, 2006).

Often salinity and sodicity change with soil depth, time of irrigation, soil and water management practices. Therefore it may be necessary to measure these changes to determine if the soil is suitable for agricultural practices or is degraded. Also, Qureshi and Barret-Lennard (1998) reported another classification of soil salinity/alkalinity as shown in Table 2.1 & 2.2.

Table 2.1: Classes of soil salinity

Salinity class	Electrical conductivity (dSm^{-1})
Salt-free (non-saline)	<4
Slightly saline	4-8
Moderately saline	8-15
Strongly saline	>15

Source: (Water and Power Development Authority Pakistan, 1981)

Table 2.2: Classes of soil alkalinity (sodicity)

Sodicity class	SAR
Non-sodic	<13
Slightly sodic	13-25
Moderately sodic	25-45
Strongly sodic	>45

Source: Qureshi and Barret-Lennard (1998)

2.4 Waterlogging and Rising Ground Water Table

Most of the Nigerian irrigation sites are poorly drained and some have heavy soils. Water logging is a common feature at some sites even during the dry season (Nwa, 1982; Sanda *et al.*, 2006). Compared with soils that have their exchange complex dominated by Ca and Mg ions, non-saline sodic soils tend to lose their structure when wet. This is due to the strong affinity of water to adsorb Na^+ on the exchange complex and force clay and soil particles apart. The importance of this structural instability increases as the soil clay content increases. The fine particles (clay and silt) that separate from the soil matrix tend to fill the pores and cracks in the soil structure which in turn inhibits water penetration. The consequence of this is a loss of pore space in the B horizon and the development of poor drainage or water logging, (Fitzpatrick, *et al.*, 1994). The high water table in Tungan Tudu and Kalmalo irrigation schemes resulted in a white powder containing enormous amount of salt at the surface due to shallow water table coupled with high evaporation of soil moisture.

2.5 Effects of Soil Degradation (Salinity and Alkalinity)

Salt accumulation has a direct impact on both soil and vegetation. In soil, salts reduce pore spaces and inhibits its ability to hold nutrients. For instance higher salinity was reported to decrease the concentrations of total Zn and free Zn in the soil solution in wheat sheets (Khoshgoftar et al., 2004). However, there is a shortage of reliable analysis of the predictable prospects facing, for instance, fertile soils, sustainable agricultural production, and carrying capacity of the surface layers of the earth in the face of contamination by harmful elements and destruction by physical, chemical and biological agents (Szabolcs1989). One of the hazards in high salinity of soil and waters is not only for soil fertility, but also for water purity and for plants, animal and human life (Tsuzom and Orisanaiye, 1998), because high concentration of salts may adversely affect waters, food and cells of living organisms (Richard *et al*., 2004 and Yakubu, *et al*., 2006).

More over there is serious concern on the main medium for salts accumulation which is the soil. Hence, the possible hazard of salinity and alkalinity of irrigated or proposed irrigated areas, may be determined by having good knowledge of the source of irrigation water, method, frequency, intensity of the irrigation, salt contents and composition of the water and drainage. Bali and Kanwar (1977) reported that out of 167 million ha of Indian land space, 29 million ha suffer from soil degradation of which 7 million ha are affected by salinity and another 20 million ha in the canal irrigated areas run the risk of becoming degraded. This rapid soil degradation can be seen in the Hayana soil of India, where approximately half a million ha is waterlogged saline (Datta and de Jong, 2002).

In addition to several hundred of books and papers that have been published in many countries and regions, which are directly or indirectly related to problems of soil salinity Yu and Wang (1983) reported salt affected soils in arid and semi arid regions of northern and northwestern coastal region and the Qing-Hai Tibet Plateau in China. They further explained that at the beginning of 1960’s irrigation had to be stopped temporarily because of excessive secondary salinization induced by excessive irrigation by gravity in the region and so much attention was devoted to drainage which led to significant progress in controlling the problem.

Sodic soils generally have poor physical properties (Gupta et. al. 1984; Kelly, 1937; Richard 1954) and this leads to poor crop growth. A sodium adsorption ratio, high soil pH and simultaneously high levels of calcium carbonate ($CaCO_3$), contribute to the dispersion behavior of soils that gives rise to poor aeration, poor water intake (Datta and de Jong, 2002), poor drainage and resistance to cultivation.

Swelling and shrinking behaviour of certain clay under sodic conditions contribute to poor physical properties of soils (Aldrich and Schoonover, 1951; Kelley, 1937). However, any means of increasing the soluble calcium in the soil does improve the characteristics of sodic soils (Aldrich and Schoonover, 1951; Richard, 1954). Also Quastel (1954) pointed out that soil conditions, CRD – 186 which is a VAMA (Allison and Moore, 1956), when applied to saline and alkaline soils facilitated the removal of sodium. With irrigation in the Soviet Union, it was found that the structure of alkaline (sodic) soil was improved and the salts were more easily washed from soils when treated with the polyelectrolyte (Khamraev *et al*., 1983). Bole *et al*., (1981) studied the effect of waste water irrigation and leaching percentage on soil and ground water chemistry in California. The waste water analysis result showed a salt content of 1,300 mg/liter (E.C 1.1 to 2.2 mmhos) and the salt were largely sulphates and bicarbonates of calcium, magnesium and sodium. In the Indo-Gangetic plains of India, 2.5 million ha of extensive sodic soils were formed under the influence of sodium carbonate (Na_2CO_3) (Abrol and Bhumbla, 1980). These soils owe their unproductivity to the effect of high exchangeable sodium on the soil physical properties, nutritional disorder related to high pH, etc. Hence in consequence of the great diversity of salt-affected soils and their differences in morphology, appearance, and possibilities of utilization, it is difficult to formulate general rules which can be applied to all salt-affected soils (Szabolcs, 1989).

2.6 Soil Types

The major soil type found in Nigeria are alluvial, Ferrasols. Ferroginous tropical soils, vertsoils, lithosols, brown and reddish brown soils of the semi arid (FAO, 1977).

Alluvial soils are of three different groups: the first group is found on marine deposits in mangrove areas, the second group include alluvial soils near the coast with high sulphate content and the third group are those alluvial soils that are more useful under controlled drainage and are more extensive in the lower Niger delta, upper stretches of Niger, Gongola, Sokoto and Rima Rivers.

Ferralitic and ferrasols are reddish yellow in colour, covering the southern parts of the forest zone of eastern Nigeria and extensive areas of the mid-western and eastern states. They extend northwards into parts of Benue, Plateau, Kwara and Sokoto States

The ferraginous tropical soils covering wider area in Nigeria particularly in larger part of Ogun, Oyo, Kwara, Bauchi, Kaduna, Sokoto, Borno and less extension in Benue and Plateau States. Lithosols are usually associated with ferragious tropical soils especially in central part of Niger. It is found on crystalline basic rocks, iron pan and undifferentiated soils.

Vertisols are dark-coloured soils with large amount of clay of expaning lattice tpe that are rich in calcium carbonate and gypsum. North of a line joining Kano, Potaskum and Maiduguri, semi arid brown soils predominant over the large areas. According to

Jones and Wild (1975), Iwuafor (1987), Alfisols, Entisols and Inceptisols are the dominant soil types found in Nigeria with only 2% vertisols.

2.7 Soil Quality

The availability of soil nutrients for crop growth and development is a function of soil productivity. The soils of Nigeria are principally of the orders: Alfisols, Entisols in the north (Owonubi,*et al.*, 1991; Ojanuga, 1987 and Iwuafor, 1987) and the Oxisols and Ultisol for the bulk of the soils of south (Lawson and Sivakumar, 1991).

The soils of Northern Nigeria are of poor structure with high tendency to form crust and a significant risk of erosion (Ogunwole and Owonubi (1999). They are generally well drained, coarse textured, low in organic matter, exchangeable cations, cations exchange capacity, clay and silt (Balasubramanian et al. 1984; Iwuafor, 1987 and Lombin, 1983). The inherent natural fertility of the soils is therefore generally low. Soil fertility degradation is one important biophysical constraint to soil and crop production in the Nigerian savanna. However, they appeared to be adequately supplied with available micronutrients such as copper, iron, zinc and manganese (Lombin, 1983). In addition, they are dominated by low activity clays and subject to acidification when intensively cultivated (Odunze 1998).

On the other hand, the soils of the south are generally highly weathered and leached. Some of these soils are acidic with few nutrients and their subsoils contain toxic elements that can inhibit crop growth.

2.8 Irrigation Water

Irrigation water quality determines the growth and quality of agricultural production (Russell, 1973; Michael, 1978). Between 1967 and 1970 Bingham et al. (1971) studied excessive application of irrigation water and substantial losses of NO_3-N in the effluent water draining from watersheds. The result obtained generally reflected leaching of salt during the winter season, and thus salinization was particularly evident during the period of peak water demand. Generally, it is known that poor quality irrigation water leads to the destruction of soil structure, and impairs infiltration, hydraulic conductivity and aeration (Datta and de Jong (2002), Richard *et al.*, (2004), Fauck (1977), Maurya (1982). Waterlogging, salinization and alkalization are the ultimate consequences of continuous use of irrigation water with high salt content.

2.8.1 Water Quality

Irrigation water quality determines the growth and quality of agricultural production (Russel, 1973; Micheal, 1978). Whether taken from a river or pumped from the ground water, even the best quality fresh water contains some dissolved salt (Brady and Weil, 2004). The effect is accentuated in arid regions because of high salt content of the water available from river or from under ground and the high evaporative demand of the dry climate.

If irrigation water carries a significant quantity of Na^+ ions compared to Ca^{2+} and Mg^{2+} ions, and especially if the HCO_3^- ion is present, sodium ions may come to saturate a major part of the colloidal exchange sites, creating a sodic soil. This leads to extreme unproductivity of soil (Brady and Weil, 2004). As such there are existing guidelines for assessment of water for irrigation (Table 2.3). These were documented by Ayers and Westcott (1976) and the parameters used for assessment include salinity, electrical conductivity (EC), SAR, sodium, magnesium, calcium and pH. Others are chloride, boron, carbonate, bicarbonate and nitrate concentrations. The total salt concentration or salinity of irrigation water affects osmotic activities of crops which consequently reduces absorption of water and nutrients. On the other hand, high values of SAR and sodium ion, in irrigation water tend to cause salinization and displacement of calcium and magnesium ions, resulting in soil dispersion and reduction in infiltration. Elements such as boron, Cu, Mn, Fe and Zn in concentrations above the required trace quantities create toxic conditions to plants. Generally the suitability of water for irrigation depends not only on the quality of the water itself, but also on the soil type, salt tolerance, characteristics of the crop, cultural soil management practices, climate and drainage conditions (Okereke, 1998).

Table 2.3: Guideline for interpreting chemical quality of irrigation water

Characteristic	Degree of problem		
	No problem	Increasing problem	Severe problem
Salinity (EC) dSm^{-1}	0.75	0.75-3.0	3.0
EC of Water	0.50	0.5-0.2	0.2
Sodium Adsorption ratio (SAR)	3	3-9	9
Boron (mg/L)	0.75	0.75-2.0	2.0
Chloride (mg/L)	4	4-10	10
pH	< 6.5	6.5-8.4	> 8.5
Nitrates (mg/L)	5	5-30	30
Bicarbonates (mg/L)	46.5	46.5-263.5	263.5
Total dissolved solid mg/L	< 450	450-2000	>2000

Source: Ayers and Westcott (1976)

2.8.2 Measuring Salinity and Sodicity

Salt affected soils adversely affect plants (Brady and Weil, 2004 and Richard, et al. 2004). This is because of the total concentration of salts (salinity) in the soil solution and because of concentrations of specific ions, especially sodium (sodicity). In order to assist in characterizing and managing salt-affected soil, techniques have been developed to measure and quantify the degree of soil salinity and sodicity (Richard, 1954; Ayers and Westcott, 1976; Abrol, 1988; Szabolcs, 1989; Qureshi and Barret-Lennard, 1998; Brady and Weil, 2004 and Richard *et al*., 2004).

Salinity is measured primarily as the total dissolved solids (TDS) or more conveniently, as electrical conductivity (EC). Sodicity is characterized primarily by exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR). In water to be used for irrigation, TDS typically ranges from about 5 to 1000 mg/l, while ESP levels greater than 15 and pH values of 8.5 and above are associated with severely deteriorated soil physical properties. An SAR value of 13 for the solution extracted from saturated soil paste is approximately equivalent to an ESP value of 15 (Brady and Weil, 2004).

The salinity/sodicity study at Wurno indicated that the soils were mostly sodic or saline-sodic, which are indicating salinity (pH up to 8.77; EC up to 8.05 dSm^{-1}; SAR up to 4.39 and ESP up to 68). The water analysis however, showed that the water was within the safe range for irrigation (Danmowa et al., 2006).

2.9 Water In Nigeria

The primary source of water in Nigeria is rainfall. Annual rainfall in Nigeria declined both in time and space. In the Sudan Savanna agro-ecological zone, the rainfall events are erratic and unreliable with fewer wet days, thus increasing the length of the growing season by supplementing the water supply to crops artificially through irrigation (Tsuzom and Orisanaiye 1998). Physiologically, crops generally require larger quantities of water for growth than any other growth factor, but as human population is increasing the available fresh water resources are decreasing due to pollution (Okereke, 1998). Hence paucity of water sources requires water conservation practices including waste water re-use.

The re-use of waste water on agricultural lands is advantageous because it not only provides the required crop water, but also contains some valuable plant nutrients. The work of researchers like Bangboye (1986) indicated increased yield of sorghum crop as a result of using sewage effluent for its irrigation. Duration of use can also be an important factor.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Site Description

The experimental site was the Ajiwa Dam and Water Works including the irrigated fadamas up the course of River Tagwai to Makurda in Katsina State Nigeria. It is part of Tagwai downstream irrigated land within which the largest fadama acreage of Katsina State are found.

The study area lies within latitude 12^o 30' – 13^o00' North and Longitude 7^o 30' – 8^o00' East in the Sudan Savanna ecological zone of Nigeria (Fig. 1), characterized by short rainy season (June – September) and long dry period (October – March). Annual rainfall varies between 600mm to 800mm while the annual temperature range is between 15^o – 40^o with a relative humidity of 20-40% between June and August. The mean annual evapotranspiration is 1618mm. The elevation of the site is about 518 m above sea level.

The vegetation was dominated by grass with few scattered tree species and the top soils were brown and reddish brown loamy sands formed mainly from Aeolian drifts. Classified as inceptisols (Harpstead, 1973). The soils have been classified taxonomically according to the USDA Soil Taxonomy as Ustoxic Dystropepts occurring on nearly level terrain. The soils are moderately deep to deep and well-drained. The upper layers consist of very dark grayish brown loamy sand, while the lower layers are strong brown loam sand to sandy loam and yellowish red sandy clay loam soil reaction ranges between strongly acid and slightly acid (pH 5.5-6.3). Values of exchangeable bases were very low to low for Ca, low for Mg, very low to low for K and moderate for Na. Cation exchange capacity values were very low and base saturation is moderate to high (Federal Department of Agriculture, 1990).

From the dam proceeding to just downstream wards, there was a narrow valley that further widens at the confluence with River Housaini. This wide stretch continued considerably up to Makurda village (Fig. 3). Despite the fact that the land was used, mainly for irrigated agriculture, some parts of the plains showed signs of excessive salts accumulation and chemical processes, so much so that the soils were recognized by spotty growth of crops and often the presence of white salt crusts on the surface.

Water stagnation on the surface during the rainy season was a common phenomenon and the depth of water table varied from the surface in the rainy season to within 80cm at the end of the dry season.

3.2 Land use

Although there was very little information on cropping patterns of the area, farmers practised subsistence agriculture and major crops grown include, sorghum, millet, groundnut, cowpea and rice. Almost 10% of the land was occupied by orchard, majority of which consisted of guava trees, oranges, lemon, mango and banana. Pepper is planted with various vegetable crops such as onions, carrots, lettuce, garden egg, Irish potatoes, etc. The most common methods of watering crops were through furrow and shadouf, while in some fadama, small water pump engines were often used.

The study area was chosen keeping in mind the need for monitoring the quality of the water works waste (effluent) and consequent degradation in soil properties as a result of using same for irrigation.

3.3 Processes of Water Treatment in Ajiwa Water Treatment Plant

Ajiwa water works is located at the same downstream position compared to the location of the dam (reservoir). It provides the entire Katsina city and other neighbouring towns with potable water (tap water).

The process of water treatment involves addition of alum ($Al_2\ (SO_4)_3$,-$14H_20$) to the water, followed by mixing in the mixing chamber, then separation of flocs (sludge) in the clarifier where coagulation takes place.

After separation and coagulation, water is passed through the Y-channel to the filter which is of gravitational type made up of coarse sand particles arranged in different layers for filtration.

Following the filtration process is the addition of chloride and hydrated lime for disinfection and pH correction respectively. The treated water is finally pumped to the service reservoir for distribution. In the clarifier, separated sludge is discharged as waste water which eventually is used mainly for irrigation crops in the study area.

Earlier on, the water treatment plant had the capacity of treating 5.5 million gallons of water daily, but from the year 2000, the quantity has been doubled to 11 million gallons daily. Out of this quantity, 5% is discharged in form of effluent (waste water).

The annual quantity and composition of the chemicals used in water treatment are shown in Table 3.1 below:

Table 3.1: Annual quantity and composition of chemicals used in water treatment at Ajiwa water works plant in Katsina State

Chemicals	Quantity used per annum (kg)
Alum $Al_2 (SO_4)_3$-$14H_20$	699,650
Hydrated Lime Ca $(OH)_2$	86.150
Super floc (Acetyle amide base organic flocculating agent)	1,125
High test hypochloride	8,647.4
Liquid chloride	9,772

Source: Ajiwa Water Treatment plant

3.4 Collection of Samples

Soil and water samples were taken at predetermined points for physical and chemical analysis in the laboratory. In all, a total of seventy two soil samples were collected as follows:-

(a) At the vicinity of the water works plant and at 200 meters interval for the first one kilometer;

(b) At 500 meters intervals for the next two kilometers and

(c) At 1 kilometer interval for another two kilometers.

3.4.1 Soil Sampling

Soil samples were collected from the surface to sixty centimeters depth in three depth ranges 0-15cm, 15-30cm and 30-60cm. Each of these samples were composite and each composite comprised of 10 samples taken at each predetermined point as outlined above in the study area. The samples were air-dried, ground to pass through a 2mm sieve and stored for laboratory analysis.

3.4.2 Water Sampling

Also a total of eight water samples were collected from the dam (reservoir), water works waste (waste water), tube wells, dug wells and treated (purified) tap water as control. These were stored in a refrigerator for preservation before commencing with the laboratory analysis.

3.4.3 Salt Sampling

Representative samples of the white salt on the soil sample that was observed were collected and stored for laboratory analysis.

3.5 Soil Analysis

Laboratory determination of both physical and chemical properties of soils were carried out:

3.5.1 Particle Size Analysis

Particle size analysis was performed by using hydrometer method (Day, 1965) with sodium hexametaphosphate (Calgon) as the dispersant. This was done by weighing 50g of 2mm sieved soil into a 250ml plastic beaker and 100ml calgon was added and shaken. After shaking for 30 minutes the contents were transferred into 1000cm^3 measuring cylinder and made to mark of 1000 cm^3 with water. Readings were taken for 40 seconds, 4 minutes and 2 hours as recommended. At the end of the readings, percentage clay, silt and sand were calculated and used on the U.S.D.A textural triangle to determined the soil texture.

