SALINE AND SODIC SOILS IN THE DRYLANDS OF KENYA

S.N. Wanjogu, P.T.Gicheru, P.M.Maingi and Matolo Nyamai
Kenya Soil Survey, P.O.Box 14733, Nairobi-Kenya

INTRODUCTION

Kenya lies on both sides of equator approximately 5° South and North and between 34° and 42° longitude. The country varies in altitude from sea level to more than 4000m above sea level. The equator extending to latitudes of about 4° 30' North and South, largely corresponds to a tropical climate.

Kenya has a total of 582,646 sq km which is approximately 60 million ha of which 4.5 million are arable and with permanent crops. The semi-arid and very arid areas (ASAL) cover approximately 80% of the country.

The high and medium potential lands are devoted to crop and milk production while much of the ASAL are largely used for extensive livestock production such as ranching, pastoralism as well as a habitat for wildlife both in and outside the national parks and some reserves. Therefore rainfed agriculture is confined to about 20% of the country. Appendix1 shows the distribution of the major soils in the country.

Agriculture supports over 80% of the population (total population is 32.2 million). Maize is the most important food crop in Kenya and constitutes the staple food for over 95% of the population. Subdivision of land since 1979, has led to uneconomically viable parcels of agricultural land. Population pressure has resulted in increased land pressure and the consequent farming on fragile land, with a large decrease in per capita cultivated land.

ASAL which covers the country's dryland occur in agroclimatic zones (ACZ) V,VI and VII described as semi arid, arid and very arid respectively. These ACZ are defined on the bases of the ratio of average annual rainfall (r) and average annual potential evaporation (Eo). Agroclimatic zones V, VI and VII have these upper boundaries as 40, 25 and 15 respectively. The very arid zone VII alone covers nearly half of the country.

In Kenya, the probability that precipitation is less than evapotranspiration (2/3Eo) is nil in zone I while in zones II, III, IV, V, VI and VII the chances are 0-2, 2-20, 20-65, 65-90 and 90-97 respectively. Climatic zones become drier from zones IV to VII. Consequently the chance of a partial or total crop failure increases , the more arid a zone becomes.

According to International Institute of Rural Reconstruction (2001), the following definitions are used for drylands:

- In terms of the absolute amounts of rainfall, Convention to Combat Desertification defines drylands as areas with between 0 and 600mm of rainfall per year, depending on altitude and latitude.

- In terms of the length of the wet season and the temperature, areas with less than three months of enough moisture to support plant growth and the average temperature of at least 27^{o}C.
- By comparing the annual rainfall with the amount of potential evapotranspiration. On definition in those areas where rainfall is less than 40% of the potential evapotranspiration.
- In terms of vegetation - Dryland are areas where conditions favour perennial grasses rather than annual cereals. Rainfed cropping therefore has an inherent rise of failure.
- In terms of land use - Some farming systems are more sensitive to drought than others. Pastoralists may regard grazing areas as drylands, in contrast to the wetter areas, usually highlands, where crops are grown.

The ability of the land to produce is limited and therefore there is a limit to the number of people that can subsist on a given area. The limits of production are determined by the natural environment for example climate, soils, relief, dominating geomorphological processes, vegetation cover and the prevailing land use and management level which are influenced by a range of socio – economic and cultural variables. Any use of land beyond these limits will in the long run only result in environmental degradation and lowered productivity, unless land management is strongly changed for which the costs in general are prohibitive. It is therefore important that knowledge of these limits will be known to the development planners before any development action is undertaken (Haastrecht and Schomaker, 1985).

Land degradation is a process of change of land quality that can only be assessed realistically by comparing the existing conditions with some baseline conditions established at a given period in the past. Land degradation indicators are selected to monitor the trend of change. Some indicators such as soil characteristics and climatic parameters may change over a period of decades or generations while others like vegetation, population and settlement may show significant changes even on annual basis. Land degradation encompasses changes in any or all the aspects of land (soils, minerals, water and vegetation) that adversely affect its quality and hence the ability to support societal needs, especially agricultural and forestry production and water resources (Government of Kenya and UNEP, 1997).

For sound land-use planning, particularly for agricultural purposes, there is a need for a good understanding of the nature of soil resources, the relative risks of degradation, the type of degradation and where the degradation occurs (FAO, 1979; UNEP, 1982).

Muchena (1989) and Wanjogu et al., (2001) distinguish the following groups of soil degradation processes in Kenya.

Water erosion, including splash, sheet and gully erosion measured as soil loss. Splash, sheet and rill erosion occur in all cultivated areas, especially steep slopes and are caused by land clearing and continuos cultivation without conservation measures. Gully erosion is widespread all over the country and mainly occurs on animal tracks, footpaths, uncontrolled water courses, failed conservation structures and uncontrolled grazing.

43%, 8%, 24%, 10% and 4% of the country experience very slight, slight, moderate, severe and very severe hazard water erosion respectively while 11% is non-hazard. These classes cover 253,900 km^2, 51,600 km^2, 140,100 km^2, 56,500 km^2, 22,100 km^2 and 64,091 km^2 respectively.

Landslides occur mainly in high rainfall and steep sloped areas where the soils form an abrupt transition to bedrock or have an impermeable horizon. Water infiltrates into the soil and causes concentrated flow at the soil-rock or permeable-impermeable horizon interface.

Wind erosion, includes removal and deposition of particles, measured as soil loss. It is expected to be a problem during the dry season and only in the drylands receiving less than 600 mm of annual rainfall and with sparse vegetation.

Chemical degradation includes leaching of bases leading to soil acidification and aluminium toxicity, fertility decline, salinization, sodification and pollution. Acidification and aluminium toxicity are common in high rainfall areas, which cover about 20% of the country. A free draining soil losses its bases such as calcium, magnesium, potassium and sodium through leaching, with the result that the soil becomes acidic, leading to aluminium toxicity. The main causes of fertility decline are continuous cultivation and little use of inorganic fertilizers because of the high cost of fertilizer and erratic availability. This leads to the loss of plant nutrients through erosion, harvested crops and leaching. Salinity and sodicity problems are common in the ASAL where they have naturally formed under the prevailing climatic conditions and due to high rates of evapotranspiration and lack of leaching water. About 40% or about 25 million ha of the land of Kenya is covered by soils that have salinity and/or sodicity problem(s). Land degradation by salinization is on the increase in irrigated ASAL areas where irrigation of unsuitable soils or use of poor quality irrigation water is a common practice. The land under irrigation in Kenya is estimated to be about 84,000 ha (Ngigi, 2002). According to Mugwanja et al., (1995), about 26,000ha is considered salt degraded. This is caused mainly by poor irrigation management and poor drainage, especially in areas with high ground water table. This therefore requires continuous land degradation assessment and monitoring and indication of the necessary remedial measures before reaching devastating levels.

Water pollution is a major off-site impact of soil erosion. Water pollution causes deterioration of the aquatic habitats, increased water treatment costs and clogging of water distribution systems. Sediment is a major pollutant of the surface water and is a major carrier of agricultural chemicals into the water systems. Major soil pollutants have their source from effluent disposal from industries, slaughterhouses and sewerage. Land use pattern may contribute to pollutants flowing into water or soil within a certain region and therefore determine the water and soil quality. Agrochemical wastes from horticultural farms contribute to soil and river pollution.

Physical degradation is caused by soil compaction due to use of agricultural implements and trampling by animals and this causes adverse changes in soil porosity, permeability, bulk density, water holding capacity and structure stability. Soil structure deterioration is observed mainly in saline and sodic soils, caused by sodium. The collapsed structure impairs water movement in the soil causing impeded drainage conditions and reduction in oxygen and nitrogen supply. Soils susceptible to crusting and sealing occur mainly in agro-ecological zones III to V and have low organic matter content in the top soil. These zones cover about 24% of the total area of Kenya.

Biological degradation is caused by processes that increase the rate of mineralization of humus and is measured by depth of humus layer. Microorganisms are also reduced during this process It occurs in areas practicing intensive agriculture and is more severe in the rangelands where burning and over exploitation of vegetation is common. In the ASAL zones, removal of vegetation cover by overgrazing, trampling and cutting of trees and shrubs for charcoal are the major causes of biological degradation. Devegetation for fuel wood and fencing materials account for 13% while conversion of ASAL to other uses account for 14% of the degradation. Overgrazing and arable agriculture contribute about 73%, and stand as the major cause of the degradation.

