Spatial distribution of pesticide contamination potential around lake Naivasha, Kenya

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By

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Chapter 1: Introduction

1.1 General Aspects

The republic of Kenya, covering 582,640 square kilometres, is bisected by the Rift Valley. The Lake Naivasha is the only fresh water lake in the Rift Valley. The lake is used for irrigation. Bordering it are some of the biggest flower farms in the world. 80% of the horticultural production is found around the Lake Naivasha. In the past 15 years, agricultural production of the region has increased. Other activities include ranching, small-scale agriculture, recreation and fishing (Oduory, 2000).

The most important area for cut flowers in Kenya is located around the Lake Naivasha, north of Nairobi at an altitude of 2100 meters above sea level. Because of the its ideal conditions, this area produces mainly carnations, as wells as wide range of summer flowers such as Limonium (Sinuatum and other Mediterranean types), Delphiniums, eustoma, Bupleurum, Carthamus and Alsomeria. Approximately ten years ago it had begun the roses production in the area. Some of these flowers are being grown in open fields and others under greenhouses. Approximately 220 million stems of carnations, 130 million stems of roses and 100 million other flowers are being produced every year. Kenya meanwhile exports far more than one billion cut flowers to Europe, every season, with an increasing trend. The majority of the current flower production of Kenya is exported to Holland and the remaining is shipped to Germany and England (Omniflora, 2000)
Agricultural products, especially the ones produced for export have to match a high quality standard. To achieve these quality standards it is necessary to have a good program of weed control and pest management. The use of pesticides is one of the most used tools to achieve it. But improper pesticide application results in high toxicity levels causing environmental risk. Other methods beside the chemical control are available, such as preventive management like crop rotation, resistant varieties and good lands till practice. Also some physical control like heating, hand or mechanical weeding control. The biological control is another tool in the pest control as well as petroleum oils, soaps, plastic covers for the soil, natural barriers, synthetic pheromones, food attractant traps, and light traps. To apply these non-chemical methods in commercial scale is time consuming and higher costs incurred. The combination of these methods with the pesticides is known as Integrated Pest Management.

Some of the farms around the Lake Naivasha are making efforts towards to the integrated pest management. These farms are starting at experimental level with some plots to perform trials on some of the non-chemical methods.

In the past some studies concerning to the environmental risk for pesticides use around the lake Naivasha area were carried out. A description of them is presented in the section below.

1.2 Previos studies in the area

The Naivasha Lake is a study area for the International Institute for Aerospace Survey and Earth Sciences (ITC) already for four years. Some research projects have been done related to environmental issues. Also some others institutions had been doing research in the area. Some of these studies are mentioned in the list below:

- **Inventory of the pesticides use around the lake Naivasha; Inventory and Recommendations (Maan C, 1994).**

The Ministry of agriculture, nature management and fisheries of *The Netherlands* make a consultant visit to the area on March 1994. The main task was to make an inventory of the present use of pesticides on the farms around the lake and to give recommendations as part of the Lake Naivasha Management Plan carried out by the Lake Naivasha Riparian Association. The recommendations concerning to the pesticides management enclose aspects like environmental hazard of pesticides, scouting, registered pesticides use, non-chemical methods.

- **A preliminary study on the fate of agrochemical in the vadose zone environment around Lake Naivasha, Kenya (De Silva, 1998).**

The results of the study show that based on a series of leaching simulations using the Pesticide Root Zone Model there is a relatively low risk of immediate groundwater contamination by pesticides. More of the pesticides are retained in the first 100-cm of soil depth. The depth to the groundwater table (10 m) contributes to the low vulnerability of the area.

- **A groundwater chemistry and quality assessment of the lake Naivasha area, Kenya (Morgan, 1998)**

In this study a geostatistic assessment was carried out to describe the spatial correlation of the chemical variables. A soil pollution and water quality assessment was included too. This study verified that the observed water quality is not suitable for all intended uses but went further to examine the development of cause-effect relationships between groundwater quality and environmental data like geology, hydrogeology, landuse and pollutant sources.

- **Groundwater contamination potential of agriculture around Lake Naivasha: Comparison of five unsaturated soils zones models (Jolicoeur, 2000).**

In this study, besides the comparison of different leaching models, some data was collected in the field; soil profile, soil sampling and analysis, hydraulic conductivity, infiltration basin and recharge characteristics.

Some scenarios were calculated to assess the leaching depths as a function of the meteorological/climatic conditions and the amount of pesticides applied on flower farms. According to the results of the simulation there is a threat of potential contamination of the groundwater, which depends on the pesticide properties.

- **Sensitivity of Kenyan exports to external environmental measures; A case study of the floriculture environmental project (Konijn, 2000)**

Agricultural products represent sixty percent of the total exports in Kenya. Recently more changes had been occurred concerning about the environmental protection. The use and management of pesticides is an important topic due to the possibility of pollution of the water, specially those areas around the lake Naivasha The flower production for export needs the intensive use of pesticides. The regulatory applied doses pose a threat on the groundwater quality. The Kenyan organisation FPEAK (Fresh Produce Exporters Association of Kenya) developed the Green Label for cut flowers, fruit and vegetables. In 1999 eight flower's grower of Kenya qualified for the Eco-labelling in flowers: MPS.

1.2 Problem definition

One of the problems in the Naivasha Lake area is the high amount of pesticides used for the agricultural production. Some of them reach the groundwater, the source of drinking water for the population living in the area. There is a lack of information about the areas that represent a high risk of pesticides pollution.

1.3 Objectives

The aim of this research is to describe the spatial distribution of environmental risk for contamination by pesticides used around the Lake Naivasha.
To achieve this main objective three sub-objectives were carried out.

- To evaluate and design a method to analyse the environmental risk of chemical use around the Lake Naivasha.
- To estimate the pesticides loads of the farms around the Lake Naivasha
- To assess the environmental partitioning of the pesticides in the Lake Naivasha ecosystem

1.4 Pre-fieldwork

The main activities in this period were:

- Generation of a polygon map of the farms within the area. For this purpose a Landsat image (year 2000) of the area was used to identify and digitize the farms by an existing file of the grid reference (UTM).
- Review of the cultivated areas and crops production in the farms
- Literature review

1.5 Fieldwork

The fieldwork was done for four weeks during the period within September 7th to October 3rd, 2000. The main activity in the fieldwork was the data collection in five of the farms representing the main crops systems in the area. To collect the data a semi-estructural interview was carried out. This data was concern to the main crops, crops cycle, cultivated areas, main pests and diseases in the crops and pesticides data (trade name, active ingredient, target pest, rate of application and pre-harvest intervals (PHI)).
The validation of the attribute map was done using the GPS and the existing satellite image.

1.6 Post-fieldwork

The main activities in this period were oriented to the data gathering, data analysis, data modelling, and thesis writing.

1.7 Thesis layout

Chapter 1, *Introduction*: This chapter includes:

- An introduction of the actual situation around the Lake Naivasha concerning to the production of vegetables and flowers
- Previous studies in the area
- Problem definition
- The objectives of this research
- Pre fieldwork, fieldwork and post fieldwork activities

Chapter 2, *Description of the study area*: In this chapter information is enclose concerning to the location of the area, climatic conditions, geology, geomorphology and hydrology.

Chapter 3, *Literature reviews*: In this chapter some aspects about risk assessment are described as well as the model used to assess the fate of pesticides in the environment.

Chapter 4, *Data collection and analysis*: In this chapter all the information concerning to the data collected during the fieldwork in Lake Naivasha is enclose. Some qualitative and quantitative analysis was carried out about the frequency of the pesticides used, pest and diseases presence in different crops, crops demanding highest amount of pesticides and pesticides toxicity and the spatial visualization of the load estimation in the area.

Chapter 5, *Modeling the distribution of pesticides in the ecosystem:* This chapter include the chemical data (physical properties) of the selected pesticides as well as the Naivasha Environmental data require for the ECOPLUS model and the estimations of the partitioning coefficients. The sensitivity analysis of the model to the input parameter was done as well as the relative sensitivity. The results of the modelling as well as a scenario are also presented in this chapter.

Chapter 6, *Conclusion and recommendations*: This chapter shows the final conclusions of the research on basis of the data collected during the fieldwork, the data process and analysis and the results of the model (ECOPLUS Program) and the recommendations for further research.

Chapter 2: Study area

2.1 Location

Kenya is a country located in the East Africa region. The total area is 582,650 km^2. It is border with Ethiopia, Somalia, Sudan, Tanzania and Uganda. The climate varying from tropical along the cost to arid in the interior. The terrain is low plains rising to central highland bisected by Great Rift Valley.

This study was carried out around the Naivasha Lake in Kenya. Lake Naivasha is located at latitude 0:5S, longitude 36:2E and Altitude 2100 meters above sea level in the Rift valley province, approximately 100 km north west direction from Nairobi to Nakuru (Figure 1 and 2). The length of the shoreline is 68,000 m. The catchment area is 2,378 km^2 and the population is approximately 200,000 inhabitants. The study area is located within the UTM zone 37, lying between the co-ordinates X_{min}: 19243512.12 Y_{min} 99040335.35 and X_{max}: 218173.83, Y_{max} 9929234.30.

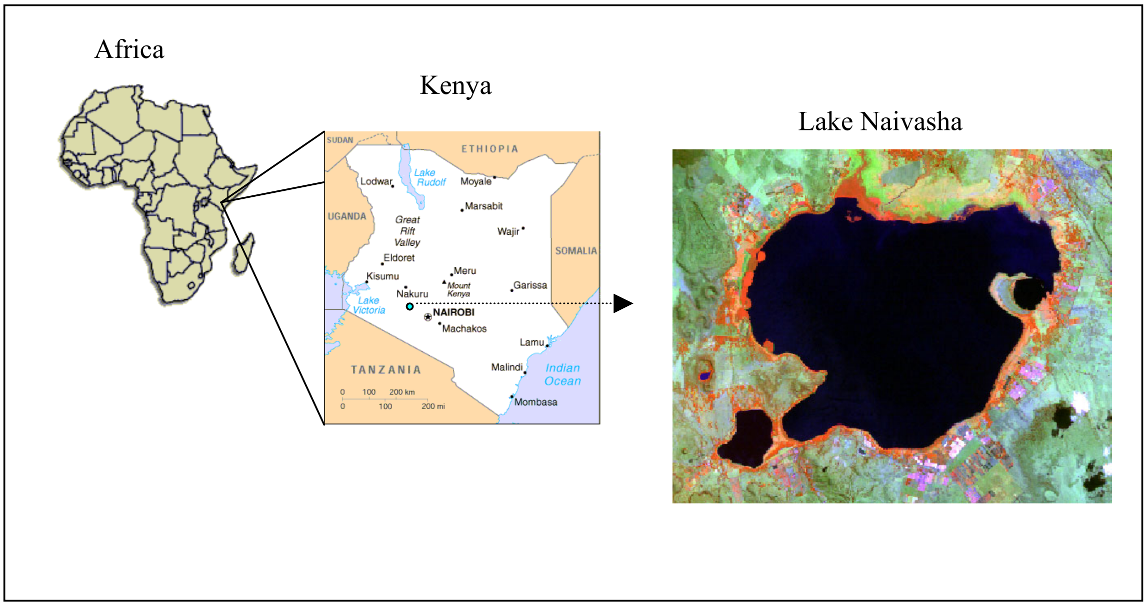


Figure 1. Location of the study area
Source: Graphic maps (2000) modified by the author

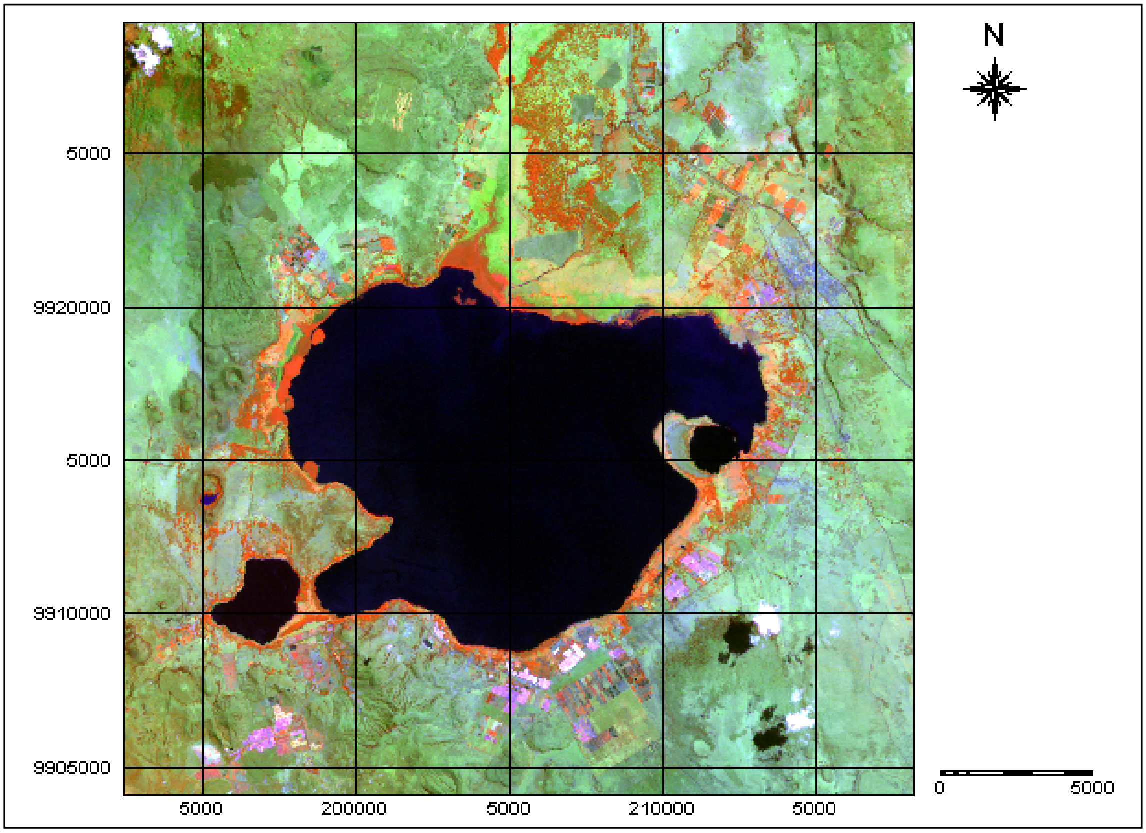


Figure 2. False colour composite (542) of the lake Naivasha area, Kenya

2.2 Climatic conditions of the study area

The climate conditions of the study area are tropical. Two dry seasons exist, from January to February and from June to September. The rainy season has also two periods, one from March to May and from October to December. According to climatic data existing from 1966 to 1993 from meteorological station W.D.D (Water Development Department).

The average precipitation is approximately 667 mm per year varying from 432 to 961 mm/year.

The maximum monthly rainfall is registered in April (117 mm) (Figure 3) (Tang, 1999 and Jolicoeur, 2000). There are variations in the temperatures during the day and also the night time. The mean maximum monthly temperature and the mean minimum monthly temperature are 29 C and 9 C, respectively. The highest temperatures are in January and February and the lowest are in July and August

(Tang, 1999). Depending on the season the wind direction comes from Southeast or Northeast. The average wind speed is 11 to 15 km/h.

The average monthly Pan evaporation is 5 mm/day. The highest rate occurred in March and the lowest in November (Figure 3). The potential evapotranspiration per year is approximately 1804 mm which is greater than the rainfall. This outcome was extracted from data recorded in the period from 1968 to 1997 (Ashfaque, 1999 and Jolicoeur, 2000).

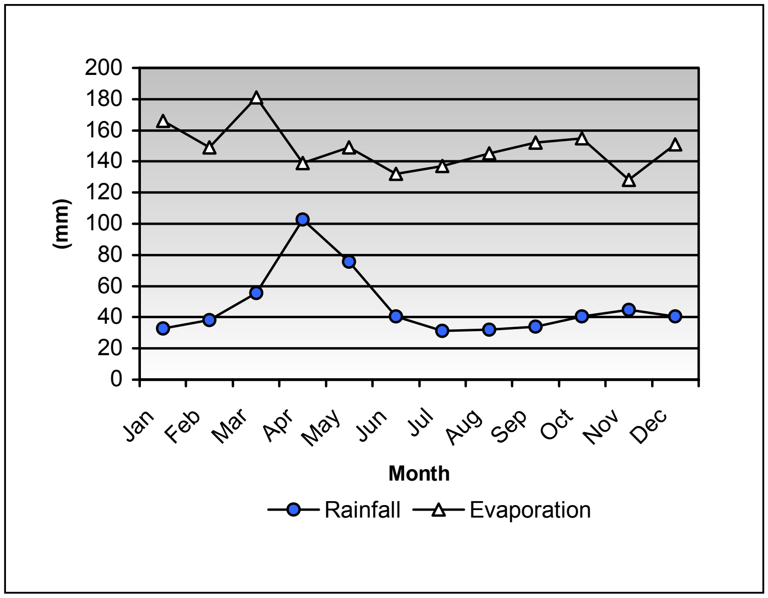


Figure 3. Average monthly precipitation for the period 1966 to 1993 and potential evaporation (1968-1997).
Source: Tang (1999).

2.3 Geology and soil types

The lake Naivasha is located in the Rift Valley, which, which spread from Egypt in North Africa down to the south, Zimbabwe. The valley was formed approximately 4 millions years ago by faulting and volcanic activities. Two types of quaternary deposits characterize the area round the Lake Naivasha: volcanic and lacustrine (Jolicoeur, 2000). The lacustrine deposits are comprises of fine volcanic ashes, clay and silt besides consolidated tuffs, diatomite, very fine pyroclastics to pumice and occasionally. In addition, due to the soil erosion and deposition resulting from the lake levels fluctuations, there appeared also some coarse loamy with occasional fine gravel deposits. The volcanic deposits are comprises of basalts, phonolites, tephrites, trachytes, rhyolites, comendites, pyroclastic of acidic nature (Siderius, 1999)

2.4 Geomorphology

According to Thompson, (1958) three types of landscapes had been identified in Naivasha catchment: the Kinangop plateau, the Mau escarpment, and the Rift valley floor. The study area is within the Rift Valley floor. In this area two major units occur. The lacustriane plains in the north and Northeast of the lake formed by terraces due to the fluctuation in the water level.

The volcanic plains that occur in the southern part of the lake formed by the lava flows from the eruptions of the Longonot volcano (Kwacha, 1998 and Jolicouer, 2000). In general the topography the area around the lake is flat. The slopes varying from 0 to 2% (Tang, 1999).

2.5 Hydrogeology

The lake Naivasha subcatchment is the most important of the Rift Valley floor because of the freshwater resources and hydrothermal potential. Due to the Rift floor geometry and tectonics is considered hydrogeologically complex.
The lake Naivasha is the second largest natural freshwater resource in Kenya. It is also very important from the economical point of view due to be an attraction for the tourist industry and also as one of the largest surface water source for irrigation. The aquifers usually occur as fractured volcanic formations or along the weathered contacts between lithological unit. The aquifers near to the lake are unconfined with high permeability. Even so in areas away from the lake the aquifers are confined or semi confined. The estimated hydraulic conductivity is in average 10 m/d and the well yield exceeds 3 liters per second per meter in those areas having high permeability due to volcanic composing sediments (Clarke et al.,1990). Data from 62 boreholes was used to generate the groundwater depth map around the lake Naivasha. Some of this data was collected in 1996 and some is this was collected by Oppong-boateng (2000). The moving average interpolation method was applied to generate the tentative ground water depth map. The groundwater depths around the lake vary from 1 to 120 meters approximately. (Figure 4). Even so the majority of the area is cover by groundwater depths enclose in the range of 10 to 50 m.

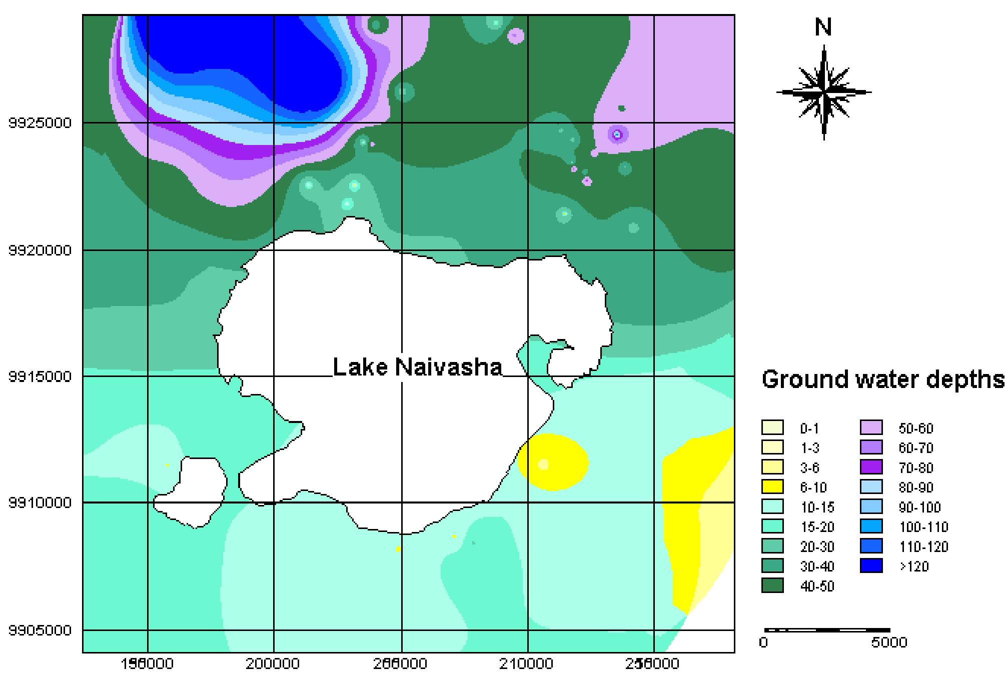


Figure 4. Groundwater depths around the lake Naivasha

Base on existing data for 41 boreholes in the study area a piezometric map was generated (Figure 5). The flow direction of the groundwater is toward the lake from the Mau escarpment north and west to south and east to the south, the outflow along the south shore.