3.5.2 pH

The pH of collected soils samples was measured in water and in 0.01M $CaCl_2$ at a soil:water ratio (1:2.5) using a pH meter with glass electrode. Ten grams of 2mm soil sample was weighted into a 50 ml plastic beaker, 25 ml of distilled water was added, stirred and left to stand for at least 30 minutes, after which pH was read and recorded. The above method was repeated using 0.01M $CaCl_2$.

3.5.3 Electrical Conductivity

The electrical conductivity of the 1:5 soil to water ratio extract was determined using a direct electrical conductivity meter (Bridge type M.C3) into aforementioned soil solution sample at room temperature. Result was expressed in micromhos cm^{-1} and there after converted to decisiemens per meter ($dS\ m^{-1}$) (US Salinity/Lab Staff 1954).

3.5.4 Cation Exchange Capacity (CEC)

The cation exchange capacity was determined by the ammonium saturation method (Black, 1965). Ten gram of 2mm sieved soil was weighed into 100ml plastic beaker collect by 40mls of 1N ammonium acetate, stirred with glass rod and left for over night. The soil was filtered and leached with 1N pH7 NH_4OAc to a volume of 250 ml and the leached was preserved for exchangeable basic cations determination. The soil was again leached about four times with 1N NH_4OAc and washed out the electrolyte with 200 mls of 99% alcohol (ethanol). After tested for chloride with 0.1N $AgNO_3$, the soil was allowed to drain. The soil was then leached with acidified NaCl to a volume of 250 mls.

50mls of 2% boric acid, few drops of mixed indicator were added into 250mls flask. The acidified sodium chloride leachate was transferred into 500ml. Kjeldahl flask followed by some antibume and 10ml of 1N NaOH and then distilled.

50mls of distillate was collectged and titrated the NH_4 borate with 0.1N HCL, CEC was calculated using titred value in the formula as follows

$$\text{CEC cmol kg}^{-1} = \frac{\text{(Titre-Blank) x Normality of acid x 100}}{\text{Weight of soil}}$$

3.5.5 Exchangeable Bases

The leachates preserved from C.E.C. determination were used for the determination of Ca and Mg using atomic absorption spectrophotometer and K and Na by flame photometer.

3.5.6 Organic Carbon

Organic carbon was determined by Walkley Black method as follows: 1g of representative soil sample was weighed into 250ml flask, 10ml of 1N $K_2Cr_20_7$ was added followed by 10ml of conc. H_2SO_4. After 30 minutes standing, 100ml of distilled water was added and left to cool again. 5ml of phosphate acid was added to the solution followed by 5 drops of indicator and finally titrated with 0.5N ferrous sulphate solution. The titred value was used with the following formula to calculate the percentage organic carbon.

$$\text{Organic carbon \%} = \frac{\text{Meq } K_2Cr_20_7 - \text{Meq Fe } SO_4 \text{ x 0.003 x 100 x F}}{\text{Wt of air dry soil taken}}$$

Where F = Correction factor 1.33

meq = Normality of solution x ml of solution used.

3.5.7 Total Nitrogen

Total nitrogen was determined by regular Kjeldahl digestion-distillation method. The method was carried out by weighing 1g of soil into a digestion tube, followed by adding few drops of water, 5g of Kjeldahl catalyst mixture ($Na_2\ SO_4$) and 20ml of conc. Sulphuric acid. The whole mixture was digested and allowed to cool. The digest was distilled and then titrated with 0.01N H_2SO_4 from green to purple end point. %N was thereafter calculated using the following formula:

$$\%N = \frac{0.014 \times (T-B) \times NA \times \text{Vol. of digest} \times 100}{\text{Wt of soil} \times \text{Aliquote distilled}}$$

Where NA = Normality of acid

T = Titre value
B = Blank value

3.5.8 Available P

Soil available P was determined by using Bray-1 (ascorbic acid molybdate) method. 5g of soil sample was weighed into a tube, followed by $35cm^3$ of extraction solution, shaken and filtered into a dry bottle. $10cm^3$ of the filtrate was transferred into another dry $100cm^3$ beaker, then $25cm^3$ of ammonium molybdate reagent, and $5cm^3$ stannous chloride dilute solution were added and mixed. After 10 minutes, the developed colour was read on a spectronic 20 at 660nm.

3.5.9 Exchangeable Acidity

Soil exchangeable acidity was determined by employing KCl extraction method, Mclean (1965). The 50ml of soil KCl extract was pipetted into flask followed by 100ml of distilled water, 5 drops of phenolphthalein indicator and titrated the solution with 0.01m NaOH to a permanent pink end, point with alternate stirring and standing. The amount of base (NaOH) used is equivalent to the total amount of exchangeable acidity in the aliquot taken.

3.5.10 Micronutrients (Cu, Mn, Zn, Fe)

Determination of micronutrients was carried out using 0.1M HCl extraction method with atomic absorption spectrophotometer (Lombin, 1983). In this method, 5g of 2mm sieved soil sample was weighed into 100ml plastic bottle, followed by 50ml of 0.1M HCl and shaken for 30 minutes. The solution was then centrifuged and Cu, Mn, Zn and Fe were determined on an atomic absorption spectro photometer.

3.5.11 Boron

Boron was determined by using Azomethine-H method. This involved weighing 20g of 2mm air dry sieve soil into plastic bottle followed by 40ml of morgan solution, shaken for 5 minutes and filtered. 4ml of filtrate was taken into plastic vial, followed by 1ml each of buffer masking and axomenthine-H reagents, mixed and allowed to stand for 1hr for colour development. The sample was then read on spectrophotometer 20 at 420nm wavelength.

3.5.12 Sulphate (SO_4^{2-})

Sulphate was determined by turbidity method. 5g of soil sample was weighed into a centrifuge tube followed by the addition of 25ml of $K_2H_2PO_4$ solution and shaken for 20 minutes and filtered using No.1 filter paper. From the filtrate 10ml was pipetted into 25ml volumetric flask, followed by 1ml of gelatin Borium chloride solution, then made to mark with distilled water shaken just to mix and allowed the content to stand for 30 minutes to develop the colour and read the colour with spectrophotometer 20 at 420nm.

3.5.13 Carbonate

Carbonate and bicarbonate were determined by titration method with 0.02N H_2SO_4 as follows: 20ml of water saturated extract of soil sample was pipetted into a 100ml conical flask, followed by few drops of phenolphthalein indicator, when pink colour appeared, it was then titrated slowly with 0.02N H_2SO_4 until the pink colour disappeared. The titred volume of 0.02N H_2SO_4 was used for carbonate. Into the same flask few drops of methyl orange was added and titrated with 0.02N H_2SO_4 to reddish end point. Recorded titred to bicarbonate and calculated as follows:-

$$\text{Mg/L } HCO_3 = \frac{2 \text{ x Phenolphthalein x Titre x N of } H_2SO_4 \text{ x } 1000}{\text{Mls of aliquot taken}}$$

3.5.14 Chlorides

Chloride was determined by titration method with silver nitrate by pipetting 20ml of water saturated extract of soil sample into a conical flask, followed by three drops of potassium chromate, while stiring, silver nitrate solution was added dropwise from the burette to a first permanent reddish brown colour and recorded the titred value for calculation as shown below:

$$\text{Mg/LCl} = \frac{1000 \text{ x N of } AgNO_3 \text{ x Mls of } AgNO_3 \text{ used}}{\text{Mls of sample used (aliquot)}}$$

3.5.15 Base Saturation

Percentage base saturation (%B.S), Exchangeable sodium percentage (ESP) and Sodium Absorption Ration (SAR) were computed as follows:-

$$\text{\% B.S.} = \frac{Na^+ + K^+ + Ca^{2+} + Mg^{2+}}{\text{C.E.C.}} \text{ x } 100$$

$$\text{ESP} = \frac{\text{Exchangeable } Na^+}{\text{C.E.C.}} \text{ x } 100$$

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

3.6 Water Analysis

Water samples were analyzed for:

3.6.1 Total Dissolved Solids (TDS)

Total dissolved solids (TDS) was determined by evaporating drying method. It involved weighing an empty petridish, then 100ml of water sample was added and taken into evaporating dish (at 108^{o}C) until all the water in the sample evaporated. The Petri-dish was then taken into dissicator, allowed to cool and reweighed. The weight difference between the empty petridish and when it had evaporated sample was recorded as TDS mg/L).

3.6.2 pH

pH of each water sample was determined using digital pH meter. The values were recorded.

3.6.3 Electrical Conductivity (EC)

Electrical Conductivity of water samples was read by using conductivity meter directly and values were recorded and converted from mmhos cm^{-1} to deci-siemens per meter (dSm^{-1}).

3.6.4 Calcium, Magnesium, Sodium and Potassium Ions

Calcium and Magnesium ions were directly determined by using atomic absorption spectrophotometer, the determination of potassium and sodium ions were done by using flame photometer.

3.6.5 Micronutrient (Cu, Mn, Zn, Fe)

Micronutrients in the water samples were determined by using atomic absorption spectrophotometer.

3.6.6 Boron

Boron was determined in the water samples by using Azomethine-H method. 4ml of water sample was taken into a plastic vial, followed by 1ml each of the Buffer masking and Axomenthine-H reagents mixed thoroughly and allowed to stand for 1 hr for color development. The sample was then read on spectrophotometer 20 at 420nm wave length.

3.6.7 Sulphate

Sulphate was determined turbidimetrically. Five grams of soil sample (<2mm sieved) were weighted into an extraction bottle followed by the addition of 50ml of Ca $Ca(H_2PO_4)$ solution, shaken for 30 minutes and then filtered. From the filtrate, 4ml of $Ca(H_2PO_4)_2.2H_2O$.

3.6.8 Carbonates and Bicarbonates

Carbonates and Bicarbonates of water were determined by pippeting 20ml of water sample into 100ml conical flask, followed by few drops of phenolphttalein indicator until pink color appeared and then slowly titrated with 0.02N H_2SO_4 from burette until the pink colour disappeared. The titre volume of 0.02N H_2SO_4 used was considered for carbonate. Into the same flask few drops of methylorange was added and titrated with same 0.02N H_2SO_4 to reddish end point. The second titred value was recorded to Bicarbonate for calculation as follows:

$$\text{Mg/L } HCO_3 = \frac{\text{Titre} - \text{Phenolphthelein titre x N of } H_2SO_4}{\text{Mls of aliquote taken}} \text{ x } 1000$$

3.6.9 Chloride

Chloride was determined in water by titration method with $AgNO_3$. 20ml of water sample was pippeted into a 100ml conical flask and followed by three drops of potassium chromate, while stirring silver nitratesolution was added dropwisely from the burette to a first permanent reddish brown colour. The titre was used for calculation as follow:

$$\text{Mg/L } Cl^- = \frac{1000 \text{ x N of Ag } NO_3 \text{ x Mls of Ag } NO_3 \text{ used}}{\text{Mls of aliquote sample used}}$$

3.7 Statistical Analysis

All the data obtained was subjected to statistical analysis using SAS (1995) Statistical Package.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Site Characterization

Figures 1 to 3 show the location of the study area, the Ajiwa township water treatment plant in Katsina State, and the problem created by the effluent discharge of sludge from the treatment plant. The white surface crust of crystallized salts resulting from the use of water from the River Tagwai for irrigation along the arable bank of the river down the stream course can be clearly seen (Plates I and II). The study highlights the problem of salt affected soils, and the influence on the agricultural prospects of the farmer and the fertility and productivity of the land. Soil and water samples collected from the irrigated terrain of the Ajiwa down stream area along the River Tagwai were analysed for the determination of the soil and water quality of the irrigated land. The data are presented.

4.2 Soil Physical Properties

The geology of the study site is partly of the Gundumi formation and essentially basement complex of the precambrian to upper cambrian era, and so the soils were highly weathered with grits and pebble beds and high in granite (See information in map by Fed. Min. of Mines and Power, 1974). This covers the entire state, with older granites and undifferentiated meta-sediments existing in small strips in the western and southern parts of Katsina State.

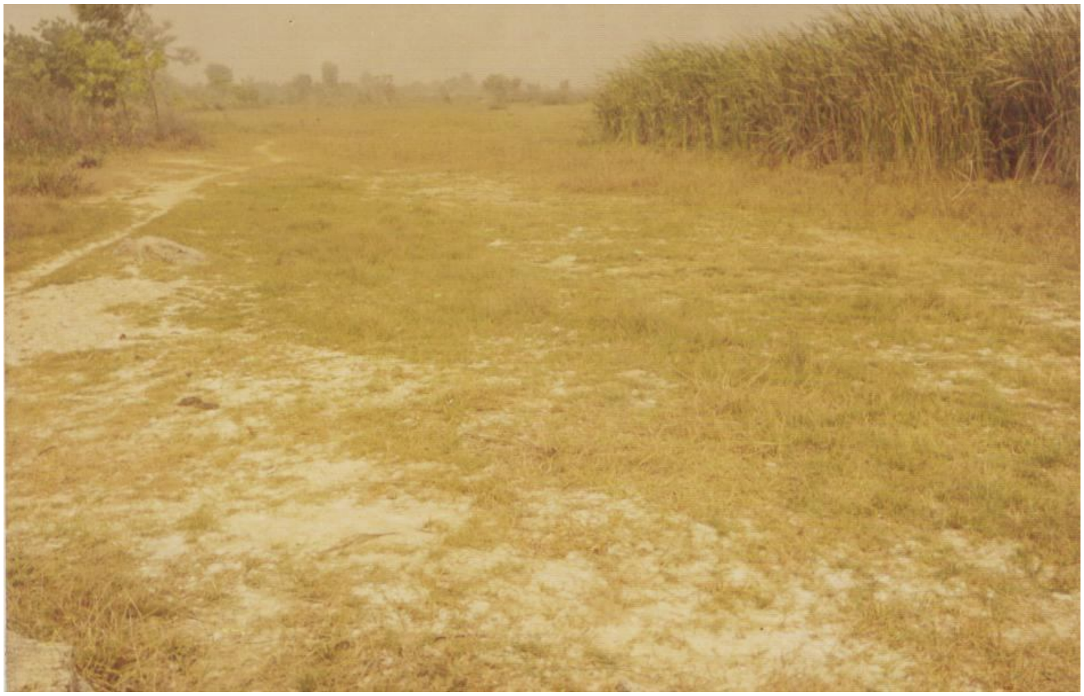


Plate I: An abandoned irrigated land showing white salt crystal deposits at the surface in the Ajiwa study area

Plate II: Seed bed preparation in progress at the Ajiwa down stream terrain. Surface salt accumulation can be clearly seen.

4.2.1 Particle Size Distribution

The particle size distribution of the soils of the irrigated river banks along the 5km course of River Tagwai studied and variation with depth to 60cm are shown in Table 4.1 The clay, silt and sand fractions of all samples ranged from 6-48% for clay, 2-30% for silt and 32-90% for sand, with average values of 17.1%, 12.4% and 70.4% respectively. The dominance of the sand fraction was observed as expected for the Sudan savanna environment, and this corroborated previous reports (Iwuafor, 1979). The textural classes varied from loamy sand at points distant from the dam to clay texture at point of effluent discharge, which was 200 meters away from the dam.

Results showed that the sand fractions increased down the river course away from the dam (Fig. 4) and also increased with depth (Table 4.1). Conversely, the clay content decreased away from the dam and down the profile. The source of the clay size particle deposit can be said to be apparent in the case. At point of effluent discharge at 200m, the clay content was as high as 44%, which decreased to 16% at 1km down the river course, and 10% at 5 km down the course. This high accumulation of the clay sized fraction would invariably influence the soil reaction and other properties appreciably. Fig. 4 shows the variation in the particle sizes of the 0-30 cm layer down the river course. The high impact of the effluent deposits from the water treatments plant on soil texture was confirmed by the results. Variation in the particle size fractions were highly significant with distance and depth (Table 4.1). There was no interaction between distance and depth, indicating that the source of these variations were from the effluent discharge. The effects of the impact of clay accumulation on the productivity of the arable lands under irrigation need to be determined.

Table 4.1: Variation in soil texture with depth and distance from point of effluent discharge along the course of River Tagwai downstream

Depth	0 – 15 cm				15 – 30 cm				30 – 60 cm			
Distance	Sand	Silt	Clay	Textural class	Sand	Silt	Clay	Textural Class	Sand	Silt	Clay	Textural class
50 m	63	12	25	Scl	74	9	17	Sl	76	10	14	Sl
200 m	39	17	44	C	51	12	37	Sl	51	23	26	scl
400 m	64	9	27	Scl	64	13	23	Scl	78	7	15	Sl
600 m	73	8	19	Sl	79	8	13	Ls	83	7	10	Ls
800 m	53	26	21	Scl	55	26	19	Sl	71	10	19	Sl
1000 m	66	18	16	Sl	70	16	14	Sl	70	16	14	Sl
1500 m	59	22	19	Sl	60	19	21	Scl	69	14	17	Sl
2000 m	71	15	14	Sl	67	15	18	Sl	75	11	14	Sl
2500 m	76	11	13	Ls	77	13	10	Ls	82	9	9	Ls
3000 m	80	7	13	Ls	77	9	14	Ls	79	9	12	Ls
4000 m	75	10	15	Ls	80	6	14	Ls	82	7	11	Ls
5000 m	82	8	10	Ls	81	8	11	Ls	84	8	8	Ls
R^2	0.82	0.80	0.82									
CV	10.37	31.43	28.63									
SE$\pm$	6.0**	3.20**	4.00**									
Interaction :	Discharge = NS											

C-Clay, Scl - Sandy clay loam, Sl – Sandy - loam, Ls – Loamy sand,

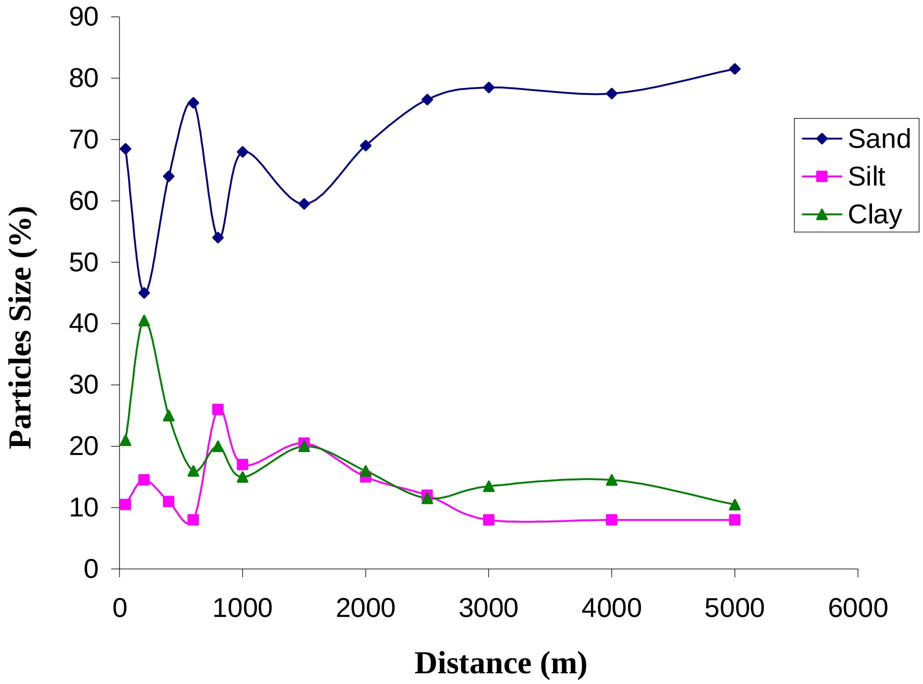


Fig. 4 Variation in particle size distribution of the 0-30cm soil layer down the river course

4.3 Soil Chemical Properties

The effects of the effluents discharged from the water works on the texture of the soils impacted by the discharge was appreciable and imply that the chemical substances used in the water purification processes would influence the chemistry and reactions of the soils irrigated with the effluent waste water introduced into River Tagwai. Table 2.1 earlier mentioned showed the treatment profile at the Ajiwa Water Works with list of standard chemicals used.

