HEAVY METAL DISCHARGE INTO LAKE VICTORIA

- A STUDY OF THE UGANDAN CITIES OF KAMPALA, JINJA AND ENTEBBE

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ABSTRACT

Water samples from different sampling sites located in the Ugandan cities of Kampala, Jinja and Entebbe as well as the remote Ssese Islands, were analyzed for concentrations of Cd, Cr, Cu, Ni, Pb and Zn. Both Kampala and Jinja have large industrial areas while Entebbe has Uganda's largest airport. Household and industrial wastes are discharged into Lake Victoria largely untreated. The objectives of this study were to: 1) evaluate concentrations of the metals in discharge from the selected sites; 2) determine whether or not wetlands impacted on the magnitude of metal discharge into the lake, 3) determine and assess heavy metal levels in drinking and irrigation water; 4) evaluate heavy metal related risks for humans and the environment.

The discharges from the cities contained rather high concentrations of Cd, Cu, Pb and Zn in comparison with Swedish environmental guidelines. In Kampala and Jinja, samples were taken before and after water had passed through areas of wetland. The results show a reduction of these metals as the water passed through these areas. The reduction was especially noticeable in Kampala, where metal concentrations were reduced by up to 99%. The concentrations of all metals but Ni were alarming in Lugogo and Mpanga along Nakivubo channel (running through central and industrial areas in Kampala), these sites also being used for household farming. Some of the results from Jinja could be explained by the former Cu mine at Kilembe. The activity at the airport of Entebbe seemed to cause heavy metal pollution in nearby waters. Areas of special concern regarding the environment were all sites along Nakivubo channel, especially since the concentrations of Cd, Pb and Zn were high already at its emergence point in Makerere. In Jinja and Entebbe, all sites had Cd- and Zn concentrations exceeding the given guideline for sub-lethal or chronic effects.

The expected result of lower concentrations in water outside Kalangala of Ssese Islands than outside Kampala, Jinja and Entebbe was not confirmed. The finding that the Ssese Islands had higher concentrations of Pb and Cr than 55% of the sampling sites in the cities was most surprising. Only 45% of the city sites had lower Cu concentrations than the Ssese Islands. The high concentration of Pb at Ssese Islands is alarming. The concentration was above the Swedish environmental guideline used, and there were no point sources of this metal on the island. Possible sources are therefore transport via air and/or water from the riparian countries as well as unauthorized dumping of wastes.

The results from all sampling sites were compared with WHO's guidelines for drinking water. Only the Kampala sites Makerere, Lugogo and Mpanga exceeded the guidelines for Pb. Similarly, Cd and Ni concentrations at Makerere and Lugogo exceeded the guidelines.

Concentrations of Pb and Cd were high at the majority of the sites. This is alarming since these metals are among the most hazardous to humans and the environment. Reduced discharge of the other metals is also important since low concentrations can accumulate and have negative longterm effects. The importance of wetlands as a purifying media must be recognized and protected. Efforts should also be put into limiting the sources of metals since treatment always means that it will end up somewhere else. Conversion to unleaded petrol as well as proper maintenance of dumping sites could lead to reduced metal leakage and decreased unlawful dumping in the lake. Implementation and enforcement of environmental legislation are most important.

Keywords: Lake Victoria, heavy metal, Cd, Cr, Cu, Ni, Pb, Zn, pollution, guideline values, water, Uganda

1 INTRODUCTION

The fieldwork of this thesis was carried out in Uganda during February and March 2001. The work was financed by the Minor Field Study (MFS) programme through Sida. In Uganda, the work was carried out with supervision from the Department of Soil Science at the Makerere University in Kampala. Water-, soil- and plant samples were collected on the shores and in the swamps of Lake Victoria. This thesis investigates heavy metal concentrations (Cd, Cr, Cu, Ni, Pb and Zn) in the water samples collected, while investigation of the plant- and soil samples was carried out by Larsson (2001).

Lake Victoria is a lake under several threats, where pollution is one. Others include manifestation of water hyacinth, introduction of alien species, overfishing, eutrophication and soil erosion. 26 million people in the riparian countries depend on the lake for their livelihood and it is therefore legitimate to say that the lake is one of the most important in the world. There are presently many different projects working on different areas of threats. The threat of heavy metal pollution may be seen as minor in the context of the other threats. But heavy metal pollution can have serious negative effects on human and environmental wellbeing and it is therefore important that this is not forgotten or overshadowed by other threats.

1.1 LAKE VICTORIA

Location: 0º20´N - 3º0´S, 31º39´ E - 34º53´ E
Area: 68 800 km^2
Volume: 2 760 km^3
Altitude: 1134 m above sea level
Depth: average – 40 m, deepest – 80 m
Catchment area: 184 000 km^2
Climate: moist sub-humid – semiarid
Rainfall: 2500 mm – 750 mm
Dependant population: 26 million
Riparian countries: Tanzania 49%, Uganda 45%, Kenya 6%
Utility: food, energy, drinking- and irrigation water, building materials, transportation, recreation, repository for wastes

(UNESCO Publishing, 1995 and World Bank, 1996).