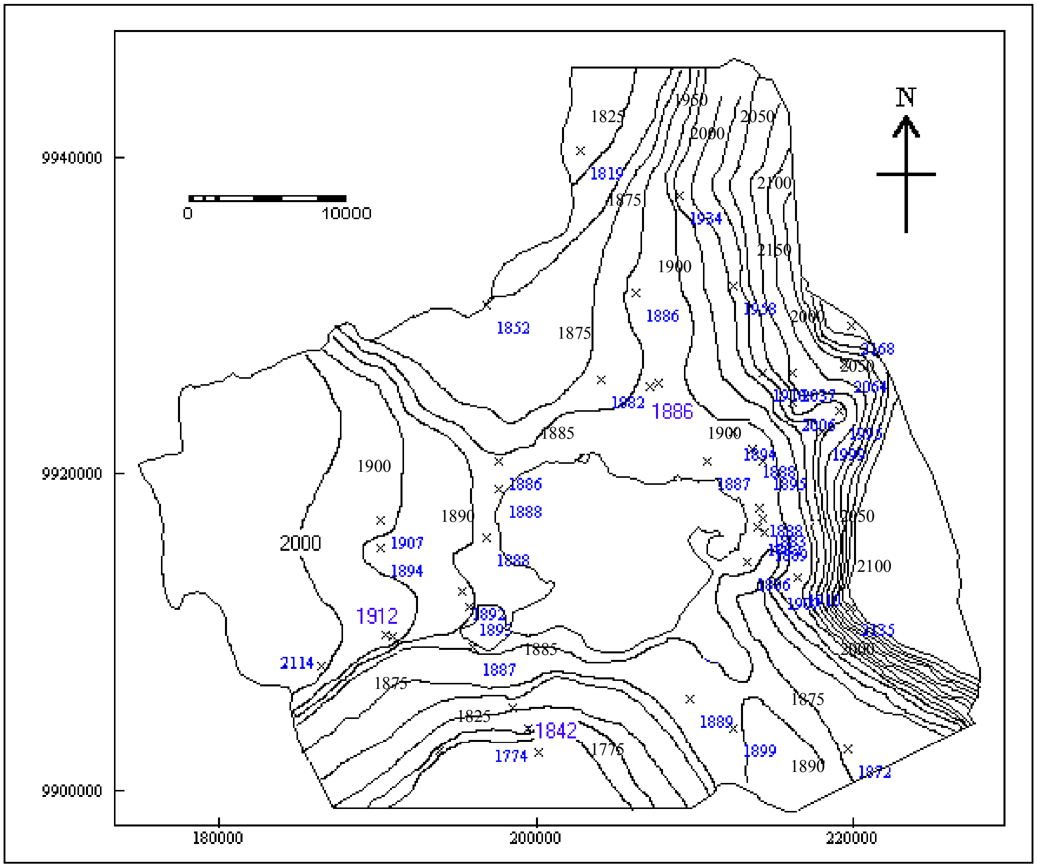


Figure 5.: Piezometric surface of the area under the natural setting during 1980 period
Source: Owor, 2000.

Chapter 3: Methods

The literature review was based on the three phases followed in the methodology to reach the objectives of this research project.

3.1 Pesticides in the Environment

Pesticides are chemical products used to prevent or control pest in agricultural fields. The use of those products aims to increase the crop yields and even so incomes. Three millions tonnes of pesticides are produced worldwide and are released in the environment. These compounds have a direct or indirect impact on human health, flora and fauna and they may pollute groundwater, rivers and lakes. Due to its persistency some of them may remain in the soil for prolonged periods. The risk analysis is a process that allows assessing the impact of these compounds in the human health and also in the ecosystems.

3.2 Risk analysis

Carter and Van Westen (1991) define a risk as the probability of meeting danger or suffering harm or loss. In this case we will refer to the risk of pesticide pollution effecting the population the study area, using relative terms to indicate the degree of risk probability (low, medium or high).
The risk assessment framework includes three phases: the hazard identification, the vulnerability or the dose-response assessment and the exposure assessment. The information generated in the risk assessment will lead to the risk management and planning process (Figure 6).

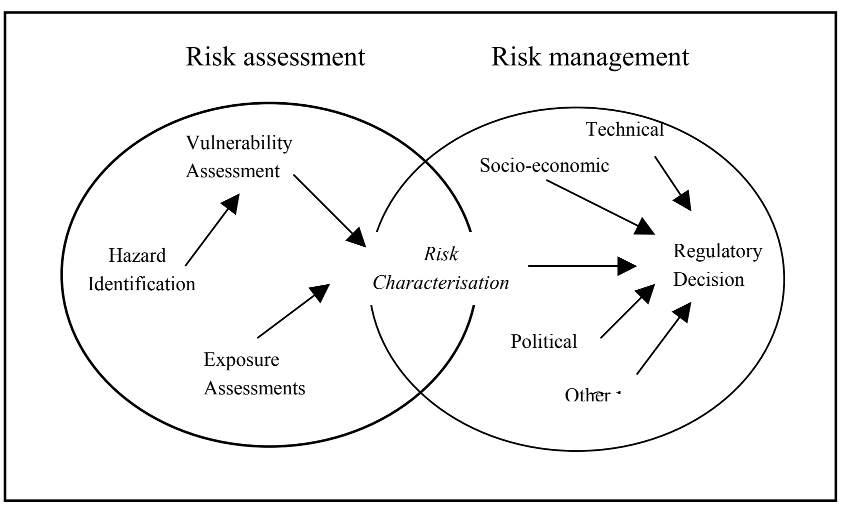


Figure 6 Risk Assessment/Risk Management framework.
Source: Patton (1995). Modified by the author.

To regulate the pesticides concentrations in the environment the Unites States Environmental Protection Agency (EPA) and other organisations as FAO and WHO, had been established the regulatory standards for maximum contamination levels in the environment.

3.2.1 Hazard Identification

The hazard assessment refers to the probability of occurrence of a potentially damaging phenomenon or event in a certain area within a specified period of time (Carter, 1991 and Van Westen, 1994). Some of the methodologies of the hazard identification process will be review below.

As a part of the hazard identification the contaminants inventory has to be generated. Actual research projects as the National Water Quality Assessment (NAWQA) in United States are studying the widespread contamination of the water resources and the potential impact of pesticides in human health drinking water, and aquatic life. The evaluation was based on the geographic and temporal distribution of pesticide occurrence in relation to the land use as a first phase of NAWQA. The results of this study reflect the influence of the land use in the pesticides distribution in the streams. Even so the compound properties and the hydrogeology influence distribution of the pesticides in the groundwater. The second phase of the project will be based on the increment of pesticides measured in the streams and groundwater. Likewise the use of an empirical and deterministic models will be use t improve the estimation of pesticides exposure patterns for unsampled water resources (American Chemical Society, 1999).

In the European inventory of emissions to inland waters published in 1998 there is a description of the sources of emissions. Those are categorised in *"point"* sources and "non-point" *or "diffuse sources"*. The Agricultural activities fall in the last mentioned source due to cannot be located individually. In the assessment for agricultural emissions the area has to be classified according to the crop types and soil type. It is not easy to assess the diffuse pollution. Some models aim to evaluate the available surplus. The current available models are designed to use national agricultural statistics as input (European Environment Agency, 1999).

3.2.2 Vulnerability assessment

The vulnerability is defined as the damage or losses caused by the direct or indirect effect of the hazard. These losses can be expressed in environmental, economical, social or physical terms. The vulnerability assessment shows where are the areas that could be damaged if the hazardous event would occur. This assessment provides information about the level of exposure of people to the hazard (Ingleton, 1999 and Carter, 1991). Vulnerability is expressed on a scale from 0 (no damage) to 1 (total loss) (Van Westen, 1994). The important parameters on the groundwater vulnerability are the attenuation capacity of the soil, of the unsaturated zone, and the aquifer with respect to the properties of individual contaminants. The attenuation capacity can be exceeded or reduced over time, which results in a changed vulnerability of the groundwater system to that contaminant. When there is a persistent and mobile contaminant the role of the attenuation process in the soil and the saturated zone is minimal and the aquifer's vulnerability depends on its thickness and permeability (residence time of the contaminant). Both parameters control the dilution of the persistent contaminant.
The hydrological characteristics of aquifers, landuse practices and the contaminant characteristics and loading all have to be considered in assessing the vulnerability. Major attributes involved in the assessment include landuse and population density. The accuracy of the vulnerability assessment of groundwater depends on the amount and quality of representative and reliable data. The vulnerability

assessment in water resources is a tool in protection, planning and decision making process or management (Vrba and Zoporozec, 1994).

3.2.3 Exposure assessment

An exposure assessment phase it is possible to evaluate how much of a substance an individual or population ingest, inhales or contacts through the skin aver a period of time. The exposure may be long term or short term and occupational or environmental. Environmental exposure estimates how much of a substance is present and how much of this substance people come into contact with. Another way to assess the exposure is through the study of body fluids (blood) or tissues to analyse the presence and amount of substances.
People in a community with a drinking water supply from groundwater polluted by pesticides are an example of long-term environmental exposure. In the environmental exposure studies two steps are carried out:

- Estimate the amount of the substance present in the environment (air, soil, water, food)
- Estimate how much of the substance people are exposed. This approach may be done using available data, models and assumptions.

Both steps include uncertainties because of the incomplete knowledge about the properties of the chemical substances, their behaviour in the environment and how these substances and humans interact Long term exposure usually is complex to estimate. Existing data is used to assess variations over time. If measurements were not made previously mathematical models may be used for the exposure assessment. Those are based on the properties of the chemical as vapor pressure, solubility, adsorption and persistence (Kamrin and Walter, 2000).

3.4 GIS used as a tool in the risk analysis

Geographic Information Systems (GIS) environment is being widely applied for diverse applications in natural resources management. The groundwater quality models can be integrated in the GIS environment to produce the hazard, vulnerability, exposure and final risk maps.
Some GIS software as ARC/Info and GRASS are being used for the integration environment. Both the raster and vector approaches are being used to implement the water quality models. Graphical user interface(s) have been developed to assist the end-user to carry out the analyses in the future.

A groundwater vulnerability study carried out within Indiana to pesticide and nitrate pollution potential was evaluated using a Geographic Information System (GIS) environment. The ARC/Info and GRASS GIS environment was used to identify and display the groundwater regions sensitive to potential pesticide and nitrate pollution as a result of non-point sources. The STATSGO database was employed to retrieve statewide soils information required for the analysis. The information was used within three models, DRASTIC, SEEPAGE, and the Soil Pesticide Interactive Screening Procedure (SPISP).

These models consider various hydrogeologic settings that affect the groundwater quality of a region. The results were compared with existing data of nitrate contamination in well water to determine the accuracy of the results. The modified DRASTIC and SEEPAGE maps show a great deal of potential as screening tools for policy decision making in groundwater management. Other detailed models are suitable to suggest conservation practices that could lessen the problem (ESARL, 2000).
The Geographic Information Systems (GIS) applied in the risk analysis allow to incorporate spatial analysis techniques, communication and management process. GIS is a tool that aims to identify the

distribution of contaminants and receptors and assess multipathway exposure patterns on a spatial and temporal basis (Beer, and Ziolkowski, 1995).

3.5 Fate of pesticides in the environment

Many factors and reactions govern the distribution of an organic compound in the elements of the environment. An ecosystem may be considered as a series of homogeneous compartments as air, water, soil, sediment and biological material. The concentration of an organic compound in each compartment is related to the concentration in other compartment by a specific distribution coefficient expressed as the ratio of the concentration of the solute in the compartments involved (Hounslow, 1995).

- Air and water — Henry's law constant
- Solid and Water — Distribution constant
- Fish and water — Bioconcentration factor

Every pesticide has different properties, which can be used to characterise them into a certain category. One of these properties is the persistence, which govern the fate of the pesticides in the environment. Most of the pesticides are degraded two days after applications except those categorised under high toxicity (Tang, 1999).

Many processes occur after a pesticide has been released in the environment. The pesticides applied on the plant sometimes can be translocated within the plant but most of the time they are applied covering the plant surface. These pesticides will be transported to the air through volatilization and photodegradation and also to the soil through washing off. Pesticides are also applied directly to the soil surface these can be transported by washing off, percolation and volatilization as well as diluted in the soil moisture and leach toward the groundwater. There area many physical processes involved in the transport of the pesticides through the soils (Hounslow, 1995 and Bonazountas et al., 1997): Those processes described in the paragraphs below.

- Advection; in this process the solute move with the same velocity of the water. In sand and gravel aquifers is the dominant factor in the migration of dissolved contaminants.
- Dispersion; The solute is spread by a non-uniform movement in porous media, effecting all solutes equally and may be consider as dilution, occurs with laminar flow and has the same effect in groundwater as turbulence has in surface water. There is two type of dispersion; *hydraulic dispersion* the solute is spread along the direction of flow and transverse to it and *molecular dispersion* occurs at very low velocities such as under stagnant groundwater conditions.
- Diffusion; refers to the dilution by spreading. The pollutant is moved relative to the mass of the medium.
- Volatilization; refers to the process in which a pollutant is transported from the soil or the plant to the air. It is an extremely important pathway for many organic chemicals.
- Sorption; refers to the adherence of ions or molecules in solution to the soil particles. For organic compounds the most important sorption mechanism is partitioning between water and the organic carbon content of the soil.

As well as physical processes, there are chemical transformation processes affecting the pesticides migration. These are described in the paragraphs below.

- Ionization; In this process occurs the separation of a molecule into particles of opposite electrical charge (ions). The ionization has an effect on the chemical behaviour of a substance. An acid or base that is extensively ionized may be altered on its solubility, sorption, toxicity and biological characteristics than the corresponding neutral compound.
- Solubility; This in an important factor in the mobility of the or transport of the compound. Pesticides having a high solubility will be dispersed quickly by the hydrologic cycle but also may will have low soil sorption and slightly bioconcentration in aquatic biota. These compounds are also easily biodegradable by microorganisms.
- Hydrolysis; this is a chemical transformation process in which organic compounds reacts with water forming a new molecule.
- Oxidation-Reduction; This process is an important degradation process under environmental conditions, most of the reactions depend on reactions with free radicals already in solution.
- Complexation; This is a process by which metal ions and organic molecules (ligands) can combine to form stable methal-ligand complex that will prevent the metal from undergoing other reactions that would free the metal cation.

There are also the biological process affecting dissolved contaminants migration are:

- Bioacumulation; In this process terrestrial organisms (plants, and soil invertebrates) accumulate and concentrate pollutants from the soil.
- Biodegradation; This process is related to the transformation of a chemical by biological agents, usually by microorganism. It is the net result of a number of different processes, such a mineralization, detoxification, cometabolism, activation and change in the spectrum.

3.6 Models used to assess pesticides transport

The purpose of modelling the fate of the pesticides is to assess the environmental quality, to assess the human exposure and the decision-making including implementation of control strategies for environmental and human protection. The modelling must quantify with accuracy the relationship between the compound released into the environment and the actual amount of it to which air, soil, water and human are exposed.

3.6.1 ECOPLUS

ECOPLUS is software developed to assess the distribution of an organic pollutant in the environment. This program consists of four interrelated and integrated programs.

- Obtains distribution parameters from a variety of input data using a series of estimation techniques.
- Allows the calculation of half-life estimates from specific laboratory or field data.
- Calculates solute concentration at a specific point after a specified period of time in a groundwater system.

- Calculates the distribution of a solute in a specified ecosystem

An ecosystem may be through of as a series of homogeneous compartments such as soil, sediments, biological material, air and water (Figure 7 and 8). The concentration of a compound in any compartment is related to the concentration in any other compartment by a specific distribution coefficient. A literature search for partition parameters usually leads to the acquisition of a set of parameters frequently expressed in different units. The parameters used as an input data for ECOPLUS is presented in table 1. The derivation of an internally consistent set of partition parameters from these data is accomplished in several stages:

- Convert the parameter to the same units
- Compare each value with others in the set and note outliers
- Calculate parameters from other parameters using regression equations
- Examine parameters starting with the parameter that is dependent on the maximum number of other parameters.
- The final selected value of each parameter is a weighted average of those reported values and estimates remaining.

Table 1. Input parameters/units for the ECOPLUS program

Parameter	Unit
Molecular weight of the compound	Grams
Melting point	^oC
Boiling point	^oC
Vapour pressure	mm Hg (Torr)
Solubility	mg/l
Water partition coefficient (K_{ow})	Log K_{ow}
Distribution coefficient (K_{oc})	Log K_{oc}
Bioconcentration factor (BCF)	Log (BCF)
Henry's law constant	Dimensionless*

* Henry's law constant has different units (see chapter 5) but for the ECOPLUS program the dimensionless was used.

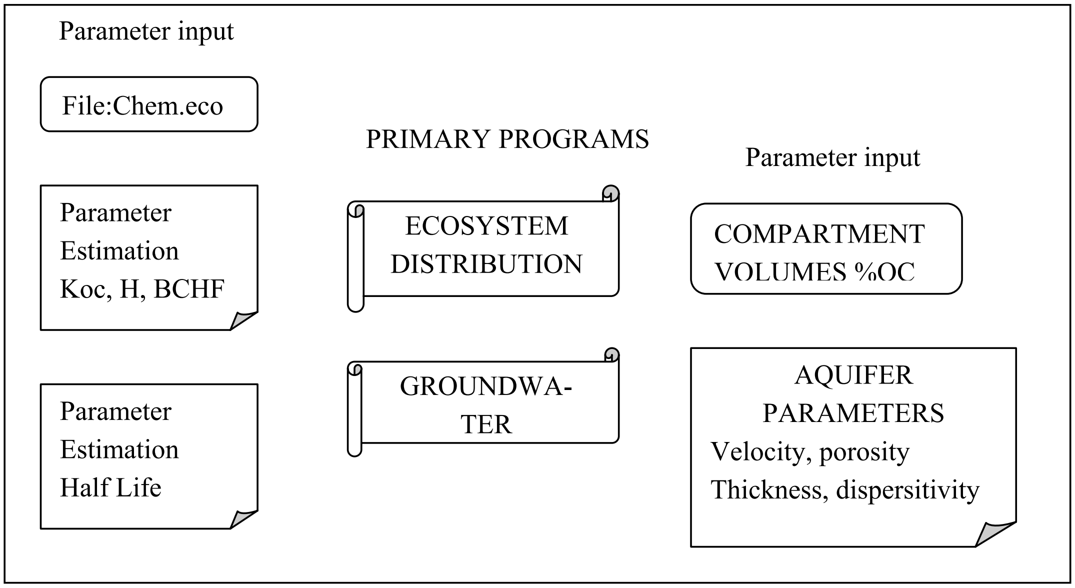


Figure 7. Environmental compartments available in the ECOPLUS program
Source: Hounslow, 1995.

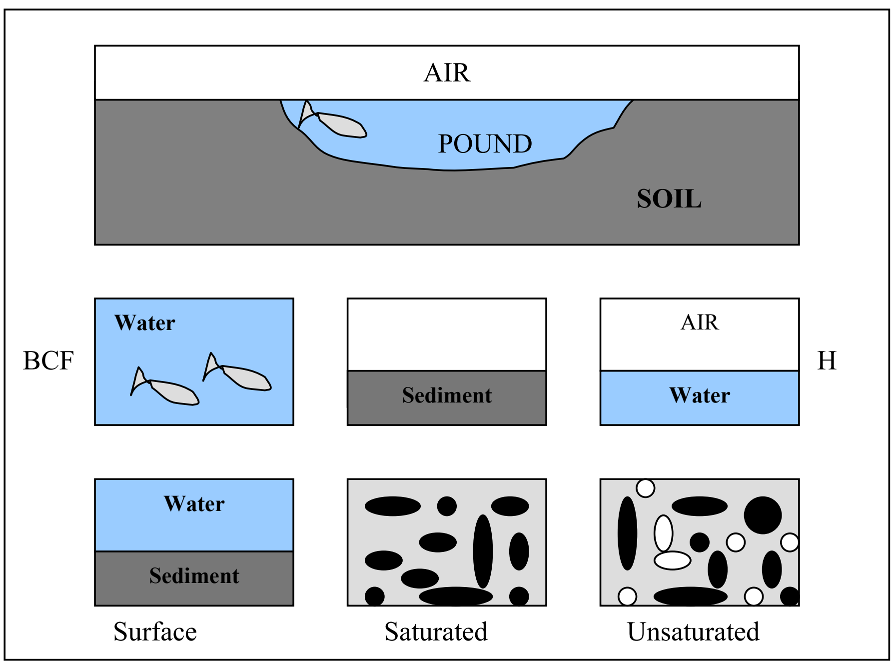


Figure 8. Outline of ECOPLUS computer program
Source: Hounslow, 1995

Chapter 4: Inventory and quantification of pesticide use

4.1 Data collection and analysis

Seven representative farming systems were selected. Those farms have different irrigation practices (dripping, sprinkle and pivots), different crop types (vegetables, flowers, cereals, mixed), different management conditions (greenhouses and open fields) and different conditional factors (soil type, microclimate and water use sources). A description of each farming system is presented below, these are denoted by capital letters from "A" to "G".

4.1.1 Pesticide use in Farming System "A"

The farming system "A" is one of the biggest farms in the area. The productive activities of de farm demand high number of human resources. The total number of employees is approximately 6000. The total area is approximately 1100 ha but under production there are around 170 ha. There are between 80-100 Ha under vegetables production; French beans, runner beans, sugar snaps, squash, Mangetout peas, Brussels sprouts, chillies, Egg plant, carrots, baby corn and herbs and 70 Ha under flowers production; Roses (40 ha), Carnations (18 ha) and Hypericon (19 ha). The production is exported to England and other countries in Europe. The vegetables are cultivated in open fields whereas the flowers are under greenhouses. The main pests and diseases affecting those crops are presented in the table below.

Table 2. Main Pests and diseases registered in farming system "A" during the period 1999 - 2000.

Crops	Main pest and diseases	
	Pests	Diseases
Vegetables	White flies, leaf miner	-------
Roses	Spidermites, caterpillars,	Powdery mildew,
Carnations	Spidermites, caterpillars	Rust, stem borer root,
Hypericon	White flies	Rust

The main control of the pests and diseases is through the use of agrochemical products. Recently some efforts have been oriented to the organic production of vegetables. The boom spraying is used for vegetables. The hose dripping (in some cases) spraying is used for the flowers. The pesticides used by farming system "A" are showed in the table below.

