Environmental Impact of Urban Storm Runoff and Sewage from Naivasha Town on Lake Naivasha

Arindita Dessi Permatasari

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by

Arindita Dessi Permatasari
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Thesis Assessment Board

Prof.A.M.J. Meijerink (Chairman)
WRS Department, ITC
Dr.E.O.Seyhan (External Examiner)
Vrije Universiteit Amsterdam
Dr. Robert Strobl (First Superviser)
WRS Department, ITC
Ing.Remco Dost (Second Superviser)
WRS Department, ITC
Ir. M.J.G. Brussel (Member)
PGM Department, ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

Signed……………………………………..

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The grand essentials of happiness are;
Something to do
Something to love and
Something to hope for
~ Allan K. Chalmers~

Abstract

Population growth urged people to spread out in order to live a better life. Town, representing the central focal point of human activity, is an interesting place to study. It represents a great concentration of resources consumers and waste producers. This urbanization process gives a lot of effects to the environment surrounding the town, especially the stream or lake near the town. As the town growing, the water supply demand, urban pollution and waste problem of Naivasha town are increasing. The activities of Naivasha town give an effect to Lake Naivasha, which is the second largest freshwater lake in Kenya. The main pollutant sources of Naivasha town to the lake come from runoff and sewage.

The main objective of this study is to assess the water quality as the impact of urban storm runoff and sewage from Naivasha town, in order to estimate the contribution of Naivasha town activities to the water quality of the lake. This main objective was achieved in a first phase by analysing water quality of drinking water, runoff water and sewage water. Then the classification of paved an unpaved area was done because the urban runoff problem has a relation with the paved area. This area collects and quickly runs off. This classification process was done using eCognition.

The result of water quality analysis and the classified paved-unpaved area involved in the estimation of pollutant loads of storm water runoff using the Simple Method. To estimate the sewage pollutant loads, a calculation of the discharge of the sewage and concentration of each pollutant was done.

Two scenarios were created to predict the pollutant loads. These two scenarios used different assumptions to compare the effect of a change in variables, which is important in a pollutant loads future prediction. In this case, those variables are population growth and increasing of the paved area. The first scenario was created based on the changes of population growth without any changes on area development. The second scenario was created using population growth along with increasing of the paved area. From these two scenarios, the pollutant loads of Naivasha town for 10-years projection were calculated.

In general, a continuous monitoring of water quality to control the pollutants of the town and the accumulation of the pollutant at the lake is proposed for the Naivasha Municipality.

Keywords: *Environmental Impact, Water Quality, Storm Runoff, Sewage*

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1. Introduction

1.1. Background

Urban growth and dynamics in developing countries are fast and unpredictable. This is related to the rapidly increasing population and the migration from rural to urban area in order to find a better welfare. Moreover, the highest population growth occurs in town. This explains why urban area becomes a unique environmental setting, which represents a great concentration of resources consumers and waste producers.

The activities of Naivasha town (*e.g.* agriculture, household, tourism, industry) carry a specific, significant and cumulative impact on the environment. As the town growths, the water supply demand, urban pollution and waste problem increases. When more people move into an area, a whole new set of support facilities such as housing developments, roads, shopping areas, commercial and industrial facilities must be built. Urban development is not only causing changes in land use, but also emerging water resources problems of the region along with the increased demand of water for people. An enormous quantity of water is needed to support the activities of Naivasha town including agriculture and industry. The larger the urban area, the greater the hydrological aspect might impact the acquisition of its water supply. Even more, these demand usually exceeds the supply of water provided either by surface or groundwater.

The rapid population growth in Naivasha town together with the increased standard of living is increasing the demands on good quality surface water. In addition, agriculture activities and development of small to medium industry also contribute to considerable demand of surface water.

A major characteristic of Naivasha town area is that it contains more hard surfaces such as rooftops and pavement where water collects and quickly runs off than unpaved surface. This has a adverse impact on the hydraulic loading rate of the runoff system (International Conference Wageningen, 1986). As the consequences, the amount of infiltration is reduced due to the addition of paved area, therefore resulting in increases of the quantity and quality of runoff.

When rainfall occurs, the constituents in urban area such heavy metals, oxygen demanding, bacteria, and nutrients are delivered by the surface runoff along both man made and nature open channel to the receiving water. The high pollutant loads from the surface runoff in the town create supplemental problem of the lake.

Considering all these factors, urban activities can significantly affect the town and its environment by increasing runoff and pollutant loads from sewage. Those impacts lead to some problems related to water resources in Naivasha town and the lake as a receiving body. Specifically, some problems that may occur in the Naivasha town are:

- Lack of source of drinking water for the town inhabitants. The population growth and activities of the town increase the water demand, therefore adequate water supply is essential and expansion of the source of water is needed.
- Water pollution in the town. This problem is caused by the activities of Naivasha Town, which affect the quality of the water from sewage wastes and runoff.
- Pollution in the main water body near the town (*i.e.* Lake Naivasha). The activities of the cities influence the water body through the wastewater, which flows to the lake.

In order to solve the problem, monitoring and assessment of the environment aspect, such as water quality in the town and wastewater quality in the water body, should takes place. Therefore, assessments of environmental impact (*i.e.* especially the water quality in the town) and water quality modeling are some of the approaches proposed to assess the amount of pollutant discharge to the water body.

1.2. Research Objectives

1.2.1. Main Objective

The main objective of this study is to assess the impact of urban storm runoff and sewage from Naivasha Town on Lake Naivasha.

1.2.2. Specific Objectives

There are some of the specific objectives to support the main objectives, which are:

- Carrying out an inventory and analysis of the drainage and sewage network of Naivasha town;
- Assessing and evaluating the environmental impact, especially related to water quality;
- Extracting data from high-resolution satellite imagery (IKONOS) to differentiate paved and unpaved area of Naivasha town;
- Creating a model of urban storm runoff of Naivasha Town to estimate the amount of pollutant loads in the Lake.

1.3. Research Questions

Considering the overall and specific research objectives mentioned above, this research tries to answer some research questions as follows:

- Does the urbanisation affect the drainage and sewage network of the study area?
- What is the potential pollutant produced by the activities of the urban area to the Lake Naivasha?
- How much are the potential pollutants contained in the water of the study area?
- What are the percentages of the unpaved and paved area in Naivasha town?
- Is there any suitable model of storm runoff for study area?

1.4. Methods

To accomplish the objectives defined, a method is developed and comprises of five main parts:

1. **Analysis on the spatial and temporal (GIS) aspect of Naivasha Town**

   In this part, most of the activities were dealing with Geographic Information System (GIS). GIS uses a computer database to store and processing spatial and temporal data. Spatial data is information that describes how a specific feature is located or distributed in the space, such as stream location, town boundary, and land use/land cover. The data sources are IKONOS and ASTER image.

   Data is entered analysed in GIS database and software, such as ILWIS, Erdas, and ArcView, and comprises the map of the study area. The maps is built using computer with geographic coordinates identifying the locations of various features. Some steps involved are the determination of study area boundary, network of sewage and runoff, and same coordinate points of sampling.

2. **Defining the characteristic and activities of Naivasha Town**

   Defining the characteristics of the population of Naivasha Town (*e.g.* the livelihood/activities of the town) is necessary to understand the life style and customs of Naivasha Town. These information are important because the population growth and activities of Naivasha town has a direct relation not only to the sewage system in Naivasha but also the environment surrounding.

   Knowledge about the characteristics of Naivasha Town supports the estimation of the pollutant in Naivasha town. In this study, such information was obtained from the municipality, the Development Impact Consulting Report and field visit. During the field visit, the built area and land cover types were distinguished as the first step of interpretation on paved and unpaved area.

3. **Urban hydrology analysis**

   Hydrology is concern with the circulation of water and it deals with a lot of factors, one of them is precipitation. Describing and predicting the variability of precipitation is fundamental requirement for various measurements in water resources management, such as estimation of pollutant loads.

   Some data that can support the estimation of pollutant loads are rainfall data, urban runoff and sewage system that are related with the hydrological aspect. This information is necessary in order to understand the behaviour of the hydrology cycle in Naivasha Town.

   The measurement of the dimension for each (main) drainage and sewage network, rainfall measurement using rain gage, and measurement of runoff using relation of the storm duration with the depth of the rainfall in the channel were done in the field. All these data support the calculation of the velocity and discharge of runoff.

4. **Environmental impact analysis (water quality of Naivasha Town)**
   Analysis on the environmental impact was done through an assessment of water quality of Naivasha town, as the impact of the activities of Naivasha town. For that purpose, some samples of water in the Naivasha Town were analysed.

   To assess the drinking water quality of Naivasha Town, some water samples were taken in the locations of borehole and tap water. Whereas to assess the quality of the water that contribute from the town to the lake, samples of Naivasha town sewage (including the inflow and outflow of Naivasha town) and samples of Naivasha town storm water runoff were taken.

   Analysis of water quality parameters was done in laboratory, while some of the special parameters (*e.g.* pH, temperature, turbidity) were analysed in the field directly. The results of the analyses then were used as inputs in Aquachem to identify the characteristic of the water.

5. **Storm Runoff of Naivasha Town Modelling**
   Creation of a storm runoff model is the last part of this study. The model attempts to predict the pollutant loads from Naivasha town. To facilitate the modelling, some data such as rainfall, storm water runoff, percentage of paved area, and pollutant concentration were involved. The storm water runoff model in this study was created using Simple Storm Water Pollutant Loads Model.

1.5. Acitivities Conducted

From the methods described above, a sequence of activities is done and categorised into three phases:

1.5.1. Pre-Fieldwork Phase

1. Literature Review
   Literature review was done to support the problem formulation and the methods developed.
2. Preparation of the image for fieldwork
   Most of the spatial and temporal analyses of Naivasha Town were done in a pre-fieldwork phase. It includes the preparation of the satellite images used in the field. The available data from different sources may have different georeference and coordinate system. Therefore, geometric correction was done to have data sources with the same georeference and coordinate system.

1.5.2. Fieldwork Phase

1. Collecting secondary data
   Some secondary data related to water resources management done by the municipality of Naivasha Town were collected and later on, involved in the analysis. The secondary data include maps and documents related to sewage system, drainage network, and water supply situation of Naivasha Town. All information collected comprises the characteristics of Naivasha Town.
2. Establishing the key for the interpretation of IKONOS image
   Based on the knowledge gathered from the field, a key of interpretation was established to facilitate the interpretation of IKONOS image. As explained in the next section, object oriented

classification technique from e-Cognition software was used to classify the satellite image based on the key of interpretation built from the fieldwork.

3. Collecting hydrological data
   Some of hydrological parameters were measured in order to develop a runoff model, which is used to establish a plan and design of a runoff model.
4. Collecting and analysing water sample
   Several water samples from Naivasha Town were analysed directly in the field and some of the parameters were analysed in the laboratory. The parameters that have to be analysed directly are temperature, pH, Alkalinity, Dissolved Solid, Total Coliform Bacteria, Turbidity, Chloride, Nitrite, Nitrate, Ammonia, Dissolved Oxygen, and Phosphate. The other parameters such as COD, Sulphates and Fluoride were measured in the laboratory.

Table 1-1 The parameters of water quality assessment

No.	Parameter	Equipment
In the Field		
1.	Temperature	Thermo-sensor
2.	pH	pH meter
3.	Turbidity	Turbidity meter
4.	Alkalinity	Field test MERCK
5.	Dissolved Oxygen (DO)	Field test MERCK
6.	Chloride	Field test MERCK
7.	Nitrate	Reflectolab
8.	Nitrite	Reflectolab
9	TDS	0.67 multiple by EC
10.	Ammonia	Reflectolab
11.	Phosphate	Reflectolab
12.	Total Coliform Bacteria	Membrane filtration Kits (44.5 ◦c)
In the Laboratory		
13.	COD	Spectrophotometer
14.	Sulphate	Spectrophotometer
15.	Fluoride (borehole only)	Spectrophotometer
16.	Cations	Inductivity Couple Plasma (ICP)

These parameters were selected based on the selection variables for assessment of water quality in relation to non-industrial water use (Chapman, 1992). However, the dominant parameters are:

- DO
  To the degree that pollution contributes oxygen-demanding organic matter (like sewage, lawn clippings, soils from stream bank and lakeshore erosion, and from agricultural runoff) or nutrients that stimulate growth of organic matter, pollution causes a decrease in average DO concentrations. If the organic matter is formed in the lake, for example by algae growth, at least some oxygen is produced during growth to offset the eventual loss of oxygen during decomposition. However, in lakes where a large portion of the organic matter is brought in from outside the lake, oxygen production and oxygen consumption are not balanced and low DO may become even more of a problem.

- pH

  When pollution results in higher algal and plant growth (*e.g.* from increased temperature or excess nutrients), pH levels may increase, as allowed by the buffering capacity of the lake. Although these small changes in pH are not likely to have a direct impact on aquatic life, they greatly influence the availability and solubility of all chemical forms in the lake and may aggravate nutrient problems. For example, a change in pH may increase the solubility of phosphorus, making it more available for plant growth and resulting in a greater long-term demand for dissolved oxygen.

- EC

  Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. EC is controlled by: rock types, the size of watershed, and other sources ion to lake, such as wastewater treatment and urban runoff.

- Temperature

  Thermal pollution (i.e., artificially high temperatures) almost always occurs as a result of discharge of municipal or industrial effluents. Except in very large lakes, it is rare to have an effluent discharge. In urban areas, runoff that flows over hot asphalt and concrete pavement before entering a lake will be artificially heated and could cause lake warming, although in most cases this impact is too small to be measured. Consequently, direct, measurable thermal pollution is not common. In running waters, particularly small urban streams, elevated temperatures from road and parking lot runoff can be a serious problem for populations of cool or cold-water fish already stressed from the other pollutants in urban runoff. During summer, temperatures may approach their upper tolerance limit. Higher temperatures also decrease the maximum amount of oxygen that can be dissolved in the water, leading to oxygen stress if the water is receiving high loads of organic matter. Water temperature fluctuations in streams may be further worsened by cutting down trees, which provide shade and by absorbing more heat from sunlight due to increased water turbidity

- Turbidity

  Turbidity refers to how clear the water is. The greater the amount of total suspended solids (TSS) in the water, the murkier it appears and the higher the measured turbidity. The major source of turbidity in the open water zone of most lakes is typically phytoplankton, but closer to shore, particulates may also be clays and silts from shoreline erosion, re-suspended bottom sediments, and organic detritus from stream and/or wastewater discharges.
  (http://waterontheweb.org/under/waterquality/parameters.html, February 2004)

1.5.3. Post-Fieldwork Phase

1. Spatial data preparation and analysis

   As the first step in data preparation and analyses, geometric correction to the satellite imagery was carried out. By having satellite image with correct geographic position and common coordinate system with other datasets, the next process can be carried out. Road and drainage network were mapped according to geographical position collected in the field. To refine the geometry of these features, digitising in GIS software was done resulting in GIS layers of road and drainage networks. Geographic location of water samples and ground truth points were input to the map as well, resulting in point maps representing those samples.

2. Non-spatial data preparation and analysis
   In this step, the non-spatial data, such as rainfall, runoff, and the result of water quality assessment were analysed. The measurement of rainfall was done using rain gage. These rain gages were located in several places in Naivasha town. The data on the amount of rainfall was interpolated using Thiessen Average Method to obtain spatial distribution of the rainfall. Beside the hydrological data analysis, water quality analysis using aquachem was done to define the characteristic of Naivasha water samples.
3. Data integration and analysis
   The paved and unpaved area of Naivasha town in eCognition was identified based on the key of image interpretation collected from the field. The last step then is combining the hydrological data, the results of water quality analysis, and proportion of paved and unpaved area in Simple Pollutant Load Model to estimate the pollutant loads from the town.

1.6. Flow Chart Methodology

The methods described above are presented in a sequential way in the flowchart in Figure 1-1.

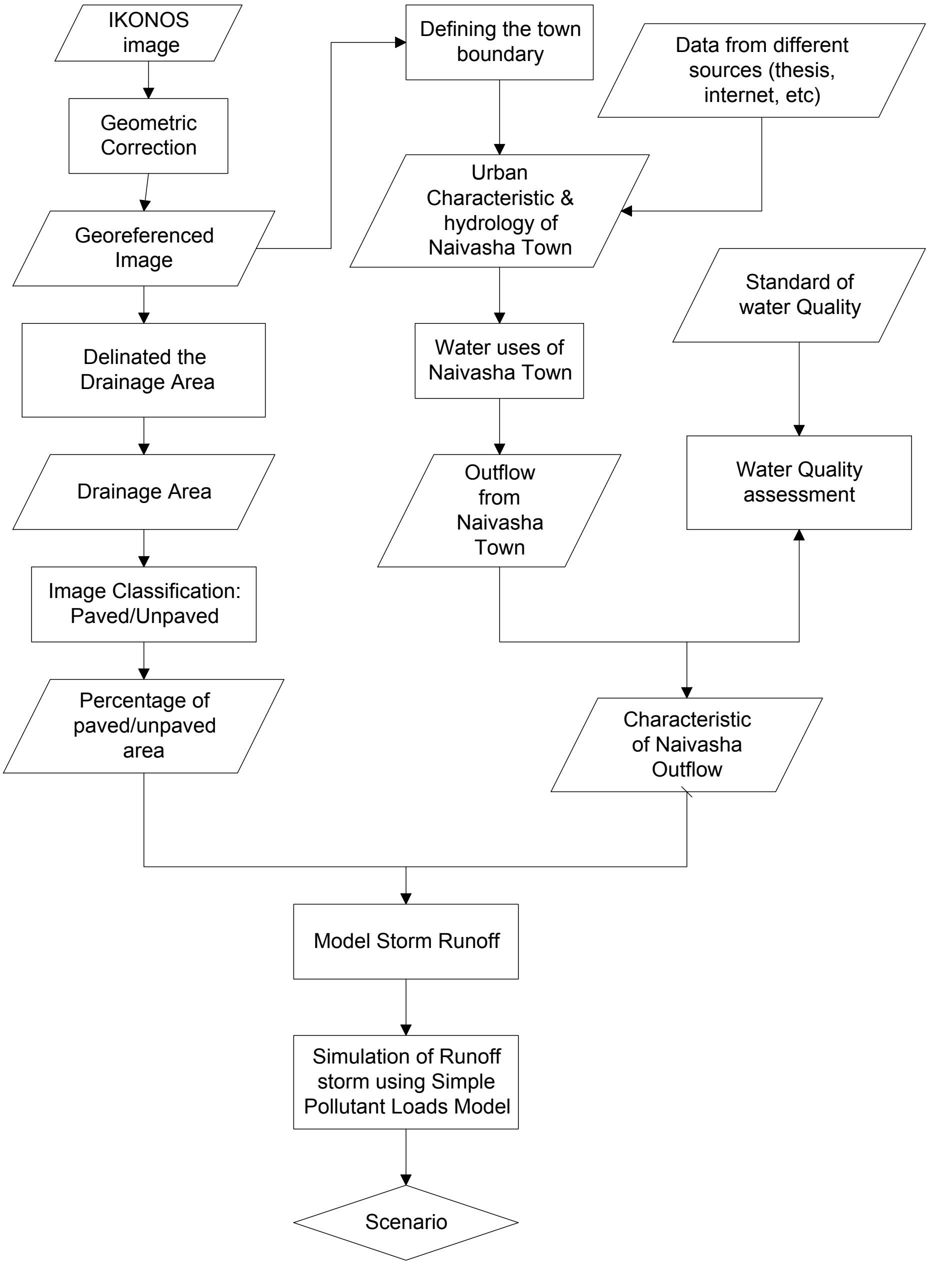


Figure 1-1 Flow chart of methodology

1.7. Materials and Data used

To identify the spatial and temporal aspects, the following data set and materials are used.

1.7.1. ASTER (Advanced Space-borne Thermal Emission and Reflection Radiometer)

ASTER is an imaging instrument that is flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER will be used to obtain detailed maps of land surface temperature, emissivity, reflectance and elevation (http://asterweb.jpl.nasa.gov, October 2003)

ASTER covers a wide spectral region with 14 bands from the visible to the thermal infrared with high spatial, spectral, and radiometric resolution. The spatial resolution varies with wavelength 15 m in the visible and near infrared (VNIR) 30 m in he short wave infrared (SWIR) and 90 m in the thermal infrared (TIR). Each ASTER scene covers an area of 60 x 60 km^2.

The ASTER image that was used in this research is ASTER 8 March 2003 to get an interpretation and information around Naivasha town. This image is covering all the area (upper and lower catchments) around Naivasha.

1.7.2. IKONOS (High Resolution Image)

IKONOS is the first of the next generation of high spatial resolution satellites and owned by Space Imaging, a USA based Earth Observation Company. The IKONOS-1 was launched on April 27, 1999, but failed to achieve orbit. IKONOS-2 was launched on September 24, 1999 and became the first commercial Very High Resolution Earth Observation satellite data since early 2000
(http://www.infoterra-global.com/ikonos.htm, August 2003)

Apart from the high spatial resolution it also has a high radiometric resolution using 11-bit quantization (Bakker,W.H, 2001). Radiometric resolution of IKONOS data is collected as 11 bits per pixel (2048 grey tone). This means that there is more definition in the grey scale values and as a viewer you can see more detail in an image. In order to benefit from this additional information, you will need specialist image processing software.

IKONOS has both cross and along track viewing instruments which enable flexible data acquisitions and frequent revisiting capabilities - 3 days at 1 metre resolution and 1 to 2 days at 1.5 metre resolution (http://www.infoterra-global.com/ikonos.htm, August 2003)

IKONOS data records 4 bands of multispectral data at 4-meter resolution and one panchromatic band with 1-meter resolution.

Table 1-2 Bands of IKONOS image

Band	Band Width	Spatial Resolution
Panchromatic	0.45 - 0.90µm	1 meter
Band 1	0.45 - 0.53µm (blue)	4 meter
Band 2	0.52 - 0.61µm (green)	4 meter
Band 3	0.64 - 0.72µm (red)	4 meter
Band 4	0.77 - 0.88µm (near infra-red)	4 meter

IKONOS data can be used for small to medium scale topographic mapping, not only to produce new maps, but also to update existing topographic maps. The spatial extent, the total area covered by an image, is 11 km wide and long. The repeat cycle of IKONOS is 5 days, 1.5 day repeat viewing with pointable sensor.

Many pervious studies using conventional satellite image data in urban or sub-urban have a limitation related to resolution of the sensor system for extraction of man made features such as buildings and roads. For instance, Landsat Thematic Mapper, which has 30 meters, can't properly distinguish the house, road, and garden. An automated classification method for mapping impervious surface by using high resolution satellite image would add significantly to the level of detail and efficiency of current effort attempting to understand and model water quality and would allow for synoptic assessments of large drainage areas in a community-based environmental strategy. Hence, in this study, an IKONOS image 3 June 2001 is used.

1.8. Tools

Some software has been used as data analysis tools for this research. These softwares are GIS and image processing software, classification software, hydrology software and other software like Ms. Office and Ms. Visio.

1.8.1. GIS and Image Processing Software

1.8.1.1. Erdas & ArcView

Erdas and Arcview are primarily to basic image processing & GIS concept. It is one way to accomplish a task, describe a process, compute an algorithm, or naming a data set. They used for spatial data processing and analysing has been applied to more diverse problems-forestry, ecology, planning, engineering, etc.

1.8.1.2. Ilwis

ILWIS (Integrated Land and Water Information System) is a window-based integrated GIS (with image processing capabilities) and remote sensing software. It has been developed by the ITC (International for Geo-Information Science and Earth Observation). The version used in this study is ILWIS 3.1.

In ILWIS, it is possible to make an input, manage, analyse and present geo-graphical data. From the data, the information on the spatial and temporal patterns and process on the earth surface can be generated (ITC, 2001).

1.8.2. Classification Software (eCognition)

eCognition Definiens Imaging provides a new powerful and universal technology for image analysis. It is based on the concept that important semantic information necessary to interpret an image is not represented in single pixels but in meaningful image objects and their mutual relations.

eCognition *elements* helps users to overcome the challenges and limitations of image classification methods, thus increasing their productivity, reducing the costs involved and improving the efficiency of operational production of geospatial information.

Based on these objects, eCognition *elements* performs sample-based classification using a Nearest Neighbour Classifier: This allows a very simple, rapid yet powerful classification, in which individual image objects are marked as typical representatives of a class (=training areas), and then the rest of the scene is classified accordingly ("click and classify"). Therefore, digitization of training areas is not necessary anymore.
With this easy to handle supervised classification even remote sensing novices achieve classification results in no time.

Classification results can be exported in standard raster or vector formats thus it provides an effective bridge among the worlds of image classification, raster analysis and vector GIS (http://www.definiens-imaging.com/ecognition/elements/index.htm, September 2003)

With eCognition, the classification has been done with a whole bundle of innovative features and techniques for efficiency image analysis. The classification by eCognition does not classify single pixels, but rather image objects, which are extracted in a previous image segmentation step.

1.8.3. Hydrology Software

- **Aquachem 3.7**

  Aquachem is a fully integrated software package developed specially for graphical and numerical analysis of geochemical data sets. It covers a wide range of calculation frequently used for the analysis, interpretation, and comparison of aqueous geochemical data.

  Aquachem is built around a customisable database that can be configured to include an unlimited number of attributes per sample, for example chemical elements, and physical parameters. Each sample can be characterized according to five basic parameter groups including:

  - Header information (sample ID, location, date, etc)

- Physical data (coordinates sample, pH, conductivity, etc)
- Cations (Ca, Mg, Na, K, etc)
- Anions (Cl, Br, SO4, NO3, etc)
- Uncharged Compounds (Al, As, CO2, etc)

The built in database in Aquachem contains most major cations and anions and the chemical properties of each.

Aquachem uses the common measured values (cations and anions) for each sample to calculate additional geochemical parameters including water type, sum of anions, sum of cations, ion balance, TDS, hardness, alkalinity, etc.
It is also possible to make the display of the interpretation using graphs, like stiff diagram, radial diagram, pie chart, piper diagram, etc.
(http://www.scisoftware.com/products/aquachem_details/aquachem_details.html, September 2003)

The result of water quality analysis with aquachem will be better such as the acceptable interval of cations and anions of data fieldwork, water type of sample water, drinking water regulation report, and display of the interpretation using graph.

- **Box car Pro 4.2**

Box Car Pro 4.2 is a powerful enhanced, offering added features for graphing, data analysis, data export and simultaneous management of multiple loggers. This study is using this software for launch and read the result from rain gage (tipping bucket) (http://www.microdaq.com/occ/software, January 2004)

2. General Description of the Study Area

2.1. Characteristics of Naivasha Town

2.1.1. Naivasha Town

Naivasha Town is the largest town in Kenya, is located near the shores of Lake Naivasha, which is the one of freshwater lake in the Rift valley, Kenya at a mean altitude of 1910 m above sea level. It is also located approximately 90 km northwest of the capital Nairobi and 70 km from Nakuru Town. Naivasha has municipality status with an area of 941 km^2 and the main town occupying 78 km^2 (Mbathi, 2001).

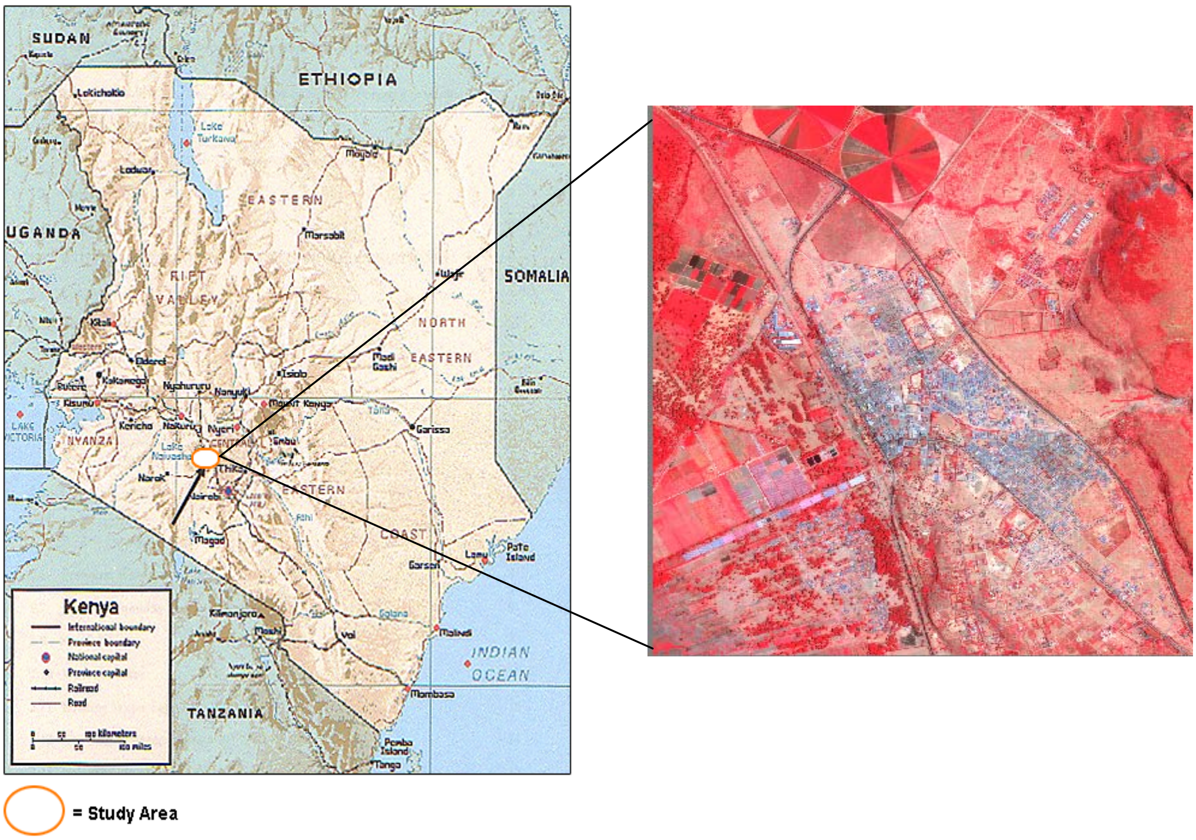


Figure 2-1 Map of study area

Based on Development Impact Consulting of Naivasha report, the population of Naivasha at 2003 is 47.695 with the growth rate 5 % per year. The percentages of the rural and urban area are 65 %, 35 % respectively. Over 60 % of the urban population stay in unplanned settlements, with little infrastructure.

Naivasha town is divided into several main areas, they are:

1. Council Estate
2. Site and Service Estate
3. Industrial Area
4. Central Business District
5. Lakeview Estate
6. Kihoto Estate
7. Kabati Estate
8. KWS (Kenya Wild Service)
9. Prison Area

Naivasha town is located in the Nakuru district of the Rift Valley province about 36°26’ longitude east and about 0° 43’ latitude south with an elevation around 1.900 m. Naivasha town is supplied with water from four boreholes generating around 50 m^3/hour and working for 12 hours. The production each borehole is:

1. Police Line Borehole, provides 30 m^3/hour = 30 x 12 = 360 m^3/day. The storage capacity of this borehole is 1100 m^3.
2. Bosster pump borehole, provides 50 m^3/hour = 50 x 12 = 600 m^3/day. The storage capacity of this borehole is 1000 m^3.
3. Waterworks borehole, provides 8 m^3/hour = 8 x 12 = 96 m^3/day. The storage capacity of this borehole is 500 m^3.
4. Slaughter house borehole, provides 8 m^3/hour = 8 x 12 = 96 m^3/day. The storage capacity of this borehole is 500 m^3.

