ASSESSMENT OF ENVIRONMENTAL DEGRADATION IN NAKAMBALA MAZABUKA ZAMBIA

BY

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ABSTRACT

An environmental degradation assessment was carried out in Nakambala Estate, Mazabuka Zambia in October 1994 to June 1995. The objectives of the study were: (a) to assess the impact of the sugar plantation expansion on demographic change, natural vegetation and land resource degradation between 1970 and 1993; (b) to assess the soil physical and chemical status in cultivated and abandoned areas; and (c) to compare current soil physical and chemical status of the study area with the status when the sugar plantation was being established.

Sequential aerial photography was used in assessing sugar plantation expansion and its impact on natural vegetation and land resource degradation. The impact of the sugar plantation expansion on demographic changes and energy needs (fuelwood) was also assessed. A field soil survey was carried out to assess soil condition in terms of general fertility and selected land qualities and characteristics matched with the requirements of irrigated sugarcane using the FAO (1983) land suitability framework. Soil degradation assessment was carried out by using indices.

The results of the study were; the sugar plantation expanded by 7 035 ha between 1970 and 1991; human population increased by 4 929 (at 4% per annum) and projected to reach 22 127 by the year 2 000. Natural vegetation was reduced by 25 % due to sugar plantation expansion aggravating the fuelwood deficit situation (5 447 m^3/year in 1970 and 4 906 m^3/year in 1991). There was no visible evidence of soil erosion although waterlogging was the prevalent form of land degradation in all the mapping units. The soils are generally eutric (base saturation > 50%) with slight acidic to neutral reaction in cultivated fields (in mapping units; 2W, 10, 11 and 12) to slightly alkaline reaction in areas with abandoned fields (soil mapping unit 13). High soil bulk densities occur in soil mapping unit 2W due to compaction by heavy machinery and due to inherent nature of the soils in mapping units 10, 11, 12 and 13 (heavy clays). Oxygen inavailability (due to poor drainage), physical degradation and poor rooting conditions (due to shallow effective soil depth) are the most limiting conditions for sugarcane growing. Over time, noticeable changes in chemical status (sodication) was low in all the mapping units except in unit 10 where sodication development was noticed. Adverse soil physical changes (crusting and surface sealing) occurred in soil mapping units 11, 12 and 13.

To stem environmental degradation in the form of deforestation, energy utilization from fuelwood should be reduced by electrifying township housing units. The continued use of vetiva grass for drain protection is advised. Alternative land uses in soil mapping units 11, 12 and 13 and complete abandonment of monocropping practices in these soils is strongly recommended.

DECLARATION

I, MELLON HALUBANJE CHINJILA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work, and has not been submitted for a degree in any other university.

Date....21.11.96.......... Signature....Chinjila..

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DEDICATION

This work is dedicated to my friends and relatives.

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1.0 INTRODUCTION

Agricultural development has a very vast potential in Zambia. With only 5% of the 24 million ha of land being cultivated, the Government is keen to encourage agricultural development (Aked, 1994).

The national economy has been dependent on one finite commodity, namely copper, for too long. It has therefore become prudent to the Government to shift the emphasis from mining to agriculture (GRZ/IUCN, 1985). The importance of agriculture on a global scale cannot be ignored. It is the largest employer of human labour and it provides many raw materials. However, limits to agricultural production are set by soil and climatic conditions and the use and management of the land. In the long term 'mining' of the land beyond these limits results in decreased productivity indicating that land resources and their production potential are not static (Dudal, 1982).

The development of agriculture, especially irrigated agriculture, should be approached cautiously since it is a natural resource dependent industry. Its survival can only be assured if the natural resource base on which it is heavily dependent is sustained. The sustenance of the agricultural resource base depends on the appropriateness, responsiveness and effectiveness of the policies that affect land resource allocation, utilization and management (Brundtland, 1987).

The knowledge of the type, location and quality of resources and how these are utilised is a pre-requesite to successful resource development and conservation. It is therefore, imperative to have inventories of past, present and future land use of an area. In this regard, both the resource and activity must be monitored if they are to be maintained in a productive state on a sustainable basis (Van Riet and Cooks, 1988).

All land in Zambia is vested in the President and allocated on a leasehold basis (Aked, 1994). The three land tenure categories viz. State land, Trust land and Reserve land are currently under revision. Since colonial times, the Southern Province (Fig. 1) has been carved into well defined areas under State land, Trust land and Reserve land. Due to the extent of State land area in the province, some areas have suffered overcrowding and overstocking with cattle. Worse still, some of the overcrowding took place on hilly areas or on wet areas threatening land resources. One district that

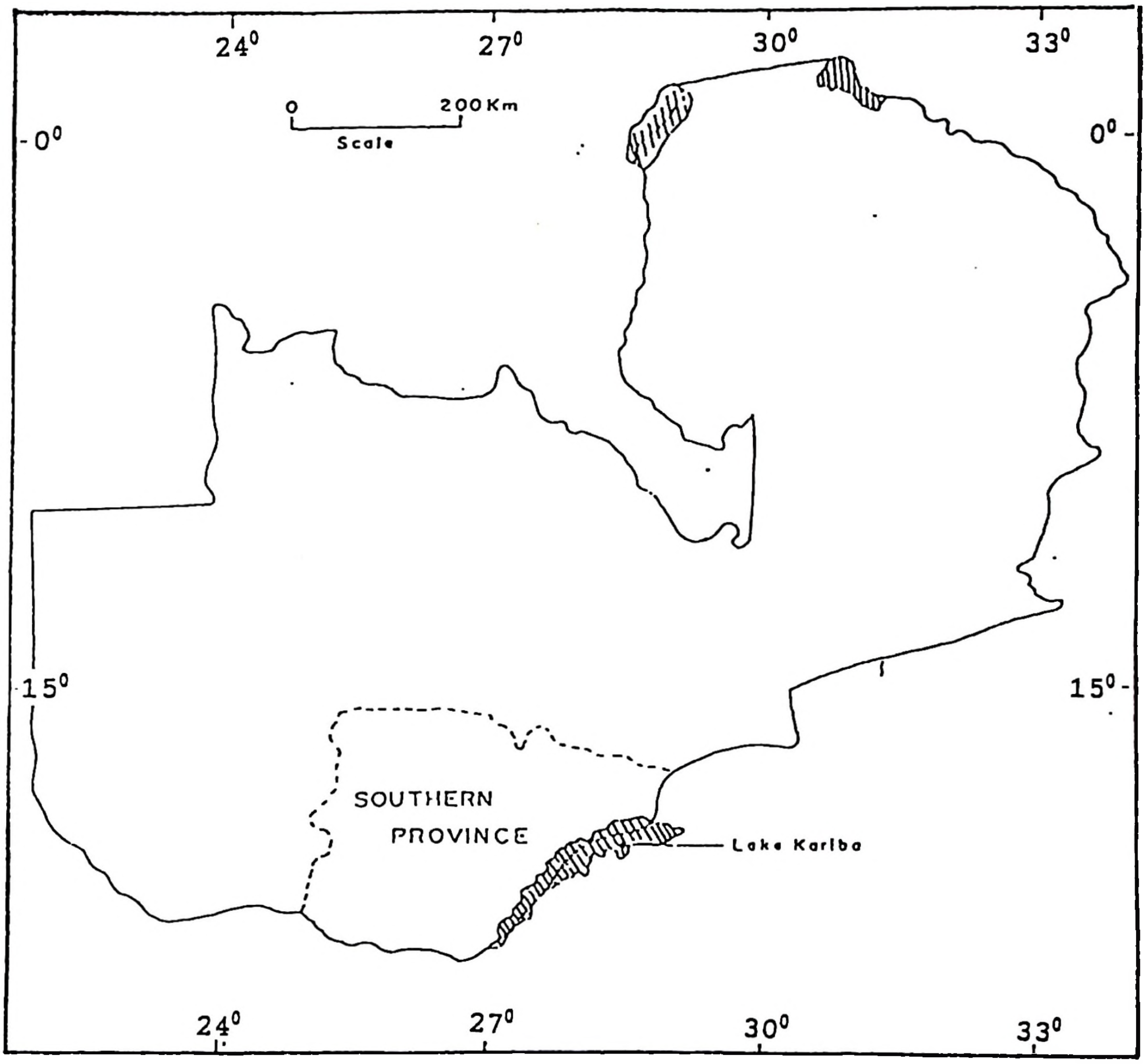


Fig. 1. Location of Southern Province in Zambia.
(Mulongo, 1993)

suffered much in this regard, is Mazabuka when the Nakambala Sugar Estate (Fig. 2) was established (McDonnell, 1975).

The many factors that would seem to favour irrigation development for sugarcane growing in Mazabuka were high degree of flatness of the land to the north near Kafue river with dominantly grassland vegetation reducing bush clearance costs, favourable location with respect to transport network and main population concentrations in the country. There was also the possibility for extension into areas with good soils and above all, there was abundant water for irrigation from the nearby Kafue river (Van Haastrecht, 1975; Williams *et al.*, 1977).

The development of commercial irrigated agriculture in the lower Kafue Basin at Nakambala can be justified from an economic point of view. The current production level of well above 100 000 Mg puts the country at the fifth production position in the continent (Simpson 1993; Zambia Sugar Company 1993). Production levels still remain encouragingly high. In 1994, the production was 135 548 Mega grammes of sugar, of which 57 503 Mg were exported earning US$ 19 million (Simpson, 1993).

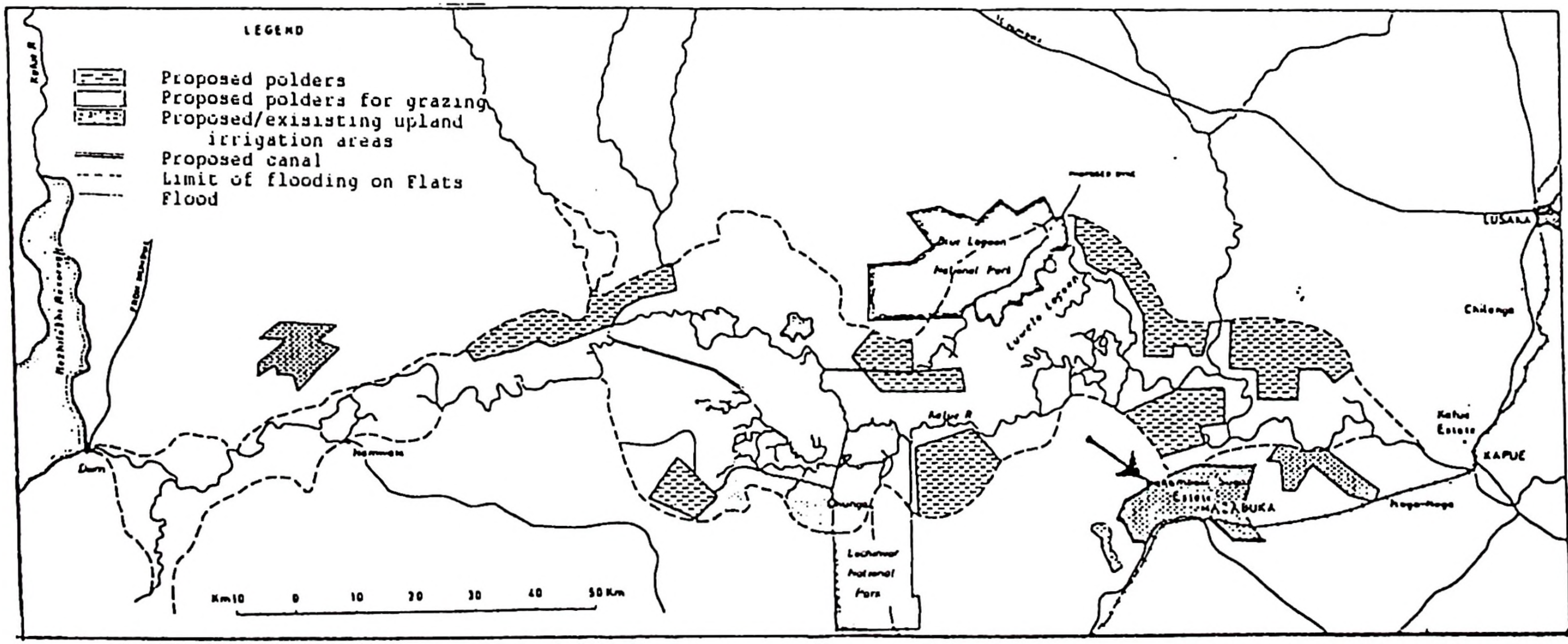


Fig. 2. Location of Nakambala in the Lower Kafue Basin.

(Williams and Howard, 1977)

The development of such a scheme however, has major implications for future generations. The problem is not that it could be uneconomical in terms of rates of return, but rather that such installations fall far short of realizing their full potential in terms of society equity and environmental management aspects by restricting the involvement of local people (except as passive recipients in the development process) and by over emphasising water resource development as opposed to the integrated development of water, land and human resources (Scudder, 1977). Another problem that arises is that delayed timing in the research related to resources other than that directly needed in the project implementation could lead to over-exploitation and subsequent degradation of the resource.

Nakambala Sugar Estate was developed in a district that was already faced with serious land shortages, especially among the indigenous population. It also falls within the Lusaka urban fringe and industrial areas of Kafue with rapid urbanisation and unplanned urban settlements servicing the industries. With rapid localised population growth, it is essential to identify, assess and report on risks of irreversible damage to natural systems and threats to the survival and well-being of the community (Brundtland, 1987).

Among the major resources available to man whose use should not cause degradation because his existence depends on their continued productivity, is land. Environmental degradation assessment, especially prior to project implementation, plays an important role in planning the use and conservation of the local resources for the present and future generation. While the forms of land degradation could be well known, especially erosion and salinization, there are only very general estimates of the extent of areas affected, of the rate of degradation and the losses of productivity which occur (Dudal, 1982).

Zambia is faced with many environmental problems as a result of rapid population growth and urbanisation. These lead to over-exploitation of natural resources and social services especially, in localised overpopulated areas. To sustainably continue utilizing Nakambala for sugarcane production merits considerable thought and analysis. The Estate lies astride the Kafue Basin (an area of intense interest because of its resources: water, copper ore, vegetation, wild animals and fish) and the southern plateau (a highly productive grain belt in the country) making it a scheme of great economic importance to the country. This is an ambitious scheme, though very little is known about the current status of land resources and the impact on the ecology due to plantation extension and corresponding localised overpopulation. It is against this background that this research was initiated.

The main objective of the study was to assess the type and extent of land resource degradation within the sugar plantation and the resultant impact due to plantation expansion.

The specific objectives of the study were:-

(a) To assess the impact of sugar plantation expansion on: demographic change, natural vegetation and other phenomena in the surrounding area between 1970 and 1993;

(b) To determine the current soil physical and chemical status in currently cultivated fields and abandoned areas;

(c) To compare current soil physical and chemical status in cultivated and abandoned areas with the status when the estate was being established.

2.0 LITERATURE REVIEW

Resource degradation is a process or state where the productive potential or capacity of a resource is lowered (Blaikie and Brookfield, 1987). Environmental degradation assessment seeks to identify the existing and potential consequences of a project and their impact on people, physical environment and economy.

Soil degradation refers to the loss of soil productivity capability as a result of one or more processes that cause deterioration in soil condition. Thus, it refers to the physical, chemical and biological soil deterioration. Soil physical degradation includes: crusting, deterioration of structure, reduced porosity, compaction and reduced hydraulic conductivity. The diagnostic characteristics include; bulk density and infiltration capacity. Chemical degradation refers to adverse changes in soil chemical properties that could lead to acidification, salinization and sodication. Biological degradation refers to decline in organic matter content of the soil (Dudal, 1982).

Methods that can be used to evaluate soil degradation include; direct observations and measurements, use of remote sensing techniques, mathematical models and assessment by parametric methods or use of fertility indices and land evaluation system (Dudal, 1982; Mukanda *et al.*, 1983; Landon, 1991).

Literature on land use studies and environmental change is scarce in Zambia (Mbewe, 1987). Most of the earlier studies in Zambia did not address the issues of land use, population and resource availability and the resultant resource degradation in localised overpopulated areas (Chidumayo, 1987). However, with the setting up of the Environmental Council of Zambia in 1990, environmental awareness has improved and this study will contribute the necessary information about the sugar plantation at Nakambala.

Van Haastrecht (1975) examined the relationship between the new sugar industry at Nakambala and other economic activities and their impact on the surroundings of Mazabuka, as an agricultural centre and the influence it had on the service apparatus of the town. Changes in land use, demographic information, estate production records, income levels and other economic indicators were used. He concluded that the industry had brought financial and employment benefits to the area. However, he could not quantify the big ecological changes over an area of 9 000 ha, that had occurred during the various stages of industrial expansion. This study will attempt to bring to the fore the ecological changes that have taken place.

Msoni *et al.* (1992) conducted a soil survey on 3% of the total land under sugarcane at Nakambala. They observed that sites with high electrical conductivity values corresponded to portions where sugarcane growth was stunted. They further conducted a land evaluation for alternative crops. At high input levels, as practised in sugarcane production, paddy rice was very suitable in some mapping units followed by soyabean and maize. This study will provide more information as a basis for future work that could eventually cover the whole sugar plantation.

Daka (1988) investigated the performance of irrigated sugarcane in montmorillonitic soils at Nakambala. He addressed the compatibility of irrigation water to the soils under sugarcane so as to find the most appropriate method of irrigation that would improve the severely impeded drainage, a subsequent cause of serious crop failure. He observed that low application rates of water using sprinkler promotes swelling and closing of cracks in heavy clays and thus the subsoil remains unwetted reducing crop growth. Furrow irrigation with high intake rates quickly fill the cracks up to root zone before swelling occurs, thus promoting good crop growth. He recommended special management practices with improved drainage to realise high yields of sugarcane under irrigation in this soil type, without looking at alternative land uses, hence the need for this study.

Chidumayo (1987) investigated and reviewed the status of the "Chitemene" system of shifting cultivation as a form of land use in northern Zambia. He observed that population increase caused deforestation and resultant reduction in (a) length of fallow period from 25 years to 12 years (b) the per capita woodland requirement from 1.1 ha to 0.53 ha. He further observed that diminishing wood resources resulted in an increase in carrying capacity (maximum number of people that the surviving forest areas could support) of forest areas from 2.4 persons/km^2 to 18.7 persons/km^2. This study will contribute further information on the issues of land use, population and wood resource availability in a permanently cultivated area.

