AN INVESTIGATION OF THE AMOUNT AND ENVIRONMENTAL IMPACT OF CHEMICAL FERTILIZERS AND PESTICIDES RUNNING OFF FROM COMMERCIAL AND TRADITIONAL FARMLANDS IN THE UPPER KALEYA CATCHMENT, MAZABUKA, ZAMBIA

By

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APPROVAL

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DEDICATION

To the Almighty God, Jehovah EL Shaddai

DECLARATION

I, Astridah Chipili Zgambo, do solemnly declare that this dissertation represents my own work and has not previously been submitted for a degree at this or other university.

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ACRONYMS

APHA	American Public Health Association
CFA	Commercial Farm A
CFA_1	Commercial Farm A down slope
CFA_2	Commercial Farm A upslope
CFA_r	Commercial Farm A river
CFB	Commercial Farm B
CFB_1	Commercial Farm B down slope
CFB_2	Commercial Farm B upslope
CFB_r	Commercial Farm B river
CS	Control Site
CS_1	Control Site down slope
CS_2	Control Site upslope
CS_r	Control Site river
CSO	Central Statistic Office
ECZ	Environmental Council of Zambia
FAO	Food and Agriculture Organization
GRZ	Government of the Republic of Zambia
K	Potassium
MIT	Massachusetts Institute of Technology
N	Nitrogen
P	Phosphorus
TF	Traditional Farm
TF_1	Traditional Farm down slope
TF_2	Traditional Farm upslope
TF_r	Traditional Farm near river
UNESCO	United Nations Education, Scientific and Cultural Organization
UNZA	University of Zambia
WHO	World Health Organization

DEFINITION OF TERMS

Terms related to pollution studies are defined below. Some words are known to have many definitions, however, the following terms are defined according to how they are used in the study:

- **Agrochemicals:** This is a composite term that includes all chemicals used to improve crop yields such as fertilizers and pesticides.
- **Contamination:** Water contamination refers to the reduction of possible usefulness of water. Contaminant is here defined to be a solute that is present in water at a concentration above levels fixed by national or international standards for portable, industrial, recreation or agricultural purposes (UNESCO, 1998).
- **Fertilizer:** In the study is any inorganic material of synthetic origin that is added to the soil to supply nutrient elements for the plant growth (UNESCO, 1998).
- **Leaching:** is the removal of material in solution from soil. In this study it refers to the transfer of nutrient material out of the soil profile and on land surface into the river system (UNESCO, 1998).
- **Nutrients:** Plant nutrients are the elements or group of elements taken in by plant which are essential to its growth and used in elaboration of its food and tissues (UNESCO, 1998). In this study it is synonymous with 'fertilizers'.
- **Pesticides:** The word pesticide is a useful omnibus term, which covers all chemical agents used by man to kill or control living organisms. It includes (weed killers) herbicides, fungicides, insecticides, nematicides, mullouscides and rodenticides and often held to include chemasterilants and growth ectarders (William *et al*, 1971; Hill and Wright, 1978).
- **Pollutant-** According to UNESCO (1998), it is a substance of effect, which adversely alters the environment by changing the population growth rate of species, interferes with food chain, is toxic or interferes with health, comfort amenities or property values of people.
- **Pollution:** Pollution of water is the addition of undesirable foreign matter, which deteriorates the quality of water. Water quality may be looked at from the

point of view of fitness for beneficial uses, which it provided in the past for drinking, by man and animals, for irrigation of land and for recreation (Turks, 1972). In this report pollution is used synonymously with 'contamination' and 'degradation' of water quality.

- **Non-point pollution:** This is one of the two broad classes of water pollution. It has its source over large areas such as farms, grazing lands, abandoned coalmines or construction sites (Owen, 1968).
- **Runoff:** This refers to the total amount of water that reaches the stream, including immediate surface runoff and the rainfall which joins the stream later by infiltration (Morisawa, 1968).

ABSTRACT

Real and potential environmental quality problems have accompanied the changes in agricultural productivity in recent decades. The development of agriculture has given rise to negative environmental impacts as large quantities of fertilizers and pesticides are used in modern agriculture to increase crop production. Historically, Zambia's efforts to maintain and enhance the quality of the environment have been directed more toward problems caused by urban centers and industrial operations than by agriculture. Upper Kaleya Catchment is an important agricultural area where farmers use fertilizers and pesticides. This, compounded by the occurrence of torrential rainfall that causes a lot of runoff on land that is almost devoid of vegetation and no riparian zone, has contributed to pollution of the Kaleya River.

This study investigated the amount and impact of fertilizer loading into Upper Kaleya River of Mazabuka District in Southern Province of Zambia. It provides an opportunity to evaluate water quality associated with nutrient and pesticide use, due to prominence of intensive agriculture in the area. Storm water runoff of fertilizers and pesticides applied on farmlands have appeared to be the predominant source of non-point source nutrients and contaminants affecting surface water quality in Upper Kaleya River, a factor very much dependent on land use in the catchment.

The study involved collection of soil and water samples (river water and surface runoff) between November 1999 and March 2000 from eight sampling stations. A total of 132 samples were collected, comprising 80 soil samples, 20 river water samples, and 32 runoff samples. Parameters analysed for were pH, conductivity, nitrate (NO_3-N) and nitrite (NO_2-N) for nitrogen and phosphorus. Ancillary data used were rainfall from Kafue Polder and discharge data from Kaleya Sediment Project, University of Zambia. A questionnaire using systematic sampling was employed capturing a sample size of 30 farmers (20 traditional farmers and 10 commercial farmers). Interviews with farmers and various authorities were also conducted. The results have been presented graphically and in tables. Correlation analysis was used to determine the relationship between rainfall and discharge. Student t-tests were carried out to test significance of differences in nutrients concentration between commercial and traditional farms. The Chi-square statistic (χ^2) was employed to compare educational background between commercial and traditional farmers as well as farmers' awareness of polluting effects of nutrients and pesticides. Frequency of use of pesticides and fertilizers was also analysed. Analysis of data revealed that nutrients and contaminants from farmlands have washed into Upper Kaleya River and more of it was from commercial than traditional farmers. In soil $NO_2 - N$ was found from trace to 28.25 mg/kg on commercial farms and from trace to 24.25 mg/kg on traditional farms. In water concentrations of $NO_3 - N$ at commercial farms ranged from 7.1 to 17.84 mg/l while at traditional farms it was from 8.4 to 13.86 mg/l. Pollution of the Kaleya River from agriculture was evidently taking place. The pH (5.9-8.0) in river water was not in conformity with WHO standards (6.5-8.5) for drinking water. Conductivity in river water (26.0 - 877.0 μS/cm) exceeded WHO standards for drinking water (0.7 μS/cm) and was severe for irrigation whose limit according to WHO standards is 3.0 μS/cm. Phosphorus concentration was higher (0.20–3.40 mg/l) than the WHO recommended limit (0.3 mg/l) but was within boundary values for fixed trophic classification system whose eutrophic limit is between 35-100 mg/l, hence rendering the Upper Kaleya River the status of not being eutrophic. This suggested that the river had no sufficient phosphorus to support the growth of aquatic weeds.

It can be concluded that Upper Kaleya River is polluted from applications of fertilizers and pesticides as used by commercial and traditional farmers. However, at the time of the study nutrient concentrations seemed not to be high. But according to WHO standards the mere presence of NO_2 –N in water renders it polluted. Nitrite preferable limit is for it to be absent in drinking water, but it was present in Upper Kaleya River. Furthermore over 90% of the farmers (subsistence farmers in particular) were not aware of the polluting effects of these chemicals in the river. The excess amount of chemicals used and the fact that rainfall is often in the form of torrential thunderstorm, which enhances erosion, may in future lead to the river becoming heavily polluted. More and long-term studies are required to evaluate environmental effects of fertilizer/pesticide use in order to provide assessments of pollution and for developing cost effective pollution control and monitoring programmes.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The impact of agricultural development on the environment is currently causing great concern especially in relation to pollution of drinking water (Tyson *et al,* 1993). Environmental protection is a universal unwritten contract in which all the countries and peoples of the world are parties. But there is a slow rate of progress towards the sustainable use of water resources. Like any other agreement, however, the contract to protect the environment is susceptible to breaches and lapses of which there have been many (Kato *et al,* 1983). The result is the alarming environmental crisis we live in today, a feature, which has grown in dimension from local levels to global scales. This can be related to the fact that field data does not currently exist which can allow for any meaningful investigations, especially on small catchments. Tembo *et al* (1997) alluded to the notion that water quality monitoring in Zambia has been restricted to big rivers especially Kafue River, very little has been done on small rivers.

Agriculture can be considered the dominant source of nitrogen leading to river and lake water impairment. The purpose of this study was to investigate nutrient loading from commercial and traditional farmlands into the Upper Kaleya River Catchment in Mazabuka District of Southern Province of Zambia (Figure 1). The study, therefore sought to determine the amount and concentration of nutrients {nitrate (NO_3 -N) and nitrite (NO_2 -N) for nitrogen (N), and phosphorous (P)} in the soil and in runoff from farmlands into the Upper Kaleya River. N and P were the only nutrients studied because they are the major elements found in chemical fertilizers, which at the same time promote eutrophication. Most commonly used fertilizers are summarized in K, N and P fertilizers, which are the most important macronutrients, used in agriculture (UNESCO, 1998).

The background to this is that recent human population growth and the associated agricultural and urban development have led to large-scale wastewater discharges to aquatic environments (Havens *et al,* 1996). But, when sources of pollution are enumerated, agriculture is, with increasing frequency, listed as a major pollution contributor (Ongley, 1996). Agricultural development, therefore, has inevitable adverse effects on the environment as large quantities of agrochemicals (pesticides and chemical fertilizers) are used to maintain high crop production.

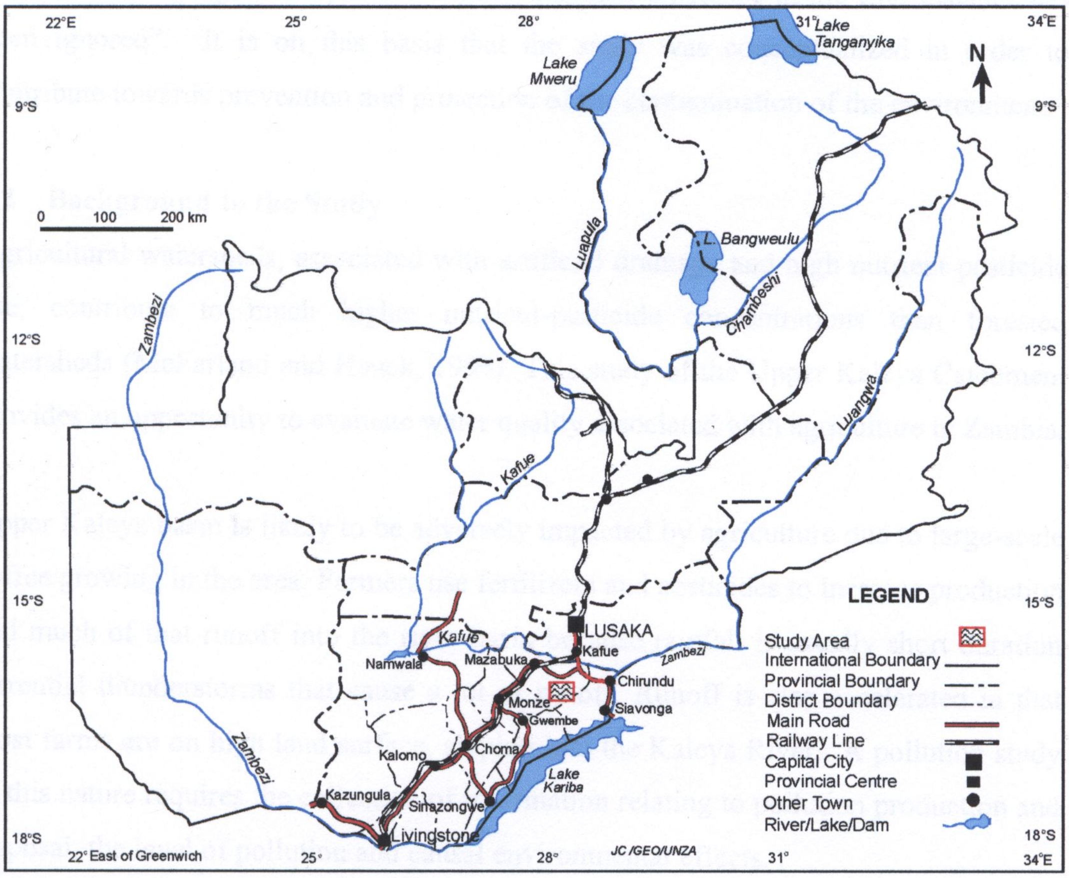

Figure 1. Location of Upper Kaleya Catchment in Mazabuka District of Zambia.

Agrochemicals eventually reach fluvial systems where they cause pollution to water bodies. Undoubtedly, their use has made enormous contributions to agriculture, for instance, without pesticides and fertilizers world food supplies would be inadequate for the growing human population (Hill and Wright, 1978). However, Hodson (1970: 84) states that "applied scientific techniques, while solving the problem with which they have been faced, more often than not, in so doing, present further unforeseen problems which become progressively harder to solve if their existence in the first instance has been ignored". It is on this basis that the study was conceptualized in order to contribute towards prevention and protection of the contamination of the environment.

1.2 Background to the Study

Agricultural watersheds, associated with artificial drainage and high nutrient-pesticide use, contribute to much higher nutrient-pesticide concentrations than forested watersheds (McFarland and Hauck, 1995). This study of the Upper Kaleya Catchment provides an opportunity to evaluate water quality associated with agriculture in Zambia.

Upper Kaleya basin is likely to be adversely impacted by agriculture due to large-scale coffee growing in the area. Farmers use fertilizers and pesticides to increase production and much of that runoff into the river basin because rainfall is usually short duration torrential thunderstorms that cause a lot of runoff. Runoff is also accelerated in that most farms are on high land surface, sloping into the Kaleya River. A pollution study of this nature requires the collection of information relating to pollution production and disposal, the level of pollution and causal environmental effects.

Farming in Upper Kaleya Catchment started a long time ago. Fertilizers and pesticides have also been in use for a long time, which gives a possibility for agrochemicals to leach into Kaleya River. Therefore, the study undertook to monitor the water for possible pesticide and fertilizer contaminants in the Upper Kaleya River. It was also important to assess the level of pollution awareness among farmers to determine whether or not they had skills in managing the environment and assess what measures have been taken to mitigate environmental impacts.

1.2.1 Statement of the Problem

Farmers in Upper Kaleya Catchment, just like anywhere else, have not been slow to grasp the significance of pesticides, such that almost all of them apply pesticides. There currently exists a wide range of pesticides, which differ greatly in their mode of action, residence times in the biosphere and toxicity. This has led to the current practice by many cultivators to apply mixtures of these pesticides in order to minimize the costs associated with treating crops for individual pests and diseases (Hill and Wright, 1978). The problem is that pesticides, which eventually move into watercourses, are toxic and cause serious pollution in aquatic environments with serious deleterious effects on aquatic life forms.

Additionally, modern farming practices involve an increasing use of chemical fertilizers to increase crop yields. However, not all the applied fertilizers are absorbed from the soil by growing crops. This leads to serious and extensive water pollution problems especially nitrogen and phosphorus which tend to cause eutrophication of inland waters and promote the growth of aquatic weeds.

Unfortunately, little do farmers, especially subsistence farmers, realize this polluting effect of agrochemicals. If agriculture has to continue, it is of utmost importance that the problems of soil and water pollution by application of pesticides and nutrients are studied in detail. The above-mentioned pollution problems apply to Upper Kaleya River because it flows in an agricultural area where large amounts of pesticides and fertilizers are used.

1.2.2 Aim

The aim of this study was to increase farmers' understanding of the movement of agrochemicals moving into the Upper Kaleya River and their impact on the river and the organisms in it. The creation of this awareness among farmers will help to increase efficiency of utilization of pesticides and nutrients and reduce opportunities for leakages of excess agrochemicals into Upper Kaleya River.

1.3 Research Objectives

The objectives of the study were to:

1. determine the difference in the concentration of chemical fertilizers in the soil and runoff between commercial and traditional farming areas;
2. determine the amount of fertilizers moved on valley slopes into the studied reach of Upper Kaleya River;
3. determine the quantity of pesticides and nutrients farmers use in pest control and soil fertility management;
4. assess ways of reducing input levels of contaminants and nutrients into Upper Kaleya River; and
5. assess farmers' awareness of the effects of agrochemicals on the soil and aquatic environment.

1.4 Research Hypotheses

This study had five research hypotheses, namely:

1. The washing of fertilizers into Upper Kaleya River is more from commercial than traditional farming areas.
2. There is a significant relationship between increase in slope gradient and amount of agrochemicals moved into Upper Kaleya River.
3. There is excessive use of agrochemicals among farmers in Upper Kaleya River.
4. Farmers in Upper Kaleya Catchment are willing to adopt conservation measures for reducing contamination of soil and water.
5. Commercial and traditional farmers are aware of the impact agrochemicals have on soil and the Upper Kaleya River.

1.5 Scope of the Study

For this study, which is an environmental risk assessment, information to give estimates of contaminant concentration from agriculture, and to assess farmers' awareness on aquatic pollution was collected. In Upper Kaleya Catchment no such data on aquatic pollution existed as few studies on small catchments in Zambia generally have been undertaken.

To come up with this kind of data, soil and water samples were collected from the commercial and traditional farming areas and were analysed in the laboratory to determine levels of pH, conductivity, nitrate, nitrite and phosphorus. No laboratory analysis of pesticide concentrations was conducted due to financial constraints.

Questionnaire surveys and interviews were conducted to collect data on the types and amounts of fertilizer and pesticide use in Upper Kaleya Catchment. Farmers' knowledge on the effects of agrochemicals on the Upper Kaleya River was also assessed. Information on the study area and farming practices was collected through visual observation and also from the Ministry of Agriculture Food and Fisheries. Rainfall and discharge data were obtained from the Zambia Meteorological Department and the Kaleya Sediment Project (UNZA, Geography Department), respectively.

The data was qualitatively and quantitatively analysed as presented in Chapter 5. This is followed up with the discussion and interpretation in Chapter 6, before conclusions and recommendations in Chapter 7.

1.6 Justification

This research is important in that it determined levels of concentration of agro-chemicals for the assessment of pollution levels. This will provide data on the possible ill-effects of agrochemicals in the aquatic environment, which have immense importance to agricultural and non-agricultural interests and more so to environmental authorities.

Through the results of this study, it is hoped that pollution and its consequences can be explained from which farmers can learn the impacts of water pollution and develop individual responsibilities required to maintain or restore the water quality. The enhancement of the farmers' knowledge and understanding of environmental pollution around them would be the necessary condition for an effective change in the state of the environment. This will allow for sustainable agricultural production to be achieved with minimum environmental damage. O'Riordan (1995) alluded to the need for the serious consideration to strike the right balance between the need to develop and improve the environment in order to achieve the goals of sustainable agricultural development. There is, therefore, great need to intensify research in environmental pollution problems with the view of providing alternative methods of solving such problems (Johnson and Roder, 1979).

Relevant literature to this study is discussed in the chapter following.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter gives an overview of the reviewed literature on fertilizer and pesticide use and their effects on the aquatic environment at global, national and local levels. It also highlights the state of the environment at all these levels and what has been done to address the situation.

Environmental degradation has become a global concern, particularly in the past two decades. This is because every human activity operates within the environment. Therefore, there is the likelihood of a harmful interaction between man and the environment through, say, agricultural activities. Unfortunately, the study of pollution problems, arising from the impact of man's activities on the environment, such as pollution from agricultural runoff, has not been examined intensively, especially in Zambia. Loehr (1974) alluded to this saying that pollution surrounds us, but scientific data on the subject does not exist. Fertilizers and pesticides are applied to increase crop yield throughout the world. This contaminates the aquatic environment. Most of these pollutants cannot be seen, smelt or tasted. While it is easy to believe they are not there, they produce measurable changes in the environment (Jolankai and Roberts, 1985).

Man is increasingly realising that earth's natural resources are limited and measures to solve environmental problems in order to ensure sustainable development for the future must urgently be undertaken. The growing presence of contaminants in major water resources such as lakes and rivers and pollution of aquifer in the world, make proper management of the aquatic environment imperative. It is well known that agriculture is the single largest user of fresh water resources, using a global average of 70% (Ongley, 1996). At the same time, it is also a major cause of degradation of surface and groundwater through erosion and chemical runoff. Agriculture, therefore, exists within a symbiosis of land and water. FAO (1989) made it quite clear that appropriate steps must be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired. Ongley (1996) argues that sustainable agriculture is one of the greatest challenges and fresh water quality will become the principal limitation for sustainable agricultural development in many countries in the next century.

This calls for more research in the field of water pollution in different parts of the world. As such there is need for national as well as global evaluation of environmental pollution. This is because pollution and its effects on environmental misuse rarely halt at national boundaries (Kessler *et al*, 1987; Ongley, 1996). Both investigation of causes and effects of pollution and control measures must be global in scope and scientifically inclusive in the range of enquiry (Hodson, 1970). In this way the effects of non-point source pollution as surface runoff from agricultural land on river water can be documented, through research such as this.

2.2 Fertilizer and Pesticide Use at Global Level

2.2.1 Fertilizer Use at Global Level

Agricultural misuse of watersheds and the resulting downstream transport of nutrients is a common problem throughout the world. Most nutrients enter as sudden events during snow melt and heavy rainfall with large nutrient loads transported over very brief periods of time, which eventually lead to eutrophication. Ongley (1996), citing Insermann (1990), noted that agriculture is a major factor in eutrophication of surface waters. The huge increase in fertilizer use worldwide over the past several decades is well documented (Goudie, 1986; MIT, 1970; Ongley, 1996). Figure 2 illustrates the increasing historical trend and predicted future need of fertilizer use around the world. It is significant to say, therefore, that fertilizer usage worldwide has been increasing in the past 40 years, suggesting that, in the absence of major changes in land use to control fertilizer runoff in large parts of the world, it may be expected that agriculture will be responsible for an ever-increasing contribution to surface water pollution. The complexity and magnitude of fertilizer impact is also increasing tremendously. Yet, while great interest has been shown in the use of chemical fertilizers (as well as pesticides), the fundamental and theoretical aspect of the problem has not been investigated. This is most unfortunate because pollution tends to pass unnoticed until it has reached higher levels and may be the effects have caused a lot of damage to the environment.

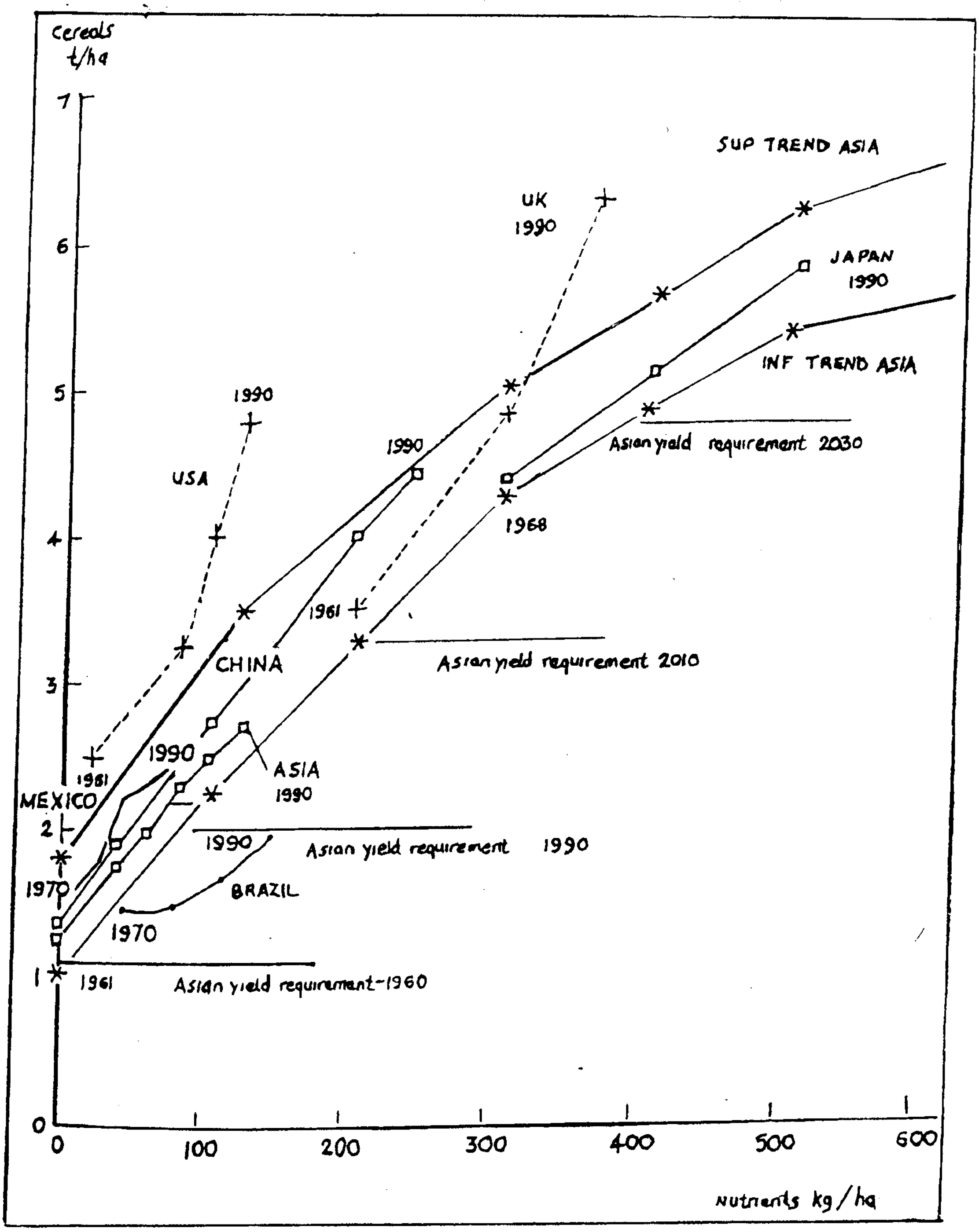

Figure 2. Fertilizer use and crop yield evolution in Asia, Europe, Latin America and United States. Source: Joly (1993).