1.1.1 Geography and Limnology

1.1.1.1 The Lake

Lake Victoria is the second largest freshwater body in the world and the largest of the Great African Lakes. The shoreline of the lake is highly irregular with extensive swamp- and marsh areas (UNESCO Publishing, 1995). Due to Lake Victoria being shallow, it holds only 15% of the water volume of Lake Tanganyika, even though the latter covers less than half the surface area. (Global Environment Facility, 2001). Of the water entering Lake Victoria ($118*10^9$ m^3) about 85% ($100*10^9$ m^3) is precipitated directly on to the lake surface, and the remainder comes from rivers which drain the surrounding catchment (UNESCO Publishing, 1996). Direct evaporation from the lake's surface represents 85% of the water leaving the lake, while 15% leaves through its sole outlet, the Nile, near Jinja in Uganda. (World Bank, 1996)

1.1.1.2 The Catchment Area

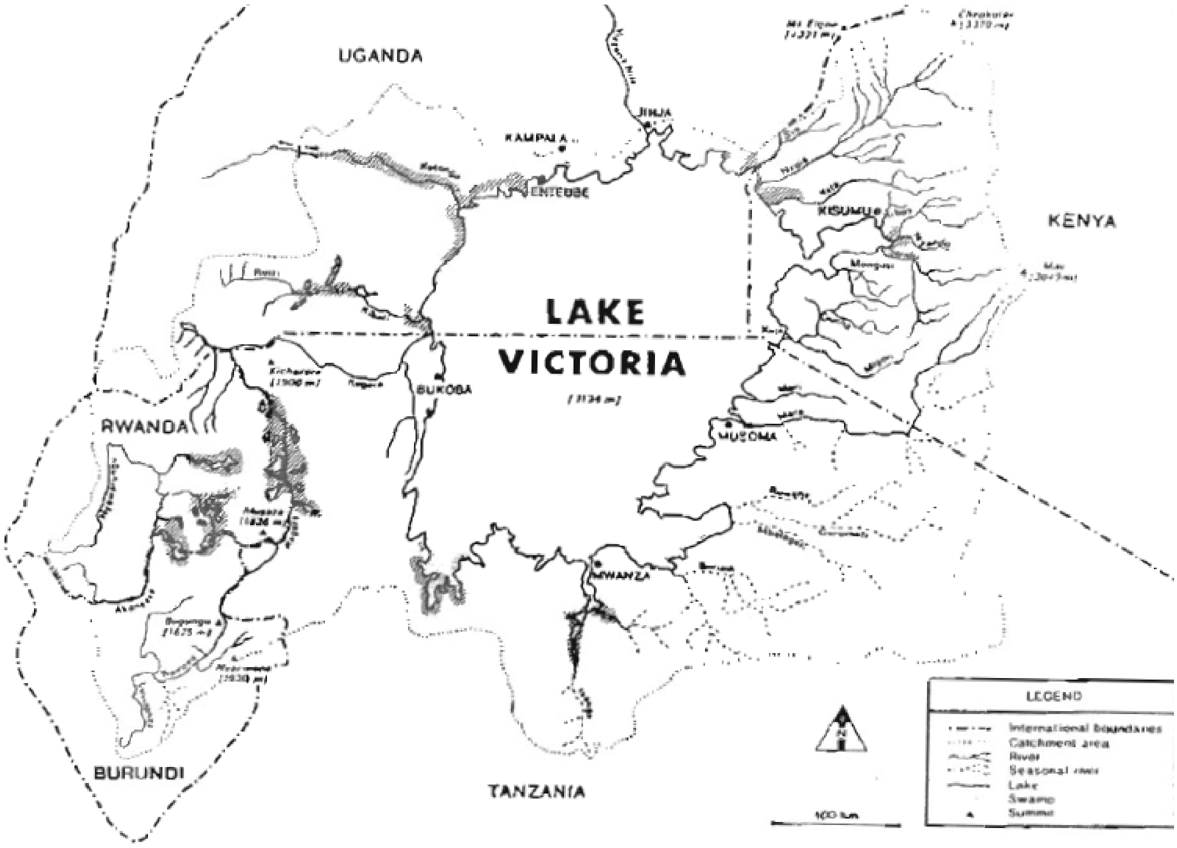


Figure 1.1 Map of the catchment area of Lake Victoria (Unesco Publishing, 1995)

The catchment area of Lake Victoria is approximately 194 000 km^2 and covers parts of Uganda, Kenya, Tanzania, Rwanda and Burundi. The vegetation in the area varies from highland forest to open savannah and grasslands. In the northern and southern parts of the basin, the watershed is locally less than 25 m above sea level, while in the east and west it borders the Eastern and Western Rift Valleys and rises to escarpments (UNESCO Publishing, 1995).

The inflowing rivers drain a variety of areas. The Kagera River contributes roughly 7% of the total inflow. This river rises in the highlands of Rwanda and Burundi and enters Lake Victoria on the Tanzanian side of the border (Global Environment Facility, 2001). Kenyan rivers drain the forested slopes of mountain regions in the north-west of the country and Ugandan rivers drain mostly wetlands and swamps. From Tanzania, the catchment receives water from the drier plains of the Serengeti (UNESCO Publishing, 1995).