Mulongo (1993) used aerial photographs, land use records and demographic information to assess the rate of land resource exploitation and the implications of the existing land policy in the reserve lands of Mboole-Muyonzo traditional land in Zambia. He observed that due to uncoordinated nature of resource utilization and localised population pressure, resource degradation in terms of forest depletion associated with bush clearing for cultivation (even on hilly terrain) had increased. This exposed the land to climatic assault, posing a serious danger of declining on soil productivity. A study to assess resource degradation in a highly commercialised agricultural area was necessary in order to check whether similar factors were at play.

In an updated regional assessment on desertification in Southern Africa, Darkoh (1989) noted that in Zambia soil erosion, desertification and drought were the triad of major environmental problems facing the country. Firewood collection, charcoal production, logging operations, open-pit mining, overstocking and overgrazing in drier portions of the country were responsible for land resource degradation. Despite her small population, Zambia is among the fastest urbanizing countries on the continent. Therefore, the spatial effect of urban demand for fuelwood is having on deforestation, cannot be ignored, necessitating carrying out site specific studies such as this one.

Williams *et al*. (1977) conducted development and ecological studies in the 1970s to assess the potential of water uses in the Kafue flats and its sustainability for hydroelectric and irrigated agricultural development. They found out that some consultants were dubious about the suitability of the soils in some areas. High capital, mechanised cultivation, heavy use of fertilizers and skilled manpower were required in order to get good production results, hence carrying out studies such as this one, could help eliminate these doubts.

Prescott (1972) used photography and field survey to examine the extent and consequences of overpopulation and overstocking in Native areas of Matebeleland in Zimbabwe. He found out that land alienation was the cause of human population and livestock congestion. Soil erosion around settlements, on stream banks and on grazing land was observed. The increase in human and livestock populations led to reduced available land per household and complete vegetation removal, respectively. The study was biased in that no reference was made to soil erosion and vegetation patterns in low density and highly commercialised agricultural land in Matebeleland.

Mpofu (1990) used aerial photographs to analyze the extent of cultivated land to assess the rate of deforestation in the Save Catchment area of Zimbabwe. The aim of the study was to assess the basic needs and the environment of the communal areas by looking at the interplay of social and political factors in land apportionment. He found out that white farming communities had more land per household and had more favourable credit and infrastructure provisions than black communities. The colonial land apportionment concentrated the majority rural black population in marginal areas with poor soils, low rainfall and reduced overall agricultural potential, threatening the sustainable use of natural resources in the catchment area. However, the study could not address the long term effects of agricultural activities on commercial farms on soil and wood resources.

Keech (1969) used sequential aerial photography and survey to analyze the changes in gully density in relation to changing agricultural practices and increased population pressure in the Mhondoro Tribal Trust land in Zimbabwe. He concluded that gully density increased with increase in human population. Chaibva (1994) attributed this resource degradation to resettling people without conducting a proper environmental impact assessment, hence the need to carry out such assessments even in commercial agricultural areas.

Kaale (1994) reviewed the efforts regarding the production of biomass fuels on a sustainable basis in the Southern African Development Community (SADC) and noted that although biomass fuels were a major source of energy for most rural and low income people in the developing world, the potential supply of fuelwood was dwindling rapidly. Fuel scarcity was causing more stress on women and children who had to spend more time collecting firewood. Agricultural production was dropping due to organic matter removal as a result of deforestation. He concluded that despite a few successful examples like tree planting programmes in Zambia management of natural woodlands and forests through traditional laws and beliefs and although fuel scarcity was site specific, it was rapidly covering more areas and affecting more people. And its commercialization, especially around urban areas, would compound the problem further, hence the need to carry out site specific studies.

Proctor (1990) used aerial photographs, census information, field environmental assessment and household survey to assess the future human and environmental crisis in Southern Swaziland, that could be caused by human growth beyond resource limits. He analyzed: population changes from 1966, 1976 and 1986, nation wide agricultural census in 1983 and

1984, land use and settlement patterns in the study area, land degradation in terms of linear valley-side gullying and used the US Soil Conservation Service land capability classification of arable land classes to classify the land units in the study area. The objective was to predict whether in AD 2 000, there would be adequate cropland, grazing land and fuelwood reserves in the study area. He observed some changes in woodland, land use and settlement patterns and concluded that; minimal constraints for fuelwood supply; extreme shortage of grazing land and unequal cropland allocation would occur in the study area. He however, could not link fuelwood supply to population growth over the study period, hence the need for this study.

Katerere (1994) studied the woodland resources in Southern Africa. He found out that about 70% of the population in the region lived in rural areas on land that is mainly communally owned and is directly dependent on biomass-based economy. Woodland and forest resources were under threat from clearing for agricultural land and from demand for other products such as; grazing, construction materials, food and fuelwood, to cater for an ever growing population. In addition to the needs of local communities, the forests and woodlands had to cater for national, regional and international biological, ecological, economic and cultural demands from an ever dwindling resource base. Such diverse demands need to be managed while enhancing the productivity of these areas. Despite the increase in population dependent on woodland resources, the extent of woodland utilization and productivity are not well understood and neglected in some cases, he concluded. This study will contribute site specific information on the effect of horizontal agricultural expansion on population, soil and woodland utilization and productivity.

Wiersum *et al.* (1985) reviewed the development of ecological methods of upland farming in west Usambara mountains in Tanzania. The study looked at changes in traditional agriculture from shifting cultivation to semi-permanent to permanent cultivation and the adaptation of different farming techniques. The Lushoto Integrated Development Project (LIDEP), initiated in 1964, placed emphasis on vegetable growing since this activity was suitable to the area and could be carried out throughout the year at a profit, therefore, improving the health and nutritional status of the indigenous population. However, the high input technology introduced by the project and its subsequent phases, was unsuitable in that it replaced the indigenous multiplecropping and crop rotation practices that ensured ecological stability. The study concluded that this problem was compounded by increase in human and livestock populations in the subsequent years that put more pressure on land resources for cultivation, grazing and wood for fuel. It was recommended that necessary, simple and practical enough (easy to apply) management techniques be introduced to maintain the ecological stability. This study will address the impact of permanent and highly commercialised cultivation in low lands on population, woodland and soil resources.

Holmgren *et al*. (1994) surveyed woody biomass on farmland on 10 million ha of high potential land in Kenya using aerial photographs and field measurements. The objectives of the survey were to estimate standing volumes, species distribution and potential future of the woody biomass outside actual forests and to assess the present annual change rate for this biomass in the face of a staggering population increase of over 3% annually. Rapid increase in planted woody biomass with annual increase estimated at 4% was discovered between 1986 and 1992. The study concluded that instead of increasing fuelwood deficit and land degradation following rapid population growth, Kenyan farmers seem to apply wise and sustainable management practices including tree growing. The land tenure system (smallholder private ownership) was a significant reason for the development. The study however, left out highly commercialised areas in which the trend could be different.

Mengistu (1994) analyzed the environmental degradation along the Blue Nile river basin as a result of water resource exploitation through modern irrigation systems and dams in Egypt and the Sudan. He observed that environmental stress was caused by the ten ethnic groups living along the basin outside the irrigation schemes, who are pastoralists who slash, burn and plough in order to produce two crops and to conduct perennial cropping. He also observed that due to population concentration in marginal areas, soil degradation was on the increase leading to changes in vegetation patterns. He warned that if the environmental degradation continued, it would lead to severe land degradation, drought, unexpected heavy floods and low agricultural productivity. The study however, left out the environmental status and impact of the irrigation schemes on population, land resources and forest within the schemes, hence the need for further studies.

Borget (1985) investigated the transformation of traditional agriculture after an unsuccessful large scale operation for mechanised groundnut cultivation in the forest zones of C.G.O.T (*Comagnie generale des Oleagineux tropicaux*) sector in the Casamance province of Senegal from 1948 to 1982. He studied the different forest types and the changes in land use type and the consequences of those changes. The traditional agriculture was garden cultivation of fruits and vegetables. Field cultivation included millet, groundnuts, sorghum and rice in wetter parts. The forest soils had more satisfactory physical and chemical conditions, but deforestation degraded the soil considerably forcing millet growing towards the forest edges. The results of soil degradation were increased soil erosion, poor soil chemical fertility, including exchangeable potassium that was deficient in groundnuts, the crop targeted for production in the directed sector. He also observed that despite the keen interest and subsequent involvement of several bodies including the World Bank, ecological degradation occurred and stabilization of the original shifting cultivation in the sector was late and partial as immigrants from other zones took up salaried work leading to rural development, a by-product not accounted for at project inception. He had no final conclusion since traditional agriculture had also evolved in line with what had been occurring in the directed sector, hence the need for a sector and site specific study for such schemes.

The International Union for Conservation of Nature and Natural Resources (IUCN) (1986) analyzed the nature, processes and causes of environmental deterioration in the Sahel region and other drought affected regions of Africa. The study looked at desertification causes, drought and natural processes of environmental degradation such as successional changes within ecosystems from grassland to shrubland thicket depending upon the desired product of the land in question. The role of man in the modification of environmental ecosystems through such activities as bush fires, trade, site selection for settlements, agricultural expansion, wetland and river impoundment and livestock rearing were looked at too. The study attributed the accelerated environmental degradation to man's activities such as poor selection of settlement sites in fragile ecosystems, extensive land clearing for agricultural expansion and fuelwood needs, unchecked livestock increase and human population growth (estimated at 7% in urban areas alone). The symptoms and results of land degradation were; famine, malnutrition and food insecurity. Since the Sahel is characterised by rising pressure of demand on declining resource base as a result of some of the mentioned factors and unfavourable rainfall and changes in land use and management patterns as well as in the political economy of production, the study recommended introducing good land use and management schemes so as to stem the resource degradation. This could bring some mixed benefits as already experienced in some parts of the region where the recommendations have taken root. In conclusion, the study stated that since food security rested on the elimination of poverty and on the restoration of environmental productivity, including the rich World emergency food resources which are rapidly disappearing, it was prudent upon governments and many agencies such as the World Bank and the FAO, to provide significant assistance for agricultural rehabilitation and sectoral support across the region and the continent. A good approach would be through a local study that could address easy to solve local problems than regional and continental problems.

Gijsbers *et al.* (1994) used aerial photograph interpretation, vegetation surveys and interviews to study the parkland degradation in the Sahel region of Burkina Faso, province of Passore. They observed that on the village territory, the density of large trees had decreased between 1957 and 1988 and the greatest decrease was on steep slopes. Although it was not possible to determine the proportions of decrease in large trees due to clearing for cropping, a general decrease in density was observed. This study will provided further information on soil status from current land use practices that could form a basis for soil data compilation about the sugar plantation.

Kapsoba (1994) in a critical review of Africa's current food crisis pointed out that among factors that have contributed to the food crisis are; (a) high population growth rate, (b) environmental degradation due to drought and deforestation, (c) slow rate of arable land development, (d) political instability and (e) unfavourable international economic environment. Population growth aggravated the food security situation by straining heavily available per capita food supplies, while causing increasing damage to the environment. Increased population and livestock densities threaten the delicate balance between land and people. Marginal land is being farmed and fallow periods reduce as population grows. He also pointed out that clearing land for cultivation without proper soil management practices and land and water conservation measures has accelerated land degradation by erosion and loss of soil fertility. Overgrazing and drought were other factors that contributed to the degradation of the environment by speeding up desertification, mostly in areas with high population density, fragile land and low rainfall. To further understand the relationship between land use and population to environmental degradation, local and site specific studies should be conducted.

Darkoh (1994) reviewed the causes and extent of desertification and land degradation in Africa. He pointed out that rapidly growing poor rural populations were increasingly forced by circumstances to degrade the environment by farming in poorer lands where returns per ha are low. Rangeland degradation took place although herds rarely reached carrying capacity during drought. Forest degradation as a result of the ever rising fuelwood demand was quite serious especially near urban centres. Except in highly populated rural areas like the Ethiopian highlands and some parts of central Tanzania, little evidence existed to suggest that rural household energy consumption was responsible for large scale deforestation. In the light of available data that showed that out of 90.22 million ha of agricultural land (irrigated and rainfed), 50.86 million ha was degraded, he recommended sustainable natural resource management through policy-oriented research and development options to ameliorate and/or reduce land degradation. This study augur well with the recommendation.

Clausen (1984) studied the relationship of traditional farming in the maintenance of soil productivity and forest cover against a background of relatively stable population. He observed that in many parts of Africa, this balance has been upset by rapid population growth and rising demand for food crops and fuelwood, particularly from urban areas. In many countries, forest cover was being irretrievably damaged with serious consequences for household fuel supplies, soil fertility and water supply. He also observed that fuelwood consumption exceeded the growth of new trees by a factor of ten in Mauritania and Rwanda, by five in Kenya and by two and half in Ethiopia, Nigeria and Tanzania. He concluded that in the face of recent droughts that had underlined the seriousness of soil erosion, deforestation and fuelwood shortages, Governments had to place community based activities to heighten awareness of the costs and dangers of deforestation and its connection with other matters of community concern such as soil protection, food supply, livestock management and land use. Carrying out environmental impact assessment studies, could provide a basis for improved community awareness of the consequencies of over exploitation of land and forest resources.

Kummer (1992) examined deforestation and its relationship to the spread of agriculture in the uplands of the Philippines between 1948 and 1980. He took the common view that population pressure, expansion of small-scale agriculture and shifting cultivation are the common causes of deforestation. Deforestation was defined, in this case, as the complete removal of forest cover followed by an alternative form of land use. He found out that deforestation was a two step process in which logging converted primary forest to a degraded secondary forest and small-scale agriculturalists converted the secondary forest to farm land and that population pressure was not a major proximate cause of deforestation. He concluded that deforestation and the spread of subsistence agriculture were both reflections of failure of development in the Philippines over the years to raise the living standards for the majority of Filipinos. The link between commercial agriculture to population pressure and deforestation was not included in the study, hence the need for further work.

Schreier *et al.* (1994) used information from aerial photographs, topographic maps and historic evaluation of land use dynamics to examine resource status in the Himalayan Nepal watershed using a Geographical Information System (GIS). All data generated from aerial photographs and maps was digitized and detailed field verification conducted in 1990. In addition, soils, forests, cropping systems and socio-economic resources were evaluated. He found out that during the 1947 to 1990 period, forest, shrubs and agriculture were the only land uses. He concluded that deforestation was significant during that period. During the 1972 to 1990 period, land use classes changed: forests increased by 10%, shrubs decreased by 6%, arable agriculture increased by 6% and grazing land reduced by 9%. He concluded that forest degradation was most critical in the middle mountains of Nepal and that a GIS and Aerial Photograph Interpretation based on resource evaluation was possible to use in identifying causes and consequences of afforestation and increased agricultural expansion by comparing the forest and agricultural land expansions and grazing land losses in relation to slopes and elevation. A study of the causes and consequencies of agricultural land expansion in low lying areas would be required for comparison.

Young (1991) examined and reviewed the adoption of new high-yielding cereal crops and Government policy towards other cash crops that could have adverse environmental effects in Bhutan. This was done against the common belief that in Bhutan, deforestation and environmental disturbances were modest or insignificant. He concluded that the pressure to transform traditional agriculture by the introduction of commercial crops such as cardamom, land clearance (90% for cardamom) and pressure for fuelwood (for treating cardamom capsules) could be environmentally destructive. Although other researchers demanded rigorous factual substantiation before assuming environmental cause, there was *prime facie* evidence for concern about the disturbances created by the agricultural development process in Bhutan. An environmental information system was recommended to monitor the effects of change at village and household level.

Garcia-Ruz *et al.* (1994) used geomorphic transects, experimental plots of different sizes, chemical and physical soil analysis and rainfall simulation to assess soil erosion and desertification as a consequence of farmland abandonment in the domaine of southern Pyrenean Flysch in Spain. Desertification in this case was used to explain land degradation in arid and semi-arid areas. During the 10th through to the 19th century, due to increased rural population, cultivation of cereals even on steep slopes had taken place. However, throughout the 20th century most fields were abandoned due to a decrease in rural population. After several years many fields showed evidence of degradation. Questions that arose were: Was soil degradation a natural or man-induced evolution on sloping fields in the temperate mountain areas; What was the role of land users? A quick overview showed that different erosion processes progressively substituted in time: severe sheet erosion, mild sheet erosion to a stable situation as shrubs developed. The only explanation for soil deterioration and intensive soil erosion was a break in plant succession due to human activities or due to natural factors such as senescence of the shrubs cover, unable to advance to maturity stages due to poor soil nutrient status. The study concluded that cereal crops on steep slopes accelerated runoff and sediment load as a consequence of high proportion of bare soil immediately after cropping and during first few years of farmland abandonment. The erosive effects of farmland abandonment however, depended upon soil characteristics and land management after abandonment. Further studies were necessary in low lying areas, where cultivation and population patterns could have been different, in order to assess the link between land use, soil degradation and population.

Crosson and Anderson (1993) reviewed the evidence of land degradation around the World. They noted that identifying natural resources and environmental consequences was relatively easy, but measuring the consequences was not. They observed that no Least Developed Country (LDC) had comprehensive data indicating either the extent of presently degraded soils or the rates of degradation from current land use practices. Cleared land (ha) in irrigated areas, could easily be measured although the environmental consequences resulting in loss of plant and animal habitat could be difficult to quantify through measurements. This study seek to provide information on the extent of presently degraded soils and rate of soil degradation from sugarcane production in Nakambala.

3.0 BACKGROUND INFORMATION TO THE STUDY AREA

3.1. Location, Extent and Brief History of the Study Area

The Nakambala Sugar Estate lies between latitudes 15°50'S and 15°53'S and longitudes 27°40'E and 27°48'E (Fig. 3), in Mazabuka district of the Southern Province of Zambia. It covers over 13 000 ha and encompasses almost the whole of Mazabuka town. The south-west and western boundaries of the estate are the railway line and road to Livingstone and the Kaleya river, respectively. The Central Research Station, Mazabuka town and the railway line to Kafue town form the south and south-east boundary although a small strip of the sugar estate extends across the railway into bordering Mweemba, Lishimba and Cantley farms. The Mazabuka river and Marshall farm form the eastern boundary while the whole northern section is bordered by the Kafue Flats (Fig. 4).