Stewart *et al* (1998) relate this to the fact that field data does not currently exist which can allow for any meaningful investigation and as such this insufficient data does not raise the alarm for designing and operating a management system in pollution control.

The three major nutrients in chemical fertilizers are Nitrogen (N), Phosphorous (P) and Potassium (K). Although both N and P contribute to eutrophication, classification of trophic status focuses on that nutrient which is limiting. In most cases P is the limiting nutrient. Undesirable, human-induced increase in the input of phosphorous and nitrogen to a water body can artificially stimulate algae aquatic plant growth to levels which can adversely affect water quality conditions. This is characteristic of a "eutrophic" water body and is termed as cultural eutrophication, a condition that represents one of the more serious and extensive forms of water pollution besetting us today (Owen, 1980). Although this process occurs naturally (natural eutrophication) during the slow aging of lakes, it can be accelerated by runoff from fertilized agricultural land and domestic sewerage discharge as well as industrial effluent. Roughly 80% of the N and 75% of P added to lakes and streams in the USA has its source in human activities (Owen, 1980). Agriculture is considered the dominant source of N and cause of river and lake water quality impairment worldwide (McFarland and Hauck, 1995; Puckett, 1995). Several studies have shown the build up of extracted phosphorous and nitrate in soil and river water with repeated application of animal manure and/or fertilizers (Reddy *et al*, 1979; Lawrence, 1992; Nelson and Logan, 1983; Sharpely *et al*, 1993; Sharpely and Smith, 1992). High levels of nitrates in drinking water are a health hazard and are thought to cause blood poisoning in young children and miscarriage in pregnant women (Jolankai and Roberts, 1985; Goudie, 1986).

2.2.2 Pesticide Use at Global Level

Conventional agriculture relies heavily on pesticides to control unwanted diseases, insects, plants and animals. Pesticides have been used for over 200 years, but the wide-scale use of these pesticides is a recent development (say within the space of about 20 years). It is actually a new type of ecological factor which has come into prominence (William *et al,* 1971). Until recently environmental ecological studies were mainly concerned with more persistent pesticide, particularly with their movement and accumulation in food chain. But of late most pesticides have been subjected to more extensive ecological investigations, although there is still a considerable lack of data (William *et al*, 1971).

There is overwhelming evidence that agricultural use of pesticides has a major impact on water quality and leads to serious environmental consequences. Research done by microbiologists, ecologists and hydrologists on different pollutants in water such as petroleum, pesticides as well as the consequences of reservoir eutrophication process, have shown changes in water micro flora as a result of these pollutants finding their way into sea or inland waters (Barges *et al*, 1990; Milburn, 1990). Hudson (1971) is agreeable with the fact that runoff by erosion contributes to pollution in fluvial systems. He cited research carried out in Central Africa where it was found that up to 50 tonnes of soil of cropped land could be lost depending on the slope, soil texture, crop management and rainfall. This simply shows that erosion from agricultural land has to be controlled if water pollution is to be controlled. It has been calculated that as much as 50% of pesticide sprays applied to crops miss their target and fall to the soil surface (Mundia and Mwangala, 1996).

Most of the pollution studies previously done have accurately described the pesticides, but have failed to accurately describe the system they affect and in what concentrations (Jenkins and Milburn, 1998). It would be true to say that most approaches to the pesticide problem are simplifications imposed for the purpose of scientific analysis, where it is often thought that effects in the field can reliably be predicted from simple toxicity tests in laboratories. But it is known that environmental conditions are quite unlikely to be the same as those in laboratories. Research like this one in the Upper Kaleya Catchment, designed to focus more on the afore mentioned may be of great use in bringing about the realization that an understanding and awareness of the environment is important for the development of future strategies on pollution control.

2.3 Fertilizer and Pesticide Effects in Developing Countries

2.3.1 Fertilizer Effects in Developing Countries

Eutrophication of large water bodies in developing countries has been studied less in comparison to developed countries, although it has been recognized as a critical environmental issue (Ramberg *et al*, 1987). Cultural eutrophication significantly decreases the recreational, municipal, industrial and agricultural use desirability of a water body, which at the same time becomes a health hazard.

Eutrophication of rivers through over fertilization is already a major problem in the middle Kafue River basin of which the Kaleya River is a tributary. This problem is not only in Zambia but many rivers and lakes throughout the world are becoming over nourished or eutrophic (Loehr, 1974; Sinkala *et al*, 1997). According to Dix (1981; 171), "up to 40% of the applied fertilizers enter water courses as runoff and leakages from agricultural land". This leads to a serious water pollution problem especially due to nitrogen and phosphorous which tend to regulate the growth of aquatic weed causing eutrophication in inland water. Unfortunately, very little has been studied in developing countries concerning this problem of nutrients in fluvial systems (Mkhandi, 1998).

Sinkala *et al* (1997) conducted research on the cause of the prolific growth of aquatic weeds in relation to the nutrients in the Kafue River. But the levels of concentration of these nutrients and their impact in the fluvial ecosystem as a whole were not studied. It must be stated that in eradicating the accumulation of pollution or nutrients in the environment, their rate of input must be determined. Holdgate (1971) emphasized this by saying that in choosing what to measure, the potential hazard posed by a pollutant should be considered in terms of its properties such as toxicity, persistence and bioaccumulation

2.3.2 Pesticide Effects in Developing countries

Pesticide consumption has rapidly increased in developing countries. It is generally believed that Africa accounts for 5% of the world pesticide use (Mhlanga and Madziva, 1990). Although developing countries have poor safety records and lack of knowledge concerning the use and effects of these chemicals, agricultural development demands the use of pesticides due to population pressure. Pesticides have become so important in these countries that it is anticipated that their use will continue as long as appropriate alternatives are unavailable (Igbedioh, 1991).

There is growing concern over the toxicological hazard caused by agricultural pesticides in developing countries. Organochlorine pesticides are still being used in Zambia for the control of maize, cotton, groundnuts and soyabeans pests (Mundia and Mwangala, 1996). Wadageneh (1995) reports that the present amounts of banned or obsolete pesticides have been ascertained and current estimates are that there are 206, 083 kg/l of these chemicals in Zambia. The cost effectiveness and broad spectrum of activities of these chemicals have continued to encourage their demand and use, in spite of international pressure calling for their ban.

In Zambia, little information is available on pesticide effects on the environment. Pesticides are applied on a prophylactic basis irrespective of pest infestation levels. This, therefore, leads to over use of pesticides. Wadageneh (1995) and Jolankai and Roberts (1985) state that the main problem with widespread use of large amounts of pesticides is that pests adapt and become immune. Efforts to control locusts in South Africa (Masters, 1974) underscore this. Hence, it is necessary for developing countries to put in place sustainable programmes to reduce such pesticide effects to the barest minimum. Options to achieve this include strategies to regulate the use of pesticides, restricting the use of persistent chemicals, alternatives to pesticide use such as biological and natural control measures, within the concept of integrated pest management practices, should be vigorously pursued. Cuba is an example of a programme that has succeeded to reduce dependency on pesticides. Since 1980 Cuba embarked on utilizing alternatives to chemical pests control, which has been remarkably successful (Purdon and Anderson, 1980).

In most developing regions, there has been less or no continuous effort to monitor pesticide residues. In Zambia most research work is mostly limited to studies at the University of Zambia for academic purposes. Yambayamba *et al* (1999) carried out an assessment on the impact of livestock on the environment in Lusitu, while many other research studies have focused only on deforestation in Zambia (Chidumayo, 1979; 1997). Other studies have been conducted solely in relation to tsetse fly eradication (Mundia and Mwangala, 1996; Maseko, 2001). Apart from the study by Munga and Mwangala (2001), there is little published information on the effects and concentration of pesticides within the agro-ecosystem in Zambia.

In Zimbabwe, some research has been conducted on the impact of aerial spraying by the Scientific Environmental Monitoring Group of Germany, the National Research Institute on DDT in the tropics, and Mathiessen (1985) conducted DDT monitoring in the Kariba basin. All this research concentrated on the impact of pesticides on target and non-target organisms in the environment resulting in population reduction. This shows that very little has been done on the determination of pesticide residues by way of establishing their levels and movement into fluvial systems.

2.4 Fertilizers and Pesticides in the Upper Kaleya Basin

Agriculture is the main activity in Upper Kaleya Catchment such that it is necessary to monitor the water for possible pesticide-fertilizer contaminants. It is notable that Zambia's large commercial farms use more fertilizers and pesticides than those in other countries of the region (World Bank, 1983). Environmental effects are also appearing as excess nutrients and pesticides have drained from agricultural land into watercourses, causing eutrophication and pollution (GRZ, 1985). Upper Kaleya Catchment is no exception as it is an important agricultural area.

It is generally accepted that modern agricultural practices contribute significantly to catchment N losses, such that the control of river-water quality in the headwater catchment could be pragmatic. Once the river water is contaminated, there is very little possibility of the in-stream nutrient-pesticide absorption operating to control river quality further upstream. Also having cleaner headwater catchment means downstream river water quality will improve significantly. The determinant of water quality of a stream is the watershed from which it originates (Ongley, 1996; Kirkby, 1978).

It is uncertain what historic nutrient and pesticide loads were in the Upper Kaleya before this study, since there is no time series water quality data. It is possible that water quality in Upper Kaleya River is declining due to agricultural activities in the catchment. Maintaining healthy streams is important since they are critical for both aquatic and terrestrial ecosystems. Studies done by Ambus (1990) and Haycock (1991) show that the integration of vegetative riparian systems within the agricultural landscape may lead to long-term benefits for the aquatic environment.

2.5 Environmental Pollution Control Measures in Zambia

For a given agricultural purpose, the type of chemical, its method of application and quantity used must be carefully controlled, if serious environmental consequences are to be avoided. In Zambia, unfortunately, such control barely exists, despite the fact that chemicals mostly used are organochlorine (GRZ, 1985). These are persistent and may take many years to decompose. Hence, they remain in the soil and are washed into watercourses. Despite Zambia using the most dangerous (toxic) pesticides, which are routinely sprayed, few precautions in doing so are taken. At present little is known about the effects of water contamination on aquatic organisms in Zambia and it is difficult to plan and implement pollution control measures (GRZ, 1985).

The continuation of pollution studies by the National Council for Scientific Research (now National Institute for Industrial and Scientific Research) will no doubt help in monitoring the status of pollution and lead to the development of pollution control programmes (Cheatle and Cheatle, 1979). But this is subject to availability of funds. The ultimate causes of failure in implementing pollution control measures in Zambia are partly ignorance, inadequacy of expertise in the field of environmental conservation and lack of meaningful coordination among institutions engaged in environmental issues (ECZ, 1993). The result is that stream management, apart from impoundment, is a neglected discipline. Aquatic resources management tends to concentrate on fisheries development and the engineering problems of water storage (Johnson and Roder, 1979). Management practices aimed at maintaining stream ecosystem functions are almost non-existent.

The Environmental Council of Zambia (ECZ) has the responsibility for monitoring and controlling water pollution. It also has the responsibility to establish water quality and pollution control standards through identification of areas of research and initiating or sponsoring research to this effect (ECZ, 1990). Unfortunately this does not seem to have worked for ECZ because very little research has been conducted by ECZ and it (ECZ) has no analytical laboratories.

A large volume of work has been carried out in river pollution control in developed countries, but very limited work has been documented for most rivers and streams in developing countries (Oluwande *et al*, 1983). In Zambia, few conservation features have been incorporated into agricultural policy to prevent and correct environmental pollution in order to maintain and restore water quality. It should be emphasized that man's survival depends on how well he manages and uses the environment today (O' Riordan, 1995). Therefore, the emphasis in water pollution control now should be on the amount of wastes or effluent that is kept out of the water rather than on the amount that can be accepted by the waters without causing serious pollution problems. This is actually a shift from water quality standards to effluent limitations. It is achieved by the availability of economical control technology, aiming at eliminating water pollution (O'Riordan, 1995; Purdon and Anderson, 1980).

2.5.1 Legal Framework on Water Pollution Control in Zambia

The 1970 Water Act of the Government of the Republic of Zambia was an Act to consolidate and amend the law in respect of ownership, control and use of water (GRZ, 1994). In this Water Act, the government made it a policy to supervise and protect the sources of all the streams in Zambia (GRZ, 1994). It is the policy of the Zambian Government to prevent any waste or unlawful diversion, abstraction, storage, use of water or lawful act calculated to diminish the quantity, quality of water in any part of the stream. According to the Water Act of 1990, any person who willfully or through negligence pollutes or fouls water so as to render it harmful to man, beast, fish or vegetation shall be guilty of an offence liable to pay a fine not exceeding K400.00 ($0.09). This was quite a weak law and is still weak after the amendment Act of 1994 that only fines a polluter K6, 000.00 ($1.33).

The 1990 Environmental Protection and Pollution Control Act was concerned with all forms of pollution control in the country (GRZ, 1995). Before this Act was passed several acts related to environmental protection existed, although they were either inadequate or out of date. This was compounded by lack of appropriate legislation and enforcement of available legislation. New legislation has now been enacted. This is the 1995 Environmental Protection and Pollution Control Act (GRZ, 1995). However, Yambayamba *et al* (1999), found the environment in Lusitu in Southern Province to be even worsened than before, an indication of still lack of enforcement of legislation. After all, what is the use of good legislation if it cannot be enforced?

It cannot be over emphasized that environmental policy without appropriate legislation will be ineffective and so will be legislation without enforcement (Dougherty and Hall, 1995; Kato *et al, 1983*). A laissez-faire policy will result in unsustainable development through uncontrolled pollution. Legal and policy issues have far-reaching consequences for the environment. In many developing countries legislation on environmental issues has been in existence for many years (Dougherty and Hall, 1995). Bradbury *et al* (1996) state that in China (like Zambia) environmental legislation is not reinforced by a system that ensures enforcement and compliance at the local level. Some of the reasons cited to be contributing to this scenario are population increase, economic decline and escalating rate of pollution.

It should however, be noted that laws and regulations cannot in themselves solve environmental problems. Whatever statutory instruments are introduced to enhance environmental protection, their success will inevitably depend on a far greater awareness of environmental issues than is common at present (Ongley, 1996). For example, decisions that affect the environment are made by a farmer who may plough his fields to the edge of a stream bank instead of leaving a buffer strip, or apply agrochemical in excess on his farm, which eventually pollutes the river.

From this literature reviewed it can be observed that surveys conducted over the years have demonstrated the general low level of information on environmental pollution in general, more so on Upper Kaleya River. This low environmental pollution awareness poses an environmental crisis that requires intensive research investigation on aspects of water pollution. Since there is no adequate definition of what constitutes environmental degradation, the development of the information essential for setting water quality standards for the protection of the water resource and aquatic life therein, require the determination of toxicants added to the water body. This, assessment of toxicants added to water bodies, is what this study sought to carry out so that the harmful side effects of agriculture technologies are recognized and prevented before they have irreversible impacts on the aquatic environment, in particular Upper Kaleya River.

The next Chapter describes the study area.

CHAPTER 3: DESCRIPTION OF STUDY AREA

3.1 Location of Upper Kaleya Catchment

The Upper Kaleya Catchment is located in Chikankata area, southeast of Mazabuka in the Southern Province of Zambia (Figure 1). It extends from near Siamakambo Hills, which are the source of the Kaleya River (Figure 3). The area lies between latitudes 16° 05' and 16° 07' South and longitudes 27° 58'and 28° 05' East. The Kaleya River is an important river to the Upper Kaleya Catchment for agricultural purposes.

3.2 Topography

The description of Upper Kaleya Catchment is based on the topography of Mazabuka District where it is found. Mazabuka District lies in high savannah country with an elevation between 1000-1300m. It is generally a plateau and mature in nature. In the north and northeast it extends to the Kafue River and its flood plain. To the east the country breaks into a zone of rugged hills known as the Gwembe Escarpment (Figure 3). The Upper Kaleya basin has a gradient of 5-16% (Chileshe, 1991).

3.3 Geology

The geology of Mazabuka District falls in the Katanga System. The Muzuma Calc-silicate Formation occupies a central position in the Katanga succession and is believed to be in the middle of the Mazabuka synclinorium. It is regarded to be among the oldest rocks of the Katanga System in the area. Bands of limestone and dolomite occur abundantly throughout the area. They are structurally concordant with the surrounding rocks. The main rock type of the Muzuma Calc-Silicate Formation is quartz, diopside, hornblende, calcite, gneiss, quartzite and impure limestone (Clarke, 1968; Brown, 1967; Gair, 1959; Newton, 1960). The mineral economic potential of Chikankata area is generally poor, although there are several small occurrences of minerals such as limestone, and dolomite.

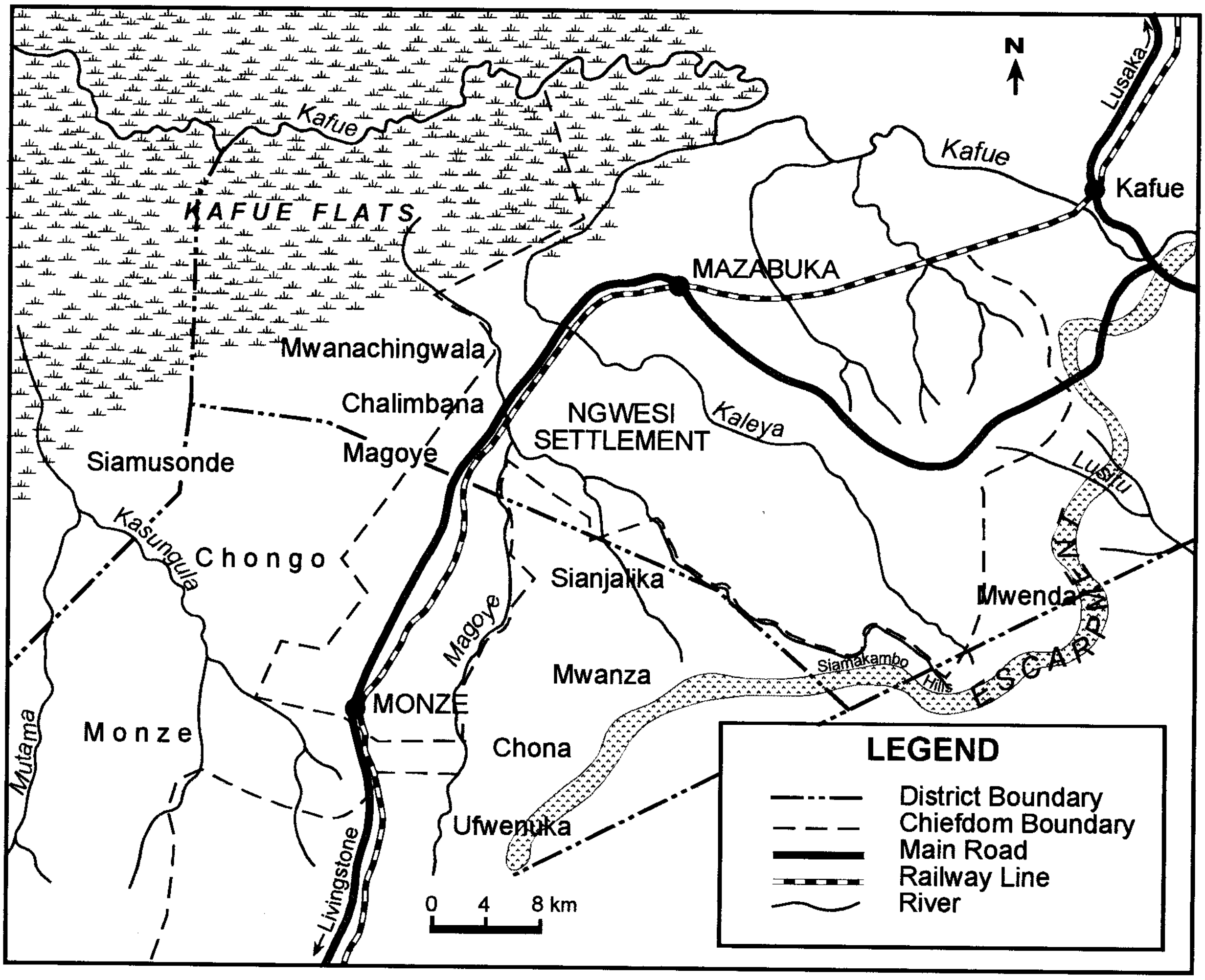

Figure 3. Kaleya River Basin in Mazabuka District. Source: Anthony and Uchendu (1970).

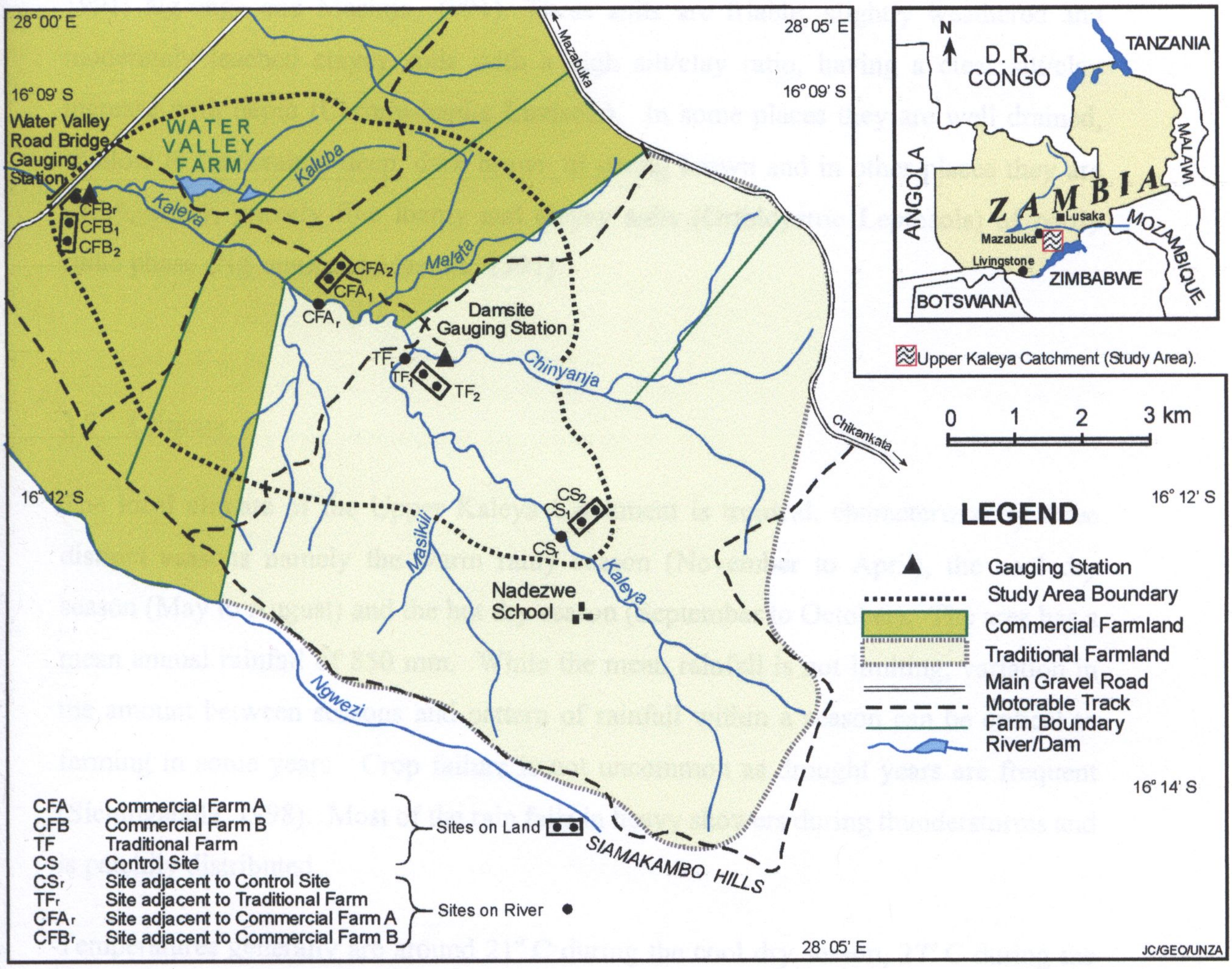

Figure 4. Upper Kaleya Catchment (study area) in Mazabuka District.