Besides those four boreholes, there are many private boreholes and wells built by the commercial side like hotels, public institute, school, hospital, and also private individuals.
These exist because the total production of water from the four boreholes is 1.152 m^3/day and the estimated of water demand is around 7.800 m^3/day. The government or Municipal Council of Naivasha cannot monitor each borehole in the town regularly. It will influence the quality of the drinking water.

The water supply of Naivasha city comes from Lake Naivasha. It relies on agriculture as a source of water for irrigation, urban needs, and industry.

For the evaluation of the drinking water quality of Naivasha Town, there are 6 sample points of drinking water (4 of borehole and 2 taps water):

Table 2-1 Coordinates of borehole point samples

Coordinate		Borehole point
215084	9919855	Borehole Police Line (top of it)
216095	9919014	Borehole KWS
214769	9922346	Borehole Slaughter House
212949	9923288	Borehole Delamere
214141	9920829	La Belle Inn
214261	9920626	Municipality

2.1.2. Climate

The area has a semi arid type of climate. The monthly average temperature range is between 15.9 to 17.8 ◦c with the coldest months being July and August. Highest temperature occurs in January and February (Ranatunga, 2001).

The seasonal distribution of the precipitation shows a long period of rain in the period from March to May, and the short period of rainfall during October to November. December to February is the driest part of the year with sunny days and cool, clear nights (Jonathan, 1998). But in 2003 the weather is different. There are storm raining on January, February, May, August and the end of September with a short rain. The rest is dry season.

2.1.3. Population and Activities

Naivasha is one of the fastest growing towns in Kenya. Based on the Municipality of Naivasha town, the population census in 1999 of Naivasha division is 158.679; with 37.264 representing the population in Naivasha Town and 11.598 is the number of household. Current population (2003) is 47.695 and the household is 14.104 with the area 77.8 km^2 and the density 582 per km^2. The concentration of town area divided into three: Sokoni (includes the Central Business District, Site and Service and major of the Kabati Estate), Lake View and G.K Prison.

Most of the activities of Naivasha town are industry (not heavy industry) and commercial activities, like:

- Flower farming, is the single most important commercial activity. It can employ some 30.000 people. It is regarded as the most highly developed in Kenya (both domestic market and export)
- Tourism, where the tourist can do some activities like, boating, fishing, etc. The hotels and travel resort are the major business also in the town
- Commercial fishing
- Slaughter house
- Industry. They are some of the important industry in Kenya like HOBRA (a spraying equipment industry), economic housing group (which manufactures wood for furniture), breweries (which produce low quality alcoholic drinks that are sold in neighbouring region), delamere dairy farm (which produce dairy product), and wine industry.

2.1.4. Soils

The soils are formed mainly from weathered volcanic and pyroclastics. Lake Naivasha soils can be grouped into soil developed on the lacustrine plain and soils developed on the volcanic plain.

The soils developed on the lacustrine plain are moderately well to well drained, very deep, very dark grayish brown, silt clay to clay loam. The soils developed on the volcanic plain are well drained, moderately deep to very deep, dark brown to pale brown, with non calcareous to moderately calcareous topsoil and moderately to strongly calcareous deep soil (Urassa, 1999).

2.1.5. Hydrology

Lake Naivasha catchment has an external drainage system. It has upper ground water inflow and outflows. The lake receives drainage water from two streams. The larger one is from Malewa River, which drains the Nyandarua Mountain with a drainage area of about 1730 km^2. The other is from Gilgil river, which drains the Rift Valley floor from the North with the drainage area about 420 km^2. Other sources of water inputs into the lake include rainfall and underground water movement from the catchment.

The lake and groundwater sources provide the water supply to Naivasha and Nakuru Township. Also it supports irrigation-based agriculture.

Analysis of rainfall in the Naivasha town is important since rainfall is the major factor to be taken into account in order to find the storm runoff network. There is no intensive rainfall record in the Town. From the Development Impact Consulting report (2003), it mentions that the average mean number of rainy days in a year is 120. The highest annual rainfall recorded is 2112 mm and the lowest 49 mm. The average annual rainfall record is 600 mm.

Table 2-2 Rainfall record from 1910 - 1962

Month	Rainfal 1910 - 1962)		
	Monthly Total		
	Average (mm)	*Highest (mm)*	*Lowest (mm)*
January	22	95	0
Febuary	35	240	0
March	57	205	0
April	100	281	0
May	84	241	9
June	41	161	0
july	32	101	0
August	44	109	0
September	44	124	7
October	47	103	11
November	58	335	17
December	36	117	5
Total	600	2112	49

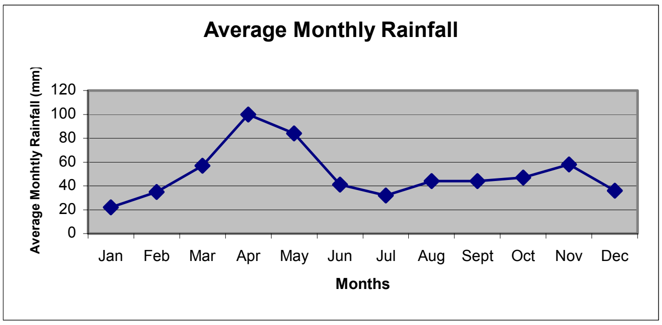


Figure 2-2 Average monthly rainfalls

An explanation and more discussion about the hydrology of Naivasha can be found in Chapter 5.

2.1.6. The Sewage and Drainage system in Naivasha

Water that enters streams and rivers from urban areas is often routed through a storm-water drainage system that collects rainwater. There two kinds of systems to carry wastewater:

1. Combine system, where the domestic sewage system and drainage network are combine together.
2. Separated system, where the domestic sewage and drainage are carried in the separate conduits.

(Huber, W.C & Philip B. Bedient, 1988)

For most of the cities, drainage system is usually separate from wastewater treatment systems or domestic sewage.

Naivasha town has a separate system for sewage and drainage. For the sewage system, they have close channel (the water flows through pipe) while for the drainage network there is an open channel (partly the water flow rely on natural channel).

2.1.6.1. Sewage System in Naivasha

Sewage pollution can be reduced and avoided by the application of various levels of treatment to remove solids, bacteria, viruses and nutrients. These treatments aim to produce a final effluent, which is clean enough to achieve certain water quality standards

Although a large area of the town is within reach of the sewerage infrastructure, only around 10– 5 % of the population is actually connected to the network. The main areas that are connected to the network are Site and service and Central Business. For the Industry area, they are not connected to the system even where the network is in place because the pump station has never been commissioned. Some part of Kabati and most of the Lake view area are not connected. But the government has planned to make the connection because both of these areas are fast growing. Kihoto area is located at a lower elevation and cannot connect into the network because the elevation and gravity flow to the network is not possible.

The sewage water from every area flows to the lake as an inflow to Lake Naivasha. Before the sewage reaches the lake, it flows to the wastewater treatment plant first to reduce some parameters that will contaminate the lake. The existing wastewater treatment plant was designed by VIAK on December 1983 and will be redesigned again. The operation and maintenance of this treatment plant is supervised by The Water and Sewage Department of Naivasha Municipal Council.

The plant consists of an inlet equipped with 2 screw pumps and manual screens that lead raw waste into 2 aeration lagoons. Sludge from the aeration lagoons is discharged into a sludge thickener from where thickener sludge is designed to be pumped into sludge drying beds located on the side aeration lagoon. The volume of sewage flow into the treatment plant is around 22.850 m^3.

There are 9 sample points of sewage water to be analysed in the laboratory. The 9 points of the sample are the main channel of sewage network. They are:

Table 2-3 Coordinates of sewage point samples

UTM Coordinates (X,Y)		Sewage point
214244	9920623	sewage 1
213683	9920529	sewage 2
214072	9921517	sewage 3
214332	9921291	sewage 4
214835	9920706	sewage 5
213860	9920702	sewage 6
214268	9920578	sewage 7
214125	9920876	sewage 8
214006	9921105	sewage 9

The Sewage network layout plan is shown in Figure 2-3.

Sewage Network Plan

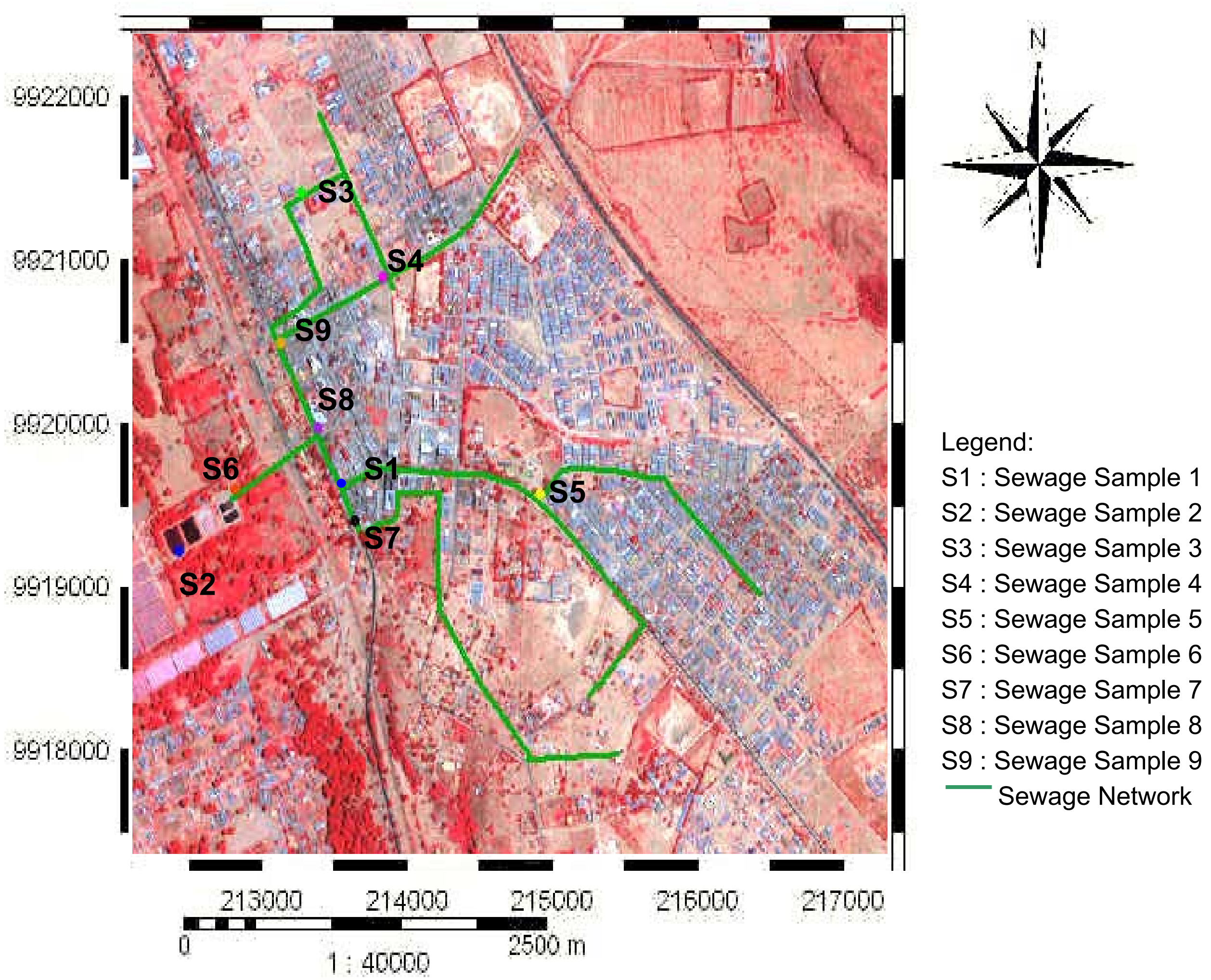


Figure 2-3 Sewage network plan

2.1.6.2. Drainage System in Naivasha

Storm water runoff from urbanized areas is generated from a number of sources including residential areas, commercial and industrial areas, roads, highways and bridges. Essentially, any surfaces, which do not have the capability to pond and infiltrate water, will produce runoff during storm events.

Urban runoff is one of the leading causes of water pollution in urban areas. Urban areas contain up to 90 percent hard surfaces such as rooftops and pavement where water collects and quickly runs off. This has a negative consequence for the hydraulic loading rate of the sewage system and in consequence for the surface water quality in combine system. But for separate system, it has a negative consequence for the runoff system only.
(http://www.mbnms.nos.noaa.gov/Resourcepro/urban.html, January 2004).

Urban runoff potentially contains a host of pollutants like trash and debris, bacteria and viruses, oil and grease, sediments, nutrients, metals, and toxic chemicals. These pollutants can adversely affect a receiving water body. It is not only a problem during rainy seasons, but also year-round due to urban water use.

Urban runoff is difficult to prevent because it is non-point pollution. That is, instead of originating from a single-point source, such as a factory or sewage treatment plant, the sources of urban runoff are spread throughout an urban area. Increasing the runoff can lead to increasing non-point source pollution levels in the urban runoff water.

The general storm water drainage is from the eastern edge of the built up of the town area along the trans African highway, towards the lake, following the general topography, thus storm water is draining through the CBD.

The drainage network system is an open channel and the channel was not design for big storm water runoff. This is a problem because in some parts of the area, if there is storm rainfall, it leads to flooding. From fieldwork, the network was measured using a GPS and visualised using Ilwis.

From the figure, there are some open channels for the drainage network. There are 6 points, where sampling was performed in order to know the quality of the runoff. 6 points were chosen because they are outlet of the 6 drainage areas. The parameter that was analysed can be seen in Chapter 1 (Table 1-1). Those points are:

Table 2-4Coordinate of runoff point samples

UTM Coordinates (X,Y)		Runoff point
214129	9920861	Runoff point 1
214205	9920705	Runoff point 2
214245	9920614	Runoff point 3
214071	9920982	Runoff point 4
213997	9921109	Runoff point 5
213952	9921215	Runoff point 6

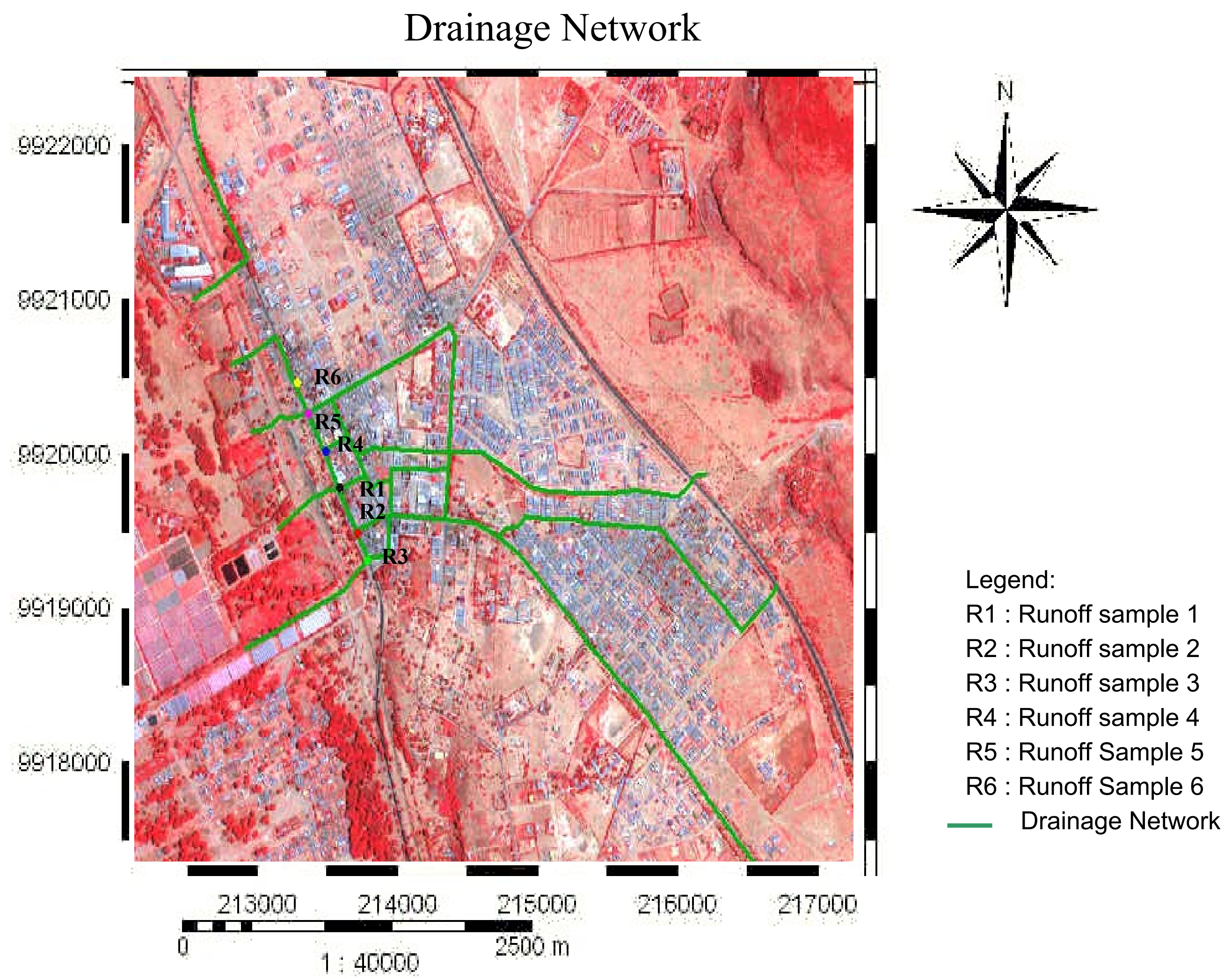


Figure 2-4 Drainage network

2.2. Spatial and Temporal (GIS) Aspect of Naivasha Town

Besides non-spatial data, this research needs also spatial and temporal data to obtain a better interpretation. For the spatial and temporal data, a GIS, a computer tool to store the database, will be used. Spatial data is information that describes how a specific feature is located or distributed in space. This type of information can include a watershed boundary, slope, contour, satellite image, aerial photographs, and land use/cover. Using GIS will allow to process and evaluate these data.

IKONOS 3 June 2001 was used as an image of Naivsaha Town. The resolution of IKONOS makes a clear interpretation of the town. In IKONOS 3 June 2001 beside Naivasha Town there is also all the area near the Naivasha Town.

The available data or maps from different sources (IKONOS or ASTER) can have different georeferences or coordinate systems which will create a wrong interpretation or overlay to data analysis. Therefore, all the data or maps must be checked if they are correctly georeferenced. In the field, some points were taken using GPS to make georeference of subset map using georeference corners. GPS (the Global Positioning System) units allow people to determine the geographic coordinates of landscape features. The projection parameters used in this study are:

- Projection type : UTM
- Spheroid name : Clarke 1880
- Datum name : Arc 1960
- UTM Zone : 37

The map with the correct georeference was created.

Created a study area map to know the boundary of study area, the result divided into 9 areas (as shown at map below):

1. Council Estate
2. Site and Service Estate
3. Industrial Area
4. Central Business District
5. Lakeview Estate
6. Kihoto Estate
7. Kabati Estate
8. KWS (Kenya Wild Service)

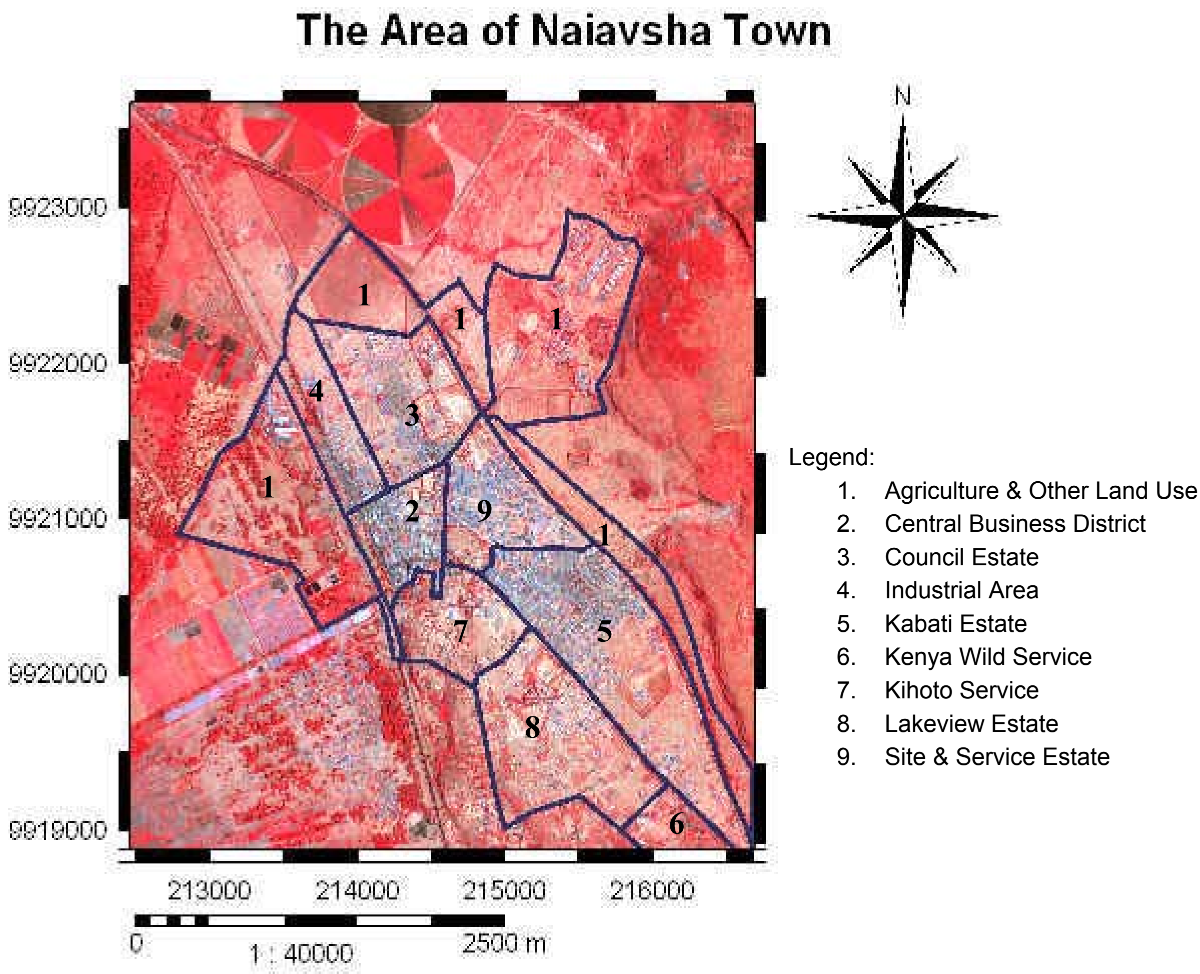


Figure 2-5 Area of Naivasha

3. Environmental Impact based on Water Quality of Naivasha Town

3.1. Introduction

3.1.1. Study of Water Quality

Every part of our world is continually changing including the unpredicted pollutants as well as the essential ecosystems. Some changes occur imperceptibly on a geological time scale while others are rapid occurring within days, minutes, or less. Control of environmental pollutant depends on understanding how environmental conditions are affected by pollutant and learning how to bring about desired changes.

The pollutants occurred in urban areas vary widely, from common organic material to highly toxic metals. Some pollutants, such as insecticides, road salts, and fertilizers, are intentionally placed in the urban environment. Other pollutants, including lead and oil drippings machineries, are the indirect result of urban activities (Chapman, 1992).

In this study, a practical evaluation of water quality depends on how the water is used, as well as its chemical make up. Water uses must be identified before water quality can be judged. Water quality refers to the composition of a water sample. Measuring the chemicals composition of a water sample collected in the field is just one step in determining water quality. The sample data must then be compared with the standards assigned to that water body (Weiner, 2000). But the interpretation of water quality data may be difficult and time consuming.

Because they are strongly influenced by other water quality parameters, the controlling variables listed below are usually included among the parameters that are measured in water quality sampling process.

- pH
- Temperature
- Alkalinity or Acidity
- Total Dissolved Solid or Conductivity
- Oxidation-reduction (redox) potential

3.1.2. Environmental Impact of Urban Activities with Respect to Water Quality

The European Commission has defined the environment as the combination of elements whose complex inter-relationships make up the settings, the surroundings and the conditions of life of the individual and of society, as they are or as they are felt (Gilpin, A, 1995). The meaning of impact itself is the effect of one thing upon another.

Environmental Impact Assessment (EIA) also sometimes referred to, as Environmental Assessment (EA) is the information gathering and analytical process that helps to ensure environmentally sound development. The EIA process attempts to identify potential problems so that economic feasibility (and environmental impact) of alternative approaches can be assessed for which there is still time to make changes. The purpose of EIA is to ensure that the development options under consideration are environmentally aspect and sustainable, and that any environment consequences are recognized early in the project cycle and taken into account in project design. EIA identifies ways of improving projects environmentally and minimizing, mitigating, or compensating for adverse impacts (Clark, B.O et al, 1980)

Water pollution has many sources. The most polluting of them are the city sewage and industrial waste discharged into the rivers. Due to this, pollutants enter groundwater, rivers, and other water bodies. Such water, which ultimately ends up in our households, is often highly contaminated and carries disease-causing microbes. Agricultural run-off, or the water from the fields that drains into rivers, is another major water pollutant as it contains fertilizers and pesticides (Metcalf and Eddy, 1991)

Particular attention is the quality of water. The water with worse quality will give a bad impact to health of the people around there. The effects of water pollution are not only devastating to people but also to animals, fish, and birds. Polluted water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of lakes and rivers. More seriously, contaminated water destroys aquatic life and reduces its reproductive ability. Eventually, it is a hazard to human health.

Regarding to Deesawasmongkol (2003), classes of pollutants typically found in urban storm water runoff could be:

- Total Coliform bacteria
- Suspended Sediments
- Nutrients
- Organics
- Oxygen Demanding Substance

3.1.3. Environmental Impact Assessment of Water Quality Analysis in Naivasha Town

The quality of the water that flows from the town to Naivasha Lake, were sampled from four different sources: borehole, tap water, runoff, and sewage were collected. The distribution of the samples collected is:

- 4 samples of borehole water, which are the borehole of the municipality (Table 2-1)
- 2 samples of tap water, these which are tap water from the municipality and "La Belle Inn"(Table 2-1)
- 7 samples of runoff water, these samples are the outlet of the each drainage area for runoff (Table 2-4)
- 9 samples of sewage water, these samples are the main channel in the town (Table 2-3)

The field survey for water quality was done from 16th of September until 10th of October 2003. Especially for samples collected from Naivasha Town, it was done from 27th of September until 8th of October 2003. Some of those parameters were analysed in the field and the other parameters were analysed in the ITC laboratory. The results of the water quality analysis is presented in Table 3-1

Table 3-1 Analysis results of Naivasha water samples

Parameters	Unit	Borehole				Tap Water		Sewage									Runoff						
		B1	B2	B3	B4	T1	T2	S1	S2	S3	S4	S5	S6	S7	S8	S9	R1	R2	R3	R4	R5	R6	R7
Temperature	^{o}c	18.3	18.7	18.1	19.1	19.1	18.5	22.7	22.7	22.8	22.9	22.3	20	22.7	22.5	22.7	21.5	22.4	22.5	21.3	21.2	21.6	21.2
pH		7.12	7.25	7.14	6.75	7.25	7.8	6.89	7.25	6.67	6.95	7.23	7.12	7.04	8.33	8.26	7.08	7.05	7.5	7.88	7.38	7.92	7.78
Turbidity	NTU	1.18	1.27	0.46	0.26	7.15	0.5	300	70.7	202	353	225	86.5	67.9	149	286	24000	3000	3000	896	4000	3000	1257
Alkalinity	mmol/l	1	1	1	1	15.5	6.5	16.5	20	26.5	22.5	27.5	23	14.5	29.6	27	15	3.5	2.5	1.5	3.5	4	2.6
TDS	mg/l	3.685	3.162	3.437	2.492	3.283	3.544	0.06	0.054	0.04	0.074	0.73	0.235	0.402	1.005	0.737	1.474	1.206	1.139	1.206	1.474	0.938	0.536
DO	mg/l	5.5	4.72	5.13	3.72	4.9	5.29	0.09	0.08	0.06	0.11	1.09	0.35	0.6	1.5	1.1	2.2	1.8	1.7	1.8	2.2	1.4	0.8
Nitrate	mg/l	5	4	1	1	5	3	2	2	2	2	3	2	1	2	1	6	21	18	25	40	99	45
Nitrite	mg/l	0.8	0.5	0.6	0.5	0.7	0.7	1.1	0.8	0.8	0.8	1	0.8	0.7	0.6	0.5	1.7	2.4	2.7	1.9	4.5	3.3	4.3
Ammonia	mg/l	0.4	0.4	0.4	0.4	0.4	0.4	134	138	138	36	186	192	2.5	2.5	2.5	30	2.5	2.5	2.5	27	36	20
Phosphate	mg/l	9	8	8	6	13	6	82	57	57	78	173	88	28	105	73	43	9	13	7	10	18	5
EC	µs/cm	743	774	680	413	1888	755	2600	2560	2560	3530	4350	3710	1407	4230	3590	1150	548	471	302	428	664	538
Chloride	mg/l	30	20	30	10	120	30	170	160.3	130	250	310	170	60	300	250	80	80	30	20	20	40	30
E-Coli	CFU/ml	4	4	32	0	5	14	76	53	90	180	150	>2000	27	80	61	-	-	-	-	-	-	-
Total Coliform	CFU/ml	8	12	62	2	10	17	150	160	>2000	>2000	>2000	>2000	190	>2000	>2000	-	-	-	-	-	-	-
COD	mg/l	37	40	42	20	1	1	1584	260	1360	1329	1225	1116	1552	1128	277	156	170	230	96	250	270	270
Sulphate	mg/l	44	22	23	12	2	2	34	22	142	178	168	66	38	72	78	26	82	56	18	78	120	124
Fluoride	mg/l	0.9	0.91	0.91	0.83	0.98	0.83	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Al	mg/l	0.02	0.06	0.01	0.06	0.11	0.06	0.12	0.08	0.21	0.32	0.64	0.23	0.17	0.29	0.21	0.30	0.42	0.20	0.60	0.58	1.44	0.81
Ca	mg/l	8.0	8.5	8.0	18.8	13.5	13.5	20.1	40.6	30.1	24.3	21.2	31.7	18.8	34.8	26.8	39.2	48.4	68.4	21.8	44.8	55.6	40.1
Cd	mg/l	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cu	mg/l	0	0	0	0	0	0	0	0	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0
Fe	mg/l	0.01	0.01	0.01	0.60	0.06	0.02	0.12	0.07	0.35	0.51	0.69	0.29	0.17	0.54	0.40	1.15	2.79	4.25	0.55	2.09	1.74	2.29
K	mg/l	19.5	20.3	20.5	12.3	15.6	17.4	47.9	76.4	183.5	148.1	157.5	126.8	55.7	77.9	158.3	31.3	27.9	25.0	19.9	29.5	50.4	26.6
Li	mg/l	0.09	0.07	0.06	0.03	0.02	0.02	0.09	0.07	0.06	0.08	0.06	0.09	0.10	0.08	0.06	0.04	0.02	0.02	0.01	0.02	0.04	0.02
Mg	mg/l	0.54	0.67	0.79	1.99	2.22	2.17	4.64	10.86	17.86	17.64	16.19	9.55	5.31	11.14	2.06	3.52	3.6	3.25	1.67	3.95	6.56	3.05
Mn	mg/l	0	0	0	0.02	0	0	0.12	0.24	0.22	0.37	0.44	0.11	0.20	0.42	0.01	1.26	2.19	2.44	0.59	2.96	2.39	2.25
Na	mg/l	125.0	124.8	107.4	57.1	51.6	52.8	182.4	187.7	288.0	278.3	291.8	273.3	191.2	193.8	282.8	88.8	61.6	51.4	33.3	45.3	62.5	58.5
Pb	mg/l	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zn	mg/l	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.10	0.10	0.10	0.04	0.03	0.06	0.05	0.04	0.02	0.01	0.14	0.01	0.03	0.02

3.2. Water Quality Analysis

3.2.1. Analysis Water Quality Using Aquachem

The results of water quality assessment either in the field or in the laboratory were used as input for characterising the water quality. Aquachem, a software package developed specifically for graphical and numerical analysis and modelling of water quality data, was used in this study. Aquachem was used to analysing the groundwater supply wells, identifying concentrations of pollutants of the sample sites and provide the reports of analyses. The result then compared with the limits of contaminations as defined in the guideline for water quality (Calmbach.L, 1998).