The rate of soil degradation is influenced by human activity through different land use and management. Soil salinization and sodification have been identified as major causes of land degradation and decline in crop yields especially in the ASAL. Therefore, agricultural research programmes should be directed towards investigations leading to the development and adoption of soil and water management practices for sustainable use of these soils.

Drylands cover 80% of Kenya. The major production constraints in the drylands include: Salinity, Sodicity, Drainability, Effective rooting depth, Availability of oxygen for root growth, Capacity of water retention, Workability of the soils, Moisture availability, Soil fertility(availability of nutrients), Conditions for germination, Ease of land clearing and Freedom for layout of field plans.

The pressure exerted on the fragile ecosystems such as the ASAL with the introduction of irrigation has an effect on salinisation and sodification in soils with salic and/or sodic phases.

SALT AFFECTED SOILS IN THE DRYLAND ECOSYSTEMS OF KENYA

Assessment and monitoring salinity/sodicity

Very few studies have been undertaken in monitoring salinity and sodicity in Kenya. Though the Ministry of Agriculture should be monitoring the irrigation schemes in the country, this has not been vigorously done and the information collected is either not available or not accessible. In the field, samples are taken from different horizons and the of supernatant solution of 1:2.5 soil to water ratio is measured using an Ec meter. The ECe is estimated by multiplying the EC values by a factor 3. Sodicity in the field is assessed by measuring the pH and noting the soil structure and other related soil characteristics. pH values >8.0 mostly indicate a sodic soil which could be accompanied by a prismatic or columnar structure.

Assessment and monitoring has been going on in the Hola irrigation scheme whereby the data acquired by Muchena (1987) formed the baseline information. Monitoring was done by Wamicha in 1992, 1997 and by Muya in 2002 to check changes in pH, ECe and ESP in the topsoils and subsoils.

THE EXTENT OF SALT-AFFECTED SOILS

Source of information

The exploratory soil map of Kenya (E1) at the scale 1:1 million (Sombroek et al., 1982) was compiled using mainly two different basic sources of information:

(a) Published information or information that was in preparation at the end of 1979.
(b) Exploratory field work during the period 1973 – 1977.

The maps and reports published by the Kenya Soil Survey (KSS) were a major source of information. During the field trips, scattered soil descriptions were made throughout the country. The sites were chosen after consulting existing topographic, geologic and vegetation maps, aerial photographs and satellite imageries (ERTS- LANDSAT) to ensure a high degree of representativeness of the sites. Some of the soil survey reports and maps that were used include van de Weg and Mbuvi (1975), Gelens and Kinyanjui (1976), Sketchley et al., (1978) and Michieka et al., (1978), were used in the compilation of the exploratory soil report (E1) at scale 1:1million.

During the establishment of the Kenya Soil Terrain (KENSOTER) database in the early 1990's, the soils information acquired after 1979 was entered into the data base to update the E1 report. Such soils information was acquired from all the soil surveys which were conducted after 1979 and these included Muchena and van der Pouw (1981), Wielemaker and Boxem (1982), Touber (1983), van Wijingaarden and van Engelen (1985, Kekem (1986), Ahn and Geiger (1987), Gicheru and Gachene (1997) and, Gicheru and Kiome (2000). There after, any soils data or information acquired is used continuously to update the KENSOTER database. This database therefore was the source of the information used to get the distribution of the saline-sodic soils in the country.

Physical and Chemical analysis

The hydrometer method was used in the texture analysis. KSS has been following the USDA classification for texture whereby the diameter for clay, silt, sand and gravel are <0.002mm, 0.002 – 0.05mm, 0.05 – 2.0 and >2.0 respectively. The Walkley and Black method (Black,1965) has been used for organic carbon determination. Organic carbon, ESP and ECe classes are shown in table1. Table shows the pH classes used. The pH and EC were determined in a 1:2.5 soil – water suspension.

Table 1. Rating organic carbon, ESP and ECe

% organic carbon	Rating	ESP	Rating	ECe	Rating
<1.2	Low	0-5	Non-sodic	0-4	Non-saline
1.2 – 2.0	Moderate	5-10	Slightly	4-8	Slightly ‘’
>2.0	High	10-15	Moderately	8-15	Moderately
		>15	Strongly	15-30	Strongly
				>30	Excessively

Table 2. Rating pH

PH	Rating
<4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
>9.0	Very strongly alkaline.

Macharia (1984) assessed the quality of borehole waters for irrigation covering nine regions in the dry parts of Kenya. The parameters used to determine the quality were the contents of sodium, calcium, magnesium, potassium, carbonates, bicarbonates, chlorides, sulphates, nitrates, pH and electrical conductivity (EC). In order to quantify the various water quality hazards, the following parameters were calculated; sodium adsorption ratio (SAR), total dissolved solids (TDS) and residual sodium carbonate (RSC).The United States Department of Agriculture classification of salinity (1954) was used to assess the quality of the water. In this study it was found that borehole waters from the coastal strip, Thika-Kitui, Voi-Taita, Nairobi (Karen) and Machakos to Mtito Andei regions have low permeability (sodication) and alkalinization hazards. The parameters used included: pH, bicarbonates, carbonates, residue carbononates

The only regions where no water quality hazards may occur if the borehole waters are used are Ndeiya-Karai and Nakuru-Njoro. These waters are in safe range of salinity hazard and may not cause any hazard if used for irrigation.

The borehole waters from coastal, Kitui, near lakes Turkana, Elementaita and Naivasha, Embakashi and Athi River, Garissa and Isiolo are in unsuitable class due to salinity hazard.

There are various ways of classifying saline and sodic soils but the basic three groups are; the saline, sodic and those that are saline and sodic whereas these waters are in very high alkalinization hazard range and in very high permeability hazard

Soil Legend and Classification

The soils pattern in Kenya is very intricate because of striking differences in altitude, landforms, geology and climate. The methodology developed by KSS for mapping soil units reflects landforms at the highest level and there is a subdivision according to important differences in geology at the second level which is followed by the description of individual soil mapping units.

In Kenya a system whereby landscape attributes (physiography and parent materials) are used during the mapping of soils has been developed. The parent materials and physiographic units were defined by van de Weg (1977) and Sombroek et al., (1982) as shown in tables 3 and 4.

The soil classification of the E1 report was based on the FAO/UNESCO (1974). During the establishment of the KENSOTER, the FAO/UNESCO (1989) was used to update the previous classification which has been close checked with the FAO/UNESCO (1997).

Table 3. Soil parent materials influencing salinity and alkalinity in Kenya

Code	Definition
I	Intermediate igneous
B	Basic igneous
P	Pyroclastics
V	Undifferentiated volcanics
N	Biotite gneisses
F	Gneisses rich in unafic minerals
U	Undifferentiated metamorphics
S	Sandstones
K	Siltstone
D	Mudstones
W	Marls
T	Shales
L	Limestones
O	Plio-Plestocene bay sediments
A	Alluium
E	Eolian deposits
J	Lagoonal deposits

X	Various parent materials

Table 3. Physiographic units where saline and sodic soils occur

Code	Unit	Main diagnostic criteria	Slopes %
H	Hills	-	>16-30%
R	Volcanic Footridges	Dissected lower slopes of major volcanoes	5 - 16
F	Footslopes	Foot of Mountains, hill, scarps and plateaus	3 – 16
U	Uplands	Relief between 150 to 1,200m above local Base level	2 – 16
L	Plateau	Higher than bordering scarp(s)	0 – 8
Y	Piedmont plains	Border hills and mountains	0 – 8
P	Plains	Flat landscape to undulating	0 – 8
B	Bottomlands	No drainage exit	0 – 2
A	Floodplains	Seasonally flooded	0 – 2
S	Swamps	Flooded for most of the year	0 – 2
W	Badlands	Severely gullied	variable

Extent and distribution

The definition of saline and sodic soils has been adopted from FAO (`1997). A saline soil has an electrical conductivity of the saturation extract (ECe) of 4 dSm^{-1} or more and an ESP of less than 15. A saline – sodic soil has both ESP greater than 15 and an ECe greater than 4 dSm^{-1} (table 4)

Table 4. Saline and sodic soils in Kenya

Class	ECe(dS/m)	ESP	Soil classification
1 Saline	>4	<6	Vertisols, Fluvisols
2. High salinity	>15	<6	Solonchaks
3. Saline-sodic phase	>4	>6	Vertisols, Fluvisols. Geysols,Regosols, Planosols, Phaeozems, Luvisols
4. High salinity and sodicity	>15	>15	Solonchaks, Solonetz
5. Sodic phase	<4	>6	Vertisols, Fulvisols, Andosols, Chemozems, Phaeozems, Luvisols, Cambisols
6. strongly sodic	<4	>15	Solonetz

Sodic phase marks soils, which have more than 6 percent saturation extract with exchangeable sodium at least in some horizons within 1 meter of the surface. The sodic phase is not shown for soil units which have a natric B-horizon or which have sodic properties since a high ESP is already implied in their definition.