4.3.1 Soil Reaction (pH in H_2O and $CaCl_2$)

Table 4.2 shows the pH values in H_2O and $CaCl_2$ down the river course and down the profile. The pH values in H_2O ranged from 4.8 at point of effluent discharge into River Tagwai, to 6.6 at 5km down the river course away from the dam and in $CaCl_2$. Values ranged from 4.1, also at point of effluent discharge (200m) to 6.3 at 5km away. The soils were acidic at the point of effluent discharge. At about 800 meters away, the acidifying influence weakened considerably as the soils become only slightly acidic and posed no danger to soil productivity. This trend was consistent with the $CaCl_2$ values, which were also consistently lower than the pH in H_2O, indicating that the soils are negatively charged (Balasubramanian *et al*., 1984). It can be inferred from the results that though hydrated lime ($Ca(OH)_2$) was one of the chemicals used in the water treatment plant, the overwhelming influence of the huge quantity of Alum ($Al_2(SO_4)_3.14H_2O$) employed in the water treatment process as evident in the pH values, which can be said to be induced by Al in the soil system. At 800 meters, much of the soluble Al must have precipitated out in anonic complexes (Hsu 1965, 1975, Gebhardt and Coleman, 1974).

Table 4.2: Soil pH (0.01 M$CaCl_2$) as influenced by soil depth and distance from the point of effluent discharge

Solution 2:1 Ratio		H_2O			$CaCl_2$	
Depth Distance	0 – 15cm	15 – 30cm	30 – 60cm	0 – 15cm	15 – 30cm	30 – 60cm
50 m	5.9	5.8	5.4	5.2	5.3	5.1
200 m	4.8	5.0	4.8	4.1	4.6	4.5
400 m	5.3	5.8	5.7	4.8	5.4	5.4
600 m	5.1	5.8	5.7	4.5	5.1	5.1
800 m	6.0	6.3	6.4	5.0	5.9	5.8
1000 m	6.4	6.4	6.5	5.8	5.7	5.8
1500 km	6.1	6.2	6.3	5.4	5.4	5.6
2000 m	6.2	6.0	6.1	5.5	5.3	5.5
2500 m	5.6	5.9	6.0	5.0	5.2	5.6
3000 m	5.5	5.3	5.8	5.0	5.1	5.5
4000 m	6.3	6.3	6.4	5.9	5.8	6.0
5000 m	6.4	6.6	6.4	6.3	6.3	6.1
R^2	-	0.81	-			
CV	-	5.57	-			
SE$\pm$	-	0.26**	-			
Interactions: Dis x depth = NS						

The effect of Alum (aluminium sulphate, hydrated) was therefore very crucial in the evaluation of the productivity of these lands irrigated with the contaminated water from River Tagwai. The pH values significantly increased from point of discharge at 200 meters to the study limit of 5km away from the dam. Values tended to increase with depth, consistent with expected precipitation of Al with infiltration, but was not significant. The very high R^2 values of pH and particles size distribution, 0.81 and 0.82 respectively would tend to show that factors such as Al content of the effluent discharge (that influenced appreciably by pH variation), should be highly rated in the overall effects on the fertility and productivity of the soils affected. The variation in pH with depth along the river course is shown in Figure 5. The effluent was slightly more acidic in the proximal areas around the point of discharge.

4.3.2 Organic Carbon, Available Phosphorus, Total Nitrogen and C:N Ratio

The organic carbon content, available phosphorus, total nitrogen and C:N ratio values of the soils down the river course and down the profile are shown in Tables 4.3 and 4.5 Figs 6 to 8.

4.3.2.1 Organic Carbon

Variation in the soil organic carbon content of the surface soils and with depth are shown in Table 4.3. Figure 6 shows the graphic illustration of the variation in the 0-30cm layer with distance. Variation in organic carbon was highly significant both with distance and depth. The non significant interaction between depth and distance indicate that the very single source of influence was the effluent discharge from the water treatment plant.

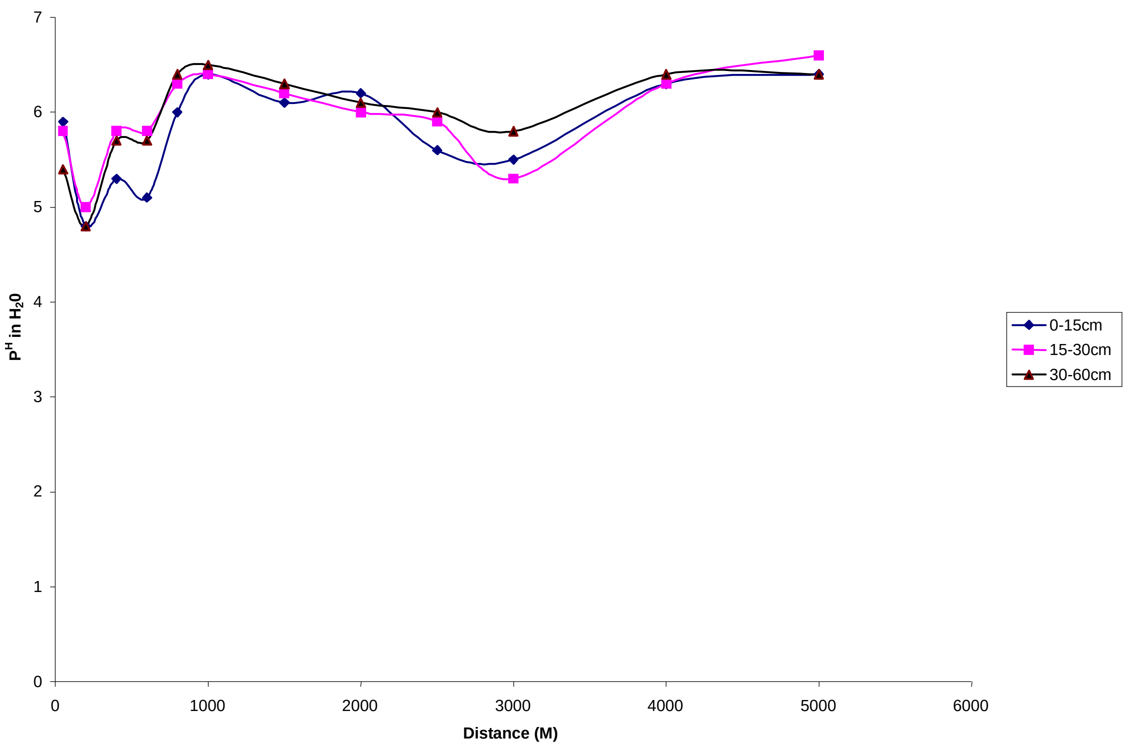


Fig. 5: Variation in pH water and $CaCl_2$ of the 0-30cm layer with distance along the river course

Table 4.3: Soil organic carbon and available phosphorus content as influenced by depth and distance from point of effluent discharge

Depth	Organic carbon %			Available P mg/kg		
Distance	0 – 15cm	15 – 30cm	30 – 60cm	0 – 15cm	15 – 30cm	30 – 60cm
50 m	0.87	0.40	0.30	19.69	14.00	9.19
200 m	1.34	0.85	0.41	10.07	11.82	12.69
400 m	0.76	0.44	0.21	15.32	7.00	3.94
600 m	0.70	0.20	0.16	30.19	25.82	6.13
800 m	0.83	0.59	1.00	33.69	13.13	5.25
1.0 km	0.55	0.40	0.17	26.69	17.07	5.25
1.5 km	0.64	0.44	0.25	13.13	9.63	4.38
2.0 km	0.25	0.35	0.24	11.38	7.88	13.13
2.5 km	0.33	0.21	0.11	28.01	11.38	4.28
3.0 km	0.32	0.22	0.10	25.82	24.50	5.25
4.0 km	0.28	0.15	0.13	10.50	10.50	7.00
5.0 km	0.37	0.28	0.38	14.44	12.26	15.50
	R^2	0.77		R^2	0.61	
	CV	52.69		CV	66.80	
	SE$\pm$	0.18**		SE$\pm$	7.51NS	
	Mean	0.418		Mean	13.77	
Interactions:	Dis & Depth	NS			NS	

This is not surprising considering the fact that the organic flucculant, super floc, an amide base substance was used in the sedimentation process (Table 2.3). However, organic carbon values were high at point of effluent discharge at 200m (1.34%), and decreased consistently with distance down the river course to the 5km distance (0.37%). Organic carbon content also decreased with depth as expected.

Though organic carbon is a desirable factor in soil productivity, the effects of organic flocculants may be negative, as it may tend to chelate nutrient cations as it flocculates the clay particles. On the other hand, it may be positive as the water is progressively deionized to an extent and purified with respect on ionic species.

Figure 6 shows the variation profile with distance as earlier stated. The influence of the effluent discharge on organic matter content of the soils declined to a steady state level at 2km from the dam. Table 4.4 shows the correlation matrix of the soil parameters. Organic matter was highly correlated to all the parameters determined, which is a strong indicator that it is a very vital parameter in defining the productivity of soils even in modified systems. It may also play a role in the sequestration of toxic heavy metals and there deplete the concentration of these elements from the soil solution.

4.3.2.2 Available Phosphorus

The available phosphorus contents of the soils are also shown in Table 4.3. Values were found to be low at the point of effluent discharge and only increased slightly with depth. Values increased appreciably away from the dam, down the river course, but this increase was not regular and generally non significant. Decrease in available P with depth was highly significant. Close scrutiny of the data showed that the effect of clay (Table 4.1) and aluminum in the discharged effluent strongly influenced the

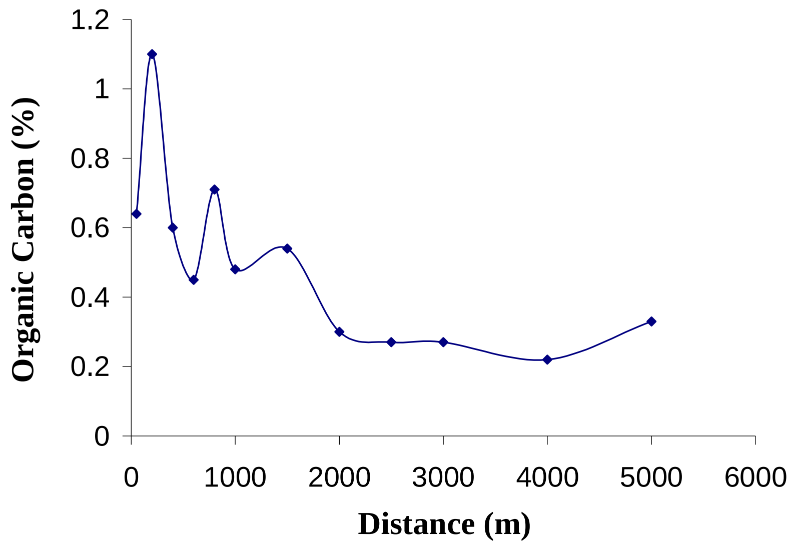


Fig. 6: Variation in the organic carbon content at the 0-30cm layer with distance from the point of effluent discharge

Table 4.4: Correlation matrix of the soil parameters

	Sand	Silt	Clay	pH	CEC	Ca	Mg	K	Na	Al	TEB	BS	ESP	EPP	EC	OC	Total N
Sand	-																
Silt	-0.77**																
Clay	-0.88**	0.37**															
pH	0.34**	0.01	-0.50**														
CEC	-0.88**	0.61**	0.83**	-0.22													
Ca	-0.85**	0.59**	0.79**	-0.16	0.87**												
Mg	-0.84**	0.49**	0.85**	-0.26*	0.84**	0,86**											
K	-0.57**	0.29*	0.61**	-0.28*	0.62**	0.55**	0.58**										
Na	-0.29*	0.05	0.39**	-0.29*	0.22	0.25*	0.22	0.36**									
Al	-0.39**	0.06	0.51**	-0.92**	0.27*	0.19	0.29*	0.29*	0.25*								
TEB	-0.87**	0.57**	0.83**	-0.21	0.88	0.99**	0.90**	0.60**	0.33**	0.23*							
BS	-0.26	-0.05	0.08	-0.09	-0.16	0.29*	0.14**	-0.01	0.31**	0.04	0.29*						
ESP	0.33**	-0.37**	-0.21	-0.12	-0.42**	-0.37**	-0.34**	-0.11	0.70**	0.04	-0.30**	0.31**					
EPP	0.30*	-0.34**	-0.18	-0.15	-0.34**	-0.30**	-0.26*	0.46**	0.17	0.10	-0.27*	0.14	0.35**				
EC	-0.30*	0.01	0.42**	-0.13	0.28*	0.39**	0.32**	0.18	0.41**	0.06	0.41**	0.29*	0.04	-0.14			
OC	-0.69**	033**	0.75**	-0.31**	0.69**	0.72**	0.70**	0.53**	0.34*8	0.34**	0.75**	0.15	-0.19	-0.10	0.36**		
Total N	-0.59**	0.35**	0.59**	-0.30*	0.60**	0.61**	0.63*8	0.50**	0.14	0.29*	0.63**	0.09	-0.26*	-0.01	0.35**	0.55**	
C/N Ratio	-0.35**	0.13	0.41**	-0.11	0.33**	0.37**	0.31**	0.20	0.23*	0.13	0.37**	0.08	-0.07	-0.12	0.12	0.78**	-0.01
P	-0.14	0.12	0.12	-0.13**	0.25*	0.22	0.12	0.25*	0.08	0.10	0.21	-0.02	-0.08	0.10	0.07	0.26*	0.33**
Co_3	-0.35**	0.09	0.43**	-0.51**	0.14	0.08	0.21	0.13	0.35**	0.62**	0.13	0.07	0.19	0.00	0.15	0.24*	0.01
SO_4	0.51**	-0.43**	-0.41**	0.17	-0.43**	-0.49**	-0.35**	-0.05	-0.27*	-0.21	0.48**	-0.20	0.06	0.42**	-0.24*	-0.37**	-0.14
Fe	-0.57**	0.46**	0.48**	-0.09	0.51**	0.53**	0.40**	0.33**	0.48**	0.11	0.54**	0.10	0.05	-0.20	0.24*	0.41**	0.14
Cu	-0.53**	0.24*	0.60**	-0.33**	0.41**	0.42**	0.46**	0.33**	0.21	0.33**	0.44**	0.10	-0.10	-0.11	0.34**	0.40**	0.43**
Mn	-0.74**	0.51**	0.70**	-0.17	0.69**	0.76**	0.68**	0.41**	0.53**	0.18	0.79**	0.28*	0.01	-0.28*	0.51**	0.66**	0.47**
Zn	-0.26*	0.13	0.29*	-0.14	0.22	0.21	0.30*	0.01	0.17	0.10	0.23*	0.09	0.00	-0.25*	0.308	0.06	0.20
B	-0.52**	0.19	0.61**	-0.62**	0.40*8	0.42**	0.43**	0.45**	0.46**	0.63**	0.46**	0.21	0.05	0.08	0.35**	0.55**	0.44**
Cl	-0.26*	0.33**	0.13	0.20	0.26*	0.18	0.14	0.11	0.04	-0.14	0.18	-0.14	-0.18	-0.20	0.10	0.06	0.11
SAR	0.14	-0/21	-0/.04	-0.17	-0.20	-0.25	-0.21	0.05	0.83**	0.11	-0.17	0.13	0.94**	0.31**	0.09	-0.07	-0.17
ECEC	-0.88**	0.56**	0.85**	-0.219*	0,88**	0.98**	0.90**	0.61**	0.35**	0.35**	0.32**	0.99**	0.28*	-0.29*	-0.25*	0.41**	0.75

Table 4.4 Cont. Correlation matrix of the soil parameters

	CN Ratio	P	CO_3	SO_4	Fe	Cu	Mn	Zn	B	C	SAR	ECEC
Sand												
Silt												
Clay												
pH												
CEC												
Ca												
Mg												
K												
Na												
Al												
TEB												
BS												
ESP												
EPP												
EC												
OC												
Total N												
C/N Ratio												
P	0.06											
Co_3	0.17	-0.04										
SO_4	-0.31**	0.03	-0.31**									
Fe	0.37**	0.00	0.30**	-0.62**								
Cu	0.19	0.11	0.35**	-0.35**	0.38**							
Mn	0.36**	0.09	0.27*	-0.64**	0.74**	0.47**						
Zn	-0.07	-0.16	0.15	-0.28*	0.298	0.31**	0.42**					
B	0.27*	0.14	0.52**	-0.43**	0.48**	0.45**	0.54**	0.24*				
Cl	-0.00	0.07	-0.03	-0.03	-0.30*	0.34**	0.30**	0.25*	0.06			
SAR	0.00	-0.03	0.28*	-0.02	0.22	-0.00	0.14	0.03	0.18	0.18		
ECEC	0.64**	0.38**	0.22	0.19	-0.48*	0.54**	0.46**	0.78**	0.24*	0.51**	0.16	-

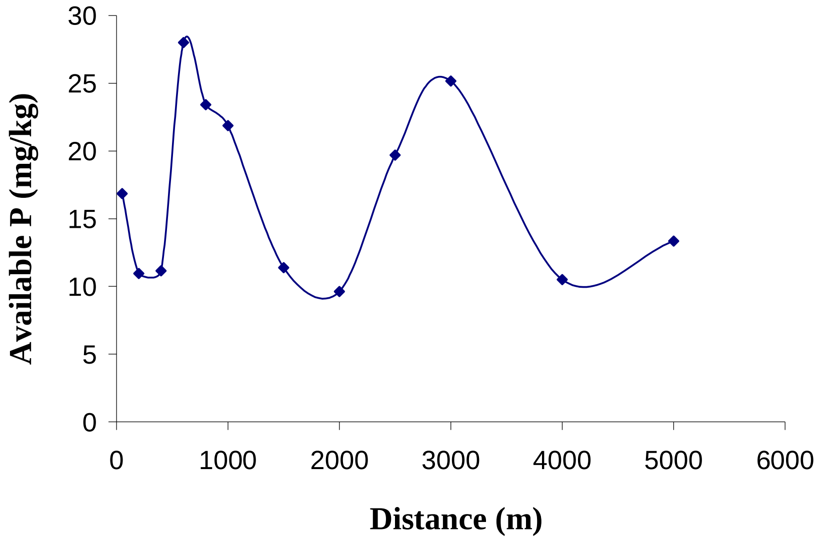


Fig. 7: Variation of available P content at the 0-30cm soil layer with distance

concentration of P in the soils. It was apparent that the relatively low P values at points of high clay and high Al content was as a result of P fixation in Fe and Al complexes (Saunders, 1965, Hsu, 1964, Uyovbisere, 1994). It can be effectively deduced that the use of the effluent discharge water from the water treatment plant for irrigation would impact negatively on the phosphorus fertility of the irrigation terrain along the river banks. Fig 7 shows the variation of available P with distance from the point of effluent discharge into River Tagwai. Available P was significantly correlated to CEC, organic carbon at P = 0.05 and 0.01 respectively.

Observed movement of P down the profile must have been mediated in organic complex (Table 4.3).