3.4 Soils

The soils of Upper Kaleya Catchment are Lithic Leptosols; this is the association of well-drained, moderately deep to deep, yellowish red to strong brown soils (Chileshe, 1991; Ng'onga and Masinja, 1991). These soils are friable, slightly weathered and moderately leached clayey soils with a high silt/clay ratio, having a clear silt/clay increase with depth (Chromi-haplic Luvisols). In some places they are well drained, shallow to moderately deep, dark brown to strong brown and in other places they are rocky, stony, gravely fine loamy and clayey soils (Orthldystric Leptosols) of partly rudic phase (Ng'onga and Masinja, 1991).

3.5 Climate

The local climate of the Upper Kaleya Catchment is tropical, characterized by three distinct seasons namely the warm rainy season (November to April), the cool dry season (May to August) and the hot dry season (September to October). The area has a mean annual rainfall of 850 mm. While the mean rainfall is not limiting, variation in the amount between seasons and pattern of rainfall within a season can be critical to farming in some years. Crop failure is not uncommon as drought years are frequent (Sichingabula, 1998). Most of the rain falls in heavy showers during thunderstorms and is patchily distributed.

Temperatures generally are around 21° C during the cool dry season, 27° C during the rainy season and 32° C during the hot dry season. October is the hottest month with a mean temperature of 25.4° C. During the coldest months of June and July the mean temperature is 15.9° C and 16.1° C, respectively. The range of temperature is small. The mean annual temperature is 21.2° C.

3.6 Hydrology

Kaleya River is one of the tributary rivers of the Kafue River (Figure 3). It is a perennial river and is very important in Upper Kaleya Catchment in terms of agriculture and water supply. The drainage area up to Water Valley Road Bridge Gauging Station is 63 km^2. The river has many tributaries, the main ones being Chinyanja, Masikili, Malafa and Kaluba (Figure 4). A number of dams have been constructed on the Kaleya River and tributary streams. Stream discharge rises significantly during the rainy season and drops in the dry months. The River has a mean annual discharge of approximately $12.71 m^3 s^{-1}$, however, mean annual discharge is very much affected by abstraction.

3.7 Vegetation and Land use

Woodlands and grasslands dominate the Southern Province's vegetation. Originally, the vegetation in Upper Kaleya Catchment (Chikankata/Mazabuka) was woodlands savannah. The predominant vegetation types were the *Brachystegia* (Miombo) and *Acacia* (Muunga) woodlands (Yambayamba *et al*, 1999). This plateau vegetation has undergone great pressure such that the Miombo/Muunga woodlands have been cleared for agricultural production. About 6.8% of the plateau Miombo and Muunga woodland areas are currently under cultivation (Chiti *et al*, 1989; Mulofwa *et al*, 1994).

The human population in the study area has been increasing, mainly by natural increase (CSO, 1995), which has led to demands to have some forest reserves degazetted and converted to arable land. The scenario at the moment is that only isolated patches of natural vegetation (in the form of secondary vegetation) is left as much of the catchment land is under cultivation and coffee plantation. The original woodland has been replaced by secondary vegetation of open bush and grassland.

Upper Kaleya is an important agricultural area where plantation and mixed farming are practiced. The Kaleya River is of vital strategic importance to the Zambian economy in terms of agricultural production. Coffee is the principal crop among commercial farmers. However, commercial farmers, using water from Kaleya River, also grow large quantities of Irish potatoes, vegetables as well as seed maize through irrigation. Subsistence farmers grow mainly maize, with some potatoes, groundnuts, soyabeans and cotton. The local people fish in the river as well as grow small vegetable gardens along riverbanks (Figure 5).

Figure 5. Local people fishing in Upper Kaleya River at Water Valley Road Bridge.

Against this background, the methods and investigation of pollution in Upper Kaleya was conducted as described in the next chapter.

CHAPTER 4: METHODOLOGY

4.1 Types and Sources of Data

The methodology of this study involved primary data collection of soil and water samples from the study area during the dry and wet seasons, the use of questionnaires, informal interviews as well as visual observations. The soil and water samples were collected on a monthly basis from November 1999 to March 2000. This was deemed reasonable in order to minimize costs and because environmental quality rarely changes drastically within one month except when seasonal conditions change. Secondary data collected included rainfall from Meteorological Department in Lusaka and discharge measurements from Upper Kaleya Sediment Project based in the Department of Geography at the University of Zambia. Both primary and secondary data collected are described below (together with those methods considered necessary for the achievement of the research objectives).

4.2 Primary Data

4.2.1 Field Work

Fieldwork involved the collection of river water samples, soil and runoff samples from the farmlands where agrochemicals (pesticides and chemical fertilizers) had been and were being applied and from one control site on uncultivated land. On the control site (Figure 6), it was believed that agrochemicals under investigation had not been applied before. Therefore, data from the control site served as background of the unpolluted natural environment. Questionnaires were administered to 30 farmers (20 traditional, 10 Commercial) through systematic sampling. Information such as land use, methods of application of pesticides and general farming practices was obtained through visual observation of the study area. Some interviews were conducted with relevant authorities at the Environmental Council of Zambia (ECZ), Ministry of Agriculture Food and Fisheries, Water Development Board and some local farmers.

Figure 6. Sampling of runoff from Control Site near the river, downslope (CS_1) in Upper Kaleya Catchment, December 1999.

4.2.2 Sampling Design

In order to detect the actual incidence of nutrient contamination in the river, eight sampling stations were established (four sampling stations on land and four others on the river adjacent to farmlands and the Control Site). Of the four sampling stations on land three were located on farming areas and the fourth one was on uncultivated land (the Control Site), which was located upstream of all the sampling stations. On all the sampling stations on land there were two sampling points on each, one upslope (near the edge of the farm) and another down slope (near the river bank). Altogether there were 8 sampling points on the four sampling stations on land and four sampling points on the river bringing the total sampling points to 12, as shown in Figure 4.

Sampling sites were categorized as follows:

A) Sampling sites on land for runoff and soil samples

   a) Control Site (CS) - uncultivated Land

   b) Traditional Farm (TF) - subsistence farming mainly growing maize

   c) Commercial Farm A (CFA) - growing coffee and vegetables

   d) Commercial Farm B (CFB) - specializing in coffee growing

B) Sampling sites on the river for river water samples

   e) Site CS_r - adjacent to Control Site

   f) Site TF_r - adjacent to traditional farm

   g) Site CFA_r - adjacent to Commercial Farm A

   h) Site CFB_r - adjacent to Commercial farm B

On each of the four sampling stations on land, two shallow trenches of 1m long and 50 cm deep were dug. This was to allow enough water to collect in the trench for sampling. One of the two trenches was dug near the edge of the farm (referred to as upslope point in the study) and the other one 60 m away from the first trench on lower ground (down slope). The 60 m distance between trenches (selected purposively) permitted comparability of data, in terms of determining whether surface slope had any influence on the amount of pollutants moved. To prevent percolation of the runoff collected in the trenches, well-secured plastic sheets were laid at the base and sides of the trenches. The runoff was collected from the trenches in 1 litre plastic bottles and taken for laboratory analysis.

C) Sampling for Soil Samples

Soil samples were collected from sites on land only, near each of the two trenches on every sampling station, using a hand soil augur (Figure 7). The coring of soil samples was conducted at uniform depths of 0-20 cm and 20-40 cm. This helped in determining whether the concentration of agrochemicals was affected by variations in soil depth. The number of soil samples collected per sampling time was 16 (four from two of the trenches from each of the 4 sampling sites), sampled once a month for 5 months. This yielded 80 soil samples, 32 surface runoff samples (sampled once a month for 4 months) and 20 river water samples (sampled once for 5 months), making a total of 80 soil samples and 52 water samples (132 samples) collected for the whole study.

Figure 7. Auguring soil samples at Control Site (CS_1) in Upper Kaleya Catchment, December, 1999.

River water and soil samples were collected during the dry season just before the beginning of the rainy season (at the beginning of November). Water samples (river water and surface runoff) and soil samples were collected four times instead of the proposed three times during the rainy season because rainfall continued into March of the year 2000.

Clean, well-labeled 1litre sampling plastic bottles were used to collect river water and surface runoff samples. River water samples were collected at an approximate depth of 0.6m below water surface (whilst the bottle was pointed upstream, Figure 8). This is because the mean velocity of a stream at any vertical is usually found at this depth. Collecting water sample at this depth of the river avoided the risk of collecting bed materials into the sampling bottles, as the river at this point was turbulent. The number of water samples collected per sampling time was 12 in all; 4 from the river and 8 from the trenches on surface slopes. All water samples were kept in a refrigerator before analysis to avoid any changes taking place in the composition of samples if stored at ordinary temperatures owing to biochemical action (Klein, 1959). Soil samples were collected in plastic bags, which were also appropriately labeled.

4.2.3 Questionnaires and Interviews

Questionnaires, which focused on determining the status of agrochemical pollution from agricultural lands into the Upper Kaleya River, were administered (Appendix 1). Through systematic sampling a sample of 20 subsistence farmers and 10 commercial farmers was selected for interviews. There were about 200 subsistence farmers in the study area. All the names (collected from the settlement advisor) were put in a basket and mixed then randomly one was picked to be the first in the sample. Thereafter every 10^{th} subsistence farmer was picked and interviewed, using a systematic sampling procedure. However in the case of commercial farmers this was not the case as almost all of them (in Upper Kaleya Catchment) were interviewed since they were few. Data on the farmers' use and types of fertilizers and pesticides used, as well as the farmers' knowledge of the impact of these chemicals on the aquatic environment was collected.

Figure 8. Sampling river water at CFB_r in Upper Kaleya Catchment, January 2000.

Interviews with farmers were conducted mainly to obtain information on the Kaleya River and on farming practices in relation to pollution. Informal interviews held with various authorities were to assess people's awareness of the polluting effects of agrochemicals and measures taken to minimize the water pollution resulting from the application of agrochemicals.

4.3 Secondary Data

4.3.1 Maps

The 1:50,000 topographic maps of Mazabuka/Chikankata of 1959 (Sheet $1628A_1$), 1981 (sheet $1628A_1$), and 1984 (sheet $1627B_2$) were used to obtain information on location and area of the basin and land use. This information was useful in determining human influence on aquatic pollution. Geological maps at 1: 100,000 from 1959 (sheet 1627) and 1968 (sheet 1628) of Chikankata area were used to obtain information on geology of the study area. Geological information was obtained from Newton (1960) and Brown (1967). Soil types were obtained from regional plan maps and soil maps of the Geological Survey (Chileshe, 1991).

4.3.2 Rainfall and Discharge Data

Rainfall data was collected from Meteorological Department in Lusaka (1997-2000) (Appendix 2), while the discharge was collected from the Upper Kaleya Sediment Project at UNZA, 1997-2000 (Appendix 3). This data was used to analyze changes taking place in the hydrological regime of the river, which may have an effect on pollution concentration in the river. General information on farming practices in Mazabuka District with special reference to Upper Kaleya Catchment was obtained from the Ministry of Agriculture Food and Fisheries.

4.4 Methods of Analysis

4.4.1 Laboratory Analysis

Water samples were analyzed at the Environmental Engineering Laboratory, School of Engineering and soil samples at the Department of Soil Science, School of Agricultural Science at the University of Zambia. The parameters analyzed were pH and conductivity for physical characteristics; nitrates (NO_3-N) and nitrite (NO_2-N) for nitrogen and phosphorous for chemical (nutrients) characteristics. These parameters were analysed for both water and soil samples (Appendices 4.1-4.4 and 5.1-5.4). N and P were the only parameters studied (and not K, even though N, P and K are the three major elements in chemical fertilizer) because N and P promote eutrophication of inland waters.

The laboratory analysis was based on standard methods for examination of water and wastewater of the American Public Health Association (APHA) (Anon, 1971; WHO, 1987).

4.4.1.1 Physical Characteristics

There is a wide range of methods for testing pH, but in this study the electronic method, utilizing the glass electrode, was preferred because it generally gives a high degree of accuracy, required in the study. Conductivity (Electrical Conductivity) in both water and soil samples was analyzed using the same method as for pH. pH has an effect on water quality. Fertilizers in water make water acidic, which may have an effect on aquatic organisms. Similarly, conductivity indicates presence of inorganic compounds when high. Conductivity was used in the study to help determine water quality.

4.4.1.2 Chemical Characteristics

Nitrate and nitrite concentration indicated nitrogen in the study. The quantitative determination of nitrate can be done using various methods and most of them do not have major disadvantages. In this study, the Electrometric method was used. In the case of NO_2-N, the Spectrophotometer method was used since other methods are suitable for river water only and not runoff water (Klein, 1959). Phosphorous was analyzed using the Vanamolybolic Spectrophotometer method. Nitrogen and phosphorous were chosen as parameters to be analysed for nutrients because they often are the limiting nutrient loading to eutrophication. All water samples were analyzed using methods in conformity with the American Public Health Association standard (Appendix 6).

4.4.2 Quantitative analysis

The results from the laboratory were analyzed quantitatively using computer statistical packages. Simple correlation methods were used in determining the relationship between rainfall and discharge. Student t-tests were used to determine significance of difference between data from commercial and traditional farms. Descriptive statistics such as percentages and the non-parametric tests like Chi-square (χ^2) were employed to analyze the information obtained from the questionnaire survey on pollution awareness and frequency of use of fertilizers and pesticides. Graphical and tabulation methods were used to summarise the data.

4.4.3 Qualitative analysis

Using frequency tables based on questionnaire responses, information on the types of nutrients and pesticides farmers used and their knowledge on pollution effects of these agrochemicals was established as discussed in Chapter 6.

4.5 Limitations of the Study

The laboratory analysis of pesticides was not conducted because of financial constraints. The laboratory method required for analysing pesticides was gas chromatography, for identification and quantification of the pesticide residues. To quantify the pesticides (i.e. Karate and Soluber), pure standard samples (about 99.9% pure) of the same pesticides were required, but these could not be sourced from within Zambia. Attempts to source these from outside proved to be prohibitingly expensive such that it was not done. There was also no secondary data collected on the concentration of pesticides in the Kaleya River, as this has not been studied before. All these factors contributed to the failure in the analysis of pesticide residues and therefore all the discussion on pesticides and their impact on aquatic environment were based on the questionnaire responses.

The other limitation was on the number of sampling times and parameters analysed, which were much reduced due to financial constraints. For instance, only N and P were studied instead of including K and ammonium (NH_4^+ - N), and the dry season sampling was reduced and undertaken only in the month of November.

Results and analysis follow in the next chapter.

CHAPTER 5: RESULTS AND ANALYSIS

5.1 Climate and Hydrology in Upper Kaleya Catchment

Rainfall data for Kafue Polder, located at 56km from Upper Kaleya Catchment, were used as representative of rainfall received in Upper Kaleya Catchment. Both rainfall (from Kafue Polder) and hydrological data (from Upper Kaleya Sediment Project at Water Valley Road Bridge Gauging Station) covered a period of three years 1997 to 2000 (Appendices 2 and 3). Rainfall in the 1997/98 seasonal year was below average (700mm), 1998/99 was above average (883 mm) and 1999/2000 was below average (800mm). The average rainfall received in the study area is 850mm (section 3.5). This rainfall data reveals that there were fluctuations in the amount of rainfall received from year to year with almost no rainfall in October and very little in the month of November, generally revealing low monthly rainfall in the area. A minimum amount of 14.5mm (October1997) and a maximum of 298.1mm (January 1998) in the period of three seasonal years (1997-2000) were received. Rainfall was generally low to moderate with alternating wet and dry periods in the period analysed (Figure 9). Studies done on Southern Province (Mazabuka in particular) indicate that rainfall has become erratic and very unpredictable in terms of amount and has been consistently poor (Daka, 1995).

Monthly mean discharge of Upper Kaleya River was calculated from daily discharge (Appendix 3). Generally discharge was low, with the 1999/2000 hydrological year showing the lowest (Figure 9). Discharge was lowest in the dry season, in general, in all seasonal years, in particular during the month of October. It started to rise in December with onset of rains and continued to rise as the rainy season progressed until maximum discharges were reached at the height of the rainy season in January and February (Figure 9).

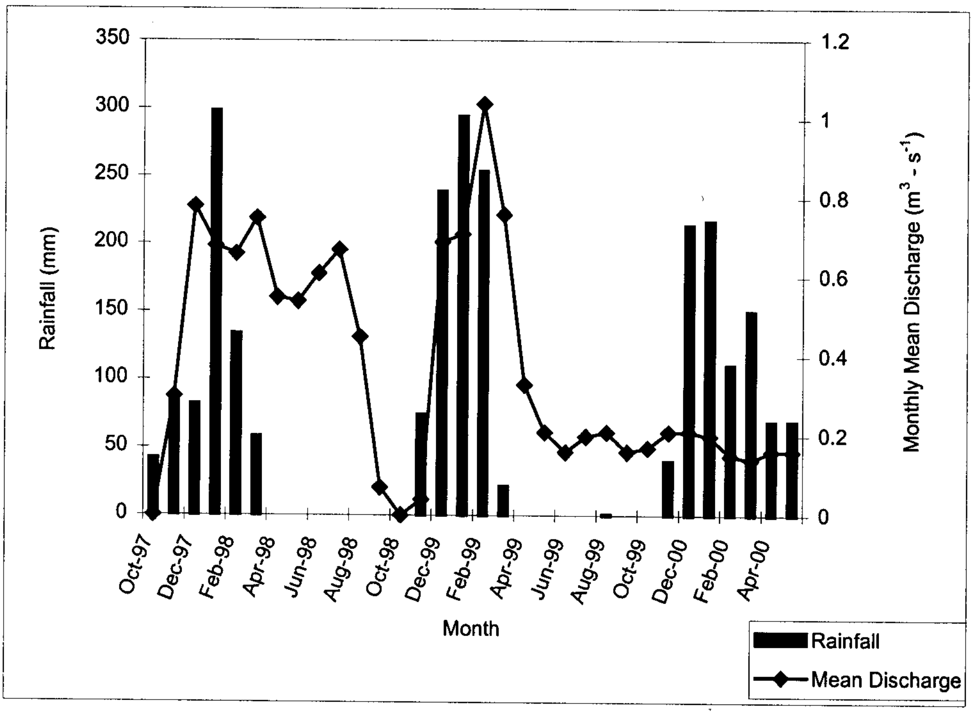

Figure 9. Hyetograph and Hydrograph of Upper Kaleya Catchment from 1997 to 2000.

5.2 Physico-Chemical Characteristics

5.2.1 pH

The pH–meter was used to measure the pH of the collected water and soil samples. It was determined as a parameter reflecting the acidity or alkalinity of water in the river. pH concentrations of acids and bases have a severe effect on aquatic life. In the study it was used to assess ultimately the extent of pollution in water with regard to fertilizer use in the area.

5.2.1.1 pH in Soils

pH in soils was found to be weakly acidic in Upper Kaleya Catchment regardless of slope and soil depth at all stations. This means that there was not much difference between soil pH on uphill sites (sampling points near edge of the farms) and down slope (sampling points near the river) or between surface soils and subsoil except at Commercial Farm A (CFA) (Figure 10). Surface soils were those collected from the depth of 0-20cm. Their pH ranged from 5.11 to 7.19 for all stations (Appendices 4.1 to 4.4). Subsoil were those collected from the depth of 20-40cm and had pH ranging from 4.75 to 7.33 for all stations. And mean pH in soils ranged between 4.86 (CFB_1, subsoil) and 6.35 (TF_2, surface soil) for all stations except station Commercial Farm A {(CFA) 5.92 to 7.13)} which was less acidic. Station CFA had slightly higher pH than all the other stations (Figure 10).

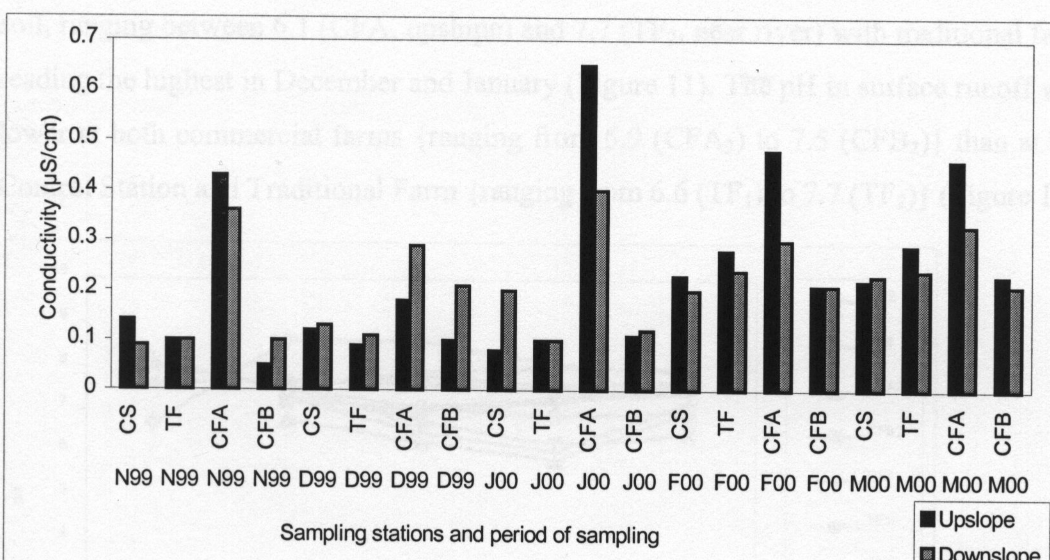

Figure 10. pH in soil of Upper Kaleya Catchment at different sampling stations and sampling periods (N99=November 1999, D99=December 1999, J00=January 2000, F00=February 2000 and M00= March 2000).

Comparing pH before the rains and during the wet season, there was not much significant difference between the dry and wet season. The wet season pH ranged between 4.75 (CFB_2, subsoil) and 7.33 (CFA_1, subsoil). The dry season pH ranged between 4.88 (CFB_1, subsoil) and 7.19 (CFA_2, surface soil) (Appendices 4.1 to 4.4). However, towards the end of the wet season pH tended to go up slightly.

The trend in pH with regard to depth of soil showed that the surface soils were more acidic (5.11 to 7.19) than the subsoil (4.75 to 7.33) since the pH for surface soils was generally lower than that of the subsoil at all stations (Appendices 4.1 to 4.4). This was an indication that fertilizer was more in the surface soils than subsoil.

5.2.1.2 pH in Water

During the dry season there was no surface runoff. In surface runoff for the months of December 1999 to March 2000, pH was slightly alkaline compared to the pH in the soil, ranging between 6.1 (CFA, upslope) and 7.7 (TF_2, near river) with traditional farm reading the highest in December and January (Figure 11). The pH in surface runoff was lower at both commercial farms {ranging from 5.9 (CFA_2) to 7.5 (CFB_2)} than at the Control Station and Traditional Farm {ranging from 6.6 (TF_1) to 7.7 (TF_2)} (Figure 11).

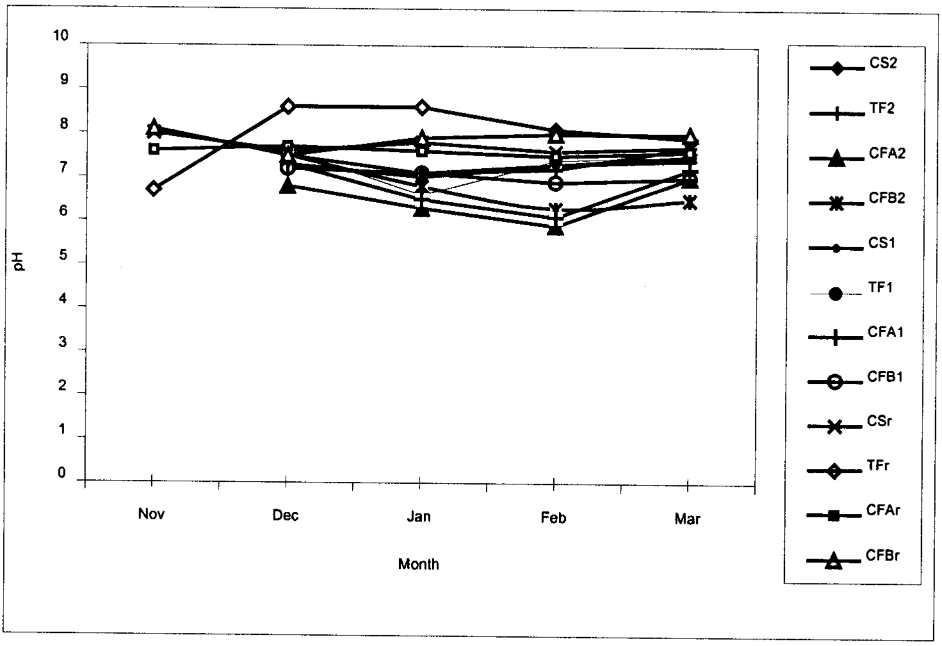

Figure 11. pH in runoff and river water of Upper Kaleya Catchment, 1999-2000.