Table 3 Pesticides used by farming system "A" for vegetables and flowers production

Abamectine	Daconil	Meltatox	Rovral
Actellic	Decis	**Mesurol**	Rubigan
Afalon	Dimethoate	Milraz	Rufast
Afugan	Dimilin	Mitac	Saprol
Alliette	Dipel	Neem	Scale
Alto	Dipterex	Neemros	Score
Antracol	Dithane M-45	**Nemacur**	Sherpa
Anvil	Dursban	Nimrod	Spore-kill
Apollo	Dynamec	Nomolt	Stomp
Bavistin	Euparen	Nustar	Stroby
Baycor	**Evisect**	Omite	Sumisclex
Bayleton	**Fastac**	Orthene	Talstar
Benlate	Folicur	Pentac	Tedion
Bravocarb	Folimat	**Peropal**	Teepol
Brigade	Furadan	Plantomycine	**Temik**
Bulldock	Fusilade	Plantvax	**Thiodan**
Captan	Hostathion	Polyram	Thiovit
Cascade	Karate	Previcur	Trigard
Confidor	Kocide	Pride	**Vydate**
Copper Oxychlo-ride	**Lannate**	Regent	Xentari
Copper Sulphate	Lasso	Ridomil	

The bold label indicate high toxicity according to the WHO and EPA regulations. Details of pesticides use in each crop and pesticide information are showed in the appendix 1. The total number of pesticides used by farming system "A" for the vegetables and flower production is approximately eighty. Those that are used in more than fifty percent of the crops are showed in the figure below. Some of those are classified with high toxicity according to the WHO and EPA regulations.

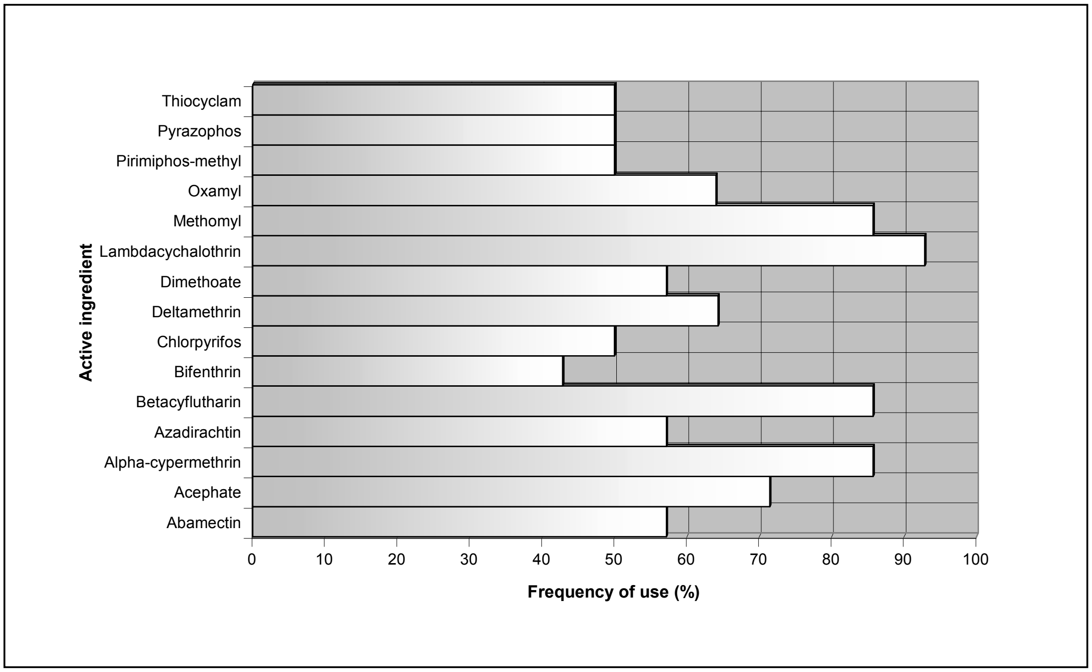


Figure 9. Frequency of pesticide use base on fourteen different crops cultivated in farming system "A" during the period enclose from 1999 to 2000

The Vegetables Department and the Crop Protection Section in Farming system A deal with the approved pesticides used for export production of each crop in the different production seasons. In this list specifications of rate of application and use restrictions are included. The criteria for the pre harvest intervals (PHI), also in the list, are taken from many agencies involved in the pesticides registration, such as:

- Kenyan registration by the pest control products board (PCPB)
- United Kingdom registration
- Greek registration
- Italian registration
- French registration
- Brazilian registration
- Dutch registration
- German registration
- Swiss registration
- South Africa registration
- European Union registration
- Spanish registration

The pre harvest intervals (PHI) are very important due to most of the vegetables are to be consumed fresh and the persistence of some pesticides is high. The pesticides spray decision is determined by program in some cases but most of them by scouting. The scouting is carried out daily and weekly depending of the crop susceptibility, crop stage and production season.

The frequency of pesticide use for crop according to the data collected is showed in Figure 10. It is important to take into account that this value can vary with the cultivated areas, the season of the year, and the history of the cultivated plot. Other remark is that some of the crops were cultivated during 1999 but not during 2000. Then these values are based strictly on spraying records coming from January 1999 to August to 2000.

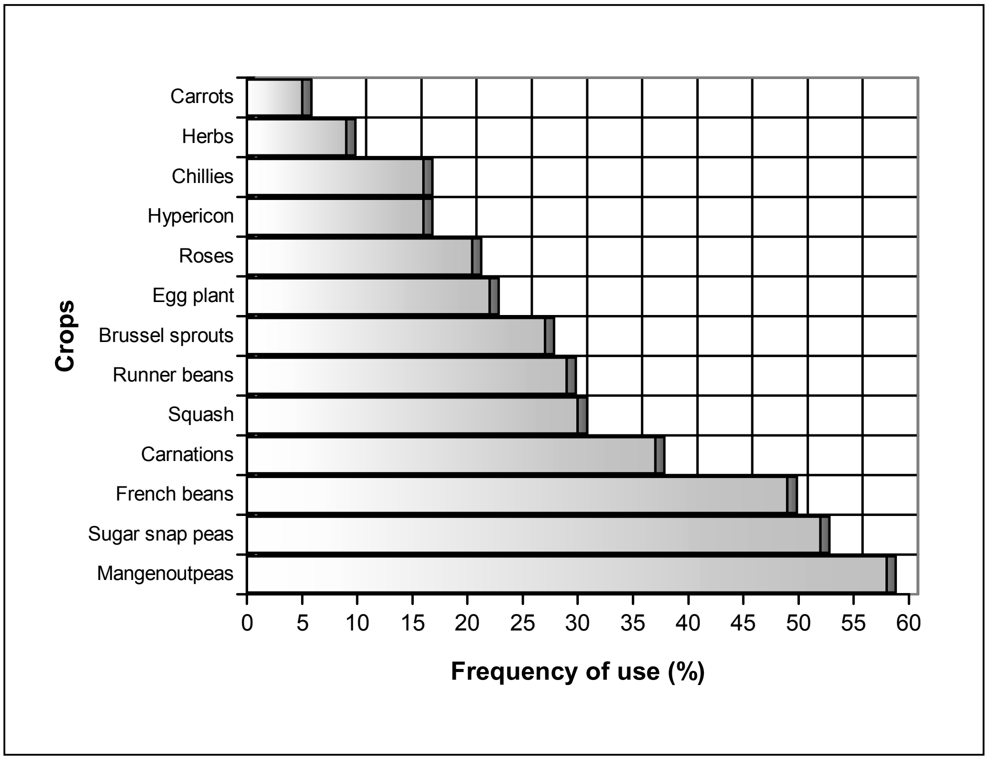


Figure 10. Frequency of pesticide use per crop in farming system "A" (Survey period from 1999 to 2000)

According to the data collected the French beans, the sugar snaps and the mangetout peas are the vegetables that demand highest use of pesticides. Those crops are susceptible to the leaf miners and white flies harm. The rotation in the use of those pesticides is done in order to avoid the development of the pest resistance. In the case of the flowers the hypericon demand less use of pesticides due to this crop is not a host of the common pests and diseases in the farm. In the blooming stage is very attractive to the white flies due to the yellow colour of the flowers causing aesthetic harm to the berries (Figure 11).

Figure 11. Hypericon crop under greenhouse in farming system A

4.1.2 Pesticide use in Farming System "B"

The farming system "B" is another big farm in the area. The total number of employees is approximately 4000. The main activity of this farm is the flower production. There are 60 ha of roses under greenhouse, 50 ha under carnations production (10 ha greenhouse and 40 ha open field) and 20 ha under limonium production making a 130 ha of total cultivated area in addition to 5 ha of vegetables destined to internal consumption. The vegetables cultivated in open fields. Those are broccoli, onions, potato, courgettes, tomato, sweet potato, lettuce, French beans, spinach, and red cabbage. The main pests and diseases are presented in the table below.

Table 4 Main Pests and diseases registered in farming system "B"

Crops	Main pest and diseases	
	Pests	Diseases
Vegetables	Caterpillars	Bacterial blight
Roses	Red spidermites, caterpillars	Powdery mildew, botrytis
Carnations	Red spidermites	Rust, ring spots
Limonium	Caterpillars	Botrytis (in open fields)

This farm also is using pesticides to control the pests and diseases. This farm has a research department in which they perform a chemical trial. The objective of the chemical trial is to determinate the effectiveness of various insecticides in controlling a specific pest or disease in a specific crop and also to determine the efficiency of some new natural insecticides.

The use of natural products like extracts of plants like neem, *Bacillus thuringiesis*, garlic concentrates and petroleum oils have a high maximum residue levels (MRL) and short pre harvest intervals (PHI) convenient for the environment and the vegetables production.
The procedure to follow for the chemical trial is based in treatments and replicates and also a control plot without application. The spraying is conducted one per week for three weeks using knapsak sprayer. The last step in the field is to assess through physical counting the live insects. This counting is conducted weekly, three days after spray. Then the statistic analysis is carried out to determine which product performs better ranking from very poor to excellent. The boom spraying is used for vegetables. The hose spraying is used for the flowers. The pesticides used by farming system B are showed in the table below.

Table 5. Pesticides used by farming system "B" for vegetable and flower production

Acrobat MZ	Delan 500 SC	Metham sodium	Previcur	**Temik**
Aliette	Dimilin	Methyl bromide	Pride	Terrachlor
Antracol	Dipel	Milraz	Promot	Thiovit
Apollo	Diterra	Mitac	Ridomil	Thiram
Bavistin	Dithane	Neemros	Risolex	Torque
Baycor	Dursban	**Nemacur**	Rovral flo	Tracer
Bayfolan	Dynamec	Nimrod	Rugby	Trigard
Benlate	Euparen M	Nustar E.C	Secure	**Vydate**
Bravocarb	**Evisect**	Omite	Spore-kill	
Brigade	Karate	Orthene	Sporgon	
Captan	Kocide	Ortiva	Stroby	
Cascade	**Lannate**	Pentac flo	Saprol	
Confidor	Masai	**Peropal**	Scale	
D/Rogor	Match	Plantvax	Sumisclex	
Daconil	Meltatox	Polar	Tecto	
DC tran	**Mesurol**	Polyram DF	Tedion	

The bold label indicate high toxicity according to the WHO and EPA regulations. Details of pesticides use in each crop and pesticide information are showed in the appendix 1.
The total number of pesticides used by farming system "B" for the flower production is approximately seventy-two. Some of them had been tested and used in the vegetable production. The frequency of use for each pesticide is not relevant because more of them are used for the three main crops taking into account the rotation of use. In this farm the carnations and roses demand almost the same amount of pesticides (Figure 12). The limoniums are more tolerant to the main pests and diseases affecting the area covering for the farm as well as that the cultivated area for limoniums is less than carnation and roses in 60%.

The rotation in the use of those pesticides is done in order to avoid the development of the pest resistance. Another crop that is have been stabilised is the hypericon the only data collected was about the current chemical trials to control *leaf rust.* The pesticides that had been tested during the data collection period were Bayleton, Baycor, Baytidan, DC tran, Delan, impulse and stroby.

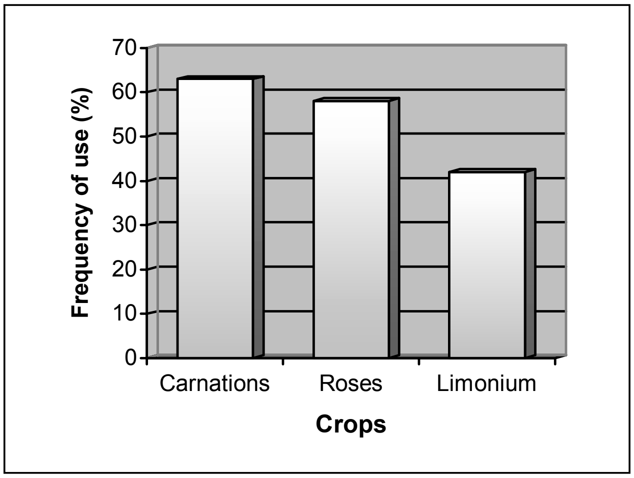


Figure 12. Frequency of pesticide use per crop in farming system "B"
(Survey period from 1999 to 2000)

4.1.3 Pesticide use in Farming System "C"

The total area is approximately 297 hectares. The pivot area under production is around 216 ha
The main activity of the farms is the vegetable production for exportation. The main crops are cabbages, garden peas, French beans and summer flowers. The cultivated area per crop especially vegetables is depending on the market requirements but those crops are planted weekly. The main pests and diseases affecting those crops and the pesticides used by the farms are presented in the tables below.

Table 6 Main Pests and diseases registered by Farming system C farm

Crops	Main pest and diseases	
	Pests	Diseases
Cabbages	Diamond Back Moth	-------
Garden Peas	Thrips, caterpillars	Powdery mildew, Downy
French beans	Thrips	Rust
Summer flowers	Leaf miner, caterpillars	Downy mildew

The main control of the pests and diseases is through the use of agrochemical products. The total number of pesticides used by the farm is around forty (Table 7) but it is important to remark that the data collected about pesticide use in this farm was limited. The boom spraying is used for vegetables and in some cases to drench some products the hose or dripping spraying is used. The pesticides with bold label indicate high toxicity according to the WHO and EPA regulations. Details of pesticides use in each crop and pesticide information are showed in the appendix 1.

Table 7. Pesticides used by farming system "C"
(Survey period from 1999 to 2000)

Actellic	**Diazinon**	**Marshall EC**	Score
Afalon	**Dimethoate**	**Match**	Spore-kill
Antracol	Dimilin	Nogos	Stomp
Alto	Dual	**Peropal**	**Thiodan**
Alto combi	**Divipan**	Pirimor	Thiovit
Anvil	**Dursban**	Plantvax	**Vydate**
Basagram	**Dynamec**	Polytrin C	
Benlate	Euparen	**Pyrinex**	
Captan	**Evisect**	Regent	
Coptrace	Goal	Round up	
Decis	Malathion	Rovral	

The pesticides spray decision is determined by program in some cases but most of them by scouting. The scouting is carried out daily and weekly depending of the crop susceptibility, crop stage and production season. The type of irrigation is sprinkle and it is supplied through pivots. Each pivot encloses 44 hectares (Figure 13).

Figure 13. Pivot area cultivated with baby corn, French beans, cabbage, garden peas and summer flowers in farming system "C"

4.1.4 Pesticide use in Farming System "D"

This farm is dedicated to the vegetable production. The total area is 1000 hectares distributed as 160 under vegetable production and 840 cover by forest and grass. The total number of employees is approximately 800. This farm is the biggest in the dairy industry in the area. The main crops are cabbages for local consumption baby corn and French beans to export to some countries in Europe, especially to United Kingdom. The planting activity is performed weekly (4 ha of baby corn, 1 ha of French beans and 1 ha of cabbage). The type of irrigation is sprinkle and it is supplied through pivots. Each pivot encloses 44 hectares (Figure 14). The main pest and diseases in the crops are showed in the table below.

Table 8. Main Pests and diseases registered in farming system "D"
(Survey period from 1999 to 2000)

Crops	Main pest and diseases	
	Pests	Diseases
Cabbages	Diamond Back Moth	-------
French beans	Caterpillars	Rust
Baby corn	Maize stalk borer	-------

The data about pesticides use in this farm was limited. The pesticides used by farming system "D" are showed in the table below. The baby corn crop is the less susceptible to the pest and diseases. Even so the cabbages is very much susceptible to the diamond black moth and its control demands a high amount of pesticides. According to the data collected, in this case it was possible to determinate the percentage of use based in the total amount of pesticides due to each one of them is used in different crops.

Table 9. Pesticides used by farming system "D"
(Survey period from 1999 to 2000)

Pesticide
Alto
Bestox
Dimilin
Dipel
Durban
Methomex
Pyrinex
Plantvax
Regent
Thuricide
Xentari

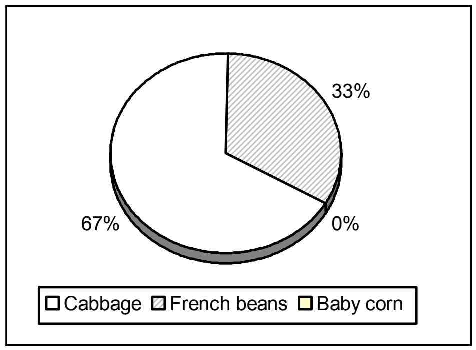


Figure 14. Percentage of pesticides use
for vegetables production in farming system "D"
(Survey period from 1999 to 2000)

4.1.5 Pesticide use in Farming System "E"

This farm is totally dedicated to the rose's production to export to The Netherlands. The production is held during the whole year. The market is seasonal with peaks in some months of the year. The total cultivated area is approximately 200 hectares (110-120 open fields and 85 under green houses). The total number of employees is approximately 3000.The water for the irrigation is take it from the lake Naivasha and is supplied by drips. The main pest affecting the roses is the *red spidermite* and the main disease is the *Powdery mildew.* Other pests affecting the crop are aphids and caterpillars as well as leaf rust. The date about the pesticides use by the farm was not available nevertheless the list of the pesticides used to control this pests and diseases in roses in the area are available in the table below.

Table 10 Pesticides used for roses production in the lake Naivasha area
(Survey period from 1999 to 2000)

Alliette	Dithane M45	Mitac	Rafast	**Temik/Furadan**
Apollo	Dynamec	**Nemacur**	Rovral	**Thiodan**
Bavistin	Equation PRO	Nimrod	Rubigan	Thiovit
Bravocarb	**Fastac**	Nomolt	Saprol	**Vydate**
Bulldock	**Karate**	Nustar	Scala	
Cascade	**Lannate**	Oscar	Spare-kill	
Daconil	**Meltatox**	Previcur	Stroby	
Dimilin	Milraz	Pride	Tedion	

4.1.6 Pesticide use in Farming System "F"

This farm is dedicated to flower's production; roses, carnations, lisanthus, eysophila, astis and limonium. The total area of the farm is 298 ha. The cultivated area is approximately 32 ha (30 ha under green houses and 2 ha cultivated in open fields). The total number of employees is approximately 900.The main pests and diseases are: red spidermites, thrips, nematodes, downy mildew, powdery mildew, leaf miner and rust. The pesticides used by the farm were not available. The table above shows those used for roses. The pesticides used for carnations and limoniums are listed in the table 11.

This farm has forty hectares under vegetable's production in Marula State. The main crops there are French beans, baby corn and Brussels sprouts. Those crops are to export to the United Kingdom in Europe.

Table 11. Pesticides used for carnations and limoniums production in the lake Naivasha area (Survey period from 1999 to 2000)

Abamectine	**Brigade**	Diterra	**Marshal**	Oscar	S-1283	Tedion
Acrobat MZ	Bulldock	Dithane M45	Match	Pentac	Saprol	**Temik**
AHO 100 SL	Captan	Dursban	**Mesurol**	**Peropal**	Scala	Terrachlor
Alto	Cascade	Euparen	Metham sodium	Plantvax	Secure	**Thiodan**
Antracol	Crymax	**Evisect**	Methyl bromide	Polyram DF	Shelltorque	Thiram
Apollo	D/Rogor	**Fastac**	Mitac	Pride	Sporgon	Torque
Basamid	Daconil	Folicor	Neemrock	Promot	Stroby	Tracer
Bavistin	DC Tran	Impulse	**Nemacur**	Rizolex	Sumico	Trigard
Baycor	Delan 500 SC	Karate	Omite	Rovral flo	Sumilex	**Vydate**
Bayfidan	Dimilin	Kocide	Orthene	Rufast	Switch	Xentary
Benlate	Dipel	**Lannate**	Ortiva	Rugby	Tecto	

4.1.7 Pesticide use in Farming System "G"

This total area of this farm is approximately 180 hectares. The activity of this farm is the vegetable's production. The main crops are cabbages, beans and wheat. Information about pest and diseases was not available. The pesticides used are Altellic, Anvil, baycor, bayfolan and buctrid. Even so data collected in other farms about these crops, pest and diseases is available and can be used for to cover the gaps of information because of the homogeneity of the study area. The irrigation system is almost the same in every farm. The new pivot system for sprinkle irrigation is being adopted for the vegetable production. In some of the farms is already implemented like Farming system C, Farming system D and Marula states. For the flower production under greenhouses and open fields the water is supplied by drip irrigation. The pesticides' spraying in general is the same in every farm. In the open fields is done with booms and in the greenhouses is done manually with the lances attached to the hose connected to spraying a tractor spray tank or different kind of distribution systems (Figure 15).

Figure 15 (a) Drip irrigation for roses in Greenhouse (b) Manual pesticides spraying for Hypericon under greenhouse

4.2 Quantification of pesticide loads

In all the crops the spraying decision to control the pests and diseases is make it by scouting and in some cases by program. In general, the pest and diseases infection is fluctuating during the year due to the natural conditions than affect its reproduction and dispersion. These conditions are dependent on the seasonal variations as rain, temperature, humidity, and wind velocity. In the case of the insects there is others factors that affect the populations densities as predation, parasitism, disease, inadequate food, limited nesting or hiding places and overcrowding, which can lead to cannibalism.

4.2.1 Estimation based on crop rotations

According to the season variability as a dependent factor for the insect's population three scenarios were conducted to estimate the pesticides loads per crop cycle:

- Scenario 1: Dry season during the months of January and February; average of two spraying per week.
- Scenario 2. Dry season during the months of June, July, August and September; average of one spraying per week.
- Scenario 3. Rainy season; average of three sprayings per week. The rainy season in the area is split it in two periods, March, April and May and the other one October, November and December. In this case although the precipitation is different in every period the conditions for the insects populations are similar

For the pesticides loads estimations, 11 more used components by the farm and classified under toxicity Ia, Ib, II (WHO) and I, II (EPA) was taking into account. Those components are Afugan (Pyrazophos), Brigade (Bifenthrin), Dimethoate, Dursban (Chlorpyrifos), Decis (Deltamethrin), Evisect (Thiocyclam), Fastac (Alpha cypermetrin), Karate (Lambdacychalothrin), Lannate (Methomyl), Nemacur (Fenamiphos), Endosulfan (Thiodan) and Vydate (Oxamyl).