4.3.2.3 Total Nitrogen

The variation of the nitrogen content of the soils down the river course and with depth are shown in Table 4.5. The values ranged from 0.03-0.14% N with a mean of 0.06% and standard deviation of 0.024%. Though values were very low indicating that the soils are very poor in nitrogen, the comparatively higher value at the point of discharge of the waste effluent may have been derived invariably from the amide base organic flucculating agent used in the water treatment plant. The availability of this additional increment in N may not be confirmed in view of the acid digest used in N estimation. The high R^2 value (0.75) and the highly significant differences in the mean values indicate that the N content of the effluent influenced the variation in the soil N appreciably. Figure 8 shows the variation in the N content of the 0-30cm layer with distance. Total N correlated significantly with nearly all parameters (Table 4.4).

Table 4.5: Total nitrogen content of the soils and C/N ratio as influenced by depth and distance from the dam and water treatment plant.

Depth / Distance	Total N % 0 – 15cm	15 – 30cm	30 – 60cm	C/N ratio 0 – 15cm	15 – 30cm	30 – 60cm
50 m	0.11	0.06	0.07	8.68	7.23	4.18
200 m	0.12	0.10	0.05	11.15	9.95	8.71
400 m	0.09	0.06	0.03	9.25	7.95	7.00
600 m	0.07	0.05	0.03	9.88	3.67	5.32
800 m	0.10	0.06	0.04	8.76	9.83	6.00
1.0 km	0.07	0.06	0.04	7.86	6.58	4.25
1.5 km	0.12	0.07	0.07	5.80	6.79	3.92
2.0 km	0.08	0.06	0.06	3.50	6.66	3.90
2.5 km	0.08	0.05	0.06	4.41	4.29	1.72
3.0 km	0.08	0.07	0.06	3.94	3.30	1.50
4.0 km	0.07	0.06	0.05	4.00	2.50	2.71
5.0 km	0.07	0.05	0.05	5.62	5.46	9.08
	R^2		0.75		R^2	0.57
	CV		26.89		CV	75.44
	SE$\pm$		0.014**		SE$\pm$	4.00NS
	Mean		0.005		Mean	6.47
Interaction: Dis x depth			NS			NS

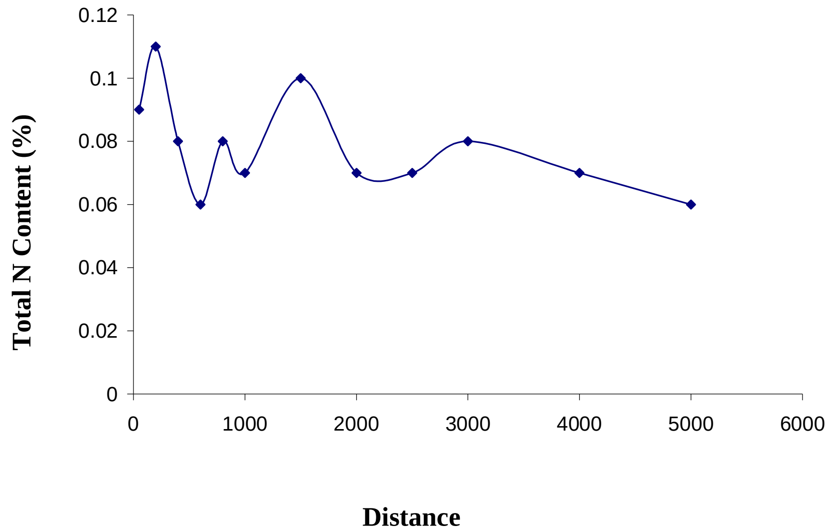


Fig. 8: Variation of the total N content at the 0-30cm soil layer with distance from the point of effluent discharge

4.3.2.4 C:N Ratio

The values of the organic carbon: total nitrogen ratio of the soils are shown in Table 4.5. Values of the surface soil ranged from 3.50-11.15 with a mean of 6.90. Values decreased down the profile as expected because of the strong decrease in organic carbon and N contents with depth. The C:N ratio was highly correlated with OC (r = 0.78**) as expected, though the variation with distance and depth were non significant. This corroborate the finding that the C:N ratio often decreased with depth to even values as low as 1.72 (Stevenson, 1959). This dramatic decrease have been attributed to the presence of fixed NH_4^+ at lower depths (Wild, 1988). Generally, values were less than 14, which indicated that no partially decomposed plant matter existed in the sample considered, and indicates high level of humification (Parson and Tinsley, 1975).

4.3.3 Exchange Properties

The cation exchangeable properties of the soils are given in Tables 4.6, 4.7 and 4.8, and in Figures 9 to 12. Summarily, the CEC and ECEC values were significantly and positively correlated with clay content and organic matter, and also negatively but significantly correlated with the sand fraction. These parameters influenced the variation in the exchange properties in the soils (Table 4.4).

4.3.3.1 Exchangeable Calcium

The exchangeable calcium content of the soils are shown in Table 4.6. Ca^{2+} was the dominant cationic species in the soil, which may have resulted from the use of hydrated lime in the water purification process and subsequently discharged into the

Tagwai River. Ca^{2+} content of the surface soils ranged from 1.94 cmol/kg at 5km away from the dam, where the effects of the effluent contamination was least, to 8.35 cmol/kg where it was highest at point of effluent discharge (200m). Leaching down the profile was significant considering the high accumulation even at the 30-60cm depth. On general consideration, Ca^{2+} values ranged from 1.75-8.35 cmol/kg for all points and depths. Variation of Ca^{2+} at the 0-30cm layer across the river course is shown in Fig. 9. Values were high only up to 2 km down the river bank, thereafter, Ca^{2+} content decreased consistently to low levels. Even with a highly mobile element as Ca, significant variation down the river stretch went only up to 2.0km. This information is welcome, considering the extent of degradation the effluent discharge can cause to the environment. Ca^{2+} was significantly correlated to electrical conductivity (r = 0.39**) and negatively correlated to SO_4^{2-} (r = 0.49**). Precipitation of Ca must have been in the carbonate and sulphate forms. Correlation to CEC was high (r = 0.87**).

4.3.3.2 Exchangeable Mg

The Mg content of the soils varied from 0.27 to 2.45 cmol/kg in the surface soil, with a mean of 0.24 on a general note (distance and depth, Table 4.6). The variation along the river course in the 0-30 cm depth is shown in Fig. 9. Variation with distance was significant at the 5% level of probability, but only up to 2km down the river course. Value decreased with depth at the proximal sections of the affected area. However, the reverse was the case after 3km from the dam. The non significant interaction of distance and depth indicate that the build up of Mg in the proximal sections was from the effluent deposits, of which composition was predominantly in the clay fraction. Values were higher as was the case with Ca^{2+}, at the proximal points of effluent discharge and reduced to low levels after 2.5km from the dam. Mg^{2+} was significantly correlated with clay, Ca and CEC with value of 0.85**, 0.86** and 0.84** respectively. Its negative but significant correlation with SO_4 may tend to suggest that much of the soil sulphate precipitated as sulphate compounds of Mg..

Table 4.6: Exchangeable basic cation contents of the soils along the River Tagwai as influenced by depth and distance away from the point of effluent discharge

Depth	Ca^{2+} cmol/kg			Mg^{2+} cmol/kg			Na^{+} cmol/kg			K^{+} cmol/kg		
Distance	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
50 m	5.94	2.75	2.25	1.05	0.62	0.35	0.74	0.32	0.43	0.06	0.05	0.03
200 m	8.35	5.20	3.44	2.45	1.55	0.70	0.66	0.33	0.49	0.23	0.10	0.07
400 m	4.69	3.75	1.75	0.96	0.62	0.27	0.58	0.46	0.86	0.19	0.06	0.14
600 m	3.88	1.80	1.75	0.64	0.38	0.40	0.41	0.66	0.40	0.10	0.07	0.05
800 m	6.75	5.80	3.44	1.30	0.66	0.69	0.51	0.22	0.41	0.16	0.08	0.06
1.0 km	2.94	3.10	1.97	0.58	0.80	0.45	0.43	0.18	0.40	0.12	0.06	0.05
1.5 km	6.25	5.60	4.23	1.04	1.14	0.74	0.44	0.21	0.44	0.09	0.07	0.06
2.0 km	3.44	3.75	2.69	0.63	0.85	0.50	0.41	0.29	0.37	0.11	0.07	0.05
2.5 km	2.57	2.90	1.97	0.39	0.65	0.39	0.30	0.20	0.25	0.08	0.06	0.06
3.0 km	1.94	3.40	1.25	0,27	0.58	0.39	0.36	0.17	0.29	0.11	0.05	0.05
4.0 km	2.69	2.15	1.75	0.54	0.57	0.50	0.29	0.17	0.28	0.07	0.04	0.05
5.0 km	1.94	2.35	1.75	0.41	0.56	0.54	0.23	0.20	0.23	0.09	0.04	0.06
R^2		0.75			0.77			0.63			0.74	
CV		40.29			42.27			46.04			44.53	
SE$\pm$		1.12			0.24*			0.14*			0.028**	
Mean		3.39			0.69			0.37			0.078	
Dis. X Depth Int.		NS			NS			NS			NS	

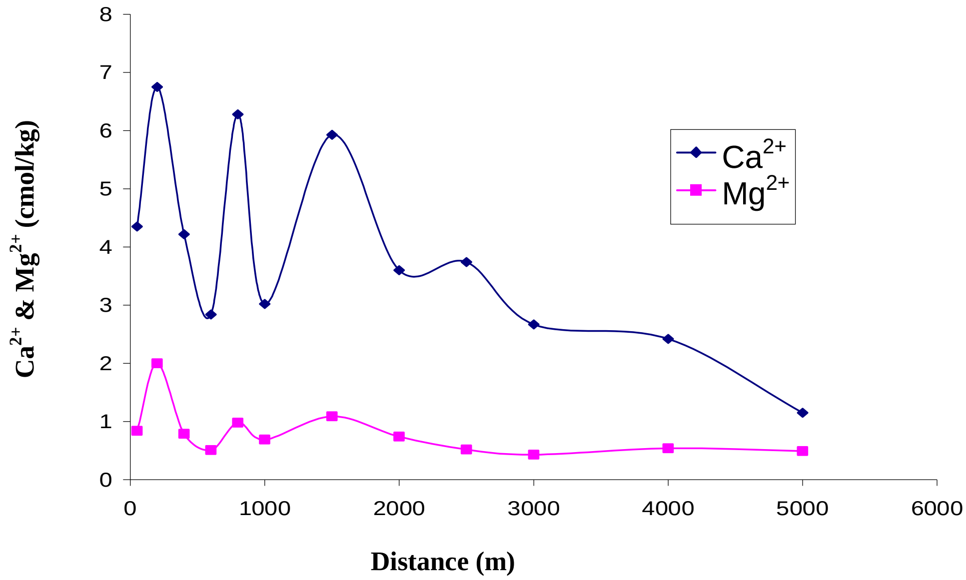


Fig. 9: Variation of Exchangeable calcium and magnesium contents at the 0-30cm layer with distance from the point of effluent discharge.

4.3.3.3 Exchangeable Sodium

Sodium content was little affected by the sludge discharge. Values ranged from 0.17 cmol/kg at 3-4km away, to 0.66 cmol/kg at point of discharge (200m) near the dam (Table 4.6). Variation with distance of the 0-30cm layer is shown in Figure 10. The impact of the discharged effluent on Na content was evident especially at the proximal distance to about 800m. The Na^+ values were considerably low and may tend to suggest low Na hazard for the soils. Na was significantly correlated with EC, CO_3^{2+} and SO_4^{2-} (r = 0.41**, 0.33** and -0.27*) respectively. Its contribution to the soil salt content could be said to be high occurring as the Na_2SO_4 salt. A large proportion of the white crystallized salts at the surface could have been Na_2SO_4, suggesting the possible development of a sodic condition in the soils.

4.3.3.4 Exchangeable Potassium

The exchangeable K^+ values were very low in the soils, and like Na^+, the effect of sludge deposit only affected the variation slightly (Table 4.6). Exchangeable K values of the surface soil ranged from 0.06 cmol/kg to 0.23 cmol/kg. at point of discharge. Figure 10 shows the variation of exchangeable K^+ along the river course in the 0-0.30cm layer. Clay content and OC were the two main parameters that explained the variation of K in the soils. R values were 0.61** and 0.53** with clay and OC respectively. Potassium forms neutral salts essentially which explains the low r values with EC (0.18NS), Co (r = 0.13 and SO_4^- (r = -0.15) Potassium was highly correlated with the metal cations (Table 4.4)

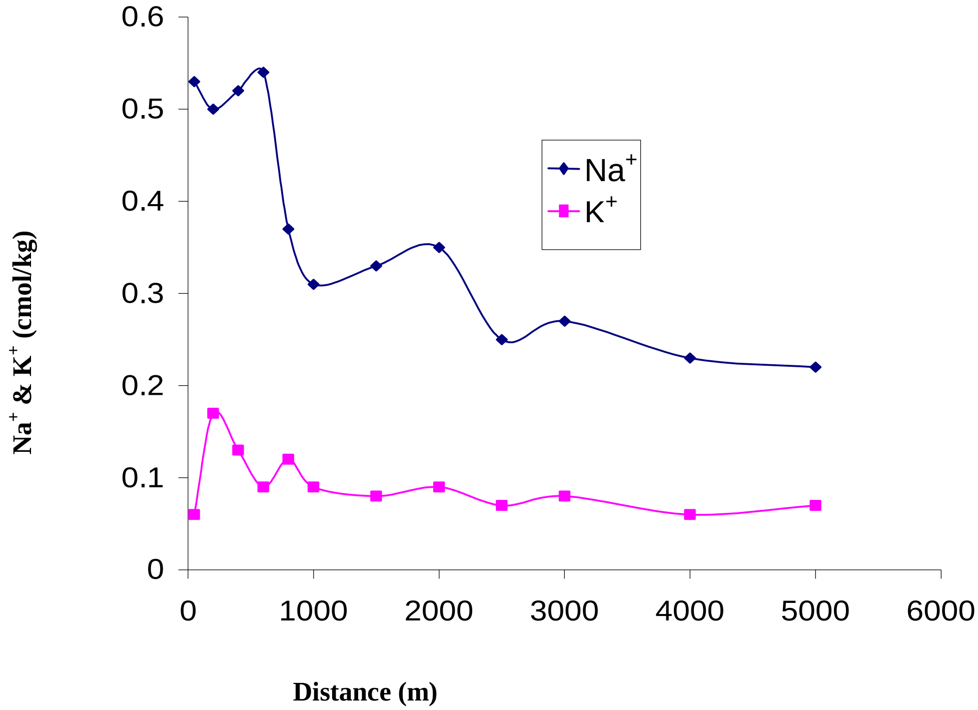


Fig. 10: Variation of Na^+ and K^+ content of the 0-30cm soil layer with distance from the effluent discharge.

4.3.3.5 Exchangeable Aluminum

Variation in the exchangeable Al contents of the soils are given in Table 4.7, and also depicted in Figure 11 (0-30cm layer). Values were significantly high at 200m, the point of effluent discharge, and for about one half of a kilometer down stream. However, at 3km, there was an increase in the Al content possibly as a result of an intervention by the inflow of a tertiary riverlet. Surface soil values ranged from 0.10-0.80 cmol/kg. values did not vary significantly with depth. With the high CV observed, it can be inferred that the Al discharged into the river was quickly adsorbed on the clay surfaces of the accompanying clay sediments, such that the effect was restricted to about 800m from the discharge point. The acidity deduced by Al hydrolysis may not have been significant and was only restricted to the 500 meters down stream (Fig. 5). Large amount of Alum ($Al_2(SO_4)_3.14H_20$) was used in the purification of water in the water treatment plant (Table 2.3). With respect to influencing the acidity of the soils irrigated with the effluent water, it can be said that this amount is within the safe limits. However, the high amount of sulphate ions in solution results in the formation of insoluble Ca^{2+} and Mg^{2+} sulphate, as well as Na^{2+} sulphates, effects of which were seen as salt crystal deposits on the surface of the irrigated lands (Plates I and II). The effects of these surface salt crystals will be discussed subsequently. Because of the high amount of sulphate compounds in the effluent, the crystal deposits may still be present even at distances of 4-5 km along the river course, where the reactive divalent basic cation content may even have been inadequate to crystallize all the soluble SO_4^{2-} resulting from the effluent and other natural sources. Al was highly correlated with N, OC and CO_3^{2-}, (Table 4.3). A good possibility exists that much of the P fixed in Al complexes was not extractable. As shown in Figure

Table 4.7: Exchangeable aluminum, cation exchange capacity, total exchangeable bases and percentage base saturation as influenced by depth and distance along River Tagwai.

Depth	Exch Al cmol/kg			CEC cmol/kg			TEB cmol/kg			% BScmol/kg		
Distance	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
50 m	0.25	0.20	0.50	10.00	6.70	5.00	7.79	3.73	3.06	78.09	56.20	61.20
200 m	0.80	0.70	0.90	18.00	15.50	13.45	11.38	7.18	4.70	70.27	48.02	31.29
400 m	0.50	0.20	0.30	12.60	9.80	5.85	6.32	4.89	3.02	59.66	52.41	55.20
600 m	0.60	0.30	0.30	10.70	4.95	5.30	5.02	2.90	2.60	48.94	58.08	48.31
800 m	0.35	0.10	0.10	16.30	11.35	9.50	8.72	6.75	6.59	53.47	59.72	47.08
1.0 km	0.10	0.10	0.10	10.15	7.50	6.80	4.06	4.14	2.87	38.44	54.68	43.63
1.5 km	0.15	9.15	0.15	14.50	12.80	8.50	7.82	7.02	5.49	56.67	53.43	64.19
2.0 km	0.10	0.15	0.15	10.70	9.75	7.10	4.58	4.95	3.61	41.83	50.44	57.33
2.5 km	0.30	0.15	0.25	5.30	6.90	4.05	3.33	3.31	2.66	60.22	55.00	66.45
3.0 km	0.35	0.50	0.15	5.40	8.90	4.30	2.58	4.20	1.98	50.08	48.08	43.92
4.0 km	0.10	0.10	0.10	6.85	6.80	4.80	3.58	2.93	2.58	50.64	43.85	53.21
5.0 km	0.10	0.10	0.10	5.40	6.65	5.45	2.66	3.15	2.57	49.77	44.44	56.26
R^2		0.84			0.65			0.768			0.50	
CV		50.50			43.84			36.40			23.50	
SE$\pm$		0.109**			3.11			1.35**			10.18	
Mean		0.265			-			4.53			53.0	
Interaction:		NS			NS			NS			NS	

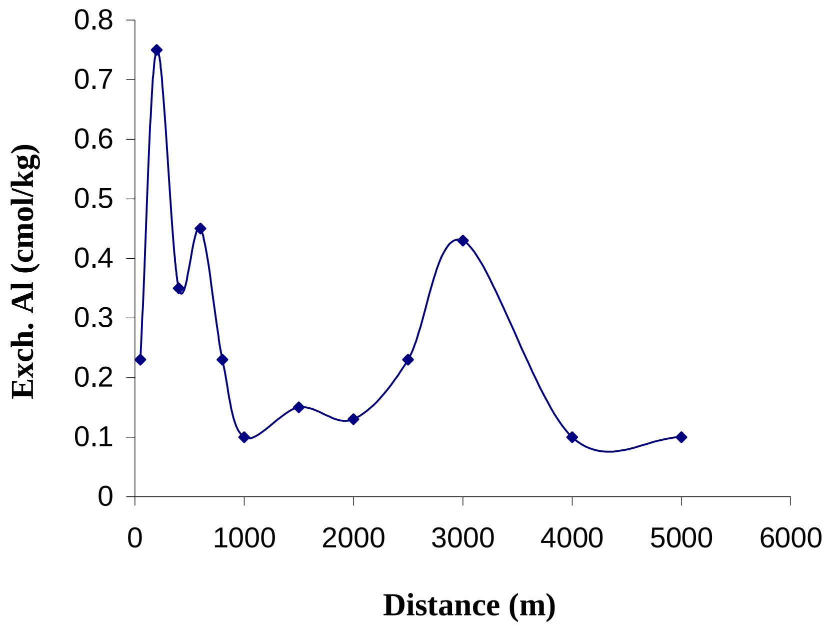


Fig. 11: Variation of the Exchangeable Aluminium content in the 0-30cm layer with distance from the effluent.