River water pH was quite high ranging from 6.7 (TF_r) to 8.1(CFB_r) during the dry season and 7.5 (CFA_r & CFB_r) to 8.6 (TF_r) during the wet season. There was a trend of higher pH in river water (6.7TF_r to8.6 TF_r) than in surface runoff {5.9 (CFA_2, upslope) to 7.7 (TF_2, upslope)}.

5.2.2 Conductivity

Conductivity is a numerical expression of water's ability to conduct an electric current. It is measured in micro Siemens per centimeter (µS/cm). An increase in conductivity could be due to introduction of effluent, so it could be used as an indication of the amount and type of dissolved solids. Low conductivity could mean that the dissolved solids present do not have a high ionic conductance such as inorganic compounds (Klein, 1966). The determination of conductivity was a useful check on chemical analysis, which could give an indication of the presence of organic compounds like chemical fertilizer, giving a description of water quality in this study.

5.2.2.1 Conductivity in Soils

Maximum conductivity in soils during the dry season was 0.5µS/cm (CFA_2, subsoil) and the lowest was 0.0µS/cm (CFB_2, surface soils) (Appendices 4.1 to 4.4). It was generally observed that at all sampling points conductivity was higher in surface soils than subsoil especially during the wet season. The reason for the downward decrease from surface soil to subsoil could be that much of the nutrients were still in surface soils. Leaching could have been minimal, considering the low rainfall received during the period of study. Conductivity in soil was higher generally on upslope sampling points than down slope sampling points and particularly at CFA sampling points. This could mean that the effluent had not been washed downstream, as erosion may have been low due to low rainfall.

During the wet season, conductivity ranged between 0.07µS/cm (TF, subsoil,) to 0.77µS/cm (CFA, surface soil). Conductivity in soils was generally low at all stations during wet and dry seasons, although much lower in the dry season except for station

CFA, which generally indicated high conductivity in all the months except December (Figure 12).

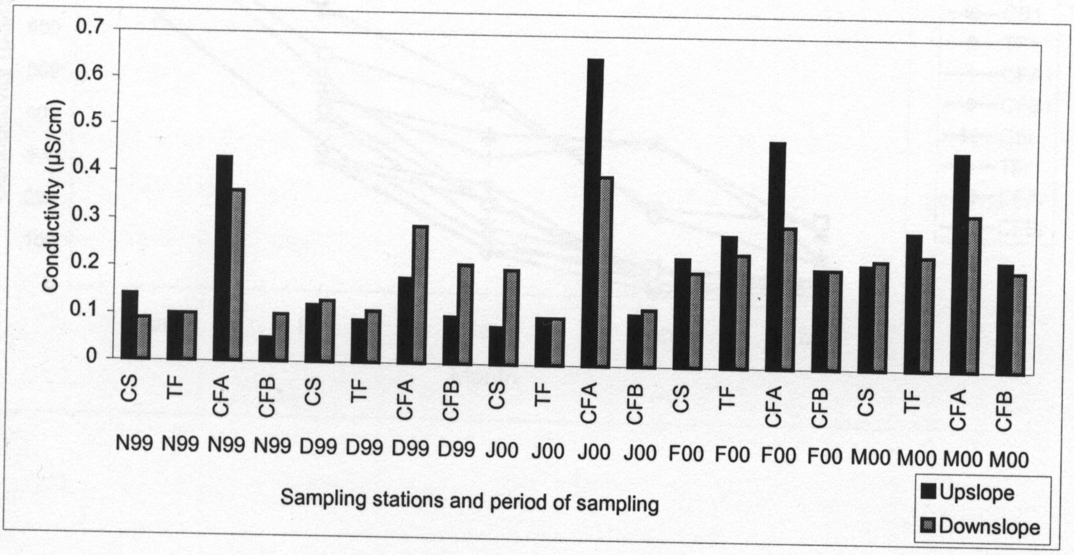

Figure 12. Conductivity (µS/cm) in soil of Upper Kaleya Catchment at different sampling stations and sampling periods (N99=November 1999, D99=December 1999, J00=January 2000, F00=February 2000 and M00= March 2000).

5.2.2.2 Conductivity in Water

Surface runoff conductivity was higher on down slope sampling points ranging from 24 µS/cm (CS_1) to 466 µS/cm (CFA_1) than on uphill sampling points {(12 µS/cm (CS_2) to 450 µS/cm (CFA_2)} at all stations. It was actually highest at commercial farm A (101 - 466 µS/cm) (Figure13). This could be due to the variety of crops grown there (apart from coffee) which require more fertilizers such as hybrid maize. Surface runoff conductivity was high on commercial farms A in particular, and B, compared to traditional farm. The trend was a decrease in runoff conductivity towards the end of the wet season at all sampling points (Figure 13).

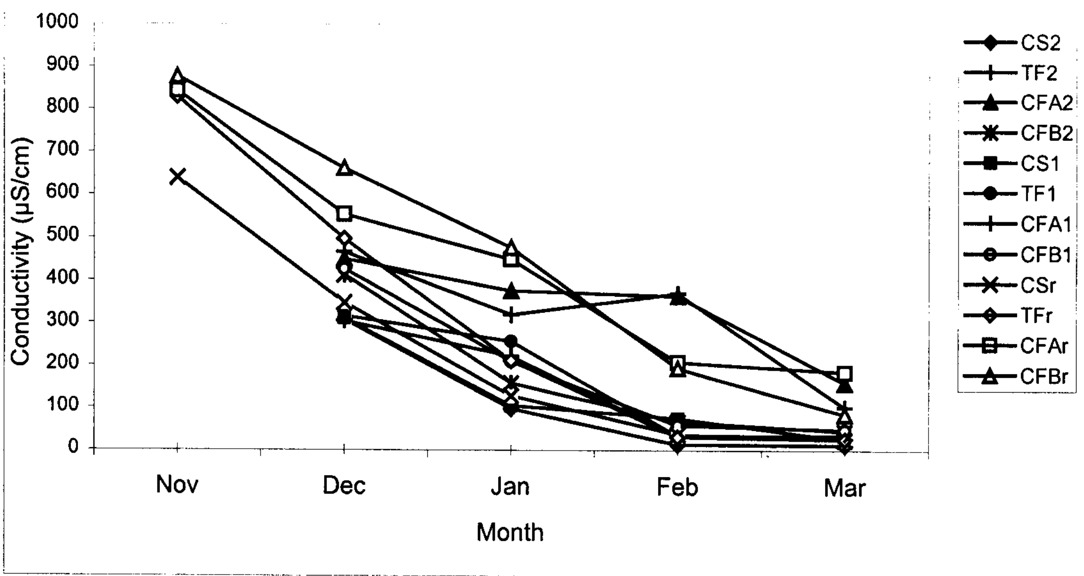

Figure 13. Conductivity (µS/cm) in runoff and river water of Upper Kaleya Catchment, 1999-2000.

River water conductivity in the dry season was high, ranging from 639 µS/cm (CS) to 877 µS/cm (CFB). Control site (CS) had the lowest (24 to 347 µS/cm) with Commercial Farm B having the highest conductivity (84 to 662 µS/cm) in river water, indicating an increase in conductivity down stream since CFB was down stream. This may have been due to commercial farms being down stream meaning more effluent was being discharged into the river at points where the river was thought to have purified itself. In the wet season, river water conductivity was much lower, ranging from 24 µS/cm (CS) to 662 µS/cm (CFB), compared to the dry season at all sampling points (Figure 13). This could have been due to fertilizer dilution during the rainy season. At all stations during the wet season, December recorded the highest conductivity in river water. Conductivity decreased with the progression of the rainy season, with March having the lowest of all stations.

5.2.3 Phosphorous

5.2.3.1 Phosphorous in Soils

Concentration of phosphorous was generally minimal in soils, especially during the dry season, at all stations (trace to 7.49 mg/kg) although Commercial Farm A_1 (CFA_1) surface soils had very high phosphorous concentrations (21.18 mg/kg). Control Site showed low concentrations, mostly only traces of phosphorous in the dry season, regardless of slope and soil depth. In the wet season, phosphorous mean concentration was higher on commercial farms than on traditional farms, with lowest concentrations observed at the Control Site (Figure 14).

There was a general decrease in phosphorous concentration from surface soil (trace to 21.18 mg/kg) to subsoil (trace to 11.13 mg/kg) (Appendices 4.1 to 4.4). On Traditional Farm, P tended to be higher on upslope surface soils than down slope surface soils. The opposite was true for subsoil on Commercial Farm A in the wet season, which had P higher upslope than down slope on both surface and subsoil. However, P on Commercial Farm B was inconsistent, showing no trend (Figure 14). Phosphorus concentration was generally higher on upslope soils than on down slope soils, apart from CFA and CFB (Figure 14). In the months of December and January P concentration was high at both down slope and upslope sampling points, but it decreased towards the end of the wet season especially at the down slope points. Comparing the concentrations of P between traditional and commercial farms, traditional farms had lower P concentrations (0.42 to 3.71 mg/kg in the dry season and trace to 5.04 mg/kg in the wet season) than commercial farms (trace to 21.18 mg/kg in the dry season and trace to 16.49mg/kg in the wet season). CFA had the highest P concentration in both seasons (Figure14).

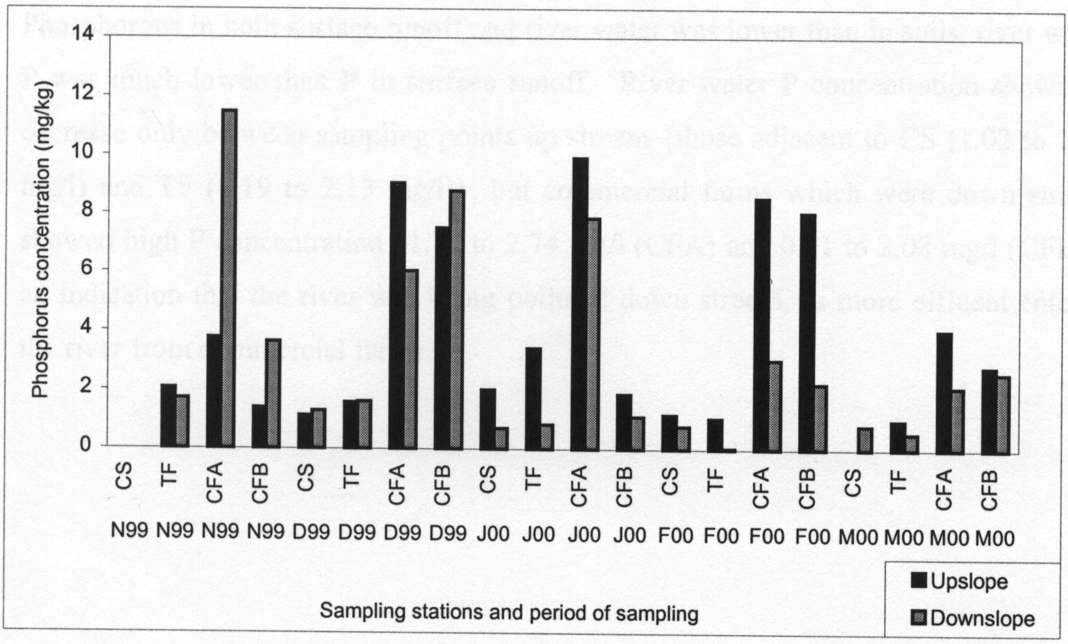

Figure 14. Phosphorus concentration (mg/kg) in soil of Upper Kaleya Catchment at different sampling stations and sampling periods (N99=November 1999, D99=December 1999, J00=January 2000, F00=February 2000 and M00= March 2000).

5.2.3.2 Phosphorous in Water

In surface runoff water, there was not much difference between upslope and down slope concentration of phosphorous. Phosphorous was fairly consistent at all stations ranging from 0.21 mg/l (TF_1) to 3.40 mg/l (CFA_1), although commercial farms had the highest concentration during the wet season. Commercial farms tended to have higher P concentration in surface runoff than traditional farms, the values being 7.58 mg/l (CFA) and 8.24 mg/l (CFB).

Phosphorous in river water was highest at Control Site (CS) and Traditional Farm (TF) during the dry season than in the wet season, whereas commercial farms had P concentration lower in the dry season than in the wet season, particularly Commercial Farm B (Figure 15). The trend of phosphorous decreasing with decrease in rainfall was evident at all stations. Phosphorous was higher in river water adjacent to commercial than traditional farms.

Phosphorous in both surface runoff and river water was lower than in soils, river water P was much lower than P in surface runoff. River water P concentration showed a decrease only between sampling points up stream {those adjacent to CS (1.02 to 2.73 mg/l) and TF (0.19 to 2.13 mg/l)}, but commercial farms which were down stream showed high P concentration {1.11 to 2.74 mg/l (CFA) and 0.91 to 2.08 mg/l (CFB)}, an indication that the river was being polluted down stream, as more effluent entered the river from commercial farms.

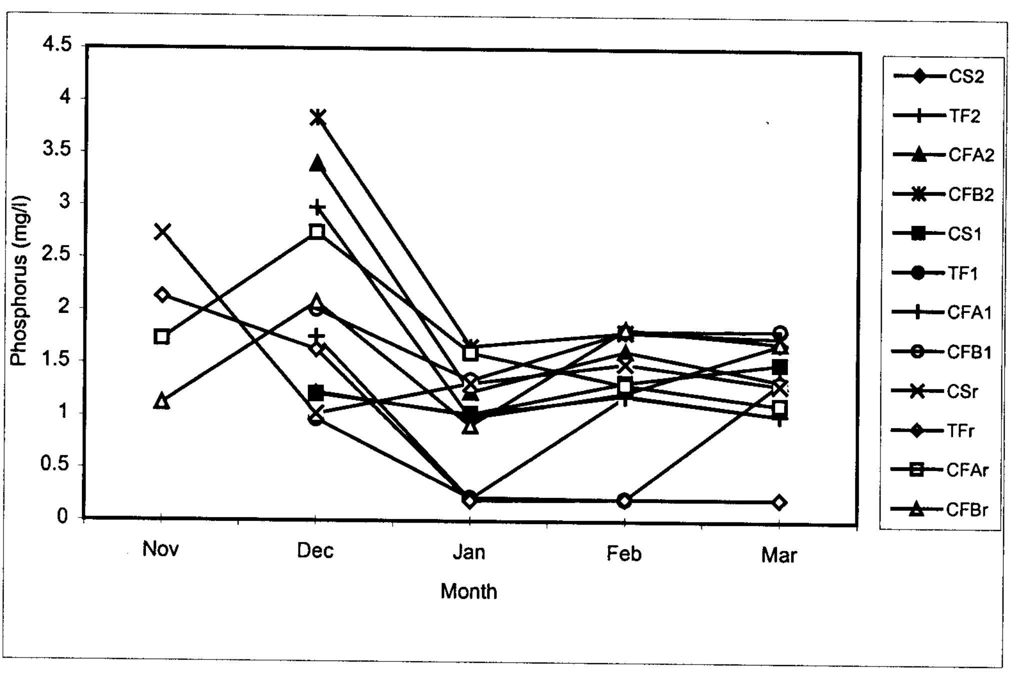

Figure 15. Phosphorus concentration (mg/l) in runoff and river water of Upper Kaleya Catchment, 1999-2000.

5.2.4 Nitrate

5.2.4.1 Nitrate in Soils

Dry season nitrate concentrations were lower {5.25 mg/kg (CFA, subsoil) to 17.50 mg/kg (CFA, subsoil)} than the wet season concentrations {trace (TF, surface soil) to 24.50 mg/kg (TF, surface soil)}, with December concentrations being the highest at all stations (Figure 16). Nitrate had similar trends of increasing especially in December and then decreasing through February and March (this could be due to dilution of fertilizer by rain), with commercial farms in particular having higher concentrations than traditional farms.

Generally, nitrate in soils was higher at all stations than phosphorous. Nitrate in dry and wet seasons was higher in surface soils (trace to 24.50 mg/kg) than subsoil (2.55 to 18.34 mg/kg) at all stations. It was, however, difficult to distinguish the trend of nitrate concentration between upslope and down slope sampling points at all stations due to inconsistencies. In some cases upslope nitrate concentrations were lower than down slope and in other cases it was vise versa, showing no consistency (Figure 16).

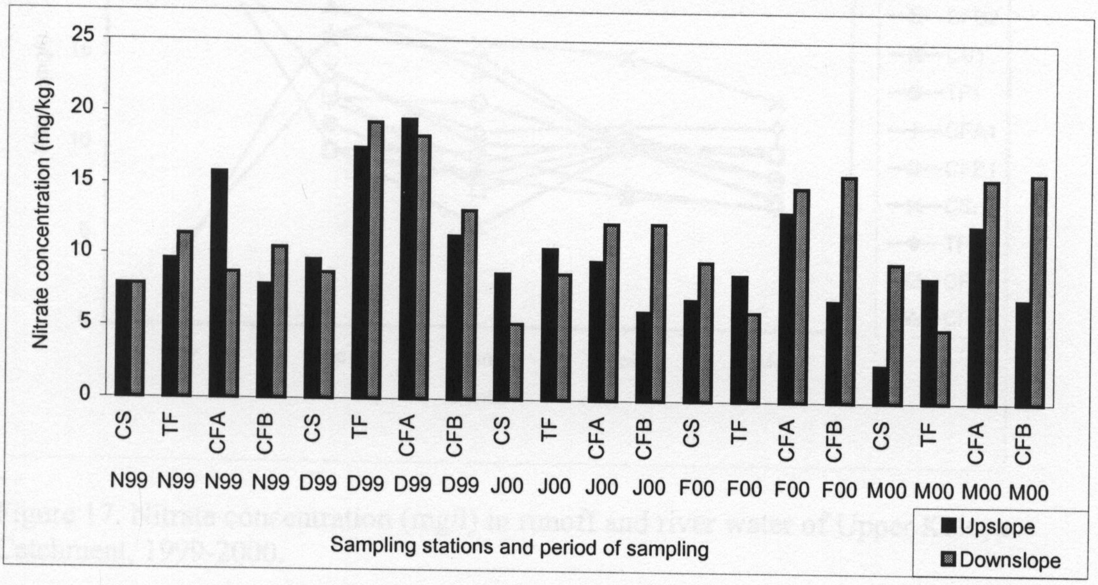

Figure 16. Nitrate concentration (mg/kg) in soil of Upper Kaleya Catchment at different sampling stations and sampling periods (N99=November 1999, D99=December 1999, J00=January 2000, F00=February 2000 and M00= March 2000).

It may be concluded from this that Nitrate was not so much affected by slope.

5.2.4.2 Nitrate in Water

Nitrate in runoff was highest in December, and like in soils there was no consistency in concentration between upslope and down slope (may be slope had no effect on nitrate concentration). This could be because most farms go so near the river that there isn't much difference between upslope and down slope in real sense. On the Traditional Farm nitrate in runoff ranged between 8.4 mg/l and 13.86 mg/l while on commercial farms it was 7.1 mg/l to 17.64 mg/l, generally showing a slightly higher concentration in surface runoff on commercial farms than on traditional farms. The trend was similar to that of nitrate concentrations in soils with a slight decrease in concentration in runoff from January going down to March (Figure 17).

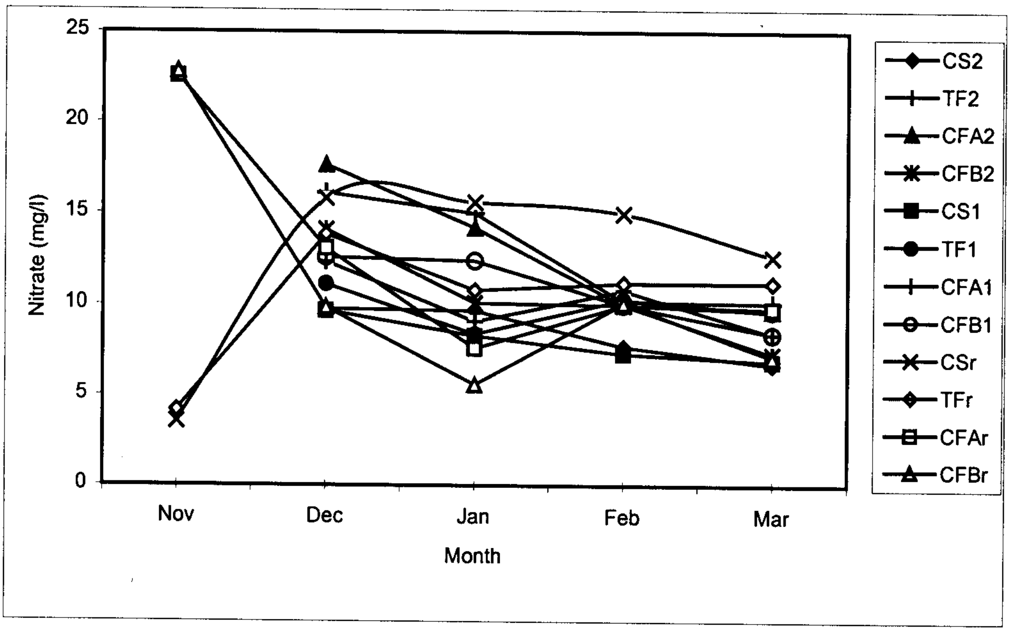

Figure 17. Nitrate concentration (mg/l) in runoff and river water of Upper Kaleya Catchment, 1999-2000.

Nitrate in river water in the dry season was low at Traditional Farm (4.18 mg/l) as compared to commercial farms {22.55 mg/l (CFA) and 22.8 mg/l (CFB)}. In the wet season on traditional farm it was higher (10.8 to 13.86 mg/l) than in the dry season (4.18 mg/l), even though there was a decrease towards the end of the rainy season, but still higher concentration than in the dry season (Appendices 5.1 to 5.4). The concentration of nitrate in the dry season on the commercial farms was higher (22.55 mg/l, at CFA and 22.80 mg/l at CFB) than in the wet season (5.60 mg/l to 13.08 mg/l at CFB).

5.2.5 Nitrite

5.2.5.1 Nitrite in Soils

Nitrite concentration in soils was generally low in soils at all stations. The lowest nitrite concentrations were recorded at the Control Site (CS) where there were only trace concentrations at almost all sampling points (trace to 0.25 mg/kg in the dry season and trace to 9.75 mg/kg in the wet season). The trend of higher nitrite concentration on surface soils than subsoil was evident. But there was no consistent pattern depicted along surface slope just as was the case with nitrate and phosphorous. This could indicate that slope did not affect NO_2-N concentration. The Traditional Farm station in the dry season had nitrite concentration in soil ranging from trace to 12.50 mg/kg while commercial farms had trace to 4.75 mg/kg, an indication of traditional farms having higher nitrite concentrations than commercial farms in the dry season (Figure 18). This could be because commercial farmers irrigate in the dry season causing dilution, hence lowering nitrite concentration. In the wet season traditional farms had trace to 24.25 mg/kg while commercial farms had trace to 28.25 mg/kg, an indication that commercial farms had higher concentrations of nitrite than traditional farms in the wet season. This implies that commercial farms applied more fertilizers than traditional farms during the growing season.

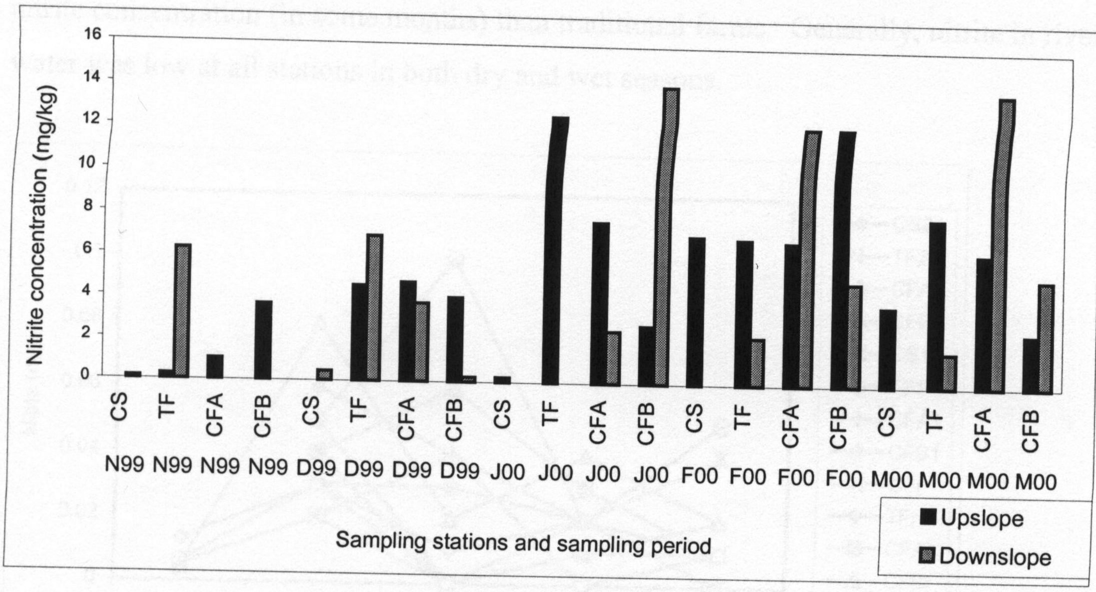

Figure 18. Nitrite concentration (mg/kg) in soil of Upper Kaleya Catchment at different sampling stations and sampling periods (N99=November 1999, D99=December 1999, J00= January 2000, F00=February 2000 and M00= March 2000.