The study area was chosen because:-

- No study of this nature has been carried in the area on the effect of horizontal agricultural expansion of this scale;
- The sugar estate is the largest single agricultural employer in the district;

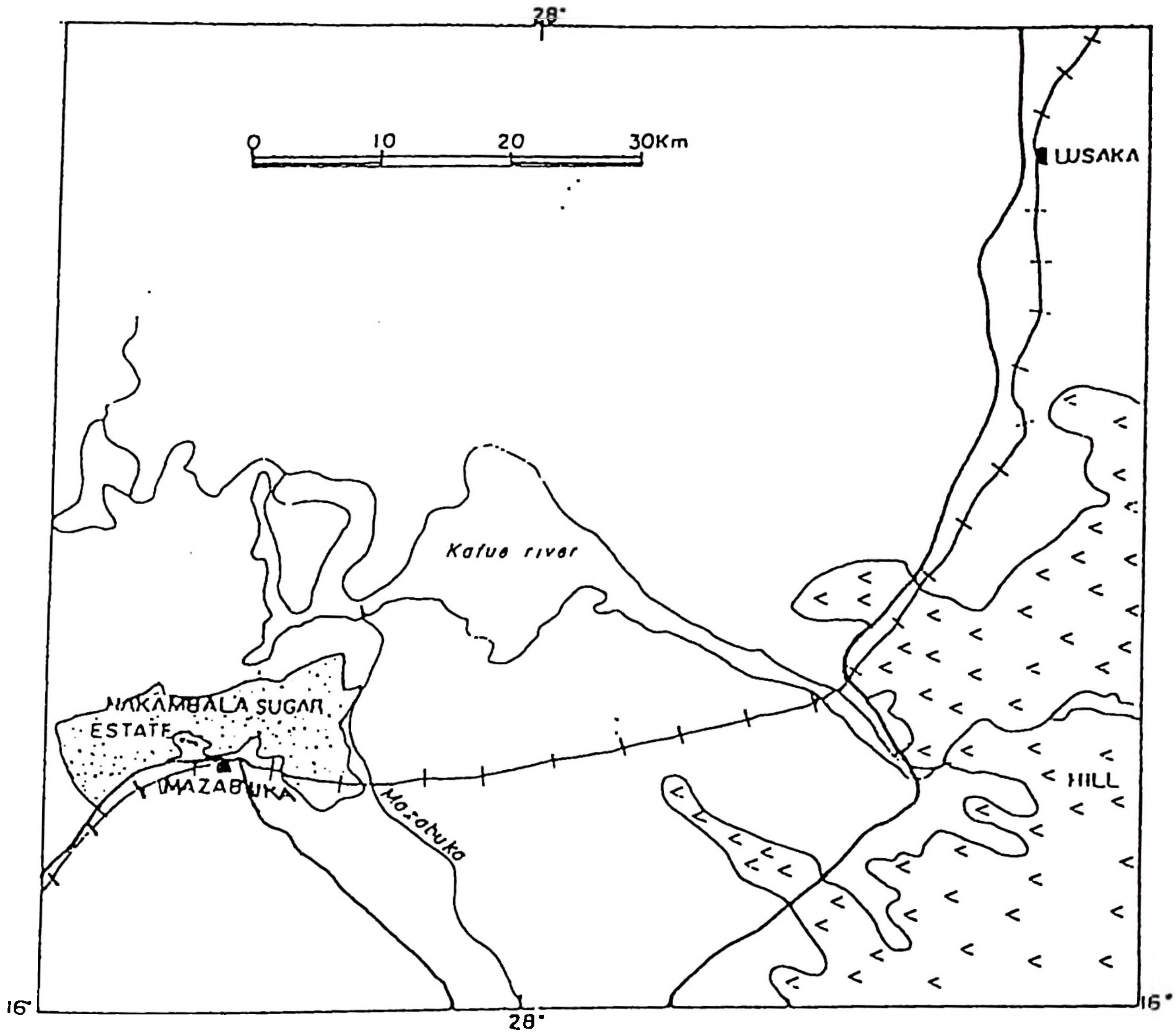


Fig. 3. Location map of Nakambala Sugar Estate. (Msoni and Mulenga, 1992)

- The area lies astride the Kafue flats (an area of intense national interest due to, water, copper ore and vegetation resources.

In 1962, many white commercial farmers left the country due to political changes. Around Mazabuka, once an area selected to resettle demobilized officers from the First World War, many farmers left, among them Duploy, Van Wijk and Arrison who had land in the area which is now Nakambala. The alienation of almost all land around Mazabuka town as early as 1924 created land shortages for the indigenous population pressing the concentration in a rim about the escarpment hills, wetland and small corridors on the fringes of stateland.

Nakambala Sugar Estate was started in 1964 replacing the sugar estate in Chirundu. Mazabuka was chosen as the site for the industry because of good soils, abundance of irrigation water and access to the good railway and road network leading to population centres. The prospects of extensions were quite bright till 1992 when the last 360 ha was acquired from the Central Research Station.

The displaced peasant farmers had to either migrate or seek employment at the new industry. Initially, the industry had the capacity to provide accommodation for all its employees. With rapid increase in population however, services were getting inadequate leading to unplanned settlements within the sugar estate and in Mazabuka town.

3.2. Geology, Geomorphology and Drainage

The area is a typical part of the Kafue fringe with long and gentle to very gentle slopes rising above the Kafue valley floor with scattered ridges and rock outcrops in some areas. Elevation varies from 1 000 m to 1 048 m above mean sea level (a.m.s.l).

The estate is drained by the tributaries of the Kafue river namely, Kaleya, Nakambala and Mazabuka rivers and minor inter dambos and field drains. Underground drainage is influenced by the Kafue flats and the Kafue river (Fig. 4).

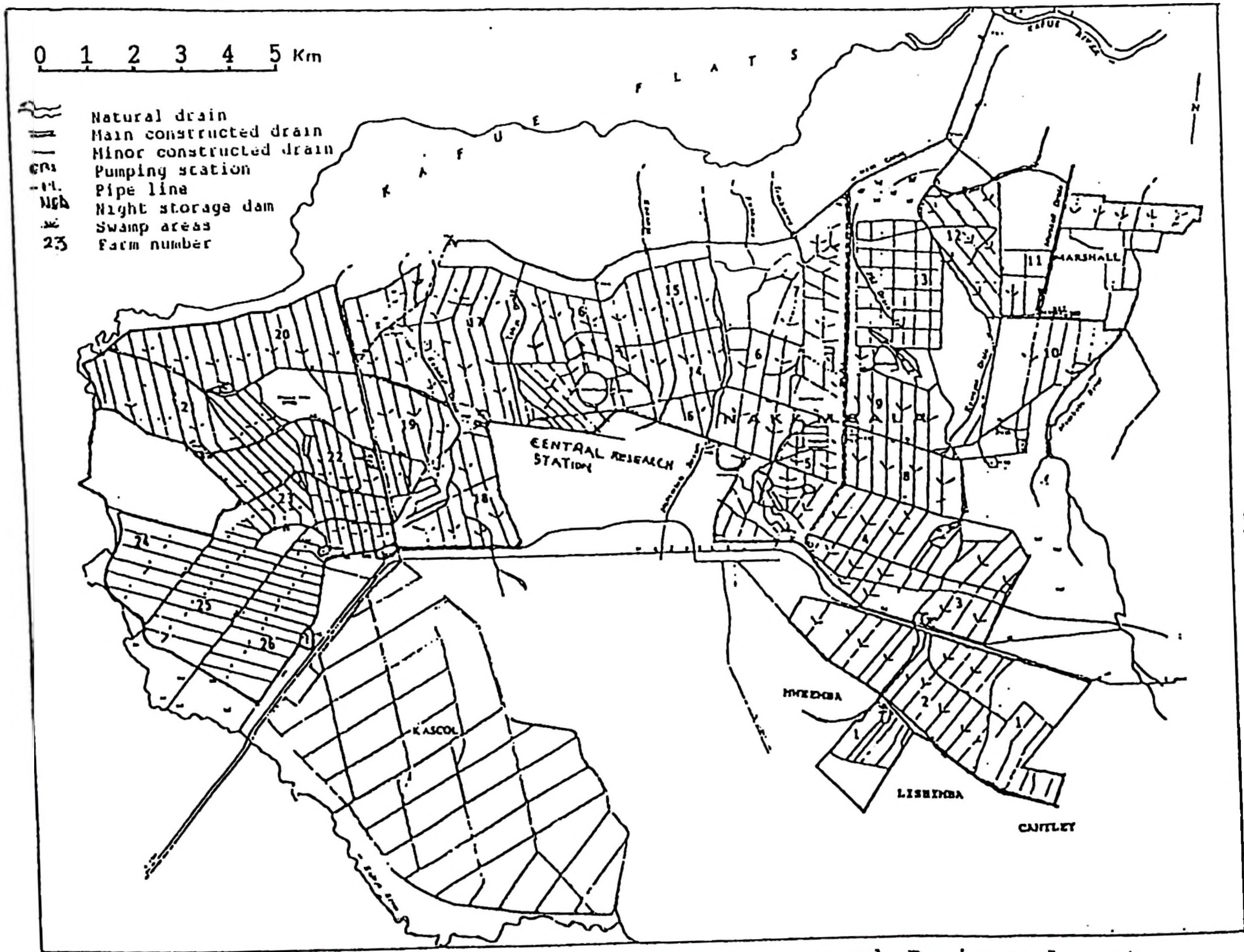


Fig. 4. Boundaries of Nakambala Sugar Estate and Drainage Layout. (Base map from Estate field layout, 1982)

According to the geological map of the country around Mazabuka area (Smith, 1963), the geology of the study area includes alluvium and residual deposits. The sources of the parent rock material include Kafue and Kaleya alluvium and colluvium from Mazabuka escarpment. The common rocks in the area consist of calc silicate schists and limestones with biotite schists and quartzites. These belong to the Mazabuka group of the Katanga age.

3.3 Climate

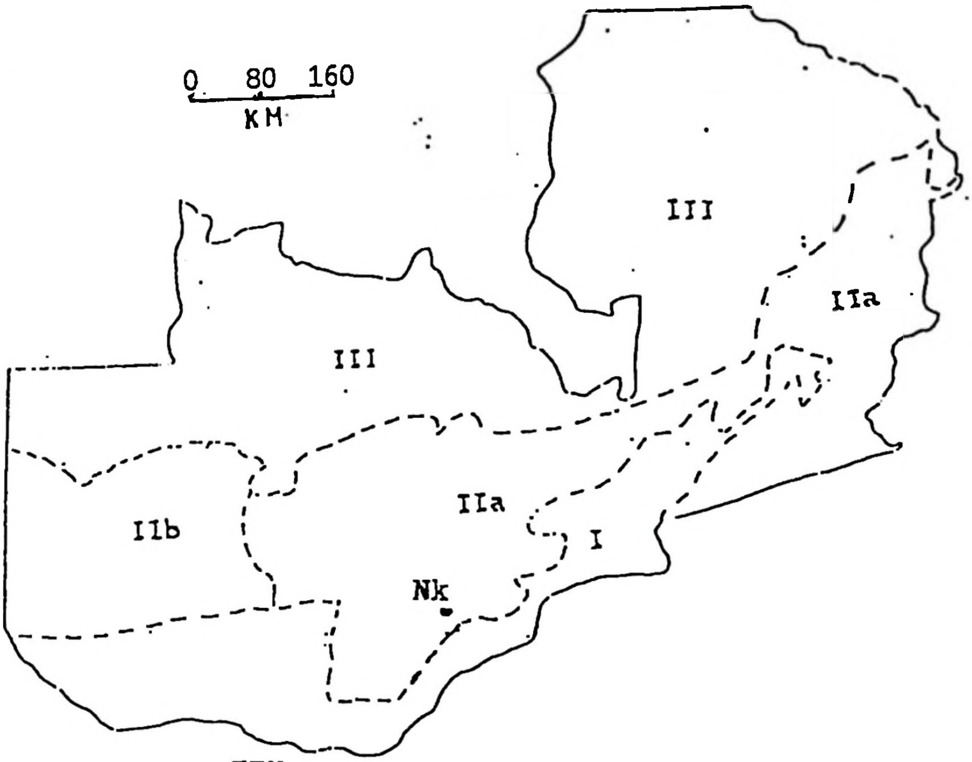
3.3.1. Agro-ecological zonation

The sugar estate is situated in the agro-ecological zone II a (see Fig. 5) with a growing period of 100 to 120 days that is characterised by drought periods ranging from 30 to 40 days (Veldkamp, 1987). However, this has since changed as drought periods have become more prevalent and quite devastating (Msoni and Mulenga, 1992).

3.3.2. Rainfall

Zambia experiences a sub-humid tropical climate (Fig. 6) with an average precipitation of 1 024 mm that is higher towards the north and lower in the south. The length of the rain season also decreases from north to south with longer dry spells in the south than in the north (Darkoh, 1989).

The study area is characterised by three distinct seasons: the warm rainy season, November/March; cool dry season, May/August and the hot dry season, September/October. The area has a mono-modal rain season and receives mean annual rainfall of 600 - 800 mm (Njos, 1974). Potential evaporation exceeds rainfall by 1 300 mm for the whole year, an indicator of an average dry climate. Figure 7 shows the long term monthly rainfall and total pan evaporation.



KEY
--- Region boundary

Region	Annual rainfall
I	Less than 800 mm
II	800 mm - 1 000 mm
IIa	Degraded (Sandveld) plateau
IIb	Aggadation plateau (Kalahari and Zambezi flood plain
III	More than 1 000 mm
NK	Study area (Nakambala)

Fig. 5. Agro-ecological Regions in Zambia.
(Veldkamp, 1987)

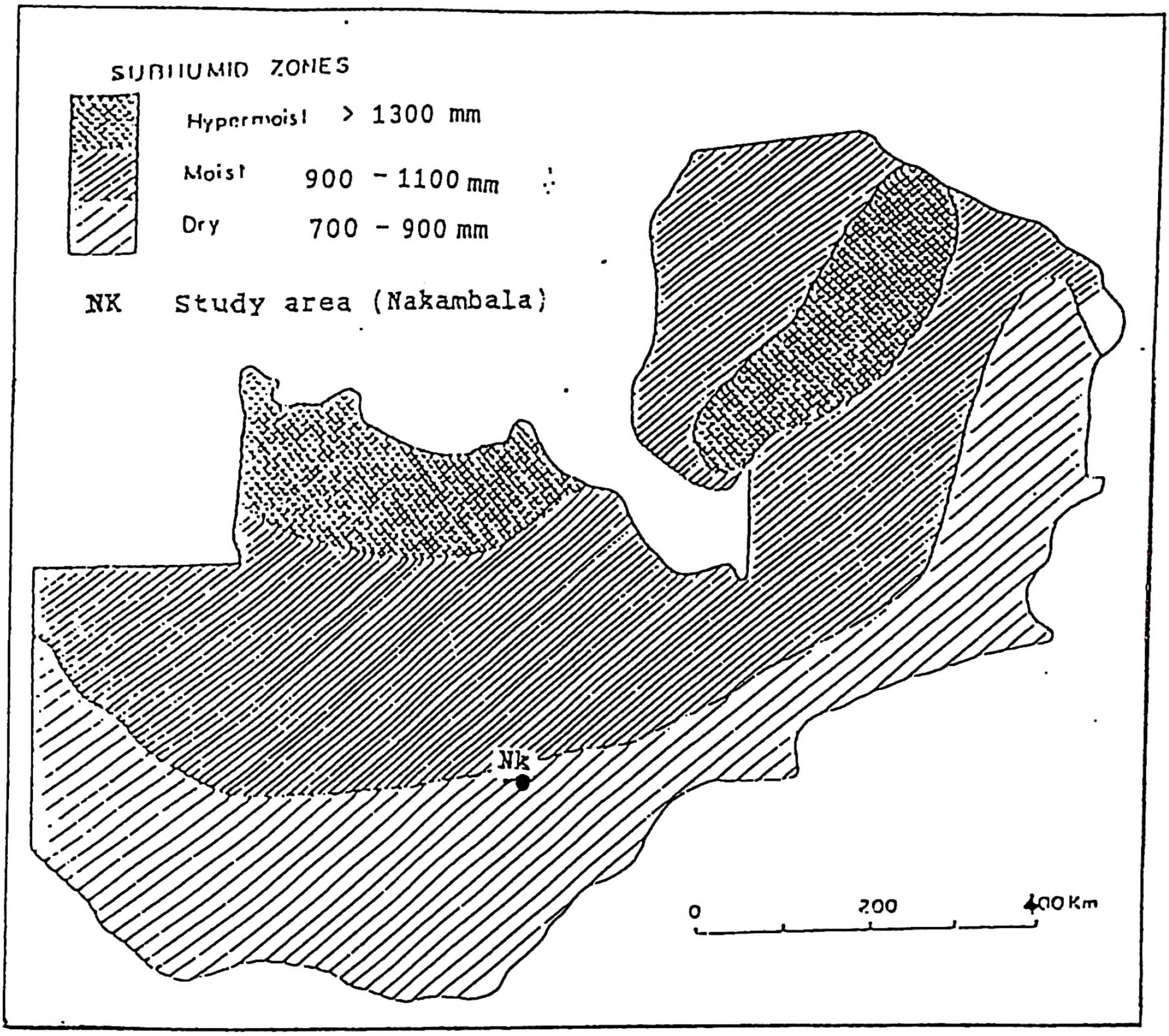


Fig. 6. Precipitation and evaporation zones in Zambia.