Many of the soils considered as saline do not necessarily have salic properties. Similarly, those considered as sodic do not necessarily have a natric horizon. However, both saline and sodic soils must have a horizon within the upper 1 metre of soil with ECe of more than 4 dS m^{-1} and ESP of more than 15, respectively.

According to FAO (1997), the term salic properties refers to an ECe of more than 15 dSm^{-1} at 25 ^{o}C at some time of the year within 30 cm of the surface or more than 4 dSm^{-1} within 30 cm of the surface if the pH exceeds 8.5.

A natric subsurface horizon shows distinctly higher clay than the overlying horizon, columnar or prismatic structure in some part of the B-horizon and a saturation with exchangeable sodium of more than 15 percent within the upper 40 cm of the horizon.

Phases are limiting factors related to surface and subsurface features of the land. They are not necessarily related to soil formation and cut across the boundaries of different soil units. Salic phase marks soils, which in some horizons within 1 metre of the surface show ECe higher than 4 dS m^{-1} at $25^{o}C$. The salic phase is not shown for Solonchacks because their definition implies a high salt content. Salinity in a soil may show seasonal variations or may fluctuate as a result of irrigation practice.

Salic phase indicates present or potential salinization. However, the effect of salinity varies greatly with the type of salts present, soil permeability, climatic conditions, and the kind of crops grown.

The most extensive soil classification units in the dryland are Solonetz, Solonchaks and Vertisols (appendix 1).

10% of Kenya covering about 6 million (m) hectares has saline and sodic soils on slopes >5% mainly associated with footslopes and uplands while about 25% covering approximately 16m ha has soils on plateaus, piedmount plains and plains with slopes 0-8%. 5% covering 3m ha is covered by bottomlands, floodplains, swamps and badlands with slopes 0-2% have saline and sodic soils.

About 24m ha of Kenya has saline-sodic soils on altitude ranging from sea level to about 1,500m above sea level. About 40% of Kenya has saline – sodic soils in the ASAL areas covering agro-climatic zones V, VI and VII. The ASAL area which forms the drylands of Kenya covers approximately 47 million ha (about 80% of Kenya's surface area). The soils occur predominantly in Eastern, Northern, North Eastern (NE), North Western (NW), Coastal and Rift Valley (RV) regions of the country (appendices 2, 3 and 4).

Agroclimatic zone V covers 8.4 million ha of the drylands (18%) of which 1.1 million ha (13%), 312,353 ha (4%) and 150,986 ha (2%) are slightly saline, moderately saline and severely saline respectively. The slightly saline soils occur in Narok, Laikipia and Baringo districts in Rift Valley Province, Machakos district in Eastern Province, Kwale, Kilifi and Lamu in coast Province, Moyale district in NE Province and Turkana in the NW part of the country. The moderately saline soils are found in Malindi, Kilifi and

Kwale districts in the coast province, Baringo district in Rift Valley Province and Moyale district in north eastern Province. The severely saline soils occur in Malindi and Kajiado districts in coast and Rift Valley provinces respectively.

In this zone, the slightly sodic soils cover 13,921 ha (0.2%), moderately sodic soils 151,392 ha (1.8%), severely sodic soils 10,378 ha (0.12%) and very severely sodic soils 18,498 ha (0.2%). The slightly sodic occur in Turkana district in north western Kenya while the moderately sodic soils are found in Kilifi and Malindi districts in coast Province, and Kajiado and Narok districts in the Rift Valley Province. The severely and very severely sodic soils occur in Machakos and Baringo districts respectively.

Agroclimatic zone VI covers 12.4 million ha (26%) of the drylands. 2.3 million ha (18%) has soils that are slightly saline and 1.4 million ha (12%) moderately saline. The severely saline class occupies 1.9m ha (15%) of the zone's area. The slightly saline soils occur in Malindi and Ijala districts in Coast Province, Kajiado, Baringo and West Pokot in Rift Valley Province, Moyale, Isiolo and Marsabit in north eastern Province and Turkana district in north western part of the country. The moderately saline soils occur in Malindi, Ijara and Tana River districts in Coast Province, Moyale in morth eastern Province and Turkana in north western Kenya. The severely saline soils are found in Tana River and Ijara districts in Coast Province, Garissa in eastern Province, Turkana district in NW and Kajiado district in Rift Valley Province.

In this zone, 68,702 ha (0.5%), 66,019 ha (0.5%) and 25,329 ha (0.2%) have slightly sodic, moderately sodic and very severely sodic soils respectively. The slightly sodic soils occur in Turkana district, the moderately sodic soils in Kilifi, Malindi in coast Province, Kajiado and Narok districts in Rift Valley Province and the very severely sodic soils in Samburu and Baringo districts in the same region (RV).

Agro climatic zone VII covers about 26 million ha (56%) of the dryland area, whereby 3.7 million ha (14%), 6.7m ha (25%) and 2.8m ha (11%) are slightly, moderately and severely saline respectively. The slightly saline class is predominant in Tana River district (coast region), Moyale, Mandera, and Wajir districts (North Eastern region), Marsabit district in the Northern part of Kenya and Turkana district in the North Western Kenya while the moderately saline soils are found in Garissa district (eastern region), Isiolo district (North eastern), Marsabit district (North) and Turkana district in NW Kenya. The Severely saline class of soils occurs in Tana River and Taita –Taveta districts in coast region, Isiolo and Moyale districts in NE part of the country and Garissa and Ijala districts in eastern region of the country.

In this zone, 247,262ha (0.9%) and 177,548ha (0.7%) are slightly and very severely sodic soils respectively. The slightly sodic soils occur in Turkana and Marsabit districts in north western and northern part of the country respectively.

In ACZ V, VI and VII Solonchaks are the dominant soils in the slightly sodic soils. The main land use of these soils is nomadism. The dominant soils in the moderately sodic class are Solonchaks, Luvisols, Lixisols and Arenosols. Major land use types on these soils are agro-pastoralism, ranching and parks.

Severely sodic soils occur on Gleysols and Fluvisols where extensive grazing is the major land use. This class of sodicity occurs in ACZ V where selective felling of vegetation also takes place.

The very severely sodic soils occur in ACZ VI, and VII on Fluvisols and Luvisols. Semi nomadism and nomadism are the major land uses.

The slightly saline soils cover a wide range of soils in all the ACZ. However, they are mainly found in Vertisols, Solonchaks, Solonez, Fluvisols and Luvisols. In ACZ V, rainfed arable agriculture takes place in Alluvial plains while ranching, semi-nomadism nomadism and agro-pastoralism also take place in this zone. Semi-nomadism and nomadism dominate ACZ V and VII.

The moderately saline soils in ACZ V include, Fluvisols, Vertisols, Planosols and Luvisols. Ranching, semi-nomadism and nomadism form the major land uses.

In ACZ V the moderately saline soils include, Solonchaks, Solonetz, Planosols, Vertisols, Regosols, Gleysols, Fluvisols and Luvisols. Semi-nomadism and nomadism are the major land uses on these soils.

In ACZ VII Fluvisols, Gleysols, Luvisols, Lixisols, Solonchaks, Vertisols, Solonetz and Planosols show moderate salinity. Nomadism is the main land use system.

In ACZ V strongly saline soils occur in Cambisols, Vertisols, Regosols, Solanchaks and luvisols. Agro- pastoralism, semi-nomadism and nomadism take place. Clearing vegetation for various uses such as construction of cattle kraals, houses and fuel wood take place while some areas are left unused.