5.2.5.2 Nitrite in Water

Nitrite in surface runoff did not show any trend in concentration between upslope and down slope points (Appendices 5.1 to 5.4). There was a decrease in concentration with the advance of the rainy season. In surface runoff at the Traditional Farm station nitrite concentration ranged between 0.01mg/l and 0.04 mg/l, while at the commercial farm stations it ranged from 0.00 mg/l to 0.05 mg/l. Commercial Farm A (CFA) had lower nitrite concentration than CFB in the month of January, particularly. There was no apparent difference between upslope and down slope concentration of nitrites.

Nitrite concentration in river water was low ranging from 0.004 mg/l (CFB_r) to 0.013 mg/l (TF_r) in the dry season at all sampling points compared to the wet season when it was slightly higher 0.00 (TF_r, CS_r) to 0.1 mg/l (CFB_r). Farm CFB had higher nitrite concentration even though it was a station down stream, especially in December and February (Figure 19). From this, commercial farms could be said to have slight higher nitrite concentration (in some months) than traditional farms. Generally, nitrite in river water was low at all stations in both dry and wet seasons.

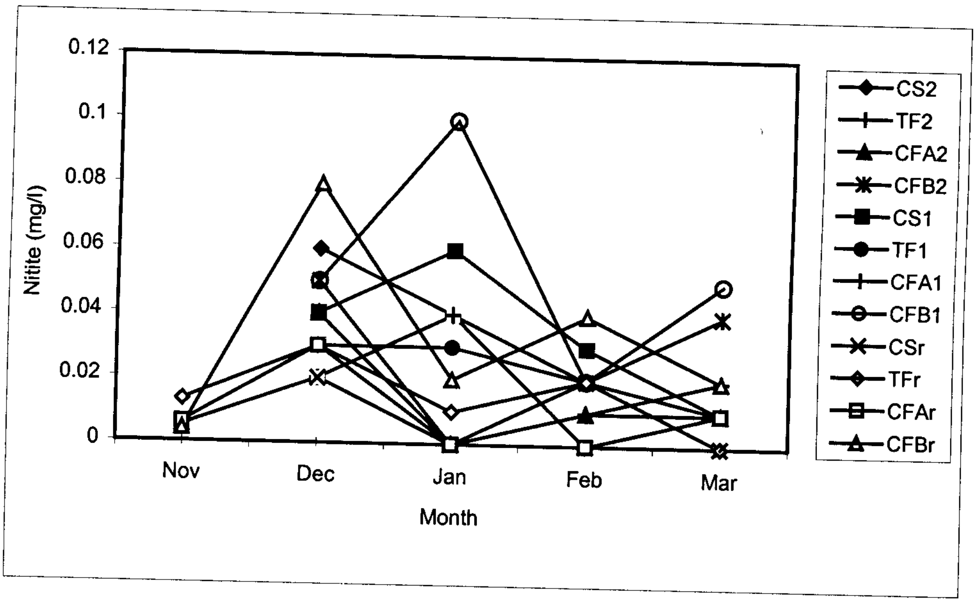

Figure 19. Nitrite concetration (mg/l) in runoff and river water of Upper Kaleya Catchment, 1999-2000.

5.3 Pesticide and Fertilizer Use in Upper Kaleya Catchment

A questionnaire survey was conducted in order to complement the findings of the physico-chemical evaluation of water pollution problems in Upper Kaleya River. Commercial and Traditional farmers were used in this survey as a basis for comparison of any variations that might occur in the use and impact of nutrients and pesticides in the study area.

5.3.1 Educational Background of Farmers in Upper Kaleya Catchment

Most of the subsistence farmers (75%) had only primary education, while 80% of the commercial farmers had attained tertiary education with no one having only primary education or having never been to school (Table 5.1). The lowest educated among commercial farmers had gone as far as secondary education. The commercial farmers were generally more educated than subsistence farmers. The Chi-square supports this where $\aleph^2 = 20.58$, $p=0.01$ indicating a significant difference in education attainment between commercial and traditional farmers.

Table 5.1. Educational background of farmers in Upper Kaleya Catchment

Type of Farmer	**Never been to School**		**Primary Education**		**Secondary Education**		**Tertiary Education**	
	No.	**%**	**No.**	**%**	**No.**	**%**	**No.**	**%**
Commercial	0	0	0	0	2	20	8	80
Traditional	1	5	15	75	3	15	1	5

All the farmers that were interviewed were male because no woman farmer was found in the study area, perhaps no woman owned any land or no woman was sampled. But women were mostly just working on farmlands owned by their husbands or male relatives or as workers on commercial farms especially during coffee harvest. Of those sampled, male farmers (67%) were subsistence farmers owning land mainly in the area designated as traditional land (Figure 3), and only 33% were commercial farmers. In spite of commercial farmers being few in number, they own and cultivate more land than traditional farmers (section 6.5.1).

Agriculture in this area is the major income-earning activity with 97% of the people engaged in farming (Ng'onga and Masinja, 1991). Arable farming was seen to be more prominent even though some animals like cattle, goats and sheep were kept but not in large numbers. Dairy farming and ranching are mostly practiced in the Middle and Lower Kaleya, but this was outside the study area. About 80% of the farmers in Upper Kaleya (both commercial and subsistence) have lived and farmed on their land for many years most of them more than 10 years, some even over 20 years (Table 5.2). The minimum years of farming for both commercial and subsistence farmers were five years.

Table 5.2. Length of time farmland has been cultivated

Type of Farmers	More than 10 years		10 years		5 years		2 years		Total
	No.	%	No.	%	No.	%	No.	%	No.
Commercial	8	80	1	10	1	10	0	0	10
Traditional	16	80	2	10	2	10	0	0	20

5.3.2 Pesticide Use

Farmers in Upper Kaleya Catchment identified insects/pests and soil infertility as their major production problems. Among subsistence farmers over 95% identified soil infertility as their major problem and only 5% insects/pests as their major production problem. Over 80% commercial farmers find soil infertility, insect/pest and weeds to be their major problem (Table 5.3).

Table 5.3. Major production problems in Upper Kaleya farming area

Type of Farmer	Insect/pest and weed		Insect/pest and soil infertility		Insect/pest		Weeds		Soil infertility		Total
	No.	%	No.	%	No.	%	No.	%	No.	%	No.
Commercial	3	30	3	30	2	20	2	20	0	0	10
Traditional	0	0	0	0	1	5	0	0	18	95	20

The above problems have compelled farmers in Upper Kaleya Catchment to use artificial fertilizers and pesticides in order to achieve high crop production. Results of analysis show that all (100%) of the commercial farmers interviewed used pesticides and only 15% subsistence farmers used pesticides while 85% did not use any form of pesticides (Table 5.4).

Table 5.4. Number and percentage composition of farmers using and not using pesticides in Upper Kaleya farming area

Type of Farmer	Used Pesticides		Used no Pesticides	
	No	%	No	%
Commercial	10	100	0	0
Traditional	3	15	17	85

The most common types of pesticides used by both commercial and traditional farmers are shown in Figure 20.

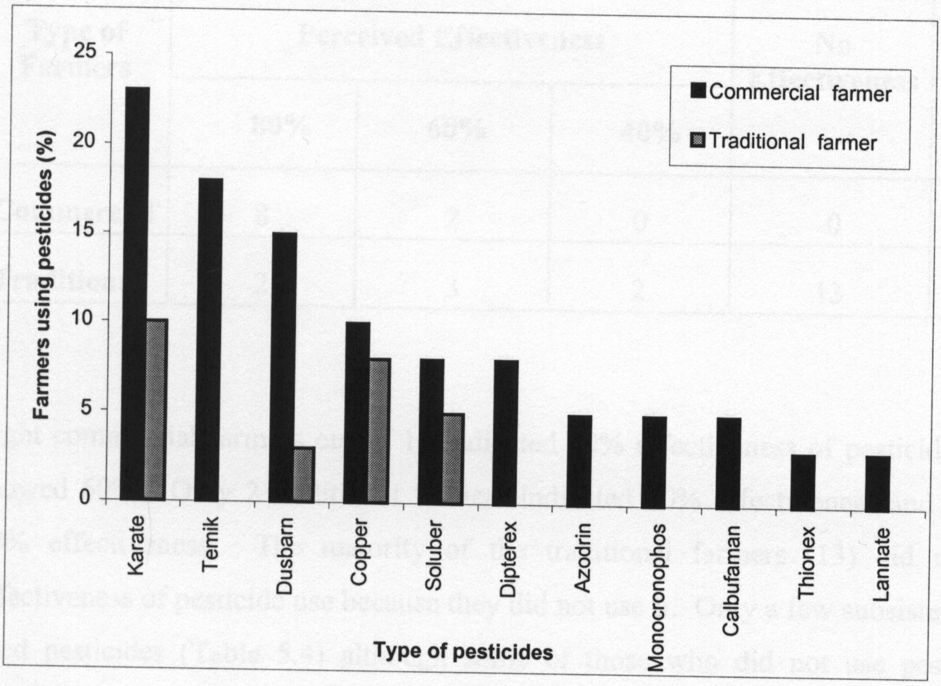

Figure 20. Pesticides used by farmers sampled in Upper Kaleya Catchment, during 1999/2000growing season.

Karate, Soluber, Copper, Dusbarn were all found to be commonly used by both commercial and traditional farmers (Appendix 7). Karate rated the most highly used by both types of farmers. However, Commercial farmers used more and a wider range of pesticides than their counterparts, the traditional farmers (Figure 20). The observed $\chi^2 = 23.51$, $p = 0.813$ showing a significant difference in pesticide use between commercial and traditional farmers. This confirms that commercial farmers used more and different types of pesticides.

Both commercial and traditional farmers applied pesticides weeks after planting irrespective of pest infection levels, an indication of excessive use of pesticides. The fact of over use of pesticides could also be seen from the farmers' response on how effective the pesticides used were, which was expressed in percentages and number of times pesticides were applied in a year (Table 5.5).

Table 5.5. Farmers' perception of pesticide effectiveness in Upper Kaleya farming area

Type of Farmers	**Perceived Effectiveness**			**No Effectiveness**	**Total**
	80%	**60%**	**40%**		
Commercial	8	2	0	0	10
Traditional	2	3	2	13	20

Eight commercial farmers out of 10 indicated 80% effectiveness of pesticide use and 2 showed 60%. Only 2 traditional farmers indicated 80% effectiveness and 3 indicated 60% effectiveness. The majority of the traditional farmers (13) did not see the effectiveness of pesticide use because they did not use it. Only a few subsistence farmers used pesticides (Table 5.4) although some of those who did not use pesticides still answered that pesticides were effective. This could be due to the fact that they had learnt of it from fellow farmers or they had worked or were working on some commercial farms.

Over 57% of commercial and traditional farmers indicated their intentions to increase on their use of pesticides on their farms in the following growing season (1999/2000) as a way of increasing their yields. Among traditional farmers those that intended to decrease on the use of pesticides indicated that this was because they perceived the use of pesticides to be very expensive. Some commercial farmers expressed the same sentiments and intended to decrease on the use of pesticides as it was becoming unaffordable. In addition, other commercial farmers included environmental concerns as their reason for wanting to decrease pesticide use.

Commercial farmers sprayed pesticides more frequently than traditional farmers, some as much as 75 times in a year (Table 5.6). From the survey it was found out that workers, who were not properly trained, do the spraying on farms. Therefore, the question of excessive use of pesticide cannot be ruled out in such cases, which in turn would pollute the environment.

Table 5.6. Average number of times pesticides were sprayed during 1998/99 growing season

Farmers	**75**	**50**	**30**	**10**	**Nil**	**Total**
Commercial	2	1	3	4	0	10
Traditional	0	0	1	1	18	20

In Upper Kaleya, farmers use hand sprayers (especially traditional farmers). Commercial farmers use the hand sprayers too, but they mostly use the mist blowers, where the Knapsack is mounted on a tractor (Figure 21). This method poses a danger to the aquatic environment as pesticides falling not only on the target (crops like coffee), but also on the ground can be blown off the coffee plantations to some other surrounding areas and in some cases directly into the river especially that most farms are close to the edge of the river bank.

Figure 21. A Knapsack mounted on a tractor spraying pesticides on coffee, February 2000.

5.3.3 Fertilizer Use

Both commercial and traditional farmers use a wide range of fertilizers (Appendix 8). Urea was the most commonly used fertilizer among both commercial and traditional farmers followed by D - compound, as shown in Figure 22. Observed Chi-square was $\chi^2 = 8.92$, $p = 0.169$ revealing no significant difference in the range of fertilizers used between commercial and traditional farmers.

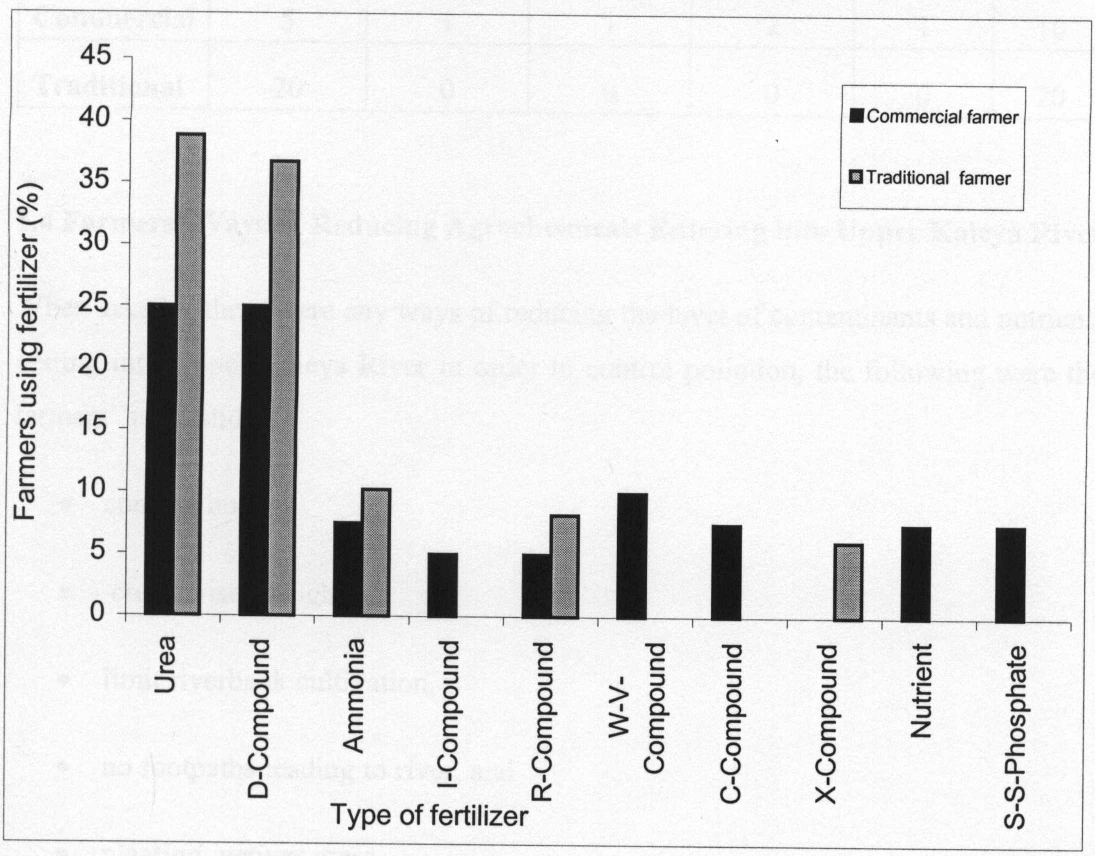

Figure 22. Fertilizers used by farmers sampled in Upper Kaleya Catchment, during 1999/2000 growing season.

Table 5.7 shows that it was common practice among farmers in Upper Kaleya Catchment to apply fertilizer many times per growing season of the year. Some commercial farmers applied fertilizer as much as 23 times per year. Traditional farmers who only grow crops seasonally applied fertilizer twice at the most in a year. This then shows that commercial farmers used fertilizers more than traditional farmers who grow crops on a small scale.

Table 5.7 Average number of times commercial and traditional farmers applied fertilizer during 1998/99 growing season

Type of Farmer	3	8	13	18	23	Total
Commercial	5	1	1	2	1	10
Traditional	20	0	0	0	0	20

5.4 Farmers' Ways of Reducing Agrochemicals Entering into Upper Kaleya River

When asked if there were any ways of reducing the level of contaminants and nutrients getting into Upper Kaleya River in order to control pollution, the following were the farmers' suggestions;

- contour bunds,
- cross-wise ploughing,
- limit riverbank cultivation,
- no footpaths leading to river, and
- planting vetiver grass.

Farmers in the Upper Kaleya Catchment knew some of the measures to take if they have to control erosion and ultimately water pollution. But it was surprising to note that much of what is listed above was not actually practiced. For instance, as already mentioned, most farms were very close to the riverbank, but not many contours were constructed at the edge of most farms. Vegetation cover has been depleted and no reforestation practice in place (Figure 23). The planting of vetiver grass seemed to be a new thing because none of the farms visited in Upper Kaleya, even those in the Middle Kaleya had it planted, except on one farm where it was planted near the farm house. Vetiver grass grows very close together and can be useful in the control of erosion.

Figure 23. Continuously cultivated land at CFA with no vegetation to prevent soil erosion in Upper Kaleya Catchment, November 1999.

5.5 Farmers' Awareness of the Pollution Effect of Agrochemicals

5.5.1 Storage and Disposal of Chemicals

The storage of pesticides and spraying machines was fairly satisfactory among commercial farmers because storehouses on commercial farms were found where huge amounts of pesticides and fertilizers were stored. This agrees with what Wadageneh (1995) reports on Zambia storing huge amounts of pesticides. This then cannot rule out excessive use of these chemicals. But no storehouses were found on traditional farms owned by those farmers that used pesticides. From data analysis it was observed that most traditional farmers used pesticide and fertilizer empty containers and bags for their household purposes. This was an indication of lack of awareness of the effects of pesticides as these can have adverse effects on human health as well as the environment.

5.5.2 Nearness of Farm to Kaleya River

About 90% of the commercial farms were very close to the river with a distance of 0.5 km or less away from the river (Table 5.8). This is supported by what was visually observed during the period of study, where almost all commercial farms ended near the edge of the riverbank. About 60% of the subsistence farmers were also in the range of 0.5 km away from the river. Generally, it can be said from this data that most of the farms (both commercial and traditional) were near or close to the edge of the riverbank, with only 5% (mostly subsistence farmers) of all the sampled farmers at a distance of 6.5 km. This is a poor farming practice in a river catchment. It may cause flooding and siltation downstream during heavy rains and may also result in water pollution by pesticides and fertilizers. The nearness of the farm to the river was also another indicator that farmers were not aware of the pollution effects of the agrochemicals used on their farms.

Table 5.8 Average distance of farm from Kaleya River from sampled farmers in Upper Kaleya Catchment

Type of Farmers	0.5km		2.5km		4.5km		6.5km		Total
	No.	%	No.	%	No.	%	No.	%	
Commercial	9	90	1	10	0	0	0	0	10
Traditional	12	60	4	20	3	15	1	5	20

5.5.3 Effects of Agrochemicals on the River

From the analysis of data, it was revealed that over 27% of the traditional farmers had no idea of the effects pesticides and fertilizers would have on the water quality if the chemicals entered the Kaleya River. In comparison, about 27% commercial farmers were aware of the polluting effect of agrochemicals.

Some of the common effects cited to indicate awareness, were: living organisms such as fish would die, water pollution/poisoning, human health problems, and rapid growth of plants in the river (Table 5.9). Those farmers (especially traditional farmers) who were not aware of the effects agrochemicals had once they reached the river thought agrochemicals applied on the farm did not get into the river and so had no effect. Also they thought there was no effect because the river purifies itself. Whereas there could be some truth in the second point, however, the river can purify itself only up to a certain extent, beyond which it cannot.

Table 5.9 Farmers' awareness of pollution effect of agrochemicals

Type of farmer	No idea		Poison/pollution of water		No effect, river purifies itself		Chemicals do not reach river		Total
	No.	%	No.	%	No.	%	No.	%	No.
Commercial	1	10	8	80	1	10	0	0	10
Traditional	8	40	7	35	3	15	2	10	20

The next chapter discusses and provides interpretation and implications of the results.

CHAPTER 6: DISCUSSION, INTERPRETATION AND IMPLICATIONS

6.1 Introduction

The most important environmental and agronomic factors to be considered in water pollution include soil properties, climatic conditions, crop type, water management methods and cropping practices. Many of the environmental factors are time dependent. According to Wheater and Kirby (1998), a more prudent approach to prevention or reduction of surface and ground water contamination by fertilizers/pesticides must be based on understanding the relationship between chemical properties, soil system properties and climatic and agronomic variables that combine to induce leaching and soil erosion. Some of these variables are discussed below.

6.2 Climatic and Hydrological Characteristics

Rainfall and discharge data from 1977 to 2000 seasonal years were used for correlation and graphical interpretation, to help in the discussion of water quality. Results of the analysis revealed that rainfall fluctuations correlated positively with discharge ($r = 0.368$, $p = 0.53$), indicating a significant correlation between rainfall and discharge. This is to say that discharge is dependent upon rainfall to a certain extent.

The hydrograph (Figure 9), which is a plot of stream flow or discharge against time, is affected by seasonality of climate. Consequently, discharge showed fluctuations following the rainfall regime, being high in wet months and low in dry months. However, in the hydrological year 1999/2000 (the year when samples were collected) discharges were much lower than expected compared to the amount of rainfall received due to the increase in the existence of a series of dams and weirs on Kaleya River and commercial farming areas and also by abstraction directly from the river. Water abstraction from Upper Kaleya River has increased over the years. In 1952, the volume of water abstracted was 675 m^3 and this has progressively been increasing almost every year such that by 1998 over 5.5 million m^3 per day was used for irrigation on commercial farms (Appendix 9). An effluent discharged into a slow moving river may take some time to become diluted. In a turbulent river, mixing is obviously much quicker and dilution is achieved sooner. This is not the case with Upper Kaleya River, where the amount of discharge is influenced by irrigation activities, affecting water flow especially in the dry season.

Rainfall is more prominent in dictating the rhythm of the life of the Upper Kaleya Catchment as an ecosystem. However, there are also human pressures bearing on the river. Rainfall interacts with chemical properties to transfer and transport nutrients within and out of the soil profile and on land surfaces into the river system. These natural and human pressures are indicators of the nature of pressures influencing water quality of a river system. Under increased climatic and human pressure regime, the surface water recharge may not be sufficiently rapid to sustain the river's self-purification, as pointed out by some farmers in Upper Kaleya.

6.3 Seasonal Quality of Soil

6.3.1 pH

The pH mean values were fairly constant (acidic) at stations TF (5.23-6.35) and CFB (4.86-5.46) except at CFA (5.92-7.13) where it was slightly less acidic. Generally, pH exhibited acidic soils in Upper Kaleya Catchment. According to Monkhouse (1965), soils with pH of 7.2 are neutral, less than 7.2 acidic, above 7.2 alkaline, 4.5 or less are categorized as very acidic soils. The soil acidity in Upper Kaleya farming area could be due to the application of fertilizers on the farms. Fertilizers lower pH and it was found out that pH was lower during the height of the rainy season and was slightly going up when dilution by rain was reduced towards the end of the rainy season (Appendix 4.1-4.4) especially at CFB. The surface soils were more acidic than subsoil at all stations, an indication that the surface soils contained more fertilizers that lowered the pH than the subsoil.

There was not much difference between dry season pH (5.14 CS_1 to 7.04 CFA_1) and wet season pH (4.86 CFB_1 to 7.13 CFA_2) in soils. This is difficult to explain because in the rainy season pH was expected to be lower due to application of fertilizer during the growing season and due to dilution by rainfall, as both of these factors enhance soil acidity. The use of many types of fertilizers as was revealed in the survey, pollutes the soil, resulting in acidification which releases toxic substances into the soil that eventually reach the river and subsequently polluting the river. There was significant difference in mean pH at the upslope of TF vs CFA ($t = 5.24$, $p = 0.003$), but no significant difference at upslope of TF vs CFB ($t = -2.15$, $p = 0.064$). Down slope mean pH of TF vs CFA yielded $t = 3.76$, $p = 0.021$ and TF vs CFB $t = -7.29$, $p = 0.0002$, both indicating significant differences in pH between the aforementioned stations, even as raw data showed some differences between commercial and traditional farms.

6.3.2 Conductivity

Conductivity was higher in surface soils (0.00 µS/cm CFB_2 to 0.77 µS/cm CFA_2) than subsoil (0.01 µS/cm CFB_2 to 0.53 µS/cm CFA_2) (Appendices 4.3 and 4.4), an indication that effluent was more in surface soil than subsoil. Conductivity in the wet season was higher than in the dry season (section 5.2.2.1), since during the rainy season more effluent was released through fertilizer application. However, conductivity was within permissible levels in soils that do not pose a threat to the environment according to WHO (1970) standards.