The number of spraying in each crop is depending on the crop cycle itself. Also taking into account that the first fifteen days is the initial stage of the crop and fewer incidences of pests and diseases will be found. This is a general assumption but it is important to take into account that every crop has different hosts and susceptibilities in the different stages of the cycle.
The estimated pesticides load for every crop was calculated adding the rate per hectare (specified by the product manufacturer, appendix 2) of the total sprayings during the three scenarios.

The planted area per week was fixed to one hectare during the whole year (Appendix 2). The number of crop cycles per scenario was estimated according to the duration of the crop cycle and the spraying period.
The methodology to estimate the pesticides load was explained in the paragraph above. It was the same for all the crops. The only difference was with the flowers due to the cultivated areas are known and also less variable.
The calculation for the flower was based in a yearly period due to they are perennial crops. A short description of the crops is presented in the paragraph below.

- **French Beans (***Phaseolus vulgaris)*

They are by far the most important pulse crops in Kenya. Considerable quantities of beans are sold in Kenya; they are either exported to Europe. The crop cycle is around 9 weeks (60days). The planting is one per week. The cultivated area is approximately one hectare that makes around 52 hectares per year. The total crop cycles per year is around 40. The pests and diseases have specific host. Some crops are more susceptible to one determined pest or disease. Other factor that determines the pest attack is the crop stage. The use of pesticides to control them has to be restricted to a certain frequency of use due to the ability of the organisms to develop resistant to the product's action. Many products target to the same pest or disease. Those are rotated in its use during one crop cycle. The Pre Harvesting Interval (PHI) is a restricted time (days) to spray a pesticides. The PHI will change from one pesticide to another one due to its toxicity and persistence properties. The figure below shows the estimated distribution of spraying during one crop cycle of French beans. The PHI for most of the organic components range from 21 to 3 days. For natural products the PHI is zero.

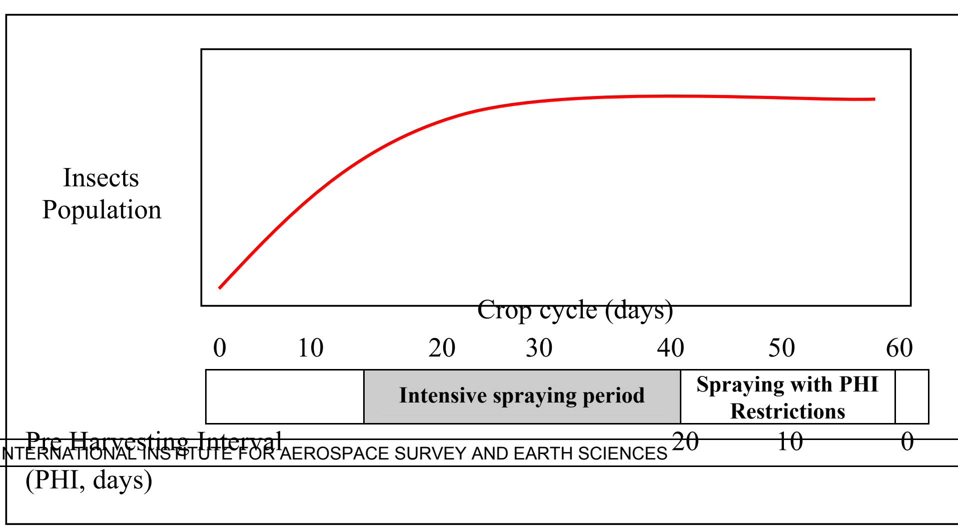


Figure 16. Assumed insect population and estimated spraying calendar for one crop cycle of French beans

- **Runner beans (***Phaseolus coccineus)*
- **Sugar Snap peas & Mangetout peas (***Pisum sativum variety macrocarpon (Edible-podded pea*)

Both crops are grown at high altitudes. They are exported to Europe and also consumed at the local market. The crop cycle is around 9 weeks (60days). The planting is one per week. The cultivated area is approximately one hectare that makes around 52 hectares per year. The total crop cycles per year is around 40. The spraying period is approximately six weeks.

- **Brussel sprouts (***Brassica oleracea;* gemmifera group)

The crop cycle is around 18 weeks (120 days). The planting is one per week. The cultivated area is approximately one hectare that makes around 52 hectares per year. The total crop cycles per year is around 31. The spraying period is around fifteen weeks.

- **Cabbage** (*Brassica oleracea*; capitata group)

The crop cycle is around 13 weeks (90 days). The planting is one hectare weekly. The total crop cycles per year is estimated to be 37. The spraying period is around eleven weeks.

- **Squash (***Cucurbita pepo)*

. The crop cycle is around 9 weeks (55-60 days). The planting is one per week. The cultivated area is approximately one hectare that makes around 52 hectares per year. The total crop cycles per year is around 40. The spraying period is around six weeks.

- **Roses (***Rosoidea rosasea)*

This is a perennial crop. The crop's duration under favourable conditions can be up to seven years. It consists of a large number of species or wild types from many parts of the world. The first harvest is at the two years.

- **Carnations** (*Dianthus Caryophyllus*)

This is an annual crop. The crop's duration under favourable conditions can be up to two years. The first harvest is about twenty weeks after planting.

- **Gold flower** (*Hypericon mum*)

This is a perennial crop. It is a dwarf to small-sized, deciduous shrub that normally doesn’t grow over 20 inches high making it a great groundcover. The first harvest is about twenty-six weeks after planting. The duration of the crop can be up to five years.

- **Statices** (*Limonium macrophyllum*)

There area many varieties of statices some of them are annuals and some are perennials
Annuals - L. sinuatum; L. Bonduellii; (These two are used for drying.); L. Suworowii. ***Perennials*** - L. macrophyllum; L. latifolium; L. tataricum nanum (also known as L. incanum nanum); L. Gmelinii; L. binervosum; L. caesium; L. minutum; L. spathulatum; L. eximium.

The crop duration can be up to 2 years. The first cutting is around eighteen weeks.

4.2.1.1 Farming System "A"

The pesticides load per crop cycle in Farming system A is showed in the table 12. In the case of the vegetables the estimation was carried out according to the number of crops based on one hectare because of the variability in the cultivated areas. To estimate the annual pesticides load for vegetables different crops rotation were assumed (Table 13). In the case of the flowers it was possible to make the estimations more accurately because these are perennial crops that stay longer in the field. This allowed making the estimations based on cultivated area per each scenario (Appendix 2). Both results are presented as kg of active ingredient (a.i.) per hectare/per year (Table14).

Table 12. Pesticides load estimation (kg a.i./crop cycle /ha) in Farming system "A"
(Survey period from 1999 to 2000)

Crop	Pesticides loads(kg a.i./crop cycle/ha)				
		Crop cycle Duration (weeks)	Scenario 1 (Jan-Feb)	Scenario 2 (Jun-Sep)	Scenario 3 (Mar-May) (Oct-Dec)
French beans		9 (60 days)	2.8-3.9	2.37-3.19	4.5-5.8
Runner beans		9 (60 days)	3.2-4.0	2.07-2.59	4.19-5.2
Mangetout peas		9 (60 days)	4.5-5.5	4.09-4.83	6.61-8.04
Sugar snap peas		9 (60 days)	3.2-4.7	2.47-3.24	4.97-6.02
Brussels sprouts		18 (120 days)	3.7-5.6	2.38-4.16	6.48-10.16
Squash		9 (55-60 days)	4.8-6.2	2.3-2.83	5.56-7.15

Table 13. Assumed crop rotations for the annual pesticides loads estimations based on one hectare for farming system "A".

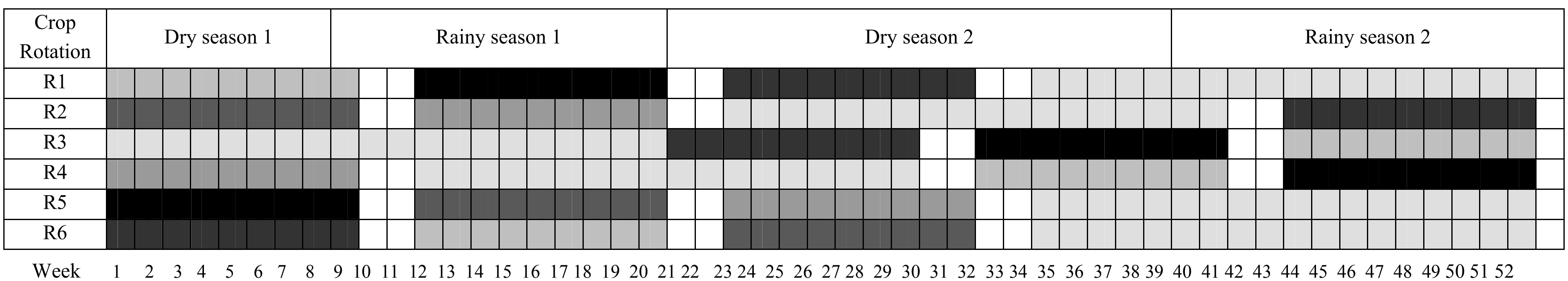


Table 14. Annual pesticides loads estimation for vegetables (based on crop rotation) and flowers (based on cultivated area) In farming system "A" (Survey period from 1999 to 2000)

Crops rotation	Pesticides load (kg a.i./ha/year)		Flowers	Pesticides load (kg a.i./ha/year)	Pesticides load per cultivated area
R1	18.79 - 26.41		Roses	48	2092 (44 ha)
R2	16.08 - 20.90		Carnations	60	358 (6ha)
R3	21.77 - 29.73		Hypericon	38	726 (19 ha)
R4	16.99 - 25.55				
R5	17.96 - 24.96				
R6	17.46 - 24.54				
Annual average	**18.10 -25.00**				

It is important to take into account that these values showed in the table above referring to the vegetables are based on a specific group of pesticides, an assumed spraying frequency and an assumed crop rotation. These assumptions were conducted on bases of the data collected in the field, and previous knowledge about the conditions of the area and crop's production.

The estimated cultivated area under vegetable production is varying from 80 to 100 hectares. According to the values estimated per hectare the total pesticides load vary from 1448 to 2000 kg of active ingredient for 80 hectares and from 1810 to 2500 kg of active ingredient for 100 hectares.

4.2.1.2 Farming System "B"

For Farming system B the estimations were based on the three main crops (roses, carnations and statices) and the cultivated areas (Table 15).

Table 15. Annual pesticides loads estimation for flowers (based on cultivated area)
in farming system "B" (Survey period from 1999 to 2000)

Crops	Pesticides load (kg a.i./ha/year)	Pesticides load (kg a.i.) per cultivated area
Roses	76	4543 (60 ha)
Carnations	68	3405 (50 ha)
Statices	71	1342 (19 ha)

4.2.1.3 Farming System "C"

The estimation of pesticides load was based on the main crops and the pivot cultivated area. As it was done for farming system "A", four crop rotations were assumed (Table 16 and 17).The total annual load taken into account the total cultivated areas are showed in the table 18.

Table 16. Pesticides load estimation (kg a.i./crop cycle /ha) in Farming system "C"
(Survey period from 1999 to 2000)

Crop	**Pesticides loads(kg a.i./crop cycle/ha)**				
		Crop cycle Duration (weeks)	Scenario 1 (Jan-Feb)	Scenario 2 (Jun-Sep)	Scenario 3 (Mar-May) (Oct-Dec)
French beans		9 (60 days)	2.8-3.9	2.37-3.19	4.5-5.8
Cabbage		13 (90 days)	3.2-4.0	2.07-2.59	4.19-5.2
Green peas		9 (60 days)	4.5-5.5	4.09-4.83	6.61-8.04

Table 17. Assumed crop rotations for the annual pesticides loads estimations based on one hectare for farming system "C"

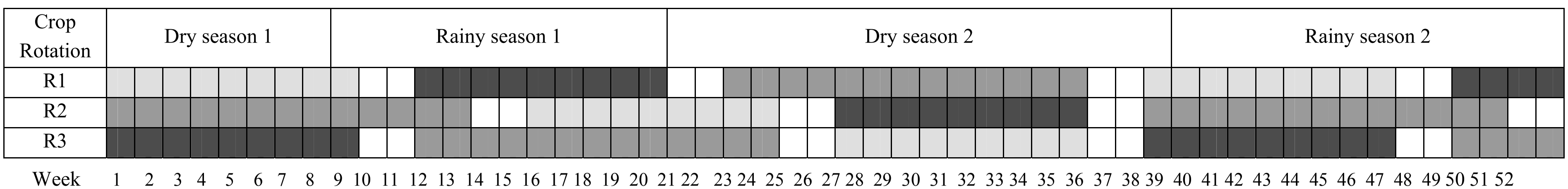


Table 18. Annual pesticides loads estimation for vegetables (based on crop rotation) and flowers in farming system "C" (Survey period from 1999 to 2000)

Crops rotation	Pesticides load (kg a.i./ha/year)
R1	16.37-21.88
R2	15.41-22.52
R3	15.36-22.00
Average	**16-22**
Summer flowers	**70.5**

According to the crops rotation the average pesticides load per hectare vary from 16 to 22 kg of active ingredient per hectare. The total pivot cultivated area is approximately 216 ha. According to the field observations around 97 percent of the area is under vegetables production and 20 percent under flowers production. The annual pesticides load according to the cultivated area under vegetables production vary from 3292.61 to 4609.44 kg of active ingredient and 456.77 kg for the area under flowers production.

4.2.1.4 Farming System "D"

The pesticides load per crop cycle in Farming system D is showed in the table 19. In the case of the vegetables the estimation was carried out according to the number of crops based on one hectare because of the variability in the cultivated areas. To estimate the annual pesticides load for vegetables different crops rotation were assumed (Table 20 and 21).

Table 19. Pesticides load estimation (kg a.i./crop cycle /ha) for farming system "D"
(Survey period from 1999 to 2000)

Crop	Pesticides loads(kg a.i./crop cycle/ha)				
		Crop cycle Duration (weeks)	Scenario 1 (Jan-Feb)	Scenario 2 (Jun-Sep)	Scenario 3 (Mar-May) (Oct-Dec)
French beans		9 (60 days)	2.7-3.7	2.37-3.19	4.48-5.78
Cabbage		13 (90 days)	3.0-5.0	1.75-2.88	5.42-8.45
Baby corn		13 (90 days)	3.4-3.7	1.99-2.24	5.14-5.56

Table 20. Assumed crop rotations for the annual pesticides loads estimations based on one hectare for farming system "D".

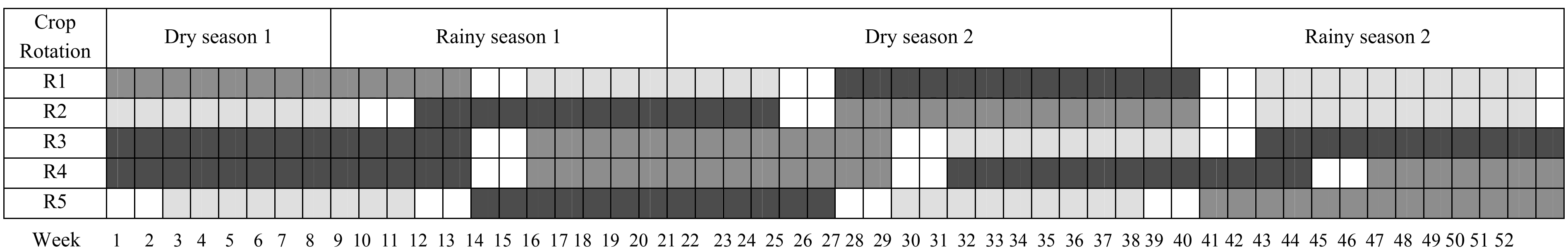


Table 21. Annual pesticides loads estimation for vegetables (based on crop rotation) for Farming system "D" (Survey period from 1999 to 2000)

Crops rotation	Pesticides load (kg a.i./ha/year)
R1	13.83-19
R2	13.52-17.86
R3	13.38-16.61
R4	13.18-17.32
R5	15.6-21.08
Average	**13.9-18.4**

According to the crops rotation the average pesticides load per hectare vary from 14 to 18 kg of active ingredient per hectare. The total cultivated area under vegetables is approximately 160 ha, the rest of the area is cover by grass and forest. The annual pesticides load according to the cultivated area varies from 2224 to 2944 kg of active ingredient.

4.2.1.5 Farming System "E"

The estimation of pesticides load for this farm was based on the total cultivated area. Data of pesticides use was not collected in this farm. The estimation is based on the pesticides and rates used by Farming system A due to the geographic proximity and similarity on pests and diseases in the lake Naivasha area. The total area under rose production varies from to 205 hectares. The pesticides load per hectare in this crop is approximately 48 kg of active ingredient. The annual pesticides load for this farm varies from 9360 to 9840 kg of active ingredient.

4.2.1.6 Farming System "F"

The total cultivated area in this farm is approximately 30 hectares under flower production. Detail of the cultivated area per crop was not possible to collect. Then the distribution of the cultivated areas was done according to the field observations. As well as Farming system E the estimations were based on the data collected in Farming system A due to the availability of data. The annual pesticides loads are showed in the table 22.

Table 22. Annual pesticides load estimation for flowers (based on cultivated area) for the farming system "F" (Survey period from 1999 to 2000)

Crops	Pesticides load (kg a.i./ha/year)	Pesticides load (kg a.i.) per cultivated area
Roses	48	1514 (20 ha)
Carnations	60	340 (5 ha)
Summer flowers	71	353 (5 ha)

4.2.1.7 Farming System "G"

The total cultivated area is approximately 180 hectares under cabbages, beans and wheat production. Wheat is the most important crop in the large scale, mixed farming areas of Kenya. The cycle of life is depending on the varieties and the altitude. In the area is around 4.5 months. It is strongly recommended to grow only one crop of wheat per year in a farm to have a better control of the disease's proliferation and a better soil structure. There was not enough data collected in this farm. The pesticides load estimation for vegetables (French beans and cabbages) was based in the existing data from other farms. For the wheat some literature was reviewed to determine the main pest that are also common in the lake Naivasha area as well as the pesticides used to control them. The annual estimated pesticides load is showed in the table below. The three scenarios that were carried out to estimate these values according to three different crop rotations are presented table 23 and table 24). It is important to notice that in table 25 the values of pesticides load for wheat are highest because of the difference on the crop cycle.

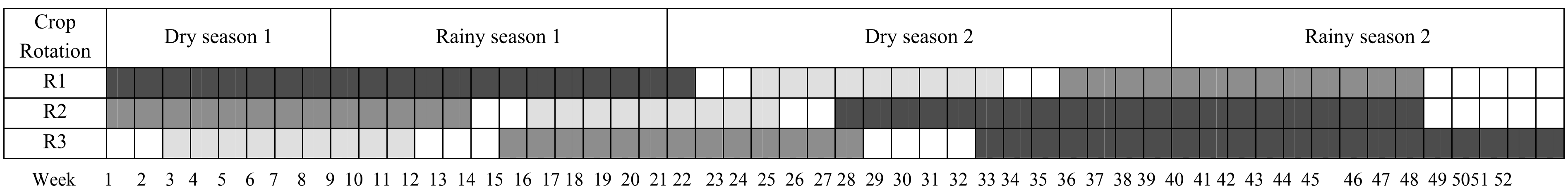
Table 23. Annual pesticides loads estimation for vegetables (based on crop rotation) for farming system "G" (Survey period from 1999 to 2000)

Crops rotation	Pesticides load (kg a.i./ha/year)
R1	18.3-22.83
R2	15.6-20.0
R3	16.95-20.79
Average	**16.95-21.20**

Table 24. Pesticides load estimation (kg a.i./crop cycle /ha) for Farming system G according to the data collected from 1999 and 2000.

Crop	Pesticides loads(kg a.i./ha)				
		Crop cycle Duration (weeks)	Scenario 1 (Jan-Feb)	Scenario 2 (Jun-Sep)	Scenario 3 (Mar-May, Oct-Dec)
French beans		9 (60 days)	2.7-3.7	2.37-3.19	4.48-5.78
Cabbage		13 (90 days)	3.0-5.0	1.75-2.88	5.42-8.45
Wheat		21 (147)	4.4-5.1	5.3-6.09	11-13

Table 25. Assumed crop rotations for the annual pesticides loads estimations based on one hectare for farming system G.



The final step in the calculations was to estimate the annual pesticides load (kg of active ingredient) per individual compound in the total area. The estimations were based on the scenarios carried out for the farms, the total cultivated area in each farm and also on the crop rotation per hectare proposed. The final estimations are showed in the table below.

Table 26. Final annual load estimation per pesticide (kg a.i.) in each farming system
(Survey period from 1999 to 2000)

Pesticide	**Active ingredient**	**Farming Systems**							**Annual loads Kg a.i.**
		A	**B**	**C**	**D**	**E**	**F**	**G**	
Afugan	Pyrazophos	56.25	0.00	99.00	39.60	0.00	0.00	30.11	224.96
Brigade	Bifenthrin	9.02	214.20	41.05	4.83	0.00	13.05	6.80	288.95
Decis	Deltamethrin	19.00	0.00	33.13	24.60	0.00	0.00	60.86	137.59
Dimethoate	Dimethoate	377.83	2486.40	902.56	403.20	0.00	129.60	1596.0	5895.6
Dursban	Chlorpyrifos	330.6	1212.0	628.4	466.6	0.00	0.00	466.6	3104.1
Evisect	Thiocyclam	166.75	225.00	275.00	86.40	0.00	0.00	54.00	807.15
Fastac	Alpha-cypermethrin	216.36	0.00	37.70	39.70	594.09	70.38	61.83	1020.06
Karate	Lambda-cychalothrin	53.80	88.62	57.63	67.65	990.02	17.75	52.20	1327.66
Lannate	Methomyl	1307.76	4046.40	902.47	963.36	2324.70	401.40	356.40	10302.49
Nemacur	Fenamiphos	1104.00	4160.00	0.00	0.00	3280.00	480.00	0.00	9024.00
Pride	Fluridone	307.20	388.00	0.00	0.00	984.00	119.00	0.00	1798.20
Thiodan	Endosulfan	861.84	0.00	0.00	0.00	2712.15	318.15	0.00	3892.14
Vydate	Oxamyl	1402.20	702.00	1330.99	0.00	2952.00	342.00	1036.80	7765.99
Total load per farm		6212.6	13522.6	4307.9	2095.9	13836.9	1891.3	3721.6	45588.9

4.3 Visualization of pesticides uses around the lake Naivasha.

To visualize the geographical distribution of the pesticides use in the study area the methodology of the National Water Quality Assessment (NAWQA) Program of the United States Geological Survey was followed with some modifications according to the data available for this study. The NAWQA Program shows the occurrence of pesticides in streams and groundwater in geographical patterns that follow land use and related pesticide use.