A list of the parameters was input to Aquachem in format of ASCII file (filename.txt). The major ions that must be present as inputs are: Na, Ca, Mg, Cl, SO4, and HCO3. In case of one parameter is absence, the Aquachem software can estimate the concentration for the missing major parameter. The concentration of the missing ion is calculated using the theoretical ion balance between the major ions. This does not work if more than one of either major cations or anions is missing in the analysis.

The sum of anions and cations, expressed as milliequivalents per litre, must be balanced since all potable waters are electrically neutral. The test is based on the percentage difference computed by the equation as follows:

$$\%\ difference = 100\frac{\sum cations - \sum anions}{\sum cations + \sum anions}$$

Equation 3-1 Percentage of balance between cations and anions

The acceptable interval is approximately 10 %. However, it depends on the type of the water sampled. The 10 % interval is only valid for drinking water sample, the other may have interval more than 10 %. The electro neutrality results for the water sample of Naivasha town are given in the following table:

Table 3-2 Difference of anions and cations

Samples	Anions (-)	Cations (+)	Anion-Cations Balance (%)	Samples	Anions (-)	Cations (+)	Anion-Cations Balance (%)
B1	6.01	6.48	3.8	R6	7.63	10.67	16.6
B2	6.02	6.53	4.1	R7	5.52	7.42	14.7
B3	5.2	5.75	5.1	S1	9.35	19.96	36.2
B4	3.65	3.93	3.8	S2	11.12	18.01	23.7
T1	3.56	3.53	-0.4	S3	15.53	25.38	24.1
T2	3.21	3.62	6	S4	14.8	23.63	23
R1	6.53	9.22	17.1	S5	15.13	27.93	29.7
R2	5.73	8.69	20.5	S6	14.29	26.67	30.2
R3	6.23	8.38	14.7	S7	9.71	15.64	23.4
R4	1.9	4.68	42.3	S8	11.12	16.96	20.8
R5	5.18	8.27	23	S9	13.82	22.23	23.3

The differences over the acceptable criteria are related to several factors:

1. Type of water
2. The use of different equipments
3. Some of the parameters were not analysed on the same day, so the property of the samples were changed (like COD, Fluoride, Sulphate and Cations)

Chemical that determine the type of water are calculated by converting the value in milliequivalents per litre of the cations (Na, Ca, Mg) and anions (Cl, SO4, HCO3) to percentages. The water type expression then determined by listing the major ions in order of ion composition. The cations listed first and followed by the anions, considering the composition of each ion and listed in descending order.

Table 3-3 Type of the water samples based on Aquachem

Sample ID	Resulting water type	Sample ID	Resulting water type
B1	Na-HCO_3	R6	NH_4-Ca-Na-SO4-HCO_3
B2	Na-HCO_3	R7	Na-Ca-NH_4-SO_4-HCO_3
B3	Na-HCO_3	S1	NH_4-Na-Cl-HCO_3
B4	Na-Ca-HCO_3	S2	Na-NH_4-HCO_3-Cl
B5	Na-Cl	S3	Na-NH_4-K-HCO_3
B6	Na-HCO_3-Cl	S4	Na-NH_4-Cl-HCO_4
R1	Na-NH_4-Ca-HCO_3	S5	Na-NH_4-Cl
R2	Na-NH_4-Ca-Cl-SO_4	S6	Na-NH_4-HCO3-Cl
R3	Ca-Na-NH_4-HCO_3	S7	Na-NH_4-HCO_3
R4	NH_4-Na	S8	Na-NH_4-Cl
R5	NH_4-Ca-Na-HCO_3	S9	Na-NH_4-K-Cl-HCO_3

For runoff and sewage water samples, K+ and NH4- are also present as a major cation and anion, therefore indicates that the water sampled are polluted.

The report of the water quality analysis in Aquachem comprises of:

- Water type: expressed by the list of major ions in descending order based in the composition, where cations were listed first and anions were listed afterwards.
- Ion balance: expressed by the balance of sum of anions and cations. This value is useful for evaluating the water quality (value should be < 5 %, but < 10 % still accepted) and to find out error in the input data (see Table 3-2).
- Hardness: expressed by the sum of ions that can be precipitated from water as hard particles.
- Concentrations: expressed by the concentrations of major parameters in mg/l, mmol/l, meg/l, and meg %
- Ion ratios: expressed by the amount of Na/Cl, Ca/SO4, and Ca/Mg, Cl/Br compared to corresponding ratios that usually found in the seawater.
- Dissolved minerals: expressed by the weight in mg/l of the following minerals: halite, sylvite, anhydrite, calcite, chalcedony, or Na feldspar.

The general report of each sample can be seen in Appendix A.

Regarding the water quality, only the borehole and tap water samples were adequately fulfil drinking water regulations. The water quality regulations report lists all the parameters of the selected records that exceed recommended limits. Each line of the report contains the actual value, a recommended tolerance interval, and a maximum tolerance interval. List of parameters for water that suitable for irrigation purposes also mentioned in the report (Lloyd and Heathcote, 1985 cited in Calmbach, 1998).

The results also described in graphs. In the piper graphs, major ions are plotted as cation and anion percentages of milliequivalents in two base triangles. Those data can be projected into the square grid. Every sample is represented by three data points: one in each triangle and one in square grid. The main purpose of the piper graphs is to show the clustering of the sample. The piper graphs for each sample can be seen in figure B.1

A stiff graph is constructed by plotting the milliequivalents per litre of three or more anions and three or more cations. These graphs can be used to evaluate the change in a water quality at a single location over a period of time, or to evaluate the change in water quality as the water passes through different geologic formations or different subsurface conditions. The results of each sample can be seen in figure B.2.

3.2.2. General Water Quality Analysis of Drinking Water, Sewage, and Runoff Samples of Naivasha Town

3.2.2.1. Water Quality Analysis of Drinking Water Samples

Groundwater used for drinking water should be monitored for variables that may pose a potential human health risk. Guidelines for maximum levels of such variables in drinking water have been set by several organizations. One of them is WHO (World Health Organization). This organization made the standardization of drinking water to help the supply of public health water. When the result from field and laboratory compared with the standard of WHO, there were some parameters that have higher value than the WHO standard. In Table 3-3 the average pollutions of the borehole sample is shown.

Table 3-4 Comparison between the results of drinking water quality in the field and laboratory with WHO Standard

Parameters	Borehole				Tap Water		WHO	Unit
	B1	B2	B3		T1	T2		
Temperature	18.3	18.7	18.1	19.1	19.1	18.5	-	°C
pH	7.12	7.25	7.14	6.75	7.25	7.8	<8.0	
Turbidity	1.18	1.27	0.46	0.26	***7.15***	0.5	***5***	NTU
Alkalinity	1	1	1	1	15.5	6.5	-	mmol/l
TDS	3.575	3.068	3.3345	2.418	3.283	3.5443	1000	mg/l
DO	5.5	4.72	5.13	3.72	4.9	5.29	-	mg/l
Nitrate	5	4	1	1	5	3	50	mg/l
Nitrite	0.8	0.5	0.6	0.5	0.7	0.7	3	mg/l
Ammonia	0.4	0.4	0.4	0.4	0.4	0.4	1.5	mg/l
Phosphate	9	8	8	6	13	6	-	mg/l
EC	743	774	680	413	1888	755	-	µS/cm
Chloride	30	20	30	10	120	30	250	mg/l
E-Coli	***4***	***4***	***32***	***0***	***5***	***14***	***ND***	CFU/ml
Total Coliform	***8***	***12***	***62***	***2***	***10***	***17***	***ND***	CFU/ml
COD	37	40	42	20	1	1	-	mg/l
Sulphate	44	22	23	12	2	2	250	mg/l
Fluoride	0.9	0.91	0.91	0.83	0.98	0.83	1.5	mg/l
Al	0.02	0.06	0.01	0.06	0.11	0.06	0.20	mg/l
Ca	8.0	8.5	8.0	18.8	13.5	13.5	-	mg/l
Cd	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.01***	***0.003***	mg/l
Cu	0	0	0	0	0	0	1	mg/l
Fe	0.01	0.01	0.01	***0.60***	0.06	0.02	***0.30***	mg/l
K	19.5	20.3	20.5	12.3	15.6	17.4	-	mg/l
Li	0.09	0.07	0.06	0.03	0.02	0.02	-	mg/l
Mg	0.54	0.67	0.79	1.99	2.22	2.17	-	mg/l
Mn	0	0	0	0.02	0	0	0.1	mg/l
Na	125.0	124.8	107.4	57.1	51.6	52.8	-	mg/l
Pb	0	0	0	0	0	0	0.01	mg/l
Zn	***0.01***	***0.01***	***0.01***	**0.02**	***0.01***	***0.01***	***0.001***	mg/l

In Table 3-4 it is shown that some parameters exceed the WHO standard, for example, in all samples of drinking water, E-Coli, total colifrom, Cd, and Zn is higher than the threshold value of the WHO standard, whereas for turbidity and Fe, only one drinking water sample was found higher than the threshold value of the WHO standard.

- Total bacteria: The surrounding of the boreholes and wells was contaminated by the E-Coli, which only comes from human and animal faecal waste. The presence of E-Coli potentially indicates the presence of other bacteria
- Cd: This parameter comes from corrosion of water supply pipe, erosion of natural deposits, and runoff. One extreme effect of the presence of Cd in drinking water is the malfunction of the human's kidney.
- Zn: The maximum concentration of Zinc allowed in drinking water, based on WHO standard, is 0.001 mg/l. In addition, there is no significant health effect caused by the presence of Zn in drinking water. The factors that inhibit zinc concentration in natural water are interaction of pre-existing mineral surface through simple adsorption, or a co precipitation process.

- Fe: This parameter comes from the corrosion of water supply pipe and erosion of natural deposit. The effect of this parameter for children is the delay in physical or mental development and for adult is kidney problem and high blood pressure.
- Turbidity: It caused by runoff. This indicates the presence of microorganism.

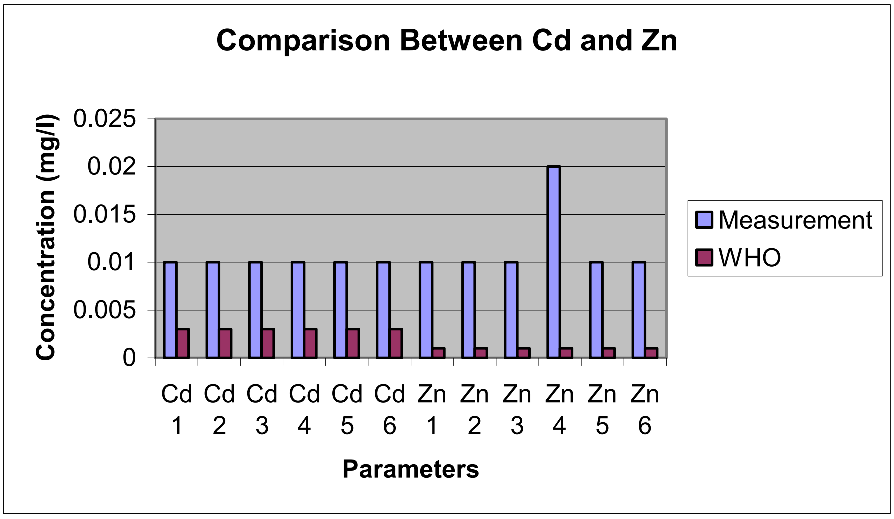


Figure 3-1 Comparison of Cd and Zn measurement and WHO Standard

Univariate statistics of drinking water samples were calculated and presented in Table 3-5. From that summary, the maximal concentration of total bacteria, Cd, Fe, and Zn is higher than WHO Standard.

Table 3-5 Summary of univariate statistic of drinking water samples

Parameters	Unit	Max	Min	Mean	Median
Temperature	°C	19.1	18.1	18.633	18.6
pH		7.8	6.75	7.2183	7.195
Turbidity	NTU	7.15	0.26	1.8033	0.84
Alkalinity	mmol/l	15.5	1	4.3333	1
TDS	mg/l	3.58	2.418	3.2038	3.309
DO	mg/l	5.5	3.72	4.8767	5.015
Nitrate	mg/l	5	1	3.1667	3.5
Nitrite	mg/l	0.8	0.5	0.6333	0.65
Ammonia	mg/l	0.4	0.4	0.4	0.4
Phosphate	mg/l	13	6	8.3333	8
EC	μS/cm	1888	413	875.5	749
Chloride	mg/l	120	10	40	30
E-Coli	CFU/ml	32	0	9.8333	4.5
Total Coliform	CFU/ml	62	2	18.5	11
COD	mg/l	42	1	23.5	28.5
Sulphate	mg/l	44	2	17.5	17
Fluoride	mg/l	0.98	0.83	0.8933	0.905
Al	mg/l	0.11	0.01	0.05	0.06
Ca	mg/l	18.8	7.98	11.71	10.98
Cd	mg/l	0.01	0.01	0.01	0.01
Cu	mg/l	0	0	0	0
Fe	mg/l	0.6	0.01	0.1183	0.015
K	mg/l	20.5	12.32	17.608	18.46
Li	mg/l	0.09	0.02	0.0483	0.045
Mg	mg/l	2.22	0.54	1.3967	1.39
Mn	mg/l	0.02	0	0.0033	0
Na	mg/l	125	51.58	86.427	82.21
Pb	mg/l	0	0	0	0
Zn	mg/l	0.02	0.01	0.01	0.01

In Table 3-5, the maximum concentration of EC is extremely high. This extraordinary value comes from the concentration of EC in the sample of tap water no 1. This fact implies that water provided from tap water no 1, is not advisable to use for drinking water. This was confirmed by the finding of previous study (Natalie E. Morgan, 1998), which shows the extreme concentration of EC (1450 μS/cm). This is because the borehole has already contaminated.

3.2.2.2. Water Quality Analysis of Sewage and Runoff Samples

The contamination sources of sewage and runoff pollutant are non point sources. Such pollutants are originated from water flows over the land surface. Various land use types such as urban, agriculture, and natural (runoff), produce predominantly non point sources.

Typical influent concentrations of municipal wastewater treatment plants are shown in Table 3-6.

Table 3-6 Typical influent municipal waste concentrations (Maidment, 1992)

Constituent	Concentration, mg/l		
	Strong	*Medium*	*Weak*
Solid total	1200	720	350
Dissolved, total	850	500	250
Fixed	525	300	145
Volatile	325	200	105
Suspended, total	350	220	100
Fixed	75	55	20
Volatile	275	165	80
Settable solids, ml/L	20	10	5
Biochemical oxygen demand, 5 day, 20, (BOD5 20)	400	220	110
Total Organic Carbon (TOC)	290	160	80
Chemical oxygen demand (COD)	1000	500	250
Nitrogen (total as N)	85	40	20
Organic	35	15	8
Free Ammonia	50	52	12
Nitrites	0	0	0
Nitrates	0	0	0
Phosphorus (total as P)	15	8	4
Organic	5	3	1
Inorganic	10	5	3
Chlorides	100	50	30
Alkalinity (as CaCO3)	200	100	50
Grease	150	100	50

Apart from wastewater treatments, the range of typical concentration for water quality parameter in streams and rivers is well documented in Maidment (1992).

A univariate statistic calculation for sewage and runoff were done to define and summarize the average, minimum and maximum pollutants of the samples.

Table 3-7 Summary of univariate statistic of sewage water samples

Parameters	Unit	Max	Min	Mean	Median
Temperature	°C	22.9	20	22.37	22.7
pH		8.33	6.67	7.304	7.12
Turbidity	NTU	353	67.9	193.3	202
Alkalinity	mmol/l	29.6	14.5	23.01	23
TDS	mg/l	1.005	0.04	0.371	0.2345
DO	mg/l	1.5	0.06	0.553	0.35
Nitrate	mg/l	3	1	1.889	2
Nitrite	mg/l	1.1	0.5	0.789	0.8
Ammonia	mg/l	192	36	137.3	138
Phosphate	mg/l	173	28	82.33	78
EC	μS/cm	4350	1407	3171	3530
Chloride	mg/l	310	60	200	170
E-Coli	CFU/ml	-	-	-	-
Total Coliform	CFU/ml	190	150	166.7	160
COD	mg/l	1584	260	1092	1225
Sulphate	mg/l	178	22	88.67	72
Al	mg/l	0.64	0.08	0.252	0.21
Ca	mg/l	40.6	18.75	27.6	26.81
Cd	mg/l	0.01	0.01	0.01	0.01
Cu	mg/l	0	0	0	0
Fe	mg/l	0.69	0.07	0.349	0.35
K	mg/l	183.5	47.9	114.7	126.78
Li	mg/l	0.1	0.06	0.077	0.08
Mg	mg/l	17.86	2.06	10.58	10.86
Mn	mg/l	0.44	0.01	0.237	0.22
Na	mg/l	291.8	182.4	241	273.31
Pb	mg/l	0	0	0	0
Zn	mg/l	0.1	0.02	0.059	0.05

By comparing the maximum concentration of the sewage samples with the typical influent Municipal waste concentration in Table 3-6, it could be concluded that the Naivasha sewage samples has a large concentration (except for alkalinity). As an implication, the sewage of Naivasha Town needs to be reduced before it flows to the lake. Otherwise, it will pollute the lake.

Table 3-8 Comparison between pollutant input and output waste water treatment plan

Parameters	Unit	WWTP	
		Input	*Output*
Temperature	°C	20	22.7
pH		7.12	7.25
Turbidity	NTU	86.5	70.7
Alkalinity	mmol/l	23	20
TDS	mg/l	0.228	0.052
DO	mg/l	0.35	0.08
Nitrate	mg/l	2	2
Nitrite	mg/l	0.8	0.8
Ammonia	mg/l	192	138
Phosphate	mg/l	88	57
EC	μS/cm	3710	2560
Chloride	mg/l	170	160.3
E-Coli	CFU/ml	>2000	53
Total Coliform	CFU/ml	>2000	160
COD	mg/l	1116	260
Sulfate	mg/l	66	22
Al	mg/l	0.23	0.08
Ca	mg/l	31.66	40.6
Cd	mg/l	0.01	0.01
Cu	mg/l	0	0
Fe	mg/l	0.29	0.07
K	mg/l	126.8	76.38
Li	mg/l	0.09	0.07
Mg	mg/l	9.55	10.86
Mn	mg/l	0.11	0.24
Na	mg/l	273.3	187.7
Pb	mg/l	0	0
Zn	mg/l	0.04	0.03

Table 3-8 shows that the waste from Naivasha town was decreased through Waste Water Treatment Plant (WWTP). WWTP in Naivasha town comprises of sludge-drying bed, 2 aerated lagoon and 3 maturation ponds. All units used for biological treatment of wastewater. The units are used to convert the finely divided and dissolved organic matter and inorganic matter in wastewater. In contrast, this WWTP does not work efficiently. The evidence of this statement is the fact that these units only decreased the concentration of COD for 76 % (see Table 3-8) instead of the optimal condition where the units should decrease COD for 80 – 85 % (Metcalf and Eddy, 1991).

Table 3-9 Summary of univariate statistic of runoff water samples

Parameters	Unit	Max	Min	Mean	Median
Temperature	°C	22.5	21.2	21.5	21.5
pH		7.92	7.05	7.5	7.5
Turbidity	NTU	24000	896	3000	3000
Alkalinity	mmol/l	15	1.5	3.5	3.5
TDS	mg/l	1.474	0.536	1.206	1.206
DO	mg/l	2.2	0.8	1.8	1.8
Nitrate	mg/l	99	6	25	25
Nitrite	mg/l	4.5	1.7	2.7	2.7
Ammonia	mg/l	36	20	28.5	28.5
Phosphate	mg/l	43	5	10	10
EC	μS/cm	1150	302	538	538
Chloride	mg/l	80	20	30	30
COD	mg/l	270	96	230	230
Sulphate	mg/l	124	18	78	78
Al	mg/l	1.44	0.2	0.58	0.58
Ca	mg/l	68.38	21.81	44.76	44.76
Cd	mg/l	0.01	0.01	0.01	0.01
Cu	mg/l	0	0	0	0
Fe	mg/l	4.25	0.55	2.09	2.09
K	mg/l	50.37	19.89	27.87	27.87
Li	mg/l	0.04	0.01	0.02	0.02
Mg	mg/l	6.56	1.67	3.52	3.52
Mn	mg/l	2.96	0.59	2.25	2.25
Na	mg/l	88.81	33.27	58.49	58.49
Pb	mg/l	0	0	0	0
Zn	mg/l	0.14	0.01	0.02	0.02

To identify whether the water from the sewage and runoff water samples potentially contribute to the pollution of Naivasha Lake, the results of the water quality analysis of those samples were compared with the EPA Water Quality Standard for Aquatic Life. According to the EPA, two standards are used, *i.e,* The Criteria Maximum Concentration (CMC) and the Criterion Continuous Concentration (CCC). CMC is an estimation of the highest concentration of a material in surface of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable effect. Then CCC is estimation of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect.

Table 3-10 Comparisons between maximum measured concentrations of pollutant in sewage and runoff samples with EPA Aquatic Life Standard

Parameters	Unit	EPA Standard		Sewage	Runoff
		CMC	*CCC*		
Temperature	°C			22.9	22.5
pH			6.5 - 9	8.33	7.92
Turbidity	NTU			353	24000
Alkalinity	mmol/l		400	29.6	15.0
TDS	mg/l			1.0	1.5
DO	mg/l			1.5	2.2
Nitrate	mg/l			3.0	99.0
Nitrite	mg/l			1.1	4.5
Ammonia	mg/l			192.0	36.0
Phosphate	mg/l			173.0	43.0
EC	μS/cm			4350.0	1150.0
Chloride	mg/l	0.019	0.011	310.0	80.0
E-Colli	CFU/ml			-	
Total Coliform	CFU/ml			190	
COD	mg/l			1584	270
Sulfate	mg/l			178	124
Al	mg/l			0.64	1.44
Ca	mg/l			40.60	68.38
Cd	mg/l	0.0043	0.0022	0.010	0.010
Cu	mg/l	0.013	0.09	0	0
Fe	mg/l		1	0.7	4.3
K	mg/l			183.5	50.4
Li	mg/l			0.1	0.0
Mg	mg/l			17.9	6.6
Mn	mg/l			0.4	3.0
Na	mg/l			292	89
Pb	mg/l	0.065	0.025	0	0
Zn	mg/l	0.120	0.120	0.1	0.14

As can be seen in Table 3-10, most of the maximum concentrations of the measured parameters are exceeding the EPA aquatic life standard.

According to the results of comparisons of measured parameters with typical influent municipality and EPA aquatic life standard, the concentration of pollutants in the sewage and runoff samples of Naivasha Town is higher than the two standards. Those pollutants are:

- Nitrogen (Ammonia, Nitrate and Nitrite) and Phosphate: These pollutants are nutrients for living or algae growth. At elevated levels, algae upset the normal ecosystem balance and decay of algae depletes the water's oxygen supply. Comparing with typical influent municipality and EPA aquatic life standard, the value of Ammonia (192 mg/l) and phosphate (173 mg/l) is indicated as strong concentration.
- COD: COD is the important pollutant to be measured concerning sewage network. COD is chemical oxygen demand. It means concentration of oxygen that involved in the chemistry reaction in the water. If concentration COD is higher, the oxygen supply for bacteria to do some re-

action is lower. It will affect the self-purification of the natural water. The higher maximum concentration of COD was obtained from sewage sample, which is 1584 mg/l.

- Total bacteria: Total bacteria determine the microbial quality of water. The higher pollutant of total bacteria makes water not suitable to use for human being. The average amount of total coliform from the sewage measurement is more than 2000 CFU/ml.

Concentration of those main pollutants then should be reduced in the wastewater treatment plant before reaching the lake.

3.2.3. Discussion of Each Parameter

Temperature

The temperature of water is a very important parameter since its effect on chemical reactions, aquatic life, and suitability of the water of beneficial uses (Chapman, 1992). The temperature of wastewater (20 - 22.9 °C) or runoff (21.2 – 22.5 °C) is higher than that of the drinking water (18.1 – 19.1 °C). This is because of the addition of warm water from households and industrial activities. It indicates the thermal pollution where the temperature changes affect the water. However this value is still acceptable because the range values of temperature observed in streams and rivers is 0 – 30 °C (Maidment, 1992).

pH

Measurement of pH is the most important and frequently used tests in determining the chemical and biological property of water. A pH range of 6.5 - 8.5 is adapted for best environmental and aesthetic results (Chapman, 1992). For the Naivasha water samples, the average pH range from 6.75 – 8.33. The range of drinking water is 6.75 – 7.8, for runoff samples between 7.05 – 7.92 and sewage sample is 6.67 – 8.33. These ranges are still within typical value (4.5 – 8.5) (Maidment, 1992).

Turbidity

Turbidity, a measure of the light-transmitting property of water, is another test used to indicate the quality of waste discharge and natural water with respect to colloidal and residual suspended matter. The more turbid the water the more microbes present (Chapman, 1992). The drinking water sample turbidity from water tap 1 is higher than the WHO standard; it has no health effects but can interfere with disinfections and provide a medium for microbial growth. The turbidity of runoff (896 – 24000 NTU) is higher than sewage (67.9 – 353 NTU) because runoff carries sand, mud, and sediment. The higher concentration of turbidity can affect the lake because the sediment that was carried by runoff will deposit in the lake and in the future can change the size of the lake.

Alkalinity

Alkalinity is more common than acidity (Weiner, 2000). Wastewater is normally alkaline (more alkaline than drinking water). It receives its alkalinity from the water supply, the ground water and material added during domestic activity. It can be shown from the univariate statistic table that the alkalinity of the sewage samples (maximum concentration is 29.6 mmol/l) is higher than alkalinity of the runoff samples (maximum concentration 15 mmol/l) and drinking water (maximal concentration is 15.5 mmol/l). It was exceeded the EPA standard of natural alkalinity in freshwater aquatic life, which is 20 mg/l. Even though 20 mg/l is recommended alkalinity for environmental water, based on Weiner (2000) alkalinity as $CaCO_3$ the level between 25 and 400 mg/l are generally beneficial for aquatic life. Alkalinity is positively related with pH, the higher pH, the higher alkalinity. From Table 3-6, the concentration of pollutants found in the sewage sample is low.

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is terms generally associated with freshwater systems and consists of inorganic salts, small amounts of organic matter, and dissolved material. TDS value may be obtained by multiplying the conductance of each sample by a factor, which is commonly between 0.55 and 0.75. For this analysis, 0.67 was used as a factor to determine the TDS value. This value usually used for the water that dominated by Na and Cl and for water that containing high concentration of sulphate (Chapman, 1992). TDS may have adverse effects on health and/or the durability of household appliances. From the result of water quality analysis, higher concentration of TDS was found in the drinking water sample (the range is from 2.418 – 3.58 mg/l). This value is under the typical value (73 – 89 mg/l) (Maidment, 1992).

Dissolved Oxygen (DO)

Determination of DO concentration is a fundamental part of a water quality assessment since oxygen is involved in, or influences, nearly all chemical and biological process within water bodies. DO is required for the respiration of aerobic microorganisms as well as all other aerobic life forms. The range of average DO is 15 mg/l at 0 °C to 8 mg/l at 25 °C. Concentration below 5 mg/l may adversely affect the functioning and survival of biological communities and below 2 mg/l may lead to the death of most fish (Chapman, 1992). From the result of the analysis, the DO of the drinking water sample (3.72 – 5.5 mg/l) is higher than runoff (0.8 – 2.2) and sewage (0.06 – 1.5). The DO concentration in Naivasha Lake is low with the average of 0.55 – 4.33 mg/l. This indicates that the water is polluted since the bacteria and organic matter use the oxygen to support their life in the water. It can be dangerous to the aquatic life and organisms that are responsible for the self-purification process in natural waters.

Nitrogen (Nitrate, Nitrite and Ammonia)

Nitrogen is comprised of organic nitrogen, ammonia, nitrate, and nitrite. For ammonia, a concentration >0.5 mg/l can cause significant toxicity to fish. A high concentration could be an indication of organic pollution such as from domestic sewage, industrial waste and runoff (Weiner, 2000). Therefore, ammonia is a useful indicator of organic pollution. The concentration of chloride of sewage water (36 – 192 mg/l) is higher; it means that the organic pollution in sewage is also higher. For drinking water (0.4 mg/l), it is less than samples from runoff (20 – 36 mg/l).

The standard of nitrate in drinking water is strict because the nitrate ion is reduced to nitrite ion in the saliva of humans. The nitrate may vary between 0 – 20 mg/l for wastewater effluents. In the case of extreme pollution, concentrations may reach 200 mg/l. However, 10 mg/l or greater of nitrate has been regarded as an indicator of pollutant from fertilizer, septic tank or cultivation of grassland (Chapman, 1992). In the Naivasha water samples, the average concentration of Nitrate is not really extreme. The higher concentrations are found in the runoff samples (6 – 9 mg/l) because runoff is a medium that carries nitrate to the surface water system. It means that the water is polluted.

The concentration of nitrite presently is low (except for the runoff water: 1.7 – 4.5 mg/l), but it can be very important in water pollution studies because it is extremely toxic to fish and other aquatic life. These values are still in the range of generally observed values (< 0.002 – 10 mg/l) (Maidment, 1992). High concentrations of nitrite are general indications of industrial effluent and associated with unsatisfactory microbiological quality in water. Higher concentrations of Nitrites usually not found in drinking water supplies. As can be seen in the Table 3-4 of drinking water samples: the concentration of nitrite is below the WHO standard. The presence of high nitrite is a sign of bacteria presence.

Phosphate

Phosphate is one of the forms of Phosphorus that is found in aqueous solutions. High concentration of phosphate indicates the presence of pollution and largely responsible for eutrophic conditions (Chapman, 1992). The concentration of Phosphate in sewage (28 – 173 mg/l) is higher than in runoff (5 – 43 mg/l). The principle cause of higher phosphate concentrations is due to human activities. There is no standard of Phosphate for drinking water. The standard for freshwater aquatic life based on EPA is 25 µg/l in the lake or 50 µg/l in any stream within the lake or reservoir. The concentration measured was exceeded that value, hence it may occasionally stimulate excessive growths of algae and other aquatic plants.

Electrical Conductivity (EC)

Electrical Conductivity (EC) is a measure of the ability of water to conduct an electric current. It is expressed as microsiemens per centimetre and related to the concentration of total dissolved and major ion. The normal concentration of EC is from 10 – 1000 µS/cm, but it may exceed 1000 µS/cm, especially in polluted water or those receiving large quantities of runoff. (Chapman, 1992) EC in sewage samples (1407 – 4350 µS/cm) is the highest concentration because of the elevated ability in the wastewater to conduct electricity.