(Darkoh, 1989)

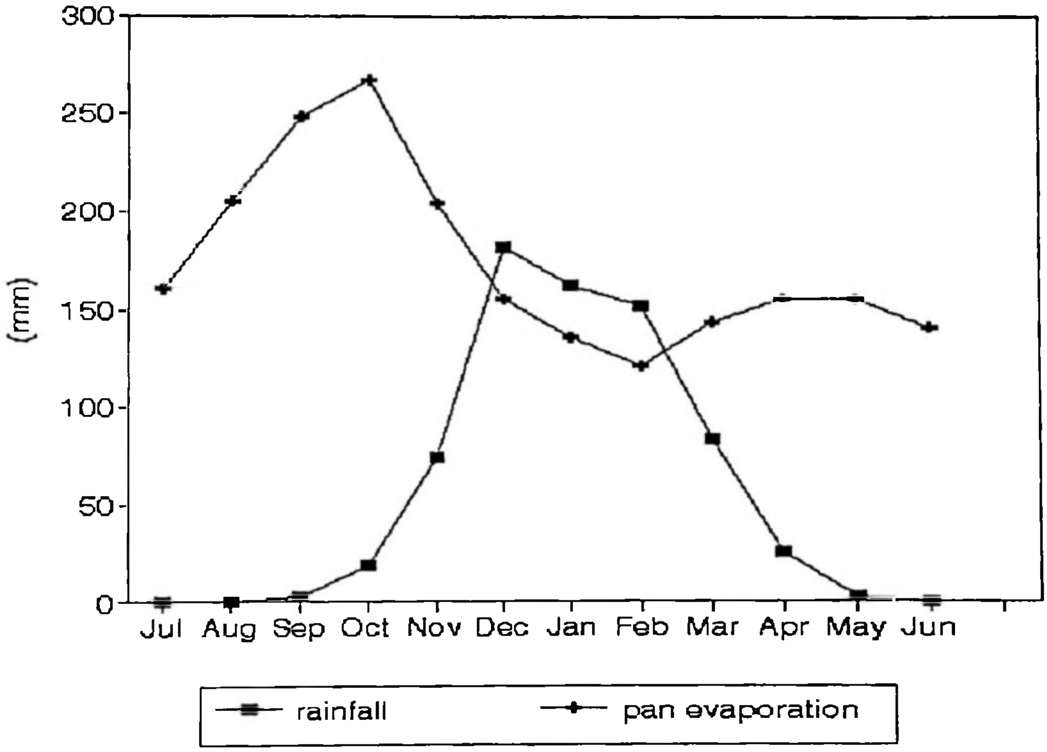


Fig. 7. Long term monthly rainfall and pan evaporation (Nakambala Meteorological Station, 1994)

3.3.3. Temperature

The maximum and minimum recorded temperature in the area is 35.9°C and 5.7°C in October and July, respectively. The long term mean maximum and minimum temperatures are illustrated in Figure 8.

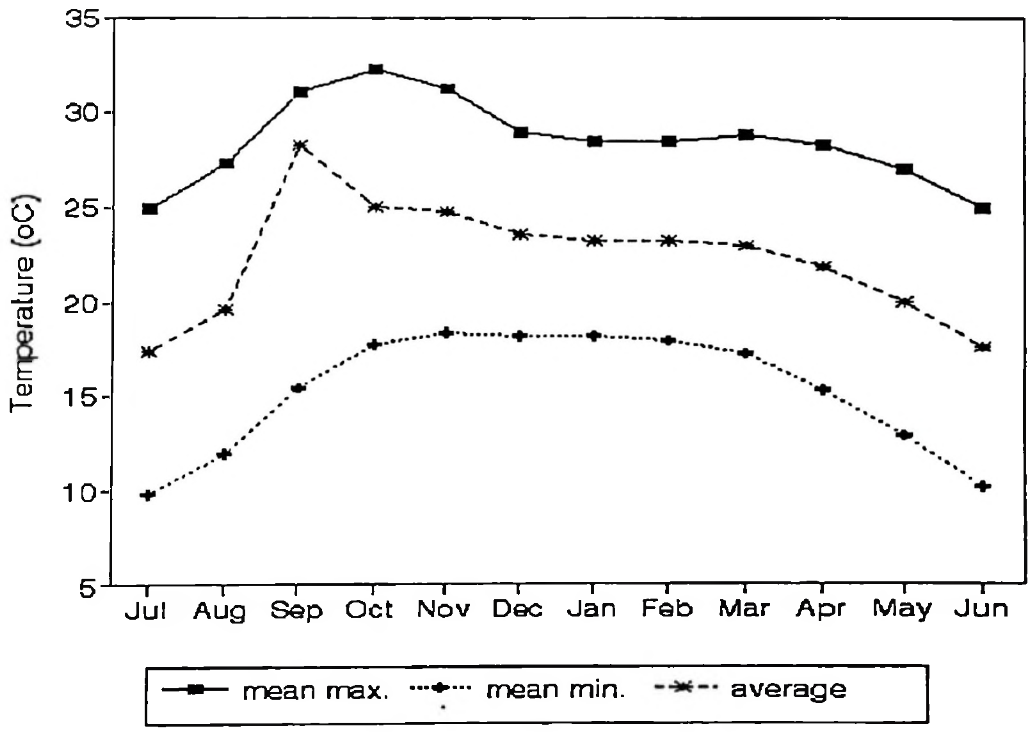


Fig. 8. Long term mean temperatures for Nakambala (Nakambala meteorological station 1994)

3.4. Vegetation and Land use

The Nakambala Sugar Estate falls within the Munga woodland that gives way to the Hyparrhenia grassland that occur in the Kafue flats (Huckabay, 1975). The Munga woodland is open with one or two storeyed deciduous woodland or savanna with scattered or grouped emergents characterised by Acacia, Combretum and Terminalia tree species.

There is a little remnant of the original vegetation due to intense cultivation and fires that characterise the Munga ecological complex. Along the Kaleya river, there are Albizia harveyii, Acacia seyal, Acacia nigrescens, Lonchocarpus capassa and some Adansonia digitata (baobab) trees. The north-eastern corner has some shrubs of mixed tree species dominated by Acacia albida useful as livestock feed. Grassland with Hyparrhenia spp. dominates the northern edge whilst Dactyloctenium aegyptium and Rottboellia exaltata grasses are common weeds. In abandoned fields, Hibiscus cannabinus and Bidens pilosa occur with other mixed natural vegetation, mainly of secondary bush.

The present land use is predominantly sugarcane growing (over 10 300 ha) and other related activities like housing, factory, a small orchard (1.68 ha) and a fisheries unit. In marginal land and abandoned fields, Eucalyptus spp. and Pinus kesiya trees (12.68 ha) and various crops and vegetables are grown.

3.5 Soils

According to the soil map of Zambia (Soil Survey Unit, 1983), the area lies astride Luvisol-Phaeozems on the upland near Mazabuka town and Vertisols that occur in the Kafue basin. Well drained, deep sandy clay loams, deep fine grained sandy loams and moderately deep sandy clays occur in gentle and even patches where sugarcane is predominantly grown. Rapidly permeable sandy loams to sandy clay loams and coarse grained sand to loams of restricted permeability and some friable sandy loams with moderate depth, occur in gentle and concave slopes. On relatively steep slopes, well drained fine to loam sand soils with rock outcrops near ridge summits occur. Pan land type occurs in localised depressed topography largely of olive coloured solenetzic clays subject to severe wetness. Soils with strongly developed gilgai relief consisting mainly of olive grey clays with restricted permeability occur mainly in the north-east, east and south-east sections of the sugar plantation.

4.0 MATERIALS AND METHODS

4.1 General aspects of the Methodology

In this study, many aspects and interactive effects of population and land use dynamics that could cause environmental degradation were studied. The study is however, limited in scope due to lack of accurate up todate records of resource inventories for the study area. Therefore, the study took a general overview in assessing the impact of sugar plantation expansion on demography, natural vegetation and soil productivity in some areas that had given low yields, over the study period (1970-1994).

4.1.1 Methods and modes of data collection

A pre-field operation was carried out and involved assembling data source materials namely: aerial photographs, maps, reports and publications. Data generation was through aerial photograph interpretation (API), measurements, calculations, field check, interviews and general observations on various features relevant to the study.

Aerial photographs taken in 1970 and 1991 (1:30 000) were interpreted on a mirror stereoscope after developing interpretation keys from interpretation elements such as; spectral and spatial aspects of basic features of physical objects on aerial photographs, as a guide to correct identification of features such as fields and settlements. Spatial, qualitative data such as; major land use cateogories, types of crops and configuration of land cover types and quantitative data such as; size of crop, forest and settlement areas, was obtained from aerial photographs by looking at interpretation elements and characteristics such as shape, size, pattern, tone (or hue), texture, shadows, site and associations of objects and features (Lillesand *et al.*, 1987). Other features, especially man-made, such as tracks, settlements, drains, dams and roads, were delineated visually (without using a stereoscope).

4.1.2 Sugar plantation expansion and impact on demographic changes

In assessing the impact of sugar plantation expansion on demographic changes, census maps (1:50 000) for the study area were used to examine settlement types and changes over the study period and population figures from 1969 and 1990 were examined and the population categorised by settlement type. The census information, households and some employment figures for the study area in 1969 and 1990, were collected from the Central Statistical Office (CSO) in Lusaka. This was supplemented with some information from literature and local employment records for 1968, 1970, 1975, 1990, 1991 and 1994. Population growth and dependency rates were calculated from the data collected according to Van Haastrecht, (1975). Projected population for the year 2 000 was calculated using the exponential population growth model (Haggett, 1983):

$$N_t = N_o e^{rt} \qquad (1)$$

Where N_t = Population at time t,

N_o = population at time 0,

r = annual population growth rate,

t = time of projection (years),

e = 2.71828, the base of natural or Napierian logarithm.

The problem of projections are that answers to future situations cannot be given with great specificity. The uncertainties lie in giving specific figures although a general direction of change can be derived. In projecting the population for the year 2 000 in Nakambala, the following questions pose some difficulties:

1. What will be the population growth rate and how many people will remain in the area during the projection time?
2. How will the housing and employment situation change?
3. Will the sugar plantation productivity remain sustainably high during the projection period?

The population projection was done to determine fuelwood requirements based on the following assumptions:

1. Annual population growth rate derived from the population figures for 1969 and 1990 census data will remain constant during the projection period.
2. No sugar plantation expansion will take place during the projection period.
3. Immigration and emigration will remain equal, thus net migration will equal to zero.

4.1.3 Rate of sugar plantation expansion and impact on natural vegetation

The rate of sugar estate expansion in relation to cleared land for cultivation (ha) and subsequent changes in natural vegetation area (ha) were determined from aerial photograph interpretation using the square grid method (Lillesand *et al.*, 1987). Budgetary restrictions and the timeliness of the study could not permit the determination of tree tariffs and stand tariffs (Cailliez, 1980), and therefore, a field check was conducted in order to categorise the vegetation into biomass classes (such as forest, shrub and grassland) according to predominant and surviving tree species from which estimations of potential annual cut in terms of fuelwood volume (m^3/ha) and corresponding energy supply levels, were determined according to de Montalermbert *et al.* (1983). In this case, fuelwood being wood and the other parts of trees and shrubs to be used as fuel for cooking, heating or generating energy (de Montalembert *et al.*, 1983, Philip, 1983, Mulomfwa *et al.*, 1994; Kalonda, personal communication, 1994). Although aerial photograph interpretation gives a rapid but also subjective classification of the woody biomass into crude classes, an attempt was made in this study, to convert the interpretations (area covered by different tree species) into objective yield volume figures based on available qualitative information (Appendix III) and ground evidence (field check) in some cases, to obtain a general energy utilization trend linked to environmental degradation in the form of deforestation (Hosier *et al.*, 1990).

4.1.4 Fuelwood consumptive trends

Fuelwood consumptive trends and uses were obtained by form of interviews and inquiries based on a questionaire designed to determine; household size, source of energy for cooking and lighting and fuelwood utilization (number of charcoal bags used per month weighing on average 60 kg). The questions that pose difficulties in assessing fuelwood consumptive trends are:

1. How does one account for variations in fuelwood energy utilization habits?
2. Does the energy requirement per person remain stable across the seasons?
3. What is the efficiency of the equipment and methods used in fuelwood utilization?

In assessing fuelwood consumption trends and uses, the following assumptions were made:

1. All employees living in the townships in 1969 and 1970 were dependent on fuelwood for cooking and heating.
2. All households in unelectrified houses in 1990 to 1994 used fuelwood.
3. Only 42 % of housing units in the townships were electrified at any given time.
4. Minimum energy requirements for cooking and heating per person per month remained constant (thus, domestic energy use habits did not change) and obtained from tree species of the same calorific value.

Housing unit records supplemented the fuelwood consumptive information to give an overall estimate of fuelwood consumption on the sugar estate. The difference between needs (consumption) and accessible wood supplies estimated from fuelwood volume (m^3/ha) in 4.1.3 and the minimum energy requirements for cooking and heating, estimated at 8 Giga joules or 0.75 m^3 of fuelwood per person per year (de Montalermbert *et al.*, 1983) and calorific value, estimated at 4.5 kilocalories (18 834.75 kilojoules) per gram of dry weight of all woody species (Philip, 1983) were calculated to determine fuelwood balances. A distinction in case of an imbalance was introduced to classify the situation as either of an acute scarcity or deficit, to underline the seriousness of the problem.

4.1.5 Other biophysical effects of sugar plantation expansion

Irrigation tail water management in relation to land degradation due to poor drainage was examined from 1991 aerial photographs by looking at the extent and spatial distribution of swamp areas. The area affected by poor drainage (proliferation of aquatic weeds) was determined by the square grid method (Lillesand *et al.*, 1987) and inundation effects delineated by observing and noting crop growth variations in the nearby fields. Erosion hazard was studied by looking at major linear gully development and drain network deterioration (by bank scouring) from aerial photographs, field check and verification. The concentration was on the 1991 aerial photographs because this was considered the prime time to observe negative trends in the situation after 27 years of practising irrigated agriculture in the area.

4.2 Soil Physical and Chemical status assessment

4.2.1 Pre-field work

The pre-field work included collecting relevant information about the area from literature and Sugar Estate Management since soil physical and chemical status assessment could not be done from aerial photography interpretation. A soil map of the sugar estate (1:30 000) was obtained and taking into consideration the limited budget (all thirteen soil mapping units on the 10 000 ha sugar estate could not be studied) and in consultation with Sugar Estate Management, an area with five soil mapping units (600 ha) and experiencing low yields due to suspected soil fertility deterioration, was chosen for the study. Field layout sheets and a map were used to draw transects (500 m apart) and sampling sites and mini-observation pits (soil profile pits below 60 cm deep used for quick soil morphological characterisation) randomly located in all the five soil mapping units on the transects (Dent and Young, 1981).

4.2.2 Field work

In the study, the soil physical and chemical status assessment was done by first considering the soil mapping units already established (Doyle *et al.*, 1969). Stratified sampling according to Petersen *et al.* (1986) was conducted in the soil mapping units by augering (0-30 cm) and surface composite samples collected from different sites within the soil mapping units and combined by quartering method (Landon, 1991) to produce composite samples.

The objective was to obtain a rapid and general appraisal of the study area in terms of soil productivity potential in each soil mapping unit (inclusive of abandoned sections). In order to obtain a general trend into the subsoil, six representative soil pits (based on morphological characterisation) were dug in each soil mapping unit. However, no soil classification nor very detailed profile description was done since the objective was to assess the soil condition in terms of fertility characteristics and not pedogenic characteristics. Both disturbed and undisturbed soil samples were collected from 0-30 and 30-60 cm depths and various soil physical and chemical analyses conducted. All soil laboratory analyses were done at the Soil Science Laboratory at the University of Zambia in Lusaka.

Infiltration tests were conducted in the soil mapping units at field capacity (two days after irrigation) using a double ring infiltrometer (Klute, 1986). Soil colour was determined using Munsell colour chart (Munsell Color Co., 1975). Other land characteristics and land qualities examined in the pits were: rooting conditions, drainage and soil structure.

4.2.3 Soil physical and chemical laboratory analyses

Several soil physical parameters were determined from each soil mapping unit by the following standard procedures and methods according to Klute (1986). Bulk density was determined from undisturbed soil samples using the core method, water retention by membrane and pressure plate apparatus. Particle size and particle density were determined by the hydrometer and pycnometer methods, respectively. Total porosity was determined from the calculation of bulk and particle densities.

Composite and disturbed soil samples from representative pits were used to determine the following soil parameters using the standard procedures and methods according to Page *et al.* (1982); P^H by electrode P^H meter in 1:2.5 soil/water suspension and 1M KCl; total Nitrogen by the semi-macro Kjeldahl; available Phosphorus by Bray and Kurtz 1 method;

exchangeable bases (Ca^{2+}, Mg^{2+}, K^+ and Na^+) by atomic absorption spectrophotometry in neutral NH_4OAc leachate; cation exchange capacity (CEC) by Kjeldahl distillation titration method; trace elements (Fe, Mn, Zn and Cu) by atomic absorption spectrophotometry; electrical conductivity (ECe) from saturated extracts using an electrical conductivity meter, and organic carbon by the Walkey-Black procedure.

4.2.4 Interpretation of soil physical and chemical parameters

Soil parameters determined in sections 4.2.2 and 4.2.3, were interpreted, rated and classified according to Landon (1991) and Dent and Young (1981). The following land qualities were considered important and used for land suitability classification for irrigated sugarcane (Dent *et al.*, 1981 and FAO, 1983): oxygen availability, nutrient availability, nutrient retention, excess salts, soil workability, rooting conditions, physical degradation hazard and soil erosion. These qualities were assessed and rated using the diagnostic factors critical for irrigation (Dent and Young, 1981), taking into account the presence of condition modifiers (FAO, 1983). The other qualities proposed in the guidelines were considered as not limiting (FAO, 1983, pp 78).

The FAO (1976a, 1983) land suitability frame work was used to match the requirements of irrigated sugarcane (*Saccharum officinarum*) to land attributes (diagnostic factors) in each soil mapping unit (Landon, 1991). The procedures of limiting conditions and subjective combinations were used in the overall suitability classification (Dent and Young, 1981).

4.2.5 Soil status comparison and degradation assessment

The risk of soil physical degradation was determined using the following index (FAO, 1983; Dudal, 1979);

$$Index = \frac{Zf+Zc}{C} \tag{2}$$

In which Zf = % fine silt (0.002 - 0.02 mm)

Zc = % coarse silt (0.02 - 0.05 mm)

C = % clay

In non crusting soils, the index is < 1.5 and > 2.5 for soils subject to intense crusting. The other soil physical aspect assessed using indices is bulk density changes (increase with respect to initial levels) as shown in table 4.1 below.