A satellite image (Landsat) taken in May 2000 was used to identify the land use of the area and the farming system units. A false color composite (FCC) was generated using the bands (5,4 and 2). This image shows the irrigated croplands as well as natural areas in the study area. After the data collection and field observations two paths were used to estimate the final pesticides loads in each farming system.

The first path was using only the data collected through the semi-structural interview referred to the irrigated cropland areas and pesticides use (previous section). The second path was using the data of pesticides use collected in the field and the remote sensing data interpretation to estimate the irrigated cropland areas and farming system units. The process to generate the final geographical distribution of pesticides use is showed in the figure below.

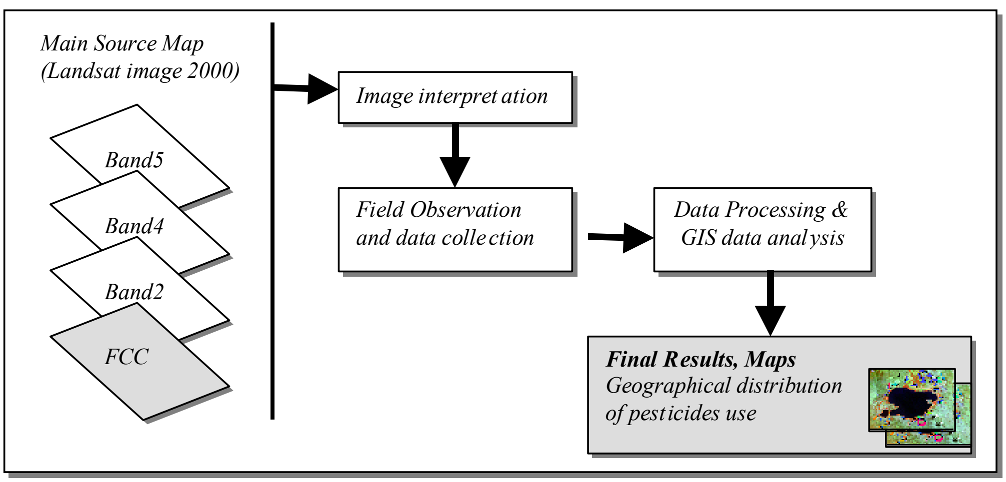


Figure 17. Interpretation of remote sensing data and data analysis process using GIS in producing geographical distribution of pesticides use maps

Through this process was possible to estimate the spatial distribution of annual loading of pesticides even for those farming systems that were not surveyed. The data collected in the seven farming systems surveyed was used to estimate the average loading for the rest of the farming systems according to the land use (vegetables, flowers, grasslands and natural areas) identified in the satellite image (reinterpretation (Figure 18). It is important to remark that those areas surrounding the landuse units are consider being a natural areas.

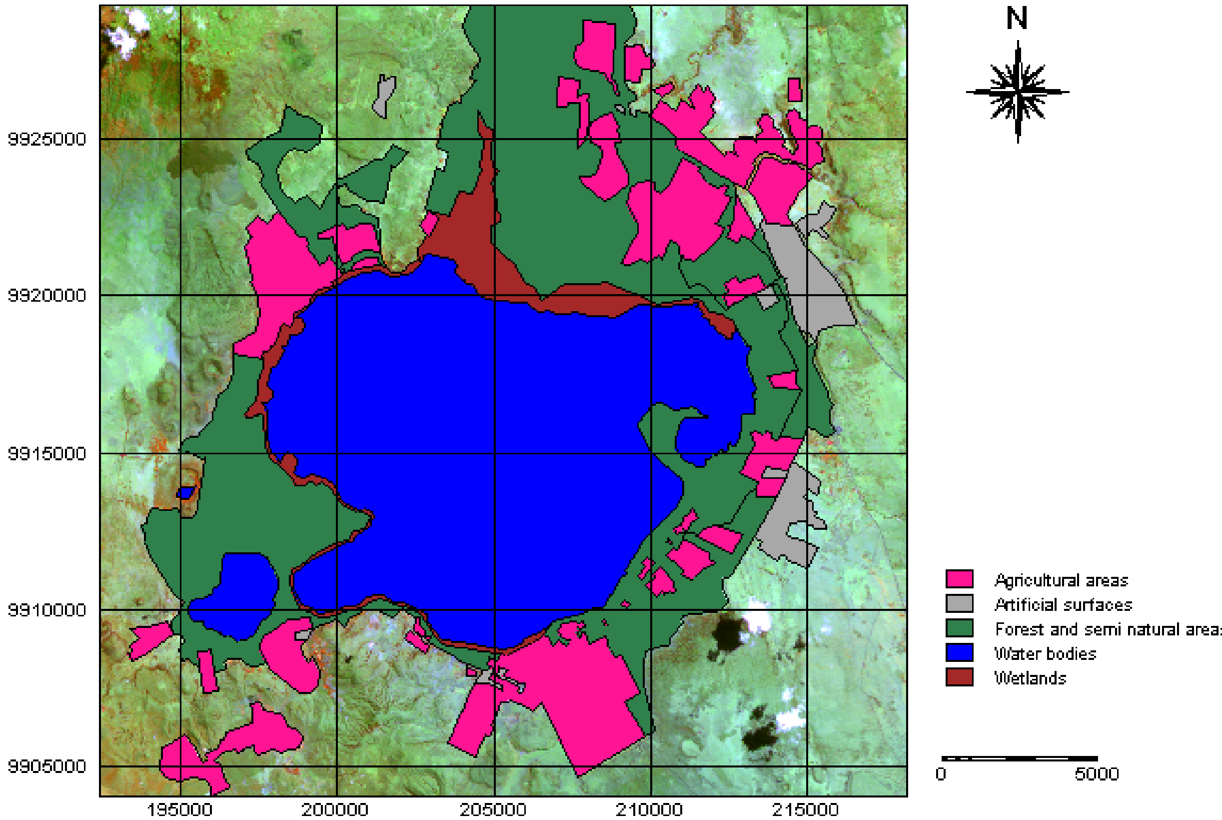


Figure 18. Landuse map around the Lake Naivasha, Kenya.

The tentative land use map was generated based on the *CORINE land cover nomenclature* (Coordination of information on the environment, European Environmental Agency) considering at level 1 which enclose five categories:

1. Artificial surfaces
2. Agricultural area
3. Forest and semi natural areas
4. Wetlands
5. Water bodies

According to the land use map around 20% of the area are under agricultural production including irrigated grasslands, vegetables, flowers, fruit plantations and cereals. Approximately 35% is covered by forest and semi natural area, including shrub and herbaceous vegetation, mixed forest and shavana.

The Figure 19 shows the total loading of 13 compounds selected on basis of frequency of use and risk (toxicity and persistence) in the Lake Naivasha area. It is important to remark that the average loads were estimated according to the cultivated areas identified in the satellite image and the GIS data analysis process using The Integrated Land and Water Information System (ILWIS). Therefore it is important to take into account that the variability of the cultivated areas and crop rotations

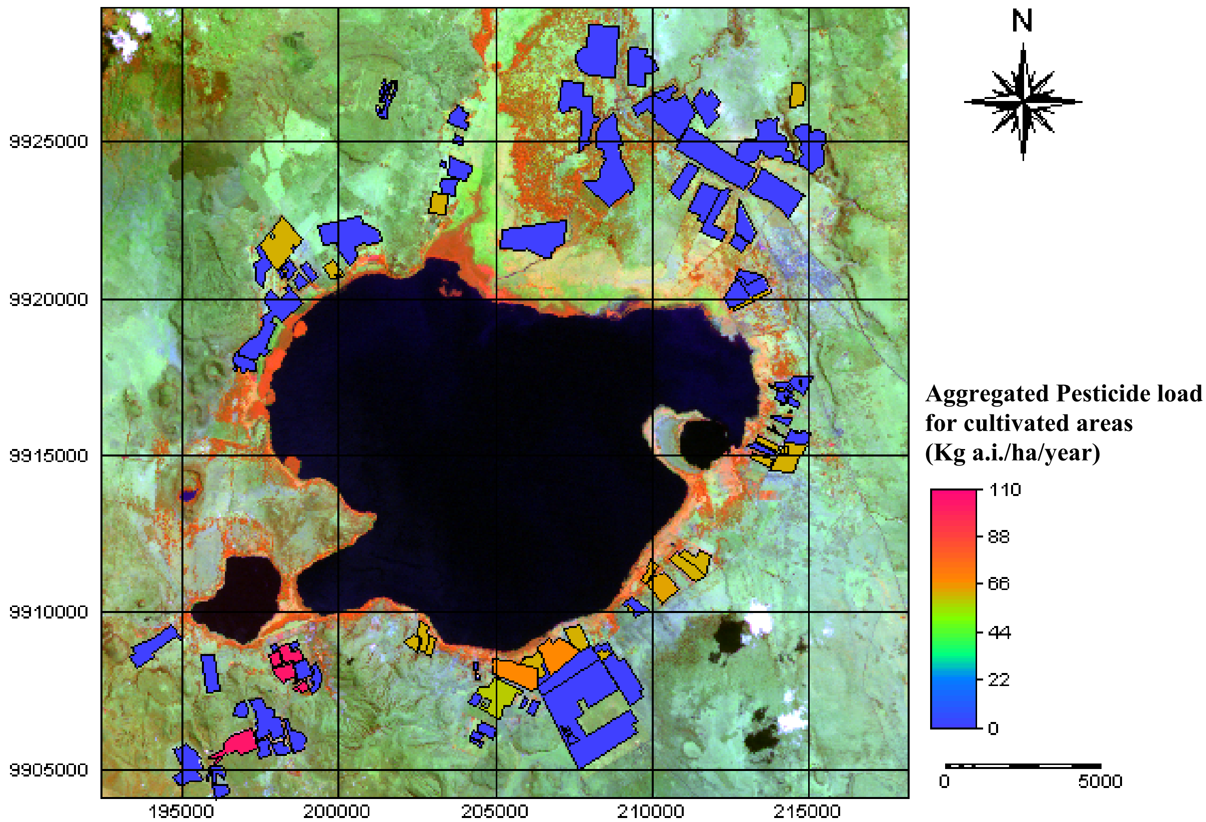


Figure 19 Spatial Distribution of annual (aggregated) loading of pesticides in kg of active ingredient (a.i.) per cultivated area around the Lake Naivasha, Kenya

The average annual loads per hectare varies from zero, valued assigned to the grasslands, to 110 kilograms of active ingredient. The amount of pesticides is directly related to the farming system area. The natural areas were considered to have not pesticides loads. Also the loads will depend on the crop type. The Figure 20 shows the loads for two groups, flowers and vegetables. An average value of 19 kilograms of active ingredient per hectare per year was estimated for cropland under vegetables and 69 kilograms of active ingredient per hectare per year for flower production. Also it was taken into account that both groups (flowers and vegetables) have different kind of species and the demands of pesticides are different for each one.

It was also possible to visualize the spatial distribution of individual compound. An example of two of these products is showed in the Figure 21. Fenamiphos used most for the flowers production and Methomyl used for both crop type (flowers and vegetables).

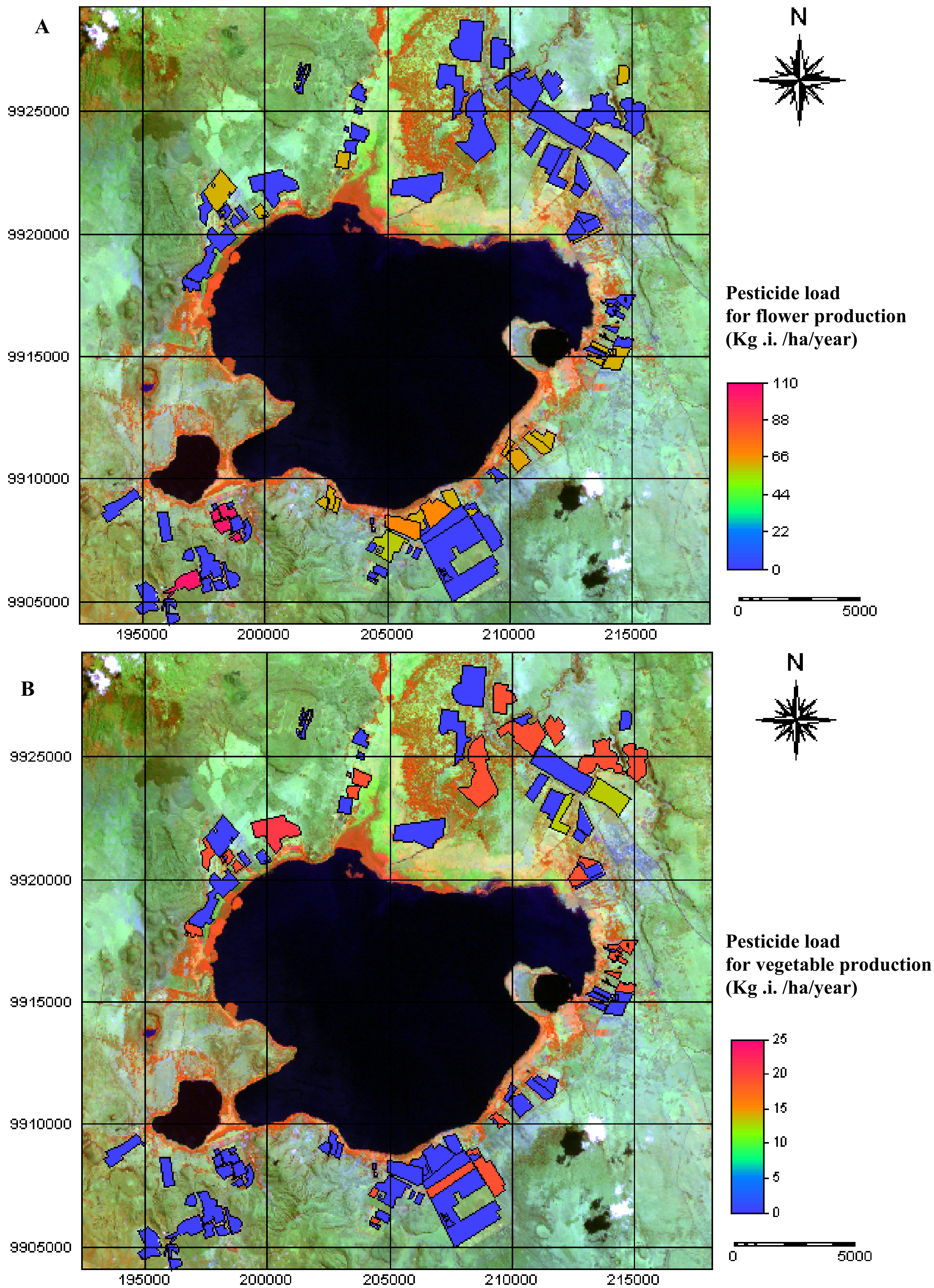


Figure 20. Spatial Distribution of annual (aggregated) loading of pesticides in kg of active ingredient (a.i.) per crop type around the Lake Naivasha, Kenya. **A** Flowers, **B** Vegetables

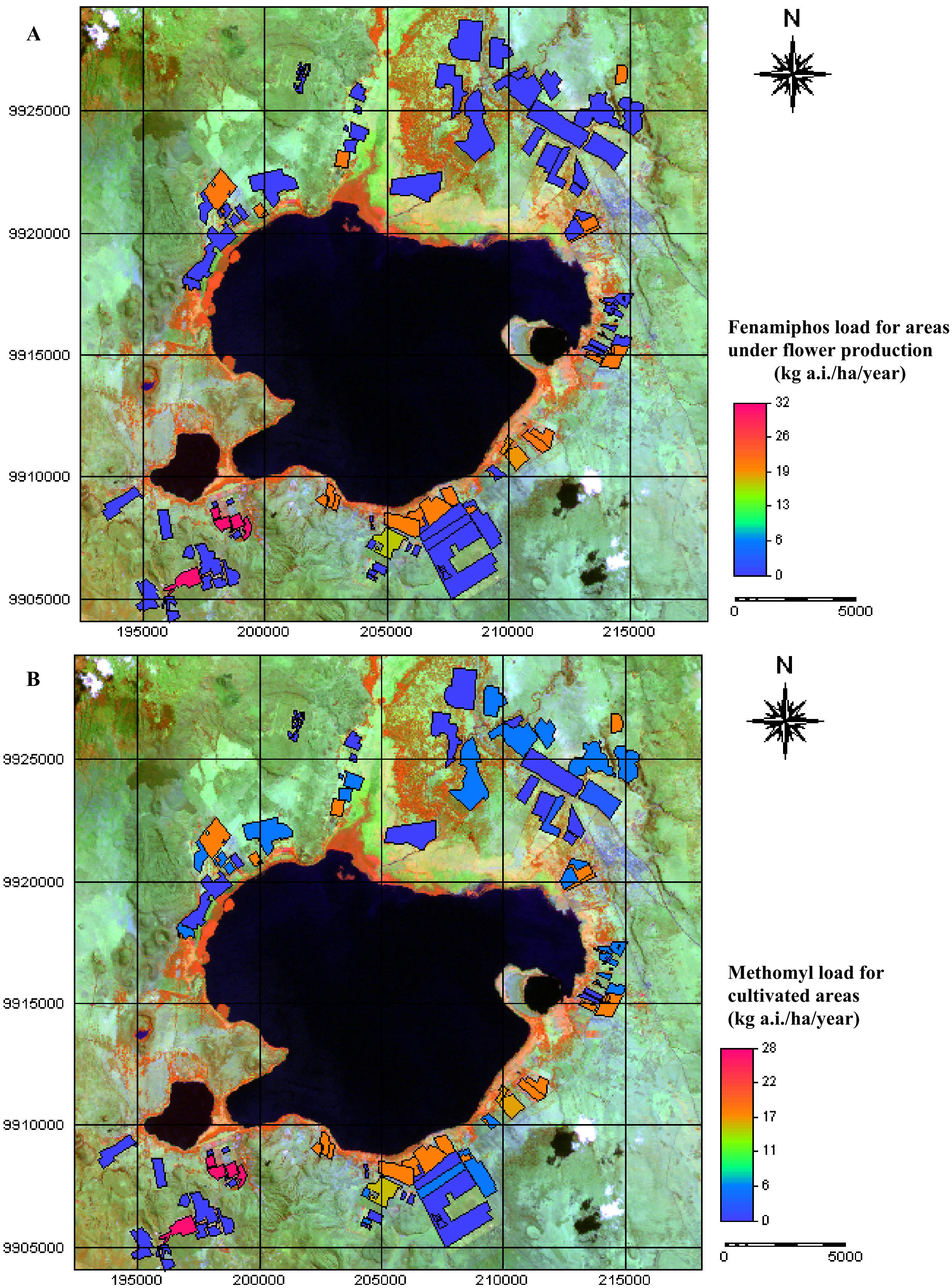


Figure 21. Spatial Distribution of annual load of Fenamiphos (**A**) and Methomyl (**B**) in kg of active ingredient (a.i.) around the Lake Naivasha, Kenya.

Chapter 5: Preliminary environmental impact assessment of pesticide use

The preliminary EIA was done using an environmental partitioning approach. The ECOPLUS program was used to assess the distribution of pesticides in the environment. A sensitivity analysis was performed to assess the response of the model to a change in the input parameters and the precision of the model output results followed by a scenario analysis.

5.1 M odeling the distribution of pesticides in the ecosystem

As it was discussed in the chapter three the ECOPLUS model assess the distribution of an organic pollutant in the environment which is divided in different compartments as the air, soil, water and biological material (Figure 7). All of these compartments are related to each other as well as the distribution of the pollutant concentrations on each one of them. The concentration of a pesticide in a compartment is related to its total load and the distribution of it is based on its affinity to a certain medium. This affinity is expressed as partitioning coefficients[1].

5.1.1 Model data requirement

The data needed to model the pesticides distribution is basically related to the ecosystem characteristics, physical properties of the pesticides and its loads in the ecosystem (explained on the chapter four). A detailed description is presented in the section below.

5.1.1.1 Naivasha ecosystem data.

In general an ecosystem has a different mediums enclose on it. The properties of these mediums determine the ecosystem characteristics. In this case the description in the table below is concerning to the study area around the lake Naivasha (Figure 22).

Table 27. Naivasha ecosystem data

Naivasha ecosystem parameters	Values/units
Naivasha ecosystem area	$6.517 * 10^8$ m^2
Height of the air column	6000 m
Area covered by water bodies	$1.337 * 10^8$ m^2 (20.5%)
Average water depth	3.4 m
Sediment thickness	7 cm
Suspended sediments	36 ppm
Organic carbon in sediments	10%
Fish concentration in the lake	0.001 ppm
Depth of the soil	9 cm
Organic carbon in the soil	2.4 %

[1] Mannaerts C., 1999. Environmental fate and risk analysis of agrochemical use; Lake Naivasha. Presentation notes. ITC, The Netherlands.

The Naivasha ecosystem data showed in the table above was obtained from image processing, existing data and survey period from 1999 to 2000. The total ecosystem area as well as the area covered by water bodies was taken from the image processing (False Color Composite FCC452, Landsat image 2000). The average water depth, the sediment thickness, and the suspended sediment values were taken from Mclean, P. 2000[2] and laboratory analysis performed by Waterschap Regge En Dinkel laboratory[3]. The data related to the soil depth and organic carbon content on it was taken from Girma A. 2000[4]. The analysis of the soil samples was performed by ISRIC laboratory, Wageningen, The Netherlands.
The height of the air column is considered to be around 6000 meters[1] and the fish concentration in the lake was taken from Ahmed, 1999.