In ACZ VI Cambisols, Vertisols, and Regosols show the strongly saline class. Agro-postoralism, semi-nomadism and nomadism take place.

In ACZ VII Solonchaks, Solonetz, Luvisols, Fluvisols, Vertisols, Arenosols, Regosols and Cambisols are strongly saline. Nomadism is the major land use system.

Irrigated agriculture

Kenya has a relatively limited irrigation tradition and the majority of existing irrigated areas were developed between 1960 – 1980, although there is evidence that local communities may have practiced some form of irrigation for the last 500 years. Despite strong gains in the 1970s but during 1980s the rate of irrigation development declined, with the area under irrigation now being estimated at 84, 000 ha which is far less than the potential irrigable areas estimated between 244,700 – 539,500 ha (Ngigi, 2002).

Irrigation projects that had been initially successful have in many cases declined in productivity and, in some cases, have been abandoned.The emergence of small-scale irrigation technologies that poor farmers can easily understand, and invest in and use to grow crops for food and cash is important. Two main technologies that have been adopted by Kenyan farmers are the small-scale drip-irrigation systems and treadle pumps (Sijali, 2002). These technologies not only reduce the workload on women who are the main users but also improve incomes and family nutrition. The bucket drip-irrigation kits have been distributed by Kenya Agricultural Research Institute and other non-governmental organizations in Kajiado district (Rift Valley Province), Meru and Tharaka districts (Eastern Province) among others. Over 600 kits have been distributed to smallholder farmers in Kenya. Poverty is one of the greatest challenges to the adoption of small-scale irrigation technologies in the country.

Categories of irrigation schemes

a. Public irrigation schemes

This category includes the settlement schemes managed by the National Irrigation Board (NIB) and the Bura irrigation scheme run by the Ministry of Agriculture. These schemes are based on a tenant-farmer system where each tenant is generally allocated 0.4 – 1.0 ha. Other schemes in this category are managed by regional authorities and are operated as commercial estates for example the Sigor irrigation scheme under Kerio Valley Development Authority (KVDA) and the Kibwezi and Tana delta, under the Tana and Athi River Development Authority (TARDA). Irrigated land under this category rose from 8,500ha in 1975 to 9,000ha in 1998.

b. Smallholder irrigation schemes

These schemes can be further grouped into two types.

- Schemes where the irrigation infrastructure and water distribution systems are operated and maintained by a water undertaker. Example of this type include the Yatta Furrow and Njoro Kubwa Furrow where the Ministry of Water Resources is the water undertaker.
- Schemes where the Water User Association has full responsibility for operating and maintaining the irrigation infrastructure and for distributing the water to all the members. Most of the schemes supported by the Ministry of Agriculture fall into this subcategory for example Mitunguu, Ishiara, Kibirigwi, Eldume, Kwa Kyai and Ngaare Ndare.

Private commercial irrigation

These are commercial farms or estates that produce high value crops such as floricultural and horticultural crops, mainly for the export market. Often, these farms are highly specialized in their production of technologies such as drip, sprinkler and even center pivots, Most of these farms are found in the Athi River area, Naivasha, parts of Central Province around Nanyuki, and in the peri-urban areas of Nairobi

Trends of Irrigation Development in the Drylands of Kenya

Most of the drylands in the country occur predominantly in Rift Valley, North Eastern, Eastern and Coast Provinces. A study carried out for the 5 years between 1995 and year 2000 showed that in Coast province there was a general decline in irrigation development. This was attributed to insecurity, salinity and sodicity problems, water scarcity and destruction of irrigation structures by El Nino floods. Diminishing financial support, inadequate marketing and infrastructure, in adequate technical know-how and lack of both credit facilities and exposure of farmers to new irrigation technologies were other factors contributing to the decline in irrigation development in the coast province. The trends showed a shift from group-based to individual farmers and also a shift in irrigation technology from gravity furrow to motorized pumps (Ngigi, 2002).

In Eastern province, there was a slight increase in the area under irrigation in the Ukambani district attributed to external support and growing of high value crops. There was an increased demand for high-valued horticultural produce, mainly grown under irrigation, leading to increased incomes. This has led to increased interest in irrigation enterprises and water – saving irrigation technologies being promoted and supported by NGOs and church organizations. Precision irrigation technologies such as low-head drip kits and treadle pumps are being adopted in the region. Isiolo district recorded an irrigation growth of 117 percent over the 5 year period. This was attributed to a shift in food-security strategies i.e. adopting irrigation by the traditionally pastoral communities.

In North Eastern province, irrigation is limited to Garissa district, in particular along the Tana river. Irrigation development increased by 161 percent within the same period. The trend was attributed to training farmers in irrigation activities and funding for rehabilitation and development by various NGOs. However, despite the increase in acreage, furrow irrigation still predominates.

In the Rift Valley province, there was a positive irrigation development trend in Laikipia, Kajiado and Turkana districts where the area under irrigation for both group-based and individual smallholder schemes increased. In Laikipia, water-saving technologies such as water harvesting and precision irrigation are practiced. Low-head drip systems and treadle pumps are common which has contributed to a 10% increase in area under small scale farmers.

In Turkana district, irrigation technologies are shifting from heavily mechanized to furrow and micro-basin irrigation to facilitate organization and development by farmers.

Availability and quality of irrigation water, especially groundwater is a constraint to irrigation development in some parts of the province. Other constraints in the province are inadequate awareness of the importance of irrigation, lack of technical know-how on the management of irrigation water, lack of capital, poor marketing and infrastructure, and lack of credit facilities.

MAJOR CAUSES AND PROCESSES OF SALINIZATION AND SODICATION IN KENYA

i) Natural causes

Pedological processes

Saline and sodic soils have their pedogenesis greatly influenced by high salt contents and high exchangeable sodium respectively. High salinity generally limits plant growth and high sodium affects adversely soil physical conditions and hence soil management. FAO/UNESCO (1973) enumerated the environmental conditions under which salts or sodium accumulated in soils of areas like Kenya as follows:

1. Young volcanic high areas which comprise the geochemical discharge areas,
2. Depressions with insufficient natural drainage to where the geochemical discharge is directed,
3. A climate such that evapotranspiration predominates over run-off in the water balance

Salinity in soils is caused by the presence of ions occurring in the forms of chlorides, sulphates and nitrates and predominate in the arid and semi-arid areas where they cause high osmotic pressure in soil solution and toxic effect of chlorides while sodic soils are due to sodium ions capable of alkaline hydrolysis and occur in semi-humid to semi arid environments resulting in high pH, poor soil and water physical conditions and calcium deficiency. In gypsiferous soils, calcium causes salinity in ASAL soils causing low pH and nutrients deficiency while magnesium rich soils causes high osmotic pressure and calcium deficiency in semi-humid to semi-arid areas. In sulphate soils, ferric ions and aluminium ions on the seashores and lagoons with heavy sulphate containing sediments causes high acidity, toxic aluminium effect and nutrients deficiency.

Most of the saline-sodic soils are developed due to natural, geological, hydrological and pedological processes. Saline-sodic soils in Kenya have originated mainly due to marine and inland salinization-sodification processes. Therefore the parent materials are marine sediments and volcanics. They occur mainly in low altitude areas characterized by high rainfall to potential evaporation ratio.

The soil parent materials of saline and sodic soils in Kenya include; intermediate igneous rocks such as phonolites, basic igneous rocks such as basalts, pyroclastic rocks, undifferentiated volcanic rocks, biotite gneisses, gneisses rich in mafic minerals, undifferentiated metamorphics, sandstones, siltstones, mudstones, marls, shales, limestones, Plio-Pleistocene bay sediments, alluvium, eolian deposits, lagoonal deposits and various parent materials.

Approximately 15% of the area of Kenya with these soils are developed on Miocene to Recent volcanic parent materials. 20% is found on Pleistocene to Recent depositional parent materials. The volcanic areas of saline and sodic soils lie above 600m while the areas with depositional parent materials are in the lowland plains. In these salty areas, the ratio of rainfall to evaporation is generally low, less than 40%. Salinization in Kenya has therefore occurred mainly on young volcanics and sediments in areas of high evaporation rates.

The physiographic units where saline and sodic soils are found in Kenya include hills, volcanic footridges, footslopes, uplands, plateaus, piedmont plains, plains, bottomlands, floodplains, swamps and highly eroded badlands.