Chloride

Another significance water quality parameter is the chloride concentration. The higher concentration of chloride can be taken as an indication that the body of water is being used for waste disposal. It can be seen from the higher concentration of sewage water (60 – 310 mg/l). Compared with Table 3-6, the concentration of chloride for sewage sample is categorised as strong because it contains more than 100 mg/l of chloride. Chloride concentration is often incorporated into assessments as an indication of possible faecal contamination or as a measure of the extent of the dispersion of sewage discharges in water bodies (Metcalft and Eddy, 1991).

Chemical Oxygen Demand (COD)

COD test is used to measure the content of organic matter of both waster water and natural water that contain compounds that are toxic to biological life. Concentrations of COD observed in surface water range from 20 mg/l or less unpolluted waters greater than 200 mg/l (Metcalf and Eddy, 1991). The concentration COD range from 23.5 mg/l (drinking sample) to 1584 mg/l (sewage sample). The concentration of COD categorised as strong concentration based on Table 3-6. Pollution source of COD is mainly from the sewage plant. This is confirmed by the highest concentration of COD in sewage plant, as compared to runoff and drinking samples. This is because there are more chemical processes in the sewage than runoff. In the sewage water sample no 2, the concentration of COD is lower than other samples. Sample sewage 2 is the point sample of the WWTP outlet. The WWTP reduces the concentration of COD, so the COD concentration in sewage 2 is lower than in other points.

In general COD is higher than BOD because more compounds can be chemically oxidized than can be biologically oxidized (Metcalf and Eddy, 1991). In this study there was no measurement of BOD because it needs five days for the measurement of BOD, while COD can be determined in three hours.

Sulphate

Sulphate occurs naturally in most water supplies and is present in wastewater as well. This can be seen from the concentration of sulphate in sewage. The concentration sewage (22 – 178 mg/l) is higher than runoff (18 – 124 mg/l). This is the sign of the presence of bacteria sulphur. The concentrations of Sulphate are not higher because usually the Sulphate concentration is arise from the leaching of Sulphur compounds (Weiner, 2000). For the drinking water, it is good to have a lower concentrations, because if the concentration more than 400 mg/l this may cause unpleasant taste on drinking water. The concentration of drinking water (2 – 44 mg/l) is below the WHO standard (250 mg/l).

Fluoride

The measurement of fluoride concentration was done only in the borehole and tap water. A concentration of fluoride that more than 1.5 mg/l (as a WHO standard) can reduce dental caries (Chapman, 1992). In this study, the concentration of fluoride in the drinking water samples is lower than 1.5 mg/l.

Cations

Cations of wastewater are usually supplied from commercial and industry activities. The cations have to be removed if the wastewater is going to be used for other purpose then drinking water. Traced quantities of many metals, such as nickel, manganese, lead, cadmium, zinc, copper, etc are important constituents of most water. US EPA considers eight trace elements as high priority: As, Cd, Cu, Pb, Hg, Ni, and Zn (Chapman, 1992). Zinc is a common pollutant in surface and groundwater, storm water runoff and industrial wastewater stream (Weiner, 2000). Higher concentrations of cadmium and zinc were found in the samples of drinking water. While for the samples from sewage and runoff:

- Al, Aluminium, the concentration is small (maximal concentration for sewage is 0.64 mg/l and runoff is 1.44 mg/l) because the typical value in streams and rivers is 50 mg/l
- Ca, Calcium, the concentration is higher (maximal concentration for sewage is 40.6 mg/l and runoff is 68.38 mg/l) because the typical value in the stream and river is 13 – 15 mg/l
- Cd, Cadmium, these concentration (maximal concentration for sewage and runoff is 0.01 mg/l) are small and still within the typical value range (0 – 5 mg/l)
- Cu (Copper) and Pb (Lead) are not found in sewage and runoff water
- Fe, Iron, maximal concentration for sewage is 0.69 mg/l and runoff is 4.25 mg/l. These concentrations are higher because the typical value for iron is 0.04 mg/l. This parameter can caused corrosion on the pipe.
- Maximal concentration Li (Lithium) for sewage is 0.1 mg/l and runoff is 0.04 mg/l and maximal concentration Zn (Zinc) for sewage is 0.1 mg/l and runoff is 0.14 mg/l. These concentration are small because the typical value for Li is 12 mg/l and Zn is 30mg /l
- For K (Potassium), the concentration of sewage (183.5 mg/l) and runoff (50.37 mg/l) is bigger because the typical value of K for streams and rivers is 1.3 – 2.3 mg/l
- It is also happened for Mg (Magnesium) and Na (Sodium). Maximal concentration of Mg for sewage is 17.86 mg/l and runoff is 6.56 mg/l is higher than typical value in stream and river 4 mg/l. For Na, maximal concentration for sewage is 291.8 mg/l and runoff is 88.81 mg/l. the typical values of Na in stream and river is 5.1 – 6.3 mg/l

- Mn, Manganese, has a lower concentration (maximal concentration for sewage is 0.44 mg/l and runoff 2.96 mg/l) than typical value in stream and river (8.2 mg/l). The standard of Manganese from EPA is 100 µg/l for protection of consumers of marine molluscs. (http://epa.gov/waterscience/standards/wqcriteria.html, January 2004)

Total Bacteria

Bacteriological water quality criteria are generally expressed in MPN (Most Probable Number) or determinations of microbial species populations. Some bacteria can be used as a parameter of the good water especially for drinking water (Chapman, 1992).

Total coliform is the standard indication for important contamination of drinking water. The drinking water should not contain coliforms.

E-Coli is a single species of faecal coliforms that occurs only in faecal matter from human and other warm-blooded animals. Hence, these bacteria can be used to indicate the presence of human faecal matter and other pathogens possibly associated with it.

Human beings who are infected with disease or who carries particular diseases will discharge these bacteria. That is the reason why drinking water should not contain the bacteria (http://www.who.int/water_sanitation_health/en/, December 2003)

In the drinking water sample, the E-Coli and total coliform still found even in the small amount. The amount of E-Coli is 32 CFU/ml and for total coliform is 62 CFU/ml. According to the standard of drinking water, bacteria should not present in the drinking water, especially in tap water. This explains why the water from the tap on Naivasha town cannot drink directly.

The standard of bacteria (E-Coli) for freshwater aquatic life is 126 per 100 ml. At this concentration, the water is proper for recreation (*e.g.* swimming).

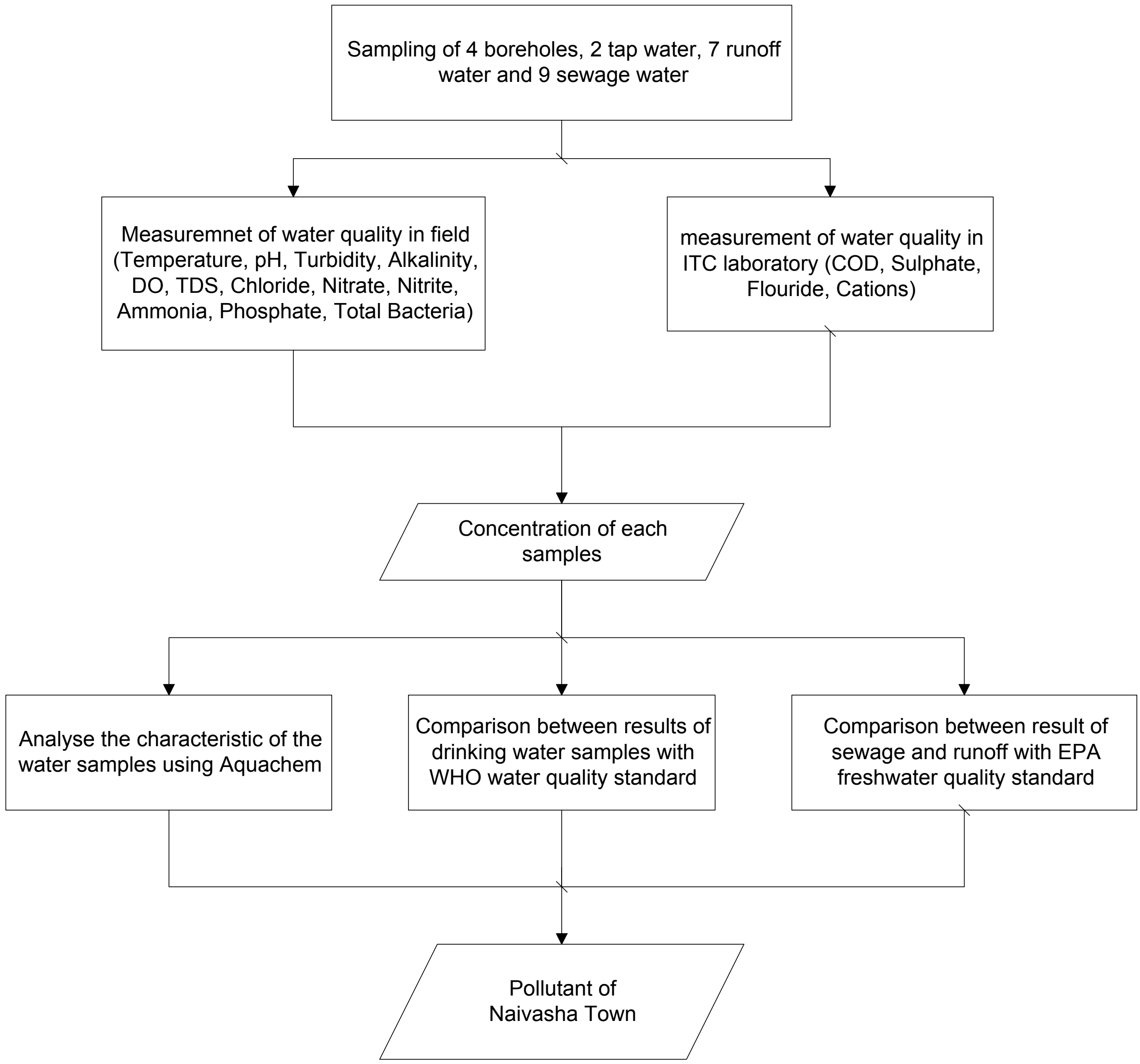


Figure 3-2 Flow Chart of methodology for analysing the water quality of Naivasha town

3.3. Conclusions

Water quality (a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose, such as evaluation of the stream water) is a very big issue today, partly because of the tremendous growth of the population and urban expansion and development.

The combined effects of population growth, urbanisation, and industrialisation change the hydrological response of the affected areas and cause various in environmental impacts. When urbanisation and industrialisation reach a certain degree or level of development, changes of the environment become inevitable.

Water that enters streams and rivers from urban areas can affect the aquatic life. To know the quality of the water from Naivasha Town, measurements of some parameter at various points in the town were done. 6 points of groundwater and drinking water, 7 samples of runoff and 9 samples of sewage water were taken. Some of the parameters were measured in the field and the rest were measured in the laboratory. An assessment was done to investigate whether or not water quality is adequately fulfil the criteria for specific purposes, such as drinking water supply, irrigation or industry. The results of the assessment facilitate the prediction of the total pollutant for the future from the Naivasha town to the lake Naivasha as the receiving water body.

In Naivasha, groundwater cannot drink without treatment. It is because some parameters in drinking water exceed the limit as defined in WHO standard guidelines. Some parameters that exceed are total bacteria, Cd, and Zn. Concentration of turbidity in sample water from tap water 1 and Fe in borehole 4 are higher than in others. Hence, water from these sources was polluted and need a treatment (such as boiling the water) before people can drink it.

Water quality assessments often examine the effects of specific activities on water quality. There should be continuous monitoring to assess the quality of drinking water in Naivasha. Typically such assessment is undertaken in relation to sewage and urban storm runoff water. The EC of the sewage water sample is higher than in other samples. Also for COD, the sewage water sample has a higher concentration because there is more chemical oxygen demand in sewage than in runoff. For the runoff water samples, the turbidity of runoff is higher because runoff carries sand, mud, sediment and other materials.

After comparison of measured water quality parameters with some standards (WHO and EPA), the potential pollutants from Naivasha town that may influence the water quality of Naivasha Lake are Ammonia, Nitrate, Nitrite, Phosphate, COD and total bacteria.

For assessment of the sewage in a Waste Water Treatment Plant, there should be measurement of BOD. The measurement of BOD is important because BOD approximately measures the amount of biochemical degradable organic matter present in a water sample. But in this study there was lack of measurement of BOD due to time constraint in which measuring COD was more practical.

The concentration of COD and total bacteria resulted from analysis of Naivasha water quality samples, especially in the sewage point 2, which is the outflow of Waste Water Treatment, is not very high. But it does not mean that the sewage from Naivasha Town does not significantly affect the Lake Naivasha. Currently, only around 10 – 15 % of the residential area connected to the sewage network. With the increase of the number of residential area connected to the sewage network, the concentration of COD and total bacteria may increase as well.

On the other side, the Waste Water Treatment Plant does not operate well as required, as indicated by the poor quality of the effluent (300 mg/l BOD) compared to the effluent discharge standard of 20 mg/l BOD (Development Impact Consulting, 2000).

4. Classification of Paved (Impervious) Surfaces and Unpaved (Pervious) Surfaces from IKONOS Using e-Cognition

4.1. Introduction

The next step in this research was the classification from the IKONOS image using the software eCognition.

The information contents such as area (town) are very detailed (like some buildings, trees, roads) so information extraction currently is performed on the basis of visual interpretation of very high-resolution aerial photograph or image. It will add significantly to the level of detail and efficiency of current efforts attempting to understand and model the water quality. Therefore, using the IKONOS image should be an alternative during this analysis.

eCognition follows an object-oriented approach towards image analysis, provided set a bundle of innovative features and techniques for efficient image analysis. In contrast to traditional image processing methods, the basic processing units of object oriented image analysis are image objects or segments, and not single pixels. The segments are subsequently classified using combinations of spectral and spatial information

The principal concept behind eCognition is that important semantic information necessary to interpret an image is not represented by single pixels, but in meaningful image objects and their mutual relationships. The basic difference especially when compared to pixel-based procedures, is that eCognition doe not classify single pixels, but rather image object which are extracted in a previous image segmentation step (Team Definiens Imaging, 2000)

4.2. Class Description

The final classes used only two classes; they are unpaved and paved areas. This information will be used for Simple Storm water Pollutant Model in the next step.

4.2.1. Paved/Impervious Area

Impervious surfaces can be generally defined as any material- of natural or anthropogenic source that prevents the infiltration of water into the soil and thereby changing the flow dynamics, sedimentation load, and pollution profile of storm water runoff (Slonecker, E.T, 2001).

It can be defined also as any surface which water cannot penetrate, like paved road, sidewalks, building, etc. In urban area, it can be divided into categorized belonging to the transportation (paved road, parking lots, etc) and rooftops (building, house, etc).

During urbanization, pervious spaces, including vegetated and open forested areas, are converted to land uses that usually have increased areas of impervious surface, resulting in increased runoff volumes (because it will be decreasing the infiltration capacity) and pollutant loadings (Slonecker, E.T, 2001).

4.2.2. Unpaved/Pervious Area

The contrary of paved/impervious surfaces are unpaved/pervious surfaces, which are surfaces that allow water to infiltrate into the soil. The unpaved/previous surfaces in urban area are gardens, bare lands, agriculture land, and parks.

4.3. Classification Using eCognitions

4.3.1. Multi-resolution Segmentation Process

In eCognition, features for classification are computed based on image objects, not on single pixels. Therefore, classification can address an astonishingly broad spectrum of different kinds of information. Beyond the spectral information there is shape information, texture information and operating over the network of image objects, many different relational or context features.

First, four layers from IKONOS which already were georeferenced were imported into eCogniton. eCogniton supports a variety of raster file formats including the most commonly used. The *.img Erdas Imagine Images format was used to import the image into eCognition. After importing the image, the priority of layer that will be used for classification processing can be assigned (the layers are assigned using false colour)

Multi-resolution segmentation is a method of generating image objects with different resolution and high quality. The resulting image segmentation can be universally applied to almost all the data types (IKONOS, Quick bird, Landsat TM, and Aerial Photo). It is especially suited for high-resolution data or highly textured data. Several parameters should be set to segment an image, like shown in Figure 4-1:

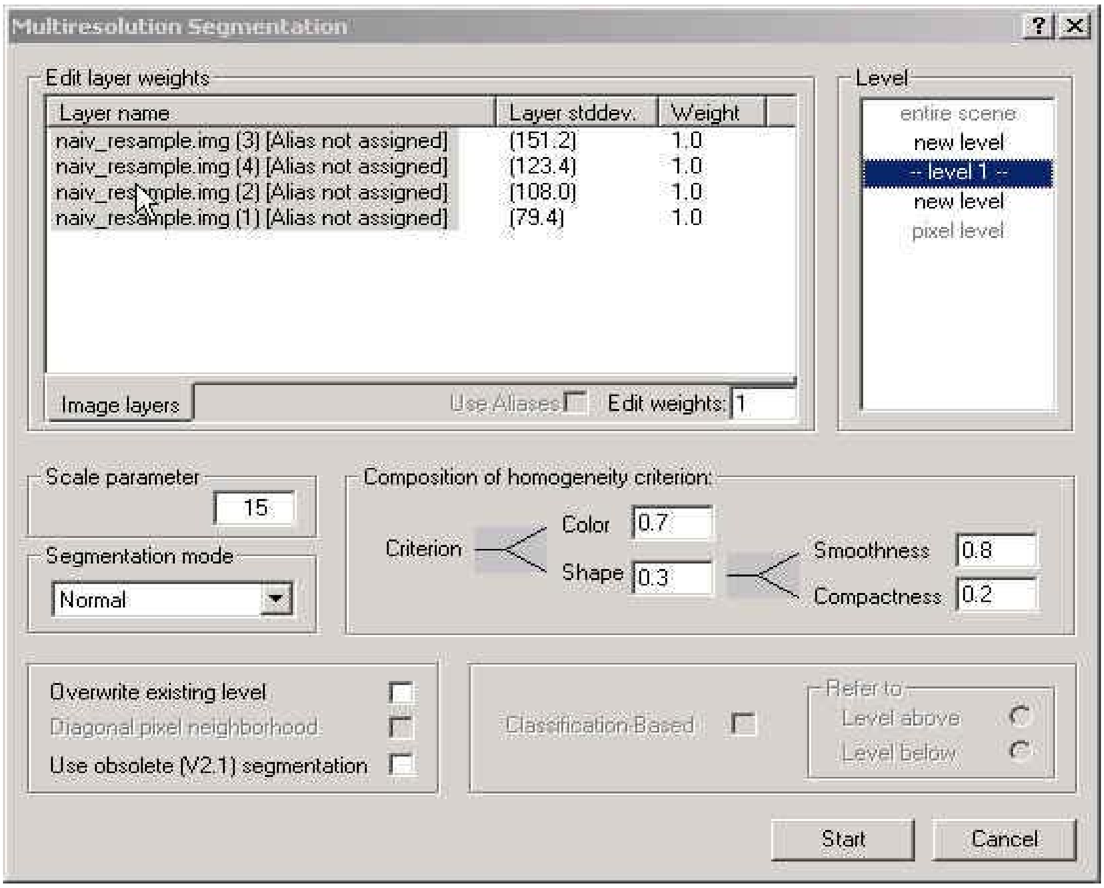


Figure 4-1 Multiresolution segmentation window in eCognition

Image layers can be assessed differently depending on their importance or suitability for the segmentation result. The higher the weight, which is assigned to a layer the more of its information, will be used during the segmentation process (Team Definiens Imaging, 2000). The image layers do not contain information intended for presentation by the image objects should be given little or no weight. For this image, the layer weight for all layers 3-4-2-1 is 1, which is internally equal to 0.25.

For **image object level**, is the level to created segmentation. For this classification, one level of image object is already satisfactory for classification because the final classes are only two classes pave and unpaved area.

The scale parameter is an abstract term, which determines the maximum allowed heterogeneity for resulting image objects. By modifying the value in the scale parameter, the size of image objects can be changed. With the trial and error scale parameter, the segmentation was defined and evaluated visually. The values of 10 – 25 are used and set at 15. In this scale parameter, the objects can be easily extracted visually.

The object homogeneity to which scale parameter refers is defined in the **Composition of the homogeneity criterion**. eCognition internally computes three criteria : colour, smoothness, and compactness. These three criteria for homogeneity can be applied in a mixed form. In this study, the percentages of spectral values of the image layers, contributing to the entire homogeneity criterion, in the colour field was set 0.7 and the percentages of shape homogeneity, in the shape field was set 0.3 depending on the visual assessment of the result of segmentation. The shape criterion is composed of two parameters. They are smoothness and compactness. The weight defined to compactness was 0.2 and the opposite of ones defined for smoothness was 0.8.

The segmentation result shows the object extraction. Image regions of different texture are separated. Multi-resolution segmentation is unsupervised. As seen in figure 4.2, it cannot extract one object as one complete object. This is because the difference in tone or non-homogeneity of the object. But this will not affect the classification process because they do still have the similar spectral values and afterwards will be classified as the same class or merged into the same class. (Team Definiens Imaging, 2000)

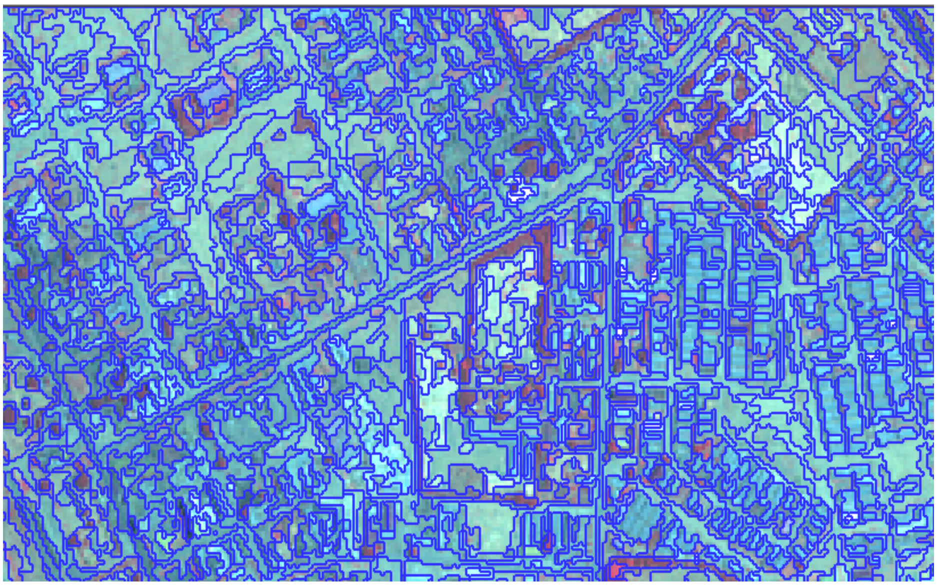


Figure 4-2 Segmentation with the scale parameter 15

The strategy for the identification of the "best" parameters for a particular task is not very clear. A visual inspection of a number of segmented images with different parameters, and the prior knowledge of the area was the method used to tune the segmentation process.

4.3.2. Classification Process

Classification is the process of connecting the classes in a class hierarchy with the image objects in a scene. The classification process in eCognition is supervised, allowing you to train the system by introducing samples objects (nearest neighbour) or classification concepts (membership functions and logic combination). After the process of classification, each image object is assigned to a certain class and thus connected with the class hierarchy. The result of classification is a network of classified image objects with concrete attributes, concrete relations to each other, and concrete relations to the classes in the class hierarchy (Team Definiens Imaging, 2000)

The class in eCognition was created in Class hierarchy. The class hierarchy is the framework of the knowledge base in eCogniton. It contains all the classes of a classification scheme. This hierarchy distinguishes between the passing down of class description from parent to child classes on the one hand (inheritance) and meaningful semantic group on the other.

A total of 9 subclasses (or children classes in eCognition) are used by Houses, Agriculture, Road, Train network, Trees, Water Green Houses, Scrub, and Baresoil to created 2 classes: paved and unpaved. The class paved was divided into only 4 subclasses (Houses, Green Houses, Water and Road) and the class unpaved was divided into 5 subclasses (Agriculture, Train Network, Trees, Scrub and Baresoil).

First, the training area was established and few sample objects were assigned on the segmented image. The advantage of eCognition is that it can extract objects from the image layer by layer. Therefore, the classification can be evaluated visually immediately after classification. In the case classification is not satisfying, it can be deleting and with selection of new sample objects, the classification can be performed again.

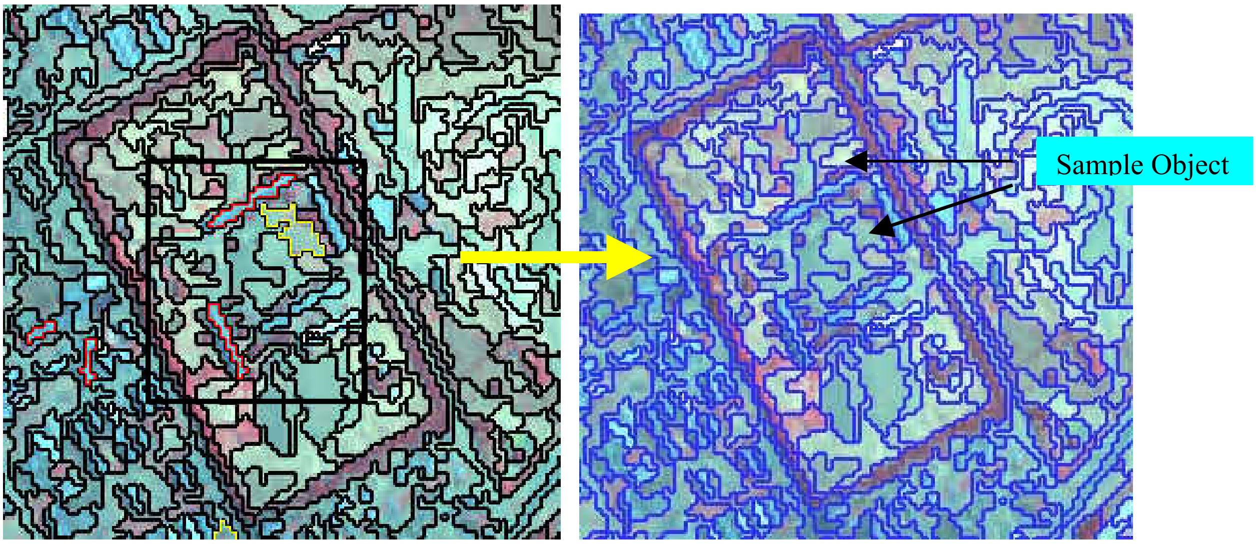


Figure 4-3 Sample object (red is paved and yellow is unpaved)

This study generated image segments that hold more spectral information compared to the pixels' digital numbers. For most simple classes spectral nearest neighbour classification is sufficient (Hofmann.P, 2001).

Checking spectral values of all bands and some other attribute data features can be clarified and later on will be used for implementing the classification. Unfortunately, there are still some wrong classified objects due to the wide range of overlapping spectral reflectance between 0.5 – 0.9 μ. This value can be checked using the sample editor window of eCognition by comparing the training class with the already-classified class. The solution to a wrongly classified class is to train the wrongly classified class as a new class and then reclassify it again.

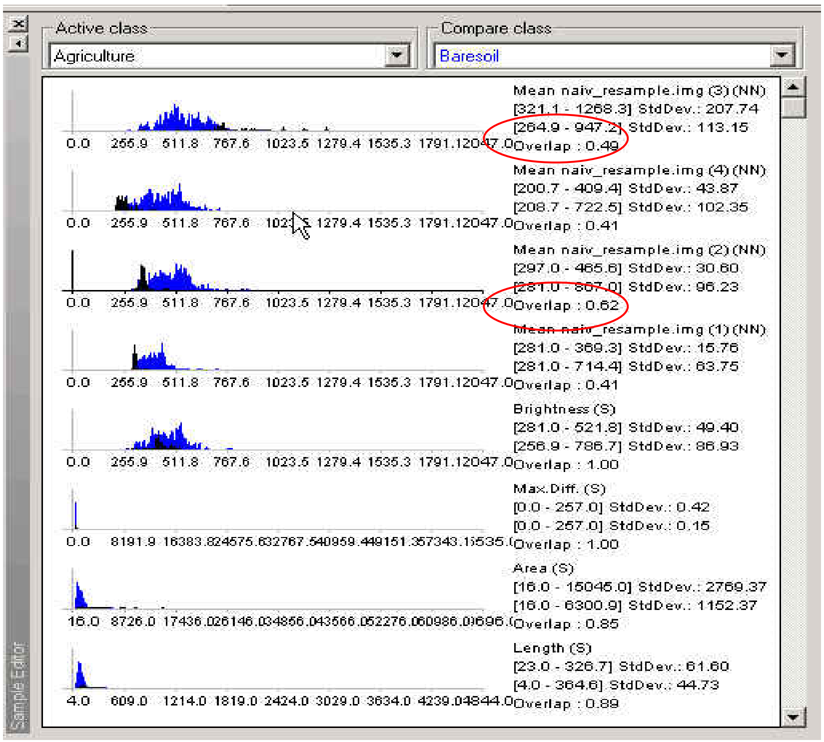
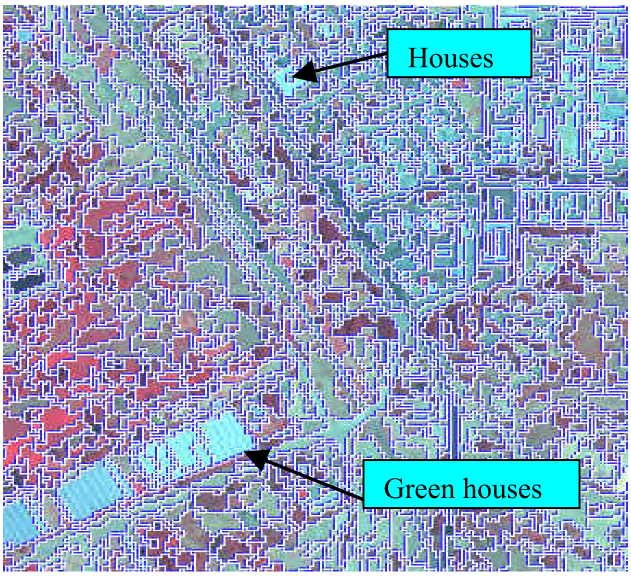


Figure 4-4 Some Overlaps of spectral reflectance between Agriculture and Baresoil

The classification procedure is applied based on the nearest neighbourhood method to all classes. The strength of the new object-oriented approach is that apart from layer values like mean of each bands, brightness and maximal differential, it also uses shape features such as surface area, length and width of objects during the classification process. In some classes with high value of NDVI like Agriculture, Scrub, Trees and Baresoil, feature NDVI was created to determine those classes.

Some classes are difficult to separate because of an overlapping of the spectral value. For example, class Agriculture with Baresoil and class Houses with green Houses.



Features	Houses	Green Houses	Overlap (%)
mean_band 1	297.0 - 1565.4	353.2 - 698.4	42
mean_band 2	264.9 - 2047	425.5 - 842.9	44
mean_band 3	144.5 - 1886.5	377.3 - 794.7	34
mean_band 4	168.6 - 1958.7	337.2 - 698.4	39
brightness	216.7 - 1862.4	409.4 - 722.5	52
area	16.0 - 1928.8	16.0 - 5207.8	34

Table 4-1 The Percentages of the overlap between Houses and Green Houses

Figure 4-5 The Same of spectral reflectance between Houses and Green Houses

Figure 4-5 shows that those two classes are difficult to separate by eCognition due to the similarity of the spectral reflectance. Also in Table 4-1, it shows some overlapping between houses with green houses.