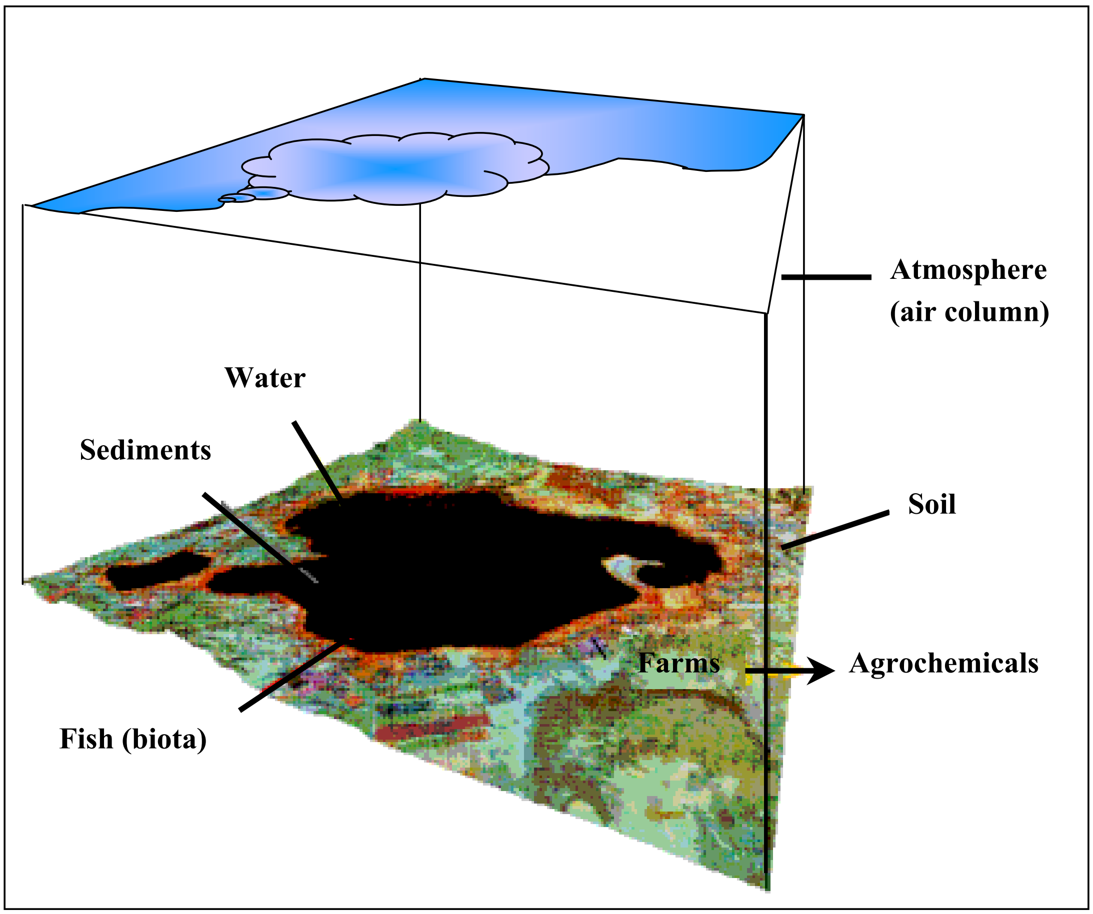


Figure 22 Three-dimensional view of the lake Naivasha ecosystem and its compartments
Source: Mannaerts, 1999

[2] Mclean P., 2001. Data collected during the fieldwork 2000. MSc student, Water management division, ITC, The Netherlands.
[3] Waterschap Regge en Dinkel laboratorium. Kooikersweg 1, 7609 PZ Almelo, Postbus 5006. 7600 GA Almelo, The Netherlands.
[4] Girma A., 2001 Data collected during the fieldwork 2000. MSc student, Soil Science division, ITC, The Netherlands.

5.1.1.2 Chemical data

Based on the data collected during the fieldwork an inventory of the pesticides use around the Lake Naivasha had been done. The criteria to choose the pesticides to model were based on the frequency of use in the different crops and the toxicity classification (I and II) according to EPA and WHO. These pesticides can be considered as a risk not only to the human health in a direct or indirect way but also to the environment due to some specific properties as a persistence, solubility and sorption coefficient. Those pesticides and its properties are showed in the table 28. This data was gathering from five different databases:

- Agrochemical Handbook; Royal society of chemistry (1991).
- The Unite State Department of Agriculture: ARS Pesticide Properties database (1999)
- The Physical Properties database (PHYSPROP): Syracuse Research Corporation (SRC) (2000).
- The extension Toxicology Network (EXTOXNET); Pesticide Information Profiles (PIPs), supported by University of California-Davis, Oregon State University, Michigan state University, Cornell University and University of Idaho
- The PAN Pesticide Database; that is a project of the Pesticide Action Network of North America (PANNA), 2000.

Table 28. Physical properties of the pesticides selected to model in the Naivasha ecosystem

Pesticides (trade name)	Active ingredient	Molecular weight (g)	Solubility (mg/l)	Melting Point(°C)	Vapor pressure (Kilo pascals)	Persistence (Days)*
Afugan	Pyrazophos	373.4	4.2	50.8	2.2E-07	19
Brigade	Bifenthrin	422.9	0.1	69.2	2.4E-08	35
Decis	Deltamethrin	505.2	0.0341	99.3	2.0E-09	7
Dimethoate	Dimethoate	229.3	25000	48.6	6.7E-07	12
Dursban	Chlorpyrifos	350.6	1.3	42.6	2.5E-06	90
Evisect	Thiocyclam	271.4	84000	126.5	5.2E-07	1
Fastac	Alpha cypermetrin	416.3	0.01	73.5	2.9E-10	76
Karate	Lambda cychalothrin	162.2	0.005	49.2	2.0E-10	56
Lannate	Methomyl	162.2	57950	78.1	6.7E-06	24
Nemacur	Fenamiphos	303.4	700	48.3	1.2E-07	61
Pride	Fluridone	329.3	11	154.5	1.3E-08	28
Thiodan	Endosulfan	406.9	0.32	96.3	2.3E-08	55
Vydate	Oxamyl	219.3	280000	101.0	3.1E-05	13

* Persistence expressed as half life (days) of the pesticides in soils

5.2. Partitioning coefficients

The pesticides properties are an important data in the estimation of the partitioning coefficients needed as an input for the model. These partitioning coefficients represent the affinity of the pesticides (distribution) to the compartments. The relationship between these distribution coefficients and the solute concentration in the ecosystem compartments is showed in the Figure 23

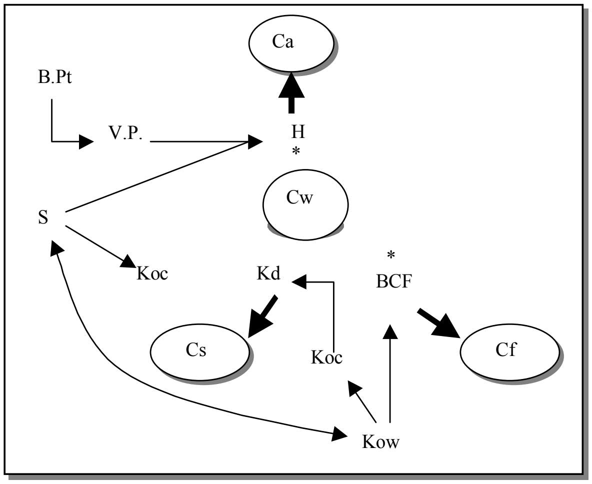


Figure 23. Distribution coefficients and their relationship to solute concentrations in the ecosystem
Source: Hounslow, 1995

The principal parameters for estimating environmental partitioning area the solubility (S) and the vapor pressure (VP). Hounslow (1995) mention that many regression equations have been proposed the relation of solubility, Kow, Koc and BCF. The vapor pressure is used to estimate the volatility of the solutes. The solubility and vapor pressure as well as the molecular weight and temperature are used to estimate the Henry's law constant (H) that is the coefficient used to estimate water/air partitioning. The high vapor pressure and low solubility will result in a high Henry's law value.

Each part of the ecosystem has a specific volume (*Va*: air, *Vw*: water, *Vs*: soil, *Vsw* sediments & water, *Vse*: sediments and *Vf*: fish) and the solute concentrations are related to that of the water. An example is given below.

Ca = H*Cw   *Cf* = BCF*Cw

Being *Ca* concentration in the air and *Cf* concentration in the fish

The mass balance of a solute ***X*** may be expressed as:

Xt = *Xa* + *Xw* + *Xs* + *Xse* + *Xf*

Where:

Xa	is the mass of X (solute) in the air = Ca*Va
Xw	is the mass of X (solute) in the water = Cw*Vw
Xs	is the mass of X (solute) in the soil = Cs*Vs
Xse	is the mass of X (solute) in the sediment = Cse*Vse
Xf	is the mass of X (solute) in the fish = Cf*Vf

5.2.1 Henry's law constant (H)

This coefficient describes the relationship of the concentration of a solute (pesticides) in water to its partial pressure, air -water distribution:

Equation 1

$$H = \frac{Concentration\ in\ air}{Concentration\ in\ water} = \frac{Ca}{Cw}$$

A large value of the Henry's law constant implies a high concentration of the pollutant in the air. The greater the Henry's law constant the better the efficiency of the procedure to remove it. Many units are used to describe the distribution constant. Some of them are given in the table 29. In the ECOPLUS program the Henry's law constant (dimensionless) is derived from the values of solubility (mg/l) and vapor pressure (mm Hg) of the compounds (Hounslow, 1995).

Table 29. Different units for Henry's law constant

a. *H* (atmos-liter/gram)	$H = \frac{P(atmos)}{Cw(g/l)}$
b. *H* (Atmos-liter/mole)	$H = \frac{P(atmos)}{Cw(mol/l)}$
c. *H* (atmos/mole fraction)	$H = \frac{P(atmos)}{Xw(molefraction)}$
d. *H* (dimensionless)	$H = \frac{Ca(mol/l)}{Cw(mol/l)}$

Dilling (1997) estimated the H constant (dimensionless) for a compound as:

Equation 2

$$H(Dimensionless) = 16.04 * \frac{Po(mm\ Hg) * M}{T(°K) * Csat(mg/l)}$$

Where:

Po is the pressure for a pure solute (*atmos*) converted to *mm Hg.*
M is the molecular weight of the solute
16.04 is factor derived from the gas constant (*R*) and the vapor pressure of mm Hg
T is temperature at vapor pressure in Kelvin degrees
C(sat) is the solubility of the solute in mg/l

5.2.2 Normalized Distribution coefficient (Koc)

This coefficient (Koc) expresses the partitioning of a solute between the water and the organic carbon (solid phase). The organic carbon content of the soil plays an important role in the adsorption (inactivation) of the pesticides. The relationship between them is proportional. Soils with a large percentage of organic carbon are more able to inactivate these compounds. As the sorbing medium is considered to be the soil organic matter (*SOM*) and it is assumed than 58% of *SOM* is organic carbon the *Koc* can be derived from *Ksom*

Equation 3

$$Koc = Kd * \frac{100}{\%oc}$$

Where *Kd* is the soil sorption constant that describe the behavior of the concentration of solute in the water with respect to the soil expressed as mg/l.

Equation 4

$$Kd = \frac{Concentration\ in\ soil\ (Cs)}{Concentration\ in\ water(Cw)}$$

Some other authors had been estimated *Koc* from solubility. These estimations were based on many solubility regression equations. In 1979 Chiou et al., obtained a relationship between the distribution coefficient and the solubility for a large number of compound. In ECOPLUS program the equation used is the one recommended by Lyman et al., (1982). As *Koc* is unitless is expressed as log form. In the equation below the unit of the solubility is mg/l. Other equations are used for other units (Hounslow, 1995).

Equation 5

$$\log koc = -0.55 * \log S + 3.64$$

5.2.3 Octanol/water partitioning coefficient (Kow)

It is also possible to estimate the *Koc* from the *octanol/water partitioning coefficient (Kow)*.
This coefficient describes the distribution of a solute between two immiscible mediums being these octanol and water. This coefficient is dimensionless and has been used to estimate the trend of the concentration of solutes on biological organisms.

Equation 6

$$kow = \frac{Concentration\ in\ octanol\ (Co)}{Concentration\ in\ water\ (Cw)}$$

Chiouet al., (1979) and Banarjee et al., (1980) correlated octanol/water partitioning (*kow*) and solubility (Table 30). Chiou and Schmedding (1980) state that most of the inaccuracy in this relationship is due to impure compounds and solvents.

Table 30. Correlation between Koc and solubility

a. $\log kow = 5.0 - 0.67 \log S(\mu mol/l)$	Chiou et al., (1979)
b. $\log kow = 5.2 - 0.68 \log S(\mu mol/l)$	Benerjee et al., (1980)
c. $\log kow = 6.5 - 0.89 \log S - 0.015 * Tm$	For solids with melting point in °C
d. $\log kow = -0.862 \log S(mol/l) + 0.710$	Chiou and Schmedding (1980)

Some authors had been studying the relationship between the adsorption of many organic chemicals and the partitioning between water and immiscible organic solvent. Many equations are being developed during 1973 and 1981 and are recommended by Lyman, (1982) to be used in the ECOPLUS program (Hounslow, 1995),(Table 31).

Table 31. Equations used in ECOPLUS program to estimate *Koc* from the octanol/water partitioning coefficient (*Kow*)

a.	$\log Koc = 0.544 * \log Kow + 1.377$	(Kenaga and Goring, 1980)
b.	$\log koc = 0.937 * \log kow - 0.006$	(Brown and Flagg, 1981)
c.	$\log koc = 1.00 * \log kow - 0.21$	(Karickhoff et al., 1979)
d.	$\log koc = 0.94 * \log kow + 0.02$	(Brown, 1979)
e.	$\log koc = 1.029 * \log kow - 0.18$	(Rao and Davidson, 1980)
f.	$\log koc = 0.524 * \log kow + 0.855$	(Briggs, 1973)

5.2.4 Bioconcentration Factor (BCF)

The bioconcentration factor is a relationship that describes the partitioning of a compound between the water and the fatty tissue of a living organism as fish or other foods. The bioconcentration factor is directly proportional to the *Kow* coefficient. The higher the *BCF* or *Kow* the more likely a toxic chemical is concentrated in an organism. Kenega and Goring (1980) calculated the relationships in terms of log *BCF* and log *Kow.*

Equation 7

$$BCF = \frac{Concentration\ in\ Fish\ (Cf)}{Concentration\ in\ water\ (Cw)}$$

Equation 8

$$Log\ BCF = 0.935 * \log Kow - 1.495$$

5.2.3 Estimation of the partitioning coefficients

The estimation of the coefficients has been done for those pesticides that were selected to use for the ECOPLUS program. The detail physical properties to perform the calculations are presented in the appendix 3. The table below shows only the final results.

Table 32. Estimation of partitioning coefficients for the pesticides to use in the ECOPLUS program

Pesticides (trade name)	**Active ingredient**	***H***	***Log Kow***	***Log Koc***	***Log BCF***
Afugan	Pyrazophos	8.026E-06	3.8	3.64	2.06
Brigade	Bifenthrin	4.095E-05	6.0	4.73	4.12
Decis	Deltamethrin	1.197E-05	5.4	4.86	3.56
Dimethoate	Dimethoate	2.160E-09	1.8	1.56	0.20
Dursban	Chlorpyrifos	2.742E-04	4.8	4.02	3.03
Evisect	Thiocyclam	6.928E-09	-0.1	1.5	-1.56
Fastac	Alpha cypermetrin	4.954E-06	6.6	5.27	4.68
Karate	Lambdacychalothrin	7.385E-06	7.0	5.48	5.05
Lannate	Methomyl	7.511E-09	0.6	1.18	-0.95
Nemacur	Fenamiphos	2.134E-08	3.2	2.54	1.53
Pride	Fluridone	1.570E-07	1.9	3.12	0.25
Thiodan	Endosulfan	1.180E-05	3.7	4.12	1.97
Vydate	Oxamyl	9.799E-09	-0.5	0.74	-1.93

5.3 Sensitivity Analysis

The sensitivity is a measure of the impact of change in one input parameter on an output result. Then, the purpose of the sensitivity analysis is to assess the response of the model to a change in the input parameters. Also is done to reduce the overall uncertainly in the model results, as well as to identify which parameters require less or more precision. To perform a sensitivity analysis some steps has to be followed[5]

- *Gathering of input parameters*: identification of the data set (estimations based on the literature or existing data or experimental data)
- *Sensitivity analysis performed* by changing one parameter at a time that the rest of them are keeping constant. The change of the parameter can be done in a range bases (increasing and decreasing a percent of the base set value)
- *Examination of the outputs:* response of the model to the change in the input. These results can be presented making use of ranking descriptors or making use of a graphical representation of the outputs versus the inputs.

The output of the ECOPLUS model is given for three phases, the first one is for the full ecosystem, the second one is for the terrestrial partitioning and the third one for the pond partitioning. To perform the sensitivity analysis the set of base input parameters were ranged on 25 and 50 percent. (Increased and decreased). The variation on the input over the output is defined by the equation below.

Equation 9

$$S_{ij} = \frac{\partial y_i}{\partial x_j}$$

Where: ***i*** is the index for the model dependent variable (*model output*)

j is the index for the *model input* parameter

[5] Mannaerts C., 2001. Sensitivity Analysis Discussion and Demonstration. ITC, The Netherlands. (paper notes)

The main output of the model is the concentration of the chemical compound in the different compartments of the ecosystem. Another output of the model are: the total volume of each compartment and a its percentage in the total ecosystem and the percentile distribution of the chemical compound (solutes) on every one on them are another output. To perform the sensitivity analysis the outputs (concentration of chemical compound in each compartment: air, water, soil, sediment and fish) of the full ecosystem partitioning were explored. Chlorpyrifos and Fenamiphos, both compounds belonging to the organophosphate chemical family were selected under the persistence and toxicity criteria. The annual load of Chlorpyriphos was estimated on 4949 kg of active ingredient. The same amount was used for fenamiphos. The distribution of the solute on the compartments was slightly influenced by the changes on the input parameters on both cases. An average value was computed. In Both cases most of the solute (%) was deposited on the soil/sediment compartment. The percentile distribution on the air and the water/water-sediments compartments varies for each compound (Figure 24). It is important to notice that the distribution of the solute is influenced by the physical properties of each pesticide.

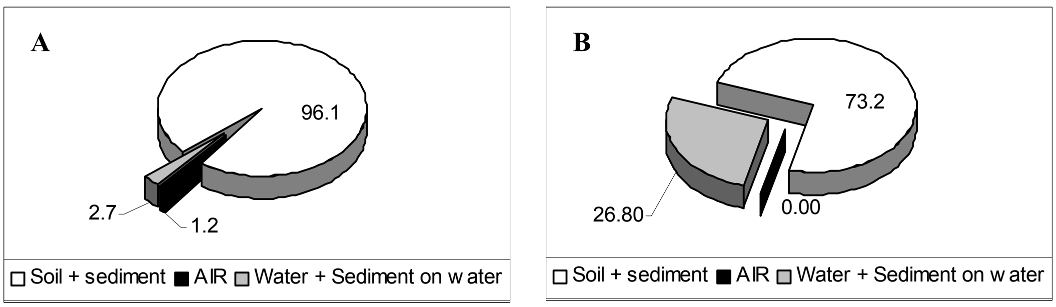


Figure 24 Percentile distribution of chemical in the Naivasha Ecosystem.
A: Chorpyrifos **B**: Fenamiphos

An example of the results of the sensitivity analysis is showed in the table below. In this example the organic carbon in the sediment was the parameter changed keeping the rest of parameters fixed. The effect was examined on the concentration of Chlorpyrifos in the fish tissue. The percentile difference between the base input value and the estimated values were computed using the equation below.

Equation 10

$$\%\,of\ change = \frac{|\,output(base\,input) - (output(ranged\,input)\,|}{output\ (base\,input) * 100}$$

Table 33. Effect of the variation of the content of organic carbon in sediment over the concentration of Chlorpyrifos on the fish tissue

	Ranged Input Parameter				
Organic carbon in sediments (%)	-50%	-25%	**Base input value**	+25%	+50%
	8.5	12.75	**17**	21.25	25.5

	Output variation				
Concentration of Chlorpyrifos in the fish tissue (ppm)	0.178	0.146	**0.125**	0.107	0.095
Percentage of change based on the base input parameter	42.5	17.1		13.0	23.6

For convenience of computing the sensitivity coefficients of varying parameters and dependent variables a normalized form of the sensitivity coefficients (relative sensitivity) is utilized using the equation below the value obtained is dimensionless.

Equation 11

$$S_{i,j}^{\,r} = \frac{\partial y_i}{\partial x_j}\frac{x_i}{y_i} \approx \frac{\Delta y_i}{\Delta x_j}\frac{x_i}{y_i}$$

Where:

$S_{i,j}^{\,r}$ is the relative sensibility of the dependent variable y_i with respect to independent input parameter x_j and

Δy_i is the change of y_i due to a change (Δx_j) in x_j.

Following the previous examples the effect of the variation of the percentage of organic carbon in the sediments was plotted against the concentration of Chlorpyrifos and Fenamiphos in the fish tissue (Figure 25 and 26)

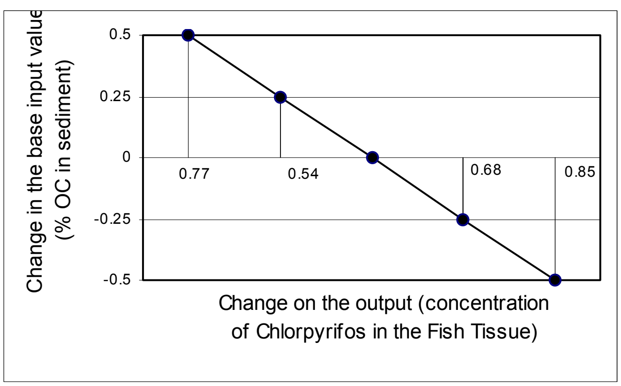


Figure 25 Relative sensitivity of the organic carbon in sediment over the concentration Chlorpyriphos in the fish tissue.