13, exchangeable Al was high at the proximal distance, and again at 3 km where pH was lower. Exchangeable Al was highly and negatively correlated with pH (r = -0.92**). Al was more soluble at lower pH values as expected.

4.3.3.6 Cation Exchange Capacity (CEC), Total Exhangeable Bases (TEB, Percentage Bae Saturation (%BS)

The variation in CEC of the soils, TEB and %BS with distance and depth are shown in Table 4.7. Figure 12 shows the variation in CEC and ECEC with distance in the 0-30cm layer of the soils. Both parameters were significantly and positively correlated with clay (r = 0.83** and 0.85** respectively), and negatively correlated with the sand fraction (r = 0.88** for both). This tends to suggest that the significant part of the contribution to CEC was derived from the effluent deposits of the clay fraction. This was estimated at about 70% (R^2 = 0.69), with only 30% of the basic cations derived from in-situ fertility (r value for CEC and clay = 0.83**).

The CEC varied from 4.05-18.00 cmol/kg and consistently decreased with distance and with depth because much of the reactions were surface phenomena, with high contributions from effluent deposits. Variation with depth also diminished with distance.

The total exchangeable bases (TEB) and the % base saturation (% BS) were found to follow same trend as the CEC. Both factors decreased with distance and with depth. The effective cation exchange capacity (ECEC) obtained by summation, was consistently less than the CEC, derived by ammonium saturation at pH 8.2 (Tables 4.4 and 4.5). For variable change soils such as these, increase in available exchange sites is expected with increase in pH as more functional group dissociate with increase in pH (Sanchez 1976,

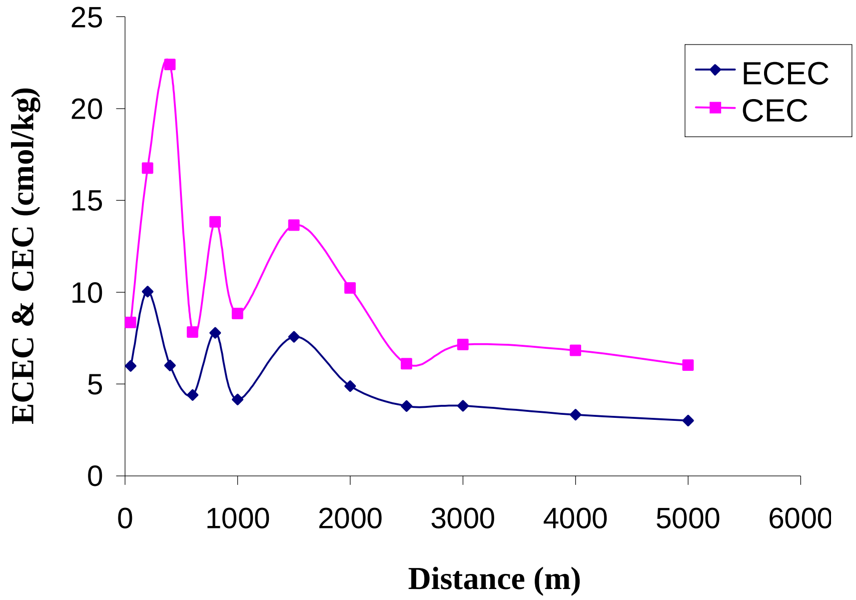


Fig. 12: Variation of effective Cation Exchange Capacity and ammonium acetate cation exchange capacity contents of the 0-30cm layer with distance

Theng, 1980). ECEC values ranged from 2.13 – 12.18 cmol/kg. The soils were observed to be poor, but modification due to effluent deposits improved the fertility index of the soils by about 76% (R^2 = 0.70). Correlation of clay and TEB was 0.53**. The fertility of the soils was very poor after 1.5 km down the river course.

4.3.4 Anion Properties

The anion exchange properties of the soils define a significant aspect of the fertility of soils. The carbonate, bicarbonate, sulphate and chloride anionic species occur in reasonable quantity in tropical soils (Wilson, 1984). Variation in CO_3^{2-}, SO_4^{2-} and Cl^- contents of the soils are presented in Table 4.8. The R^2 values for the parameters ranged from 0.62-0.81. Generally, chloride and sulphate compounds are mainly responsible for the formation of saline soils. More importantly, NaCl and $MgSO_4$ salts have more potent effects (Szabolcs, 1989).

4.3.4.1 Carbonates

The carbonate contents of the soils are shown in Table 4.8. Values ranged from 2.13-9.90 mg/kg, decreasing significantly from point of effluent discharge to 5 km away from the dam. Variation with depth was not consistent and non-significant. However, values tended to increase with depth on the average. Carbonates can be bound to the basic cations Ca, Mg and Na, with solubility and toxicity to plants increasing in the order Ca < Mg < Na. Variation with distance in the 0-30cm layer along the river course is shown in Fig. 13 and values were found to decrease with distance. Deriving from the other parameters, such as the pH values that ranged from 4.8 – 6.6 (Table 4.2), the most abundant carbonate compounds must have been the Na and Al compounds. However, evidence of peptization of the soil colloids were observed soon after irrigation, resulting

Table 4.8: Carbonate, sulphate, chloride and Effective CEC values of the soils as influenced by depth and distance along the river Tagwai.

Depth / Distance	CO_3^{2-} mg/kg			SO_4^{2-} mg/kg			Cl^- mg/kg			ECEC cmol/kg		
	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm	0-15 cm	15-30 cm	30-60 cm
50 m	4.63	7.00	6.63	0.11	0.16	0.16	3.25	3.13	1.88	8.04	3.93	3.56
200 m	9.90	11.50	11.65	0.22	0.20	0.13	2.88	2.25	2.75	12.18	7.88	5.60
400 m	5.25	6.28	6.13	0.25	0.19	0.33	3.13	3.00	2.38	6.92	5.09	3.32
600 m	6.50	7.00	7.63	0.24	0.30	0.28	2.50	2.88	2.25	5.62	3.20	2.90
800 m	4.00	4.50	5.38	0.20	0.16	0.11	4.00	3.25	3.88	9.07	6.85	4.69
1.0 km	5.58	5.63	5.88	0.22	0.28	0.20	3.88	4.75	4.63	4.12	4.20	2.97
1.5 km	2.88	4.00	5.00	0.16	0.15	0.14	3.00	3.50	2.75	7.97	7.17	5.64
2.0 km	3.00	3.50	2.88	0.24	0.23	0.26	4.13	4.75	4.75	4.68	5.10	3.76
2.5 km	3.88	3.25	3.50	0.41	0.23	0.26	3.25	1.88	2.75	3.63	3.96	2.91
3.0 km	3.65	2.00	2.88	0.47	0.34	0.55	2.38	2.75	2.63	2.93	4.70	2.13
4.0 km	2.38	2.63	4.13	0.39	0.31	0.62	2.50	2.75	2.25	3.63	3.03	2.68
5.0 km	3.63	3.5	2.13	0.51	0.42	0.56	2.38	2.63	2.00	2.76	3.25	2.67
R^2		0.72			0.82			0.65			0.80	
CV		41.71			32.52			27.56			33.18	
SE$\pm$		1.64**			0.073**			0.69*			1.30**	
Mean		5.00			0.274			3.05			4.797	
Interaction Dis x Depth		NS			NS			NS			NS	

in reduced permeability and creating poor water physical properties in the soils. Similar observation was been observed in previous studies (Kelly, 1948). Plate 3 shows some extent of peptization of the soils after irrigation. This is a clear evidence of active Na_2 CO_3 in the soils. Toxicity of the highly soluble Na_2CO_3 compound in the soils can therefore be expected. Mg CO_3 and $MgSO_4$ are only sparingly soluble. The CO_3 content of the soils was significantly, but negatively correlated with pH (r = -0.53**), and positively correlated with Na^+ (r = 0.35**) and Al^{3+} (r = 0.62**). This is expected at the pH values observed for the soils.

4.3.4.2 Sulphates

Sulphates in soils may be bound to cations including Ca^{2+}, Mg^{2+}, Na^+, Al^{3+} and Fe^{2+}. Sulphate compounds have been found to acidify the soil strongly, resulting in high toxicity and very harmful effects on plants (Szabolcs, 1989). The sulphate content of the soils varied from 0.11 – 0.56 mg/kg. Values increased consistently and significantly away from the dam to the limit of 5km studied (Fig. 14). It is apparent that the amount of SO_4^{2-} ions contained in the effluent discharge overwhelmed the adsorptive and reactive capacities of the reactive cations mentioned above, such that the effect of salinity associated with sulphate must have been evident throughout the whole stretch of the irrigated lands along the banks of River Tagwai. About 700 tons of Alum ($Al_2(S0_4)_3.14H_20$) used in the sedimentation tanks of the Ajiwa water treatment plant, which gets discharged into the river, should be treated for partial recovery to save the agricultural lands in the vicinity. Though the solubility of $CaSO_4$ is low, the high solubility of $MgSO_4$ and Na_2SO_4 as well as $Al_2(SO4)_3$ and $FeSO_4$, induce high level of

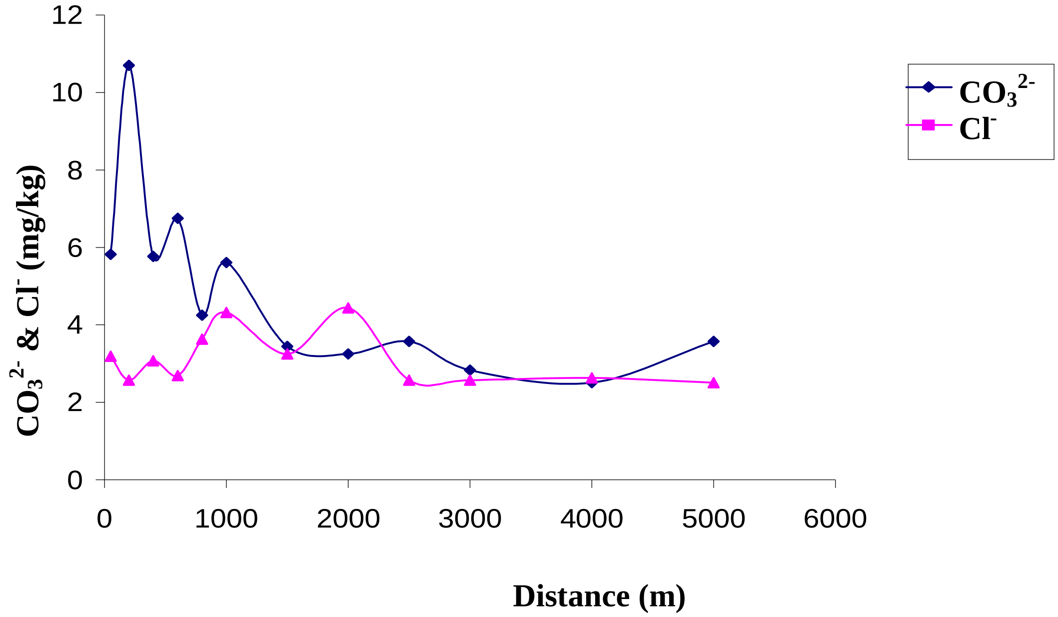


Fig. 13: Variation of carbonate and chloride content of the 0-30cm layer with distance along the river course

Plate III: Evidence of petization of the surface soil after irrigation. Process of soil turning due to high Na_2CO_3 content result in reduced permeability of the soils latent soil acidity and toxicity in the soils. The deposition or crystallization of powdery themardite (Na_2SO_4) on the soil surface (Chaudhry and Warkentin, 1968), could be one of the constituents of the white powdery salt on the soil surface shown in Plates.I and II. Plate IV shows surface salt deposits at the land, which was a regular feature along the irrigated river course.

4.3.4.3 Chloride

The variation in the chloride content of the soils is also shown in Table 4.8. Values ranged from 1.88 – 4.75 mg/kg. Though variation was significant with distance, it was not consistent with distance. Variation with depth was non-significant and inconsistent. Variation in the Cl^- content downstream was only within a narrower limit as shown in Fig. 13. Despite this, the high potential for salinization of the soil was very high. This could have been derived from the moderate quantities of high test hypochloride and liquid chlorine used annually in the water purification process (Table 2.3). Though $CaCl_2$ and $MgCl_2$ are rarely present in soils, NaCl and $MgSO_4$ are the most common components of saline soils. Both are highly soluble and toxic (Szabolcs, 1989), and their activity in these soils resulting in the salinization can be suggested. As it was with CO_3 and SO_4, the non-significant interaction of distance with depth imply that the effluent discharge is solely responsible for the variations observed in these parameters in the soils. Chlorine was not significantly correlated with clay (r = -0.04) as expected, but was significantly correlated with the cationic micronutrients (Mn, Cu and Fe, r = 0.25*, 0.35**, 0.34** respectively).

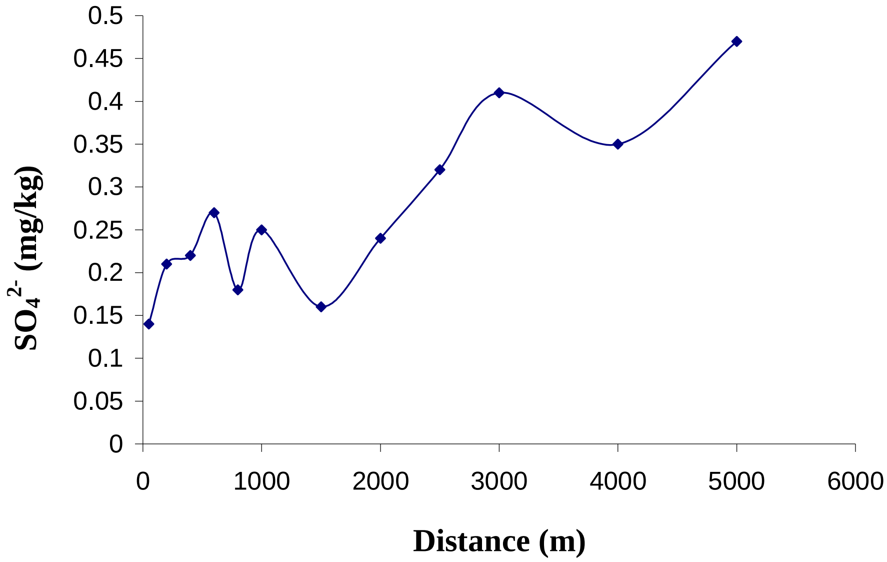


Fig.14: Variation of sulphate content in the 0-30cm layer with distance along the river course

Plate IV: Salt deposits on the surface. Picture shows part of the underlying surface soil revealed (dark portions)

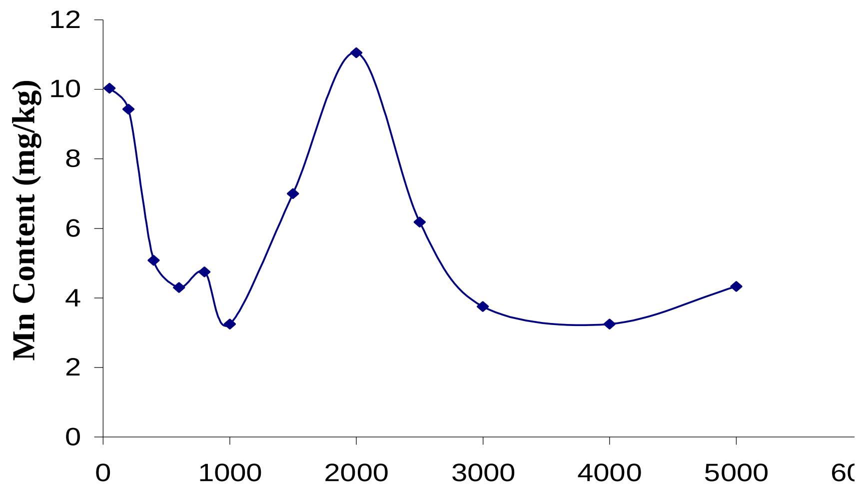
4.4 Micronutrient Content

The micronutrient content of the soil are presented in Tables 4.9 and 4.10. In all cases, values were higher at the point of effluent discharge (200m) and decreased away with distance.

The Manganese content of the soils varied from 7.3 – 84.0 mg/kg and decreased significantly with distance and with depth. These values are far lower than the 300 – 500 mg/kg Mn commonly found in soil (Ure and Berrow 1982). Values were significantly high up to 3 km as shown in Fig. 15. Mn toxicity may not be a problem in these soils. Mn was significantly correlated with CO_3 (r = 0.27*) and negatively correlated with SO_4 (r = 0.64**).

The Zn content varied significantly with distance (P = 0.05) but not with depth. Values ranged from 2.50 – 11.55 mg/kg. In comparison to the 50-300 mg/kg commonly found in soils, toxicity may not be a problem, but deficiency could arise (Ure and Berrow, 1982). At 3km, values normalized to about 4.0 mg kg, and remained so to 5 km distance. At the earlier distances, large fluctuations in amounts with distance (Fig. 16) may have arisen from inflow interventions, especially at 2000m.

Boron values were low and ranged from 0.1-0.89. Variation was significant with distance and depth, decreasing with distance and depth. Much of the boron must have been contributions from flocculated clay in the effluent discharge. The values found in these soils are common to most soils of the world. The values were low and there may be the need to apply boron to satisfy crop needs, for crops like cotton and cowpea. Boron was significantly correlated to most of the parameters considered in this study (Table 4.5).



Distance (m)

Fig. 15: Variation of Mn content of the 0-30cm layer with distance along the river course

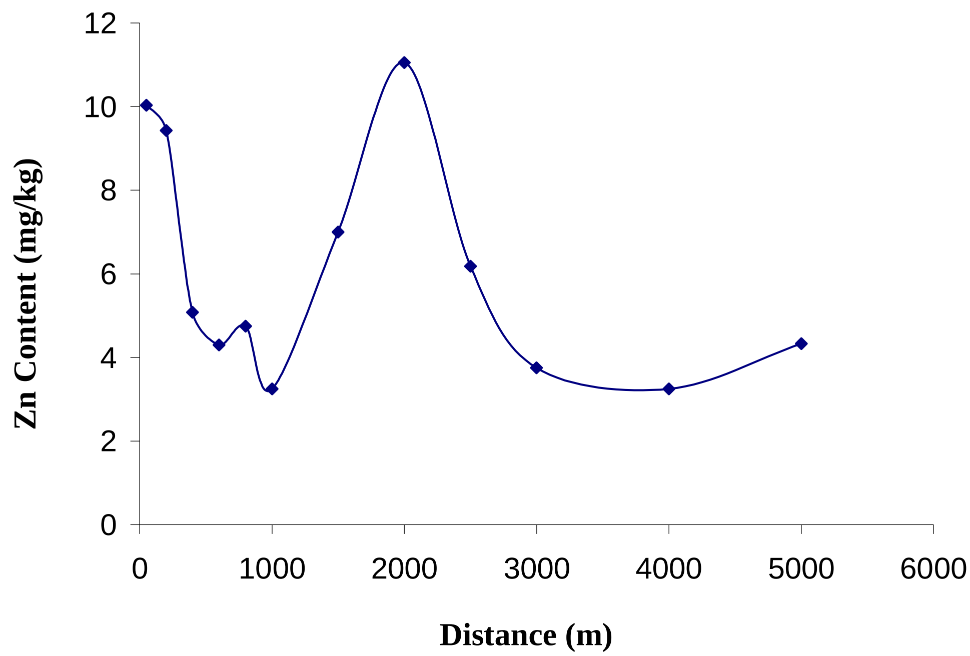


Fig. 16: Variation of Zn in the 0-30cm layer with distance along the river course

Table 4.9: Micronutrient content of the soils: Mn, Zn and B variation with depth and distance along the River Tagwai.