Climatic factors

Evapotranspiration plays a very important role in the pedogenesis of saline and sodic soils. Altitude has been used in computing the potential evaporation of a given area with Woodheads (1968) equation: $Eo= 2422-0.358h$ where Eo is evaporation and h is altitude in metres.

Salinity and sodicity problems are common in the ASAL area which form the dryland of the country where they have naturally formed under the prevailing climatic conditions and due to high rates of evapotranspiration and lack of leaching water. The saline and sodic soils are estimated to occupy about 40% of Kenya's land surface(see appendices 2, 3 and 4).

The annual rainfall divided by evaporation gives moisture availability. Kenya has been divided into five altitude zones and seven moisture availability zones. The altitude zones are sea level to 200m, 200 – 1500m, 1500-2500m, 2500-3000m and >3000m. The moisture availability zones include very arid (zone VII), arid (Zone VI), semi-arid (zone V), semi-humid to semi-arid(zone IV), semi-humid (zone III), sub-humid (zone II) and humid (zone I) (Sombroek et al., 1982).

ii) Anthropogenic causes

In Kenya, salinization is accelerated mainly by climate and water management. About 75% of the country receives less than 500 mm of rainfall annually . This coupled with an annual potential evapotranspiration of about 2000 mm makes the area conducive to salinization. Therefore, naturally occurring salinity problem cannot be solved by leaching alone. The problem is accelerated by poorly managed irrigation schemes.

Leaching soils to remove soluble salts is the most effective method known to reclaim these soils. This requires good permeability of the soil and good quality irrigation water. Removal of salts by leaching reduces salt hazard for plants but might cause permeability to decrease and pH to increase (Dregne, 1976).

In saline-sodic soils leaching can lead to a drastic drop in permeability and an increase in pH to the point where decomposition of roots may occur as the soil is changed from saline- sodic to sodic.

Land degradation by salinization is on the increase in irrigated ASAL areas where irrigation of unsuitable soils or poor quality water is a common practice.

Most irrigation schemes are located in the arid environments. Kenya's estimated potential for irrigation at between 200,000 ha and 500,00 ha (Ngigi, 2002; Republic of Kenya, 1974). Arid environments of Kenya have largely been used for pastoralism and partly for subsistence arable agriculture with a high production risk in view of the considerable variation in annual precipitation.

However since 1950s, these areas have increasingly become a significant factor in the export-oriented national agrarian economy in spite of the poor agro-ecological potential of the land and their unsuitability for commercial rainfed agriculture.

The government has embarked on irrigation as a significant strategy for development of small-scale agriculture in these areas. However, there are virtually no interdisciplinary studies although far reaching repercussions on irrigation schemes are already known.

Many irrigation schemes in Kenya have been abandoned after less than twenty years of project establishment mainly due to salinisation and sodication problems. However Hola irrigation scheme ,in the arid areas of lower Tana River Basin has relatively considerable evapotranspiration rates and a highly irregular water supply. In all the ASAL, the conditions are extremely unfavourable for irrigation (for example the Perkerra and Taita Taveta schemes where salinization has been reported).

Though initially it was pointed out that the salinisation problem would not be serious for production of chillies and onions in Perkerra, yields are likely to low when compared to the genetic potential yields. The suggested solutions for this scheme were leaching excess salts with fresh water; addition of ameliorative additives to assist the washing out of salts (gypsum) and to support capillary rise and the evaporation of the soil solution by use of soil cover and mulch; husbandry practices to improve the depth of rooting zone by deep ploughing or deep loosening the soils and diminish salinity of the soil solution in the root zone through irrigation methods selected; measures related to plant culture; species clones and varieties; crop rotation and fertilizer application.

These practices were also applicable in Turkana and Marsabit, (Haastrecht and Schomaker, 1985). In addition, they underlined the importance of water harvesting techniques which would increase yields and lower the risk of crop failure due to climate, and the use of simple soil and water conservation techniques for better conservation of the environment. They further pinpointed that some of these improvements are restricted due to capital, organizational, knowledge and labour constraints as well as socio-economic barriers such as land ownership.

Other studies in West Pokot District showed that in agro-climatic zones IV, V and VI, traditional rainfed cultivation of maize and finger millet, and traditional to intermediate extensive ranching for milk and meat (cattle, goats) take place. The infrastructure involves none or inadequate advisory services and only local market is accessible in all

ACZ's. They also found that land holding is very small, (about a hectare) for arable farming and no land adjudication and communal grazing areas in all ACZ's of their study (that is IV to VI).

A study by Muya et al., (2000) in Morulem irrigation scheme in Lokori Division, Turkana District (NW Kenya), showed that non uniformity of water distribution was as a result of lack of proper leveling of the border strips and different irrigation time practice by farmers. It was further noted that the problem was aggravated by the formation of very strong surface crusts which impaired infiltration of water in the soil. In addition, most of the farmers were irrigating at a much less time and it was found to be lower as far as 20 minutes. They noted that these seemingly small problems if overlooked are the major causes of failures for many irrigation scheme.

iii. Social-economic-political driving forces

Land use in the country is controlled by several factors which include climate, soils labour, technology and markets.
In order to achieve a sustainable management of land resources, the land use policy must provide a system of laws, rules, regulations and practices that govern the rights and obligations of the land owners together with appropriate guidelines in the optimal utilisation of available land. There are good reasons for land use planning, among them being the need to identify changes required in land use practices which will increase productivity and opportunities, to decide where the changes should be and to avoid misuse of the land resources.

The government has therefore come up with the following recommendations to be incorporated in the national land use policy:

- Review land use legislation and planning with a view to increasing productivity, protecting water catchments and the fragile ecosystems, and reducing land use conflicts.
- Place greater emphasis on conservation of undamaged resources than rehabilitation.
- Involve local communities in resource management and incorporate indigenous management whenever appropriate
- Integrate conservation development planning
- Plan for long-term as well as short-term consideration, especially environmental impacts

In the semi-arid and arid areas of Kenya, land is communally owned and most of these areas have been receiving large numbers of immigrants who then often settle indefinitely provided that there is sufficient pasture and water. This leads to uncontrolled use and degradation of the land. In a system where usage rights are restricted, as with certain groups/communities in agro-pastoral areas, land degradation is less severe. This is also true in situations where rights over certain strategic resources such as land and water are either exclusively and /or the subject of very personalized investment. The free or open access system coupled with other factors as practiced in Turkana and Marsabit makes them amenable to abuse and consequently severe land degradation (Mutiso et al., 1997).

These authors further pinpoint that in the past, most studies on land degradation approached the phenomenon from climatic and vegetation view point ignoring the socio-economic factors which contribute both to causes and solutions. Phenomenon such as population distribution, settlement patterns, land tenure, income distribution and poverty relations are very complex. The human factor in the land degradation process concerns those outcomes which are incidental and unanticipated effects of economic activity.

Effects of policy on degradation is evident in agricultural systems through increased pressure on pastures, soils and forest resources. Fiscal, price and income policies often contribute directly to increased pressure on soils, vegetation and water for example subsidies designed to promote cash cropping through increased export revenues have contributed to salinization and sodification and hence a reduction in the resilience of the ecosystem.

Various policies contribute to increased livestock densities in fragile pastoral lands. Many of the changes in land use in the ASALs are the consequences of inappropriate land use policies for example the Livestock Development policies increased grazing pressure in Turkana and Marsabit (Haastrecht and Schomaker, 1985). These authors also indicate that concerns over the linkage between poverty in rural areas and land degradation had been expressed since 1970 when several reports revealed a striking connection between them. By th1980s, land degradation in the fragile areas was thought to have reached crisis proportion.

Policy, Legal and Institutional issues on water use

Policy, legal and institutional issues need to be addressed to resolve conflicts over water resources, marketing of produce, planning of irrigation and drainage activities, stakeholder coordination and collaboration, and enforcement and implementation of policies and laws. These issues have not been addressed adequately, leading to uncontrolled and illegal abstraction of water, conflicts among uses and users, poor marketing of produce, poor infrastructure, weak farmer organizations, lack of reliable data for planning, low priotization of irrigation and drainage, underutilization of irrigation potential, inadequate financial resources, drastic shifts in government policies, uncoordinated efforts by stakeholders, conflicts of interest among stakeholders, breakdown in law and order in most group-based irrigation schemes, low morale of District Irrigation Unit staff, and farmers being exposed to different project-implementation approaches.