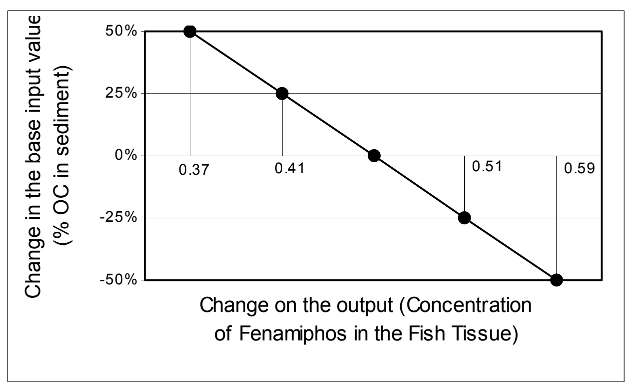
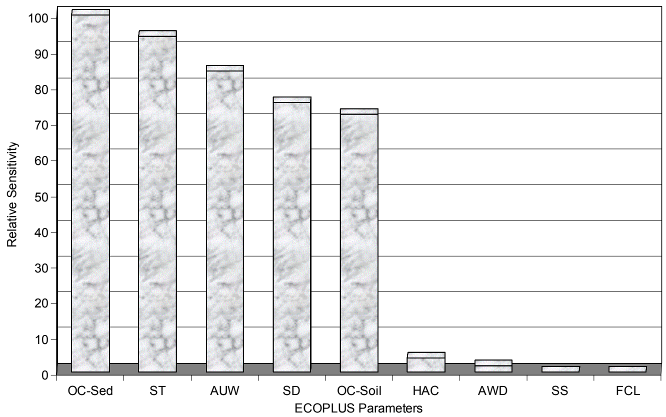
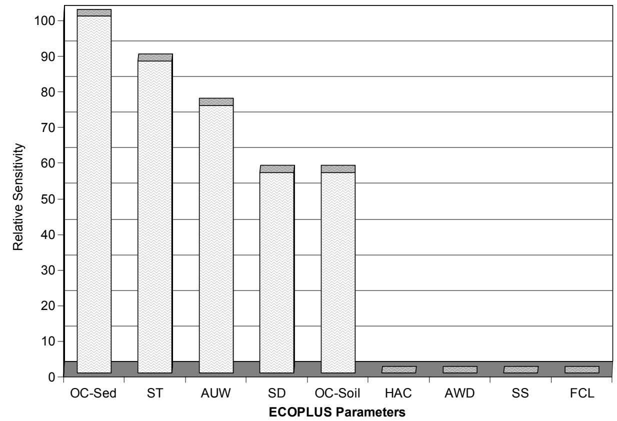


Figure 26. Relative sensitivity of the organic carbon in sediments over the concentration of Fenamiphos in the fish tissue.

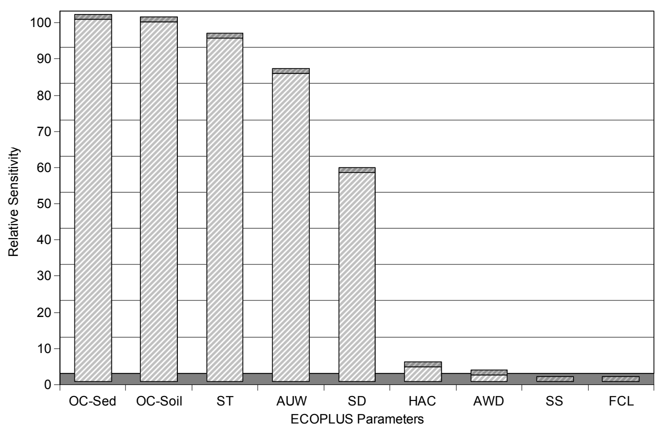
The results of the relative sensibility are presented for each compartment of the ecosystem. In this case the parameters most significantly affecting the concentration of Chlorpyrifos in all the compartments in descendent order were:
Organic carbon in sediments (OC-Sed), sediment thickness (ST), area under water (AUW), organic carbon in soil (OC-soil), Soil depth (SD), height of the air column (HAC), average water depth (AWD), suspended solids (SS) and fish concentration in the lake (FCL). A relative ranking of the sensitivity of the tested parameters assigning a value of hundred to the most effected parameter OC-Sed is showed in the figure 27. In the case of Fenamiphos the most significantly parameters affecting the concentration of this solute in all compartments in descendent order were:
Area under water (AUW), organic carbon in sediments (OC-Sed), sediment thickness (ST), organic carbon in soil (OC-soil), Soil depth (SD), average water depth (AWD), suspended solids (SS), height of the air column (HAC) and fish concentration in the lake (FCL). A relative ranking of the sensitivity of the tested parameters assigning a value of hundred to the most effected parameter AUW is showed in the figure 28. It is clear than in both cases the parameters most significantly affecting the outputs of the model area the organic carbon in the sediments (OC-Sed), sediment thickness (ST) and the area under water (AUW).
It is important to remark that these results are particularly refereed to these two compounds in the Naivasha ecosystem. These compounds have different physical properties and consequently different distribution coefficients Also it is necessary to take into account that the annual load of the active ingredient has a direct effect on the concentration found it in the environment.



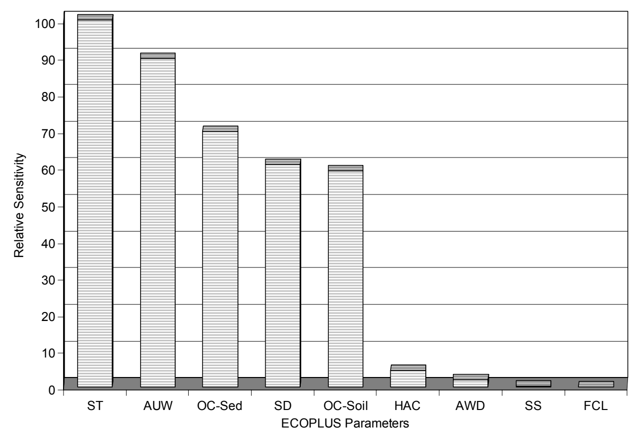
Relative Sensitivity of ECOPLUS Input Parameters
(**Concentration of Chlorpyrifos in the AIR**)



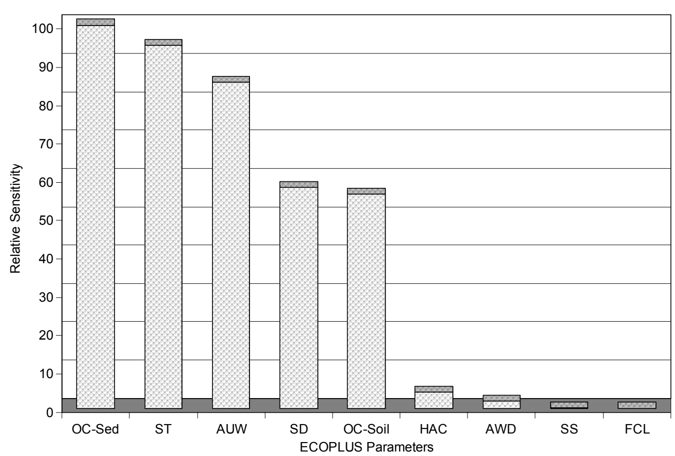
Relative Sensitivity of ECOPLUS Input Parameters
(**Concentration of Chlorpyrifos in the WATER)**



Relative Sensitivity of ECOPLUS Input Parameters
(**Concentration of Chlorpyrifos in the SOIL)**



Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Chlorpyrifos in the SEDIMENT**)

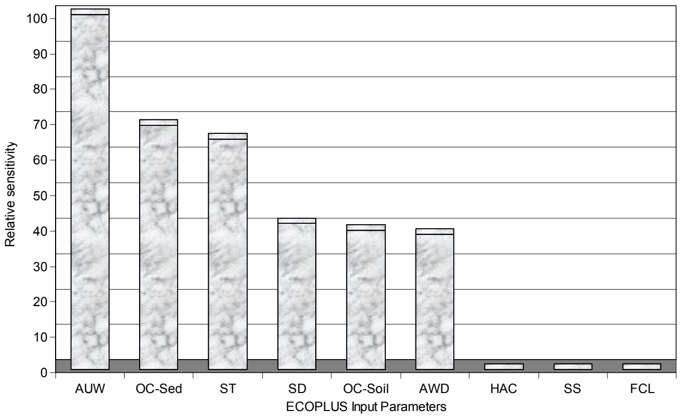


Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Chlorpyrifos in the FISH TISSUE**)

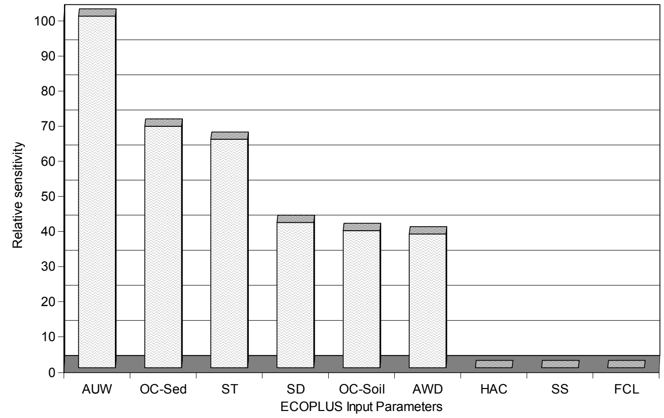
Legend:

ST	Sediment Thickness
OC-Sed	% organic carbon in the sediments
AUW	% of area under water
SD	Soil Depth
OC-Soil	%organic carbon in the soil
HAC	Height of the air column
AWD	Average water depth
SS	Suspended solids
FCL	Fish Concentration in the lake

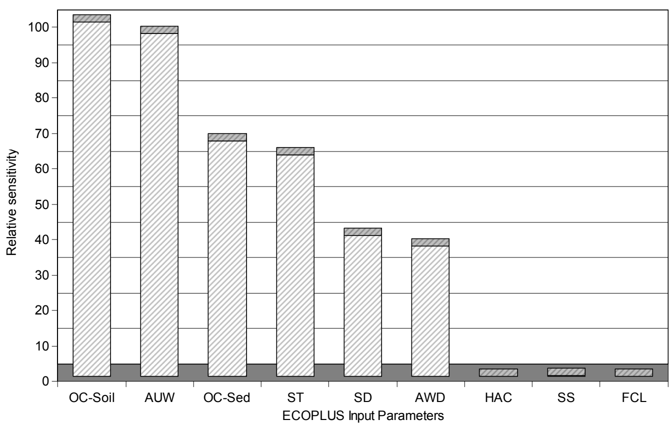
Figure 27. Relative Sensitivity of ECOPLUS Input Parameters in the five compartments of the Naivasha Ecosystem, using the quantified annual load of Chlorpyrifos



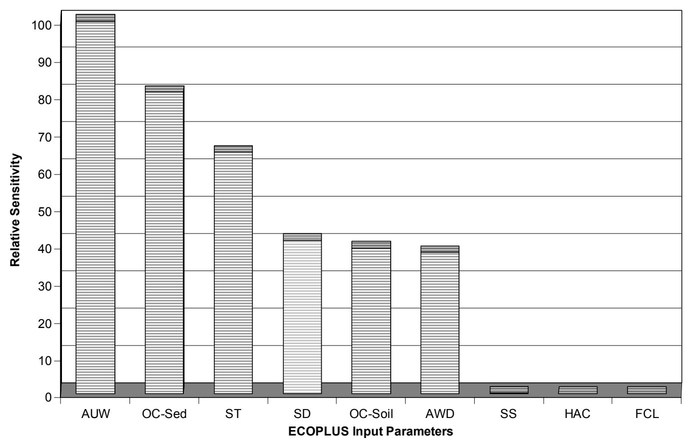
Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Fenamiphos in the AIR)**



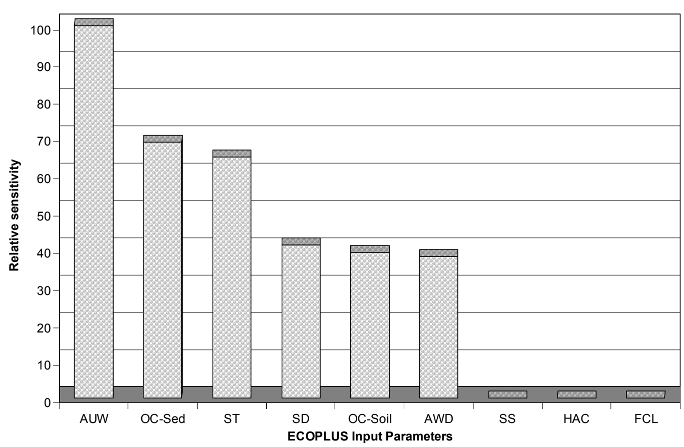
Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Fenamiphos in the WATER)**



Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Fenamiphos in the SOIL**



Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Fenamiphos in the SEDIMENTS)**



Relative sensitivity of ECOPLUS Input Parameters
(**Concentration of Fenamiphos in the FISH)**

Legend:

ST	Sediment Thickness
OC-Sed	% organic carbon in the sediments
AUW	% of area under water
SD	Soil Depth
OC-Soil	%organic carbon in the soil
HAC	Height of the air column
AWD	Average water depth
SS	Suspended solids
FCL	Fish Concentration in the lake

Figure 28. Relative Sensitivity of ECOPLUS Input Parameters in the five compartments of the Naivasha Ecosystem, using the quantified annual load of Fenamiphos

5.4 Model Results Analysis

The model was run for each of the 13 pesticides selected under the toxicity criteria. The outputs concerning to the partitioning of each compound in the full ecosystem are shows in the table below and also detailed on Appendix 4. In the figure 29 it is possible to visualize that the highest pesticide's concentrations were find in the sediments and fish compartments.

Table 34. Partitioning of the pesticides in the compartments of the Naivasha ecosystem obtained from the ECOPLUS program.

Active Ingredient	Concentration of Solute (ppb)					
	AIR	WATER	SOIL	SEDIMENTS	FISH	Total
Pyrazophos	1.58.E-07	0.02	2.1	8.6	2.3	12.9
Bifenthrin	6.83.E-08	0.00	2.2	9.0	21.8	32.9
Deltamethrin	1.55.E-08	0.00	2.3	9.4	4.7	16.3
Dimethoate	4.20.E-08	19.44	16.9	70.5	30.3	137.1
Chlorpyrifos	3.32.E-05	0.12	30.4	126.7	124.7	281.9
Thiocyclam OH	1.17.E-08	1.71	1.3	5.4	0.1	8.4
Alpha cypermetrin	8.79.E-09	0.00	7.9	33.1	84.9	125.9
Lambdacychalothrin	1.00.E-08	0.00	9.8	40.8	153.1	203.7
Methomyl	1.69.E-07	22.44	8.2	34.2	2.6	67.4
Fenamiphos	1.09.E-07	5.16	42.5	177.1	169.3	394.1
Fluridone	5.21.E-08	0.33	10.5	44.0	0.6	55.5
Endosulfan	9.18.E-07	0.08	24.7	103.1	7.2	135.2
Oxamyl	2.30.E-07	23.49	3.1	12.8	0.3	39.7
Total	3.50.E-05	72.8	162	675	601.6	1510.8

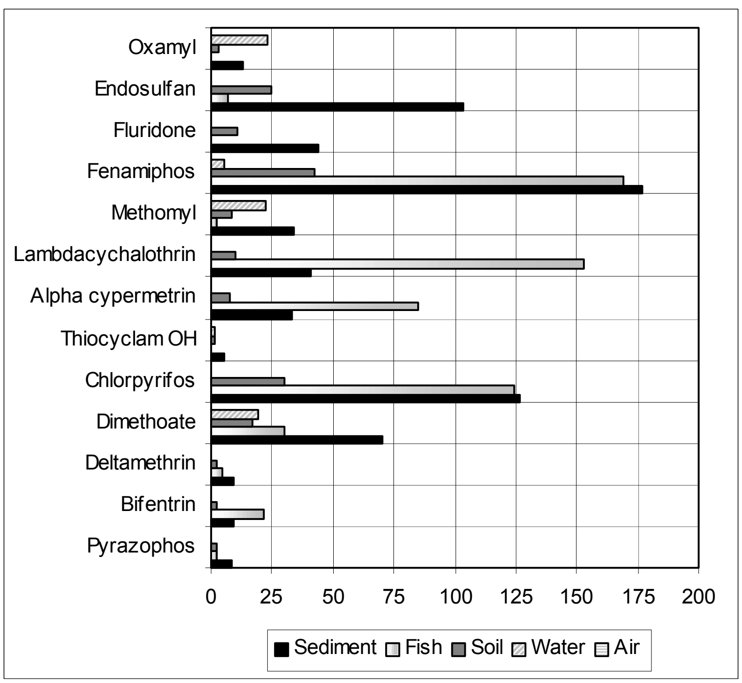


Figure 29. Concentration of pesticides (ppb) in the Naivasha Ecosystem compartments.

The total amount of pesticides in the Naivasha environment was estimated by adding the set of concentration values generated by the ECOPLUS program

Equation 12

$$TCP\_FE = \sum_{i=1}^{i=5} Xij$$

Where:
TCP_FE is the total concentration of a specific pesticide in the full ecosystem
i is each of the compartments
j is each an specific pesticide

Equation 13

$$TCP\ in\ C = \sum_{i=1}^{i=13} [X_{ij}]$$

Where:
TCP in C is the total concentration of all the set of pesticide in a specific compartment
i is each of the pesticides
j is an specific compartment

5.4.1 Correlation Analysis

A correlation analysis was performed to explore the relationship between the input variables and the concentration of pesticides in the five compartments, outputs, (Table 35). The previous step to the analysis was to standardize all the values transforming them to 0 - 1 ratio scale. The method of the maximum raw score was applied. The results of the standardized values are showed in the table 36.

Equation 14

$$Stardard\ value(i) = \frac{Raw\ value\ (i)}{maximum\ \ raw\ value}$$

The PEARSON correlation coefficient (r), was calculated. This value is dimensionless and it is ranging from -1 to 1. This coefficient reflects the linear relationship between the two data sets.

Equation 15

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

Table 35. Set of variables (input parameters and model outputs) before standardization

	Input Parameters						*Concentrations (ppm)*				
Pesticide	**Annual load (g)**	**Solubility (mg/l)**	**Log kow**	**Log koc**	**Henry's Law (H)**	**Log BCF**	**Air**	**Water**	**Soil**	**Sediments**	**Fish**
Pyrazophos	330	4.2	3.8	3.64	8E-06	2.06	1.6E-10	2.0E-05	0.002	0.01	0.00
Bifentrin	336	0.1	6	4.73	4.1E-05	4.12	6.8E-11	0.0E+00	0.002	0.01	0.02
Deltamethrin	351	0.034	5.41	4.86	1.2E-05	3.56	1.6E-11	0.0E+00	0.002	0.01	0.00
Dimethoate	11691	28700	1.81	1.56	2.2E-09	0.20	4.2E-11	1.9E-02	0.017	0.07	0.03
Chlorpyrifos	4920	1.3	4.84	4.02	2.7E-04	3.03	3.3E-08	1.2E-04	0.030	0.13	0.12
Thiocyclam OH	996	8400	-0.07	1.5	6.9E-09	-1.56	1.2E-11	1.7E-03	0.001	0.01	0.00
Alpha cypermetrin	1236	0.0	6.60	5.27	5E-06	4.68	8.8E-12	0.0E+00	0.008	0.03	0.08
Lambda cychalothrin	1525	0.0	7	5.48	7.4E-06	5.05	1.0E-11	0.0E+00	0.010	0.04	0.15
Methomyl	11730	57950	0.59	1.18	7.5E-09	-0.95	1.7E-10	2.2E-02	0.008	0.03	0.00
Fenamiphos	1798	700.0	3.24	2.54	2.1E-08	1.53	1.1E-10	5.2E-03	0.042	0.18	0.17
Fluridone	9024	11.0	1.87	3.12	1.6E-07	0.25	5.2E-11	3.3E-04	0.011	0.04	0.00
Endosulfan	3892	0.320	3.71	4.12	1.2E-05	1.97	9.2E-10	8.0E-05	0.025	0.10	0.01
Oxamyl	11425	280000	-0.46	0.74	9.8E-09	-1.93	2.3E-10	2.3E-02	0.003	0.01	0.00
Maximum	***11729***	***280000***	***7***	***5.48***	***2.74E-04***	***5.05***	***3.32E-08***	***2.35E-02***	***0.042***	***0.18***	***0.17***

Table 36. Set of variables transformed to 0 - 1 ratio scale (standardization)

	Input Parameters (unitless)						*Concentrations (unitless)*				
Pesticide	**Annual load**	**Solubility**	**Log kow**	**Log Koc**	**Henry's Law (H)**	**BCF**	**Air**	**Water**	**Soil**	**Sediment**	**Fish**
Pyrazophos	0.03	0.00	0.54	0.66	0.03	0.41	0.00	0.00	0.05	0.05	0.01
Bifentrin	0.03	0.00	0.86	0.86	0.15	0.81	0.00	0.00	0.05	0.05	0.13
Deltamethrin	0.03	0.00	0.77	0.89	0.04	0.71	0.00	0.00	0.05	0.05	0.03
Dimethoate	1.00	0.10	0.26	0.28	0.00	0.04	0.00	0.83	0.40	0.40	0.18
Chlorpyrifos	0.42	0.00	0.69	0.73	1.00	0.60	1.00	0.01	0.72	0.72	0.74
Thiocyclam OH	0.08	0.03	-0.01	0.27	0.00	-0.31	0.00	0.07	0.03	0.03	0.00
Alpha cypermetrin	0.11	0.00	0.94	0.96	0.02	0.93	0.00	0.00	0.19	0.19	0.50
Lambda cychalothrin	0.13	0.00	1.00	1.00	0.03	1.00	0.00	0.00	0.23	0.23	0.90
Methomyl	1.00	0.21	0.08	0.22	0.00	-0.19	0.01	0.96	0.19	0.19	0.02
Fenamiphos	0.15	0.00	0.46	0.46	0.00	0.30	0.00	0.22	1.00	1.00	1.00
Fluridone	0.77	0.00	0.27	0.57	0.00	0.05	0.00	0.01	0.25	0.25	0.00
Endosulfan	0.33	0.00	0.53	0.75	0.04	0.39	0.03	0.00	0.58	0.58	0.04
Oxamyl	0.97	1.00	-0.07	0.14	0.00	-0.38	0.01	1.00	0.07	0.07	0.00

The results of the correlation analysis are showed in the table below. Very low concentrations were found in the air compartment. Maximum Concentration Limits are not available for these specific compounds. The concentration of Chlorpyrifos was the higher found in the air. This result may be explained by the strong correlation (0.99) between the henry's law coefficient (H) and the concentrations in the Air (Table 37). Within the set of pesticides Chlorpyrifos has the highest H value. The concentrations found in the water are very low, having the high values Dimethoate, Methomyl and Oxamyl. The high solubility of these pesticides as well as the high load of its active ingredient may explain this result. The correlation analysis show a high correlation between the concentration of pesticides found in the water and the solubility and annual load, 0.84 and 0.73, respectively. The concentrations found in the fish tissue are correlated to the Logkow and Bioconcentration factor. There is a poor correlation between the distribution coefficient (Log Koc) and the concentrations found in the soil. According to Harris (1964) in most of the soils the adsorption of insecticides is proportional in the organic content of the soil. Stevenson (1976) stated that the mechanisms of pesticides-organic matter interactions would remain obscure until more is known about the nature of chemical composition of the organic fraction of soil. The soil is a very complex system and considerable variations may occur from one area to another one.