1.1.1.3 Uganda as part of the Lake Victoria basin

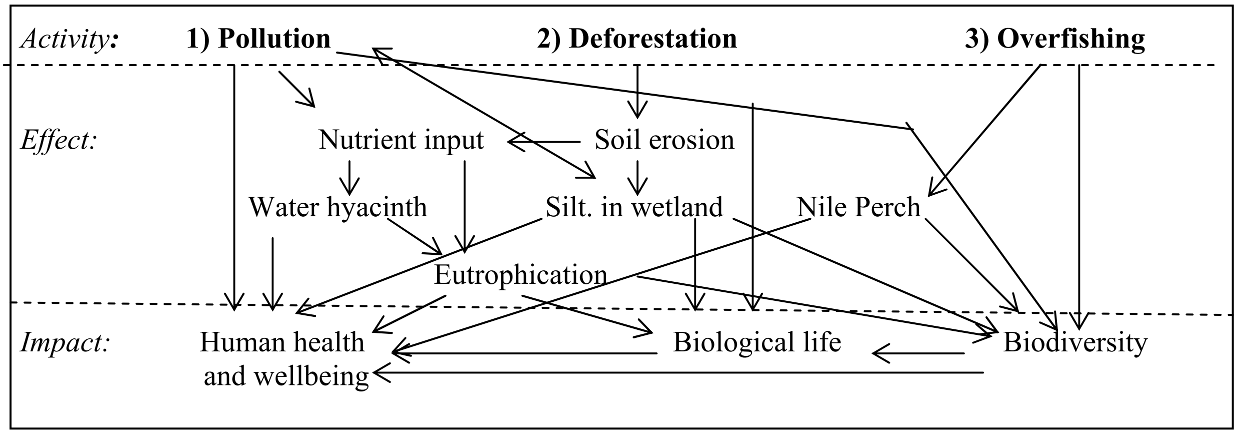
Uganda is situated on the northern and western shores of Lake Victoria, at an average altitude of 1 400 meters above sea level. The Ugandan part of the lake's catchment is 38 800 km^2 and the dominating land types are game reserves, national parks, forest reserves and arable land. Uganda's climate is classified as moderately humid and the catchment has two twin peaks of heavy rainfall in March-May and October-December. Most of the southern part of the country drains into Lake Victoria (Ministry of Natural Resources, 1995). Uganda also holds the lake's only outflow through the Nile in the city of Jinja (Africa Water Network, 1998). This flow is believed to contribute 14% of the flow in the combined White and Blue Niles making the lake not only of great importance to the riparian countries, but also to countries downriver (UNESCO Publishing, 1995).

Uganda's current population is growing at a rate of about 3.2% and has doubled over the last 20 years from 9.8 million in 1970 to 21.3 million in 1995. Over 40% of the population, or 8.5 million people, live in the lake basin. The majority of people in Uganda draw water from unprotected sources, such as Lake Victoria (Ministry of Natural Resources, 1995). The land area in the basin represents less than 20 % of the total land area of Uganda, making the average population density in this area 88 persons/km^2. The density varies between 10-750 persons/km^2 depending on the location. (UNESCO Publishing, 1995).

1.1.2 Importance of the lake

1.1.2.1 Local importance

With the lake basin supporting over 26 million people, it must be considered as one of the world's most important freshwater bodies. People depend on it for their everyday lives. From the lake they recieve food, water, energy, building material and use it as a means of transport as well as a source of income. The lake catchment is estimated to provide the livelihood of one-third of the population of the three riparian countries. (World Bank, 1996) When the water quality of the lake deteriorates, the quality of life for these people does the same. A reliable water resource is therefore essential for human wellbeing. As can be seen in Figure 1.1, human health and wellbeing connected to the lake depends on several factors, all of which are threatened by the present situation in the lake:



1) *Pollution* promotes diseases. It also affects the availability and quality of fish. Another problem related to pollution is increased growth of water hyacinth which clogs waterways for fishermen.
2) *Deforestation.* Land is cleared for energy, housing and farming purposes. This causes nutrients to leave the soil and enter the lake, adding to the already present eutrophication. This in turn affects fish populations with smaller catches as a result. Polluted eroded material is an environmental and health hazard. Sedimentation decreases purification capacities in wetlands, allowing increased amounts of pollution to reach the lake.
3) *Overfishing.* Large commercial catches for export threatens the fish stock in the lake, including Nile Perch. Domination of Nile Perch has changed the ecosystem and eliminated many native species, traditionally caught from the lake. It also promotes deforestation.

Figure 1.2 Degrading activities around the lake and its effects and impacts on human health and wellbeing:

Water from the lake is also used for livestock, especially in the semiarid pastoral areas of the lake basin (Ehlin Consulting, 1997). Since livestock is an important source of income and nutrition for many people, a safe water supply should be considered a necessity for this activity.