Policy is the main factor affecting irrigation development in Kenya. Until the policy issues are fully addressed, no meaningful progress will be realized in the irrigation sector. The Ministry of Agriculture has drafted an irrigation policy but this has not been adopted. There has been a change in government policy, from donor reliance to self-reliance, from grant to cost-sharing and recovery. This sudden shift in policy ha impacted negatively.It is felt that the new policy was implemented too fast, farmers were not given enough time, and there was no transition period; hence farmers could not cope with the policy. Group-based irrigation has decreased tremendously. This could probably be attributed to a new policy by Ministry of Natural Resources that requires improvement in the efficiency of irrigation water conveyance.

Cases of illegal water abstraction are rampant. This makes planning for irrigation development virtually impossible, as accurate data are not available. Continuous monitoring of water abstraction needs urgent attention to enhance water management. There is need to harmonize the operations of the stakeholders involved in irrigation development in order to reduce duplication and confusion. There is need to address institutional confusion to minimize existing conflicts. This is possible through collaboration and networking.

5 SUCCESSFUL AND FAILURE CASES

Origin of the irrigation schemes

Formal irrigation development started during the construction of the Kenya – Uganda Railway (1901 – 1905) with some Indian workers allocated 30 ha of land in the Kibwezi and Makindu area to grow horticultural crops to supply to the railway construction crew. The irrigation was abandoned after the completion of the railway construction.

During the second word war, irrigation activities were initiated at Taveta, Naivasha and Karatina but they also ceased after the war.

In 1946, African Land Development schemes were started. The onset of Mau Mau war, coupled with the need to find work for the Mau Mau detainees gave added impetus to these schemes and hence the implementation of Mwea, Ishiara, Perkerra and Hola irrigation schemes during the 1952 – 1960 period.

These schemes occur in agro-climatic zones IV, III, IV-V and V-VI respectively. Historically, the first planned irrigation project go back to the 1950's. these projects were drawn up against the background of the restrictive land and policy of the colonial administration, which mainly reserved the more favourable highlands for the whites and tended to allocate the Africans less favourable from the physical geography point of view (Obara, 1983). Further he points that efforts to exploit land use potential in the arid regions was due to:

- Increasing population pressure on the periphery thinly populated white highlands as well as deterioration of land in the overstocked and thus overgrazed regions
- The specific need to find suitable employment for those evicted as a result of the Mau Mau rising

After independence National Irrigation Board was inaugurated to continue with the schemes initiated by the colonial administration as well as initiating new ones. However schemes drawn up after 1963 were found in North east of Lake Victoria and are mainly pilot schemes.

CASE STUDY 1 : Management and Rehabilitation of the Kimorigo-Kameleza Irrigation Scheme (Taita – Taveta District , Coast Province)

Kimorigo/ Kameleza irrigation schemes are in Taveta division of Taita-Taveta District. The area lies at latitude 3^o 27'S and longitude 37^o 41.6'E at an elevation of 730m.

The idea of utilizing the land for irrigation farming around Taveta dates as far back as 1931 when a British Hydraulic Engineer working for the Public Works Department submitted a report on irrigation potentialities in Taveta. Following this report, irrigation schemes were proposed with the dual aim of putting the spring water of Njoro Kubwa into good use and of draining local swamps by diverting dry season flows and preventing them from entering lake Jipe.

In 1942, colonel Grogan who was an employee of British Army, made a proposal that prisoners of war should be taken away from areas surrounding Nairobi and proposed a large agricultural base with the prisoners of war providing labour should be started at Ziwani near Taveta. An Italian surveyor was sent to Taveta in the same year to make investigations and submit reports on possible irrigation schemes. The Director of Agriculture undertook to provide soil information. Flood waters were used to grow rice in an area (block C) covering 400ha. However, this scheme ultimately failed due to mounting problems of increasing salinity and sodality, setting of drains through continual flooding and variations in the ground water levels.

In 1945, G. Egan, working with Hydraulic Branch of the Public Works Department compiled a map of scale 1:25,000 marking out suitable and non suitable areas for irrigation. The map gave 2,280 ha as very suitable, 3440 ha as suitable, 280ha as less suitable and 1,000 ha as unsuitable. Works done in the area include the work of Mugai (1976), Bonarius and Njoroge (1976) and Irrigation and Drainage Research Project (1979).

From the experience of all the earlier works and studies in Taveta, it was concluded that the major problem in the area was poor drainage bringing about subsequent salinisation and alkalization of the soil.

Another irrigation scheme (Ziwani) covering 440 ha was concurrently developed with Block C. Kanake (1982) noted that ground water level in the area varies between 10cm below the soil surface to about 1.5-2.0m below the soil surface. In the Kimorigo-Kamleza area the ground water table fluctuates with the seasons, from 30cm in places in the wet season to below 1m in the dry season.
The hard "caliche" layer is generally found at 0.9m – 1.7m below the soil surface. The layer has a low hydraulic conductivity and is therefore likely to impede the soil drainage.

The chemical analysis of several ground waters samples taken from various locations in the area show that the water has a high degree of salinity and sodicity. It also has a high content of bicarbonates and other toxic elements. Good soil management and adequate drainage conditions are recommended at all levels when irrigation is applied.

According to Kanake (1982) large areas of the already existing schemes (Kimorizo and Kamleza) are found on soils that are initially generally well drained, moderately deep to deep) over hard Caliche layer at 70 –180cm depth), friable clay soils. The soils are non saline and non sodic.

Therefore salinisation and sodification occurs as an influence of ground water table rising after irrigation. However, salinity and sodicity presents a major threat to irrigated agriculture in the region. For this reason, extensive tracks of irrigated fields are abandoned every year (Wakindiki, 1993). In this study Wakindiki et al (2001) the final infiltration rates (IR) of Gleysols and Fluvisols were found to be 6.73 and 7.46 cmh^{-1} while Solonchacks showed a final IR of 3.08 cmh^{-1}.

The average vertical hydraulic conductivity was 0.03, 0.21 and 0.12 cmh^{-1} while the average HC in the horizontal direction was 0.28, 0.40 and 1.28 cm/h in Solonchacks, Gleysols and Fluvisols respectively.

The soil survey of Kimorigo and Kamleza irrigation schemes was done with an aim of carrying out a rehabilitation and expansion programme of both schemes. They covered 2,165 ha. The irrigation and drainage project (IDRP) identified the problem of drainage which is associated with the salinity and sodicity of the soils. IDRP recommended further research and investigations to find out ways of improving the drainage systems in the schemes and reclamation of the saline and sodic soils. Cotton, bananas, maize, beans, citrus, mangoes and a variety of vegetables are widely grown under furrow irrigation by the predominantly small-scale subsistence farmers.

Table 5. Changes in soil pH, ECe and ESP at Kimorigo/Kamleza between 1981-1993

Soil type	**Parameter**	**1981**		**1993**	
		Topsoil	**Subsoil**	**Topsoil**	**Subsoil**
Solonchak	PH ECe ESP	9.3 10.5 4.0	9.4 – 10.2 12.0 – 40.0 22.0 - 70.0	10.4 25.5 95	10.1 - 10.2 6.0 - 15.0 95 - 98
Gleysols	PH ECe ESP	8.6 – 9.5 0.9 – 3.0 4.0 - 24	7.9 – 9.0 4.0 – 30 6 - 59	7.7 60 40	9.0 – 9.2 60 25 – 67
Fluvisols	PH ECe PH	8.2 – 11.1 1.5 – 30.0 3.0 – 97	7.9 – 10.7 0.3 –16.5 1.o – 90	8.1 4.3 50	8.2 10.50 –10.70 33

From the above table, in the period 1981-1993, ECe changed from 10.5dSm^{-1} in 1981 to 25.5dSm^{-1} in 1993, while in the subsoil it reduced from 6.0 –15.0 dSm^{-1} in the same period. This indicated accumulation of salts on the surface. ESP increased to both the topsoil and subsoil. ESP in Gleysols and Fluvisols increased during that period indicating sodication process taking place. ECe values in Gleysols indicated salinisation process taking place due to the rise in the saline groundwater.