This problem also happened when making a classification of the road and train network. It occurred because most of the road and train network in urban area is covered by dust, sand or reflectance from the trees. Therefore, manual interpretation and manual digitising should be used to extract the classes that have similar spectral reflectance.

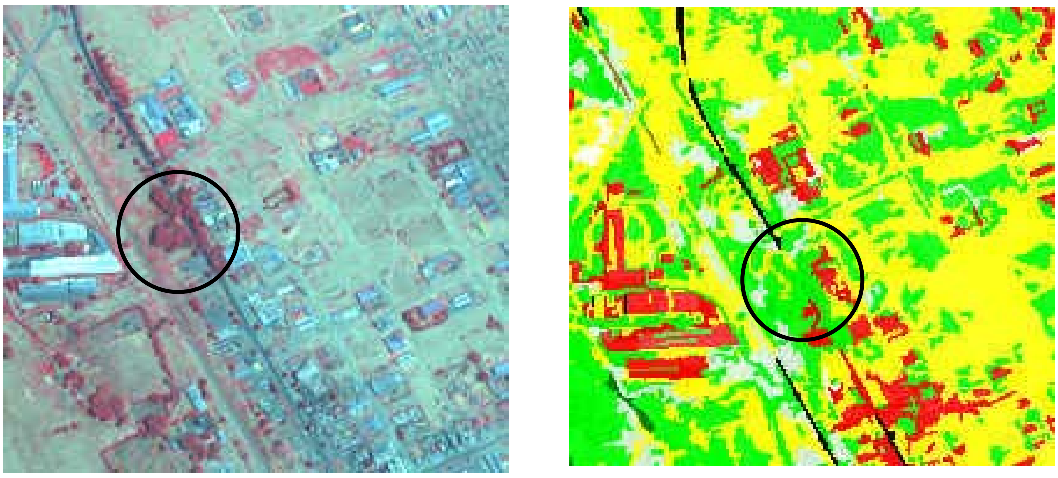


Figure 4-6 Road classification problems because of trees reflectance

It takes a long time to train the sample, classify, and validate the result (including separating the overlapping classes). After checking the classification result, the final classes of this study could be seen in next level up in Class Hierarchy.

Then, the paved and unpaved map was imported to Ilwis. In Ilwis, the map was resampled in order to have the georeference from fieldwork (same georeference with the rest image in Ilwis). From the histogram of the paved-unpaved map, there is information that 10.57 % is paved area and 89.24 % is unpaved area. With a conditional function in Ilwis, the digitised road and paved-unpaved classified map from eCognition were merged.

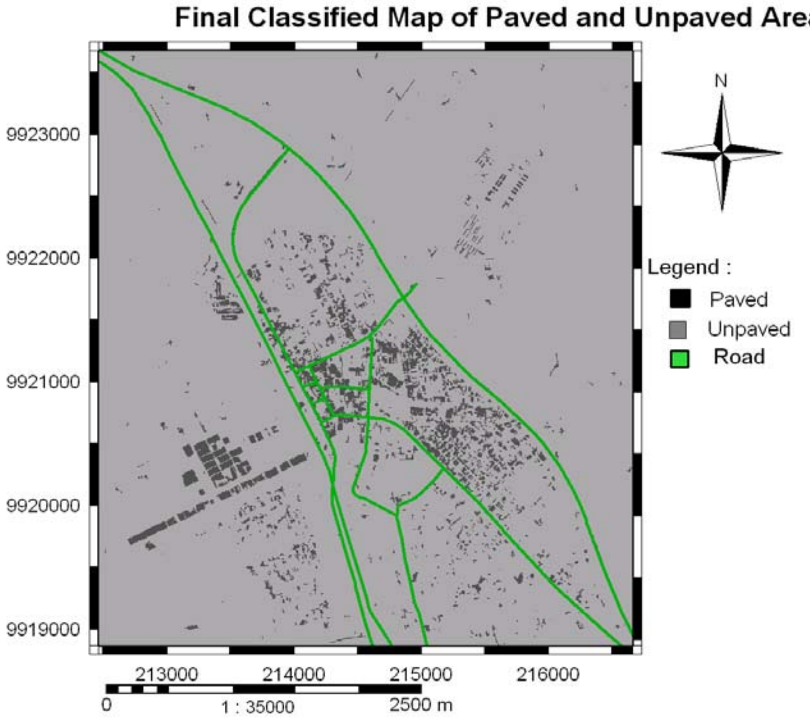


Figure 4-7 Final Classes: Paved and Unpaved area with digitise road

4.3.3. Accuracy Assessment

The accuracy assessment was performed applying independent field reference data that considered one image object as one reference point. It is a method to validate the classification result. The definition of different types of errors and accuracy are following;

- Overall accuracy: is the number of correctly classified pixel
- User accuracy: is the probability that a certain reference class has also been labelled that class. It is also the corollary of commission error.
- Producer accuracy: is the probability that a sampled point on the map is that particular class. It is also the corollary of omission error.
- Error of omission: is the number of pixels that are omitted in the interpretation
- Error of commission: refers to incorrectly classified samples.

The final classified map is in a raster format in which pixels have a class label assigned. The classified map from eCognition was crossed with the ground truth points from fieldwork in Ilwis. The accuracy assessment of the subclasses is 67.05 % (see Table 4-2). This accuracy is low because there is a low of user accuracy in the road. The problem in the classification of road is because most of the road in the urban was covered by dust, sand, and the shadow of the trees.

Table 4-2 Error matrix for the subclasses/children classes

Classified \ Reference	Houses	Agriculture	Road	Train Network	Trees	Water	Green Houses	Scrub	Bare soil	Total	Error of com-mission	User Accu-racy (%)
Houses	19	0	0	0	4	0	0	0	0	23	17.39	82.61
Agriculture	0	5	0	0	2	0	0	0	0	7	0.00	100.00
Road	0	0	2	1	0	0	0	0	7	10	80.00	20.00
Train Network	0	0	2	2	0	0	0	0	1	5	40.00	60.00
Trees	0	0	0	0	8	0	0	1	3	12	0.00	100.00
Water	0	0	0	0	0	4	0	0	1	5	20.00	80.00
Green Houses	0	0	0	0	0	0	10	0	0	10	0.00	100.00
Scrub	0	0	0	0	4	0	0	4	1	9	0.00	100.00
Bare soil	0	0	0	0	1	0	1	0	5	7	14.29	85.71
Total	19	5	4	3	19	4	11	5	18	88		80.92
Error of Omission	0.00	0.00	50.00	33.33	21.05	0	9.09	0	44.44			
Producer Accuracy (%)	100.00	100.00	50.00	66.67	78.95	100	90.91	100	55.56	82.45		67.05

Table 4-3 Error matrix for the Paved and Unpaved class

Classified \ Reference	Paved	Unpaved	Total	Error of com-mission	User Accuracy (%)
Paved	35	13	48	27.08	72.92
Unpaved	3	37	40	7.50	92.50
Total	38	50	88		82.71
Error of Omission	7.89	74.00			
Producer Accuracy (%)	92.11	26.00	59.05		81.82

The same way was done also to get an accuracy assessment for paved and unpaved area. The final map of paved and unpaved area from eCognition was crossed with the ground truth points from fieldwork. The error matrix of the aggregated class result (shown in Table 4-3) indicates an accurate classification for the classes with an accuracy assessment 81.82 %.

From the confusion matrix, it can be assumed that the approach used in this classification is reliable enough to extract those two main classes. It is because the classes that not should be assigned in those classes (error classification) are 18.18 %.

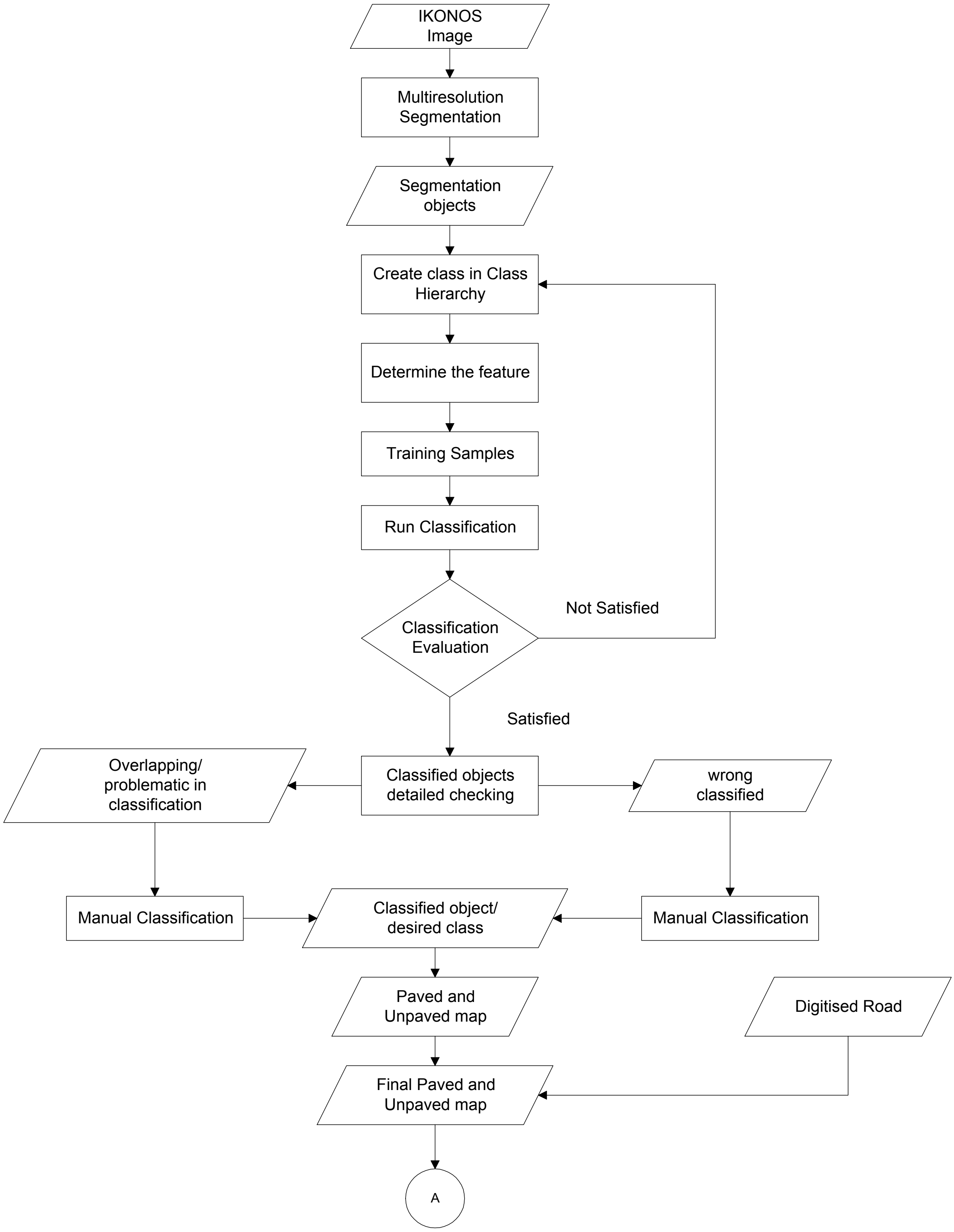


Figure 4-8 Flow chart of Methodology to make a Paved and Unpaved classification using eCogniton (1 of 2)

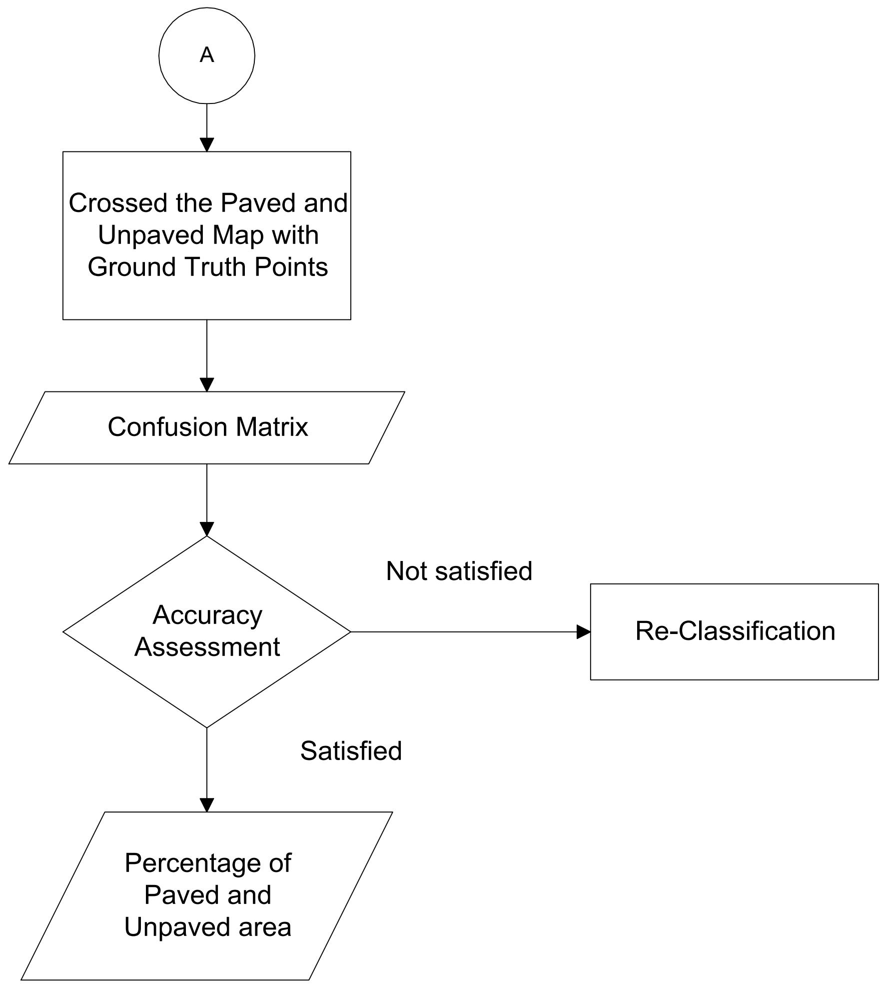


Figure 4-9 Flow Chart of methodology to make a Paved and Unpaved classification using eCogniton (2 of 2)

4.4. Conclusions

Using high resolution imagery such as IKONOS data should make it possible to detect man-made features such as buildings and roads more easily than with conventional satellite image data. This image could be one of the alternatives to extract a complex of urban context, such as single pixel based supervised classification.

eCognition is using a multi-resolution segmentation method for generating image objects of different resolution and high quality. Some parameters in eCognition should be selected and adapted until the segmentation gives a good result, which is easily to interpret visually. From the trial and error in the segmentation process, the proper scale parameter for this study is 15. Then the weight should be assigned on colour (0.7) and the rest (0.3) for the shape. Also the different weight between smoothness (0.8) and compactness (0.2) should be assigned. The weight in smoothness is higher than compactness to create a proper rooftop.

9 classes (Houses, Agriculture, Road, train Network, Trees, Water, Green houses, Scrub and Baresoil) were used to delineate two main classes (paved and unpaved). The difficulty of this classification using eCognition is the heterogeneity of some objects and the strong overlap of spectral signature among different classes. The classification was created using nearest neighbour. The additional feature "NDVI" was created to make classification easier for the class, which will assign with high NDVI. For the next study, it is better to give more weight for infrared layer in order to facilitate a better classification of the vegetation.

With regard to the high correlation and high similarity of the spectral reflectance, the training sample is carefully assigned to avoid overlap of each class. But because some of classes have a similar spectral reflectance, some misclassification cannot be avoided. To solve this problem, the misclassification should be defined manually, deleting the wrong training class and training the new class, then reclassifying until the result is satisfactory.

In the segmentation process, eCognition can segment the target objects very effectively, except for the road. This happened because the road is most of the time covered with other materials like dust or sand or trees shadows along the roads. This kind of object should be classified manually by digitising.

To assess the accuracy of the result, a confusion matrix, which contains the error of omission and commission, was created. The accuracy assessment for 9 classes is 67.05 % and the accuracy for the main classes is 81.82 %. The low accuracy in the classification of 9 classes is because the accuracy in the road is low. It is difficult to get a good classification in the road because the road in town usually was covered by dust, sand, and the shadow of trees.

That value accuracy was assumed to be sufficient to validate the paved and unpaved classification. For this study, to make classification can be applied using eCognition.

5. Urban Runoff Loads Pollutant Modelling and Sewage Loads Pollutant in Naivasha Town

Runoff is one of the most important hydrologic variables used in most of the water resources applications. It is generated by rainstorm and its occurrence and quantity depend on the characteristics of the rainfall event, like intensity, duration, and distribution.

The flow of streams is controlled primarily by variations in precipitation. Relationships between precipitation and runoff are the basis for the operation of the hydraulic projects and efficient forecasting. Despite the complex nature of the rainfall-runoff process, the practice of estimating runoff as a fixed percentage of rainfall is the most commonly used method in the design of urban storm drainage system. Because runoff carries a lot of substances, it is important to estimate storm water pollutant loads from urban areas to a water body as part of non-point source control. It can help in predicting the water quality response of a stream, lake, or estuary from urbanization (www.Stormwatercenter.net, January 2004). Storm water pollutant load models allow quantitative assessment on water quality as the impacts from urban activities and benefit wastewater treatment plant monitoring.

Storm water pollutant load models vary widely in their cost, effort, and accuracy depending on the complexity of the model used, data requirements, drainage area, and the need for model calibration. In the complex one, the model needs to consider several factors such as rainfall, infiltration, evaporation rate, overland flow, depression storage, slope, soil type, and the other hydrology factors. Two well-known examples of complex models are Storm water Management Model (SWMM) from EPA and Hydrology Stimulating Programming-FORTRAN (HSPF). These two models are able to simulate the hydrologic and hydraulic conditions in the watershed.

A commonly used simple model, the Simple Method, estimates storm water pollutant loads as the product of mean pollutant concentrations and runoff depths over specified periods of time. This model does not consider a lot of factors. The most important factors are percentage of paved area, rainfall data per time interval, and runoff data. This Simple Method was developed by Metropolitan Washington Council Governments (Akan, A. Osman & Robert J. Houghtalen, 2003).

5.1. Simple Method Stormwater Pollutant Load Model

The Simple Method estimates runoff pollutant loads for urban areas. In general, the Simple Method is only appropriate for small watersheds (< 640 acres) and when quick and reasonable storm water pollutant load estimation are required (see Table 5-1).

Table 5-1 Conditions for using The Simple Method for estimating urban storm water pollutant loads (www. Stormwatercenter.net, January 2004)

When to be used	When not to be used
• Small urban watershed (< 640 acres) • Only storm water runoff and pollutant load estimates are desired • Need for quick and reasonable load estimates • Only percent imperviousness and runoff pollutant concentration are available • Only planning level estimates are needed	• Base flow runoff/pollutant loads are desired • Large watershed (> 640 acres) • Non urban landuse, like construction site, rural development, as reliable "C"values are unavailable • Ambiguity about watershed's percent imperviousness

This model requires a modest amount of information, including the drainage area and the percentage of paved cover, storm water runoff pollutant concentrations, and precipitation.

5.2. Data Requirements for The Simple Method

5.2.1. Rainfall

Rain consists of liquid water drops mostly larger than 0.5 mm (0.02 inch) in diameters. (Linslye, 1982). Rainfall intensity is defined as the ratio of the total amount of the rain (rainfall depth) falling during a given period. It is expressed in depth units per time unit, usually mm per hour (mm/h) (www.fao.org, 2004, January 2004).

A variety of instruments and techniques have been developed for gathering information on rainfall. Instrument for measuring the amount and intensity of precipitation is important in collecting rainfall data. There are several types of rain gage but for this research, 5 tipping bucket gages were used to record the rainfall in Naivasha town. The rain gages were installed separately within the town.

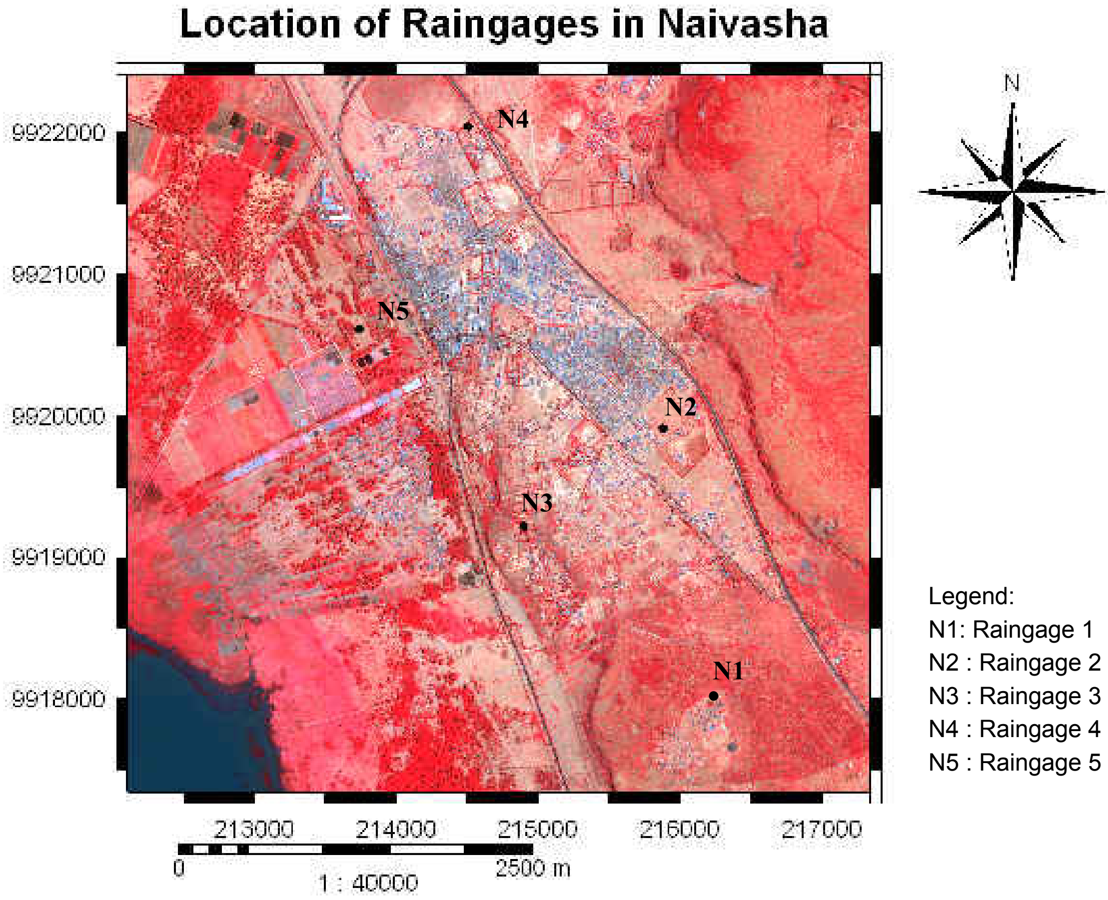


Figure 5-1 Location of raingages in Naivasha town

In tipping bucket gages, water caught in the collector is funnelled into a two-compartment bucket. 0.333 mm of rain will fill one compartment and overbalance the bucket so that it tips, emptying into a reservoir and moving the second compartment into place beneath the funnel. As the bucket is tipped, it actuates an electric circuit and makes a record of it.

Three rain gages were installed from 21st of September until 9th of October 2003, while the others were installed from 23rd of September until 9th of October 2003. At the end of the period of rainfall data collection, rainfall data from each rain gage were downloaded to the computer using Box Car Pro 4.2. This software is used to install and download the data from the rain gage. The record of rainfall from the rain gages were collected from rain occur at 22, 27, 28, 29 September 2003 and 1,2,3,4,5,8 October 2003.

5.2.2. Create a drainage area

To create the drainage area, manual digitising of drainage area for each runoff sample points based on fieldwork observation was done. From this digitised map, each drainage area was determined.

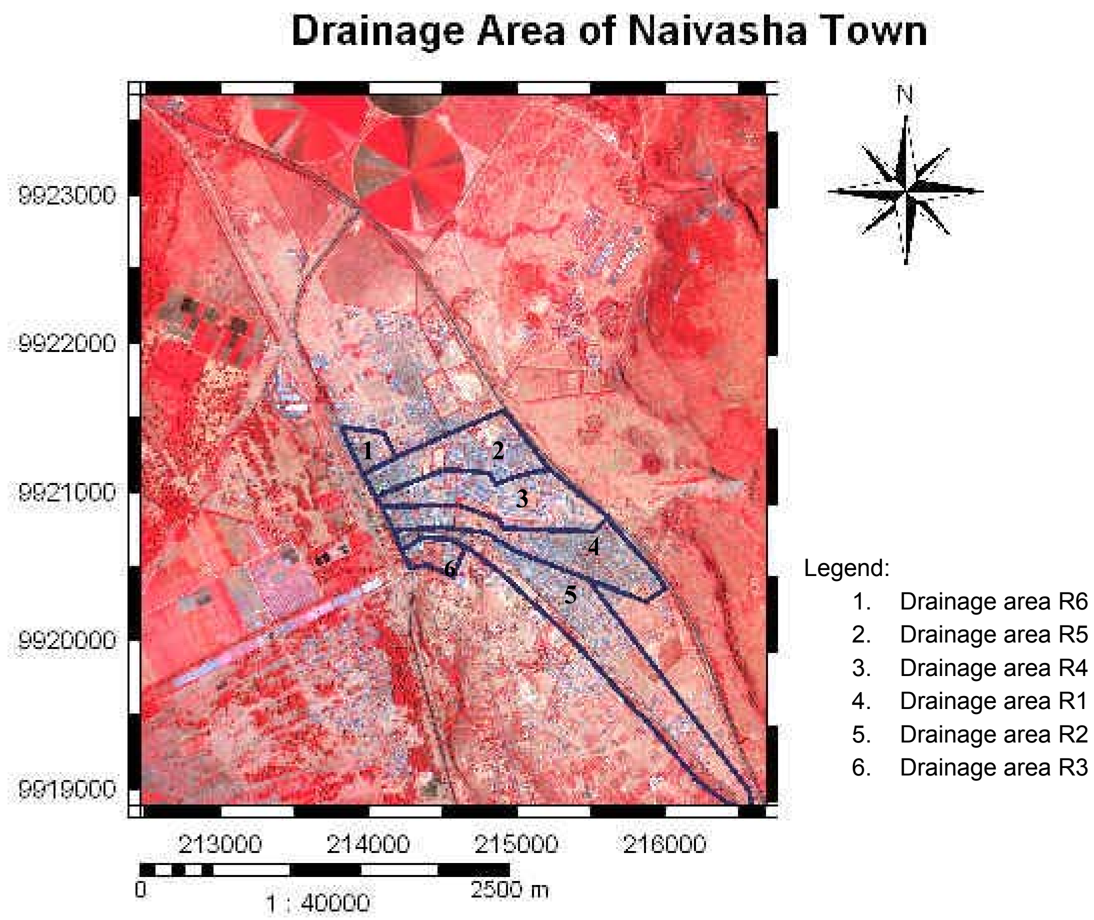


Figure 5-2 Drainage areas as the result of manual digitising

5.2.3. Determination of Rainfall Distribution for each Runoff Sample Points

Rainfall measurement in the watershed is better than rainfall measurement in the point because error in the point is more than in the watershed (Dunne T & Luna B. Leopold, 1974). The rainfall record in the watershed can be used to define the rainfall distribution over the watershed.

There are three ways to determine spatial distribution of the rainfall, namely the Arithmetic Average, Thiessen Average and Isohyetal method. For this study, the Thiessen Average method was used to determine the spatial distribution of the rainfall and the distribution of rainfall for each drainage area. This method is a better measure where the precipitation gradients are strong and without topography data (Dunne T & Luna B. Leopold, 1974). This method is most widely used among three available methods. With Thiessen Average method, the "weight area" of rainfall from each rain gage can be determined.

Determination of spatial distribution of the rainfall was carried out using ILWIS. First interpolation using nearest point and weight map was done to determine the rainfall distribution from each rain gage point in the study area. Then, the weight map and the runoff area map were crossed to calculate the amount of rainfall and its distribution to each rain gage corresponding to each runoff sample points.

Table 5-2 Distribution of rainfall for each runoff sample point

Point sample	Total area Per-drainage area (m^2)	Rainfall (mm)
R1	402667	2.9986
R2	717947	5.0836
R3	71824	0.6372
R4	382432	2.4751
R5	311413	1.6710
R6	71824	0.5238

Total area of drainage area is 1.958107 m^2 or 483.859 acres.

5.2.4. Percentage of Paved Area

A paved area is a surface that has very low infiltration or equal to zero. These areas decrease the natural ability of rainfall infiltration and depression storage, which in turn increase the runoff volume. They also accelerate overland flow velocities, which reduce flow travel times.

This explains why the percentage of a paved area has relatively direct relationship with the runoff coefficient value. In the Simple method, the runoff coefficient is calculated based on percentages of the paved area in the drainage area. The estimated paved and unpaved area can be determined with several ways, but in this study, the percentage of paved areas in this study was estimated by classifying a satellite image using eCognition.

To calculate the percentage of paved area for each point sample, map of the drainage area of each point sample (as created in ILWIS in the previous step) was crossed with the map of paved and unpaved areas. From that map, paved areas for each point were compiled in Table 5-3.

Table 5-3 The Area Paved and Unpaved in the drainage area

Sample point	Paved area (m2)	Paved area (%)	Unpaved area (m2)	Unpaved area (%)
R1	116274.5	29	286392.7	71
R2	113890.1	16	600029.4	84
R3	14693.4	20	57130.3	80
R4	116629	30	265802.6	70
R5	105335	34	206078.3	66
R6	18076.8	28	47012.5	72

5.2.5. Runoff Coefficients Data

Apart from the above-mentioned site-specific factors, which strongly influence the rainfall-runoff process, it should also be considered that the physical conditions of a drainage area are not homogenous. Each drainage area has its own runoff response and therefore will respond in a different way to different rainstorm events.

5.2.5.1. Runoff Data

In Chapter 2, there are 6 points where runoff water samples taken. At those 6 points, dimension of the channel, such as depth, length and width of the channel were measured. In addition, there was a measurement done on the depth and time of the runoff during the rainfall event for point 1.

From that measurement, the best-fit function method was used to obtain the same information for other points (the discharge data for other point samples beside point 1). This function tried to find the same function of the data from two points sample. It assumed that data from other point sample has the same curve with the data in point 1.