Table 4.1 Soil physical degradation assessment indices

Class	Bulk density, Initial level (g/cm^3) < 1.0	1.0-1.25	1.25-1.40	1.4-1.6
None to slight	< 5	< 2.5	< 1.5	< 1.0
Moderate	5 -10	2.5-5.0	1.5-2.5	1.2-2.0
High	10-15	5.0-7.5	2.5-5.0	2.0-3.0
Very high	> 15	> 7.5	> 5.0	> 3.0

Source: Dudal, 1979

Biological soil degradation was assessed using soil degradation concepts by Dudal (1982) as given in Table 4.2, below.

Table. 4.2 Biological degradation assessment

Decrease in humus (%/year) Class	% change in humus
none to slight	< 1.0
moderate	1.0 - 2.5
high	2.5 - 5.0
very high	> 5.0

Source: Dudal, 1979

Chemical degradation was assessed by increase in electrical conductivity, ECe (mS/cm/year) of saturated extract, increase in exchangeable sodium percent (ESP) per year and decrease in base saturation (percent per year) to assess the risk and presence of salinization, sodication and acidification, respectively, as shown in Table 4.3a and Table 4.3b, below.

Table 4.3a Soil chemical degradation assessment (Salinization and sodication) (0-60 cm layer)

Class	Increase in Salinization EC (mS/cm /Year)	Increase in Sodication ESP % / year
None to slight	< 2	< 1
Moderate	2 - 3	1 - 2
High	3 - 5	2 - 3
Very high	> 5	> 3

Source: FAO (1983); Dudal (1979)

Table 4.3b Soil chemical degradation assessment (acidification)

Acidification Class	Decrease in Base Saturation (BSP) (%)/year If BSP < 50%	If BSP > 50%
None to slight	< 1.25	< 2.5
Moderate	1.25 - 2.50	2.5 - 5.0
High	2.50 - 5.00	5.0 - 10.0
Very high	> 5.00	> 10.0

Source: FAO (1983); Dudal (1979)

Other diagnostic soil characteristics interpreted and subjected to land suitability ratings in section 4.2.4 according to the FAO (1983) frame work and Landon (1991), were compared to those in Doyle *et al*. (1969) to further assess other soil degradation aspects in the study area.

5.0 RESULTS AND DISCUSSION

5.1 Impact of sugar plantation expansion on demographic changes

Demographic changes for Nakambala and Mazabuka town for the period 1969 to 1990 are given in Table 5.1. The population for Nakambala increased from 7,903 to 14,832 between 1969 and 1991 with an annual increase of 4%. This was however, lower than that for Mazabuka town with 7% annual increase. The higher population growth that Mazabuka town, could be attributed to the services that the town had to provide to the emerging sugar industry.

Table 5.1 Demographic changes for Mazabuka town and Nakambala (1969 and 1990)

	Mazabuka		Nakambala	
	1969	1990	1969	1990
Total	8 411	21 421	7 903	14 832
Employed	2 744	5 842	2 544	5 132[1]
Unemployed	5 667	15 579	5 359	9 700
Dependency/ Worker	2.00	3.00	2.00	2.00
Growth rate (% per annum)		7.00		4.00

Source: Central Statistical Office (CSO) 1969 and 1990 censuses, 1 excluding 3 298 seasonal employees.

Dependency per worker increased for Mazabuka with three dependants per worker while that for Nakambala remained at two dependants per worker. Employment trends from Table 5.1 show an annual increase of 11% for Nakambala between 1969 and 1990, 6% higher than that for Mazabuka town of 5% for the same period. Table 5.2 show the labour statistics for Nakambala by employee status. The increase in population during the study period was attributed to sugar industry growth that attracted people by creation of employment opportunities.

Table 5.2 Labour statistics by employee status for Nakambala

Year	Staff	Permanent	Seasonal	Temporal	Total
1968	-	-	-	-	1 968[2]
1969	-	-	-	-	2 544[1]
1970	145	-	-	-	2 911[2]
1975	314	3 085	1 083	-	4 382[2]
1990	298	3 384	4 579	169	8 430[3]
1994	314	3 118	4 397	60	7 891[3]

Source: 1 Central Statistics Office (CSO)
2 Van Haastrecht, 1975
3 Employment records, Nakambala (1994)

Using the formula in 4.1.2, i.e. eq. (1), the projected populations for the year 2,000 for Nakambala and Mazabuka were; 22,127 and 43,136, respectively.

5.2 Rate of sugar plantation expansion and impact on natural vegetation

Cultivated land and infrastructure expansion trends and changes in land cover types are given in Tables 5.3 and 5.4, respectively. Figures 9 and 10 show the spatial distribution of the land use and land cover types for the period 1970 and 1991. Figure 11 show the actual expansion plan for Nakambala Sugar Estate. Much of the extension took place in the northwest and western sections of the sugar plantation, in areas where cultivation of other crops had been going on for a long time.

Table 5.3 Land use changes in Nakambala between 1970 and 1991

Year	1970	1991
Total area (ha)	3 622.27[1]	10 656.76[1]
Harvested area (ha)	2 660.00[2]	8 518.00[2]
Infrastructure and unharvested area (ha)	962.27	2 138.76
Expansion rate (ha/year)		335.00

Source: 1 Aerial photography, 1970 and 1991.
2 Local cane records, Nakambala, 1994.

Cultivated land with a harvestable crop of sugarcane increased by 5 858 ha between 1970 and 1991. The whole sugar

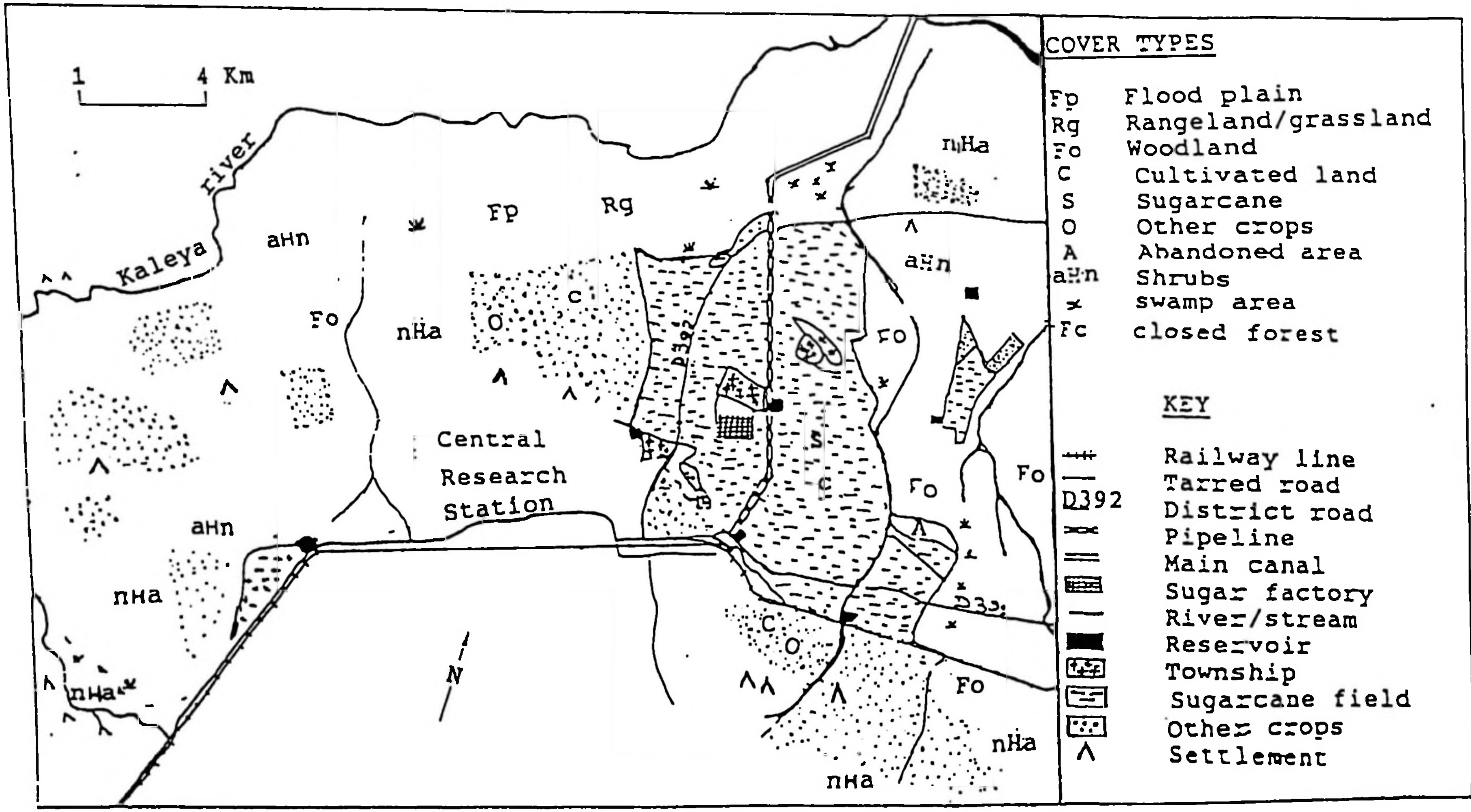


Fig. 9. Land cover/land use of Nakambala
Source: Aerial photography 1970

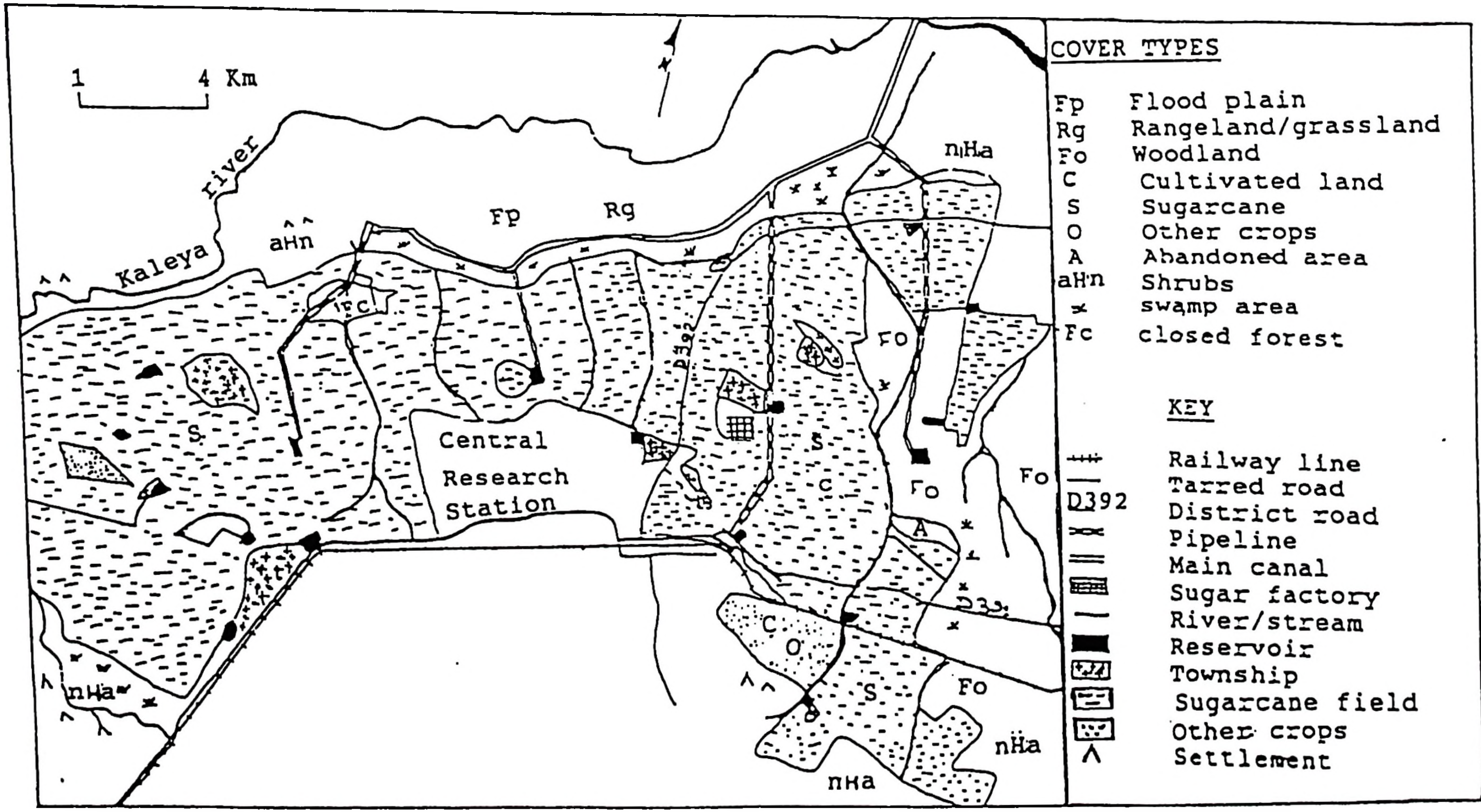


Fig. 10. Land cover/land use of Nakambala
Source: Aerial photography 1991

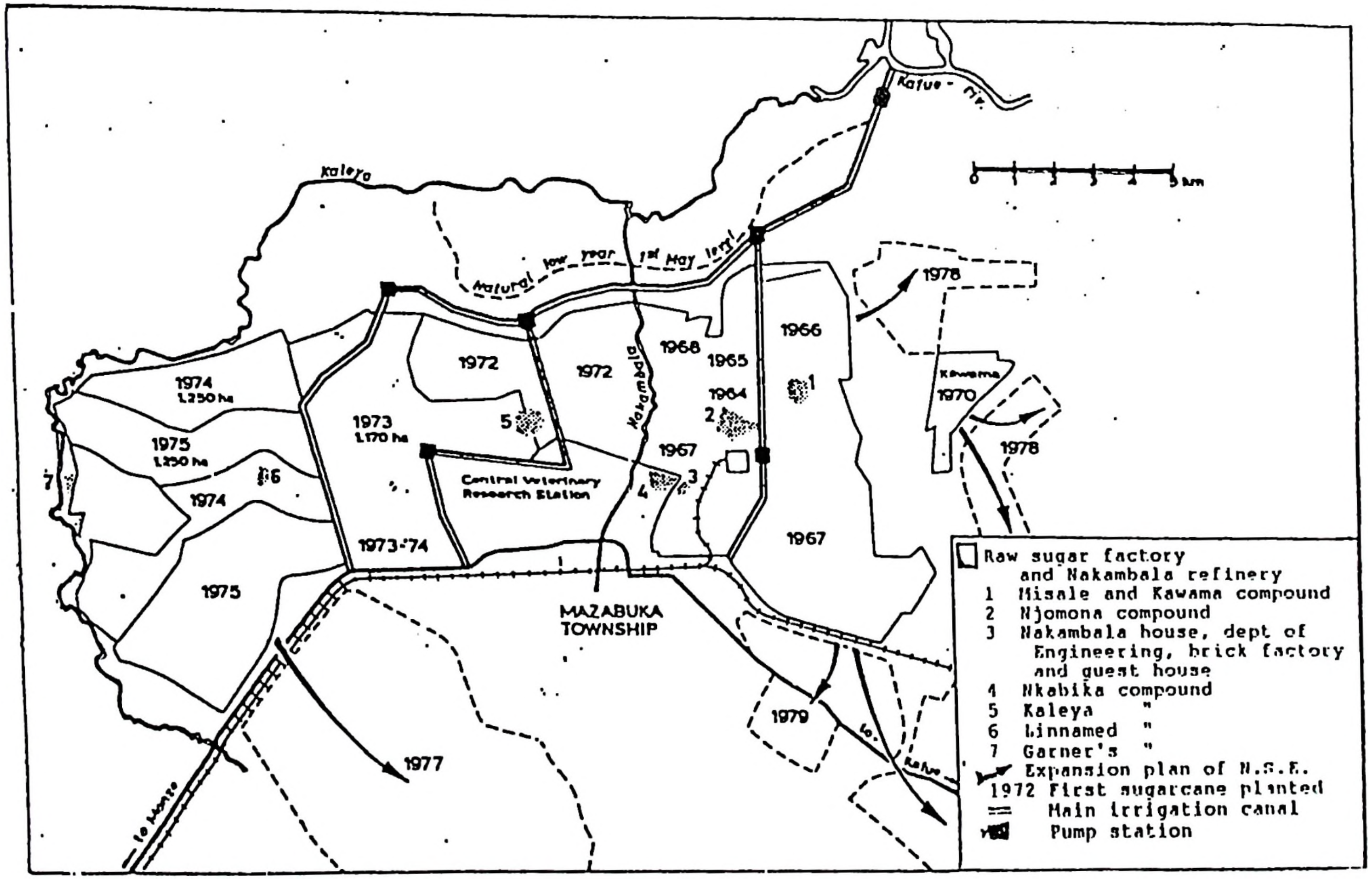


Fig. 11. Nakambala extensions
Source: Zambia Sugar Company map (1-8-1973) and ten years development map

plantation expanded by 7 034.5 ha over the same period, at a rate of 335 ha/year.

Table 5.4 Land cover type area (ha) changes in Nakambala

Land cover type	Year 1970	1991
Sugarcane	2 660.00	8 518.00
Shrub formations	1 560.49	144.11
Wooded savanna	-	73.47
Forest-grassland	1 354.02	1 022.55

Source: Aerial photography 1970 and 1991 and local records.

The changes in land cover types classified according to de Montalembert *et al.*, (1983) and given in Table 5.4 above, show that much of the shrubland was cleared to pave way for the sugarcane plantation. The mixed deciduous wooded savanna forest-grassland formation dominated by Acacia spp. and Albizia harveyii and Piliostigma thonningii locally known as *Mukangala* and *Musekese*, respectively, was reduced by 25% while a protected mixed forest-grassland formation area became part of the sugar plantation, but was not cleared due to traditional beliefs. In this shrine area, tree cover increased to over 80% in some cases.