1.1.2.2 National importance

Agriculture and fishing form the backbone of the lake catchment's economy. The income and livelihood of the people in the catchment area largely depend on these activities. Cash crops such as tea, sugar and coffee are produced and several tonnes of fish are exported annually. The large plantations use water from the lake for irrigation, although this practice is not widespread. The lake is estimated to provide one-third of the combined gross domestic product and the World Bank has estimated that "if the deterioration of the lake resulted in a 5% reduction in productivity of the region, the consequent loss would be of the order of US$150 million annually." (World Bank, 1996).

Lake Victoria is also important for transport between the riparian countries as well as within them. The transport of people and goods across borders has been reduced since the break-up of the East-African Community in 1976. Today, transport by lake is aggravated by the infestation of the water hyacinth, blocking ports and landing sites. (Ehlin Consulting, 1997)

1.1.2.3 International importance

There is great concern among international biologists and ecologists for the development in the lake. In the past centuries, there has been a rapid change in the lake's ecosystem with decreased biodiversity as a result. The introduced predator Nile Perch has caused an alarming reduction of the native species. These native species feed on algae and plankton, and have in the past regulated the addition of nutrients to the lake. With their decline, eutrophication is a big threat to the surviving species, as well as the Nile Perch.

The fauna of Lake Victoria, as well as Lake Malawi and Lake Tanganyika, exhibit the products of very few ancestors. More than 90% of the fish family Cichlidae is endemic in the lakes. The cichlid faunas in the different lakes are very similar and are examples of evolutionary parallelism. There is today great concern for the endemic species of Lake Victoria, which holds more than 200 endemic species and 4 endemic genera of cichlids. Of the around 50 species of non-cichlids, 29 are endemic. The World Conservation Red Book listed in 1988 all of the lake's endemic fish species under "Endangered". (The Mandala Projects, 2001) These vertebrae are now facing the fastest mass extinction ever witnessed on Earth. All over the world, cichlids have adapted to an incredibly wide range of condidtions. Their decline in Lake Victoria is therefore a sign of drastic and/or rapid changes that the cichlids are unable to adapt to. (The Mandala Projects, 2001) The ecosystem of Lake Victoria is therefore fragile and important, why additional pollution can be seen as a threat in this context.

1.2 Wetlands of Uganda

Uganda is rich in water resources due to its high rainfall and many lakes. The wetlands of Uganda cover 29 589 km^2 – over 10% of the country's total land area. 8 832 km^2 (29.8%) of the wetland area is swamp, 365 km^2 (1.23%) swamp forest and 20 392 (68.9%) km^2 wetland sites with impeded drainage. The wetlands bring benefits to both rural and urban communities and are also of great importance to biodiversity. Due to increasing population, the wetlands are now under great pressure because of their high fertility and relative accessibility (Ramsar List, 2001). A Ministry of Environment Protection was formed in 1986, now the Ministry of

Natural Resources, which banned wetland drainage and initiated the development of a National Wetland Programme (Mafabi & Taylor, 2001). Uganda has signed the Ramsar Convention which came into force on 4 July 1988 and has presently one site designated as a Wetland of International Importance, namely Lake George. (Ramsar List, 2001) For more details on the Ramsar Convention, see 1.4.2.

In Uganda's National Wetlands Programme, a number of biological and economic values of the wetlands are listed. Values of specific concern include

1) stabilization of water availability, moderation of floods and water supply,
2) high biological diversity,
3) high biomass production, because of the water retention ability and role as sink for atmospheric carbon, and
4) retention of nutrients, sediment and toxins for purification of water.

(Mafabi & Taylor, 2001)

Wetlands in Uganda provide building and thatching material, important materials for carpet and screen-making enterprises and are a source of renewable energy through harvesting and briquetting or through biogas plants. Because of the wetlands' high productivity and role as shelter for innumerous fish, fishermen catch large amounts of catfish, lungfish and haplochromids in the swamps. The purification capacities of wetlands are especially important. Wetlands outside the major towns recieve polluted discharge from industries as well as untreated sewage and runoff. The wetlands efficiently remove pollutants, sediment and nutrients, thereby lowering the costs for water treatment. (Mafabi & Taylor, 2001)

In spite of the many advantages of preserving Ugandan wetlands, they stand under threat. This is largely due to the rising population and increasing demand for land for agricultural and industrial purposes. In the National Environment Action Plan for Uganda (Ministry of Natural Resources, 1995), the greatest threats to wetlands in the country include drainage, grazing, brickmaking, cutting of vegetation, rice growing as well as industrial and sewage discharge. There are also a number of management-related threats, including inappropriate land tenure systems, unregulated and unplanned fisheries development, some sectoral policies that encourage wetlands drainage and conversion to unsustainable uses (Ministry of Natural Resources, 1995). Current problems have arisen from past misuse, present development projects without concern for the importance of wetlands, and as a result of neglect in enforcing current public health and pollution legislation. (Mafabi & Taylor, 2001)

1.2.1 Wetlands in sampling areas

The wetland areas along the shores of Lake Victoria where sampling was carried out consist of seasonal flooded wetland, with crop production during the dry season, and swamp areas with floating flora, such as papyrus, water hyacinth and water lettuce. These wetland areas are believed to receive untreated sewage as well as industrial waste and are therefore of great importance for the treatment of discharge from the larger towns.