From those data, the hydrograph of the runoff was created for 6 point samples. (See Figure 5-3)

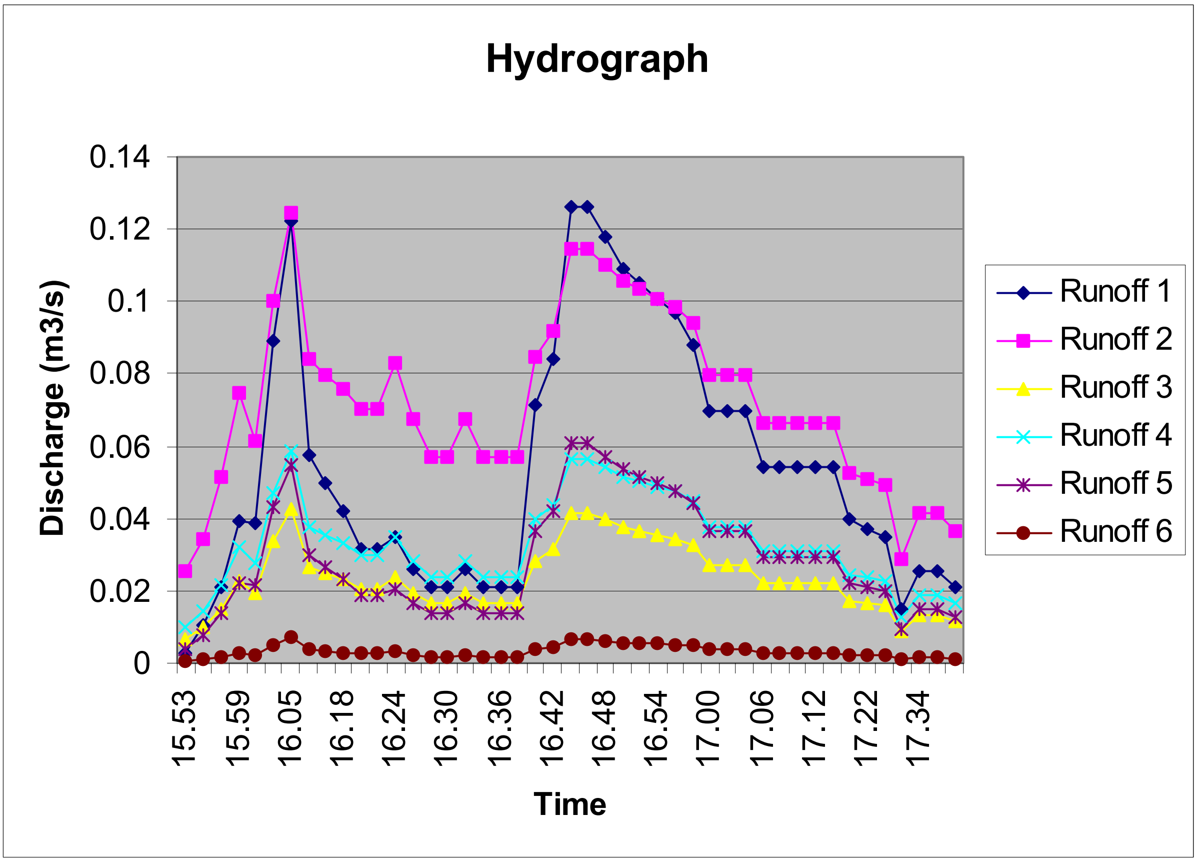


Figure 5-3 Hydrograph of runoff discharge

5.2.5.2. Runoff Coefficient

Regarding the quantity of runoff produced by rainstorm in a drainage area, it is commonly assumed that the quantity (volume) of runoff is a proportion of the rainfall depth. (Maidment, 1988)

There are two ways to determine the runoff coefficient.

1. Runoff coefficient from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as depth over watershed area (mm). This method is the most commonly applied to storm rainfall and runoff. (Maidment, 1988)

$$Rv = \frac{\text{Runoff (mm)}}{\text{Rainfall (mm)}}$$

Equation 5-1 Runoff coefficient

From that equation, the Rv or runoff coefficient for each point is calculated and the results are presented in Table 5-4:

Table 5-4 Runoff coefficient

Sample point	Rainfall (mm)	Runoff (mm)	Rv
R1	2.9985984	0.859741495	0.286714
R2	5.0836113	0.656280042	0.129097
R3	0.6372288	2.141585487	3.360779
R4	2.4750558	0.560233251	0.226352
R5	1.670994	0.587676625	0.351693
R6	0.523809	0.320522698	0.611908

From the Table 5-4, the runoff coefficient (Rv) of sample point 3 is unreliable as the (estimated) runoff is so high. This happened because the runoff data for the sample point was calculated from the best-fit function based on the data from sample point 1 (the measurement result). In fact, this is physically impossible and is probably due to some measurement error.

2. Determining the runoff coefficient using the runoff coefficient formula in the Simple Method (www. Stormwatercenter.net, 2004). This runoff coefficient is related to the surface area, especially the percentages paved area.

$$Rv = 0.005 + 0.009(I)$$

Equation 5-2 Runoff coefficient based on Simple Method

where, Rv = runoff coefficient
I = Percent of paved/impervious area

Table 5-5 Runoff coefficient using Simple Method Formula

Sample Point	Paved area (%)	Rv
R1	29	0.31
R2	16	0.19
R3	20	0.23
R4	30	0.32
R5	34	0.35
R6	28	0.30

The value resulted from this calculation is more realistic for runoff coefficient. The bigger the paved area, the larger the runoff coefficient will be. This is because the volume of runoff is increased along with the increase in the extent of paved area and therefore the runoff coefficient is larger.

Chow V.T (1964) offered another estimation of runoff coefficients, which calculate runoff coefficients based on the land use. The runoff coefficients are presented in Table 5-6.

Table 5-6 Runoff coefficient based on land use

Type of area	Runoff Coefficient
Central areas	0.60
Residential areas	0.40
Industrial areas	0.50
Educational areas	0.35
Parks, cemeteries, playground, and rural areas	0.15

The runoff coefficients from Table 5-6 are not appropriate to use because in this study the runoff coefficient was calculated based on the land cover paved and unpaved area. In each drainage area, some land uses occurred and therefore it is difficult to have one runoff coefficient. Hence, runoff coefficient calculated from land cover data was preferred than the one calculated from land use.

5.2.6. Pollution Concentrations

The assessment on the water quality in Naivasha was discussion in chapter 3. The results were used to estimate the load pollutant.

5.3. Simple Method Stormwater Pollutant Load Model

The Simple method estimates storm water runoff pollutant loads for urban areas. This estimation should provide reasonable estimates of changes in pollutant export resulting from urban development activities. This method is appropriate for assessing and comparing the relative storm flow pollutant load changes of different land use and storm water management.

In the simple method, the pollutant export from development is determined using:

$$L = 0.227\,(P)(Pj)(Rv)(C)(A)$$

Equation 5-3 The Simple Method

where : L = load pollutant export in pounds
P = rainfall depth in inches over the desired time interval
Pj = fraction of rainfall events that produce runoff
Rv = volumetric runoff coefficient expressing the fraction of rainfall converted into runoff
C = flow weighted mean pollutant concentration in milligrams/litre, and
A = total area of the site in acres
0.227 = conversion factor

Equation 5-3 can be used for a time period of any length. (Akan, A. Osman & Robert J. Houghtalen, 2003)

For Pj, there is much uncertainty in the selection of a storm correction factor. For Naivasha, there is no previous study of one value for this coefficient, so the value commonly used by others (0.9) was applied in this study. This value was obtained from the study in Washington DC. There is no other study about storm correction factor, so this study used the same value: 0.90. It means 90 % of the storm in a given time period generates runoff.

The rainfall data for this calculation was use rainfall data from the measurement in the fieldwork (1st of October 2003).
The loads pollutant result using the Simple Method can be seen in Table 5-7.

Table 5-7 Pollutant result using Simple Method

Parameters	Storm water Pollutant	
	(kg/d)	*(kg/s)*
Alkalinity	2077.855203	0.02404925
TDS	4.597169295	5.3208E-05
DO	6.86144671	7.94149E-05
Nitrate	107.1732141	0.001240431
Nitrite	11.47645792	0.000132829
Ammonia	56.24804926	0.000651019
Phosphate	57.73597079	0.00066824
EC	2477.13495	0.028670543
Chloride	219.8043218	0.002544032
COD	760.5266333	0.008802392
Sulphate	290.125029	0.003357929
Al	2.161256945	2.50145E-05
Ca	165.7642661	0.001918568
Cd	0.040743799	4.71572E-07
Fe	8.073726827	9.34459E-05
K	111.0400197	0.001285185
Li	0.090643632	1.04912E-06
Mg	13.1094367	0.00015173
Mn	7.599954289	8.79624E-05
Na	244.8733069	0.002834182
Zn	0.166128768	1.92279E-06

5.4. Estimation of Naivasha Pollutant Loads From Sewage

The major water pollutant loads in Naivasha comes from sewage and runoff. The pollutant from runoff were described in the previous section, while for the contributions of sewage to the pollutant, the calculation was done using the following equation (Maidment, 1992):

$$L = C * Q$$

Equation 5-4 Pollutant Loads of Sewage

where : L = pollutant in kg/s
C = concentration of pollutant in mg/l
Q = the discharge of sewage in m^3/s

The sewage pollutant from Naivasha Town can be seen in Table 5-8.

Table 5-8 Pollutant sewage of Naivasha town

Parameters	Sewage water Loads Pollutant	
	(kg/d)	*(kg/s)*
Alkalinity	3416.727616	0.039545459
TDS	0.549981466	6.36553E-06
DO	0.82086786	9.50079E-06
Nitrate	2.80215936	3.24324E-05
Nitrite	1.170313615	1.35453E-05
Ammonia	137.0585593	0.001586326
Phosphate	122.1411815	0.001413671
EC	4703.836568	0.054442553
Chloride	296.7486762	0.003434591
COD	1620.472275	0.018755466
Sulfate	131.536657	0.001522415
Al	0.374170691	4.33068E-06
Ca	40.95108655	0.000473971
Cd	0.014834961	1.71701E-07
Fe	0.517575317	5.99046E-06
K	170.1141498	0.001968914
Li	0.113734703	1.31637E-06
Mg	15.70033406	0.000181717
Mn	0.351094085	4.06359E-06
Na	357.5769626	0.004138622
Zn	357.9280567	0.004142686

After the estimation of pollutant loads from sewage and storm water runoff calculated, the total pollutant loads in Naivasha town at 2003 was determined by summing the pollutant loads from sewage and storm water runoff. It is presented in Table 5-10.

Table 5-9 Total Pollutant Loads of Naivasha town at 2003

Parameter	Total Pollutant Loads	
	kg/d	kg/s
Alkalinity	5494.583	0.064948
TDS	5.147151	6.08E-05
DO	5499.73	0.065009
Nitrate	109.9754	0.0013
Nitrite	12.64677	0.000149
Ammonia	122.6221	0.001449
Phosphate	179.8772	0.002126
EC	7180.972	0.084881
Chloride	7360.849	0.087008
COD	2380.999	0.028144
Sulphate	421.6617	0.004984
Al	2802.661	0.033128
Ca	206.7154	0.002443
Cd	0.055579	6.57E-07
Fe	206.7709	0.002444
K	281.1542	0.003323
Li	0.204378	2.42E-06
Mg	281.3585	0.003326
Mn	7.951048	9.4E-05
Na	602.4503	0.007121
Zn	610.4013	0.007215

A comparison of the pollutant as input (sewage sample point 6) and output (sewage sample point 2) in the wastewater treatment plant can be made in order to make an assessment on the efficiency of the wastewater treatment plant.

Table 5-10 Comparison between input and output waste water treatment plant

Parameters	Pollutant Input of WWTP		Pollutant Output of WWTP	
	(kg/d)	*(kg/s)*	*(kg/d)*	*(kg/s)*
Alkalinity	379.4530911	0.004391818	329.9592096	0.003818972
TDS	0.038653316	4.47376E-07	0.008835044	1.02257E-07
DO	0.057691516	6.67726E-07	0.013186632	1.52623E-07
Nitrate	0.329665807	3.81558E-06	0.329665807	3.81558E-06
Nitrite	0.131866323	1.52623E-06	0.131866323	1.52623E-06
Ammonia	31.64791748	0.000366295	22.74694069	0.000263275
Phosphate	14.50529551	0.000167885	9.395475501	0.000108744
EC	611.5300721	0.007077894	421.972233	0.004883938
Chloride	28.0215936	0.000324324	26.42271444	0.000305818
COD	183.9535203	0.002129092	42.85655492	0.000496025
Sulphate	10.87897163	0.000125914	3.626323878	4.19713E-05
Al	0.037911568	4.38791E-07	0.013186632	1.52623E-07
Ca	5.218609726	6.04006E-05	6.692215883	7.74562E-05
Cd	0.001648329	1.90779E-08	0.001648329	1.90779E-08
Fe	0.047801542	5.53259E-07	0.011538303	1.33545E-07
K	20.89751551	0.000241869	12.58993717	0.000145717
Li	0.014834961	1.71701E-07	0.011538303	1.33545E-07
Mg	1.574154229	1.82194E-05	1.790085332	2.07186E-05
Mn	0.018131619	2.09857E-07	0.039559897	4.57869E-07
Na	45.05048086	0.000521418	30.94243265	0.00035813
Zn	0.006593316	7.63115E-08	0.004944987	5.72336E-08

From the result of the comparison between input and output wastewater treatment plant, it can be seen that the waster water treatment plant reduces several parameters, such as alkalinity, TDS, DO, Ammonia, Phosphate, EC, Chloride, COD, Sulphate and some of the Cations. The pollutants, which are not reduced by the wastewater treatment plant, were Nitrate, Nitrite, Ca, Cd, and Mg. However, there should be a continuous monitoring on the pollutants of the wastewater treatment plant output.

5.5. Scenarios for Predicting Naivasha Pollutant Loads in the Future

For predicting the loads pollutants in the future, two scenarios were created.

1. Scenario 1: The prediction of pollutant loads is calculated based on the population growth. In other words, only changes in sewage loads were considered without considering any changes in runoff loads. This scenario assumes that the annual rainfall is the same each year and there are no changes in the area (paved and unpaved area). The purpose of this scenario is to know the effect of changes in one variable to the amount of the pollutant.

2. Scenario 2: The prediction of the pollutant loads is calculated based on the increases of paved area along with population growth. The population growth assumes to have an effect on land use and land cover.

For these two scenarios, it is assumed that for each sewage and runoff samples is constant within any period of time. The concentration of pollutant used is the result of the field measurement

5.5.1. Scenario 1

5.5.1.1. The Population Projection of Naivasha Town

This scenario was created based on the change of one variable, i.e. population growth. The population in Naivasha in 2003 was 47.695 people, which is concentrated in three areas, i.e. Sokoni (which includes the Central Business District, Site and Service and major part of Kabati Estate), Lake View and G.K Prison (Development Impact Consulting, 2003). The population growth for Naivasha town is 5 %. The projected Naivasha population for 10 years can be seen in Table 5-11 below.

Table 5-11 Naivasha population projections in 2003

Area	Population 2003	Population 2006	Population 2009	Population 2013
Sokoni	35.769	41.407	47.934	58.264
Lake View	9.526	11.028	12.765	15.516
G.K Prison	2.400	2.400	2.400	2.400
Total	47.695	54.835	63.099	73.780

(Development Impact Consulting Report, 2003)

The assumption of the population projection for G.K Prison does not change because this area is not developed, i.e. it is allocated only for the prison. From the three areas, G.K Prison also does not connect to the sewage network. It is the linked to the wastewater treatment plant through a truck sewer that serves the slaughterhouse and some part in industrial area.

Each area of Sokoni and Lake View is divided into three classes of housing: low, medium, and high class. The percentage portion of each area is presented in Table 5-12:

Table 5-12 Percentage proportion based on class housing

Class housing	Sokoni	Lake View
Low	40 %	15 %
Medium	35 %	25%
High	25 %	60%

The population distribution by class of housing for each area is presented in Table 5-13:

Table 5-13 Population distribution by class of housing

Class of Housing	2003		2006		2009		2013	
	Sokoni	*Lake View*	*Sokoni*	*Lake View*	*Sokoni*	*Lake View*	*Sokoni*	*Lake View*
Low	14308	1429	16563	1654	19174	1915	23306	2327
Medium	12519	2382	14492	2757	16777	3191	20392	3879
High	8942	5716	10352	6617	11983.5	7659	14566	9310
Total	35769	9526	41407	11028	47934	12765	58264	15516

5.5.1.2. The Projection of Water Consumption and Waste Water Treatment

Based on Development Impact Consulting report, water consumption patterns and the reduction factors that indicated the sewage flows resulting from the water consumption based on the type of the housing are defined as follow:

- The low class has a water consumption rate of 75 litre/capita/day with a reduction factor of 85 %
- Water consumption for the medium class is 150 litre/capita/day with a reduction factor of 80%
- The biggest water consumption is for the high class, it is 300 litre/capita/day with a reduction factor of 75 %.

Based on the information above, the projection of water consumption and wastewater flows were calculated. This projection assumes that there is an adequate water supply and each household is connected to the water supply network.

Table 5-14 Population, reduction factors, and anticipated sewage flow for 2003

Class of housing	Population	Water consumption l/cap/d	Reduction factors %	Anticipated daily sewage l/cp/d	Total Flow rate (m^3/d)
Low	15.737	75	85	64	1.003
Medium	14.901	150	80	120	1.788
High	14658	300	75	225	3.298
Total	14689				6.089

In addition to the information presented above, the municipality also has an estimation of the anticipated flow that connects to the wastewater treatment plant.

Besides the sewage from the residential, sewage is also coming from industrial and commercial area. The assumed water demand for the industrial area was 0.2 litre/s/ha, while the commercial demand was assumed to be about 0.15 litre/s/ha. The municipality also made a calculation of the sewage flow from the industrial and commercial areas, which is 2.430 m^3/day and assuming that there is no enhancement of this flow.

Table 5-15 Projection of the sewage flow

Area	2003 m^3/d	2006 m^3/d	2009 m^3/d	2013 m^3/d
Residential	6.089	7.056	8.166	9.925
Industry& Commercial	2.340	2.340	2.430	2.430
Total	8.429	9.396	10.596	12.355
Connected Flow	990	3.320	6.345	9.88
Prediction of the connected flow	12%	35%	60%	80%

With the same increasing percentage in the input of the wastewater treatment plant (sewage sample point number 2, the outlet point of waste water treatment plant), the discharge flow in the other point samples can be calculated.

5.5.1.3. Projection of total Pollutant Loads from Sewage and Storm water Runoff of scenario 1

After the discharge from all points have calculated, the loads pollutant from sewage can be determine using Equation 5-4.

The pollutant loads from storm water runoff has the same amount with the 2003 pollutant loads. This is because the scenario assumes that annual rainfall will not change significantly and there is no extension of the paved area.

The projected total of the pollutant can be seen in Table 5-16.

Table 5-16 Projection of Naivasha total pollutant using scenario 1

Parameters	Pollutants (kg/d)				Pollutants (kg/s)			
	2003	*2006*	*2009*	*2013*	*2003*	*2006*	*2009*	*2013*
Alkalinity	414999.7	424236.9	434361.2	449546.6	4.905434	5.014621	5.134293	5.31379
TDS	935.5328	936.945	938.6494	941.0938	0.011058	0.011075	0.011095	0.011124
DO	1396.318	1398.425	1400.969	1404.618	0.016505	0.01653	0.01656	0.016603
Nitrate	24212.34	24219.98	24228.22	24240.67	0.286198	0.286288	0.286386	0.286533
Nitrite	2440.965	2444.135	2447.597	2452.798	0.028853	0.02889	0.028931	0.028993
Ammonia	13484.71	13910	14261.37	14870.52	0.159394	0.164421	0.168574	0.175774
Phosphate	11958.53	12291.87	12650.66	13193.51	0.141354	0.145294	0.149535	0.155952
EC	490484.4	503498.5	517139.5	538045.4	5.797688	5.951519	6.11276	6.359875
Chloride	38016.78	38802.6	39698.36	41017.24	0.449371	0.45866	0.469248	0.484837
COD	160222.1	164616.3	169404.7	176606.8	1.893878	1.94582	2.00242	2.087551
Sulfate	56989.18	57332.36	57734.55	58319.16	0.673631	0.677687	0.682442	0.689352
Al	464.9301	465.9295	467.0504	468.7134	0.005496	0.005507	0.005521	0.00554
Ca	32984.14	33097.08	33216.19	33398.2	0.389883	0.391218	0.392626	0.394778
Cd	8.213574	8.253683	8.297639	8.363572	9.71E-05	9.76E-05	9.81E-05	9.89E-05
Fe	1532.53	1533.897	1535.463	1537.763	0.018115	0.018131	0.01815	0.018177
K	22793.33	23259.92	23757.31	24513.37	0.269425	0.27494	0.280819	0.289756
Li	18.46757	18.7824	19.11206	19.61755	0.000218	0.000222	0.000226	0.000232
Mg	2677.232	2719.113	2766.201	2835.98	0.031646	0.032141	0.032697	0.033522
Mn	1542.687	1543.566	1544.676	1546.237	0.018235	0.018245	0.018259	0.018277
Na	47801.07	48785.59	49827.34	51416.57	0.565024	0.576662	0.588976	0.607761
Zn	35.97802	36.20384	36.47307	36.86134	0.000425	0.000428	0.000431	0.000436

From the prediction based on scenario 1, the pollutant loads of Naivasha town are slightly increasing. The percentage of loads pollutant at 2006 is increasing by 0.03 % for the minimum and the maximum percentage is increasing by 3.05 %. For 2009, the minimum is increasing by 0.03 % and the maximum is increasing by 2.84 %. Then for 2013, the minimum is increasing by 0.05% and the maximum is increasing by 4.11%.

Even through the percentage of increasing pollutant loads for 10 years projection based on scenario 1 is not significant, but it is important to know the result of the prediction. The increased pollutant loads shown by this projection, even slight, it gives general description on how the Lake will be contaminated in the future.

The result of this scenario could be inappropriate because in reality, the population growth goes along with the development of area as well. However this scenario was indicated the increasing of pollutant loads with the change of one variable, i.e. population growth.

5.5.2. Scenario 2

The second scenario is the estimation of the pollutant load of Naivasha town based on the increasing of paved area along with the population growth.

5.5.2.1. Projection on the increasing of the paved area

This scenario assumes that the increasing population will increase the paved area because they develop more buildings to support their life. The projection of the increasing paved area was based on the land use area changes in Naivasha town as presented in Table 5-17.

Table 5-17 Naivasha urban land use class and area

Landuse \ Period	1980 – 1990 (Ha)	1990 – 2000 (Ha)	% Increasing
Residential	133	390	66
Industrial	39	84	54
Educational	70	84	17
Recreational	97	100	3
Public Utilities	222	278	20
Commercial	33	49	33
Transport	29	29	0
Agriculture	-	183	100

Assuming the dynamic of the extent of land use is constant up to year 2013, the percentage of land use change in Table 5-17 was used to estimate the projection of the increasing paved area. The map of land use in the drainage area was crossed with the paved and unpaved map to obtain the percentages of the paved and unpaved area in each land use of the drainage area.

Those data were combined with the increasing of paved area to come up with increasing of each land use in the drainage areas. As the final result, the increasing of the paved and unpaved areas in each drainage area was calculated and presented in Table 5-18.

Table 5-18 The increasing percentages of Paved and Unpaved area

Sample Points	2003		2006		2009			
	%Unpaved area	*% Paved area*	*%Unpaved area*	*% Paved area*		*% Paved area*	*%Unpaved area*	*% Paved area*
R1	71	29	65	35	55	45	41	59
R2	84	16	72	28	51	49	9	91
R3	80	20	77	23	73	27	69	31
R4	70	30	55	45	32	68	32	68
R5	66	34	14	86	14	86	14	86
R6	72	28	53	47	17	83	17	83

Table 5-19 Projection of area and percentage of paved area each drainage area

Sample Points	2003		2006		2009		2013	
	area (m^2)	*% paved*	*area (m^2)*	*% paved*	*area (m^2)*	*% paved*	*area (m^2)*	*% paved*
R1	116275	29	40993.7	35	51785.3	45	68066.34	59
R2	113890	16	31385.7	28	56103.3	49	104040.7	91
R3	14693.4	20	3411.97	23	3901.08	27	4494.532	31
R4	116629	30	52069.5	45	79297.4	68	79307.72	68
R5	105335	34	90408.7	86	90588.1	86	90588.1	86
R6	18076.8	28	8419.64	47	15019.2	83	15003.74	83

The increasing area was calculated based on the capability of the area to be developed. If the percentage of paved area, as the result of calculation, reaches 100 %, the percentage of paved area was assumed as constant (same with the previous extent). For example in the point R5, the percentage of paved area is not increasing from 2006 – 2009. Because, after the calculation, the percentage of paved area exceeded 100 and that is practically impossible. For cases like these, it is assumed that there is no change of paved area or the area is stable. This is also the case for point R4, R5 and R6 for 2013.

The percentages of paved area as calculated above were used to obtain the runoff coefficient values. The calculation of runoff made use of Equation 5-2.

Table 5-20 Runoff Coefficient based on the projection of percentages paved area

Sample Points	2003		2006		2009		2013	
	Paved	*Rv*	*Paved*	*Rv*	*Paved*	*Rv*	*Paved*	*Rv*
R1	29	0.3099	35	0.3673	45	0.4508	59	0.5769
R2	16	0.1936	28	0.298	49	0.4933	91	0.8722
R3	20	0.2341	23	0.259	27	0.2889	31	0.3253
R4	30	0.3245	45	0.4518	68	0.6619	68	0.662
R5	34	0.3544	86	0.8225	86	0.824	86	0.824
R6	28	0.3	47	0.4692	83	0.7978	83	0.797

5.5.2.2. Pollutant Loads of Storm water Runoff

The data to calculate the pollutant loads of storm water runoff are:

- Annual rainfall depth, the annual rainfall of Naivasha town is 600 mm (Mbathi, 2001)
- Fraction of rainfall coefficient, using 90 % as fraction of rainfall coefficient
- Runoff coefficient, this value can be seen in Table 5-19

- Concentration of pollutant, for this value, it is assumed that there are no changes in the concentration values of pollutant
- The extent of drainage area is the same, only the percentages paved area are different

The calculation made use of Equation 5-3.

5.5.2.3. Projection of total Loads Pollutant from Sewage and Storm water Runoff of scenario 2

The total pollutant loads from sewage and storm water runoff of scenario 2, is determined by the sum of the total pollutant storm water runoff (based on the increasing of the paved area) and the total sewage pollutant loads (based on the population growth).

Table 5-21 Projection of Naivasha total pollutant using scenario 2

Parameters	Pollutant load rate (kg/d)				Pollutants load rate (kg/s)			
	2003	*2006*	*2009*	*2013*	*2003*	*2006*	*2009*	*2013*
Alkalinity	414999.7	581514	748461	987752	4.9159	6.7305	8.6627	11.432
TDS	935.533	1446.3	1878	2402.7	0.0111	0.0167	0.0217	0.0278
DO	1396.32	2158.7	2803	3586.2	0.0674	0.025	0.0324	0.0415
Nitrate	24212.3	37571	48515	59055	0.2862	0.4349	0.5615	0.6835
Nitrite	2440.97	3797.7	4756	5965.9	0.0289	0.044	0.055	0.0691
Ammonia	13484.7	20986	25114	29830	0.1578	0.2429	0.2907	0.3453
Phosphate	11958.5	16871	21870	28334	0.1418	0.1953	0.2531	0.3279
EC	490484	704439	929283	1E+06	5.8146	8.1532	10.756	14.33
Chloride	38016.8	54407	76348	110684	0.5202	0.6297	0.8837	1.2811
COD	160222	246574	316008	408262	1.899	2.8539	3.6575	4.7253
Sulfate	56989.2	85937	112095	150094	0.6739	0.9946	1.2974	1.7372
Al	464.93	694.76	912.74	1128.7	0.0316	0.008	0.0106	0.0131
Ca	32984.1	49827	65261	86632	0.39	0.5767	0.7553	1.0027
Cd	8.21357	12.244	16.093	20.767	1E-04	0.0001	0.0002	0.0002
Fe	1532.53	2321.4	3055.6	4211.9	0.0187	0.0269	0.0354	0.0487
K	22793.3	34543	45518	59218	0.27	0.3998	0.5268	0.6854
Li	18.4676	26.994	35.284	46.214	0.0002	0.0003	0.0004	0.0005
Mg	2677.23	4121.9	5397.7	7079.6	0.034	0.0477	0.0625	0.0819
Mn	1542.69	2438.7	3091.1	4050.7	0.0182	0.0282	0.0358	0.0469
Na	47801.1	69500	92188	123557	0.5663	0.8044	1.067	1.4301
Zn	35.978	50.084	70.522	81.309	0.0059	0.0006	0.0008	0.0009

Considering the pollutant loads estimated in scenario 2, there should be a strict monitoring of total loads pollutant from Naivasha town. It is because the total loads pollutants from the two sources are increasing and therefore affected the Naivasha Lake. The waster water treatment plant should be redesign to reduce the pollutant of the town, so the loads from the town are not considerably influence the Lake.

5.5.3. Comparison between Scenario 1 and Scenario 2

Two scenarios were established to predict the loads pollutant of Naivasha town in the future. One was using one variable, i.e. population growth and the other was using two variables, i.e. population growth and increasing of the paved area.

The predicted pollutants are coming from storm runoff and sewage of Naivasha town. Those pollutants affect the Naivasha Lake in terms of the quality, in contrast water from Naivasha Lake as the main freshwater supply for inhabitants in Naivasha town.

The comparison of the loads pollutant from scenario 1 and scenario 2 can be seen in Table 5-22.

Table 5-22 Comparison of pollutant loads scenario 1 and 2

Parameters	Rate Pollutant Loads (kg/s) using scenario 1				Rate Pollutant Loads (kg/s) using scenario 2			
	2003	*2006*	*2009*	*2013*	*2003*	*2006*	*2009*	*2013*
Alkalinity	4.9159	5.014621	5.134293	5.31379	4.9159	6.730482	8.662744	11.43232
TDS	0.011059	0.011075	0.011095	0.011124	0.011059	0.01674	0.021736	0.02781
DO	0.067355	0.01653	0.01656	0.016603	0.067355	0.024985	0.032442	0.041507
Nitrate	0.286207	0.286288	0.286386	0.286533	0.286207	0.434853	0.561519	0.683511
Nitrite	0.028857	0.02889	0.028931	0.028993	0.028857	0.043954	0.055046	0.06905
Ammonia	0.157833	0.164421	0.168574	0.175774	0.157833	0.242891	0.290676	0.345254
Phosphate	0.141754	0.145294	0.149535	0.155952	0.141754	0.195269	0.253123	0.327937
EC	5.814555	5.951519	6.11276	6.359875	5.814555	8.153234	10.75559	14.33041
Chloride	0.520174	0.45866	0.469248	0.484837	0.520174	0.629712	0.883652	1.28107
COD	1.898951	1.94582	2.00242	2.087551	1.898951	2.853868	3.657505	4.725253
Sulfate	0.673931	0.677687	0.682442	0.689352	0.673931	0.994642	1.2974	1.737196
Al	0.031574	0.005507	0.005521	0.00554	0.031574	0.008041	0.010564	0.013064
Ca	0.390027	0.391218	0.392626	0.394778	0.390027	0.576702	0.755332	1.002685
Cd	9.71E-05	9.76E-05	9.81E-05	9.89E-05	9.71E-05	0.000142	0.000186	0.00024
Fe	0.018737	0.018131	0.01815	0.018177	0.018737	0.026868	0.035365	0.048748
K	0.270001	0.27494	0.280819	0.289756	0.270001	0.399808	0.526828	0.685392
Li	0.000219	0.000222	0.000226	0.000232	0.000219	0.000312	0.000408	0.000535
Mg	0.034049	0.032141	0.032697	0.033522	0.034049	0.047707	0.062474	0.08194
Mn	0.018236	0.018245	0.018259	0.018277	0.018236	0.028226	0.035776	0.046883
Na	0.566267	0.576662	0.588976	0.607761	0.566267	0.804403	1.066988	1.430053
Zn	0.005898	0.000428	0.000431	0.000436	0.005898	0.00058	0.000816	0.0009

From Table 5-22, the comparison of scenario 1 and scenario 2 has a considerably difference of total loads pollutant. The average percentages of increasing load pollutant for scenario 1 are 1.21 % (2006), 1.25 % (2009), and 1.85 % (2013). Then for scenario 2, the average percentages of increasing load pollutant are 33.10 % (2006), 23.33 % (2009), and 22.63 % (2013). More increases of pollutant loads in scenario 2 are caused by the change of the two sources (sewage and runoff).