The natural woody vegetation types determined earlier (in Table 5.4 above) could provide the fuelwood productivity (potential annual cut, m^3/ha/year) and corresponding energy levels. The potential annual cut for 1970 and 1991 given in Table 5.5 are based on natural woody vegetation productivity level and the corresponding energy levels based on 8 Giga J (10^9 J) to 0.75 m^3 requirements per person per year according to de Montalermbert *et al.* (1983).

The shrubland formation could provide only 19% of the total productivity level in 1970, although this type of vegetation covered a larger area of land, 1 560.49 ha. This was probably due to alterations by farming, that could have affected the mean annual increment (MAI).

Table 5.5 Fuelwood productivity and energy levels

	Year			
	1970		1991	
Vegetation Type	Productivity m3 /ha/year	Energy 10^9 J	Productivity m^3/ha/year	Energy 10^9 J
Shrub formation	156.05	1 665	14.41	154
Wooded savanna	-	-	73.47	784
Forest grassland	667.01	7 115	511.27	5 454
Total	823.06	8 780	599.15	6 392

Source: Aerial photography, 1970 & 1991 and de Montalembert *et al.* (1983)

The mixed deciduous wooded savanna forest-grassland formations had the highest productivity potential (m^3/ha/year) of 81% in 1970. The productivity levels in 1991 showed a reduction to 2.4% for shrubland while deciduous forest-grassland formations remained relatively high at 85%. The overall energy productivity potential dropped by 27%, indicating an average drop of 1.3% per year.

5.3 Fuelwood consumption trends

The fuelwood consumptive trends in terms of charcoal utilization in the townships of Nakambala was 20 kg per person per month (two bags of 60 kg charcoal per household of six people). Thus, an annual consumption of 240 kg or 4.42×10^{12} J, was envisaged per person (Philip, 1983).

The distribution of housing units and electrification in the townships of Nakambala are given in Table 5.6. The dependency on fuelwood for energy based on electricity supply to housing units fluctuated with 58% of the units unelectrified and therefore, implying that the occupants were generally dependent on fuelwood for energy.

Table 5.6 Township housing units in Nakambala

Township	1970[0]	1990[1]	1991		1994[2]	
			a^{Ef}.	a^{NEf}.	a^{Ef}.	a^{NEf}.
Nkabika	454	-	-	-	440	388
Njomona	783	-	-	-	826	123
Misale	435	-	-	-	-	431
Kaleya	-	-	-	-	17	585
Chuula	-	-	-	-	2	309
Total	1 672	2 443	1 063	1 468	1 295	1 825

Source: 0 Van Haastrecht (1975)
1 Central Statistical Office (CSO) 1990 census
2 Local Nakambala housing records, 1994

Note: a^{Ef} = Electrified; a^{NEf} = Not electrified

Housing units without electricity, population estimate dependent on fuelwood for energy and minimum fuelwood requirements are given in Table 5.7. There was an increase in electrification for domestic consumption between 1970 and 1990 leading to a reduction in fuelwood demand for energy. The situation however, changed in 1991 as more people became dependent on fuelwood for energy. This was attributed to the severe drought experienced during the previous year and the slow pace of electrification in the townships that could not carter for the increase in housing and increase in demand for energy by the rising population.

Table 5.7 Unelectrified housing stocks and fuelwood dependent population and minimum energy requirements

Year	Housing stock[1]	Population[2]	Minimum Fuelwood requirement[3] m^3/year
1970	1 672	8 360	6 270
1990	1 417	7 085	5 314
1991	1 468	7 340	5 505
1994	1 825	9 125	6 844

Source: 1 Local records and CSO 1990 census
2 Central Statistical Office (CSO) 1969 and 1990 censuses and derived population growth
3 de Montalermbert *et al.* (1983)

The fuelwood consumption derived from actual consumption trends and population dependent on fuelwood as given in Table 5.7 were used to derive woody biomass in terms of charcoal (240 kg per person per year or 4.42×10^{12} J) needed and the energy needed to meet the minimum requirement of the population. The woody biomass (charcoal) and energy production required to meet the needs of the population without access to electricity, are given in Table 5.8. Fuelwood consumption for energy respond to changes in demand as population increases.

Table 5.8 Fuelwood consumption and energy production

Year	Wood biomass (Charcoal, Mg)	Energy (10^{12} J)
1970	2 006.40	37 787.20
1990	1 700.40	32 024.20
1991	1 761.60	33 176.80
1994	2 190.00	41 245.00

Source: Aerial photography, 1970 and 1991; Central Statistics Office reports; 1970, 1991 and 1994 Philip (1983); de Montalembert, *et al.*, 1983

The fuelwood potential cut (m^3/ha/year) and energy supply derived in Table 5.5 and the minimum energy requirements per person per year in Table 5.7 were used in combination with the fuelwood consumption and energy in Table 5.8 for 1970 and 1991 to derive a fuelwood balance based on the potential annual cut from 1970 and 1991 aerial photography. There was a negative balance in potential annual cut of 5 447 m^3/year and 4 906 m^3/year in 1970 and in 1991, respectively. The potential energy supply based on actual comsumption trends showed negative balances of 37 778.42 x 10^{12} J/year for 1970 and 33 169.61 x 10^{12} J/year for 1991.

The potential annual cut drop of 224 m^3/year widened the fuelwood deficit by 765 m^3/year. The corresponding overall drop in energy productivity of 27% was 2 389 x 10^9 J between 1970 and 1991. The negative balance in 1970 and 1991

(Appendix IV) show that the high use frequency of fuelwood in households caused an acute scarcity situation in the area. This implied that fuelwood supply level was so notoriously inadequate that even overcutting of resources could not provide the population with sufficient supply and that the fuelwood consumption was clearly below minimum requirements.

5.4 Land resource degradation status

The study area is drained by furrows and several drains and water courses (Fig. 4). However, swamp areas had expanded from below 20 ha (aerial photography, 1970) to over 500 ha (aerial photography, 1991) adversely affecting sugarcane yields in the nearby fields. Figure 12 show drainage pattern, contours and spatial distribution of swamp areas. This could be attributed to the increase in waterlogged areas (as observed from the extent of swamp areas) to the generally gentle to flat lands that are prone to flooding and surface water ponding and to poor drain maintenance near discharge areas into major river systems.

Channel bank protection by stone pitching and by growing perennial grass, Vetiva (*Vetiveria zizanioides*) in field drains greatly reduced erosion hazard. Available qualitative evidence indicate that erosion is not serious in the area. This could be attributed to low rainfall with low erosivity experienced in the area (Lenvain *et al.*, 1988) and that sugarcane has low erosion hazard at maturity (Landon, 1991).

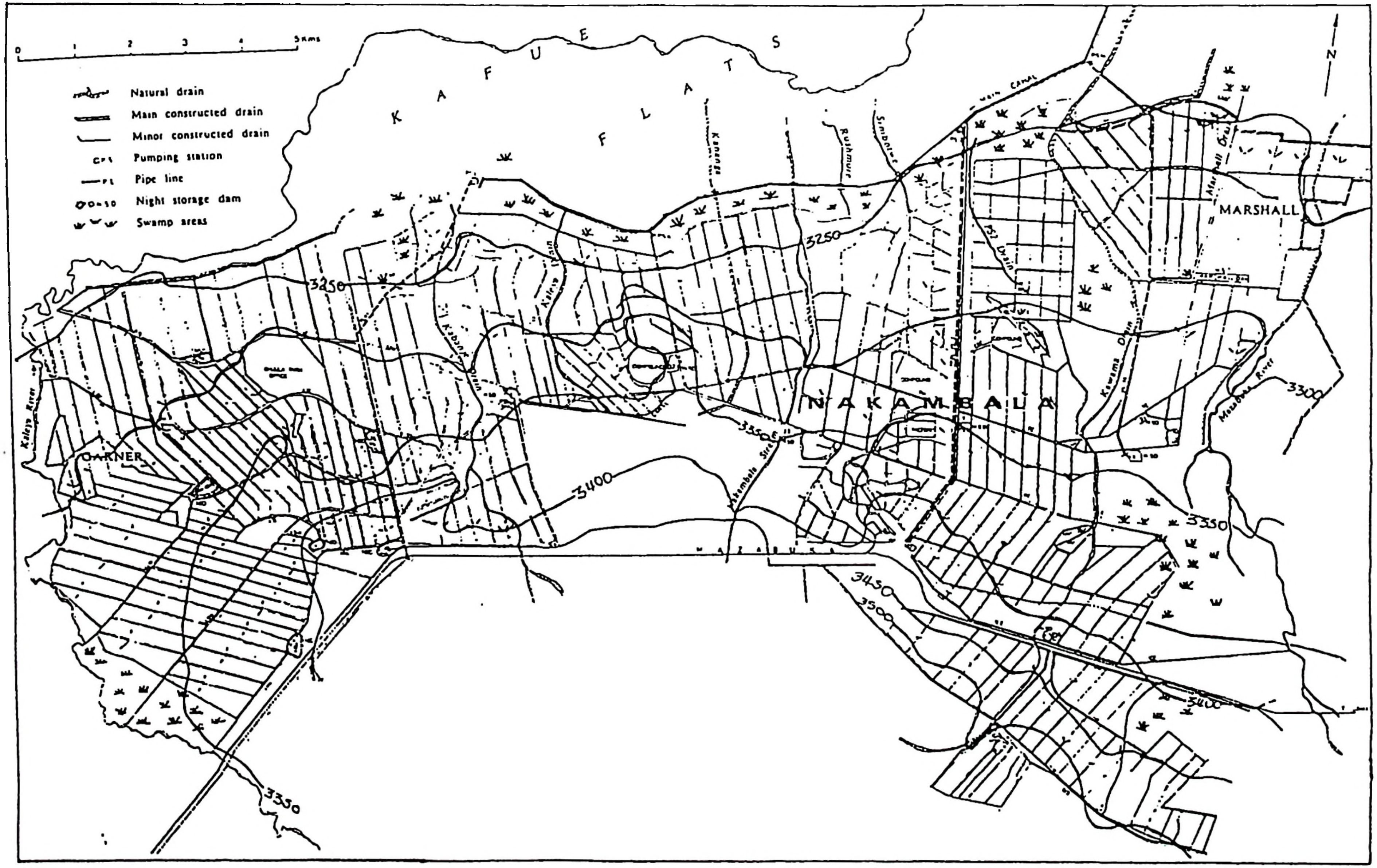


Fig. 12 Drainage and contour map of Nakambala.
Extract from estate field layout and 1991 aerial photography.

5.5 Soil physical and chemical status

The soil map of the study area from Doyle *et al.* (1969) is given in Figure 13. The classification of land mapping units in Doyle *et al.* (1969) and Msoni *et al.* (1992) were used in the study. The results of soil physical and chemical composite analyses are given in Table 5.9. The soils in the study area are mainly clayey of low soil porosity and medium to high bulk densities and show significant differences in soil properties.

Table. 5.9a Summary of soil physical composite analysis

	Mapping unit					
	2W(r)	2W(y)	10	11	12	13
Lab. No.	S/157	S/158	S/159	S/160	S/161	S/162
Particle size						
Sand (%) (2.0-0.02mm)	46.4	46.5	46.4	19.9	25.0	15.0
Fine silt (%) (0.02-0.002mm)	8.5	6.5	5.6	13.0	10.0	11.5
Clay (%) (< 0.002mm)	30.5	27.5	43.6	46.5	40.0	46.0
Silt (%) (0.05-0.002mm)	24.2	25.5	17.2	20.6	25.0	27.5
Textural class	CL	CL	C	C	C	C
Bulk density (g/cm^3)	1.43	1.32	1.34	1.42	1.49	1.45
Particle density (g/cm^3)	2.40	1.79	2.10	2.42	2.45	2.57
Porosity (%)	40.42	26.26	36.20	41.32	39.20	43.60

Source: Soil survey, 1994

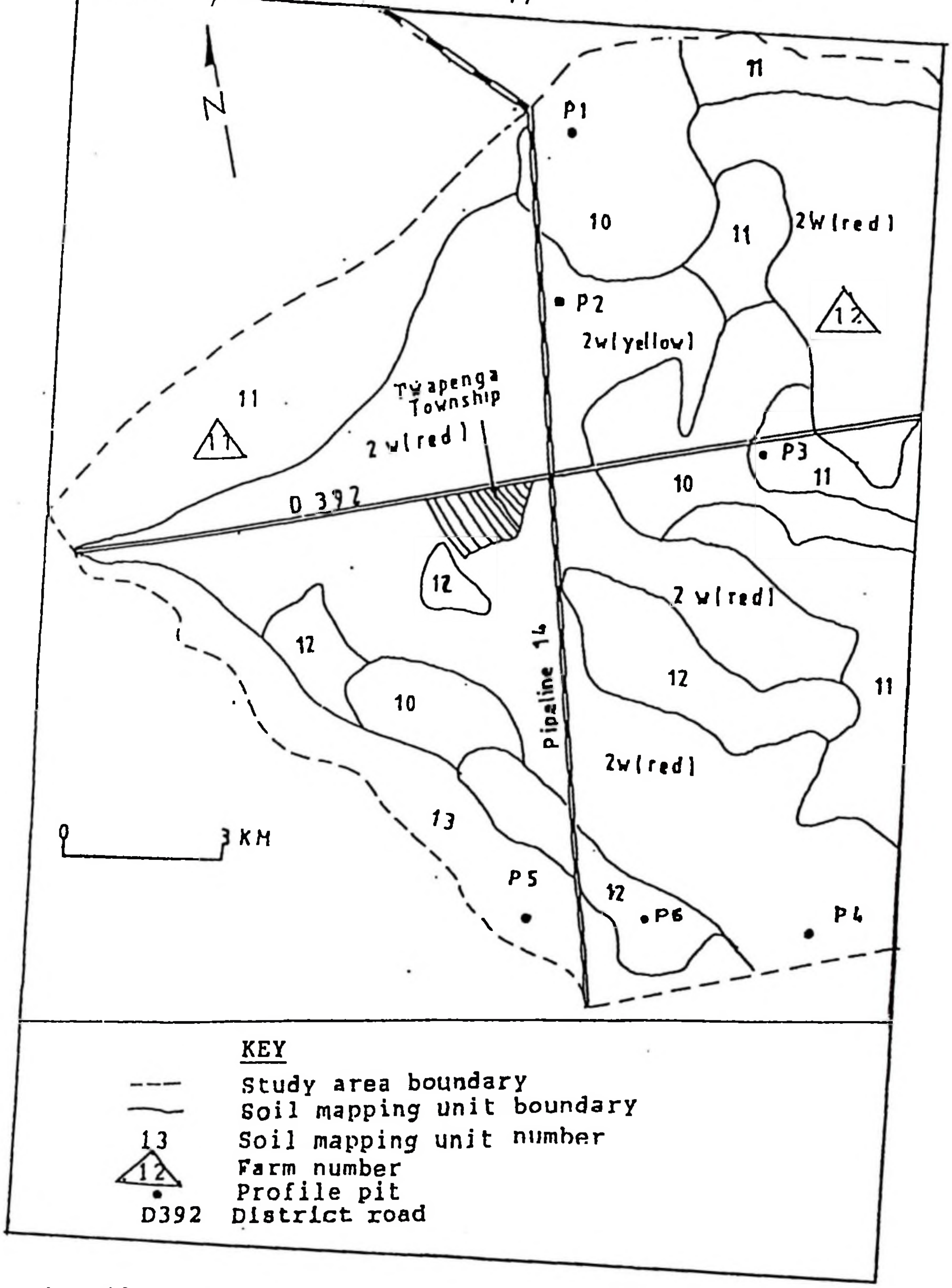


Fig. 13 Soil map of farm 11 and 12, Nakambala

Table 5.9b Summary of soil chemical (composite) analysis

	Mapping unit					
	2W(r)	2W(y)	10	11	12	13
Lab. No.	S/157	S/158	S/158	S/159	S/160	S/161
Exchangeable cations (me/100 g soil)						
Ca	19.65	19.60	17.65	20.40	24.20	20.50
Mg	9.70	8.25	4.76	7.83	4.70	9.75
K	1.00	1.66	1.94	1.61	1.10	0.90
Na	2.28	1.04	2.76	1.61	0.91	1.00
CEC (me/100 g soil)	40.50	38.00	30.10	39.80	36.00	39.20
BSP (%)	72.5	76.0	70.0	80.0	56.0	86.2
ESP (%)	5.63	2.74	6.90	4.05	2.53	2.55
Org. Carbon (%)	1.5	1.35	1.42	1.50	1.44	1.41
Total N (%)	0.14	0.75	0.29	0.34	0.10	0.12
Avail. P (ppm)	24.15	11.27	5.15	14.6	10.0	4.00
Trace elements						
Cu (ppm)	3.38	4.96	3.96	3.64	nd	nd
Fe (ppm)	3.04	2.38	2.74	3.60	nd	nd
Zn (ppm)	0.36	0.74	0.60	0.68	nd	nd
Mn (ppm)	14.80	7.24	17.10	10.64	nd	nd
PH (1:2.5)						
H_2O	6.3	6.0	6.0	6.6	7.0	6.5
KCL	5.9	6.1	5.9	5.8	6.8	6.0
EC (mS/cm)	0.87	0.99	2.45	2.10	1.10	0.95

Source: Soil survey, 1994

nd = not done

The soils in the study area are generally eutric with base saturation greater than 50%. The soil mapping units are slightly acid to neutral except soil mapping unit 12 with alkaline top soils. Soil salinity is currently low in most soil mapping units with potential buildup in soil mapping units 10 and 11. Trace elements in all the mapping units show normal ranges although low levels of manganese occur in soil mapping unit 2W(yellow) (Landon, 1991).

5.5.1 Soil properties of Mapping Unit 2W(r) subunit

Simecha clay loam is the most prevalent in the 2W(red) subunit. The subunit 2w(r) extends 212 ha and has generally deep, moderately well drained, high ground water table, dark brown (10 YR 3/3) clay loams. The subsoils are characterised by dark yellowish brown colour. The soil structure is coarse moderate subangular blocky with a weak, medium crumb structure. The analytical results, physical and chemical analyses are given in Table 5.10. The soils have a good textural composition with minimum textural changes with depth probably due to agricultural activities like ripping, ploughing and mechanical weeding, although sand is lower in the subsoil.