1.3 Heavy Metals In Fresh Water

Heavy metals occur naturally in our environment. Metal concentrations are usually higher in soil and sediment than in water due to natural magnification. The substance level in fresh water depends on rock and soil type in the catchment area. The pH value and content of organic material also affect the level and bring about a natural variation. (Naturvårdsverket[b], 2001) Heavy metals are defined by having a density greater than 5 $g*cm^{-3}$ and are relatively stable, which means that they do not decompose easily. Some heavy metals, such as Cu, Zn and Cr, are essential to biological life in small supplies while others do not have a vital function, such as Pb and Cd, and can therefore be harmful to organisms even in small concentrations. (Institutionen för miljöanalys, 2001)

Environmental guidelines for protection of aquatic life are usually much lower than those required to protect human consumers of the water. The latter are derived from considerations of safe body burdens, and safe concentrations for drinking water are based on the proportion of metals ingested via water. Aquatic organisms, on the other hand, are continually immersed in the water, and some are filtering it. (Smith, 1986)

Heavy metals enter the water bodies of our environment by a variety of routes, of both natural and anthropogenic origin: atmospheric deposition, weathering of rocks, erosion, runoff, untreated sewage, agricultural activities and industries. They have received considerable public attention all over the world, partly because of concern that they will cause long-term damage to the environment. Such long-term damage can be caused by highly concentrated pollution, produced over a short time, remaining in one place, or due to low concentration, insidious pollution, requiring a considerable time to produce an effect. These insidious effects are difficult to measure and establish with certainty. (Smith, 1986)

No data on background values for heavy metal concentrations in Lake Victoria have been found. A list of globally derived background concentrations of the metals of concern for this report is given below. It is difficult to derive global mean background values for individual heavy metal concentrations in fresh water because of variation in rock types and flow regimes. The levels in Table 1.1 are presented to give an idea of background concentrations.

Table 1.1 Estimated global background concentrations ($\mu g*l^{-1}$) for dissolved metals in fresh water (Smith, 1986)

Element $\mu g*l^{-1}$	**Borg (1984)**	**Forstner and Wittman (1983)**
Cd	0.005-0.05	0.07
Cr	0.1-0.5	0.5
Cu	0.2-2	1.8
Ni	0.01-1	0.3
Pb	0.05-0.5	0.2
Zn	0.5-5	0.5

1.3.1 The status of chemicals in Uganda

Currently, there are no manufacturers of chemicals in Uganda. The major importers of chemicals are industries which use the chemicals to manufacture other substances that cannot be classified as chemicals. Most users of chemicals are unaware of proper disposal methods. Many chemicals end up in drinking water and are a potential danger to health of urban dwellers and fish consumers. The greatest number of chemicals imported into the country are used in the vicinity of Lake Victoria and drain into the lake. Solid waste, which is carelessly dumped anywhere is one source of chemicals which end up in the water. (Kiremire, 2001)

1.3.2 Legislation on the use of chemicals

In Uganda, the policy on chemicals is exemplified in various laws which are in place to protect public health, general safety and welfare of society and the environment. The general laws include The Public Health Act and Food and Drug Act of 1964. But more specific legislation with provisions for control of chemicals started with the Uganda National Bureau of Standards Act of 1983. The implementation of this act started in 1989. This was followed by the Control of Agricultural Chemicals Statue of 1989 and later by the National Environment Management Bill of 1994. Towards the end of 1991, Uganda Revenue Authority was established, to be responsible for the examination and verification for taxation of all imported goods imported into the country. (Kiremire, 2001)

1.3.3 Disposal of chemicals

A survey was carried out by the Department of Chemistry at Makerere University in Kampala, to establish present disposal methods of chemicals. The results presented in Table 1.2 show that 61% of the dealers in chemicals disposed of their waste and/or expired chemicals by methods that were likely to pollute drinking water directly. 7% of the dealers disposed of chemicals that would indirectly pollute the water and plants. This group includes those who dump on Kampala city dumping sites and in pits. Old dumping sites provide fertile soil for farmers and are therefore likely to expose the population to toxic material through food. On the other hand, dumping into pits transports toxic chemicals to lake water through underground aquifers. Only a small percent of the dealers use incinerators. An equal percentage of users ship the expired chemicals back to the suppliers while another small percentage sells the chemicals for recycling. (Kiremire, 2001)

Table 1.2. Methods used to dispose of expired chemicals and/or industrial effluents (Kiremire, 2001)

Disposal Method	%
Municipal sewers/drainage	26.56
Streams	35.22
Pits	9.31
KCC* dumping sites	18.22
Incinerators	4.26
Shipped back to supplier	4.31
Sold for recycling	2.13

*KCC – Kampala City Council

1.4 Literature Review

A more thorough review of the topics mentioned above is given below.