Depth Distance	Mn mg/kg			Zn mg/kg			B mg/kg		
	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm
50 m	82.5	51.0	37.0	10.05	10.00	11.55	0.76	0.47	0.34
200 m	84.0	50.0	41.5	10.05	8.80	8.10	0.89	0.55	0.59
400 m	51.0	47.0	44.5	5.05	5.10	5.10	0.68	0.47	0.34
600 m	40.0	29.0	29.0	4.00	4.60	5.60	0.76	0.30	0.21
800 m	60.0	57.0	44.0	5.50	4.00	7.75	0.43	0.09	0.17
1.0 km	46.0	40.0	30.5	3.00	3.50	2.50	0.26	0.15	0.34
1.5 km	62.5	59.5	44.0	6.15	7.80	10.05	0.30	0.13	0.39
2.0 km	41.0	44.0	33.0	12.35	9.75	8.25	0.38	0.22	0.09
2.5 km	15.5	19.5	18.5	4.55	7.80	5.05	0.22	0.21	0.09
3.0 km	9.0	12.5	14.0	4.00	3.50	8.75	0.13	0.05	0.05
4.0 km	18.0	11.3	7.8	3.50	3.00	3.00	0.09	0.01	0.06
5.0 km	14.3	12.5	7.3	4.60	4.05	5.10	0.05	0.01	0.01
R^2		0.84			0.59			0.84	
CV		34.10			53.44			51.07	
SE$\pm$		10.12**			2.72			0.12**	
Mean		36.33			6.22			0.284	
Interactions Dis x Depth		NS			NS			NS	

The Fe content of the soils were comparatively high at the point of discharge to just about 2km down stream (Table 4.10). Values ranged from 18.0-126.0 mg/kg. Iron sulphate, just like $AlSO_4$, induce very acid conditions when they occur in soils (Szabolcs, 1989). The lower values observed in the soils at the initial stretch of the river course derives from some amount of influence from iron and its reactions, especially with sulphate and chlorine in soils. The variation of the Fe content along the river course in the 0-30 cm layer is shown in Fig. 17. At about 2km down stream, the Fe content of the soils dropped dramatically, which indicated that the composition of the effluent was high in Fe at the point of discharge. The sorptivity or adsorption of P was therefore high in the proximal areas highly influenced by the effluent discharge. After 2km downstream, values normalized to an averge of 30 mg/kg from the high level of about 100 mg/kg before this distance. Values varied little with depth, though surface values were slightly higher.

The variation in the Cu contents of the soils down the course of River Tagwai was non significant (Table 4.10). Values ranged from 1.50 mg/kg at 5 km distance to 3.75 mg/kg at the discharge point in the surface soils. This slight increase at the proximal areas could have been due to the high colloidal content of the effluent which contained normal levels of cupper. Copper content was not influenced by treatments used in water purification in the water treatment plant. Copper content did not vary significantly with depth as there was little or no contribution from the materials used for the treatment of water in the water works. Cu was significantly correlated with all parameters except P, CO_3 and Na (Table 4.5). The single factor that influenced the variation of cupper the most was clay (r = 0.66**).

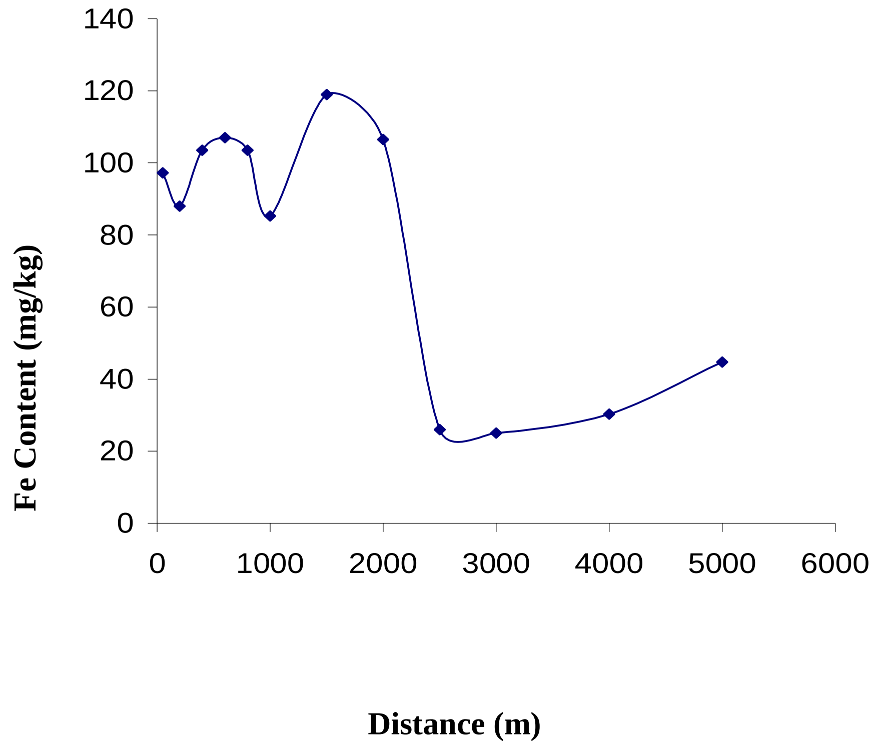


Fig. 17: Variation of Fe content of the 0-30cm layer with distance along the river course

Table 4.10: Micronutrient contents of the soils: Fe and Cu variation with depth and distance.

Depth	Fe mg/kg			Cu mg/kg		
Distance	0 – 15cm	15 – 30cm	30 – 60cm	0 – 15cm	15 – 30cm	30 – 60cm
50 m	93.50	101.00	76.00	3.75	2.50	2.00
200 m	93.50	82.50	90.00	3.25	3.00	2.75
400 m	106.00	101.00	119.00	2.75	2.50	2.00
600 m	119.00	95.00	90.00	2.00	1.50	2.00
800 m	106.00	101.00	106.00	1.50	2.00	2.00
1.0 km	90.00	82.50	82.50	2.00	2.75	1.50
1.5 km	126.00	112.00	114.00	2.00	2.50	1.50
2.0 km	101.00	112.00	76.00	2.50	2.50	1.50
2.5 km	30.00	22.00	18.00	2.00	1.00	2.00
3.0 km	18.00	32.00	35.00	2.00	2.00	1.50
4.0 km	33.00	27.50	22.00	1.50	1.50	1.00
5.0 km	41.00	48.50	38.00	1.50	1.50	1.50
R^2		0.90			0.55	
CV		21.56			38.6	
SE		13.65**			0.64NS	
Mean		76.13			2.035	
Interaction (Dis x Depth		NS			NS	

4.5 Estimate of Soluble Salts and Impact on Soil Quality (EC, ESP, SAR)

4.5.1 Electrical Conductivity (EC)

Generally, the salt content of soils is specified by the electrical conductivity because it is easily measured. The electrical conductivity measured in dS m^{-1} multiplied by a factor of 15 gives an approximate value of its soluble salt concentration in meq/L, with electrolyte solution of mixed salts of Fe^{2+}, Al^{3+}, Ca^{2+}, Mg^{2+}, Na^{+}, K, SiO_4^{2-}, Co_3^{2-}, HCO, SO_4^{2-} and Cl^{-} predominating (Szabolcs and Darab, 1982).

The electrical conductivity of the soils of the study area is given in Table 4.11. The values for the soils were low and changed from 0.03-0.23 dSm^{-1}, with the highest values near the dam. Though the values ranged significantly with distance and depth (P = 0.01, and 0.05 respectively), they were below the initial value of 0.25 dSm^{-1} at all points even at the point of discharge, and so are classified as low. A saline soil should have electrical conductivity values of >4 dS m^{-1} (Landon, 1984). These soils may therefore be said generally not to be saline based on this parameter as being considered. The observed salt crystals on the soil surface (Plates III and IV) need to be explained.

The low EC values along the banks of River Tagwai is expected as is often observed for flowering rivers as opposed to stagnant waters. The very high CV, which indicate maxing of treatment effects (that is composition of effluent discharge), due to high levels of variation of the influencing factors, may suggest continuous dilution and dissolution of the salt concentration which was dominated by Ca and Mg salts. The Na content of the soils were low (Table 4.6). Fig. 18 shows the variation of the electrical conductivity of the 0-30cm layer of the soils along the river course. The salt content was

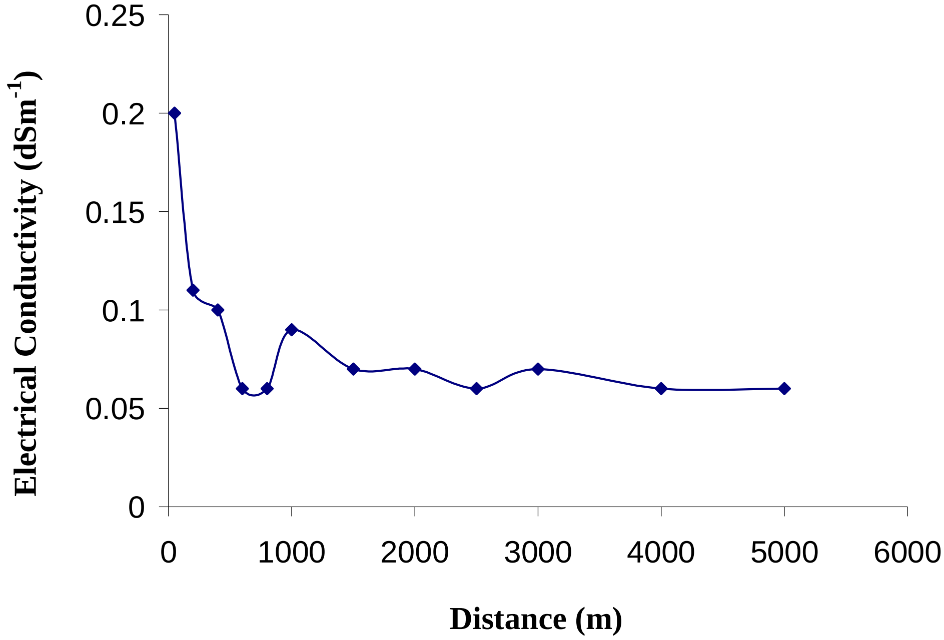


Fig. 18: Variation of EC content of the 0-30cm layer with distance along river course

high only at the initial few hundred meters from the dam, thereafter, values stabilized to the 5 km distance.

4.5.2 Exchangeable Sodium Percentage (ESP)

The exchangeable sodium percentage, which is the amount of exchangeable sodium as a percentage of the cation exchange capacity for the soils is given in Table 4.11. Values ranged from 1.79-18.15%. Mean differences were generally not significant, especially with distance. However, values increased significantly with depth. The ESP is an estimate of the effect of sodium on soil aggregate stability. By the USDA classification, values above 15% is regarded as critical, above which the soil structure becomes unstable, resulting in reduction in permeability. The tendency for the soils to attain this condition existed at 400 to 600 meters down stream away from the point of effluent discharge (Table 4.11, 400m 30-60cm). All other points were far below this critical value. Sulphate and carbonate salts of Na can be implicated at these points (400-600 meters), though the effect of flowing water and intervening entry of reverlets along the river course may have diluted and caused the dissolution of the sodium salts with distance. But the deposition of salt crystals or the surface may occur as the soil dries out. The soils can only be said to be saline-sodic at these points, though at no point were the soils alkaline (> pH 8.5). Fig. 19 shows the variation in ESP at the 0-30 cm layer along the river course. The 400-600 meters area of the river bank can be said to be prone to the development of saline-sodic conditions, though substantially lower than the 15% ESP necessary for this to be (Landon, 1984).

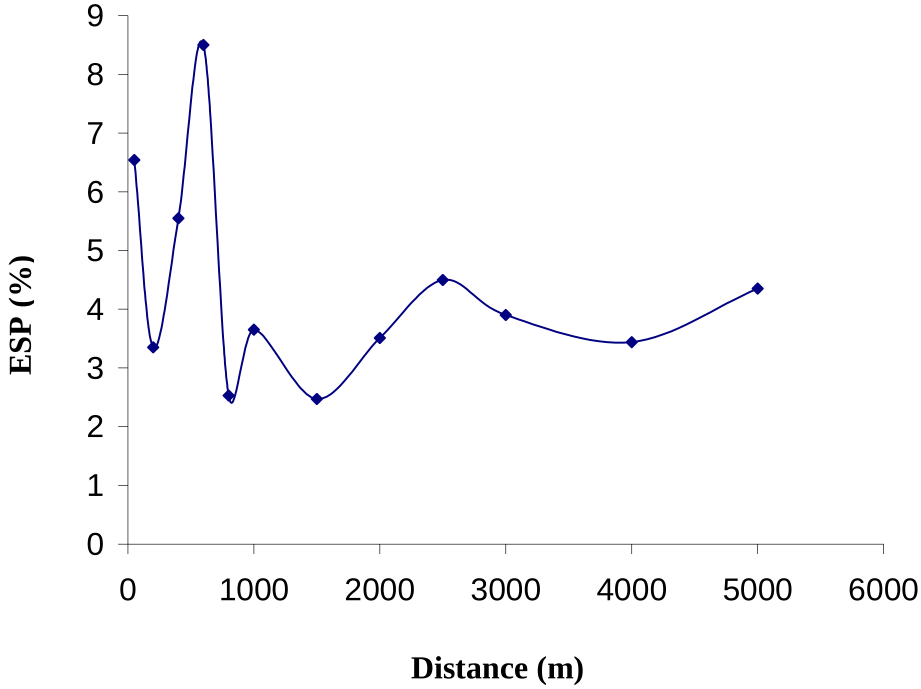


Fig. 19 variation of ESP content of the 0-30cm layer distance along the river course

Table 4.11: Electrical conductivity, exchangeable sodium percentage and sodium adsorption ratio of the soils down the river course as influenced by depth and distance from the dam.

	EC (dSm^{-1})			ESP (%)			SAR		
Depth	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm	0–15 cm	15–30 cm	30–60 cm
Distance									
50 m	0.23	0.17	0.09	7.45	5.63	8.60	0.39	0.26	0.38
200 m	0.13	0.08	0.07	4.20	2.50	3.65	0.29	0.19	0.35
400 m	0.10	0.10	0.06	6.00	5.10	18.15	0.35	0.31	0.93
600 m	0.06	0.05	0.03	4.15	12.85	7.70	0.27	0.61	0.40
800 m	0.04	0.07	0.05	3.15	1.90	4.35	0.25	0.12	0.28
1.0 km	0.07	0.10	0.05	4.85	2.45	6.00	0.36	0.13	0.37
1.5 km	0.07	0.06	0.06	3.15	1.79	5.74	0.23	0.12	0.29
2.0 km	0.07	0.06	0.05	3.86	3.16	5.66	0.29	0.19	0.29
2.5 km	0.06	0.05	0.06	5.94	3.05	6.16	0.29	0.15	0.23
3.0 km	0.07	0.07	0.05	5.30	2.50	6.87	0.25	0.13	0.32
4.0 km	0.07	0.05	0.04	4.34	2.53	5.76	0.22	0.15	0.26
5.0 km	0.07	0.05	0.06	5.01	3.68	4.14	0.22	0.20	0.21
R^2		0.68			0.58			0.62	
CV		54.32			73.08			57.37	
SE$\pm$		0.031			3.10NS			0.13NS	
Mean		0.070			5.20			0.283	

4.5.3 Sodium Adsorption Ratio (SAR)

The sodicity hazard of irrigated soils is evaluated by the SAR, which is the ratio of the sodium ion concentration to the sq root of the calcium + magnesium ion concentration expressed in mmols L^{-1}. The ESP of soils is conditioned by SAR which is constantly changing to relation of the buffer power of the soil for sodium ion. Generally, the SAR value limit of 13 was suggested by Qureshi and Barrett-lennard (1998) for soils that are non sodic, with no sodium hazard. The higher the EC, the less the SAR that could cause sodium hazard in irrigated soils.

The SAR values for the soils are shown in Table 14. Variation with distance and depth were non-significant, and were not specifically influenced by the elemental content of the effluent discharge. Values ranged from 0.22 to 0.39 in the surface soil. Even at depth, variation was not dramatic. Though values tended to be higher within the 400-600 meter area along the river course, there is no evidence of sodium hazard developing in these soils. Figure 20 shows the variation in SAR with distance. Though the effluent discharge may have resulted in slight increase just after the point of discharge (400-600 meters), values were considerably low.

4.6 Chemical Properties of the Salt Deposit Layer Sampled

The white salt compounds that accumulated at the surface was sampled along with a few millimeters of soil and analysed for chemical properties. The relevance of this was that this development could summarize the influence of the soil chemical properties on field grown plants. The farmers recourse to abandon the lands on which the salt crust developed show in all clear terms that this factor must have prevailed on the farmers to make their decision.

Values of the soil-salt crust layer sampled are shown in Table 4.12. The pH values in water averaged 7.6, possibly tending towards alkalinity (pH > 8) in places (400 meters). The elelctrical conductivity was 4.3 dSm^{-1} implying that the salt content was not composed of neutral salts. Though Ca^{2+}, Mg^{2+} and K^{+} ion were high, the Na^{+} ion was significantly very high (38.45 cmol/kg) and the SAR was high (14.95) much above the critical value for sodic soils. It can be said therefore that the soils were saline-sodic at these surface crusts, which must have influenced the plants sufficiently to result in farm abandonment by the farmers. This condition did not go deep, deriving from the discussions. So far, the widespread occurrence of this problem makes the condition significant, requiring putting in place good management strategies for the amelioration of the irrigated lands of sodium hazard and problems of salt affected soils. Fig. 4, 5 and 18 show the magnitude of this problem and should be addressed.