Rehabilitation work

In Kenya the major areas with salinization problem include Kimala, Kimorigo and Kamleza irrigation schemes in Taveta area in the coast region covering about 20,000 ha. (Mugwanja, 1995). The Kimala and Kimorigo schemes have been out of operation since 1996 due to salinity and sodicity problems

According to Mugwanja (1997), trials on the management of salt affected soils in Kenya were initiated by the Kenya Agricultural Research Institute (KARI) in Kimorigo-Kamleza irrigation scheme, Taita – Taveta District Coast province ,during the year 1994. The soils in these areas have an electrical conductivity of 11.1dSm^{-1} (1:2.5) and pH of 8.0. The management techniques experimented was leaching, planting methods and use of different crops. Leaching and drainage showed that crop production in the area can be greatly improved in areas which have otherwise been abandoned due to salinisation and sodification. Though the initial results indicated a positive rehabilitation possibility, the project could not continue due to lack of funds. However, there are plans to start once again the rehabilitative work very soon.

Case study 2: Bura and Hola Irrigation Schemes

Muchena (1987) carried out a study to compare the soils and soil conditions of three areas, situated in different physiographic positions in the lower Tana region of Kenya in respect of their suitability for irrigated agriculture.

The study area comprised the proposed Bura East Irrigation Scheme, the Bura West Irrigation Scheme and the Hola Scheme. The schemes are situated between Latitudes 0^o45’ South and 1^o 30’ South and Longitudes 39^o 20’ East and 40^o 30’ East. During this time of study a 2,500 ha and 872 ha were under irrigation in Bura West and Hola respectively with cotton as the main cash crop. Other crops were maize, cowpeas, groundnuts, green grams and vegetables.

The climate of the region is semi-arid to arid with an average annual rainfall of 300 to 400 mm, falling in two short rainy seasons. The temperatures are high throughout the year. On average potential evapotraspirations exceeds the rainfall by a factor of two or more throughout the year. Hence the chances of a successful rainfed crop production in the three areas is very small.

Tana River is the only year round source of surface water and the water is of excellent quality for irrigation purposes. The schemes lie between 70 and 112 metres above mean sea level. Six major soils occur in the area. These include Fluvisols, Vertisols, Cambisols, Calcisols, Solonetz and Luvisols according to FAO (1987).

The soils vary widely in both physical and chemical properties. More notable is the degree of variation in salinity and sodicity in the various soils. The soil drainage classes vary from well drained to poorly drained. The bulk of the soils have clayey textures and have low to moderate infiltration rates and slow hydraulic conductivity particularly in the subsoil.

Typical saline and sodic soils in the drylands have properties that vary substantially. The saline soils are characterized by high amounts of soluble salts. In this study area, the soils showed ECe values ranging from 4 to 45 dSm-1. The amount of salts varies with depth. Some of the soils have high salts content near the surface. This causes formation of whitish salt crusts and glazed polygonally shaped cracks. Sometimes, the surface consists of loose, powdery, fine-crumb or granular soil with salt crystals. Some of the saline soils have non-saline topsoils but have subsurface horizons within a depth of 1 meter which have ECe values of more than 4 dSm^{-1}. For these soils, the surface conditions are different, that is salt crystals are absent.

The saline – sodic soils are characterized by ECe values more than 4 dSm^{-1} in combination with ESP values of more than 15%. The amount of salinity and sodicity varies with depth. In some cases, the soils are saline and sodic from the surface downwards, while in other cases salinity and sodicity start in the subsoil.

Some of the saline – sodic soils have thin A-horizons and weakly differentiated E-horizons. In some cases the E-horizons are distinguished only by sporadic bleaching of the top part of the soil immediately above the B-horizon. The structure of the A-horizon (surface soil) is massive to weak, platy or blocky, whereas that of the B-horizons is prismatic, columnar or coarse blocky. The consistency is extremely hard when dry, firm when moist, sticky and plastic when wet.

The sodic soils have ESP values of more than 15% and ECe values less than 4 dSm^{-1} . They have structures similar to those of the saline-sodic soils. However, in some cases columnar or prismatic structures occur close to the surface. Sometimes the upper part of the columnar structure forms a hard pan. With increasing depth, the structure changes to angular or subangular blocky.

The study by D'costa and Wamicha (1997) in Bura irrigation scheme found that Solonetz occupied the highest lacustrine plain lying at 115 – 120m asl, Cambisols occurred on intermediate positions at 95 – 105m asl, Vertisols on low level lacustrine positions at altitude 85 –90m asl and Fluvisols on the flood plains at altitude 70 – 80m asl. Table 6 shows some chemical characteristics of these soils.

Table 6. Some chemical and physical characteristics of the Bura soils

Horizon	pH-H2O	ECe(dSm^{-1})	S	Si	C	TC	CEC	ESP	Position	Soil type
Topsoil	6.9	1.5	78	8	14	SL	49	5	Highest	
Subsoil	9.5	9.0	72	7	21	SCL	65	39	Level	Solonetz
Topsoil	7.1	1.1	38	36	26	L	46	4	Middle	
Subsoil	8.5	7.5	40	36	24	L	61	14	Level	Cambisols
Topsoil	8.5	1.5	16	14	70	C	56	5	Low	
Subsoil	9.1	12.3	13	12	75	C	63	9	Level	Vertisols
Topsoil	7.5	0.4	80	4	16	SL	56	2	Flood	
Subsoil	8.9	0. 8	74	18	8	SL	69	7	Plain	Fluvisols

In the above shown soils, there has been deteriorating soil physical and chemical conditions such as increasing salinity, sodicity and bulk density coupled with declining soil porosity together with the crop yields since 1987. These parameters also correlate with the amounts of ESP leading to the conclusion that increasing sodium content is a major cause of soil deterioration in ASAL. There is also a need to adapt soil management practices which ameliorate the adverse effect of sodium in the soils. These include addition of gypsum, deep soil drainage and mulching (table 7).

Table 6. Mean values of monitored topsoil soil characteristics in Hola irrigation scheme 1987 - 2002

Year	ECe (dSm^{-1})	ESP	Bd(gcm^{-3})	Porosity (%)	Soil classification
1987	1.4	10	1.2	53	
1992	1.8	10	1.3	50	
1996	2.1	16	1.3	49	
2002	4.4	24	1.3	48	Calcic Solonetz

In all cases the soils have pH- H2O (1:2.5 soil:water ratio) of more than 7.5. The pH-saturation extract is also in most cases more than 7 and less than 8.3. Sodium is the dominant cation in the saturation extract while chloride and sulphate ions are the dominant anions in saline soils and carbonates and bicarbonates in sodic soils. Soil texture varies from loamy sand to clay. Organic matter content is low as reflected by organic carbon less than 0.7%. The saline soils have moderate hydraulic conductivity, whereas the saline-sodic and sodic soils have moderately slow to slow conductivity.

These soils are generally dark coloured with colour hues of 5 to 10YR, values 3 to 5 and chromas from 0 to 4. Their topsoil structure is mainly fine angular blocks or crumbs due to exposure to extreme alternating wetting and drying conditions of the ASAL. The topsoils overlie subsoils with coarse prismatic or columnar structure. The textures are mainly clays in Vertisols and Solonchaks but the Solonetz have textures ranging from sandy clay loam to clay. Bulk densities range from 1.0 – 1.7gcm^{-3}. The 2:1 clays are dominant with some illite and traces of kaolinite. The 2:1 clays make the soils have high CEC of 20 – 60 cmol/Kg and calcium is the dominant cation ranging from 16 – 50 cmol/Kg. ESP increases with depth and ranges from 5 to more than 60. The soils have high salinity with EC and ECe ranging from 1 to 33 dS/m. The pH ranges from 7.5 in Vertisols to 11.0 in Solonetz.

These soils have low conductivity. This is due to the soil structure deterioration caused by the structure collapse as a result of low organic matter content and high ESP values. This impairs water movement in the soil causing impeded drainage conditions and reduction in oxygen and nitrogen. All these factors together with the flat topography make the soils difficult to drain both internally and externally. High salinity and pH causes nutrient imbalances. Also, high salinity limits the choice of the crops/plants.