1.4.1 Major threats to Lake Victoria

Lake Victoria is today facing a number of threats that have alarmed both the local and international community. The introduction of Nile Perch as well as the spreading of water hyacinth are the two threats that have recieved most attention. Eutrophication, overfishing, deforestation and pollution are other factors that threaten the wellbeing of the people and environnment in and around the lake. The lake's declining biodiversity is a cause for concern both for ecological reasons, with several endemic species being threatened to extinction, and for economic reasons, as 26 million people's livelihood depend on sources received from the lake. A description of threats to the lake is given below.

1.4.1.1 Water pollution

There are a number of polluting industries that are common to the urban areas around the lake. These include breweries, tanning, fish processing, agroprocessing (sugar and coffee), and abattoirs. In general, the level of discharge treatment is low, with a few exceptions. These industries discharge polluted effluent into rivers and wetlands draining into the lake, or directly into the lake (The Mandala Projects, 2001).

There is also a large problem of untreated sewage entering the lake. The treatment facilities are not proportioned to the increased urban population and therefore release raw sewage into the streams of the lake. At the same time, wetlands are being converted into farming land and housing areas, and thereby the purifying capacities of the wetlands are being diminished. (Ehlin Consulting, 1997)

1.4.1.2 Deforestation, seasonal burning and destruction of wetlands

Deforestation in the catchment area is a growing threat to the lake. Overpopulation is accompanied by increased demand for land for cultivation, animal keeping and firewood. In Uganda, woodfuel represents more than 94% of the energy source (Ministry of Natural Resources, 1995). Wetlands and forests in the area are therefore being put under great pressure. The deforestation causes soil erosion which in turn causes a transportation of material from land to the lake via water and wind (Ehlin Consulting, 1997).

Seasonal burning is carried out in order to prepare land for cultivation, rejuvenation of pastures or facilitating of game hunting grounds. Through this procedure, the soil is subject to erosion and soil compaction (Ministry of Natural Resources, 1995).

Soil erosion by water is a growing problem all over the world. It not only removes nutrients from the soil, but may also reduce the soil's capacity to retain added nutrients. Erosion reduces the pedon thickness and the volume of soil available for water storage and root exploration for nutrients. (Singer & Munns, 1999) The eroded material also causes problems where it is deposited. It is transported by streams and rivers and finally ends up in wetlands and in the lake itself. This leads to sedimentation, reducing the purification capacity of the wetland as well as the depth of an already shallow lake. The deposited material may also be polluted, adding toxic chemicals and nutrients to the ecosystem. Addition of nutrients leads to increased growth of, eg., water hyacinth, and increased eutrophication, putting more pressure on the already disturbed ecosystem.

Wetlands are of great importance for water treatment and nutrient removal purposes, especially in areas with no or few treatment facilities. By removing or draining wetlands, eroded material as well as the sewage and discharges from agricultural, urban and industrial activities enter the lake untreated. For more information about the importance of wetlands, see 1.4.2.

1.4.1.3 Water-related diseases

The increasing population around the lake uses the lake's water as their main source of washing, drinking and cooking water. It is only in the major towns that this water is treated, and only a minority of the city's inhabitants have access to this treated water (Ministry of Natural Resources, 1995). Lake Victoria has, in its natural state, good quality water, but due to increased pollution input to the lake as well as increased population, water-related diseases have become a major problem. Water-borne infections such as typhoid fever, cholera, bacillary dysentery, polio and infective hepatitis were the leading cause of mortality in Uganda in 1988, 1989 and 1990. Other water-related diseases include intestinal worms, bilharziasis, malaria and river blindness. Malaria is the leading cause of death of persons up to 15 years of age and resistance to the present standard treatment has evolved, causing a need for more expensive drugs (Ministry of Natural Resources, 1995). The mats of water hyacinth promote an increase of bilharzia, malaria and are also a common habitat for snakes. Good news is therefore the present decrease in water hyacinth. But as the population around the lake increases, pollution concentrations are bound to increase, as well as the problem of these diseases. (Ehlin Consulting, 1997)

1.4.1.4 Introduction of alien species

Pressure on fish in the lake began to intensify in 1905 when flax gill nets were introduced, instead of the local papyrus nets and fish traps. This resulted in reduced fish catches and fishermen turned to nets with smaller mesh sizes that allowed catchment of both the breeding adults and the young of many native fish species. This caused a near extinction of common species in the lake, mostly cichlids, and in the 1950's four species of tilapia *(Orechromis niloticus)* were introduced into the lake. These fish thrived and there were suggestions of introducing the Nile Perch *(Lates niloticus)*, a big predator which could feed on the tilapia and be more suitable for consuming and selling. Ecologists opposed to introducing such a predator, considering the welfare of the local species. (The Mandala Projects, 2001)

The Nile Perch was first introduced into Lake Kioga in 1955. A few years later it was found in Lake Victoria. Steps were taken to ensure its establishment and until 1978, Nile Perch remained a very small proportion of the commercial catch with less than 5%. In 1978, a very rapid expansion of the proportion accounted for by the Nile Perch took place and by 1990, the commercial catch of fish in the lake had changed to 60% Nile Perch and almost 40% of the native species Omena *(Rastrineobola argentea)*. The remaining species of fish in the lake had virtually vanished from the commercial catch (World Bank, 1996).