Conductivity in soils did not show any significant difference between commercial and traditional farms at upslope sampling points as revealed by the t- test (upslope TF vs CFA $t = -24.10$, $p = 0.203$ and TF vs CFB $t = -26.7$, $p = 0.117$. Down slope of TF vs CFA $t = 4.55$, $p = 0.003$ showing a significant difference. TF vs CFB yielded $t = 0.29$, $p = 0.78$) showing no significant difference. However, a significant difference was observed on upslope between Control Site and Commercial Farmer A where the t =

3.49, $p = 0.02$. This implies that conductivity was higher on farming areas where fertilizers were applied than on the Control Site where fertilizer was not applied.

6.3.3. Phosphorus

The increase of phosphorous concentration in the soil between December and January and the gradual decrease with the progression of the rainy season corresponds with the trend shown by conductivity (section 6.3.2), an indication that when effluent is introduced conductivity increases. This is because planting of most crops was done in December/January at a time when farmers (traditional and commercial) applied fertilizers as was confirmed by the questionnaire responses. The higher concentrations of phosphorous in surface soils than subsoil at all stations is a clear indication that leaching was quite minimal. This was probably caused by compaction of topsoil by heavy machinery on commercial farms and cattle drawing the plough on traditional farms. Low rate of leaching could also be probable considering that rainfall in the area during the period of study was just average or lower, not enough to seep through and down wash chemicals, resulting in increases in P concentration in surface soils than subsoil.

The trend of phosphorous concentration decreasing with the progression of the rainy season and much lower at the end of the rainy season, could have been due to dilution by rain and also due to reduction in the application of fertilizer towards the end of the growing season. Generally, phosphorous concentration in soils was low. When the presence of phosphorous in soil decreases due to absorption by plants, no soluble phosphorous can be mobilized. This reaction could have been produced by pH changes in soils. To maintain the highest level of solubility pH must be maintained at almost neutral level (7.2) (section 6.3.1). But, pH in soils was between 4.75 and 7.19, that is, fluctuating between being very acidic and being neutral. This could be the reason why phosphorous was low in soils despite high fertilizer application in the area. The t- test in soils between commercial and traditional farms showed no significant difference (at .05 significant level, two-tailed), regardless of slope (TF vs CFB $t = 1.67$, $p = 0.164$;

down slope TF vs CFA $t = 2.361$, $p = 0.08$ and TF vs CFB $t = 2.46$, $p = 0.057$), except for upslope TF vs CFA $t = 4.18$, $p = 0.001$, which showed significant difference.

6.3.4. Nitrate

Nitrate concentrations were generally high ranging between the means of 2.55 mg/kg (CS_2) and 19.47 mg/kg (CFA_2). Surface soils had higher concentrations of nitrate than subsoil, just as was the case with phosphorous. This could mean that much of the nutrient had not been leached to subsoil in the torrential down pours that are common in Upper Kaleya, considering that rainfall was generally low during the period of study.

At all stations nitrate did not show any significant difference in upslope vs down slope concentrations in soils (upslope TF vs CFA $t = 1.29$, $p = 0.23$ and TF vs CFB $t = -1.64$, $p = 0.155$; down slope TF vs CFA $t = 1.28$, $p = 0.240$ and TF vs CFB $t = 1.24$, $p = 0.269$), although from Figure 16, one would assume it was higher on commercial farms than traditional farms and would expect a significant difference. It was also found that soils on commercial farms had higher nitrate concentrations than on traditional farms. The reasons why there was no significant difference in concentration of nitrate in river water between commercial and traditional farms are not known. Probably it could be because nitrates in soil/water also result from organic decomposition that could have taken place since there was little vegetative matter at all the stations. However, this could be an area for further research.

6.3.5. Nitrite

Nitrite concentration in soil was very low as Figure 18 shows (mostly CFA). This could be because nitrites can be reduced to harmless nitrates or to simple compounds through nitrification. This process could have been quite significant in the studied area because nitrate concentrations were higher {2.55 mg/kg (CS_2) to 19.47 mg/kg (CFA_2)} than nitrites {mostly traces to 12.25 mg/kg (CFA_1)} at almost all stations. Between

Commercial Farm B (CFB) and Traditional Farm (TF) at upslope stations there was no significant difference in nitrite concentration as indicated by the t-test ($t = 12.99$, $p = 0.278$). There was also no significant difference in nitrite concentration between Traditional Farm (TF) and Commercial Farm A (CFA) upslope ($t = 0.61$, $p = 0.73$), TF vs CFB upslope ($t = -1.50$, $p = 0.206$). Comparing nitrite concentration for down slope Commercial Farm A ($t = 0.99$ $p = 0.36$), while for the Commercial Farm B and Traditional Farm ($t = 0.49$, $p = 0.631$), both showing no significant difference.

6.3.6 Nutrients

Nutrient concentrations (nitrogen and phosphorous) were found in soils, runoff and river water as revealed by the study. And chemical fertilizers present in soils can eventually pollute surface water especially with the ever-increasing rate of mineral fertilizer application in Upper Kaleya Catchment, like elsewhere in the world (Figure 2). Soil samples, therefore, were used as a measure of the potential contamination of the surface water in Upper Kaleya River. Although the study only gives information about the amount of nitrogen and phosphorous that is potentially available for entering the water body, it provides an opportunity to compare the expected effects of certain control strategies, thus serving as a tool for management modeling. And proper N and P management, by adopting fertilization rates to plant demands, may greatly reduce pollution (UNESCO, 1998).

6.4 Seasonal Quality of River Water

6.4.1 pH

The study revealed that there was not much difference in river water pH on the stations located up stream (CS, TF) and those downstream (CFA, CFB) in the dry season and wet season. Although pH for the dry season was slightly higher than the rainy season as could be expected, due to fertilizer application and dilution by rain in the wet season, which lowered the pH. Generally pH was higher in river water (6.7 to 8.1) in the dry season and in the wet season (5.9 to 8.0) than in soils in the dry season (4.88 to 7.19) and in the wet season (4.75 to 7.33). However, water quality in Upper Kaleya River in terms of pH during the time of study was generally within the recommended WHO (1971) standard, at some stations only, (6.5 – 8.5) for drinking water, irrigation and livestock use (Appendix 10). River water pH did not show any significant difference between traditional and commercial farms for TF_r vs CFA_r ($t = 0.59$, $p = 0.583$), while TF_r vs CFB_r ($t = 1.87$, $p = 0.11$). This could be that the difference in mean pH between traditional and commercial farmers, though showing in figures obtained, was too small to statistically come out as significant.

6.4.2 Conductivity

Conductivity in the river generally was high. It was higher at sampling points adjacent to commercial farms than traditional farms, an indication that some effluents had been discharged into the river through runoff. However, river water conductivity did not show any significant difference between commercial and traditional farms (TF vs CFA $t = 0.66$, $p = 0.525$ and TF vs CFB $t = -0.17$, $p = 0.867$). The decrease in river conductivity at the height of the rainy season (Figure 13) could have been caused by dilution.

But all in all, conductivity in water was very high at all stations ranging from 12 μS/cm (CS_2) to 877 μS/cm (CFB_r) rendering the quality of water outside WHO commended standards (0.7 μS/cm). And anything above 3.0 μS/cm is severe for irrigation. In irrigation the water quality parameter of major importance is salinity, as measured by conductivity, which seriously affects crop growth when present in high concentration.

6.4.3 Phosphorus

Phosphorus was generally lower in both runoff and river water than in soils, with river concentrations much lower than that of runoff (Appendix 4.1 to 4.4). This was due to the fact that soils have a great phosphorous fixing capacity. Although soils had high phosphorous content, only a small amount added to agricultural land was leached into the river. However, the presence of phosphorous in river water in an area where fertilizer was used is an indication of pollution from farmland. Phosphate fertilizers and sewage disposal are probably the most important causes of high concentrations of phosphorous in surface water (leading to eutrophication). In Upper Kaleya Catchment, the Kaleya River is not affected by sewerage disposal and that leaves fertilizer as the most probable and major source of phosphorous. In Upper Kaleya River there was some pollution by phosphorous since concentrations were greater than 0.3 mg/l for drinking water (WHO, 1971). However, phosphorous was within the boundary values (Appendix 10) for fixed trophic classification system (0.21 to 3.40 mg/l) in both wet and dry seasons, since the eutropic limit is between 35 and 100mg/l, (Rast and Holland 1998). There was, therefore, insufficient phosphorous in Upper Kaleya River to support the required abundance of microorganisms (aquatic weed) to grow (Figure 24).

Figure 24. Upper Kaleya River with little aquatic weed (not eutrophic), January 2000.

The Student t-test also proves this; TF_r vs CFA_r ($t = 1.49$, $p = 0.178$), TF_r vs CFBr ($t = 1.25$, $p = 0.257$), which showed no significant difference in P concentration between commercial and traditional farms. This explains why Upper Kaleya was not eutrophic as phosphorous, which is the most limiting nutrient for aquatic plant growth, was in considerably small amounts.

6.4.4 Nitrate

The reason for high nitrate concentration in the river during the dry season could be due to the fact that discharge was much lower coupled with high abstraction of water and limited dilution by rain. Nitrate was higher than phosphorous in the wet season and in the dry season. This could be due to the fact that phosphorous losses from the soil into the river were generally small, relative to the much more soluble nitrate. This can be supported by UNESCO's (1998) statement, that although nitrate is readily assimilated by plants, it is highly water-soluble and, therefore, rapidly leached from soils receiving high rainfall or irrigation.

Commercial farms had higher nitrate concentration than the tradition farm (Appendices 5.2, 5.3 and 5.4) since the soils on adjacent commercial farms had high concentrations and at the same time nitrate is more soluble than phosphorous, especially the fact that river water was the accumulation of runoff from the large areas of the catchment. It is quite surprising that there no significant difference in nitrate concentration between commercial and traditional farms at all sampling points on the river (TF_r vs CFA_r $t = -0.76$, $p = 0.476$; TF_r vs CFB_r $t = 0.24$, $p = 0.81$). This could be because traditional farmers had been over applying fertilizer, or commercial farmers reduce on fertilizer application when coffee trees are fully grown. This disapproves the hypothesis stating that more fertilizers runoff from commercial than from traditional farms.

Nitrate concentration was beyond WHO (1985) recommended standards for drinking water (10 mg/l) at sampling sites, but was within limit levels for irrigation (30 mg/l) and livestock (100 mg/l). The presence of nitrate (and in the case of quite high nitrate concentrations) was an indication that nitrogen pollution from inorganic compounds had taken place in the watercourse especially the area being a farmland where artificial fertilizers were used. Therefore, Upper Kaleya River water quality is not recommended for drinking as revealed by phosphorous and nitrate concentrations. In fact, even the local people without the knowledge of the presence of the chemicals in it, do not use Kaleya River for drinking water especially during the rainy season when it is highly turbid due to high sediment content from farmland. It is a well-known fact that pollutants are carried along by sediment in runoff. In this case, sediment may be considered as a pollutant, Sichingabula *et al* (2000) allude to this.

6.4.5 Nitrite

Nitrite was present in river water although in low concentration as discussed in 5.2.5.2. However, the mere presence of nitrite in water may pose a danger in water quality for drinking (WHO, 1971). Nitrite concentrations in Upper Kaleya River were beyond the recommended limits for drinking water since it was present (Appendix 10). Fish can survive up to 1 mg/l of nitrite concentration (WHO, 1971). Some fish were found in the river, which local people were fishing (Figure 5). This explains the reasonably low amount of nitrite in the river to have allowed the survival of fish even though only one species type was observed.

River nitrite concentrations showed no significant difference between commercial and traditional farms (TF_r vs CFA_r $t = -0.72$, $p = 0.49$; TFr vs CFB_r $t = 1.30$, $p = 0.25$).

6.5 Pesticides and Fertilizers

Table 5.2 shows that Upper Kaleya Catchment has been under cultivation for many years. This explains why vegetation is mostly of secondary type, of tall grass and open bush as the original vegetation has been cleared for cultivation over the years (Figure 25). This is supported in Chiti *et al* (1989) and Mulofwa *et al* (1994) surveys of Mazabuka and Southern Province as a whole. The importance of vegetation in pollution control and environmental management cannot be over emphasized.

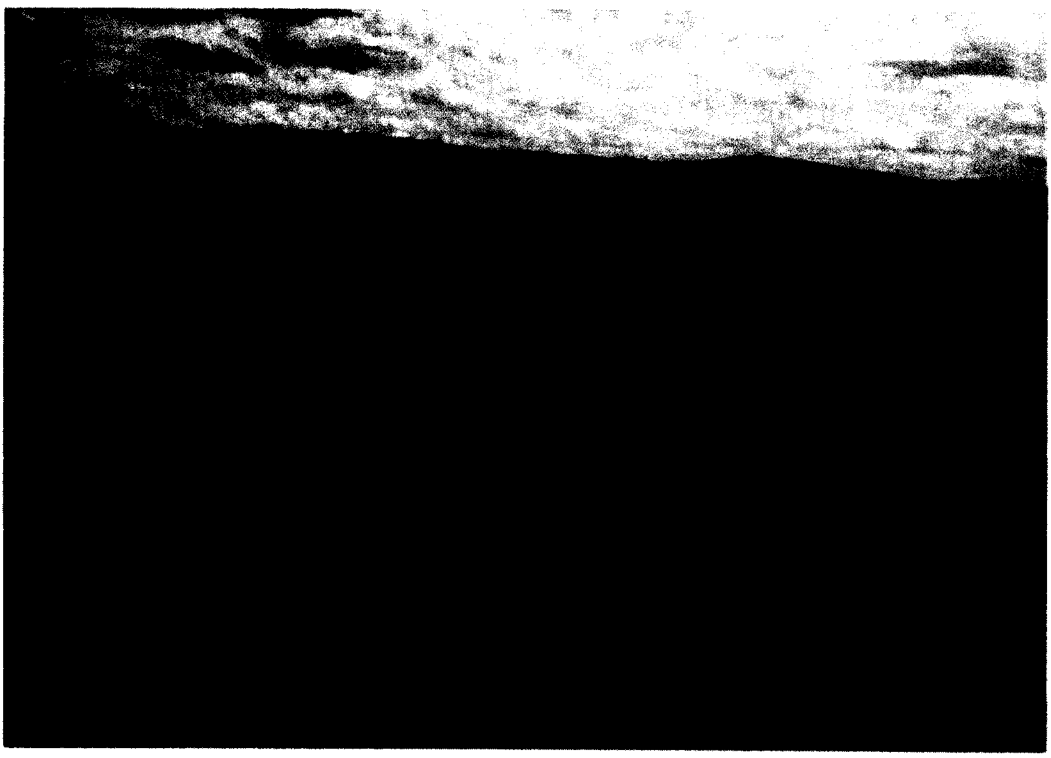

Figure 25. Original woodland vegetation cleared for cultivation, resulting in secondary vegetation type of grass and open bush in Upper Kaleya Catchment, January 2000.

6.5.1 Pesticide Use

Agriculture in Mazabuka is prominent and can be traced back to many years even before independence. Elgie and Johnson (1975:26) state that "Mazabuka District was well known as an area where commercialism had a relatively early and pronounced effect on traditional (village) agriculture that by the time the ecological survey visited this area in 1933 commercial maize production using ox-drawn implements and transport was well established". The land that is cultivated over and over usually becomes prone to soil erosion, eventually polluting the water body.

Since agriculture started many years back in Mazabuka and as the need to produce more food for the increasing population increased, the need for the use of agrochemicals in the form of pesticides and nutrients must have become indispensable. At the time of the study, all commercial farmers used pesticides and in great variety of types. Commercial farmers own and cultivate large pieces of land compared to subsistence farmers, as seen from the following statistics; commercial farmers own land ranging from 806 to 3400 hectares and out of that about 220 to 1200 is cultivated, while traditional farmers own land between 10 to 1000 hectares but only between 3 to 550 hectares of land is cultivated as revealed by the survey.

The survey revealed some evidence of excessive use of pesticides due to the fact that coffee is the major crop grown in the area among the commercial farmers and that many different types of pesticides were used. The other factor that attributed to excessive use of pesticides was that people who were not even trained sprayed pesticides on crops such as most workers on commercial farms, wives of traditional farmers and most traditional farmers themselves. This leads to over application of pesticides. The questionnaire responses on the use of nutrients and pesticides are supportive of the hypothesis that there is excessive use of agro-chemicals among farmers in the Upper Kaleya Basin.

Figure 20 shows that Upper Kaleya Catchment farmers used many different types of pesticides, with Karate, Temik, Dusbarn, Copper and Soluber being the most commonly used. Karate, the most frequently used pesticide by both commercial and traditional farming systems, is mainly used in the spraying of potatoes. Soya beans is also a common crop among both farming systems and Dusbarn is the most common pesticide used for its proper growth, hence it's being common between both types of farms. However, commercial farmers only commonly use those pesticides that are typical of coffee growing. The study revealed the list of pesticides used by commercial farmers to be longer than that of traditional farmers, an indication that a mixture of pesticides was used (Figure 20). Hill and Wright (1978) have pointed out that it is common practice among cultivators to apply mixtures of these pesticides in order to minimize the costs associated with treating crops for individual pests and diseases. This in itself is a sure sign that pesticide over use in the form of various types was possible in Upper Kaleya Catchment. Unfortunately, pesticide concentrations were not quantified due to factors already stated in section 4.5. But from the questionnaire survey there is sufficient evidence that pesticides were used excessively in the study area. This argument can be supported by the number of times pesticides were sprayed in a year (Table 5.6) which shows that spraying was done up to as much as 75 times in a year for the same type of pesticide, especially among commercial farmers, although it was very low among traditional farmers (to only a maximum of 30 times).

The other factor is when the application was done. Usually pesticides were applied before planting, weeks after planting and thereafter until the coffee plant is old or until the crop is ready for harvest in the case of other crops. All this points to the fact that pesticides are frequently sprayed, usually on a prophylactic basis irrespective of pest infection levels. From this high rate of use of pesticides, it would be very unlikely for farmers to drastically reduce on the number of sprays, even though they would like to, to reduce environmental pollution. This in a way defeats the hypothesis that states that farmers in Upper Kaleya Catchment are willing to adopt environmental conservation measures.

Almost all commercial farmers in the study area found the use of pesticides to be a very effective way of insect/pest and weed control, up to as much as 80% perceived effectiveness (Table 5.5). This too points to the likelihood of excessive use of pesticides with an indication of an effective increase in their use. However, pesticide over application has ecological effects on the ecosystem and the environment. It leads to outbreak of secondary pests, which builds up a resistant pest population and also leads to pest resurgence. The culmination of all this is the need for more and many different types of pesticide applications to eradicate the pests. This explains why most farmers were using a mixture of pesticides (Figure 20).

The other indicator showing that most farmers in Upper Kaleya will continue to use pesticides is that most farmers do not know or do not practice alternative pesticide use. Farmers need to adopt biological pest-control measures instead of using only pesticides. But on how effective they (biological pest-controls) may be in pest control could be an area for future research. For with this excessive use of pesticides, water pollution is expected to take place as excess pesticides reach the Kaleya River through soil erosion since rainfall in this area falls as heavy thunderstorms causing a lot of runoff especially in the absence of adequate vegetation cover (Figure 23). Unfortunately, during the study it was not possible to establish in what concentration pesticide pollution was taking place. Objective 2 has therefore been partially achieved only on determining the amount of fertilizers and not pesticides running off into the Kaleya River. However, from the data analyzed from the questionnaire survey, there is some evidence that pesticides have been polluting the Kaleya River. The concentrations of pesticides at the moment may be minimal because the river still carries some fish.

6.5.2 Fertilizer Use

The types of fertilizers used by commercial and traditional farmers were wide, an indication that substantial amounts of fertilizers were used in the Upper Kaleya Catchment (Figure 22). But, commercial farmers use more fertilizers than traditional farmers. Application of fertilizers, like in the case of pesticides, is done routinely usually before planting and also weeks after planting. Therefore, it is likely that there was excessive use of fertilizers in the Upper Kaleya, this is also evidenced by phosphorus and nitrogen (nitrate and nitrite) being found in concentrations higher than WHO (1970) recommendation limit levels for drinking water (sections 6.4.3, 6.4.4, 6.4.5). Coupled with lack of or no training received by the workers on commercial farms in particular, fertilizer could be excessively used. Additionally, traditional farmers' educational level was low (Table 5.1), so most of the traditional farmers cannot read instructions from the pack, and would not apply the right measurement to the crop. There were no extension workers visiting farmers to advise or train them in the proper use of fertilizer (or even pesticides). Some of the farmers in this area who received some training did it about 20 years prior to this study with a few in the last 10 years because the staff from the Department of Agriculture no longer conduct extension services. From the data analyzed, there was evidence that farmers will continue using fertilizers and even use much more to increase production.

Excessive use of fertilizer pollutes the soil and ultimately the aquatic environment. This can lead to fish kills and algae growth. However, no prolific algae were seen growing in the stream and there were some fish in the river, a sure sign that the river has not yet become over nourished or heavily polluted with nutrients from farmlands (Figure 24). But if the use of fertilizers continues to increase, then in a few years to come, the eutrophic status of the Kaleya may change to support the growth of algae and plants leading to eutrophication.

6.6 Farmers' Adoption of Measures to Conserve and Protect Water in Upper Kaleya River

From the survey it was revealed that farmers in Upper Kaleya Catchment did not put much effort in controlling agrochemicals from washing into the Kaleya River. They had some idea on how best to control pollution (section 5.4), but failed to put them into practice. This points to failure to strike a balance between agricultural development and environmental protection to enhance sustainable agricultural development. This disproves the hypothesis that states that farmers in Upper Kaleya Catchment are willing to adopt conservation measures for reducing contamination of soil and water.

6.7 Farmers' Awareness of the Polluting Effects of Agrochemicals

6.7.1 Pesticide Use and Disposal

It was found to be common practice in Upper Kaleya for the people to reuse pesticide containers to store food and water. Storage and disposal of pesticides, pesticide wastes, machines used for spraying, used containers and contaminated materials are indicators of whether or not one is aware of effects of the pesticides (or fertilizers). The reuse of pesticide containers is an indication that farmers and their households, especially traditional farmers, were not aware of the polluting effects of the pesticides (and fertilizers). This is common practice in most developing countries even as revealed by studies done in Zimbabwe from 1985 to 1986 pesticide spraying seasons. Wadageneh (1995:118) reports that "one third of the workers believed that discarded pesticide containers could be used for domestic purposes, such as for storing water and other purposes on the farm". These Zimbabwean studies also showed that workers involved in mixing, loading or spraying pesticides had significant blood chemistry change from pesticide exposure and even farm workers and other people not directly involved in handling pesticides showed blood changes (Alexander and Anderson, 1984). Human health in this case could be impaired through people unknowingly using pesticide wastes or being exposed to pesticides. Also pesticides not properly used are associated with contamination of water bodies.

Commercial farmers, on the other hand, seemed to be aware of the effects of the pesticides as they burnt or buried empty containers and bags of pesticides and fertilizers. Some were kept in the storehouses on farms, although sometimes workers stole them for reuse. This disposal practice is in line with the Law of Zambia, Cap 214 of 1990 on pesticides and toxic substances where pesticides and toxic substances are recommended to be kept in a safe storehouse that is well ventilated and away from populated areas, on well-drained land and away from domestic supplies. FAO (1989) also has similar recommendations.

The commercial farmers showed more awareness of the polluting effect of agrochemicals than most traditional farmers as shown in Table 5.9, which suggests a difference in pollution awareness between commercial and traditional farmers. This can be attributed to the fact that commercial farmers were more educated than traditional farmers in the Upper Kaleya Catchment. And also because most commercial farmers have received some training in farming practices as was revealed by the survey. So commercial farmers were concerned about poor storage and disposal of pesticide wastes that could affect human health and pollute the environment.

From the above findings, it can be said that formal education, somehow, enhances an individual's awareness of environmental problems. Lack of education, as in the case of most traditional farmers, is an indicator of ignorance of the pollution effect that can result from pesticide/fertilizer use as well as from improper storage and disposal of pesticide wastes and containers. This is because pollution, especially water pollution, is not easily perceived. It requires some prior knowledge about its occurrence, which in turn requires attainment of some education to a high level other than no education at all or the lower primary education, which most traditional farmers (80%) in Upper Kaleya had. Education is, therefore, an important variable for creating awareness, positive attitude and development of values towards the environment. It can, therefore, be asserted that well educated people are more aware of environmental pollution than those less educated. Education in this case has an evident role to play as a promoter of environmental change (Kessler, 1996).

Another contributing factor to lack of pollution awareness could be lack of Agricultural Extension Services. As data analysis revealed, extension workers did not visit farmers in Upper Kaleya Catchment and both commercial and traditional farmers confirmed this. No advise or training was given to farmers. Initially when settlement schemes were formed, to which most traditional farmers belonged, a settlement advisor was appointed, whose job was to give day-to-day advice on management of crops and livestock. But because of the non-compulsory nature of the advice given, which was often ignored, the settlement advisor's job was made very difficult (Elgie and Johnson, 1975). Moreover, there was no incentive given in terms of allowances or transport and so the advisor stopped working. This is why one finds some traditional farmers in Upper Kaleya talking of having received their training through a settlement advisor.