Table 37. Correlation between the distribution coefficients and the concentrations of the pesticides in the compartments of the ecosystem.

Criteria	Air	Water	Soil and Sediment	Fish
Pesticide load	0.03	***0.84***	0.05	-0.30
Solubility	-0.11	***0.73***	-0.24	-0.27
H	***0.99***	-0.23	***0.38***	***0.35***
Log koc	0.13	-0.80	-0.01	***0.36***
Log kow and Log BCF	0.17	-0.68	0.08	***0.51***

5.5 Scenario Analysis

To perform the impact scenario analysis two pesticides were selected according to its concentrations found them in the Naivasha environment compartments. Those pesticides are Fenamiphos and Chlorpyrifos. The impact of the estimated concentrations was assessed according to the criteria the Acceptable Daily Intake (ADI) and the Maximum Residue Limit (MRL) and the Median Lethal Concentration (LC50).

- **Maximum Residue Limit (MRL)**

"MCL" is the maximum contaminant level of a pesticide residue (expressed in different units as ppm, ppb, mg/l, ug/l) recommended by the Environmental Protection Agency (EPA) to be legally permitted in the water, air, sediments and soil. These values has to be without appreciable risk to the environment and consequently to the human.

- **LC50 (Median lethal Concentration)**

The LC50 is the concentration (i.e. ppm) of a toxicant that will cause death in 50% of the exposed animals over a specific exposure and observation period. This test is generally used when the route of exposure is inhalation, but also for aquatic toxicity testing (when the exposure route is water (EPA, 2000).

- **Acceptable Daily Intake (ADI)**

"ADI" of a chemical is the daily intake which, during an entire lifetime, appears to be without appreciable risk to the health of the consumer on the basis of all the known facts at the time of the evaluation of the chemical. It is expressed in milligrams of the pesticides residues per kilogram of body weight. (FAO, 2000)

5.5.1 BAU "Busines as Usual" Scenario

In this scenario the analysis was done for the current estimated pesticides load on the Lake Naivasha area for chlorpyrifos and Fenamiphos.

- **Chlorpyrifos**

The concentration of Chlorpyrifos in the water was **0.00012 mg/l**. This value is lowest than the LD50 (96 hours) for rainbow trout that is **0.003 mg/l** and also the LC50 (24 hours) for goldfish that is **0.18 mg/l**. Nevertheless the concentration found it in the sediment was **0.1267 mg/l** this value exceed the LC50 for rainbow trout in 42 times higher.

The Acceptable Daily Intake (**ADI**) is **0.01 mg/kg/day.** The concentration of chlorpyrifos found it in the fish tissue was **0.1246 mg/l** this value is 12.5 times higher than the ADI value. This may be a risk in the long term to the human exposed to consume this fish as a part of the basic alimentation.

- **Fenamiphos**

The concentration of Fenamiphos in the water was **0.00516 mg/l**. This value is lowest than the LD50 (96 hours) for bluegill sunfish that is **0.0096 mg/l** and also the LC50 (96 hours) for rainbow trout that is **0.11 mg/l** and the LC50 for goldfish (**3.2 mg/l**). Nevertheless the concentration found it in the sediment was **0.17714 mg/l** this value exceed the LC50 for rainbow trout in 1.61 times as well as the LC50 for bluegill sunfish in 18.5 times.

The Acceptable Daily Intake (**ADI**) is **0.005 mg/kg/day.** The concentration of chlorpyrifos found it in the fish tissue was **0.1693 mg/l** this value is 33.8 times higher than the ADI value. This may be a risk in the long term to the human exposed to consume this fish as a part of the basic alimentation.

5.5.2 Pesticides Load Reduction Scenario

This Scenario was done to estimate how the concentration in the fish and sediments varies with the reduction of the annual pesticides load.

- **Chlorpyrifos**

To reduce the concentration of Chlorpyrifos found in the fish tissue to the accepted levels**, 0.01 mg/kg/day** the annual load had been modified. The ***BAU*** annual load (4919.88 kg a.i.) was reduced from 25% up to 92%. The results obtained from the ECOPLUS program are showed in the figure below.

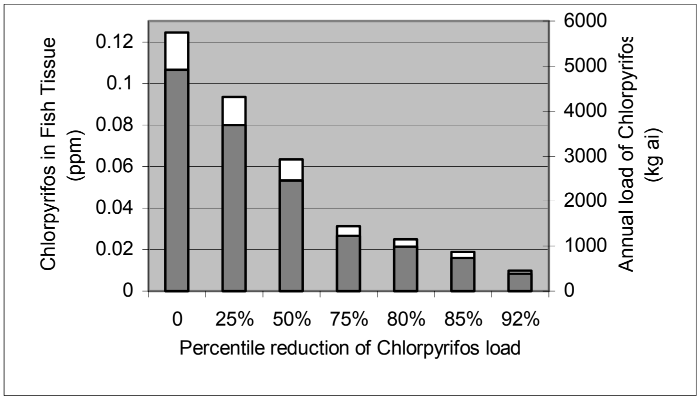


Figure 30. Reduction of annual load of chlorpyrifos and the impact of its bioacumulation in the fish tissue

As it is possible to observe in the figure above, to reduce the concentration of chlorpyrifos in the fish from ***0.1246 to 0.01*** the annual load has to be reduced in 92%. This can be explained by the high BCF value that is around 3.5 as well as the concentration found it in the sediment. The figure below shows the depletion of the concentration of Chlorpyrifos in the sediments. To deplete to the LC50 for rainbow trout the load had been reduced up to 98%. This may be due to chlorpyrifos adheres to the sediments and suspended organic matter.

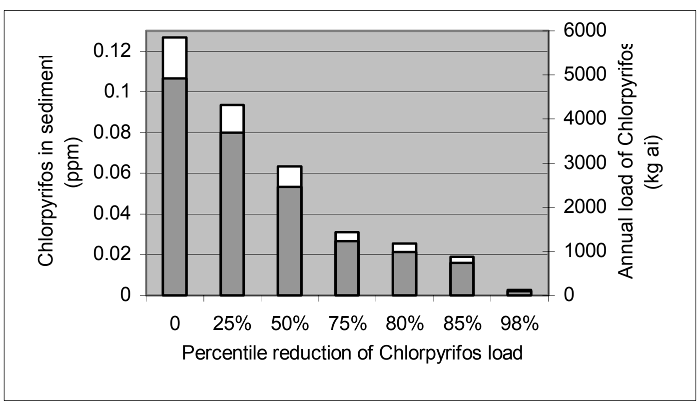


Figure 31. Reduction of annual load of chlorpyrifos and the impact of its concentration in the sediment

As it was mentioned before Chlorpyrifos is and insecticide tightly absorbed by soil, then it is not expected to leach significantly and its soil persistence can vary greatly according to the soil type. A general soil persistence of 60 to 120 days had been reported. If is released to water chlorpyrifos partitions significantly from the water to the column of sediments, the measured hydrolysis half-life at 25 degrees at neutral conditions is around 35-78 days.

The photolysis half-life in the US during the mid summer at the water surface measured is around 3 to 4 weeks at surface water conditions, but decreases significantly with increased water depth. Photolysis is not expected to be a significant removal mechanism. Its BCF value around 3 indicates potential significant bioconcentration. The half-life in sediment-water studies ranged from 1.2 to 34 days.

Laboratory experiments have indicated that volatilization from soil surfaces under field conditions is expected to contribute to its loss from the soil and probably the primary route of loss from water. Volatility half-life of 3.5 and 20 days had been estimated for pond water. Concentration of Chlorpyrifos in water will depend on the type of formulation and rapidly declines due to its adheres to sediments and suspended organic matter. Research suggests that is unstable in water.
Chlorpyrifos may be toxic to some plants as lettuce. Residues remain on plant surfaces for approximately 10 to 14 days. Data indicate that this insecticide and its soil metabolites can accumulate in certain crops.

- **Fenamiphos**

As it was done for chlorpyrifos the ***BAU*** annual load (9024 kg a.i.) was reduced from 25% up to 97% to reduce the concentrations of Fenamiphos found in the fish tissue to the ADI level 0.005 mg. The result of the ECOPLUS program is showed in the figure below.

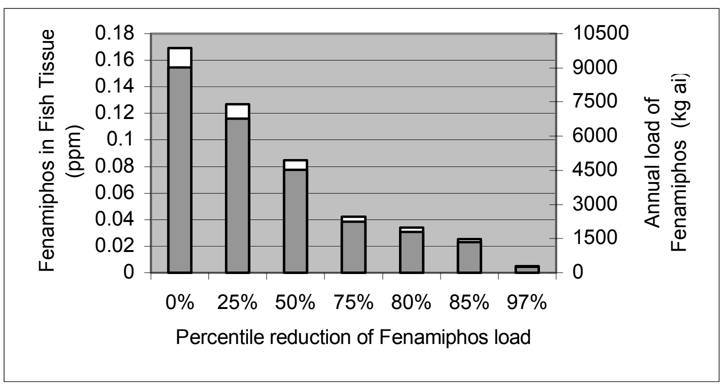


Figure 32. Reduction of annual load of Fenamiphos and the impact of its bioacumulation in the fish tissue

As it is possible to observe in the figure to reduce the concentration of Fenamiphos in the fish from ***0.1693 to 0.005*** the annual load has to be reduced in 98%. This may be explained by the high value of the partitioning coefficient (Logkow) that is around 3.2, this lead to a high concentration of the solute on the biological organism. Also the ADI value is very low for this compound due to its high toxicity. WHO and EPA classify Fenamiphos under category **Ia, I** extremely hazardous. The figure below shows the depletion of the concentration of Chlorpyrifos in the sediments. To deplete to the LC50 for rainbow trout (0.11 ppm) the load has to be reduced in 40% that is around of 5414 kg of active ingredient but for the bluegill sunfish the annual load has to be reduced in 94 to 95%.

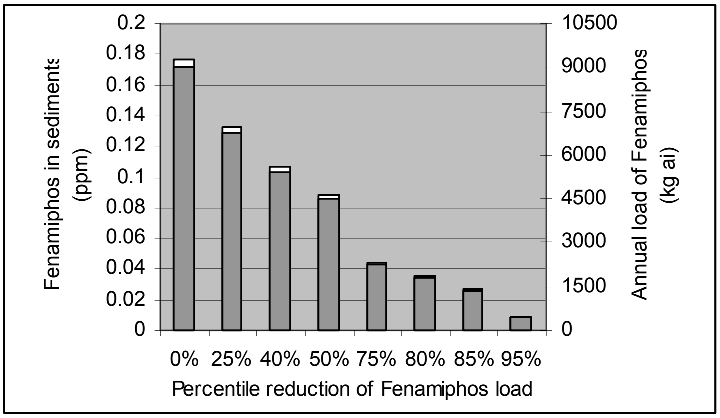


Figure 33. Reduction of annual load of Fenamiphos and the impact of its concentration in the sediment

Fenamiphos is moderate persistence in the soil environment, with a reported soil half-life of about 50 to 60 days. Fenamiphos is not strongly adsorbed to soils. Fenamiphos disappears from the water quickly in acid and alkaline conditions but is stable in neutral water when held in the dark. In a neutral solution, half of the initial amount is degraded within approximately 4 hours. In the plants Fenamiphos is absorbed through the roots and translocated to the leaves and it is broken down within the plant.

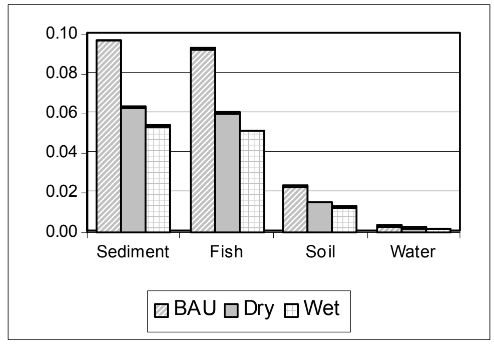
5.5.3 Variable Rainfall Scenario

This scenario was analyzed to explore the influence of the rainfall in the partitioning of the pesticides in the ecosystem. Fenamiphos and Dimethoato were selected under the criteria of toxicity and persistence. Dimethoate has a high solubility (28000) The average annual rainfall for 1992 (***704.7 mm***) was used to analyze it as a wet year. For the dry year 1993 the average annual rainfall used was (***473.8 mm***). From these values an average percentage (15%) of surface runoff was taken into account[6]. The annual load used was the same as the previous scenarios for both compounds. These results are influenced by two specific physical properties of the compound, the solubility and the persistence. In one hand Fenamiphos is more persistent (61 days) than Dimethoate (12 days) and in the other hand Dimethoate is more soluble than Fenamiphos. The concentrations of Fenamiphos in the compartments are higher than the concentrations of Dimethoate. In both cases there is slight difference between the wet and the dry year but there is a clear difference between the BAU scenario and both of the seasonal conditions. This result was expected due to the *"BAU"* water depth (3.4 cm) was increased to 14 cm for the wet year and 10.5 cm for the dry year (Figure 34).

[6] Al-Sabbagh, M. 2001. Rainfall analysis data. . MSc student, Water management division, ITC, The Netherlands.

Fenamiphos

Compartments	*BAU*	Wet year (1992)	Dry year (1993)
Water	0.003	0.0015	0.0018
Soil	0.023	0.013	0.015
Sediment	0.096	0.053	0.062
Fish	0.092	0.051	0.059



Dimethoate

Compartments	*BAU*	Wet year (1992)	Dry year (1993)
Water	0.008	0.002	0.003
Soil	0.007	0.002	0.003
Sediment	0.029	0.008	0.012
Fish	0.013	0.004	0.005

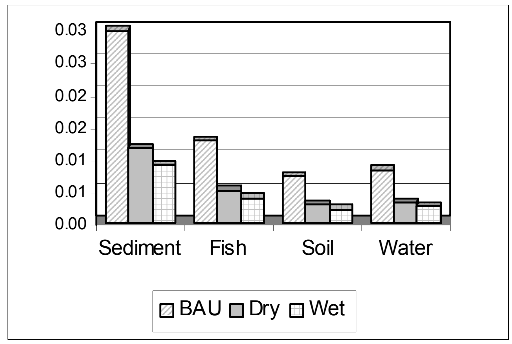
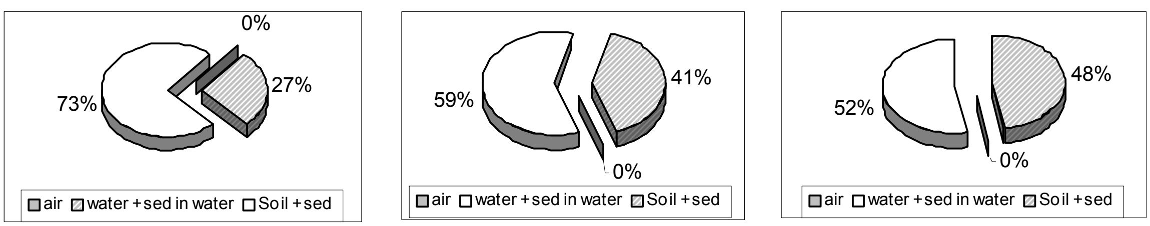


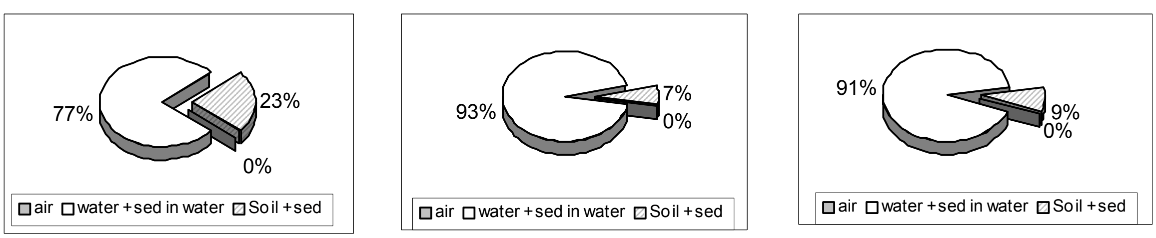
Figure 34. Partitioning of Fenamiphos and Dimethoate under different seasonal conditions around the Lake Naivasha, Kenya.

The distribution of the solute was influenced by the seasonal conditions The figure below shows the variation for both cases. In the case of Fenamiphos the percentage of solute in the water compartment is decreased within 15-20% and increased in the soil compartment. In the other hand the percentage of Dimethoate in the water increased in within 14-16% and decreased in the soil.

Fenamiphos



Dimethoate



BAU ***Wet year*** ***Dry year***

Figure 35. Percentile distribution of solute (Fenamiphos and Dimethoate) under different seasonal conditions around the Lake Naivasha, Kenya.

Chapter 6: Conclusions and Recomendations

This study aimed at surveying and assessing the use of pesticides around the Lake Naivasha for different farming systems that are under different management practices. A model method was used to evaluate the partitioning of the pesticides in the compartments of the Lake Naivasha ecosystem. A preliminary risk assessment was performed by a scenario analysis. The following conclusions were draw from this research.

Conclusions

- **Pesticides use around the Lake Naivasha.**

According to the data collected during the fieldwork in the study area approximately 114 different active ingredients are being used by the farming systems and around 30 % of them are classified by EPA and WHO under toxicity Ia, Ib and II, extremely hazardous, highly hazardous and moderately hazardous, respectively. Those may represent a risk in the short and the long term for the population exposed through the direct contact or by the consumption of contaminated food.

The data was collected mainly from three out of the seven farming systems surveyed. The pesticides use in the rest of the farms around the lake Naivasha was estimated based on the data mentioned above and using the land use classification generated from the Landsat image taken on May 2000 and the field observations.

- **Spatial distribution of pesticides use around the Lake Naivasha**

Remote sensing and GIS data analysis was an effective tool in mapping the farming systems as well as the pesticides use. The irrigated croplands had been identified mainly in three groups: Vegetables, Flowers and Grassland. The total area for each farming system was estimated as well as the area under each of the landuse mentioned above.

The total number of farming systems was estimated around 40. Fourteen of then under vegetable production makes a total of 1635 ha. Nineteen are under flower production, make 1502 ha, and six of them mixed (vegetables, flowers, wheat.) The total area irrigated cropland was estimated on 3227 ha.

The load of active ingredients was estimated based on the farming system areas and its land use. The average annual load for vegetables was estimated to be approximately 19 kg of active ingredient per hectare according to the data collected and based on the crop rotation scenarios and the four seasonal patterns identified in the area during the year (two dry seasons and two wet seasons).

For the flowers the average annual load was estimated to be 69 kg of active ingredient per hectare. This estimation was according to the data collected and based only on the seasonal patterns due to the flowers are perennial crops that are established in the same area up to seven years.
The annual load of active ingredient per hectare assigned to the grasslands was zero due to this farming systems were not part of the survey.

The total annual load for the area around the lake Naivasha for vegetable production was estimated on 27,954 kg of active ingredient. The total annual load for the flowers is approximately 70% higher that this for the vegetables.

- **Partitioning of the Pesticides in the Naivasha Ecosystem**

The results of the model shows that the partitioning of the pesticides is influenced by the physical properties of the pesticides specially the persistence and the solubility. Fenamiphos showed the higher concentrations in all of the compartments except in the air, followed by Chlorpyrifos. Fenamiphos is the most persistence (91 days) compound within the set of pesticides selected.

Chlorpyrifos is the compound with the highest Henry's law coefficient and was the one that showed the highest concentration in the air. Nevertheless the concentrations in the air were very small that can be consider as traces. Methomyl and Dimethoate showed the higher concentrations in the water compartment this can be explained by its high solubility, 57950 and 28700 mg/l, respectively.

The highest concentrations were found in the sediments and the fish compartments. The high persistence and the low solubility of the compounds can explain this result. The compounds having a low solubility have high values for the partitioning coefficients *logkow, logkow, and logBCF*. The higher the Bioconcentration factor for a compound the highest the concentrations found in the fish tissue.

- **Scenario Analysis**

The Business as usual Scenario *"BAU"* shows that the concentrations of chlorpyrifos and Fenamiphos found in the fish tissue are higher that The Acceptable Daily Intake (**ADI**). According to the Load Reduction Scenario the annual load of these compounds has to be reduced up to 98%. This fish species indicated in the **ADI** regulations shows very high sensitivity to these compounds. WHO and EPA classify Fenamiphos under category **Ia, I** extremely hazardous and Chlorpyrifos under category **II**, moderately hazardous.

Recommendations

This study focussed on the quantification and geographic distribution of pesticides use around the Lake Naivasha. A major effort was put into the detailed inventory and analysis of the farming systems with respect to agrochemical use.

A preliminary environmental impact assessment (EIA) was done using an environmental partitioning approach. This permitted a first evaluation of impact potential and residue accumulation of toxic compounds in the ecosystem compartments.

Typical pesticides pathways (i.e. surface runoff, groundwater pathways) were not investigated here. This is due because not enough soil and vadose zone data are available for this purpose, especially taken into account the complexity of the near lake environment. Based on these facts the next recommendations for further studies were formulated.

For the Future studies:

In order to assess the transport of pesticides to the ground water using the ECOPLUS program or any other model that assess the movement of the compounds a precise study may be carried out to assess the ground water flow regime and get a better understanding of it.

The assessment of the fate of pesticides *in situ* may be conducted to evaluate the environmental impact based on specific areas using the estimated annual loads in each farming system. The concentration of a solute loaded in a specific area may be assessed in its movement downgradient after the time of the application in the field.

The residues of pesticides in biota (fish) may be assessed in more detail. Sampling and Laboratory analysis should conducted to the fish population in the lake due to apparently these are very likely to concentrate residues of the pesticides used in the area specially those with high toxicity.

A risk assessment of pesticide use on the human health may be carried out for the workers in the farming systems and also to those exposed in indirectly as consumers of food (fish) and those using the groundwater as a source of drinking water.

For the farming system management:

The use of pesticides having high toxicity and high persistence should be reduced significantly. This preliminary study analysis shows that compounds can represent an environmental and human risk for the Lake Naivasha area.
We recommend a more detailed pesticide chemical analysis (laboratory) for the water and biota (fish tissue) in lake Naivasha, in order to approve/disapprove the above statement.

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