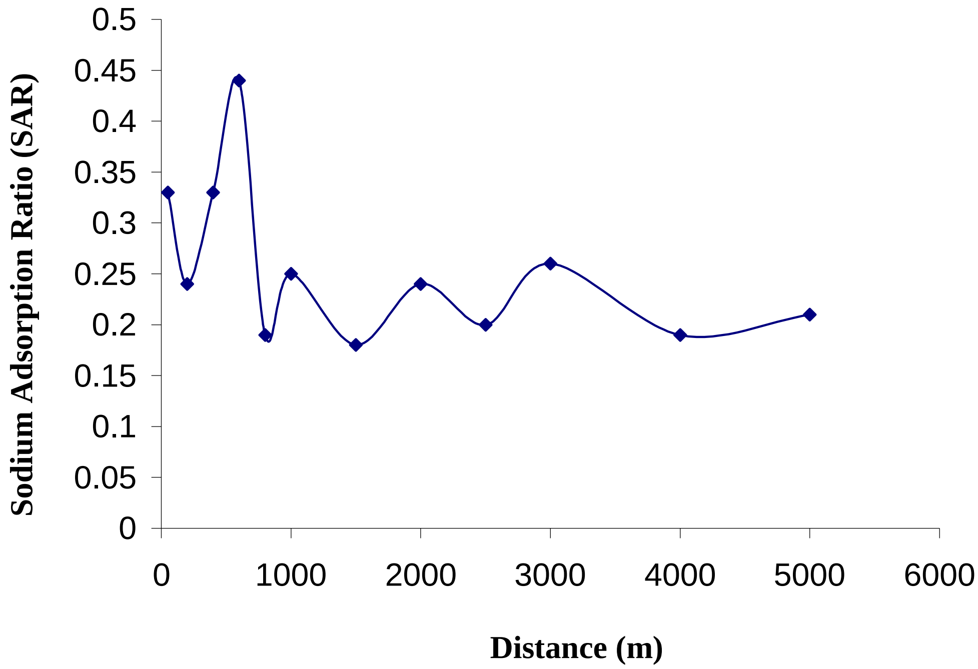


Fig. 20: Variation of SAR content of the 0-30cm layer with distance along the river course

Table 4.12: Chemical properties of the salt deposit samples at the effluent source (200 m) and about 400 meters along the sampling course.

Sample	pH H_20	pH $CaCl_2$	EC dSm-1	Ca^{2+} cmol/kg	Mg^{2+} cmol/kg	K^+ cmol/kg	Na^+ cmol/kg	P mg/kg	SAR
A (200m)	7.2	7.0	4.1	7.5	2.3	2.0	29.4	14.0	13.3
B (400m)	8.0	7.6	4.5	11.4	5.02	2.67	47.5	15.8	16.6
Average	7.6	7.3	4.3	9.45	3.65	2.34	38.45	14.9	14.95

4.7 Chemical Characteristics of the Water Samples

The chemical characteristics of the water samples taken from the study site are shown in Table 4.13. The suitability of irrigation water can be defined by the content of total dissolved solids (TDS), electrical conductivity (EC), sodium adsorption ratio (SAR), sometimes by the residual sodium carbonate (RSC) and the contents of phytotoxic elements such as boron and chlorine. Most often, the quality actually rests on the total salt content, sodium hazard and alkalinity where the residual sodium carbonate is high. In this study, data for the water quality along the river course of River Tagwai were estimated from samples of the dam water, waste water discharged into the river at 200 and 400 meters, tube wells from the irrigable lands on the river banks at 600 meter and 2000 meters, and the dug out burrow pits for harvesting naturally sand sieved water of considerable level of turbidity at points 2.5 and 5km respectively. These values are presented in Table 4.13 for all points.

4.7.1 pH

The pH of the water samples averaged at 6.41, ranging from 6.2 to 6.7. The dam water had a pH of 6.5. The values were within the normal range of 6.0-8.5 adopted by Richard (1954) as suitable for irrigation. In relation to distance, the pH of the water samples was more acidic near the discharge point, and increased away with distance in order of arrangement for the waste water, tube wells and dug out burrow pits. By all assessment, the pH of the water samples along the river course were slightly acid to neutral, which may tend to suggest that they are suitable for irrigation purposes.

Table 4.13: Chemical characteristics of the water samples collected from the study site at source and along the sampled river course.

S/N	Sample	pH	EC	TDS	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	HCO_3^-	$CO_3^=$	SO_4^{2-}	Cl^-	B	Fe	Cu	Mn	Zn	SAR
			dSm^{-1}	---- mg 1^{-1} ----														
1	Dam Water	6.5	0.08	600	18	1.6	8	27	1.5	0.0	0.47	1.5	0.42	1.8	0.0	0.25	0.15	8.62
2	Waste water (effluent) 200m	6.2	0.12	20200	10	2.6	8	29	1.6	0.0	0.14	1.1	0.17		0.0	0.3	0.25	11.55
3	Waste water (effluent) 400m	6.2	0.10	19300	10	2.0	7	28	1.2	0.0	0.26	1.1	0.09		0.0	0.25	0.25	11.43
4	Tube Well (a) 600m	6.4	0.20	400	25	4.2	10	120	2.7	0.0	0.24	1.1	0.06	0.8	0.0	0.25	0.15	31.40
5	Tube well (b) 2500m	6.5	0.05	500	18	0.4	8	33	0.8	0.0	0.42	0.85	0.17	0.8	0.0	0.25	0.15	10.88
6	Dug pits (a) 2.5km	6.4	0.20	500	18	3.6	8	97	2.0	0.0	0.6	1.15	0.06	0.8	0.0	0.25	0.05	29.51
7	Dug pits (b) 5km	6.7	0.14	500	10	2.4	8	98	1.2	0.0	0.56	1.05	0.14	0.6	0.0	0.25	0.05	39.35
8	Tap water	6.7	0.02	0.06	-	0.88	1.5	2.6	0.88	0.0	0.06	0.55	0.0	0.8	0.0	0.10	0.10	1.23
9	Mean	6.41	0.13	6000	15.57	2.40	8.14	61.71	1.57	0.00	0.39	1.12	0.16	0.94	0.00	0.26	0.16	20.39
10	Std. Dev.	0.18	0.057	-	5.79	1.26	0.90	41.22	0.62	0.00	0.19	0.19	0.12	0.40	0.00	0.12	0.07	12.57
11	SE	0.067	0.022	-	2.18	0.480	0.34	15.58	0.230	0.00	0.071	0.073	0.047	0.150	0.00	0.007	0.026	4.76

4.7.2 Electrical Conductivity (EC)

The electrical conductivity of the water samples ranged from 0.02 dSm^{-1} for tap water (control), to 0.20 dSm^{-1} for the dug out pits and tube wells, corresponding to salt content of 0.3 meq L^{-1} to 3.0 meq L^{-1}. This shows that the salt content of the water, as sampled, would pose no problems when used for irrigation. These values fell short of the critical value of 4 dSm^{-1} at what point salinity may start to develop, Table 4.13. (Appendix 1) shows the relative values of EC of the water sources. The EC values were classified as C_l indicating no problem of salinity.

4.7.3 Total Dissolved Solids (TDS)

The TDS of the water treatment plant effluent was highly turbid, with average values of 20,000 mg L^{-1}. This value is far in excess of about 100-200 mgL^{-1} TDS allowable for good quality irrigation water. Singh and Maurya (1979) found values equivalent to 330 mg L^{-1} for water used in the Wurno irrigation Project, Sokoto State, Nigeria. Values for the tube wells and dug out pits were slightly above the threshold value, and were less turbid in relation to the dam water, with a value of 600mg L^{-1}. The turbidity of the water from source (the dam) constituted the first problem. The high clay and silt sediments were bound to produce high ion exchange properties and silting out of the soil profile down the river course, resulting in poor drainage conditions, and enhancing the problem of salinity in the soils due to trapping effect of exchanged ions from the effluent sediments. Though the water samples may have showed low values for most chemical elements evaluated, the buffer for these ions in soil was high. Table 4.13 (Appendix 2) shows the differences of the TDS content for the sources. It is apparent that the high value determined in the effluent discharge, in the first place must be psychologically disturbing to the farmers who eventually devised the tube well and dug out pit techniques to reduce the turbidity that were found to be effective, considering the values for tube wells and dug out pits (500 mg L^{-1}). The need to flocculate the discharge contents to same degree is suggested by this study. Total dissolved solids was negatively correlated to all parameters determined (Table 4.14).

4.7.4 Basic Cations

The calcium content of the water samples were high, and ranged from 10-25 mg L^{-1}, with a mean of 15.6 mg L^{-1}. Values in the waste water were lower than in the tube wells and dug out pits. This inconsistency was also observed for Mg. Values for Mg ranged from 0.40 mg L^{-1} to 4.2 mg L^{-1}, with mean of 2.4 mg L^{-1}. The formation of $CaSO_4$ and $MgSO_4$ precipitations takes the divalent basic cations substantially out of solution and can be the explanation for this inconsistency. The Mg content was normal for the water samples, contrary to the high values for Ca. Ca compounds formed much of the chemicals used in the water purification plant.

Potassium values were 1.5 mg L^{-1} for tap water, and varied within the narrow range of 7-10 mg L^{-1} for all other sources. These values were high and seemed to be in equilibrium state with soils of the area. Much of the observed K must have come from mineralized rocks/soils, and K held on the exchange sites of the large amount of solid sediments derived from the effluent discharge. K was significantly correlated to the HCO_3^- content (Table 4.12).

Table 4.14: Correlation matrix of the water parameters

	pH	EC	Ca	Mg	K	Na	SAR	HCO_3	CO_3	Cl	SO_4	B	TDS	Fe	Cu	Mn	Zn
pH	1.00																
EC	-0.028	1.00															
Ca	0.170	0.343	1.00														
Mg	-0.179	0.969**	0.326	1.00													
K	0.194	0.558	0.784*	0.588	1.00												
Na	0.407	0.866*	0.455	0.768*	0.675												
SAR	0.532	0.763*	0.156	0641	0.456	0.939**											
HCO_3	-0.192	0.845*	0.631	0.912**	0.781*	0.672	0.436										
CO_3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000									
Cl	-0.010	0.052	0.114	0.164	-0.021	-0.141	-0.193	0.282	0.00								
SO_s	0.691NS	0.157	0.105	-0.048	-0.171	0.342	0.436	-0.149	0.000.	0134							
B	-0.824	-0.607	-0.020	-0.529	-0.191	0.564	-0.532	-0.318	0.00	0.676	0.088						
TDS	-0.824	-0.205	-0.662	-0.054	-0.483	-0.554	-0.486	-0.186	0.00	-0.072	-0.705	-0.146					
Fe	-0.034	-0.376	0.178	-0.254	-0.067	-0.496	-0.581	0.005	0.00	0.848*	-0.015	0.905**	-0.066				
Cu	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.000	0.000	0.000	0.000				
Mn	-0.533	-0.055	-0.426	0.070	0.070	-0.350	-0.310	0.020	0.00	-0.049	-0.595	0.041	0.666	0.064	0.00		
Zn	-0.973**	-0.199	-0.233	-0.038	-0.307	-0.602	-0.705	0.011	0.00	0.036	-0.712	-0.075	0.848*	0.157	0.00	0.548	
Esp	0.385	0.801*	0.075	0.878	0.378	0.916**	0.980**	0.429	0.00	-0.288	0.380	-0.674	-0.349	-0.694	0.00	-0.242	-0.575

Sodium content was significantly high relative to the value for tap water (2.6 mg L^{-1}). Values for the water samples ranged from 27 mgL^{-1} for the dam, to 120 mg L^{-1} for the tube well. These high values, suggest potential problem of salinization of the soils if the water is used continuously for irrigation. The low values obtained for the waste water at 200 and 400 meters (28 mg L^{-1}) may be due to the precipitation of insoluble or sparingly soluble compounds of sodium at these proximal points due to high concentration of dissolved salts. At points down stream, the removal of some anions may have resulted in the dissolution of the Na compounds, releasing the Na^{+} cation. Values were high for the tube wells and dug out pits down stream (600m and 200m respectively). The values of 40 mg L^{-1} may be allowed in irrigation water (Richard, 1954), these values strongly suggest the development of salt affected soils if irrigation is carried out with this water over time. Na was highly correlated to EC and HCO_3^{-}, two factors listed in the classification of salt affected soils.

4.7.5 Sodium Adsorption Ration (SAR)

This is a strong measurement for possible sodium hazard in the soils. By the classification of irrigation water, SAR values of 1-10 is low (S_1) with no Na hazard, 10-18 will produce sodicity hazard (S_2), 18-26 is high (S_2) and above 26 is classified as very high (S_4) (Richard, 1954, Qureshi and Barrett Lennard (1998). The higher the soluble salt content (high EC), the lower the SAR value for each class of sodicity. Though the dam water can be classified as safe and good for irrigation, values at all other points down stream will result in the development of sodium hazard when used continuously for irrigation. For reasons earlier stated (precipitation of Na compounds at the proximal points of effluent discharge) values for the tube wells and dug out pits down stream were classified as S_4 (very high SAR). SAR was significantly correlated with EC and Na as expected. The mechanism for the development of high soluble sodium content in the water samples, while values for the soils were low in this element need to be explained. It is understood that most Na salts are soluble, so remain in the solution. However a more cogent explanation lies in understanding the nature of the clay size fractions of the effluent, and the sparingly soluble chemical species of Na that existed in the system.

4.7.6 Anion Content of the Water Sample (HCO_3^-, SO_4^{2-}, Cl^-)

The bicarbonate and carbonate contents of the water samples are also shown in Table 4.13. Though HCO_3^- was detected in the samples, the CO_3^{2-} ion was not detected, indicating that the carbonate ions must have precipitated out as $CaCO_3$ or Mg CO_3. This process also kept much of the Ca out of solution. The bicarbonate contents of the water samples ranged from 0.80 – 2.7 mg L^-. Values for the tap water was 0.88 mg L^{-1} and for the dam water was 1.5 mg L^{-1}. The highest value of 2.7 mg L^{-1} recorded for the tube well would not be said to be sufficiently high to influence the pH substantially. The pH values of less than 6.7 for the water samples (Sec. 4.6.1) was as a direct result of the low bicarbonate content of the water samples and the soils. When free bicarbonate ions accumulate in irrigation water, the pH is known to rise above 80 (Suarez, 1984).

The sulphate (SO_4^{2-}) content of the water samples were low and ranged from 0.06 in tap water (control), to 0.60 mg L^{-1} in the dug out pits for water harvesting also used for irrigation (mean = 0.39 mg L^{-1}). The SO_4^{2-} ion is a strong acid and so could reduce the pH substantially if allowed to accumulate in high amounts. Much of the SO_4^{2-} is precipitated out as $CaSO_4$ and $Mg SO_4$. Values were lower in the effluent (waste) water at the proximal points and tended to increase in the tube well and dug out pit consistent with distance. The values did not influence the pH appreciably because the SO_4^{2+} content was low at all points.

Chlorine ion content was not dramatically high despite the high level of chlorine used in the process of water purification in the treatment plant. Chloride as $Mg Cl_2$ and NaCl contents are part of the problems of saline soils. This normally create high osmotic pressure in the system, thereby inhibiting water uptake by plants considerably. Values in the water samples ranged from 0.55 in tap water to 1.50 mg L^{-1} in the dam water, with a mean of 1.12 mg L^{-1}. Generally, the free Cl^- ion was low in the samples to constitute any hazard to the soils. It indicated that the problem of excess chlorine getting into the effluent was well managed in the water treatment plant. Values were not different for all the sampled points. Cl^- was significantly correlated only to Fe (r = 0.085*).

4.7.7 Micronutrient Content of the Water Samples (B, Fe, Mn and Zn)

The micronutrient content of the water samples are given in Table 4.13. Though these elements may not directly influence the formation of salt affected soils, the amounts present in the irrigation water may be such that it may be toxic and so not suitable for the crops grown in the soil being irrigated. For instance, irrigation water with boron content in excess of 0.75 mg L^{-1} is known to be toxic to most plants, and the yield of crops may be affected at this level of boron. Just as well, the contents of heavy metals in soils increase under acid conditions and so may become toxic to plants.

The concentration of the micronutrients boron, iron, manganese and zinc were low in the water samples, and so would normally not constitute any toxicity hazard to grown crops. The values for the elements were not sufficient to induce deficiency problems also.

Boron values ranged from 0.00 – 0.42 mg L^{-1} with a mean of 0.16 mg L^{-1}, iron ranged from 0.6 – 1.8 mg L^{-1} with a mean of 0.94 mg L^{-1}, manganese ranged from 0.10-0.30 with a mean of 0.26 mg L^{-1}. In all these cases, values were higher in the dam water, and decreased as sampling was done down stream (i.e with distance). The zinc content, which can be taken as an index of micronutrient fertility ranged from 0.05-0.25 mg L^{-1}. Variation in the Zn content with sources of water sampled is shown in Table 4.13 (Appendix 4). In all the cases, the values in the effluent waste water were higher than in the tube wells. Values in the dug out pits at the distance were least. Toxicity or deficiency problems are not expected.

4.8 Soil and Water Quality of the Study Area

4.8.1 Soil quality

The result obtained from the study showed that the texture of the soils was generally sandy loam to loamy sand, with few sandy clay loam and a clayey surface horizon recorded at the point of effluent discharge (200m). The chemical properties of the soils also revealed that the soil reaction (pH in H_2O) ranged from slightly acidic to moderately acid with positive difference between pH in water and in $CaCl_2$, indicating that the soils were negatively charged and contained some amount of reserved acidity.

Exchangeable bases were high and occurred in the order of $Ca^{2+} > Mg^{2+} > Na^{+}$ in decreasing order of magnitude, while K^{+} was found to be low. Both effective cation exchange capacity and CEC derived from ammonium saturation were rated moderate to high with ECEC less than ammonium acetate CEC. Base saturation was also moderate to high as well as Almunium ion concentration was detected to be high from point of effluent discharge down to 1.5km distance, while the remaining soils down to 5.0 km point had low Al^{3+}.

The organic carbon, Total nitrogen and available phosphorus contents were generally low and so was the C:N ratio. Extractable micronutrients exhibited non toxic effort nor likelihood of deficiency, except on Zinc. The soils were generally observed to have poor fertility status.

Looking at salinity/sodicity indices such as EC, pH, ESP, SAR, $CO_3^{=}$, HCO_3^{-}, $SO_4^{=}$ and Cl^{-} indicated limited salinization and sodification processes in the soils. However, there was tendency for the soils especially at proximal points of effluent discharge to become sodic.

4.8.2 Water quality

The quality of water in the study area did not indicate immediate danger of salinity as the EC values were less than 0.75 dSm^{-1} required for recognizing danger of salinity (Richard, 1954). On the other hand, SAR values for dam were safe and good for irrigation at all points in the study area, but will result in development of sodium hazard when used continuously for irrigation.

On the effluent discharged from the water treatment plant, tube wells and dug out pits waters had very high SAR values that could lead the soil to attain ESP 15% were observed. In addition to this, Total dissolve solids values were far in excess of allowable quantities for good quality water (100-200 mg L^{-1} (Singh and Maurya, 1979) and thus constituted the major problem of the water for irrigation in the area.

The sulphate, bicarbonates, chlorides values were also within the safe limits, and carbonate was not detected (possibly precipitated out). Concentrations of the micronutrients, boron, iron, manganese and Zinc were generally low in the water samples.

4.9 Management Strategies for the Salt Affected Soils of the Study Area

Close scrutiny of the problems in the study area showed that the soils have similar case of acid sulphate salt problems (Uwaniyom and CharoenChamratcheep, 1984). It is the type of salt-affected problem of soils where bases are removed as sulphates and most of the exchange complex occupied by almuminium and thus likely to become acidic, deficient in calcium and potassium. As such management practices to be employed in the study area could be as follows:

(a) Ploughing of salt surface crusts into the soil;

(b) Application of lime was known to be the best method of improving soils.

(c) Cultivation of properly close tolerant crops that can indirectly facilitate the removal of exchangeable sodium (Chhabra and Abrol, 1977) and by increasing the cross-sectional area of conducting, and resulting in an increased soil permeability (McNeal, et al., 1966).. Pearson (1960) listed these types of crops according to their tolerance to exchangeable sodium like rice, wheat, cotton, barley, tomatoes etc. Trees and grasses were also included.