The chemical status of the soil show medium cation exchange capacity, base saturation and nitrogen levels (Landon, 1991). The soil reaction show some slight acidity (P^H 1:2.5 water) that decrease with depth (6.3 to 6.0), an indication of adverse soil chemical build up in the subsoil probably due to fluctuations in the ground watertable. Calcium levels are medium while magnesium levels show stable trends in both topsoil and subsoils (Landon, 1991).

Potassium levels (0.44 - 0.53 me/100 g soil) are high, higher in the subsoils than in topsoils (Dent and Young, 1981). Sodium, although not an essential plant nutrient used as a partial substitute for potassium, show a decrease, from 0.11 me/100 g soil to 0.10 me/100 g soil. Surface levels (ESP) however, show indications of developing sodication (Landon, 1991). Available phosphorus (Olsen) levels are medium (Landon, 1991).

The trace elements; copper, zinc, iron and manganese are affected by the redox potential of the soil and their availability differ considerably from day to day (Landon, 1991). The levels of these elements in the soil show normal ranges for copper, zinc, iron and manganese deficiency (Landon,1991). The manganese deficiency could be attributed to poor soil drainage and subsequent low soil temperatures (Landon, 1991). Iron deficiency and low zinc could be attributed to poor soil aeration, low organic matter, soil compaction (as shown by high bulk densities) and high available phosphorus that adversely affect zinc availability.

Low zinc however, has little consequences since sugarcane has low zinc requirement (Landon, 1991). The soil salinity (0.3 mS/cm) is too low to have any significant effect on sugarcane yield (Bunyolo *et al.*, 1982 and Landon, 1991).

As shown in Table 5.10a below, the soil bulk density increases with soil depth. The available water capacity of 23% to 28% (vol.) show that the soils have a high moisture storage capacity (Landon, 1991).

The infiltration capacity (12.0 cm/h) show a marginally suitable soil for surface irrigation (Njos, 1974; Landon, 1991). Msoni and Mulenga (1992) reported similar trends in Typic Argiustolls at Nakambala Sugar Estate.

5.5.2 Soil properties of Mapping Unit 2W(y) subunit

Soil properties in soil mapping subunit 2W(y) are similar to those in subunit 2W(r). The results of soil physical and chemical analyses are given in Table 5.10. This subunit comprise Simecha clay loam, with topsoils predominantly yellowish brown (10YR 5/6) in colour, moderately to poorly drained, characterised by weak medium subangular blocky structure in top soils and coarse moderate subangular blocky structured subsoils. Agricultural activities have not had any serious effect on texture, although sand, like in subunit 2W(r) is lower in the subsoils. The soil subunit is suitable for surface irrigation judging from a basic infiltration rate of 10.5 cm/h (Landon, 1991.). The soil subunit has generally high bulk densities of 1.5 g/cm^3 (topsoils) to 1.6 g/cm^3 (subsoils) and low water holding capacity, an indication of soil compaction. The soil salinity is low.

The organic carbon, (0.95 - 0.63%) and nitrogen (0.31 - 0.20%) are low and show a decrease with soil depth. The low soil reaction (P^H 1:2.5 water) and low salinity level (0.40 mS/cm) show a salt free soil (FAO-UNESCO, 1979; Landon, 1991).

Msoni and Mulenga (1992) reported similar trends in farm 10 of Nakambala Sugar Estate. Exchangeable cations show varying rates; medium calcium, high magnesium, low potassium and low exchangeable sodium percent (Landon, 1991). The overall CEC and available phosphorus, are medium. Njos (1974) reported similar estimates in Simecha series during the second extension phase of Nakambala.

Table 5.10a Soil physical properties (all mapping units)

	Soil mapping unit											
	2W(r)		2W(y)		10		11		12		13	
Depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
Texture lab.	CL	CL	CL	CL	C	C	C	C	C	C	C	C
Sand (%)	42.0	34.5	40.0	38.6	40.5	34.0	34	30	32	30	22	17
Silt (%)	23.5	30.5	24.0	26.5	27.5	19.0	25	27	26	22	36	24
Clay (%)	34.5	35.0	36.0	34.9	42.0	36.9	41	43	42	48	42	59
Bulk density (g/cm^3)	1.40	1.58	1.50	1.60	1.35	1.47	1.46	1.58	1.51	1.63	1.50	1.59
Water holding capacity (v/v %) at P^F												
0.0	39	38	35	36	40	39	34	39	36	41	40	42
2.0	33	34	31	32	32	36	31	33	32	34	38	39
2.2	18	24	26	25	28	25	26	29	30	32	33	36
3.0	16	20	23	22	24	23	21	23	28	31	30	32
4.2	13	19	21	21	20	22	19	22	21	24	25	27
AWC (vol %)	28	23	10	11	12	14	12	10	11	10	13	12

Source: Soil survey, 1994

Table 5.10b Soil chemical properties and analytical data (all mapping units)

	Soil mapping unit											
	2W(r)		2W(y)		10		11		12		13	
Depth (cm)	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60	0-30	30-60
Exchangeable cations (me/100 g)												
Ca	4.2	5.1	6.5	5.0	17.6	18.9	10.3	12.5	9.0	11.0	19.4	28.9
Mg	1.3	1.3	3.5	3.3	3.1	5.6	3.35	3.17	7.2	6.3	4.0	3.2
K	0.44	0.53	0.13	0.13	0.81	0.66	0.93	0.43	0.34	0.22	0.45	0.14
Na	0.11	0.10	0.64	0.67	2.11	1.00	1.20	0.99	1.50	1.40	1.12	1.18
CEC (me/100 g)	20.01	21.59	36.0	32.0	35.0	40.0	20.0	24.9	35.0	33.0	50.0	56.0
BSP (%)	62.3	55.6	75.5	71.2	69.4	70.1	87.0	53.0	55.0	60.0	64.0	45.0
ESP (%)	1.10	0.86	1.78	2.09	6.03	2.50	6.00	3.9	2.7	4.1	2.24	2.11
Org. C.(%)	0.97	0.73	0.95	0.63	1.40	0.80	1.11	1.04	1.13	1.08	1.61	0.70
Total N (%)	0.24	0.15	0.31	0.20	0.29	0.11	0.1	0.1	0.25	0.15	0.18	0.12
Avail. P. (ppm)	10.1	8.4	12.0	15.0	5.10	11.0	14.0	9.0	15.0	12.0	6.0	7.0
PH (1:2.5)												
H_2O	6.3	6.2	7.2	7.3	6.0	6.2	6.5	7.0	7.5	7.7	7.0	7.5
KCL	5.4	5.1	6.1	6.2	5.9	6.1	5.9	6.1	6.1	6.5	5.6	6.2
EC (mS/cm)	0.3	0.2	0.4	0.3	2.4	1.8	1.0	1.1	1.0	1.2	0.4	0.1

Source: Soil survey, 1994

5.5.3 Soil properties of soil Mapping Unit 10

The soils in this mapping unit (65 ha) comprise Wanga Eutric Vertisols (FAO-UNESCO, 1974), of deep, olive black (7.5YR 3/1), poorly drained clays, characterised by dark olive brown colour in the subsoil. The soil structure is moderate fine subangular blocky topsoil, medium to angular blocky structure in the subsoil. The soil physical and chemical properties of the soil mapping unit are given in Table 5.10 above.

The soil texture is predominantly clay (42%- 36.9%) although textural variations occur with depth. The soils are slightly acidic (P^H 1:2.5 water, 6.0 - 6.2) and currently salt free with an electrical conductivity of the saturated extract ranging from 2.4 to 1.8 mS/cm (Landon, 1991). Nitrogen levels (0.29-0.11%) are medium with low organic carbon decreasing with increase in soil depth. Bunyolo *et al.* (1983) envisaged similar trends when evaluating the properties, management and classification of vertisols in Zambia.

The high base saturation (69 - 70%) and high exchangeable cations show soils of high natural fertility. Sodium levels are low in the top soil, although there is a sign of potential sodication development. Available phosphorus (8-10 ppm) indicate medium levels showing a decrease in the subsoil (Landon, 1991). Trace elements in topsoil show adequate levels as similarly reported by Daka (1988) and Bunyolo *et al.* (1982) whilst working in similar soils at the Kafue Polder.

Results in Table 5.10a above, show medium available water capacity of 110.3 mm/m, medium bulk densities (1.35-1.47 g/cm^3) and medium infiltration capacity (10 cm/h) (FAO, 1979a).

5.5.4 Soil properties of soil Mapping Unit 11

The degraded Kembe clay (Doyle *et al.*, 1969) covering 150 ha, has black (10YR 2/1) to dark grey (10YR 3/1) moist clays with fine to medium subangular blocky structure in top soils and coarse angular and coarse prismatic structure in the subsoil. The soils are hard when dry, firm when moist and sticky and plastic when wet. The soil physical and chemical properties are given in Table 5.10 above.

The soils are predominantly clay (41-43 %), with high silt, slightly acidic to neutral an indication that these soils were derived from basic rocks such as basalt and limestone (Veldkamp, 1983). The low salinity (ECe, 1.10-1.04 mS/cm), has little adverse effect on sugarcane growth requirements (Landon, 1991). The soils are characterised by low organic carbon and nitrogen with high available phosphorus (14 ppm) in top soil to medium (9 ppm) in subsoil. Exchangeable cations are adequate in the soils with a medium cation exchange capacity (CEC) and adequate to normal ranges of trace elements (Landon, 1991).

The results in Table 5.10 above show that the soils have high moisture retention capacity (Landon, 1991). The basic infiltration of 10 cm/h makes the soil marginally suitable for surface irrigation (Landon, 1991), although recorded infiltration rates vary from 0.05 cm/h to 40 cm/h in the same area depending on soil moisture condition (Bunyolo *et al.*, 1983). Bulk density increases with depth (1.46 to 1.58 g/cm^3), indicating naturally heavy soils that are prone to compaction. Njos (1974) conducted a land suitability classification whilst working in similar soils and classified such soils as less suitable (class 3) for irrigated sugarcane due to poor drainage and structure limitations.

5.5.5 Soil properties of soil Mapping Unit 12

The soil mapping unit comprises Kembe clay and cover 67 ha. The soil physical and chemical analyses are presented in Table 5.10 above.

These soils are shallow, topsoils are black (10YR 2/1) moist to dark grey (10YR 3/1) with very dark grey (10YR 4/1) subsoils, extremely hard when dry, firm when moist, very sticky and plastic when wet and have a coarse subangualr blocky structure. Stress surfaces on pedsfaces (cracks) do occur making the land unit unfavourable for cultivation. High bulk density (up to 1.63 g/cm^3) show hard pan development (compaction) that could hinder root development and promote water stagnation on surfaces, thus increasing surface irrigation efficiency (reduce percolation) but presents serious internal soil drainage (Bunyolo *et al.*, 1983). Textural changes of the soils in this land unit is minimal and available water capacity is high, an indication that with good cultivation practices, the soil structure would improve (Bunyolo *et al.*, 1982).

The soil chemical status (Table 5.10b, above) show that the soil is naturally fertile; with high base saturation (BS) (55-60%) and cation exchange capacity above the 8-10 me/100 g of soil range (minimum values in top 30 cm of soil) for satisfactory production under irrigation (FAO, 1979; Landon, 1991). The soil reaction is neutral to alkaline and increases with depth probably due to increase in calcium carbonate nodules.

Soil salinity and sodication hazard are low and no adverse effect on sugarcane growth would be anticipated. Low organic carbon, medium to low nitrogen, shallow effective soil depth, structure and poor drainage are major constraints to crop production in the unit.

5.5.6 Soil properties of soil Mapping Unit 13

The soils of this mapping unit (51 ha in extent) occur mainly near natural drainage channels. These soils are dominated by shrinking and expanding clays very dark brown (2.5YR 3/2) moist and very dark grey (10YR 3/1) dry topsoil and dark greyish brown (2.5YR 3/2) to dark grey subsoil mainly, montmorillonite and illites that are characterised by wide, deep cracks (1-1.5 cm wide) and slickensides (Daka, 1988). Doyle *et al.* (1969) and Njos (1974) classified this type of land unit as unsuitable for irrigated sugarcane production due to unfavourable soil physical characteristics. The soil chemical and physical characteristics from laboratory analyses are given in Table 5.10 above.

The soils are predominantly eutric clays with neutral to alkaline reaction attributed to high calcium carbonates (nodules). Despite the dark colour, the soils are low in organic carbon (highest in topsoil and lowest in subsoil) and subsequently low in nitrogen (Bunyolo *et al.*, 1983).

Available phosphorus is deficient in the topsoil (composite sample results) probably due to soil acidity. The natural fertility of the soil is however, reflected by high cation exchange capacity and high base saturation. The shallow effective soil depth, low basic infiltration rate, poor drainage, soil structure and irrigation management were recognized as major limitations to crop production in this mapping unit.

5.5.7 Sugarcane growth requirements

The crop requirements for irrigated sugarcane that were considered relevant in the study from the general soil resource survey are presented in Table 5.11. Other crop requirements like radiation and temperature regimes, moisture availability, condition for ripening, pests and diseases, were not considered, because these were considered optimum under the prevailing climatic conditions and crop management practices. Sugarcane growth requirements data was mainly deduced from literature (Doorenbos *et al.*, 1979; Dent and Young, 1981; Bunyolo *et al.*, 1982,1983; FAO 1983; Daka 1988; and Landon, 1991). Due to difficulties encountered in direct interpretation of some of the crop requirements, qualitative expressions, like medium to high waterlogging tolerance, were used to infer the equivalent of quantitative limiting conditions.

Table 5.11 Sugarcane growth requirements

Land attribute		
Oxygen availability		
(a) Water table (cm)		> 150
(b) Water logging tolerance		Medium to high
Nutrient requirement (availability)		
(a) Nutrient need		High
(b) N:P:K (Min. Kg/ha)		150:60:140
(c) P^H optimum range		6.0 - 7.5
absolute range		4.5 - 8.5
(d) P (ppm) High		> 21
medium		12 - 20
Low		< 11
Rooting conditions		
(a) Depth (cm)	s1	> 90
	s2	60 - 90
	s3	30 - 60
(b) Main nutrient uptake		120 - 200
(c) Soil consistence		Fine to medium
(d) Rooting pattern		85% in top 90cm
Excess of salts		
(a) Sodicity (ESP)	s1 Low	< 10
	s2 Medium	10 - 15
	s3 High	> 15
(b) Salinity (ECe mS/cm)	s1	< 4
	s2	4 - 10
	s3	> 10
Soil erosion		
erosion hazard		Low at full canopy

Source: FAO (1983); Landon (1991)

5.5.8 Land qualities

The results on land qualities (or attributes) required for land suitability assessment are given in Table 5.12 below. Oxygen availability is particularly limiting in four mapping units namely, 10, 11, 12 and 13, due to poor drainage. Nutrient availability in soil mapping units 10, 12 and 13 was limiting in all mapping units due to low available phosphorus. Nutrient retention however, was high (> 20 me/100 g soil of total exchangeable bases (TEB)) in all the mapping units (Landon, 1991). Potential dangers of sodication occur in soil mapping units 2w(r), 10 and 11. Soil physical degradation was observed (mainly capping and occurence of salty patches of bare land) in some fields with heavy clays and subsequently high compaction hazard although crusting indices showed low crusting hazard (FAO, 1983). Soil workability was mainly limiting in mapping units with high clay content, high bulk densities and firm consistence. Excess salts in terms of salinity hazard were potentially high in soil mapping units 10 and 11.

Table 5.12 Mapping unit land attributes

Land attributes	Soil mapping unit 2W(r)	2W(y)	10	11	12	13
Oxygen availability						
(a) Ground w/table (cm)	100	90	75	80	70	60
(b) Drainage class	mod.	mod.	poor	poor	poor	poor
(c) Infil. rate (cm/h)	12.0	10.5	13.0	5.0	10.0	8.0
Nutrient Avail. (a) CEC (me)	62.3	75.5	69.4	87.0	55.0	64.0
(b) P^H (1:2.5 water)	6.3	6.0	6.0	6.6	7.0	6.5
(c) Total N (%)	0.14	0.75	0.29	0.34	0.10	0.12
(d) Available P (ppm)	24.2	11.3	5.2	14.6	10.0	6.0
(e) Organic carbon (%)	1.5	1.35	1.42	1.50	1.44	1.41
(f) Base saturation (%)	72.5	76.1	70.1	80.1	56.0	86.2
Nutrient retention capacity						
Tot. exch. bases (TEB) (me)	29.4	28.8	28.1	31.8	20.2	33.8
Rooting conditions						
(a) Bulk density (g/cm^3)	1.49	1.55	1.41	1.52	1.57	1.54
(b) Effect. soil depth (cm)	>150	>150	100-150	85-100	75-100	< 75
(c) Moist consistence	friable	friab.	friab.	firm	firm	V.firm
Excess of salts (a) Sod. ESP%	5.63	2.74	6.90	4.05	2.53	2.55
(b) Salinity ECe (mS/cm)	0.87	0.99	2.45	2.10	1.10	0.95
Physical degradation						
(a) Crusting index	1.07	0.53	0.54	0.72	0.87	0.83
(b) Hazard to compaction	mod.	mod.	high	high	high	v. high
Soil toxicities: Presence of calcite nodules in the horizon.	none	none	slight	slight	pres.	pres.
Soil erosion hazard: Field observation		Very low in all the units				
Soil workability: Soil tex.	fine	fine	med.	med.	coarse	coarse
consistence	friable	friable	friab.	firm	firm	v. firm

Source: Soil survey, 1994

5.5.9 Land suitability classification

The results of a preliminary matching of crop growth requirements with land qualities are presented in Table 5.13 and the spatial distribution of the suitability of the mapping units, is presented in Figure 14 (with a legend). The overall suitability classification was based on the most limiting land quality. The common limitations in all the mapping units were, oxygen availability, rooting conditions and soil physical degradation.