But even then those are very few, majority of the farmers have not received any form of training in agriculture.

During the time of this study, no new farming methods on pest and soil fertility management were being taught to farmers, at the time when there was an urgent need for farmers' awareness in the use of pesticides and fertilizers. Consequently, farmers mostly learn from one another or through field days, and usually it is the commercial farmers who benefit from field days and not traditional farmers.

6.7.2 Nearness of Farm to the River

Assessing or determining the closeness of a farm to the Kaleya River helped to determine how much of the riparian zone had been destroyed or how much of the pollutants could be retained by the riparian zone to protect the river from pollution. This was also useful in assessing farmers' awareness of the impact of agrochemicals on the river. In the Upper Kaleya Catchment where most farms were only one kilometre or less away from the river (Table 5.8), pollutants cannot be stopped from entering the river system since much of the riparian zone has been destroyed. This confirms the studies by Petersen *et al* (1987) and Haycock *et al* (1993), which show that in most agricultural areas, riparian zones have almost been eliminated. But it cannot be over emphasized that the riparian zone is an important part of the physical and biological structure of a healthy stream.

In Upper Kaleya Catchment, the situation is worse as most farms are on moderate slopes and end close to the river. With no riparian zone to filter pollution, much of the effluent, if not all, goes into the river during heavy rains. This issue is not being addressed at the moment. The Ministry of Agriculture Food and Fisheries, which is responsible for improving farming practices and encouraging buffer strips along riverbanks, is not doing this work. On the other hand, one wonders why the buffer zone is destroyed so much in Upper Kaleya Catchment because the question of shortage of land did not arise. The only reasons that could be assumed could be lack of awareness or if farmers are aware of the effect of destroying the riparian zone, then it is due to lack of law enforcement on water pollution and control, that farmers are allowed to do farming practices that result in environmental pollution.

From the study all the objectives have been achieved except for one (objective 3) that was partially achieved, as only quantities of fertilizers were determined and not pesticides.

Summary, conclusions and recommendations to the study are outlined in the next chapter.

CHAPTER 7: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Upper Kaleya Catchment is an important agricultural area where farmers use fertilizers and pesticides. These agrochemicals leach into the Upper Kaleya River. This is compounded by the occurrence of torrential rainfall, which causes a lot of runoff on land that is almost devoid of vegetation and has no riparian zone.

The aim of the study was to increase the understanding of the movement of agrochemicals into Upper Kaleya River and their impact in the river and the organisms in it. The data so collected can be useful in planning pollution control and promote sustainable watershed management. The creation of this awareness among farmers is a necessary tool to help increase efficiency of utilization of pesticides and nutrients and reduce opportunities for leakages of excess agrochemicals into the Upper Kaleya River. To achieve the objectives of the study, soil and water samples were collected to determine nutrient concentrations from eight sampling stations on two commercial farms (CFA and CFB), one traditional farm (TF), one control site (CS) and four sites were on the river adjacent to the above (CFA_r, CFB_r, TF_r, CS_r). The soil and water samples collected were analysed in the laboratory for pH, conductivity, nitrate, nitrite and phosphorus. A questionnaire using systematic sampling was employed, which captured a sample size of 30 farmers (10 commercial and 20 traditional farmers). The questionnaire survey complemented the laboratory findings and also assessed pollution by pesticide use. Secondary data on rainfall and discharge was used to determine chemical effects on water quality. General information on the study area was collected through informal interviews with farmers and various authorities as well as through visual observations.

The laboratory analysis of the samples revealed that pollution was more from commercial than traditional farmlands even though the difference was statistically insignificant. The survey, however, supplemented the findings of the laboratory analysis, revealing that commercial farmers had more land cultivated and grew crops that required great use of fertilizers and pesticides. It was also found that farmers in Upper Kaleya Catchment use a variety of fertilizers and pesticides and commercial farmers had large quantities stored in warehouses, which pointed to excessive use of agrochemicals that eventually enter the Upper Kaleya River.

Upper Kaleya River was found to be polluted by fertilizer loadings running off from commercial and traditional farmlands of Upper Kaleya Catchment. The amount of nutrients at the time of study was relatively small and the river was not eutrophic. But with the increase in the use of agrochemicals, as was the indication from farmers responses, the river may become heavily polluted unless alternatives to fertilizer/pesticide use and conventional farming practices are put in place, and the farmers, especially traditional farmers are sensitized to water pollution control.

7.2 Conclusions

From the study the following conclusions could be made:

- Analyses of data showed that the Upper Kaleya water was polluted by nutrients from runoff due to high use of fertilizers. Based on data obtained from questionnaires, laboratory analysis and the literature reviewed, it can safely be stated that pollution by nutrients (and pesticides) in Upper Kaleya River is evident as revealed by the high concentrations of N and P that were higher than WHO recommended for drinking water. This means that Upper Kaleya River water quality is impaired and not recommended for drinking as revealed by the N and P concentrations and the mere presence of nitrite in water. But more detailed work is required to verify this observation and to determine the concentration of pesticides leaching into the Kaleya River, which was not achieved in this study.

- The study revealed that slope gradient did not have any effect on the amount of fertilizer concentration moved over the valley slope. The low rainfall in the area could have contributed to this result.

- Excessive amounts of fertilizers (or pesticides) were entering Upper Kaleya River as revealed by the concentration of N and P in river water. This may accumulate in fish and have an effect on fish, other organisms and human health as well as vegetables irrigated from the same water. However, the Upper Kaleya River water was still within recommended WHO standards for irrigation (30 mg/l) and fish was still found in the river, but not for drinking purposes.

- The soil is a major sink for chemicals applied to crops and soil erosion moves the excess agrochemicals from farmlands into the river, this is aggravated by thunderstorms experienced in the study area. Commercial farms were found to contribute more nutrient pollution to the river due to many different types of fertilizers used, leading to higher nutrient concentrations in soils on their farmland and on the river adjacent to them. Sustainable agricultural practices will inevitably be required in order to manage and protect the water resource.

- The survey revealed a risk of direct pollution by fertilizers/pesticides due to non-restricted use of fertilizers and pesticides by farmers. This was compounded by the fact that most of the farms were near the river. And most farms in Upper Kaleya Catchment did not show measures taken to protect Kaleya River from non-point source pollution. People in Upper Kaleya Catchment should learn to regard future conservation of the environment as a moral obligation if sustainable agricultural development is to be achieved. And pollution awareness campaign is imperative.

- Most traditional farmers were not aware of the polluting effects of agrochemicals into the upper Kaleya Catchment partly because of low educational levels, implying that environmental education is required in the area.

- Environmental problems are generally related to human activities in resource exploitation, resulting in the natural quality of the environment being degraded and causing health risks to humans. This implies that pollution control and environmental management is a problem of every farmer in Upper Kaleya Catchment and not the government alone.

7.3 Recommendations

Specific actions recommended for the control of fertilizer and pesticide impacts on water quality are enumerated below:

- Long-term pollution studies in Upper Kaleya Catchment should be conducted in order to monitor the problem and provide reference against which it can be assessed to identify information gaps and develop long-term cost effective pollution control and monitoring programmes. The results of such studies can be used to update rules and regulations for environmental and water quality standards for different uses.

- Since no pesticide quantitative tests were conducted in this study, further studies should carry out laboratory testing on the amounts of pesticides in runoff river water and soils in Upper Kaleya to ascertain quantities entering the environment. Such information can be useful in planning pollution control and ensure sustainable agricultural development in the area.

- Farmers should become less dependent on chemical fertilizer and pesticides in order to maintain yields and attain sustainable agricultural development. This can be achieved through the introduction and acceptance of use of less persistent pesticides, biological pest-control measures and organized integrated pest management like pesticide-use reduction and use of green manure. However, since the habitats of natural enemies have been destroyed through monoculture practices in Upper Kaleya, farmers can obtain higher plant diversity with a resulting increase in natural control by mixing the crops on adjacent fields or by planting alternate strip cropping. Agro forestry should also be encouraged.

- Riparian zones should be protected in order to control soil loss from farmlands. Watershed management should be one of the goals in Upper Kaleya Catchment. It is practical to start on a small scale with the land area of streamside vegetation (riparian zones), because it may act as nutrient-pesticide and sediment filter between cropped fields and the stream. Other soil conservation measures should be introduced and practiced such as re-vegetation, crop management, early planting, high planting population, slope runoff control (hill slope terracing, contour ploughing) and preservation of vegetation strips.

- Provision of extension services in the correct application and handling of agrochemicals, in Upper Kaleya Catchment, should be re-introduced. This will reduce the hazard of environmental pollution.

- There is great need to increase farmers' awareness towards environmental protection and sustainable management. Control of non-point source pollution, especially in agriculture, is not easy but is possible through awareness creation. The challenge is to mobilize the knowledge and make it available to farmers. Information dissemination is the key to achieving environmental protection.

- Water abstraction by commercial farmers should be strictly monitored by the Water Development Board to ensure that there is enough water in the river for aquatic life. Water pollution occurs to the greatest extent where and when water resources are limited.

- Existing water laws should be revisited so that they cater for issues on enforcement of water laws such as water sources protection, erosion, sediment control and proper watershed management. This will deter farmers and the general populace from polluting the water bodies.

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APPENDICES

APPENDIX 1

Questionnaire on the Investigation of the Amount and Environmental Impact of Chemical Fertilizers and Pesticides Running off from Commercial and Traditional Farming Areas in Upper Kaleya Catchment

Study Site:.. Location:.................................

Type of Farm: Commercial [ ] Traditional [ ]

I PERSONAL

i) Sex: M [ ] F [ ]

ii) Standard of education attained

d) Never been to school [ ]

a) Primary [ ]

b) Secondary [ ]

c) Tertiary [ ]

iii) Major source of income____

II BACKGROUND INFORMATION

i) What is the total area of your farm?__________________(hectares)

ii) What is the total cultivated area of your farm?_________(hectares)

iii) What crop do you grow on your farm and how much is the areas under each crop (hectares)?

Crop	Area (hectare)

iv) When did you start growing these crops on your farm?

2 years ____________ 10 years ________________

5 years ____________ More than 10 years ________

iv) Do you keep any livestock on your farm?

Yes [ ] No [ ]

If yes give the number: -

Cattle______ Goat ______ Pigs _______ Sheep _________

v) What do you think are the major production problems you face?

Insects/pests ________ weeds ________ infertile soil _______

vi) Has the government or NGOs introduced measures of helping solve your problems?

Yes [ ] No [ ]

III. PEST-CONTROL/SOIL FERTILITY MANAGEMENT

i) What major type of pesticides and nutrients (fertilizers) do you apply on your farm?

Pesticides	Fertilizers
a)________________	a)________________
b)________________	b)________________
c)________________	c)________________
d)________________	d)________________
e)________________	e)________________

Use none [ ]

ii) How effective do you think these pesticides are for the control of pests

100% [ ] 60% [ ]

80% [ ] 40% [ ]

iii) How many times did you spray pesticides and apply fertilizers on your farm in the previous growing season 1998/99?

Pesticides ________ times

Fertilizers ________ times

iv) Do you want to increase or decrease the number of spraying and application of these chemicals in this coming year?

Increase [ ]   Decrease [ ]

Whichever is your answer, why ________________________________

v) When do you start spraying pesticides or and apply fertilizer?

	Pesticides	Fertilizer
a) before planting	[ ]	[ ]
b) weeks after planting	[ ]	[ ]
c) after observing pests/when growing is slowed	[ ]	[ ]
d) instructions on pesticide/fertilizer pack	[ ]	[ ]

vi) Who does the spraying or apply, fertilizer on your farm?

Yourself [ ]   Workers [ ]

Wife [ ]   Children [ ]

Any reason for it ____

vii) What other methods can be used other than pesticides to control pest/disease or fertilizers for soil fertility?

____

____

____

viii) What type of sprayers do you use for spraying?

Previous year________________________

This year__________________________

In future__________________________

ix) How far is the water source (Kaleya River) from your farm? ____Km

x) Where do you keep your insecticides and spraying machine when not in use?____

And how do you dispose of the empty containers of your pesticides and fertilizers?

____

IV) <u>ADVICE/INFORMATION AVAILABILITY</u>

i) Have you ever received any training on the control of pesticides and use of fertilizers?

Yes [ ]   No [ ]

If yes when __________ and where ____________________

ii) How many times do you see agricultural extension workers visit your area especially during the growing season?

____

iii) What are the currently adopted coffee pest management and soil fertility management practices training and sources of advice available to farmers from the Ministry of Agriculture?

____

iv) What additional information would you like extension officers to give you?

____

v) What are your other sources of information on pest control and soil fertility management?

Other farmers [ ]   field days [ ]

Leaflets [ ]   mass media [ ]

Private companies [ ]

vi) Suggest some of the ways in which pesticides and fertilizers would affect the water quality if they entered the Kaleya River.

a)____

b)____ c)____

vii) Any suggestions on what the farming community in the Kaleya catchment can do to control pollution from farmland into the river basin.

____

____

____

viii) Mention some ways in which erosion from farming areas into Kaleya River can be prevented.

____

____

APPENDIX 2

Rainfall Data (1997 to 2000) at Kafue Polder

SEASONAL YEAR 1997/98					SEASONAL YEAR 1998/99					SEASONAL YEAR 1999/00				
STATION	YEAR	MONTH	VALUE (mm)	VALID DAYS	STATION	YEAR	MONTH	VALUE (mm)	VALID DAYS	STATION	YEAR	MONTH	VALUE (mm)	VALID DAYS
KAFUE001	1997	10	14.5	31	KAFUE001	1998	10	.0	31	KAFUE001	1999	10	68.8	31
KAFUE001	1997	11	87.7	30	KAFUE001	1998	11	74.3	30	KAFUE001	1999	11	40.0	30
KAFUE001	1997	12	81.6	31	KAFUE001	1998	12	238.5	31	KAFUE001	1999	12	213.5	31
KAFUE001	1998	1	298.1	30	KAFUE001	1999	1	294.4	30	KAFUE001	2000	1	216.4	30
KAFUE001	1998	2	133.5	28	KAFUE001	1999	2	253.5	28	KAFUE001	2000	2	110.4	29
KAFUE001	1998	3	57.9	31	KAFUE001	1999	3	21.3	31	KAFUE001	2000	3	150.4	31
KAFUE001	1998	4	.0	30	KAFUE001	1999	4	.0	30	KAFUE001	2000	4	.0	30
KAFUE001	1998	5	.0	31	KAFUE001	1999	5	.0	31	KAFUE001	2000	5	.0	31
KAFUE001	1998	6	.0	30	KAFUE001	1999	6	.0	30	KAFUE001	2000	6	.0	30
KAFUE001	1998	7	.0	31	KAFUE001	1999	7	.0	31	KAFUE001	2000	7	.0	31
KAFUE001	1998	8	.0	31	KAFUE001	1999	8	.6	31	KAFUE001	2000	8	.0	31
KAFUE001	1998	9	.0	30	KAFUE001	1999	9	.0	30	KAFUE001	2000	9	.0	30
Annual Total Rainfall			**700.3**		**Annual Total Rainfall**			**882.6**		**Annual Total Rainfall**			**799.5**	

Source: Meteorological Department – LUSAKA

APPENDIX 3

Hydrological Data at Water Valley Roadbridge Gauging Station from 21 November 1997 to 31 March 2000

NOV'97	DAILY DISCHARGE ($m^3 s^{-1}$)	DEC'97	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.00	1	0.89
2	0.00	2	0.89
3	0.00	3	0.89
4	0.00	4	0.89
5	0.00	5	0.89
6	0.00	6	0.79
7	0.00	7	0.64
8	0.00	8	0.79
9	0.00	9	0.85
10	0.00	10	0.76
11	0.00	11	0.70
12	0.00	12	0.67
13	0.00	13	0.65
14	0.00	14	0.63
15	0.00	15	0.61
16	0.00	16	0.63
17	0.00	17	0.71
18	0.00	18	1.01
19	0.00	19	1.91
20	0.00	20	0.79
21	0.93	21	0.73
22	0.89	22	0.73
23	0.85	23	0.72
24	0.89	24	0.63
25	0.89	25	0.67
26	0.89	26	0.66
27	0.89	27	1.27
28	0.89	28	0.79
29	0.89	29	0.74
30	0.89	30	0.61
		31	0.60
TOTAL	**8.90**	**TOTAL**	**24.08**
MEAN	**0.30**	**MEAN**	**0.78**

APPENDIX 3 Continued

JAN'98	DAILY DISCHARGE ($m^3 s^{-1}$)	FEB'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.65	1	0.89
2	0.74	2	0.90
3	0.71	3	0.81
4	0.68	4	0.96
5	0.69	5	0.53
6	0.71	6	0.28
7	0.73	7	0.25
8	0.77	8	0.24
9	0.88	9	0.34
10	1.14	10	0.49
11	0.76	11	0.35
12	0.66	12	0.43
13	0.63	13	0.80
14	0.55	14	1.06
15	0.15	15	0.47
16	0.73	16	0.25
17	0.33	17	0.80
18	0.28	18	1.71
19	0.36	19	1.14
20	0.33	20	0.75
21	0.39	21	0.72
22	0.40	22	0.28
23	0.37	23	0.58
24	0.34	24	0.47
25	0.34	25	0.97
26	0.32	26	0.51
27	1.47	27	0.57
28	1.37	28	0.83
29	1.68		
30	1.05		
31	0.91		
TOTAL	**21.12**	**TOTAL**	**18.83**
MEAN	**0.68**	**MEAN**	**0.66**

APENDIX 3 Continued

MAR'98	DAILY DISCHARGE ($m^3 s^{-1}$)	APR'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	1.09	1	0.68
2	1.15	2	0.69
3	1.15	3	0.69
4	0.84	4	0.61
5	0.80	5	0.65
6	0.78	6	0.68
7	0.80	7	0.63
8	0.78	8	0.62
9	0.72	9	0.64
10	0.68	10	0.54
11	0.65	11	0.44
12	0.66	12	0.54
13	0.66	13	0.55
14	0.66	14	0.53
15	0.74	15	0.52
16	0.81	16	0.50
17	0.76	17	0.55
18	0.76	18	0.53
19	0.74	19	0.51
20	0.77	20	0.51
21	0.78	21	0.51
22	0.69	22	0.48
23	0.65	23	0.50
24	0.61	24	0.50
25	0.62	25	0.50
26	0.64	26	0.48
27	0.62	27	0.47
28	0.62	28	0.50
29	0.64	29	0.49
30	0.66	30	0.45
31	0.68		
TOTAL	**23.21**	**TOTAL**	**16.49**
MEAN	**0.75**	**MEAN**	**0.55**

APPENDIX 3 Continued

MAY'98	DAILY DISCHARGE ($m^3 s^{-1}$)	JUN'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.47	1	0.51
2	0.48	2	0.49
3	0.48	3	0.50
4	0.48	4	0.59
5	0.52	5	0.52
6	0.47	6	0.58
7	0.48	7	0.50
8	0.47	8	0.47
9	0.54	9	0.49
10	0.53	10	0.50
11	0.55	11	0.59
12	0.55	12	0.52
13	0.54	13	0.62
14	0.51	14	0.65
15	0.60	15	0.67
16	0.62	16	0.68
17	0.66	17	0.68
18	0.68	18	0.65
19	0.69	19	0.66
20	0.69	20	0.67
21	0.64	21	0.65
22	0.63	22	0.67
23	0.66	23	0.69
24	0.61	24	0.73
25	0.42	25	0.71
26	0.43	26	0.69
27	0.40	27	0.68
28	0.46	28	0.67
29	0.40	29	0.65
30	0.49	30	0.67
31	0.62		
TOTAL	**16.77**	**TOTAL**	**18.35**
MEAN	**0.54**	**MEAN**	**0.61**

APPENDIX 3 Continued

JUL'98	DAILY DISCHARGE ($m^3 s^{-1}$)	AUG'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.68	1	0.67
2	0.68	2	0.60
3	0.65	3	0.47
4	0.66	4	0.47
5	0.69	5	0.47
6	0.68	6	0.48
7	0.68	7	0.49
8	0.63	8	0.43
9	0.62	9	0.45
10	0.67	10	0.40
11	0.67	11	0.40
12	0.63	12	0.42
13	0.68	13	0.41
14	0.66	14	0.43
15	0.69	15	0.42
16	0.71	16	0.43
17	0.70	17	0.44
18	0.70	18	0.41
19	0.66	19	0.48
20	0.64	20	0.44
21	0.67	21	0.44
22	0.71	22	0.44
23	0.68	23	0.43
24	0.65	24	0.48
25	0.66	25	0.44
26	0.66	26	0.40
27	0.68	27	0.43
28	0.65	28	0.47
29	0.70	29	0.44
30	0.66	30	0.40
31	0.66	31	0.37
TOTAL	**20.76**	**TOTAL**	**13.95**
MEAN	**0.67**	**MEAN**	**0.45**

APPENDIX 3 Continued

SEP'98	DAILY DISCHARGE ($m^3 s^{-1}$)	OCT'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.37	1	0.00
2	0.23	2	0.00
3	0.22	3	0.00
4	0.20	4	0.00
5	0.19	5	0.00
6	0.18	6	0.00
7	0.16	7	0.00
8	0.15	8	0.00
9	0.13	9	0.00
10	0.12	10	0.00
11	0.11	11	0.00
12	0.09	12	0.00
13	0.04	13	0.00
14	0.00	14	0.00
15	0.00	15	0.00
16	0.00	16	0.00
17	0.00	17	0.00
18	0.00	18	0.00
19	0.00	19	0.00
20	0.00	20	0.00
21	0.00	21	0.00
22	0.00	22	0.00
23	0.00	23	0.00
24	0.00	24	0.00
25	0.00	25	0.00
26	0.00	26	0.00
27	0.00	27	0.00
28	0.00	28	0.00
29	0.00	29	0.00
30	0.00	30	0.00
		31	0.00
TOTAL	**2.19**	**TOTAL**	**0.00**
MEAN	**0.07**	**MEAN**	**0.00**

APPENDIX 3 Continued

NOV'98	DAILY DISCHARGE ($m^3 s^{-1}$)	DEC'98	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.00	1	0.67
2	0.00	2	0.59
3	0.00	3	0.58
4	0.00	4	0.42
5	0.00	5	0.63
6	0.00	6	0.60
7	0.00	7	0.63
8	0.00	8	0.67
9	0.00	9	0.65
10	0.00	10	0.60
11	0.00	11	0.60
12	0.00	12	0.60
13	0.00	13	0.40
14	0.00	14	0.67
15	0.00	15	0.79
16	0.00	16	0.40
17	0.00	17	0.55
18	0.00	18	0.63
19	0.00	19	0.56
20	0.00	20	0.65
21	0.00	21	0.68
22	0.00	22	0.70
23	0.00	23	0.94
24	0.00	24	0.76
25	0.00	25	0.42
26	0.00	26	0.91
27	0.00	27	1.08
28	0.00	28	0.37
29	0.53	29	0.76
30	0.58	30	1.56
		31	1.41
TOTAL	**1.11**	**TOTAL**	**21.48**
MEAN	**0.04**	**MEAN**	**0.69**

APPENDIX 3 Continued

JAN'99	DAILY DISCHARGE ($m^3 s^{-1}$)	FEB'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.49	1	0.41
2	0.54	2	0.35
3	1.35	3	0.92
4	0.60	4	1.56
5	1.52	5	1.20
6	0.82	6	0.99
7	0.29	7	0.91
8	0.28	8	1.69
9	0.32	9	1.52
10	0.36	10	1.25
11	0.24	11	1.62
12	1.43	12	1.11
13	0.50	13	1.01
14	0.30	14	1.00
15	0.47	15	0.94
16	0.45	16	0.90
17	0.48	17	0.92
18	1.11	18	0.95
19	1.18	19	0.86
20	0.78	20	0.87
21	0.23	21	0.94
22	0.25	22	0.97
23	1.35	23	0.81
24	1.75	24	0.99
25	1.34	25	1.31
26	0.96	26	1.03
27	0.84	27	1.04
28	0.75	28	0.90
29	0.48		
30	0.19		
31	0.35		
TOTAL	**22.0**	**TOTAL**	**28.97**
MEAN	**0.71**	**MEAN**	**1.04**

APPENDIX 3 Continued

MAR'99	DAILY DISCHARGE ($m^3 s^{-1}$)	APR'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.49	1	0.22
2	0.76	2	0.24
3	0.84	3	0.23
4	0.88	4	0.52
5	0.85	5	0.12
6	0.96	6	0.14
7	0.86	7	0.25
8	1.22	8	0.31
9	0.96	9	0.25
10	0.83	10	0.24
11	0.80	11	0.43
12	0.76	12	0.53
13	0.80	13	0.47
14	0.76	14	0.41
15	0.74	15	0.40
16	0.75	16	0.38
17	0.72	17	0.43
18	0.75	18	0.45
19	0.79	19	0.59
20	0.82	20	0.53
21	0.79	21	0.51
22	0.74	22	0.54
23	0.72	23	0.48
24	0.72	24	0.32
25	0.72	25	0.17
26	0.72	26	0.17
27	0.73	27	0.18
28	0.76	28	0.10
29	059	29	0.12
30	0.45	30	0.12
31	0.17		
TOTAL	**23.48**	**TOTAL**	**9.85**
MEAN	**0.76**	**MEAN**	**0.33**