(d) Use of organic manure have long been known to facilitate the reclamation of soils (Yadav and Agarwal, 1961; Kanwar, *et al*., 1965).

(e) Employing good cultural practices that can enhance the reclamation of the salt affected soils, such as mulching with rice husk, wheat husk, millet husk and continuous cropping (to reduce upward movement of salts).

(f) Monitoring the chemical content of irrigation water and the soils with a view towards reducing risk potentials of using the waste water.

CHAPTER FIVE

5.0 SUMMARY AND CONCLUSION

5.1 Summary

Farmers at the Ajiwa down stream terrain irrigate their crops with water from the River Tagwai, to which has been discharged waste sludge (effluents) from the Ajiwa township water treatment plant. This practice has been said to cause soil degradation which has made the farmers to abandon their farm lands due to poor crop yields resulting from salinity problems, evidenced by the white salt crust deposits on the soil surface. A study was initiated to determine the causes of soil degradation at the Ajiwa down stream irrigated terrain, so as to proffer possible strategies of soil and water management for these degraded soils.

The study site was the Ajiwa dam and the township water treatment plant, including a 5 kilometer stretch of irrigated lands on the banks of River Tagwai, towards the Makurda Village in Katsina State. Soil samples were taken at predetermined points with distance and depth. Water samples were taken from the dam and along the River course for laboratory determination of the relevant parameters. Results derived from the study showed the following:-

1. The textural classes of the soils varied from sandy clay loam/clay at the point of effluent discharge (200m from dam), to loamy sand at distances down stream. Clay content decreased with distance and with soil depth. This showed that the high surface deposits of clay sized particles was derived from the effluent discharge and this could impact appreciably on the conditions and reactions of the

soils. Sand, silt and clay fractions ranged from 39%, 17% and 44% at the proximal points of discharge, to 82%, 8% and 10% respectively at 5 km distance away from the dam.

2. The soils were strongly acidic (pH 4.8) at the point of discharge, and were only slightly acidic (pH 6.4) at distances away, implying that the effluent waste sludge was acidic with the attendant effect on soil properties and nutrient availability. This was attributed to the large quantity of alum ($Al_2(SO_4)_3.14H_2O$) employed in the water treatment process. The influence of Al on pH, and consequently on soil fertility, can be a critical factor in these irrigated soils.
3. The soils were low in fertility but were modified by the effluent waste deposits. Soil fertility parameters were enriched at the proximal points of discharge. Organic carbon and nitrogen contents were enriched essentially by the amide based organic flocculent, super floc, used in the water purification. Phosphorus content was low at the proximal points indicating P fixation at these more acidic and high clay laden sections of the terrain. Ca and Mg were significantly enriched by over 300%, up to 2km down stream apparently due to the high amount of hydrated lime used, while K and Na were not appreciably modified and varied only slightly. The unmodified soil fertility rating was low. Mg SO_4 and Na_2SO_4 were suggested in this study as constituents of these white salt deposits on the soil surface. These are often the major salt components that cause salinity of irrigated lands.
4. The organic flocullant used have strong chelating properties and could enhance the impoverishment of the already poor soils of relevant metalic cations (micro-

nutrients). Much of the P fixed in Al complexes may have been non-extractable and could make P management in these impacted soils to be poor. Generally, the native soil fertility was estimated at 30% while the fertility enhancement by the effluent deposits was 70%.

5. The carbonate, sulphate and chloride contents of the soils ranged from 2.13-9.90, 0.11-0.58 and 1.88-4.75 mg/kg respectively. The carbonate content was high at point of discharge and decreased significantly with distance. Na_2CO_3 and $Al_2(CO_3)_3$ were observed as the more abundant carbonate compounds in the soils. Active Na_2CO_3 in the soils resulted in peptization of the soil colloids on irrigation, resulting in reduced permeability and aeration. Conversely, the SO_4^{2-} content increased significantly with distance and seemed to overwhelm the adsorptive and reactive capacity of the soils for SO_4^{2-} through out the 5 km stretch studied. This was evidenced by the crystal salt deposits all over the 5 km stretch. The amount of alum used was large and the study suggests partial recovery of SO_4^{2-} from the effluent waste before it is discharged into the river. Na_2SO_4 and $MgSO_4$ induced high levels of salinity in the soils. The variation of Cl^- was minimal, though the potential of NaCl in inducing salinity in the soils was suggested.
6. The micronutrient contents were not high to the level of toxicity in any case, though, the Fe content was high in the effluent. This could create P management implications in the soils by excessive fixation of P as shown by the low available P levels at the proximal areas.
7. The EC values ranged from 0.03-0.23 dSm^{-1}, and were therefore classified to be of low salt content (0.5-3.0 mgL^{-1}), though the high CV observed seemed to mask

the treatment effects. The ESP and SAR values were low in most places, but the tendency for soils to have high ESP existed at the 400m-600m distance. Na_2CO_3 and $NaSO_4$ were suggested to be active and could result in low aggregate stability and reduce permeability. This stretch was prone to develop saline-sodic conditions and had relatively higher SAR values. However, in situations of moisture deficit and the soil slowly dries out, white salt crystals would form on the soil surface by capillarity, and so the surface soil crust would attain the status of saline-sodic conditions. Though the condition may have been essentially a surface phenomenon, it summarized the conditions of the salt affected soils which influenced crop yields and farmers decision to abandon their farm lands. The study suggests putting in place ameliorative strategies to combat sodium hazard and problems of salt-affected soils.

8. The pH of the water samples ranged from 6.2-6.7 and were regarded as suitable for irrigation, though were more acidic at the point of discharge. The EC values were classified as C_1, indicating no salinity problem. Average value was 0.2 dSm_{-1} for the tube wells and dug out pits.

9. The total dissolved solids (TDS) of the effluent (waste water) was 20,000 mg L^{-1}, which was well above the 100-200 mg L^{-1} limit for good quality irrigation water. This level of turbidity constituted the first psychological problem to the farmers. The TDS level was reduced to 500 mg L^{-1} in tube in the wells and dug out pits. The high clay and silt sediments produced high ion exchange properties, silting out of soil pores, resulting in poor drainage conditions of the soils, enhanced salinity problems through trapping effect of exchangeable ions from the effluent,

and high buffer power of the ions. The TDS was negatively correlated to all parameters, implying that high TDS ran contrary to the conditions required for good soil fertility management.

10. The sodium content of the water samples was significantly high (as high as 120 mg L^{-1} for the tube wells). This suggests potential problems of sodicity when the water is used continuously for irrigation. Precipitation of Na salts at the proximal points was attributed to high concentration of Na from the effluent at these points.
11. The SAR values of the water samples were high. The irrigation water would therefore induce conditions of high sodium hazard when used continuously for irrigation.

5.2 Conclusion

From the parameters presented in this study, we can infer that the cause of soil degradation at the Ajiwa downstream irrigated terrain was categorically the effect of salinity/sodicity in the soils, created by the continuous use of water contaminated by the effluent discharge from the Ajiwa township water treatment plant (water works) for irrigation, and so should be treated as a case of salt-affected soils. The overwhelmingly high concentration of some anionic species in the effluent, such as sulphates, carbonates and chlorides, resulted in the formation of high contents $MgSO_4$ and Na_2SO_4, as well as the carbonate and chloride salts of Na in the soils. These salts are the causes of salinity and sodicity of irrigated lands. At instances of short or long dry spells, these soluble salts move to the soil surface by capillarity, and get deposited as white salt crusts on the soil surface, producing the conditions of salt affected soils. Through the condition was observed not to be general through out the profile, the surface salt deposits created unfavourable soil condition for crop growth, leading to the abandonment of farm lands by farmers. Strategies for good soil and water management of these degraded soils should include:

(a) Filtration of the effluent discharge to reduce the turbidity, and chemical anionic exclusion using synthetic cationic polymer resins to reduce the SO_4^{2-}, CO_3^{2-} and Cl^- contents of the effluent waste water before it is discharged into the river.

(b) Employing the technology of tube wells and dug out pits situated at intervals along the river bank from where water should be pumped for irrigation.

(c) Soil management to take care of the reclamation of salt affected soils using physical methods and other cultural practices should be adopted.

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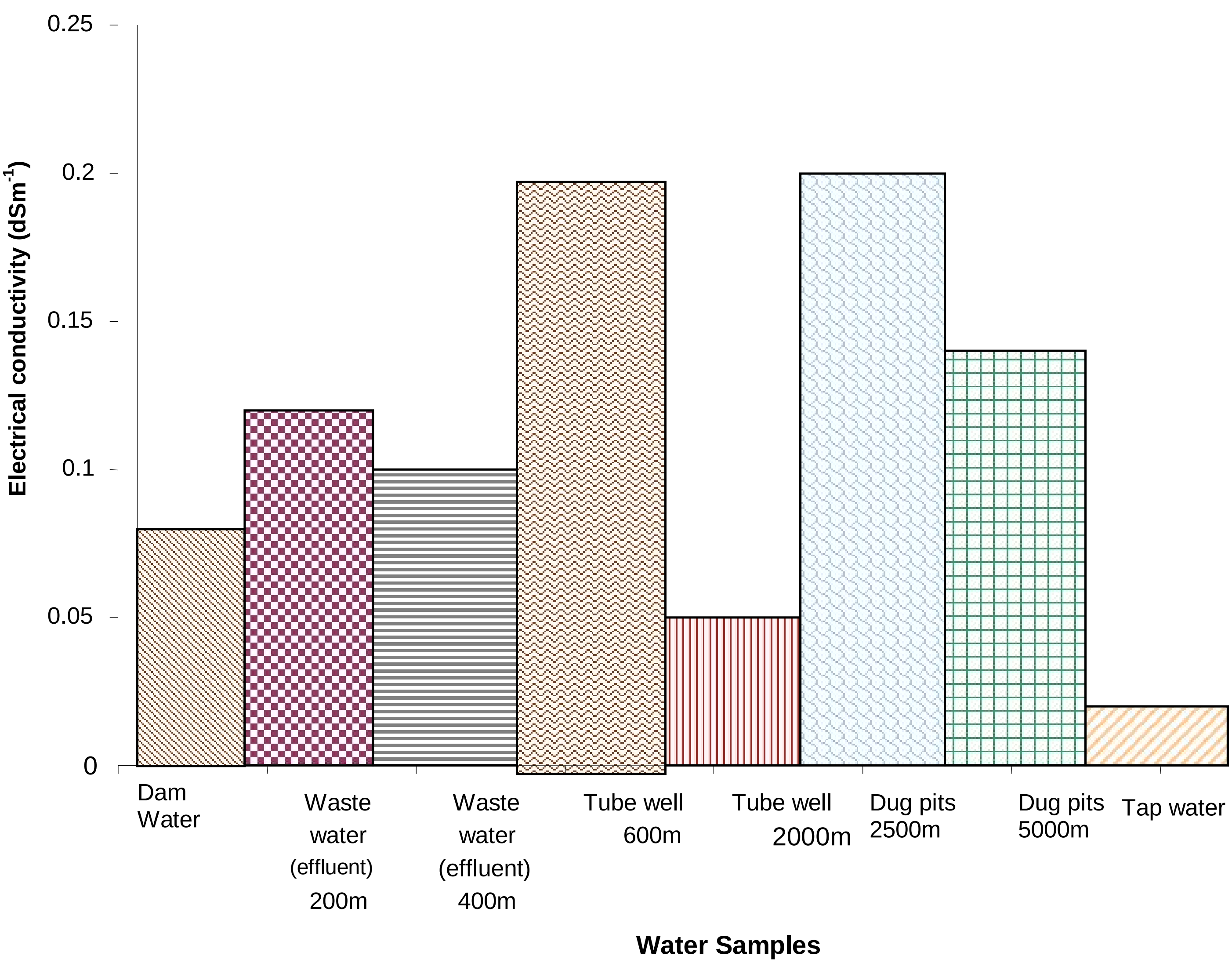
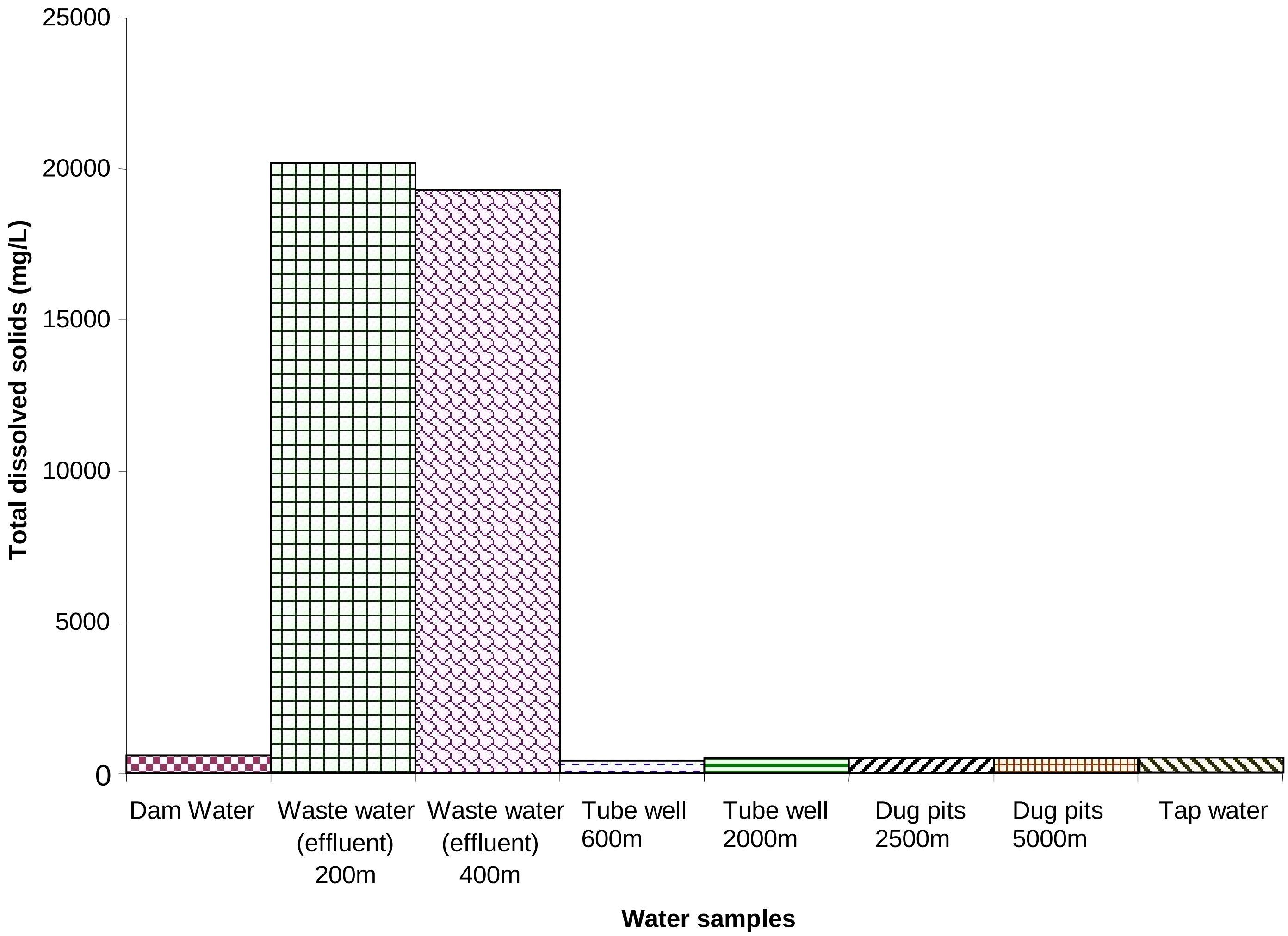
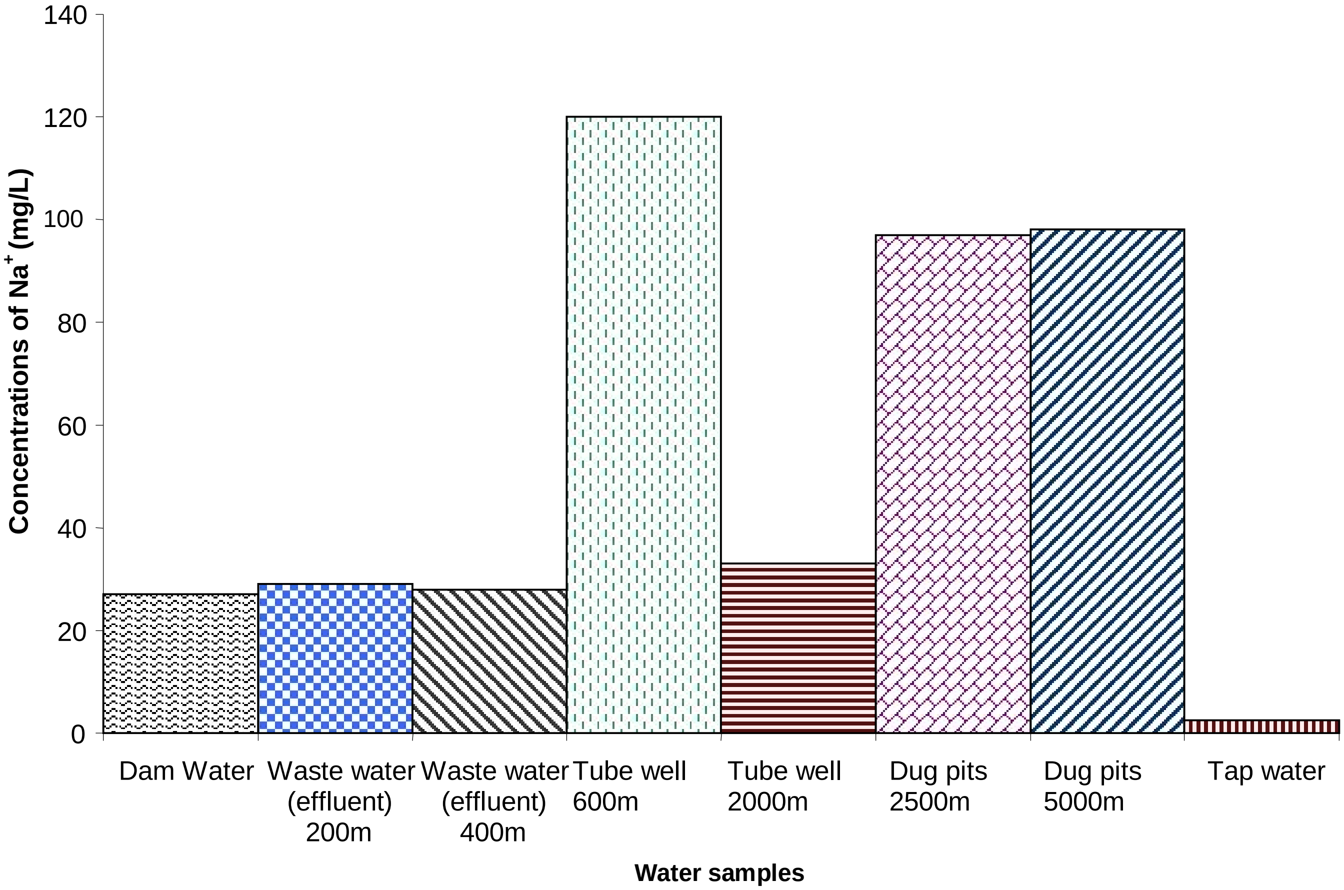
Appendix 1: Electrical conductivity of the water sampled from the various sources



Appendix 2: Total dissolved solids of the water sources along the river course



Appendix 3: Sodium content of the water sources



Appendix 4: Zinc content of the water sources