Predominance of the Nile Perch in Lake Victoria has caused problems for the local fishermen. The Nile Perch can grow up to six feet long, which demanded new and stronger fishing equipment. The perch also has a larger content of fat than the native species and has to be dried over a fire unlike the native species which can be dried in the sun. This leads to a greater demand for firewood wich promotes deforestation. This is already evident in some fishing communities. (Ministry of Natural Resources, 1995) There was also no market for it and prices were low, so most of the catch was left in the sun to rot. Today, the perch is caught primarily by large commercial enterprise influenced by a few powerful, private interests (Ehlin Consulting, 1997). The growing export trade is now becoming of great concern. The production of new plants for the fish filleting industry has severe consequences for the local market in terms of fish availability and prices. Hotels and foreigners are willing to pay high prices for the fish, prices that most people living around the lake can not afford. (The Mandala Projects, 2001)

The native species, mainly cichlids that feed on plants and detritus, were not adapted to escaping predators, since these had been absent in the lake until the introduction of Nile Perch. The introduced species not only destroyed the native fishery, but also annihilated the cichlid population and reduced its own food supply to the point where the Nile Perch were not abundant enough to be a significant food supply for humans. (Campbell, 1996)

1.4.1.5 Eutrophication

Eutrophication is caused by increased input of nutrients to waterbodies, which promotes algal growth. This organic material is then decomposed on the bottom of the lake in an oxygen-demanding process, causing oxygen depletion. In the early 1980s, the algal content of Lake Victoria was 5-10 times more than in the 1960s (The Mandala Projects, 2001). The inflow of nutrients is believed to be caused by increasing soil erosion, burning of wood-fuel and untreated sewage, which also increases the risk of diseases from water-borne pathogens (World Bank, 1996).

The deep waters of Lake Victoria are today almost completely depleted of oxygen and periodical upwelling of hypoxic water causes massive fishkills. The algal blooms have come to be dominated by the potentially toxic blue-green variety causing an increase of water-borne diseases for humans and animals, clogging of water intake filters and increase of chemical input for water treatment (The Mandala Projects, 2001).

1.4.1.6 Water hyacinth (Eichhornia crassipes)

Water hyacinth originates in Latin America and it is possible that it was brought to the African continent for decorative purposes. The flowering plant first appeared in Lake Victoria in 1988 in the waters of Uganda. Since then it has been reported in many locations all around the lake. Water hyacinth is especially concentrated in Ugandan waters due to southerly winds blowing the mats of the weed to Uganda's shores and the nutrient-rich waters that are found there (World Bank, 1996 & The Mandala Projects, 2001).

The weed causes a reduction in fish due to de-oxygenation of water and reduction of nutrients in the shallow bays, which are breeding grounds of especially tilapia. Water hyacinth also causes physical interference with fishing activities, especially in the bays where fish are brought ashore, physical interference with commercial transportation services for people and goods as well as physical interference with access to water supply from the lake with additions to the cost of purifying water. The mats of weeds also provide a preferred breeding habitat for the alternative host for bilharzia, home for the vector mosquito for malaria, as well as a haven for snakes. (World Bank, 1996)

Today, the problem has decreased due to introduction of biological control in the form of weevils (weevils of the Neochetina family). The weevils feed on the leaves of the plants and their larvae tunnel into the leaf stalks and eventually the crown of the plant, destroying its growing points. The damage caused by the weevil allows water to enter the plants and secondary rotting occurs. This reduces the plant's ability to flower, set seeds, send off shoots and replace damaged leaves. Under heavy attack from the weevils, the plants rot and become waterlogged and eventually sink (Collins, 2001).

1.4.1.7 Overfishing

During the time when Nile Perch catch increased from 5% in 1978 to 60% of the total catch in 1990, the size of the fishing industry in Lake Victoria increased by a factor of five or more. In 1978, the catch in Kenya was reported at 25 000 tonnes of fish, while in 1990, the catch was more than 175 000 tonnes. Before the boom of Nile Perch, the total catch from the lake was estimated at around 100 000 tonnes annually. Today, the figure is estimated at 300 000 to 500 000 tonnes. (The Mandala Projects, 2001)

The most important edible fishes in Lake Victoria have already vanished from the marketplaces and very nearly from the planet since the introduction of Nile Perch. The Nile Perch itself, rather than overfishing, is the cause of this. The threat to fish stocks in Lake Victoria is alarming. A fishery which once caught hundreds of species now relies on three: a native pelagic minnow called the Omena (*Rastrineobola argentea*), the alien Nile Perch (*Lates niloticus*) and the introduced Nile tilapia (*Orechromis niloticus*) (The Mandala Projects, 2001).

The fish industry in the riparian countries thrives from the alien introduction which brings job opportunities as well as large amounts of foreign currency through export. Export of fish from Lake Victoria is 200 000 tonnes annually. Large boats are hauling out the Nile Perch in the open water where local fishermen can not pole their canoes. In Uganda, the fishing industry employs 25 000 people and fish acounts for 60% of animal protein consumption. At the same time, illegal fishing and the invasion of water hyacinth as well as pollution are threatening fish stocks (The Mandala Projects, 2001).