Table 5.13 Land suitability classification

Land quality	Mapping unit 2W(r)	2W(y)	10	11	12	13
Oxygen availability	s2w	s2w	s3w	s3w	s3w	s3w
Nutrient availabilty	s1	s2	s3	s3	s3	s3
Soil workability	s1	s1	s2	s3	s3	s3
Excess of salts	s1	s1	s1	s1	s1	s1
Soil erosion hazard	s1	s1	s1	s1	s1	s1
Nutrient retention	s1	s1	s1	s1	s1	s1
Rooting conditions	s1	s1	s2	s3	s3	s3
Land degradation	s2	s2	s2	s3	s3	s3
Soil toxicities	s1	s1	s2	s3	s3	N1
Overall suitability	S2wc	S2wc	Sc3wd	S3	S3	N1

Source: Soil survey, 1994

Oxygen availability limitation is due to poor drainage and shallow ground watertable. This has adverse effects on the crop in that nutrient uptake is impaired. The shallow ground water table inhibits root growth in deeper layers and salt buildup cannot be ruled out within the root zone

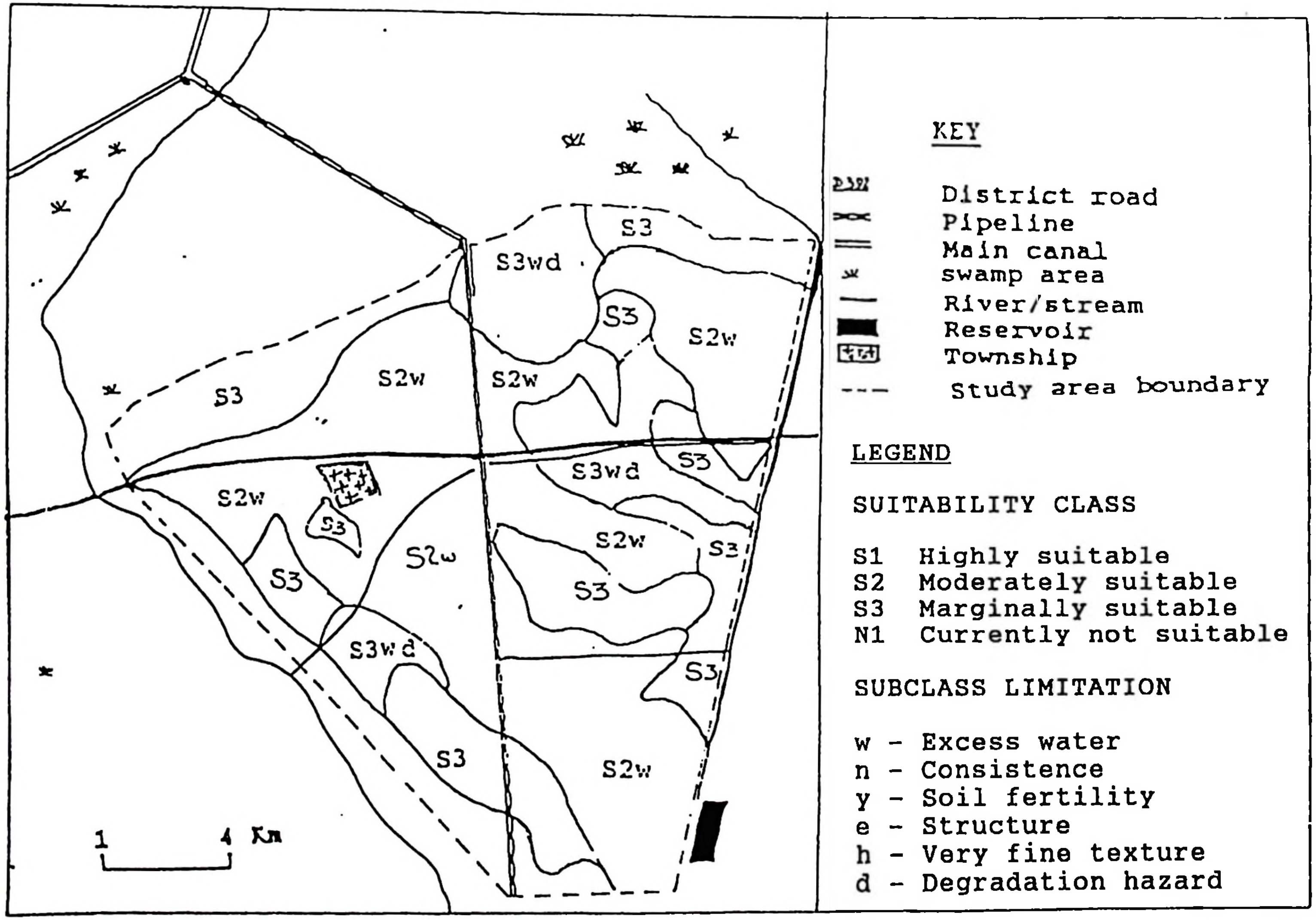


Fig. 14 Land suitability map of farm 11 & 12, Nakambala.

in fluctuating watertable. Development of anaerobic environment within the root zone could lead to reduction of nitrates and manganese dioxide (Landon, 1991). Nutrient availability is generally high in all the mapping units, however, due to poor drainage conditions, available phosphorus is low in some cases, thus lowering the initial land suitability class. Rooting conditions are limited by soil compaction that subsequently lead to high bulk densities in some soil mapping units. Soil consistence and shallow effective soil depth in heavy clays that occur in soil mapping units, 11, 12 and 13 limit rooting conditions. The likely high risk of soil physical degradation in all the soil mapping units was limiting as noted from the high bulk densities (a sign of compacted soils) and the presence of slaking and crusting in some soils that subsequently hinder root penetration.

Land mapping subunits 2W(r) and 2W(y) are classified as moderately suitable (S2) for irrigated sugarcane, due to nutrient availability (subunit 2W(y)) and oxygen availability limitations as well as moderate land degradation. Njos (1974), using irrigability and land capability classification based on soil texture, soil depth to limiting layer, drainage, slope, infiltration rate and available water capacity, classified similar soils as moderately suitable (class 2) using soil wetness as the main limiting condition. Soil drainage is recommended so as to make the soil mapping highly suitable (S2w/D/S1) for irrigated sugarcane. Soil mapping unit 10 is classified as conditionally marginally suitable (Sc3wd) because of oxygen limitation and soil physical degradation hazard. Surface and subsurface drainage is recommended so as to raise the soil mapping unit to moderate suitability for irrigated sugarcane (Sc3wd/D/S2) class (Bunyolo *et al.*, 1983).

Soil mapping units 11 and 12 are marginally suitable (S3) due to poor oxygen availability, shallow effective soil depth and soil physical degradation. Oxygen availability limitation is due to poor drainage while rooting is limited by shallow effective soil depth and firm soil consistence. The soil physical degradation hazard is due to the presence of prevalent sealing on the soil surface and high bulk densities.

Although soil physical degradation is easy to combat, soils may still suffer substantial lowering of crop yields through deterioration in physical properties (FAO, 1983). Soil mapping improvements could include drainage and regular ripping since soil structure tends to improve with cultivation. Subsurface drainage seems to be impractical because of the slow hydraulic conductivity, inherent in the soils (Bunyolo *et al.*, 1982). An alternative crop for the soil mapping units, like paddy rice would be the best and less costly management decision. Doyle *et al.* (1969) and Njos (1974) classified similar soils as marginally suitable (S3) based on poor drainage, shallow effective soil depth and soil workability.

Land mapping unit 13 is not suitable for sugarcane production under irrigation. The severe limitations include; poor drainage conditions; compaction (high bulk density) hard pans (capping), very firm soil consistence that seriously hinder root penetration and soil workability. The potential of soil physical degradation is high as slaking/sealing patches are common. Soil toxicities are also envisaged as calcite nodules are present throughout the horizons. Doyle *et al.* (1969) recommended that the development of such a land unit should be limited to assisting drainage from nearby cultivated land units. The problems of tilling these soils would be high costs as it would require a lot of power to till such naturally compacted soils (Bunyolo *et al.*, 1983).

5.5.10 Soil status comparison and soil physical degradation assessment

The soil physical degradation was further assessed by use of indices given in the tables in section 4.2.5. The comparisons were not complete, however, due to inadequate and missing relevant data from literature about the study area. Earlier works left out important soil physical parameters like bulk density and hydraulic conductivity. Table 5.14 below shows the trends in crusting hazard from textural analysis. Soil subunits in mapping unit 2W were more prone to crusting than the other soil units.

Table 5.14 Crusting indices

Soil Unit	Index 1969[1]	1994[2]
2W(r)	1.45	1.07
2W(y)	1.79	1.16
10	0.74	0.52
11	1.00	0.72
12	1.41	0.87
13	1.18	0.85

Source 1: Doyle *et al.* (1969); 2: Soil survey, 1994.

The situation has changed during the last 25 years, probably due to the beneficial effects of cultivation and the fibrous rooting nature of sugarcane. The other soil units were less prone to crusting, although there is an increasing likelihood that due to chemical degradation, the situation would deteriorate.

Table 5.15 below shows trends in biological degradation for the soil mapping units in the study area. Biological degradation was moderate in soil mapping units 2W and 11, none to slight in mapping units 10 and 12. Soil mapping unit 13 showed an increase in organic carbon content, an indication that there could have been a reduction in biological degradation hazard.

Table 5.15 Biological degradation assessment

Soil mapping unit	Organic carbon (%) 1969[1]	1994	(%) Decrease/ increase/year
2W(r)	1.45	0.97	1.32
2W(y)	1.38	0.95	1.25
10	1.13	1.40	(0.95)
11	1.67	1.11	1.34
12	1.43	1.13	0.85
13	1.01	1.61	(2.37)

Source 1: Doyle *et al.* (1969); Soil Survey, 1994.

The results of chemical degradation assessment in terms of salinity and sodication are shown in Table 5.16. The sodium and base saturation indices show that soil subunit 2W(r) had a higher risk of sodication than subunit 2W(y), although the latter had deleterious effects of inundation. Soil sodication risk was higher in soil mapping units 10, 11 and 12. Soil mapping unit 13 apparently had moderate sodication risk. Chemical degradation due to acidification risk was none to slight in all the soil mapping units.

The risk of soil physical degradation from field observations and laboratory analyses (Table 5.14) show that high bulk densities and low porosity in most soil mapping units indicate a sign of soil compaction. Slaking (surface crusting and sealing) was observed in four soil mapping units, namely; units 10, 11, 12 and 13, but it was prevalent in soil mapping units 11, 12 and 13. A comparison of crusting indices from top soils (0-30 cm) over a period of 25 years (Table 5.14) show that soil mapping units that were prone to crusting had improved probably due to beneficial effects of cultivation and the crop rooting characteristics. The slaking observed therefore, could be attributed to cation imbalance and other element ratios. When calcium is available in lower amounts than magnesium, soil structure may become weaker due to increased deflocculation of clay. High exchangeable sodium percent could also have deleterious effects on soil structure (Landon, 1991).

Table 5.16 Chemical degradation assessment

Soil unit	ESP (%) 1969[1]	ESP (%) 1994	ESP (%) Decrease/ Increase per year	BS (%) 1969[1]	BS (%) 1994	BS (%) Decrease/ Increase per year
2W(r)	0.23	0.98	(3.06)	54.4	58.9	0.33
2W(y)	2.65	1.94	1.07	50.6	73.4	1.80
10	0.67	4.26	3.37	72.0	69.5	0.15
11	0.91	4.95	3.26	70.0	70.0	0.00
12	0.21	3.45	3.76	75.1	57.5	0.93
13	4.36	2.17	2.01	89.8	54.5	1.57

Source: Doyle et al. (1969); Soil survey, 1994

Note: ESP (%) and BS (%) indicate sodication and acidification, respectively.

The use of arbitrary procedures in the selection of soil properties and ratings, the possibility of bias in choice of parameters and the complexity and obscurity of the ratings obtained (not translatable into management terms), make the use of indices in land evaluation of limited universal application. However, the use of judiciously designed index system has proved to be satisfactory guides to rural development (Landon, 1991). In Zambia, for instance, a system of land evaluation is being developed to assess the suitability of rainfed agriculture in different agro-ecological zones. The system considers soil degradation by adoption of a parametric approach in which each type of soil degradation is considered using indices (Mukanda *et al.*, 1992).

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study reveals that human population has almost doubled over the past two decades and is expected to exceed 43 000 by the turn of the century. It can therefore be said that some correlation exists between the population size and its service function in the study area.

Besides the financial and employment benefits that the sugar scheme had brought, adverse effects include ecological changes in terms of land use changes and pressure on finite land resources. The sugar plantation expansion into commercial agricultural land and into natural vegetated areas, has led to a severe fuelwood shortage.

The study brought to the fore the link between energy utilization and environmental degradation in terms of deforestation. Fuelwood and its predominant role as energy source, high end usage frequency and general scarcity in the area (due to restrictive land tenure system) had acquired a monetary value which allowed it to be trucked from long distances. Dependency on fuelwood by a rapidly growing population exposed the potential dangers of indiscriminate commercialisation of fuelwood production in the areas around the sugar plantation.

Drought, deforestation and soil erosion are the triad environmental problems in Zambia. Increasing pressure on arable land and fuelwood are the two major causes of soil erosion in the country. The indiscriminate cutting of trees in a drought prone area such as Nakambala would accentuate land degradation in the long run. The lack of visible evidence of the most common and devastating form of physical land degradation, (that is, soil erosion) in the study area, is masking the soil fertility and biological degradation. The silent buildup of present soil chemical degradation, especially sodication, could lead to soil crusting, sheet erosion and subsequently, crop failure.

The application of soil and land evaluation surveys in environmental impact assessment has shown that quick and general natural resource surveys could give useful results. Application of such assessment techniques has shown that potential soil physical and chemical degradation risks exist in the study area. It has also shown that soil mapping units with poor drainage and shallow effective soil depth, namely: soil unit 11, 12 and 13, are less suitable for sugarcane growing.

Waterlogging, is one of the forms of land degradation prevalent in the area. This has had a negative effect on the productive potential of most of the soil mapping units. The continued practice of growing irrigated sugarcane without the appropriate provisions of drainage in the less suitable soil mapping units would aggravate land degradation.

6.2 Recommendations

Among the major resources available to man is land, comprising of soil, water and associated plants and animals. The use of these resources should not cause their degradation or destruction because man solely depends on their continued productivity. Irrigation plays an important role in helping man satisfy his basic needs. The environmental impact of irrigation may include, siltation of river systems, soil erosion, soil physical and chemical degradation.

The results from this study should not be extrapolated to other schemes. It would however, be unwise to assume that pressure on limited land resources does not exist in areas with such schemes. In view of this, the following general recommendations can be made:-

1. There is a need to carry out a complete environmental impact assessment for the whole sugar scheme;
2. Soil mapping units that are less suitable for irrigated sugarcane production (i.e. units 11, 12 and 13), should be considered for other land uses such as

paddy rice production;

3. In order to minimise the build up of salts, it is advised to install a very reliable drainage (surface and subsurface) infrastructure;

4. Sugar estate management should not ignore professional and very economically rewarding advice in soil survey reports concerning the suitability of soils for various crop production scenarios since monocropping in the fragile ecosystem can prove disastrous in the long run.

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8.0 APPENDICES

Appendix I Climatic data for Nakambala (Long term means) 1965/66 to 1993/94.

Month	Rainfall (mm)	Pan Evap. (mm)	Mean Max. temp. (°C)	Mean min. temp. (°C)	Average temp. (°C)
Jul	0.0	160	24.8	9.8	17.4
Aug	0.0	205	27.3	11.9	19.6
Sep	2.7	248	31.0	15.4	23.2
Oct	19.0	267	32.3	17.7	25.0
Nov	74.3	204	31.2	18.3	24.7
Dec	181.3	156	28.9	18.2	23.5
Jan	162.2	136	28.4	18.1	23.2
Feb	152.0	121	28.4	17.9	23.2
Mar	83.5	143	28.7	17.2	22.9
Apr	25.5	156	28.2	15.3	21.8
May	3.1	155	26.9	12.9	19.9
Jun	0.3	141	24.9	10.1	17.5

Source: Nakambala Meteorogical Station (1994).

Appendix II Aerial photographs used in the study: Contracts; 70/1A Southern province, ZA91/1 Southern province May-June and 70/1-A Lusaka-Livingstone: 1:30 000.

Year	Run number	Photograph number				
1970	13	1789	1790	1791	1792	1793
1970	14	1962	1963	1964	1965	1967
		1968	1969			
1970	15	2152	2153	2154	2155	
1991	49A	35	36	37	38	
1991	50	30	31	32	33	34
		35	36			
1991	51	40	41	42	43	

Source: Survey Department, Airphoto library, Lusaka.

Appendix III Average levels of fuelwood productivity

Types & Species of wood vegetation	Productivity (m^3/ha/year)
Closed broadleaved forests (NHC)	3.0
Formations with dominant coniferous (NS)	2.0
Wooded savanna (NHO1)	1.0
Savanna with trees (NHO2)	0.5
Shrub formations (nH)	0.1
Forest fallow (NHca, NSa)	1.0

Source: de Montalembert and Clement (1983).

NHC = Species such as palms, raphias with > 50% crown cover and more than 7 m high.

NS = Predominantly coniferous species e.g. of genus *Podocarpus*, more than 7 m high in mature trees.

NHO1 = Mixed broadleaved forest-grassland formations covering more than 40 % groung.

NHO2 = As in NHO1, but the wooded savanna with trees 10- 40 % cover.

nH = Formations in which the woody element consists essentially of deciduous shrubs and bushes thickets, shrub savanna) more than 50 cm high but below 7 m high.

NHCa (NSa) = Forest fallow of all complexes of woody vegetation derived from clearing by shifting cultivation of closed, broadleaved forests or coniferous forests consisting of a mosaic of various reconstitution facies (secondary bush).

Appendix IV Energy and Fuelwood balance

	Year		
	1970	1991	2000
Energy (10^{12} J)			
Supply	8.780	6.392	5.365
Demand	37 787	33 176	68 008
Balance	- 37 778	- 33 169	- 68 003
Fuelwood (m^3/year)			
Supply (potential)	823	599	503
Demand	6 270	5 505	11 285
Balance	- 5 447	- 4 906	- 10 781

Source: Determined from 1970 and 1991 aerial photography and average fuelwood productivity by de Montalembert, *et al.* (1983).