APPENDIX 3 Continued

MAY'99	DAILY DISCHARGE ($m^3 s^{-1}$)	JUN'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.10	1	0.21
2	0.17	2	0.22
3	0.11	3	0.23
4	0.11	4	0.22
5	0.14	5	0.23
6	0.30	6	0.22
7	0.25	7	0.19
8	0.22	8	0.13
9	0.15	9	0.13
10	0.15	10	0.13
11	0.14	11	0.13
12	0.12	12	0.14
13	0.22	13	0.14
14	0.28	14	0.17
15	0.30	15	0.14
16	0.30	16	0.15
17	0.30	17	0.15
18	0.22	18	0.14
19	0.18	19	0.14
20	0.22	20	0.16
21	0.20	21	0.15
22	0.22	22	0.14
23	0.15	23	0.14
24	0.16	24	0.14
25	0.26	25	0.15
26	0.28	26	0.17
27	0.26	27	0.16
28	0.26	28	0.16
29	0.26	29	0.16
30	0.25	30	0.16
31	0.33		
TOTAL	**6.61**	**TOTAL**	**4.90**
MEAN	**0.21**	**MEAN**	**0.16**

APPENDIX 3 Continued

JUL'99	DAILY DISCHARGE ($m^3 s^{-1}$)	AUG'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.17	1	0.25
2	0.17	2	0.21
3	0.17	3	0.22
4	0.17	4	0.22
5	0.20	5	0.22
6	0.17	6	0.22
7	0.16	7	0.21
8	0.17	8	0.19
9	0.19	9	0.19
10	0.19	10	0.20
11	0.20	11	0.21
12	0.22	12	0.22
13	0.20	13	0.22
14	0.20	14	0.23
15	0.20	15	0.23
16	0.20	16	0.22
17	0.31	17	0.21
18	0.23	18	0.21
19	0.22	19	0.23
20	0.14	20	0.23
21	0.20	21	0.22
22	0.16	22	0.21
23	0.13	23	0.21
24	0.16	24	0.19
25	0.46	25	0.22
26	0.17	26	0.22
27	0.19	27	0.22
28	0.19	28	0.21
29	0.20	29	0.22
30	0.20	30	0.00
31	0.19	31	0.21
TOTAL	**6.13**	**TOTAL**	**6.47**
MEAN	**0.20**	**MEAN**	**0.21**

APPENDIX 3 Continued

SEP'99	DAILY DISCHARGE ($m^3 s^{-1}$)	OCT'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.22	1	0.17
2	0.23	2	0.17
3	0.22	3	0.20
4	0.23	4	0.17
5	0.22	5	0.14
6	0.19	6	0.15
7	0.13	7	0.15
8	0.13	8	0.14
9	0.13	9	0.16
10	0.13	10	0.14
11	0.14	11	0.14
12	0.14	12	0.14
13	0.14	13	0.15
14	0.15	14	0.17
15	0.15	15	0.16
16	0.14	16	0.16
17	0.14	17	0.16
18	0.16	18	0.17
19	0.15	19	0.17
20	0.14	20	0.17
21	0.14	21	0.17
22	0.14	22	0.20
23	0.15	23	0.16
24	0.17	24	0.15
25	0.16	25	0.17
26	0.16	26	0.16
27	0.16	27	0.17
28	0.16	28	0.19
29	0.17	29	0.19
30	0.17	30	0.20
		31	0.22
TOTAL	**4.86**	**TOTAL**	**5.16**
MEAN	**0.16**	**MEAN**	**0.17**

APPENDIX 3 Continued

NOV'99	DAILY DISCHARGE ($m^3 s^{-1}$)	DEC'99	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.20	1	0.13
2	0.20	2	0.16
3	0.20	3	0.46
4	0.20	4	0.17
5	0.31	5	0.19
6	0.23	6	0.19
7	0.22	7	0.20
8	0.14	8	0.20
9	0.20	9	0.19
10	0.16	10	0.25
11	0.13	11	0.21
12	0.16	12	0.22
13	0.46	13	0.22
14	0.17	14	0.22
15	0.17	15	0.22
16	0.19	16	0.21
17	0.19	17	0.19
18	0.20	18	0.19
19	0.22	19	0.20
20	0.20	20	0.19
21	0.20	21	0.25
22	0.20	22	0.21
23	0.20	23	0.22
24	0.31	24	0.22
25	0.23	25	0.22
26	0.22	26	0.22
27	0.14	27	0.21
28	0.21	28	0.19
29	0.20	29	0.22
30	0.19	30	0.23
		31	0.23
TOTAL	**6.22**	**TOTAL**	**6.63**
MEAN	**0.21**	**MEAN**	**0.21**

APPENDIX 3 Continued

JAN'00	DAILY DISCHARGE ($m^3 s^{-1}$)	FEB'00	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.22	1	0.22
2	0.21	2	0.21
3	0.21	3	0.21
4	0.23	4	0.19
5	0.23	5	0.22
6	0.22	6	0.21
7	0.21	7	0.22
8	0.21	8	0.16
9	0.19	9	0.17
10	0.22	10	0.18
11	0.22	11	0.19
12	0.22	12	0.19
13	0.21	13	0.19
14	0.22	14	0.19
15	0.00	15	0.15
16	0.22	16	0.09
17	0.21	17	0.09
18	0.22	18	0.09
19	0.00	19	0.10
20	0.19	20	0.10
21	0.20	21	0.10
22	0.21	22	0.10
23	0.22	23	0.11
24	0.22	24	0.11
25	0.23	25	0.11
26	0.23	26	0.10
27	0.22	27	0.14
28	0.21	28	0.12
29	0.21	29	0.10
30	0.23		
31	0.23		
TOTAL	**6.27**	**TOTAL**	**4.36**
MEAN	**0.20**	**MEAN**	**0.15**

APPENDIX 3 Continued

MAR'00	DAILY DISCHARGE ($m^3 s^{-1}$)	APR'00	DAILY DISCHARGE ($m^3 s^{-1}$)
1	0.10	1	0.10
2	0.10	2	0.12
3	0.12	3	0.11
4	0.13	4	0.13
5	0.12	5	0.15
6	0.12	6	0.15
7	0.13	7	0.16
8	0.12	8	0.16
9	0.13	9	0.15
10	0.13	10	0.22
11	0.13	11	0.17
12	0.13	12	0.18
13	0.16	13	0.18
14	0.13	14	0.18
15	0.13	15	0.18
16	0.13	16	0.17
17	0.15	17	0.15
18	0.15	18	0.15
19	0.16	19	0.16
20	0.18	20	0.17
21	0.16	21	0.19
22	0.16	22	0.18
23	0.16	23	0.19
24	0.17	24	0.19
25	0.16	25	0.18
26	0.19	26	0.15
27	0.18	27	0.12
28	0.13	28	0.11
29	0.17	29	0.10
30	0.16	30	0.10
31	0.12		
TOTAL	**4.41**	**TOTAL**	**4.65**
MEAN	**0.14**	**MEAN**	**0.16**

Source: Kaleya Sediment Project, Geography Department at the University of Zambia

APPENDIX 4.1

Control Site (CS): Physico-Chemical Characteristics of Soils in Upper Kaleya Catchment, 1999 – 2000

PARA-METER	MONTH														
	November 1999			December 1999			January 2000			February 2000			March 2000		
	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope
PH	00-20	5.31	5.55	00-20	5.52	5.37	00-20	5.20	5.13	00-20	5.19	5.24	00-20	5.16	5.26
	20-40	5.70	5.43	20-40	5.24	5.38	20-40	5.34	5.38	20-40	5.22	5.30	20-40	5.23	5.34
Mean		5.51	5.49		5.38	5.38		5.27	5.23		5.21	5.27		5.20	5.30
Conductivity (µS/cm)	00-20	00.12	00.11	00-20	00.16	00.10	00-20	00.07	00.32	00-20	00.22	00.22	00-20	00.20	00.24
	20-40	00.16	00.07	20-40	00.08	00.16	20-40	00.08	00.08	20-40	00.23	00.18	20-40	00.23	00.22
Mean		00.14	00.09		00.12	00.13		00.08	00.20		00.23	00.20		00.22	00.23
Phosphorus (mg/kg)	00-20	Trace	Trace	00-20	1.89	2.59	00-20	Trace	00.18	00-20	00.49	1.58		Trace	00.87
	20-40	Trace	Trace	20-40	00.39	Trace	20-40	4.03	1.23	20-40	1.86	Trace	00-20	Trace	00.75
Mean		00.00	00.00		1.14	1.30		2.02	00.71		1.18	0.79	20-40	00.00	0.81
Nitrate (mg/kg)	00-20	8.75	8.75	00-20	10.50	10.50	00-20	8.75	7.00	00-20	7.00	12.25	00-20	Trace	10.50
	20-40	7.00	7.00	20-40	8.75	7.00	20-40	8.75	3.50	20-40	7.00	7.00	20-40	5.10	8.75
Mean		7.88	7.88		9.63	8.75		8.75	5.25		7.00	9.63		2.55	9.63
Nitrite (mg/kg)	00-20	Trace	00.25	00-20	Trace	00.90	00-20	00.50	Trace	00-20	4.25	Trace	00-20	1.63	Trace
	20-40	Trace	Trace	20-40	Trace	Trace	20-40	Trace	Trace	20-40	9.75	Trace	20-40	5.89	Trace
Mean		00.00	0.13		00.00	0.45		0.25	00.00		7.00	00.00		3.76	00.00

APPENDIX 4.2

Traditional Farm (TF): Physico-Chemical Characteristics of Soils in Upper Kaleya Catchment, 1999 – 2000

PARA-METER	MONTH														
	November 1999			December 1999			January 2000			February 2000			March 2000		
	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope
PH	00-20	5.65	5.49	00-20	5.36	5.27	00-20	5.19	5.35	00-20	6.40	5.37	00-20	5.94	5.39
	20-40	5.69	5.57	20-40	5.55	5.43	20-40	5.27	5.60	20-40	6.30	5.47	20-40	6.31	5.41
Mean		5.67	5.53		5.46	5.35		5.23	5.48		6.35	5.42		6.13	5.40
Conductivity	00-20	00.10	00.10	00-20	00.08	00.13	00-20	00.10	00.11	00-20	00.30	00.27	00-20	00.30	00.28
(µS/cm)	20-40	00.10	00.10	20-40	00.10	00.08	20-40	00.07	00.08	20-40	00.26	00.21	20-40	00.28	00.20
Mean		00.10	00.10		00.09	0.11		00.10	00.10		00.28	00.24		00.29	00.24
Phosphorus	00-20	3.71	00.84	00-20	2.42	1.82	00-20	5.04	00.84	00-20	1.65	Trace	00-20	1.38	Trace
(mg/kg)	20-40	00.42	2.59	20-40	00.74	1.40	20-40	1.79	00.84	20-40	00.46	00.07	20-40	00.61	1.12
Mean		2.07	1.72		1.58	1.61		3.415	00.84		1.06	00.04		1.00	0.56
Nitrate	00-20	8.75	12.25	00-20	19.25	24.50	00-20	12.25	10.50	00-20	10.50	7.00	00-20	10.50	5.11
(mg/kg)	20-40	10.50	10.50	20-40	15.75	14.00	20-40	8.75	7.00	20-40	7.00	5.25	20-40	6.75	5.00
Mean		9.63	11.38		17.50	19.25		10.50	8.75		8.75	6.13		8.63	5.06
Nitrite	00-20	00.50	12.50	00-20	9.05	8.75	00-20	24.25	Trace	00-20	13.50	5.00	00-20	12.75	2.75
(mg/kg)	20-40	Trace	Trace	20-40	Trace	5.00	20-40	1.00	Trace	20-40	00.25	Trace	20-40	3.06	00.50
Mean		0.25	6.23		4.53	6.88		18.63	00.00		6.88	2.50		7.91	1.63

APPENDIX 4.3

Commercial Farm A (CFA): Physico-Chemical Characteristics of Soils in Upper Kaleya Catchment, 1999 – 2000

PARA-METER	MONTH														
	November 1999			December 1999			January 2000			February 2000			March 2000		
	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope
pH	00-20	6.61	7.19	00-20	6.22	6.43	00-20	6.93	6.08	00-20	6.89	6.02	00-20	6.91	6.02
	20-40	7.10	6.88	20-40	7.16	5.40	20-40	7.33	6.04	20-40	6.97	5.94	20-40	7.08	6.01
Mean		6.86	7.04		6.69	5.92		7.13	6.06		6.93	5.98		7.00	6.02
Conductivity (uS/cm)	00-20	00.35	00.41	00-20	00.20	00.31	00-20	00.77	00.56	00-20	00.57	00.31	00-20	00.50	00.36
	20-40	00.50	00.30	20-40	00.16	00.26	20-40	00.53	00.24	20-40	00.39	00.29	20-40	00.42	00.30
Mean		00.43	00.36		00.18	00.29		0.65	00.40		00.48	00.30		00.46	00.33
Phosphorus (mg/kg)	00-20	Trace	21.18	00-20	10.08	6.14	00-20	16.49	4.34	00-20	15.16	6.06	00-20	9.25	4.25
	20-40	7.49	1.75	20-40	8.01	5.92	20-40	3.36	1.37	20-40	1.93	Trace	20-40	00.63	Trace
Mean		3.75	11.47		9.05	6.03		9.93	2.86		8.55	3.03		4.94	2.13
Nitrate (mg/kg)	00-20	14.00	12.25	00-20	20.60	19.83	00-20	10.50	12.25	00-20	14.00	15.75	00-20	14.00	16.10
	20-40	17.50	5.25	20-40	18.34	16.82	20-40	8.75	12.25	20-40	12.25	14.00	20-40	10.50	15.00
Mean		15.75	8.75		19.47	18.33		9.63	12.25		13.13	14.88		12.25	15.55
Nitrite (mg/kg)	00-20	1.75	Trace	00-20	5.41	6.10	00-20	13.00	4.25	00-20	7.25	15.00	00-20	5.75	15.25
	20-40	00.25	Trace	20-40	4.02	1.36	20-40	2.25	00.75	20-40	6.25	10.00	20-40	6.75	12.75
Mean		1.00	00.00		4.72	3.73		7.63	2.50		6.75	12.25		6.25	14.00

APPENDIX 4.4

Commercial Farm B (CFB): Physico-Chemical Characteristics of Soils in Upper Kaleya Catchment, 1999 – 2000

PARA-METER	MONTH														
	November 1999			December 1999			January 2000			February 2000			March 2000		
	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope	Depth	Upslope	Down slope
Ph	00-20	5.36	5.40	00-20	5..35	5..30	00-20	5..11	4.97	00-20	5.19	5.27	00-20	5.25	5.28
	20-40	5.53	4.88	20-40	5.46	4.79	20-40	5.42	4.75	20-40	5.43	4.81	20-40	5.49	4.83
Mean		5.45	5.14		5.14	5.05		5.27	4.86		5.31	5.04		5.37	5.06
Conductivity (µS/cm)	00-20	00.00	00.13	00-20	00.10	00.30	00-20	00.11	00.16	00-20	00.23	00.27	00-20	00.28	00.30
	20-40	00.10	00.07	20-40	00.10	00.12	20-40	00.10	00.08	20-40	00.18	00.15	20-40	00.18	00.12
Mean		00.05	00.10		00.10	00.21		00.11	00.12		00.21	00.21		00.23	0.21
Phosphorus (mg/kg)	00-20	00.77	5.46	00-20	3.89	8.72	00-20	1.58	2.21	00-20	16.10	4.48	00-20	5.60	4.25
	20-40	2.03	1.79	20-40	11.13	2.84	20-40	2.17	Trace	20-40	Trace	Trace	20-40	Trace	00.95
Mean		1.40	3.63		7.51	5.78		1.88	1..11		8.05	2..24		2.80	2.5
Nitrate (mg/kg)	00-20	7.00	10.50	00-20	12.25	14.00	00-20	10.50	14.00	00-20	8.75	15.75	00-20	9.04	16.00
	20-40	8.75	10.50	20-40	10.50	12.25	20-40	1.75	10.50	20-40	5.25	15.75	20-40	5.25	15.87
Mean		7.88	10.50		11.34	13.13		6.13	12.25		7.00	15.75		7.15	15.94
Nitrite (mg/kg)	00-20	4.75	Trace	00-20	7.50	00.50	00-20	3.50	28.25	00-20	4.50	9.75	00-20	5.01	8.68
	20-40	2.50	Trace	20-40	00.50	Trace	20-40	2.00	Trace	20-40	Trace	Trace	20-40	Trace	1.50
Mean		3.63	00.00		4.00	00.25		2.75	14.13		2.25	4.88		2.51	5.09

APPENDIX 5.1

Control Site: Physico-Chemical Characteristics in Water, 1999 - 2000

PARAMETER	MONTHS														
	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH		
	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down Slope	River	Up slope	Down Slope	River
pH	-	-	8.0	7.3	7.5	7.6	7.01	7.1	7.8	7.3	7.3	7.6	7.4	7.5	7.7
Conductivity (µS/ cm)	-	-	639.0	307.0	310.0	347.0	97.0	104.0	128.0	13.0	74.0	37.0	12.0	24.0	24.0
Phosphorous (mg/l)	-	-	2.73	1.22	1.21	·1.02	1.01	1.02	1.31	1.2	1.32	1.5	1.01	1.5	1.3
Nitrate (mg/l)	-	-	3.56	9.78	9.67	15.8	9.7	8.3	15.6	7.7	7.3	15.0	6.71	6.89	12.65
Nitrite (mg/l)	-	-	0.005	0.06	0.04	0.02	0.04	0.06	Nil	Nil	0.03	Nil	Nil	0.01	Nil

APPENDIX 5.2

Traditional Farm: Physico - Chemical Characteristics in Water, 1999 - 2000

PARA-METER	MONTHS														
	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH		
	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down Slope	River	Up slope	Down Slope	River
pH	-	-	6.7	7.2	7.6	8.6	7.1	6.6	8.6	7.2	7.4	8.1	7.7	7.5	7.9
Conductivity (µS/ cm)	-	-	829.0	304.0	316.0	497.0	221.0	256.0	211.0	33.0	34.0	31.0	28.0	34.0	26.0
Phosphorous (mg/l)	-	-	2.13	1.75	0.97	1.63	0.21	022	0.19	1.19	0.21	0.21	1.01	1.32	0.21
Nitrate (mg/l)	-	-	4.18	12.18	11.13	13.86	9.1	8.4	10.8	10.8	10.3	11.2	8.4	9.6	11.2
Nitrite (mg/l)	-		0.013	0.02	0.03	0.03	0.04	0.03	0.01	0.02	0.02	0.02	0.01	0.01	Nil

APPENDIX 5.3

Commercial Farm A: Physico - Chemical Characteristics in Water, 1999 - 2000

PARAMETER	MONTHS														
	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH		
	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down slope	River	Up slope	Down slope	River
Ph	-	-	7.6	6.8	7.3	7.7	6.3	6.5	7.6	5.9	6.1	7.5	7.0	7.2	7.6
Conductivity (µS/ cm)	-	-	843.0	450.0	466.0	554.0	375.0	419.0	449.0	362.0	369.0	207.0	158.0	101.0	184.0
Phosphorous (mg/l)	-	-	1.73	3.40	2.98	2.74	1.23	0.98	1.60	1.62	1.22	1.30	1.34	1.69	1.11
Nitrate (mg/l)	-	-	22.55	17.64	16.11	13.08	14.2	15.0	7.6	10.0	10.2	10.0	9.7	10.1	9.8
Nitrite (mg/l)	-	-	0.006	0.04	0.04	0.03	Nil	Nil	Nil	0.01	0.01	Nil	0.01	0.02	0.01

APPENDIX 5.4

Commercial Farm B: Physico- Chemical Characteristics in Water, 1999 - 2000

PARAMETER	MONTHS														
	NOVEMBER			DECEMBER			JANUARY			FEBRUARY			MARCH		
	Up slope	Down slope	River	Up Slope	Down slope	River	Up slope	Down slope	River	Up Hill	D. Slope	River	Up slope	D. Slope	River
Ph	-	-	8.1	7.5	7.2	7.5	6.8	7.1	7.9	6.3	6.9	8.0	6.5	7.0	8.0
Conductivity (µS/ cm)	-	-	877.0	412.0	426.0	662.0	158.0	209.0	476.0	67.0	58.0	193.0	44.0	48.0	84.0
Phosphorous (mg/l)	-	-	1.12	2.84	2.01	2.08	1.66	1.43	0.91	1.8	1.81	1.83	1.75	1.82	1.7
Nitrate (mg/l)	-	-	22.8	14.1	12.6	9.87	10.1	12.4	5.6	10.0	10.0	10.1	7.3	8.4	7.1
Nitrite (mg/l)	-	-	0.004	0.05	0.5	0.08	Nil	0.01	0.02	0.02	0.02	0.04	0.04	0.05	0.02

APPENDIX 6

Analytical Methods for Physical and Chemical Analysis of Soil and Water Samples

Parameter	Units of measurement		Method of analysis
	In soil	In water	
pH			Electronic
Conductivity	µS /cm	µS /cm	Electronic
Phosphorous	mg/kg	mg/l	Vanamolybolic Spectrophotometer
Nitrate	mg/kg	mg/l	Electrometric
Nitrite	mg/kg	mg/l	Spectrophotometer

Note: APHA standard methods were used

Explanation:

µS/cm - microsiemens per centimeter

mg/kg - milligram per kilogram

mg/l - milligram per liter

APPENDIX 7

Pesticides Used by Farmers Sampled in Upper Kaleya Catchment

TYPE OF PESTICIDES	TYPE OF FARMERS			
	COMMERCIAL		TRADITIONAL	
	No.	%	No.	%
Karate	9	23	4	10
Temik	7	18	0	0
Dusbarn	6	15	1	3
Copper	4	10	3	8
Soluber	3	8	2	5
Dipterex	3	8	0	0
Azodrin	2	5	0	0
Monocronophos	2	5	0	0
Calbufaman	2	5	0	0
Thionex	1	3	0	0
Lannate	1	3	0	0
	$\sum n_1$ 40		**$\sum n_2$ 10**	

APPENDIX 8

Types of Fertilizers Used by Farmers Sampled in Upper Kaleya Catcchment

TYPE OF FERTILIZER	TYPE OF FARMERS			
	COMMERCIAL		TRADITIONAL	
	No.	%	No.	%
Urea	10	25	19	39
D-Compound	10	25	19	37
W-V-Compound	4	10	0	0
Ammonia	3	8	5	10
C-Compound	3	8	0	0
Nutriant	3	8	0	0
Single Super phosphate	3	8	0	0
J-Compound	2	5	0	0
R-Compound	2	5	4	8
X-Compound	0	0	3	6
	$\sum n_1$ 40		**$\sum n_2$ 10**	

APPENDIX 9

Water Abstracted from Upper Kaleya River, 1952 - 1998

Year	Volume Abstracted (m^3/day)
1952	675
1953	675
1954	875
1955	875
1956	875
1957	1565
1958	1565
1959	2017
1960	2017
1961	2017
1962	2475
1963	3010
1964	3010
1965	3010
1966	3010
1967	3010
1968	2582
1969	2222
1970	2432
1971	2437
1972	2442
1973	2442
1974	2442
1975	13442
1976	13442
1977	13197
1978	13197
1979	13195
1980	22397
1981	22545
1982	16545
1983	16545
1984	82545
1985	82545
1986	109545
1987	113545
1988	111795
1989	191945
1990	1465435
1991	1484935
1992	1475239
1993	1475239
1994	1485799
1995	1477299
1996	1464459
1997	5557849
1998	5541403

Source: Unpublished Data from Water Development Board, Department of Water Affairs, Lusaka.

APPENDIX 10

Water Quality Standards for various Uses

PARAMETER		DRINKING WATER		IRRIGATION WATER		LIVE STOCK
		PREFERABLE LIMIT	REJECTED LIMIT	NO USE RESTRICTING	SEVERE RESTRICTING	WATERING
1	PH	6.5-8.5	6.5&8.5	6.5-8.5	6.5&8.5	
2	Temperature (°C)					
3	Color (hazen units)	5				
4	El. Conductivity (μS/cm)			0.7	0.3	
5	Turbidity (NTU)	1-5	25			
6	TSS					
7	TDS (mg/l)					
8	TS (mg/l)	500	1500			
9	Total Alkalinity			1.5	8.5	
10	Calcuim hardness ($mgCaCo_3/l$)					
11	Total hardness ($mgCaCo_3/l$)	100	500	5000		
12	Chloride (mg/l)	250				
13	Nitrite (mg/l)	Be absent	0.1			
14	Nitrate (mg/l)	10		30		100
15	Coliform bacterial 1100ml	0	0			
16	Colony (count/ml)	100 colonies				
17	E. Col./100ml	0	0	0	0	
18	DO					
19	BOD					
20	Chlorophyll (mg/l)	1				
21	Algae cells (100/ml)					

SOURCE: WHO (1970; 1971)