As the implication of the result presented above, there must be good planning in the developing area. Because the increasing pollutant loads in scenario 1 is considerably high with the maximum increasing of 4.11 % in 2013. If it is combined with the second scenario, the increasing will be higher and therefore more pollutant from the town will affects the lake.

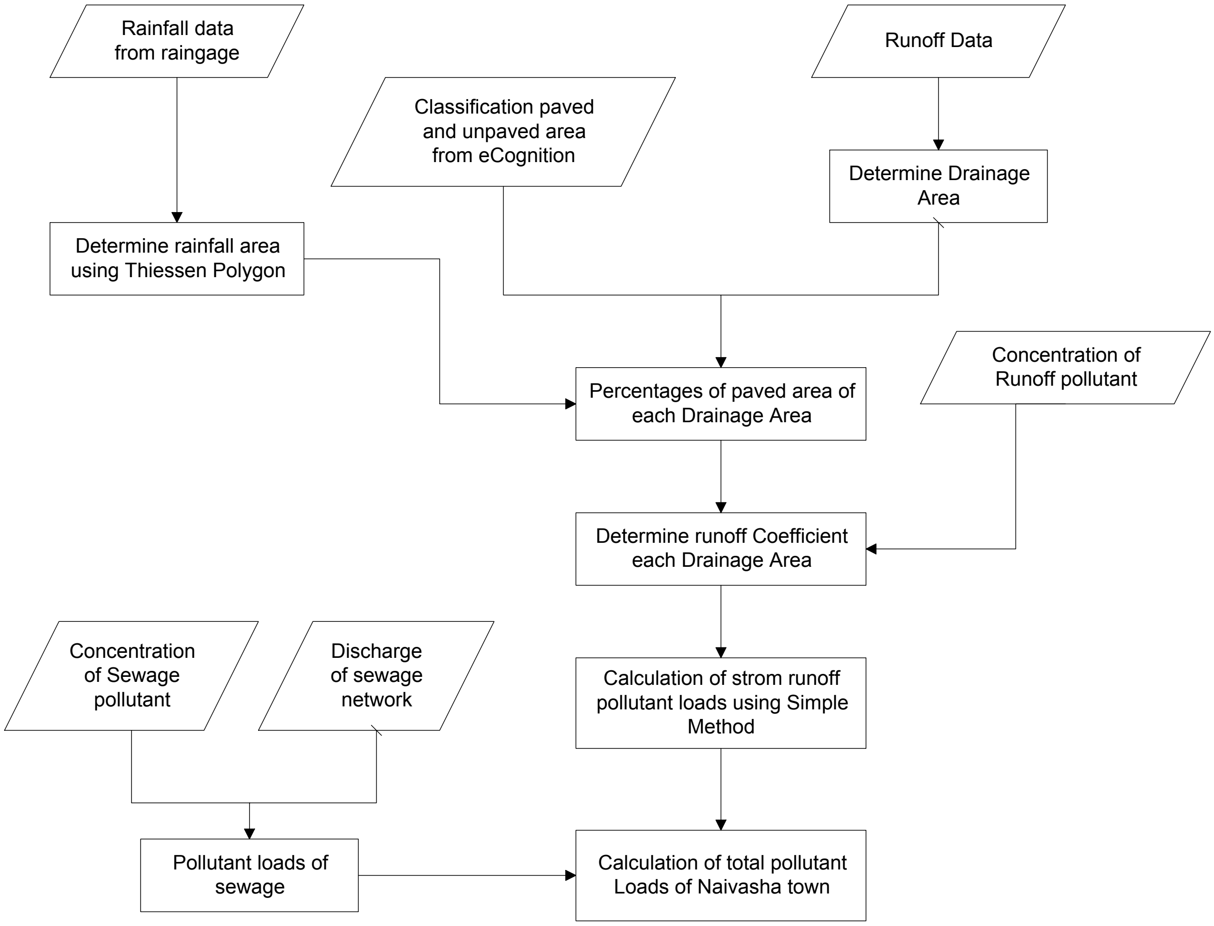


Figure 5-4 Flow chart of methodology for estimating pollutant loads of Naivasha town

5.6. Conclusions

Wastewater in urban areas can be defined as a combination of liquid or water carrying waste removed from residences, institutions, and industrial zones, along with such surface water or storm water as may be present. In other words, wastewater in urban areas is an effect of urban activities.

Because the system between sewage and storm runoff in Naivasha town are separated, the pollutant loads prediction was done separately. To calculate the pollutant loads from storm runoff, the Simple Method was used. This Simple model is used to estimate the pollutant loads of storm runoff with areas < 640 acres.

In the Simple Method, the pollutant loads have a direct relationship with rainfall depth over the desired time interval, fraction in rainfall, runoff coefficient and area. The value of the runoff coefficient is depending on the percentages of the paved area. The larger the paved area, the greater is the runoff coefficient. This simple method was adequate for this study because the data in this study fits the equation to estimate storm water runoff pollutant loads.

For sewage pollutant loads, the calculation involved the concentrations of pollutant in each drainage area and the discharges flow of the sewage network. After that, the total pollutant loads of Naivasha town were calculated by summing the pollutant loads from storm water runoff with the pollutant loads sewage.

To predict the pollutant loads in the future, two scenarios were establish. One of the scenarios only used one variable and the other scenario used two variables. In the first scenario, the pollutant load is the same (assuming that annual rainfall is the same and there is no developing area inside each drainage area), the pollutant load from sewage is assumed to increase along with population growth.

Although this scenario may be unrealistic, it shows the impact of an increasing population while keeping the extent of the paved area remaining same. This could occur if households increase their average occupancies or if the buildings were only expanding in a vertical direction (for the example in height), hence would not increase the already existing paved areas significantly.

Since presently only 15 % of the population is connected to the sewage system, this scenario may also be used as general indication of the effect of an increased population connected to the sewer system.

The second scenario assumes that the pollutant load of storm water runoff is increasing along with increasing of the paved & unpaved areas in the drainage area and also that the pollutant load of sewage is increasing along with population growth.

The summary of the increasing percentage of paved area and the increasing of sewage flow can be seen at Table 5-23 and Table 5-24.

Table 5-23 Prediction of increasing percent paved area

Runoff	2003	2006	2009	2013
	Paved area (%)	*Paved area (%)*	*Paved area (%)*	*Paved area (%)*
R1	0.3099	0.3673	0.4508	0.5769
R2	0.1936	0.2980	0.4933	0.8722
R3	0.2341	0.2590	0.2889	0.3253
R4	0.3245	0.4518	0.6619	0.6620
R5	0.3544	0.8225	0.8240	0.8240
R6	0.3000	0.4692	0.7978	0.7970

Table 5-24 Prediction of increasing sewage flow

Sewage	2003	2006	2009	2013
	Flow sewage increased (m3/d)	*Flow sewage increased (m3/d)*	*Flow sewage increased (m3/d)*	*Flow sewage increased (m3/d)*
S1	164.83	549.44	1098.89	1831.48
S2	188.76	629.19	1258.39	2097.31
S3	2037.77	6792.56	13585.13	22641.88
S4	1228.32	4094.41	8188.81	13648.02
S5	528.31	1761.04	3522.07	5870.12
S6	990.00	3318.00	6354.00	9879.00
S7	60.76	202.52	405.04	675.06
S8	750.58	2501.93	5003.86	8339.76
S9	1870.22	6234.06	12468.13	20780.22

A summary of the increasing of pollutant loads rate (kg/day) for scenario 1 and 2 is presented in Table 5-25

**Table 5-25 Summary of the increasing percentage of pollutant load rate f
or each scenario based on the year 2003**

Parameters	% Increasing pollutant load rate of Scenario 1			% Increasing pollutant load rate of Scenario 2		
	2006	*2009*	*2013*	*2006*	*2009*	*2013*
Alkalinity	2.18	2.33	3.38	28.63	22.31	24.23
TDS	0.15	0.18	0.26	35.32	22.99	21.84
DO	0.15	0.18	0.26	35.32	22.99	21.84
Nitrate	0.03	0.03	0.05	35.56	22.56	17.85
Nitrite	0.13	0.14	0.21	35.72	20.15	20.28
Ammonia	3.06	2.46	4.10	35.74	16.44	15.81
Phosphate	2.71	2.84	4.11	29.12	22.86	22.81
EC	2.58	2.64	3.89	30.37	24.20	24.95
Chloride	2.03	2.26	3.22	30.13	28.74	31.02
COD	2.67	2.83	4.08	35.02	21.97	22.60
Sulfate	0.60	0.70	1.00	33.68	23.34	25.32
Al	0.21	0.24	0.35	33.08	23.88	19.14
Ca	0.34	0.36	0.54	33.80	23.65	24.67
Cd	0.49	0.53	0.79	32.92	23.92	22.51
Fe	0.09	0.10	0.15	33.98	24.03	27.45
K	2.01	2.09	3.08	34.02	24.11	23.13
Li	1.68	1.72	2.58	31.59	23.49	23.65
Mg	1.54	1.70	2.46	35.05	23.64	23.76
Mn	0.06	0.07	0.10	36.74	21.11	23.69
Na	2.02	2.09	3.09	31.22	24.61	25.39
Zn	0.62	0.74	1.05	28.16	28.98	13.27
average	1.21	1.25	1.85	33.10	23.33	22.63

These two scenarios may not be entirely appropriate due to lack of the accurate data. The data collected during the fieldwork is not enough to make an accurate prediction for the future. The assumption was used in this study lower the accuracy of the prediction of the pollution in the future. Further research about Naivasha town is needed to make a better prediction of pollutant loads from Naivasha town to Lake Naivasha in the future. In addition, there should be a continuous monitoring of the pollutant loads of sewage and runoff network.

6. Summary, Conclusions and Recommendations

6.1. Summary and Conclusions

With the advance of industrialisation and increasing population in the town, the requirements for water have increased along with greater demands for higher quality water. Over time, in Naivasha town, the water requirements have emerged for drinking and personal hygiene, fisheries, agriculture, and recreational activities. Each of these water uses gives an impact and influence on the quality of the aquatic environment in Lake Naivasha as receiving water body. It also influences the water supply or drinking water.

The principal sources of pollutants from Naivasha town to the Lake Naivasha are from domestic sewage and storm water runoff. Because the water from Naivasha town activities can influence Naivasha Lake, there should be measurement and monitoring of the water quality. To assess the quality of the water from Naivasha town, analyses of water quality from several points were done. Four samples of borehole, two samples of tap water, six samples of runoff water, and nine samples of sewage water were analysed. Some parameters of these samples were analysed in the field and the other samples were analysed in the laboratory.

The conclusions from the analyses of the sample are:

- For drinking water samples, the tap water cannot be used for drinking because some of the parameters have a high concentration exceeding the WHO drinking water standards. Especially the presence of total bacteria in the borehole and tap water samples is not allowed.
- For runoff water samples, the parameters that exceed the EPA standard are DO, Nitrate, Nitrite, turbidity and some of Cations parameters. The turbidity is higher because runoff carries some mud, sand and sediment.
- For sewage water samples, alkalinity, ammonia, phosphate EC, chloride, sulphate, COD and some of Cations are higher than in the other samples. The most important parameter of sewage related with wastewater treatment plant is COD (Chemical Oxygen Demand).

These analyses show that, there are some pollutant parameters that are give considerable influences to the lake. They are: Ammonia, Nitrate, Nitrite, Phosphate, COD and total bacteria. These parameters can be reduced using some treatments in the Waste Water Treatment Plant before reaching the lake.

The Naivasha water supply system uses four main boreholes, which are operated by Naivasha municipality. Besides those four boreholes, which belong to the municipality, there are more private boreholes and household wells to meet the demand of Naivasha town. However, no analysis on the quality of those boreholes and wells were done considering the constraints in time and resources.

It is difficult to estimate the sewage water flow generated from Naivasha town because:

- There are no regular measurements or daily peaks of the water supply of Naivasha town during the day
- A large number of private boreholes and wells that are not registered to municipality

- Not all the sewage flow uses the network. Some sewage from some parts of Naivasha town reaches the waste water treatment plant using trucks

eCognition is one alternative in carrying out image classification. eCognition conducts classification based on the segmentation of an image instead of an image pixel and has various features to determine the classes. Regarding the result gained from the created class hierarchy consists of class (=parent class) and subclass (=children class), most of the objects of interest could be identified. But with respect to some contextual features and the similarity of some classes, a final manual revision of the classification could not be avoided.

The percentage of paved and unpaved areas in Naivasha town using eCognition is 89.24 % for unpaved area and 10.57 % for the paved area. From this result, the calculation of paved and unpaved area in each drainage area could be achieved. With all of those data, the prediction of increasing of the paved area in the future could be calculated. The increasing percentages of paved and unpaved area in each drainage area are given in Table 5-18 page 76.

The result of classification using eCognition was checked with ground control points from the fieldwork to get an accuracy assessment. The accuracy assessment of the final map consists of paved and unpaved area is 81.82 %. This result is adequate enough because the error classification of this map is only 18.18 %.

The used of High-resolution satellite image - IKONOS is good to classify the paved and unpaved area. This is mainly because the object in the image can be easily interpreted by human vision, since IKONOS has a 1-meter resolution, therefore it facilitates effective distinction of urban features.

In hydrology, there are several models to estimate the pollutant loads of storm water runoff and sewage. One of them is the Simple Method, which estimates the pollutant loads of runoff. This method is suitable for this study because it needs only rainfall data in time interval, runoff coefficient, and percentages of paved area. For sewage pollutants, it is influenced by concentration of the pollutant and discharge of the sewage.

Two scenarios were established to estimate the pollutant loads of Naivasha town for a 10 years projection. The first scenario estimated the pollutant loads of Naivasha based on the population growth. The scenario assumes that the annual rainfall is the same for each year and there are no changes in the extent of paved area. The concentration of pollutant loads was assumed to have the same concentration for each year as well. This scenario made use of one variable, in this case population growth. Even though this scenario seems unrealistic, it does provide an indication of the increase of pollutant loads by considering population growth only.

The second scenario estimates the pollutant loads of Naivasha town for a 10 years projection based on the increasing of the paved area along with population growth. This population growth gave an effect on land use and land cover. The two scenarios were compared to know how is the difference in terms of increasing pollutant loads calculated by considering one variable only and all variable. Both of these scenarios are useful to predict the pollutant loads in Naivasha town.

From those two scenarios, the area development of Naivasha town should be planned carefully. This is supported by the prediction in scenario 1, where the changes in growth population without changes in paved area result in the increasing of pollutant loads. When the increasing of the paved area involved into the prediction, then the increasing of pollutant loads will be higher. The average of increased percentages of pollutant loads from each scenario is summarised in Table 6-1.

Table 6-1 Average increasing percentages of pollutant loads (based on year 2003)

Scenario	Average increasing of Pollutant Loads (%)		
	2006	*2009*	*2013*
Scenario 1	1.21	1.25	1.85
Scenario 2	33.1	23.33	22.63

The result from the two scenarios may not be an entirely appropriate scenario because lack of accurate data. The data from the fieldwork is not enough to accurately predict pollutant loads in the future. But these predictions are useful to monitor the pollutant from activities of Naivasha town to the Lake Naivasha.

6.2. Recommendations

Based on the findings in the study, some recommendations for further study related with the water quality study in Naivasha town are presented as follow.

- The analysis of the water quality needs more detail data on the pollutant concentration in Naivasha town. The presence of any historical data will facilitate more accurate analysis about the pollutant from year to year.
- It is important to do a water quality monitoring especially for boreholes and wells in order to assess the quality of drinking water for Naivasha town from each borehole or wells. If the water quality from that borehole or well is not suitable to consume for human, there should be a treatment to the water harvested from the corresponding boreholes or wells.
- There should be monitoring of the pollutant from Naivasha town to the Lake. The wastewater treatment plant should be reviewed to reduce the pollutant from the town. There should be a standard of the waster water flow to the Lake. This is because Lake Naivasha is one from two fresh water sources in Rift Valley.
- The development of Naivasha town should be planned and controlled carefully in order to prevent more pollution from the town. From the scenarios, the results showed that the increasing of the pollution will be higher along with population growth and increasing of the paved area.
- It is better to connect all the sewage sources in the network in order to control the sewage from the town.
- Analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients would give best result if it is based on actual, simultaneous measurements of both rainfall and runoff the project area. More hydrological data should be measured in the field, especially rainfall data.
- The more data supporting the study, the better result that one will get.

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Appendix A: Some general report of Naivasha Town water samples

SampleID : BS1
Location : Police Line
Site : Borehole Police Line
Sampling Date : 9/29/2003
Geology :
Watertype : Na-HCO3

Sum of Anions (meq/l) : 6.0088
Sum of Cations (meq/l) : 6.4803
Balance: : 3.78%

Measured TDS(mg/l) : 3.6
Calculated TDS(mg/l) : 233.2

Hardness	: meq/l	°f	°g	mg/l CaCO3
Total hardness	: 0.44	2.22	1.24	22.2
Permanent hardness	: 0.0	0.00	0.00	0.0
Temporary hardness	: 0.44	2.22	1.24	22.2
Alkalinity	: 4.12	20.59	11.53	205.9

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	125.0	5.437	5.437	43.534
K +	19.5	0.499	0.499	3.995
Ca++	8.0	0.2	0.399	3.195
Mg++	0.54	0.022	0.044	0.352
Cl-	30.0	0.846	0.846	6.774
SO4--	44.0	0.458	0.916	7.334
HCO3-	251.258	4.118	4.118	32.973

Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	14.815	8.986	0.319	0.194
Ca/SO4	0.182	0.436	0.152	0.364
Na/Cl	4.167	6.425	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl) :	20.327	0.3475
Sylvite (KCl) :	37.18	0.5018
Anhydrite (CaSO4) :	62.389	0.458

SampleID : BS5
Location : La Belle Inn
Site : Tap water La Belle Inn
Sampling Date : 10/2/2003
Geology :
Watertype : Na-Cl

Sum of Anions (meq/l) : 3.5586
Sum of Cations (meq/l) : 3.5272
Balance: : -0.44%

Measured TDS(mg/l) : 3.2
Calculated TDS(mg/l) : 211.2

Hardness	: meq/l	°f	°g	mg/l CaCO3
Total hardness	: 0.86	4.28	2.40	42.8
Permanent hardness	: 0.86	4.28	2.40	42.8
Temporary hardness	: 0.0	0.00	0.00	0.0
Alkalinity	: 0.0	0.00	0.00	0.0

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	51.6	2.244	2.244	31.669
K +	15.6	0.399	0.399	5.631
Ca++	13.5	0.337	0.674	9.512
Mg++	2.22	0.091	0.183	2.583
Cl-	120.0	3.385	3.385	47.771
SO4--	2.0	0.021	0.042	0.593
HCO3-	0.0	0.0	0.0	0.0

Ratios			Comparison to Seawater	
	mg/l	mmol/l	mg/l	mmol/l
Ca/Mg	6.081	3.688	0.319	0.194
Ca/SO4	6.75	16.177	0.152	0.364
Na/Cl	0.43	0.663	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl) :	131.301	2.2445
Sylvite (KCl) :	29.744	0.4014
Carbonate (CaCo3) :	22.491	0.2249
Dolomite (CaMg(CO3)2):	16.812	0.091
Anhydrite (CaSO4) :	2.836	0.021

SampleID : SS2
Location : Outflow of WTP
Site : Sewage 2
Sampling Date : 10/8/2003
Geology :
Watertype : Na-NH4-HCO3-Cl

Sum of Anions (meq/l) : 11.1161
Sum of Cations (meq/l) : 18.0139
Balance: : 23.68%

Measured TDS(mg/l) : 0.1
Calculated TDS(mg/l) : 662.3

Hardness	meq/l	°f	°g	mg/l CaCO3
Total hardness	2.92	14.60	8.17	146.0
Permanent hardness	0.0	0.00	0.00	0.0
Temporary hardness	2.92	14.60	8.17	146.0
Alkalinity	6.1	30.52	17.09	305.2

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	187.7	8.164	8.164	28.026
K +	76.4	1.954	1.954	6.708
Ca++	40.6	1.013	2.026	6.955
Mg++	10.86	0.447	0.893	3.066
Cl-	160.3	4.521	4.521	15.52
SO4--	22.0	0.229	0.458	1.572
HCO3-	372.41	6.104	6.104	20.954

Ratios — Comparison to Seawater

Ratios	mg/l	mmol/l	Seawater mg/l	Seawater mmol/l
Ca/Mg	3.738	2.268	0.319	0.194
Ca/SO4	1.845	4.423	0.152	0.364
Na/Cl	1.171	1.806	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl)	150.2	2.5675
Sylvite (KCl)	145.67	1.9659
Carbonate (CaCo3)	33.755	0.3375
Dolomite (CaMg(CO3)2)	82.243	0.447
Anhydrite (CaSO4)	31.194	0.229

SampleID : SS6
Location : Inflow of WTP
Site : Sewage 6
Sampling Date : 10/8/2003
Geology :
Watertype : Na-NH4-HCO3-Cl

Sum of Anions (meq/l) : 14.2876
Sum of Cations (meq/l) : 26.6667
Balance: : 30.23%

Measured TDS(mg/l) : 0.3
Calculated TDS(mg/l) : 873.1

Hardness	meq/l	°f	°g	mg/l CaCO3
Total hardness	2.37	11.84	6.63	118.4
Permanent hardness	0.0	0.00	0.00	0.0
Temporary hardness	2.37	11.84	6.63	118.4
Alkalinity	8.09	40.43	22.64	404.3

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	273.3	11.888	11.888	29.027
K +	126.8	3.243	3.243	7.919
Ca++	31.7	0.791	1.582	3.863
Mg++	9.55	0.393	0.786	1.919
Cl-	170.0	4.795	4.795	11.708
SO4--	66.0	0.687	1.374	3.355
HCO3-	493.312	8.086	8.086	19.744

Ratios — Comparison to Seawater

Ratios	mg/l	mmol/l	Seawater mg/l	Seawater mmol/l
Ca/Mg	3.319	2.013	0.319	0.194
Ca/SO4	0.48	1.151	0.152	0.364
Na/Cl	1.608	2.479	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl)	90.799	1.5521
Sylvite (KCl)	241.766	3.2627
Dolomite (CaMg(CO3)2)	19.113	0.104
Anhydrite (CaSO4)	93.583	0.687

SampleID : RS1
Location : Near La Belle Inn
Site : Runoff Station Line
Sampling Date : 9/27/2003
Geology :
Watertype : Na-NH4-Ca-HCO3-Cl

Sum of Anions (meq/l) : 6.5275
Sum of Cations (meq/l) : 9.2156
Balance: : 17.07%

Measured TDS(mg/l) : 1.4
Calculated TDS(mg/l) : 387.6

Hardness	meq/l	°f	°g	mg/l CaCO3
Total hardness	2.25	11.23	6.29	112.3
Permanent hardness	0.0	0.00	0.00	0.0
Temporary hardness	2.25	11.23	6.29	112.3
Alkalinity	3.31	16.55	9.27	165.5

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	88.8	3.863	3.863	24.538
K +	31.3	0.801	0.801	5.088
Ca++	39.2	0.978	1.956	12.424
Mg++	3.52	0.145	0.29	1.842
Cl-	80.0	2.257	2.257	14.336
SO4--	26.0	0.271	0.541	3.436
HCO3-	201.959	3.31	3.31	21.025

Ratios	mg/l	mmol/l	Comparison to Seawater mg/l	mmol/l
Ca/Mg	11.136	6.755	0.319	0.194
Ca/SO4	1.508	3.613	0.152	0.364
Na/Cl	1.11	1.712	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl)	85.176	1.456
Sylvite (KCl)	59.679	0.8054
Carbonate (CaCo3)	56.313	0.5631
Dolomite (CaMg(CO3)2)	26.657	0.145
Anhydrite (CaSO4)	36.866	0.271

SampleID : RS5
Location : Near Souvenir shop Mbaria Kani
Site : Runoff Mbaria Kaniu Road
Sampling Date : 9/27/2003
Geology :
Watertype : NH4-Ca-Na-HCO3-SO4

Sum of Anions (meq/l) : 5.1760
Sum of Cations (meq/l) : 8.2714
Balance: : 23.02%

Measured TDS(mg/l) : 1.4
Calculated TDS(mg/l) : 344.7

Hardness	meq/l	°f	°g	mg/l CaCO3
Total hardness	2.56	12.80	7.17	128.0
Permanent hardness	0.22	1.09	0.61	10.9
Temporary hardness	2.34	11.71	6.56	117.1
Alkalinity	2.34	11.71	6.56	117.1

(1 °f = 10 mg/l CaCO3/l 1 °g = 10 mg/l CaO)

Major ion composition

	mg/l	mmol/l	meq/l	meq%
Na+	45.3	1.97	1.97	14.65
K +	29.5	0.754	0.754	5.607
Ca++	44.8	1.118	2.236	16.628
Mg++	3.95	0.162	0.325	2.417
Cl-	20.0	0.564	0.564	4.194
SO4--	78.0	0.812	1.624	12.077
HCO3-	142.926	2.343	2.343	17.423

Ratios	mg/l	mmol/l	Comparison to Seawater mg/l	mmol/l
Ca/Mg	11.342	6.879	0.319	0.194
Ca/SO4	0.574	1.377	0.152	0.364
Na/Cl	2.265	3.493	0.556	0.858

Dissolved Minerals:	mg/l	mmol/l
Halite (NaCl)	115.27	1.9704
Sylvite (KCl)	33.001	0.4454
Carbonate (CaCo3)	14.34	0.1434
Dolomite (CaMg(CO3)2)	29.913	0.162
Anhydrite (CaSO4)	110.598	0.812

Appendix B: Report of drinking water quality regulation

SampleID : BS1
Location : Police Line
Site : Borehole Police Line
Sampling Date : 9/29/2003

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	125	< 20	< 200
K	19.5	< 10	< 12
Cl	30	< 25	
SO4	44	< 25	< 250

Irrigation water:
Sodium Adsorption Ratio (SAR) : 11.54
Exchangeable sodium ratio (ESR) : 12.26
Magnesium hazard (MH) : 10.01

SampleID : BS2
Location : KWS
Site : Borehole KWS
Sampling Date : 9/29/2003

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	124.8	< 20	< 200
K	20.3	< 10	< 12
NH4	0.63	< .5	
Al	0.06	< .05	< .2

Irrigation water:
Sodium Adsorption Ratio (SAR) : 11.09
Exchangeable sodium ratio (ESR) : 11.33
Magnesium hazard (MH) : 11.50

SampleID : BS3
Location : Slaughter House
Site : Borehole Slaughter House
Sampling Date : 9/29/2003

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	107.4	< 20	< 200
K	20.5	< 10	< 12
NH4	0.78	< .5	
Cl	30	< 25	

Irrigation water:
Sodium Adsorption Ratio (SAR) : 9.70
Exchangeable sodium ratio (ESR) : 10.06
Magnesium hazard (MH) : 14.00

SampleID : BS4
Location : Delamere
Site : Borehole Delamere
Sampling Date : 9/29/2003

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	57.1	< 20	< 200
K	12.3	< 10	< 12
Mn	0.02	< .02	< .05
Al	0.06	< .05	< .2

Irrigation water:
Sodium Adsorption Ratio (SAR) : 3.35
Exchangeable sodium ratio (ESR) : 2.25
Magnesium hazard (MH) : 14.86

SampleID : BS5
Location : La Belle Inn
Site : Tap water La Belle Inn
Sampling Date : 10/2/2003

Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	51.6	< 20	< 200
K	15.6	< 10	< 12
Cl	120	< 25	
Al	0.11	< .05	< .2

Irrigation water:
Sodium Adsorption Ratio (SAR) : 3.43
Exchangeable sodium ratio (ESR) : 2.62
Magnesium hazard (MH) : 21.33

SampleID : BS6
Location : Municipal
Site : Tap water Municipal
Sampling Date : 10/2/2003

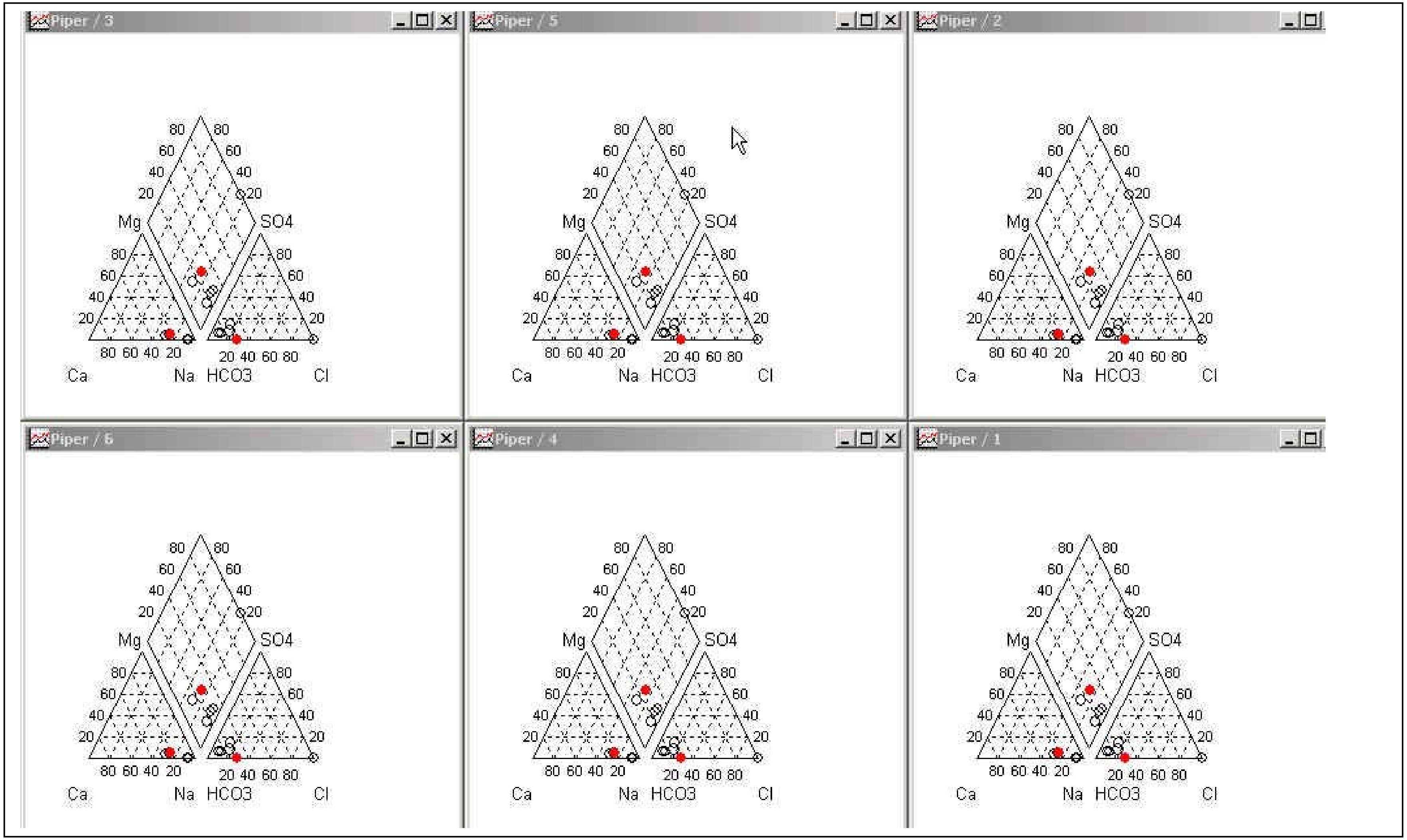
Drinking Water Quality Regulations:

Element	Measured	Recommended	Maximum
Na	52.8	< 20	< 200
K	17.4	< 10	< 12
Cl	30	< 25	

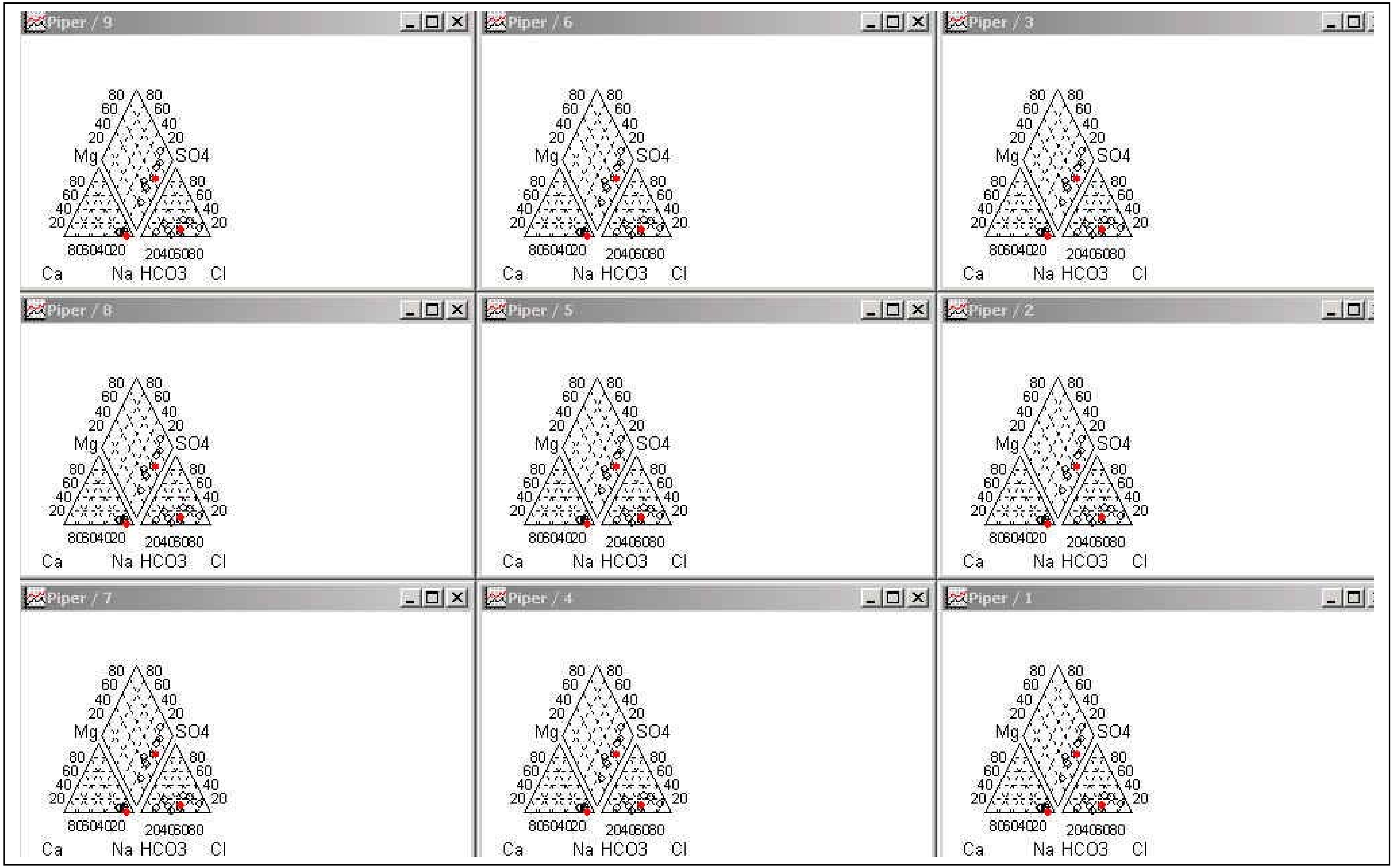
Irrigation water:
Sodium Adsorption Ratio (SAR) : 3.52
Exchangeable sodium ratio (ESR) : 2.70
Magnesium hazard (MH) : 20.95

Appendix C: The Piper graph from Aquachem

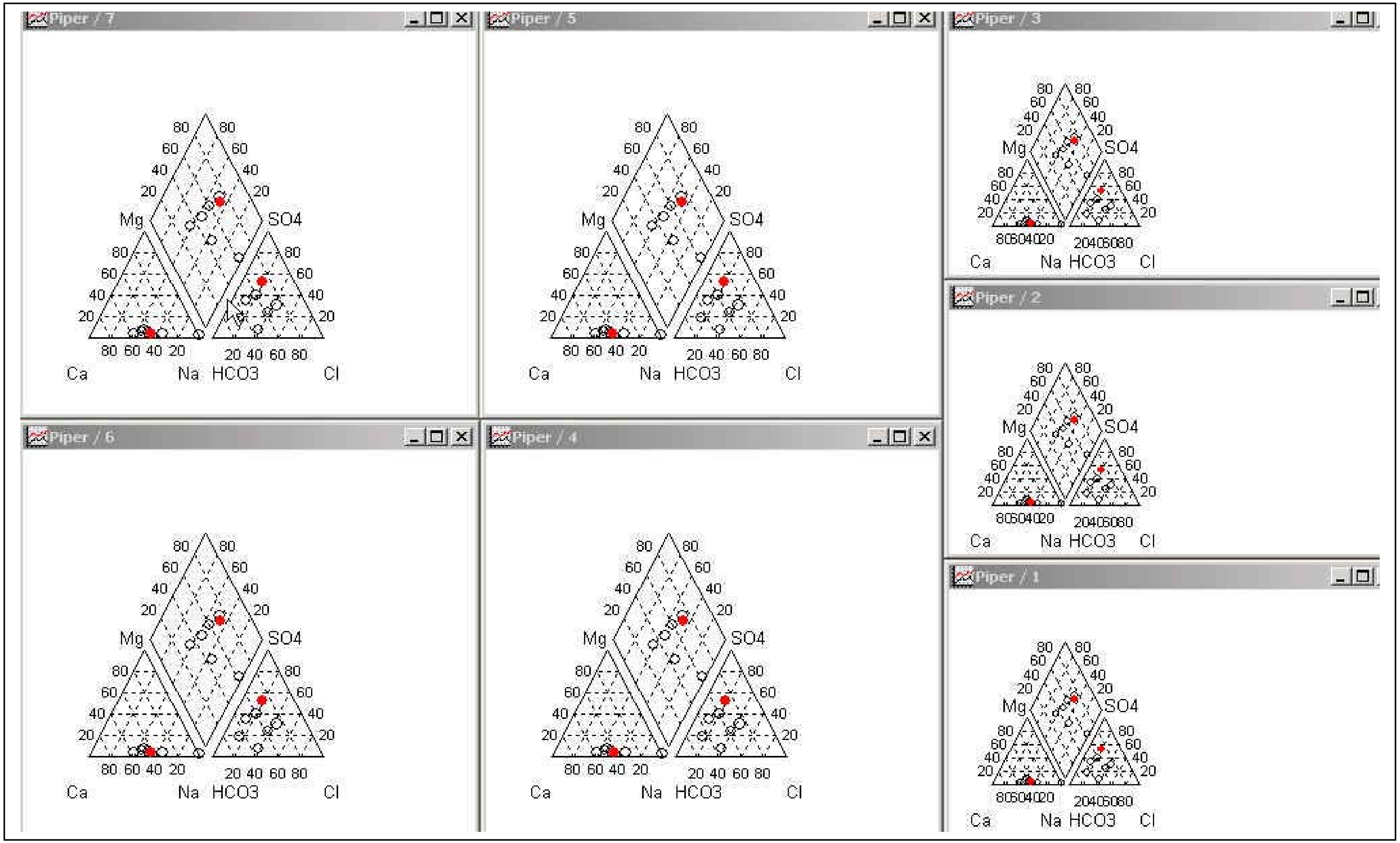
C.1 Piper graph of drinking water samples



C.2 Piper graph of sewage water samples

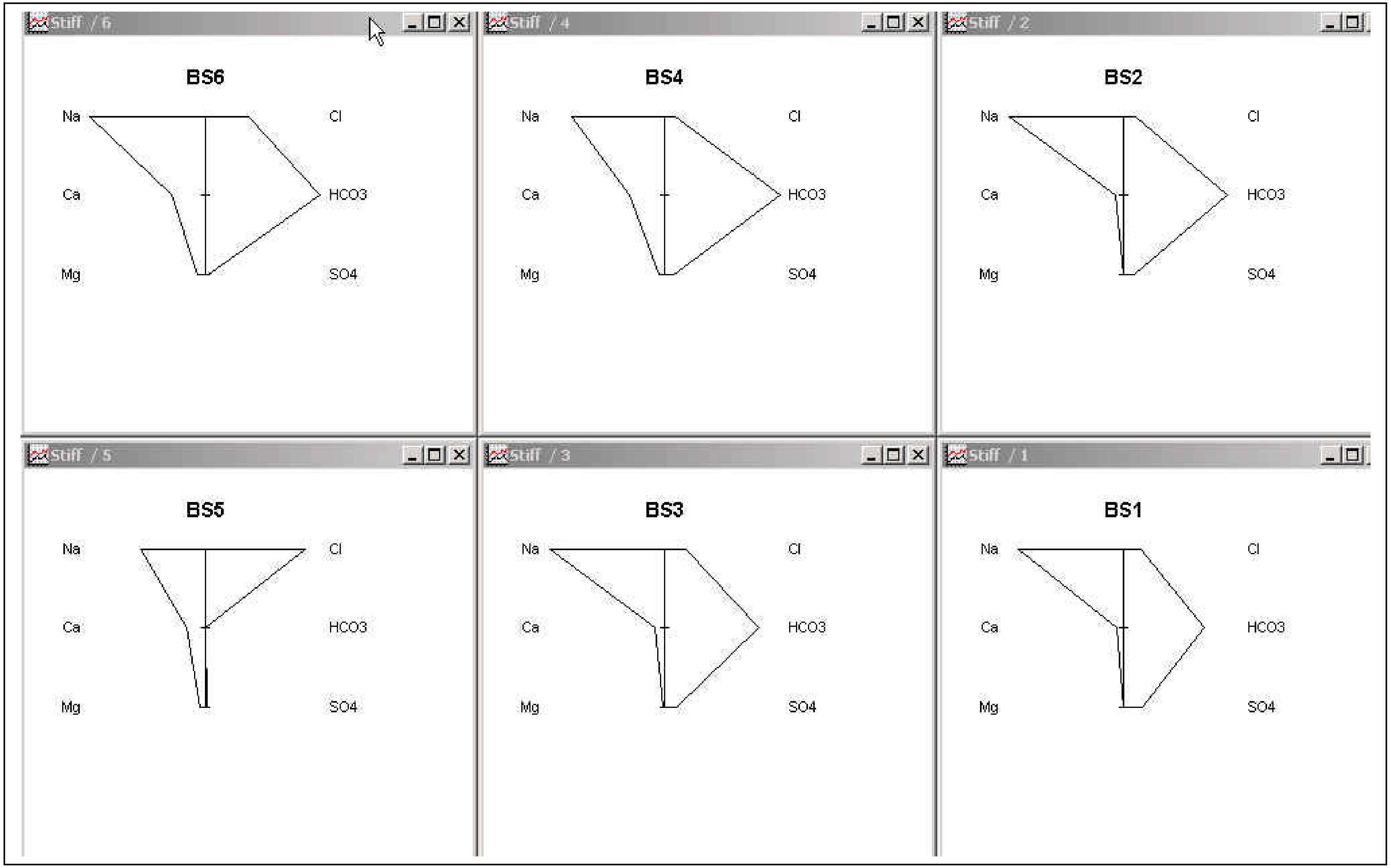


C.3 Piper graph of runoff water samples

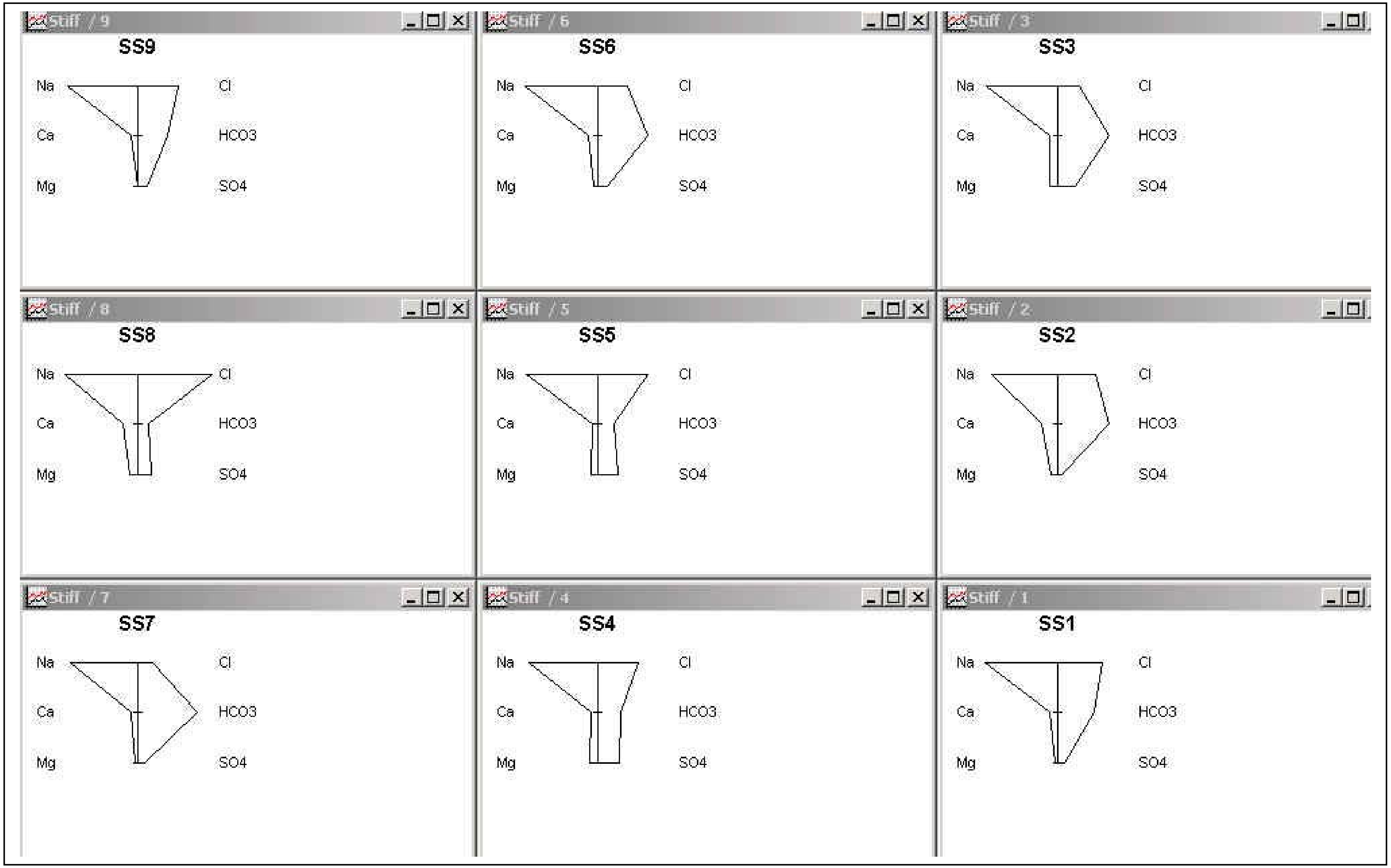


Appendix D: The Stiff graph from Aquachem

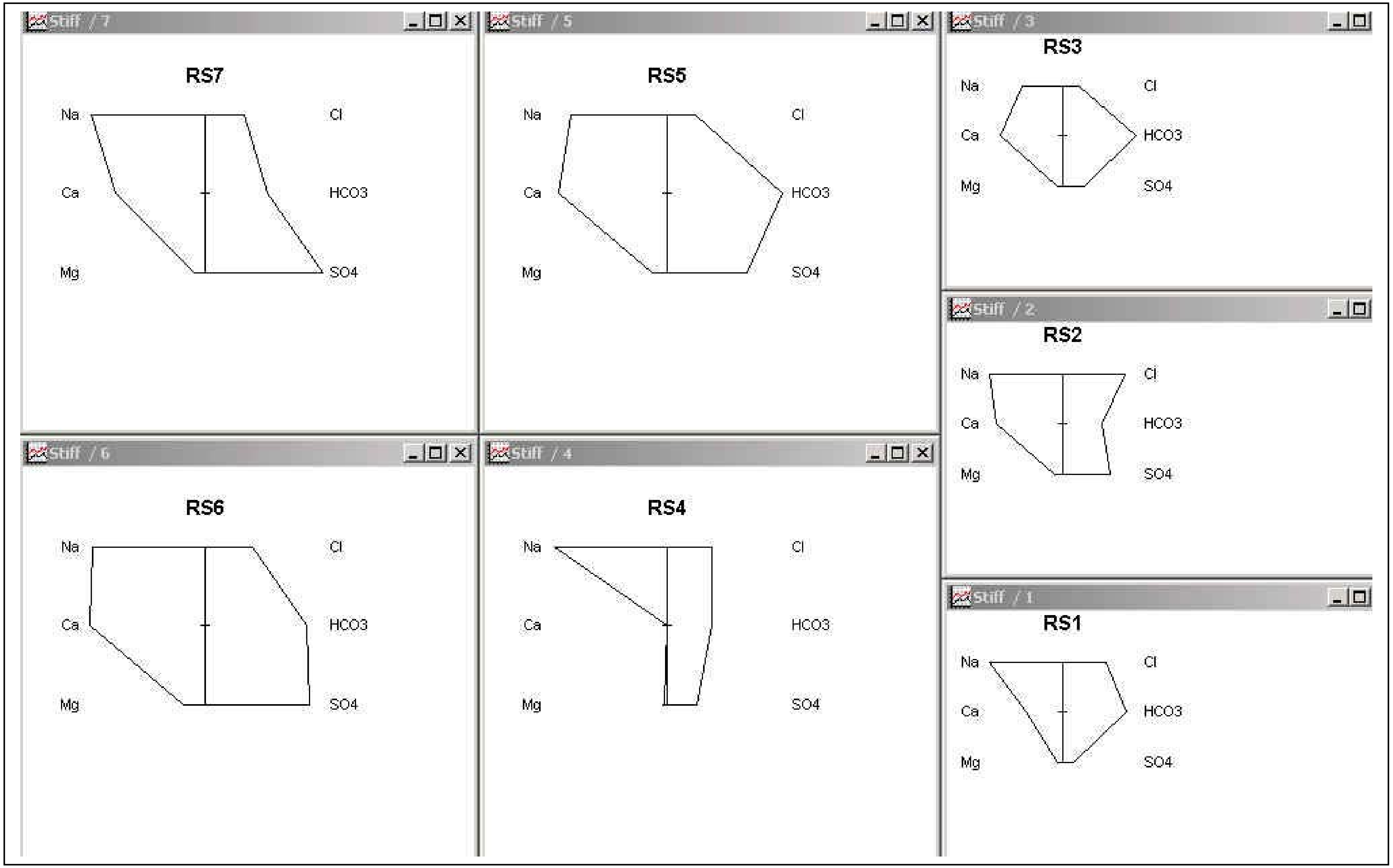
D.1 Stiff graph of drinking water samples



D.2 Stiff graph of sewage water samples



D.3 Stiff graph of runoff water samples



Appendix E: Water quality sampling

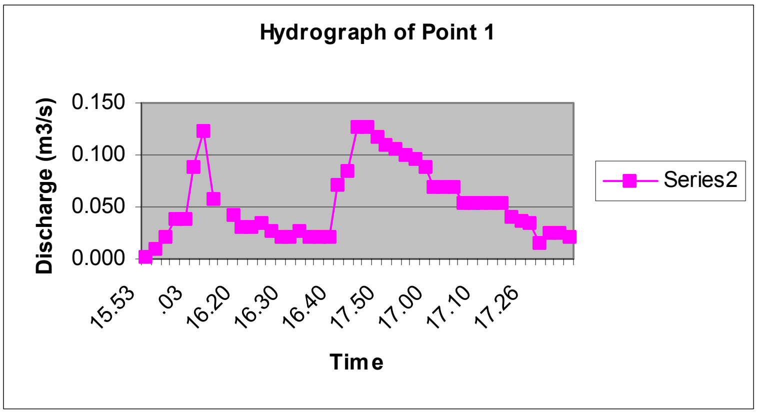
Coordinate		Samples	Temperature (°C)	pH	Turbidity (NTU)	Alkalinity (mmol/l)	TDS (mg/l)	DO (mg/l)	Nitrate (mg/l)	Nitrite (mg/l)	Ammonia (mg/l)	Phosphate (mg/l)	EC (µs/cm)	Chloride (mg/l)
X	Y													
215084	991855	Borehole Police Line	18.3	7.12	1.18	1	3.575	5.5	5	0.8	0.4	9	743	30
216095	9919014	Borehole KWS	18.7	7.25	1.27	1	3.068	4.72	4	0.5	0.4	8	774	20
214769	9922346	Borehole Slaughter House	18.1	7.14	0.46	1	3.3345	5.13	1	0.6	0.4	8	680	30
212951	9923292	Borehole Delamare	19.1	6.75	0.26	1	2.418	3.72	1	0.5	0.4	6	413	10
214141	9920829	Tap water La Belle Inn	19.1	7.25	7.15	15.5	3.283	4.9	5	0.7	0.4	13	1888	120
214265	9920613	Tap water Municipality	18.5	7.8	0.5	6.5	3.5443	5.29	3	0.7	0.4	6	755	30
214244	9920623	Sewage Near Gas Station	22.7	6.89	300	16.5	0.0603	0.09	2	1.1	134	82	2600	170
213683	9920529	Sewage outflow of WWTP	22.7	7.25	70.7	20	0.0536	0.08	2	0.8	138	57	2560	160.3
214072	9921517	Sewage Industry Area	22.8	6.67	202	26.5	0.0402	0.06	2	0.8	138	57	2560	130
214332	9921291	Sewage Near Open Market	22.9	6.95	353	22.5	0.0737	0.11	2	0.8	36	78	3530	250
214835	9920706	Sewage Near Hospital	22.3	7.23	225	27.5	0.7303	1.09	3	1	186	173	4350	310
213860	9920702	Sewage inflow of WWTP	20	7.12	86.5	23	0.2345	0.35	2	0.8	192	88	3710	170
214268	9920578	Sewage Near Municipality	22.7	7.04	67.9	14.5	0.402	0.6	1	0.7	2.5	28	1407	60
214125	9920876	Sewage Near La Belle Inn	22.5	8.33	149	29.6	1.005	1.5	2	0.6	2.5	105	4230	300
214006	9921105	Sewage in Mbaria Kaniu Road	22.7	8.26	286	27	0.737	1.1	1	0.5	2.5	73	3590	250
214129	9920861	Runoff Station Line	21.5	7.08	24000	15	1.474	2.2	6	1.7	30	43	1150	80
214205	9920705	Runoff Moi Avenue	22.4	7.05	3000	3.5	1.206	1.8	21	2.4	2.5	9	548	80
214245	9920614	Runoff Municipality	22.5	7.5	3000	2.5	1.139	1.7	18	2.7	2.5	13	471	30
214071	9920982	Runoff Postal Line	21.3	7.88	896	1.5	1.206	1.8	25	1.9	2.5	7	302	20
213997	9921109	Runoof Mbaria Kaniu Road	21.2	7.38	4000	3.5	1.474	2.2	40	4.5	27	10	428	20
213997	9921215	Runoff Gas Station	21.6	7.92	3000	4	0.938	1.4	99	3.3	36	18	664	40
214129	9920861	Runoff Station Line	21.2	7.78	1257	2.6	0.536	0.8	45	4.3	20	5	538	30

Coordinate		Samples	E-Coli (CFU/ml)	Total Coli-form (CFU/ml)	COD (mg/l)	Sulphate (mg/l)	Fluoride (mg/l)	Al (mg/l)	Ca (mg/l)	*Cd* (mg/l)	Cu (mg/l)	Fe (mg/l)	K (mg/l)	Li (mg/l)
X	Y													
215084	991855	Borehole Police Line	4	8	37	44	0.9	0.02	7.98	0.01	0	0.01	19.52	0.09
216095	9919014	Borehole KWS	4	12	40	22	0.91	0.06	8.47	0.01	0	0.01	20.3	0.07
214769	9922346	Borehole Slaughter House	32	62	42	23	0.91	0.01	8.01	0.01	0	0.01	20.51	0.06
212951	9923292	Borehole Delamare	0	2	20	12	0.83	0.06	18.8	0.01	0	0.6	12.32	0.03
214141	9920829	Tap water La Belle Inn	5	10	1	2	0.98	0.11	13.49	0.01	0	0.06	15.61	0.02
214265	9920613	Tap water Municipality	14	17	1	2	0.83	0.06	13.51	0.01	0	0.02	17.39	0.02
214244	9920623	Sewage Near Gas Station	76	150	1584	34	-	0.12	20.14	0.01	0	0.12	47.9	0.09
213683	9920529	Sewage outflow of WWTP	53	160	260	22	-	0.08	40.6	0.01	0	0.07	76.38	0.07
214072	9921517	Sewage Industry Area	90	>2000	1360	142	-	0.21	30.13	0.01	0	0.35	183.52	0.06
214332	9921291	Sewage Near Open Market	180	>2000	1329	178	-	0.32	24.34	0.01	0	0.51	148.08	0.08
214835	9920706	Sewage Near Hospital	150	>2000	1225	168	-	0.64	21.19	0.01	0	0.69	157.48	0.06
213860	9920702	Sewage inflow of WWTP	>2000	>2000	1116	66	-	0.23	31.66	0.01	0	0.29	126.78	0.09
214268	9920578	Sewage Near Municipality	27	190	1552	38	-	0.17	18.75	0.01	0	0.17	55.67	0.1
214125	9920876	Sewage Near La Belle Inn	80	>2000	1128	72	-	0.29	34.82	0.01	0	0.54	77.92	0.08
214006	9921105	Sewage in Mbaria Kaniu Road	61	>2000	277	78	-	0.21	26.81	0.01	0	0.4	158.31	0.06
214129	9920861	Runoff Station Line	-	-	156	26	-	0.3	39.18	0.01	0	1.15	31.3	0.04
214205	9920705	Runoff Moi Avenue	-	-	170	82	-	0.42	48.38	0.01	0	2.79	27.87	0.02
214245	9920614	Runoff Municipality	-	-	230	56	-	0.2	68.38	0.01	0	4.25	25.02	0.02
214071	9920982	Runoff Postal Line	-	-	96	18	-	0.6	21.81	0.01	0	0.55	19.89	0.01
213997	9921109	Runoof Mbaria Kaniu Road	-	-	250	78	-	0.58	44.76	0.01	0	2.09	29.51	0.02
213997	9921215	Runoff Gas Station	-	-	270	120	-	1.44	55.61	0.01	0	1.74	50.37	0.04
214129	9920861	Runoff Station Line	-	-	270	124	-	0.81	40.14	0.01	0	2.29	26.57	0.02

Coordinate		Samples	Mg (mg/l)	Mn (mg/l)	Na (mg/l)	*Pb* (mg/l)	Zn (mg/l)
X	Y						
215084	991855	Borehole Police Line	0.54	0	124.95	0	0.01
216095	9919014	Borehole KWS	0.67	0	124.78	0	0.01
214769	9922346	Borehole Slaughter House	0.79	0	107.36	0	0.01
212951	9923292	Borehole Delamare	1.99	0.02	57.05	0	0.02
214141	9920829	Tap water La Belle Inn	2.22	0	51.58	0	0.01
214265	9920613	Tap water Municipality	2.17	0	52.84	0	0.01
214244	9920623	Sewage Near Gas Station	4.64	0.12	182.43	0	0.02
213683	9920529	Sewage outflow of WWTP	10.86	0.24	187.72	0	0.03
214072	9921517	Sewage Industry Area	17.86	0.22	287.96	0	0.1
214332	9921291	Sewage Near Open Market	17.64	0.37	278.29	0	0.1
214835	9920706	Sewage Near Hospital	16.19	0.44	291.82	0	0.1
213860	9920702	Sewage inflow of WWTP	9.55	0.11	273.31	0	0.04
214268	9920578	Sewage Near Municipality	5.31	0.2	191.2	0	0.03
214125	9920876	Sewage Near La Belle Inn	11.14	0.42	193.82	0	0.06
214006	9921105	Sewage in Mbaria Kaniu Road	2.06	0.01	282.78	0	0.05
214129	9920861	Runoff Station Line	3.52	1.26	88.81	0	0.04
214205	9920705	Runoff Moi Avenue	3.6	2.19	61.63	0	0.02
214245	9920614	Runoff Municipality	3.25	2.44	51.36	0	0.01
214071	9920982	Runoff Postal Line	1.67	0.59	33.27	0	0.14
213997	9921109	Runoof Mbaria Kaniu Road	3.95	2.96	45.31	0	0.01
213997	9921215	Runoff Gas Station	6.56	2.39	62.47	0	0.03
214129	9920861	Runoff Station Line	3.05	2.25	58.49	0	0.02

Appendix F: The Runoff measurement

R1					
second	time	depth (cm)	second	time	depth (cm)
5.5	15.53	1.5	R2		
4.5	15.55	4.5	3	16.09	14
3	15.57	6			
2	15.59	7.5	R3		
3	16.01	11	4.5	16.11	10
2	16.03	17			
1.5	16.05	17.5	R4		
2	16.07	11	3.5	16.14	11
2	16.18	8			
2	16.20	6	R5		
2	16.22	6	4	16.16	6
1.5	16.24	5			
2	16.26	5	R6		
2.5	16.28	5	4	16.17	6
2.5	16.30	5			
2	16.32	5			
2.5	16.34	5			
2.5	16.36	5			
2.5	16.38	5			
2.5	16.40	17			
2.5	16.42	20			
2.5	16.44	30			
2.5	16.46	30			
2.5	16.48	28			
2.5	17.50	26			
2.5	16.52	25			
2.5	16.54	24			
2.5	16.56	23			
2.5	16.58	21			
3	17.00	20			
3	17.02	20			
3	17.04	20			
3.5	17.06	18			
3.5	17.08	18			
3.5	17.10	18			
3.5	17.12	18			
3.5	17.14	18			
4.5	17.18	17			
4.5	17.22	16			
4.5	17.26	15			
7	17.30	10			
5	17.34	12			
5	17.38	12			
5.5	17.42	11			



Appendix G: The Dimension of each drainage and sewage network

Sample	Depth (cm)	Width (cm)	Length (cm)
R1	60	105	100
R2	13	180	100
R3	67	120	100
R4	100	120	100
R5	35	200	100
R6	10	15	100
s1	7	26	60
s2	8.2	30.5	40
s3	30	30	60
s4	31	30	70
s5	50	10	70
s7	7	23	20
s8	25.5	39	40
s9	21	59	50