Plant growth in saline soils is adversely affected by low soil-water availability because of the soil solution's high osmotic pressure. Toxic concentration of specific ions may also affect plant growth. Therefore, strongly saline soils have little vegetation cover and are subsequently susceptible to water erosion. Excess exchangeable sodium and high pH strongly influence the soil physical properties of saline – sodic soils. As the exchangeable sodium increases, soils become more dispersed and less permeable to air and water. Dispersion causes dense impermeable surface crusts that greatly reduce seedling emergence and water penetration. The reduced infiltration of water enhances soil erosion.

Excess exchangeable sodium and high pH also strongly influence the availability and transformation of essential plant nutrients. The amount of potassium in these soils are low compared to sodium, calcium and magnesium which indicates that there is likelihood of interference in nutrient uptake and plant metabolism. Toxic levels of sodium in some of these soils may also restrict penetration of plant roots.

The results of the monitoring of soil conditions and changes under irrigation for the four years at Hola and Bura West Irrigation Schemes revealed that:-

- The two soils monitored at Hola (Calcic Vertisols and Vertic Cambisols) and Bura (Calcic Vertisols and Calcaric Cambisols) behave differently under the same irrigation practices and management.
- Soil within the various irrigation subunits monitored are not homogeneous with respect to salinity and sodicity (table 6).
- Variations in crop performance occur in the different irrigation subunits due to variations in soil conditions such as salinity, sodicity, water infiltration rates, surface crusting etc.

In this study, although the quality of irrigation water and the crop varieties grown were found to have been suitable, they noted that there was lack of proper drainage to improve the saline conditions of the predominantly smectite clay soils. The soils were found to be sodic (Solonetz) or had sodic phase (Cambisols, Vertisols and Fluvisols).

The problems they suggested could be improved by deep tillage, properly spaced drainage ways, organic manures and gypsic amendments. These management specifications they noted, were not being followed due to high costs resulting in deterioration of soil physical conditions and poor crop yields of cotton, maize, rice, sugarcane, cow peas and ground nuts. They concluded that the irrigation scheme partly failed due to deteriorating soil conditions owing to lack of proper soil amendments.

The predictive models constructed on the basis of the results of four years soil conditions monitoring at Hola and Bura West Irrigation Schemes show that salinity will increase with time in all the four soils monitored (Muchena, 1987). However, in some of the soils a decrease in salinity is accompanied by an increase in pH which may probably lead to unfavourable soil properties and hence present problem in irrigation management of these study that the soil conditions monitoring be continued in order to validate the predictions of the model and at the same time arrive at firm conclusions as to what the long term effects of irrigation would be on these soils. Trial investigations on salt movement and possible corrective measures were also emphasized.

The results of land suitability evaluation for the various land utilisation types considered revealed that the bulk of soils in the three study areas are marginally suitable to not suitable for irrigated agriculture.

The major limiting factors were identified as salinity, sodicity, drainability, effective rooting depth and workability of the soils.

Low yields of maize at both Hola and Bura West Irrigation Schemes were attributed to the high levels of salinity and sodicity. The yields of cotton, which is more tolerant to higher levels of salinity and sodicity were slightly better. Production of yield levels for cotton at Bura West since 1962 were in the order 2,000 to 2,500 kg seed cotton per hectare (ha). In Hola, average cotton yields from 1962 to 1984 ranged from 775kg/ha in 1962 to a maximum of 3,181kg/ha in 1971. From 1968, there was a steady increase until 1977 when the yields declined sharply. Reduction in yields has been possibly due to water shortage, cultural practices, and soil conditions.

This indicated that irrigated agriculture in the study areas should be accompanied by a careful selection of crops and varieties that are tolerant to high levels of salinity and sodicity. However, the final decision on whether to implement irrigation schemes under such limiting soil conditions should be made after comprehensive socio-economic studies have been carried out (Muchena, 1987)

CASE STUDY3: Kwa Kyai and Mitunguu Irrigation Schemes, Eastern Province

Introduction

Makueni and Central Meru districts have a total area of 104,520 square kilometers and an estimated population of 1.3 million people. Both districts are characterized as ASAL agro-ecological zones but with varying potential for agricultural production. These districts have a bimodal rainfall pattern with the first season known as the long rains falling between March and May and the second season known as the short rains falling between October and December.

Agriculture, including livestock is a major economic activity in the study area with a predominance of smallholder farms.

A study by Freeman and Silim (2002) gives an overview of the two irrigation schemes in Makueni and Meru Central districts. The irrigated area in Makueni district is 1,866 hectares representing 0.3 percent of the cultivable area while in Meru Central the irrigated area is 4,078 hectares representing 2 percent of the total cultivable area. The production of horticultural crops is an important activity in both districts.

Trend in demand for smallholder irrigation

Irrigation in the Kibwezi division started in the 1950s with 40 hectares under Kwa Kyai irrigation scheme. Small pockets of farmers in the division also used bucket kits to irrigate kitchen gardens outside the scheme. Since then, smallholder irrigation has evolved involving irrigation groups and individual owners cultivating food crops, horticultural crops and other high-valued vegetables and fruits for domestic and export markets. The Kwa Kyai irrigation scheme was extended under the Makueni Smallholder Irrigation Program to 80 hectares in 1993.

Irrigation in Meru Central started in the 1930s during the colonial period. It took and upward trend in 1980s with the implementation of smallholder farmers involved in this scheme produce mainly high-valued horticultural crops for export. Since the start of this scheme several individual and group-based irrigation schemes have been developed. The most recent data available for Meru Central suggest that the number of irrigation projects increased from 131 in 1990 to the current estimate of 190 in year 2000, a 45 percent increase in 10 years.

Irrigation technologies

There were differences in the types of irrigation technology used in the two districts. In the Makueni district, motorized pump-fed furrow irrigation was dominant but a few farmers along the Kibwezi river use gravity-fed furrow irrigation. The Super Money Maker manual treadle pump introduced recently has not been widely adopted. A few large-scale farmers and institutional operators use drip and sprinkler irrigation systems. In the Meru Central district, sprinkler irrigation systems are dominant due mostly to the nature of the topography. Furrow irrigation where water flows by gravity is another irrigation technique. A few farmers use the bucket kit while some large-scale farmers use motorized pumps.

PACE OF SALINIZATION AND SODICATION

Very few studies have been carried out to determine the pace of salinisation and sodication in Kenya. As noted earlier, saline and sodic soils are predominantly naturally formed. This therefore means that these processes pedogenically are slow. However the processes are accelerated in irrigation schemes where the saline or sodic ground water rises due to mismanagement of irrigation water. However due to oceanic influence, areas along the coastal region of Kenya are susceptible to salinisation and sodication due to the influence of the Indian Ocean.
Therefore the pace of salinisation and sodication in Kenya could be expected to be very slow in the ASAL where slopes are greater than 16%, slow in areas with slopes 9 – 16%,

moderate in areas with slopes 5 – 8%, high in areas with slopes 2 – 5% and very high in areas with slopes less than 2%.
The pace of these processes will be governed by the quality of the irrigation water used, kind of land use, depth and quality of the underground water, and efficient use of the irrigation water among others.
Stein and Schulze (1978) noted that most irrigation schemes are abandoned in less than twenty years of operation due to soil salinisation and/or sodication problems.
As shown in case studies 1 and 2, these processes are evidenced in irrigation schemes in the ASAL areas of Kenya.

CONCLUSIONS

- Salinisation and sodification in Kenya are mainly naturally occurring processes However in the ASAL areas, the processes could be speeded by factors related to water management
- The extent and degree of salinization and sodification in the different agro-climatic zones of Kenya and their quantifiable effect on crop yields is not well documented
- The mitigation measures taken in the country against salinization and sodification are at their formative stages
- One of the major breakthroughs in Land Degradation studies in the country is the establishment of the National Environment Management Authority to ascertain that environmental impact assessment is carried out before any development project/program undertaken in the country
- Because of constraints of labour and money, salinization and sodification poses a serious negative economic impact to farmers in the ASAL

RECOMMENDATIONS

- Degree and extent of present and potential areas with saline and sodic soils need to be assessed in the different environmental conditions (ecotopes) with diverse systems of land use and management
- Data collection on the effect of salinization/sodification on production potential of land and the economic implications of the amelioration measures necessary; and to establish the relationship between salinization/sodification, cost of amelioration and crop yields
- Document methodologies and approaches that led to success in the experimental areas and identify problem are where these methodologies can be appropriately applied
- A study of the degree and necessary remedial measures of soil structure deterioration on irrigated saline and sodic soils is required.

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