1.4.2 Wetlands – natural purifiers

Wetlands make up “the transitional zones between largely dry terrestrial systems and deep-water aquatic systems” (Goudie & Viles, 1997). They occur in every country and are estimated to cover 6% of the Earth’s surface. 20% of this area is believed to be swamp. (Ramsar[a], 2001) Wetlands are of great ecological importance because of their role as nutrient sinks or sources, their high biodiversity and their role as breeding and nursery grounds for animals and plants. Their ability to absorb and store carbon has implications for the greenhouse effect and is another important function of the wetlands (Goudie & Viles, 1997). Wetlands are also important for a number of human activities, such as source of building material and fuel, water supply, supporting of fisheries and agriculture, recreation, tourism, and the ability to absorb and store floodwater, thereby mitigating floodpeaks (Goudie & Viles, 1997, Ramsar[a], 2001). Due to the physical, chemical and biological interactions of wetlands, they perform a number of vital functions. Flood control, as metioned above, is one. Other important functions are groundwater recharge and discharge, shoreline stabilization and erosion control, stabilization of local climate conditions, and purification of water through retention of nutrients, sediment and pollutants (Ramsar[a], 2001). The latter is of special relevance regarding the objective of this study. Wetlands cannot, however, retain pollutants indefinitely.

Although wetlands are considered to be of such great importance, they are threatened. In urban areas, they are being drained and filled-in for house construction, and used as landfills for wastes. They are also being drained for crops, timber and mosquito control. Indirectly, wetlands are threatened by sediment diversion by soil erosion, dams and other constructions as well as hydrological alterations by canals, roads, etc. (Goudie & Viles, 1997) Pollution and over-exploitation are other threats to wetlands. (Ramsar[a], 2001)

The importance of conserving wetlands has been recognized by the international community. On 2 February 1971, a convention on wetlands was signed at Ramsar in Iran, known as the Convention of Wetlands, or the Ramsar Convention. Its official name – The convention of Wetlands of International Importance especially as Waterfowl Habitat – reflects its original emphasis on waterbird habitats. The convention has now broadened to include all aspects of wetland conservation and wise use. The Convention entered into force in 1975 and 124 contracting parties have now signed it, agreeing to designate at least one wetland to the ´List of Wetlands of International Importance`. They also undertake to implement their planning so as to promote conservation and “wise use of wetlands in their territory” (Ramsar[b], 2001). By signing the convention, the contracting parties also agree to establish wetland nature reserves, whether or not the wetlands are included in the Ramsar List, and to cooperate in the management of shared wetlands and wetland species. (Goudie & Viles, 1997) Uganda has at the time of writing one site designated to the Ramsar Convention, namely Lake George.

1.4.3 Environmental effects of heavy metals

Heavy metals end up in the aquatic environment by a number of routes, both natural and anthropogenic. Examples of anthropogenic sources are industry, transport, mining, municipal wastes, agriculture, dump leachates and geothermal development. Some of these activities spread metals into the atmosphere and are later deposited on land and water. Examples of natural sources are volcanic and geothermal activity as well as geologic weathering. An overview of sources of metal input into the aquatic environment can be found in Appendix 1. All aquatic organisms concentrate heavy metals from their surrounding water, sediments or food and it is important to recognise that this is a universal and often essential process. Eleven metals are known to be essential for aquatic life. (Smith, 1986) Of the metals analyzed in this report, Cu, Cr, Ni and Zn can be included in this criteria. These metals are seldom limiting in natural aquatic systems and most organisms concentrate greater quantities than they actually require. Pb and Cd are not regarded as essential to life, but these too are concentrated in the organism. Many organisms are able to regulate the concentrations of metals in their tissues (and hence regulate toxic effects) by controlling absorption, excretion, and depuration rates, or by detoxification either by changing the metal to a less toxic form or by storage at sites in the body where the metal does not have an adverse effect. The ability of marine invertebrates to detoxify some metals, or sequester them in a manner in which they do not poison the animal itself, can lead to considerable build-up of metals in some marine foods. It is common for metal concentrations in an organism to increase with increasing age, notwithstanding the ability of the organism to regulate metals concentrations (Kihlström, 1992). Appendix 2 presents an overview of the different effects of heavy metals on humans and the environment.

1.4.3.1 Toxicity of metals

The toxicity of a metal is usually defined in terms of the concentration required to cause an acute response (usually death) or a sub-lethal response. Common sub-lethal responses of aquatic organisms to increased heavy metal concentrations are inhibition of growth, inhibition of settlement by marine invertebrae larvae, and interference with reproduction, metabolism and behaviour. (Smith, 1986) The risk for adverse effects is greatest during longterm exposure, but acute effects can occur when the concentrations rise above 3-10 times as high as the lowest harmful level. (Naturvårdsverket, 2001[b]) A figure showing the effects of essential and non-essential metals at different concentrations is given below.

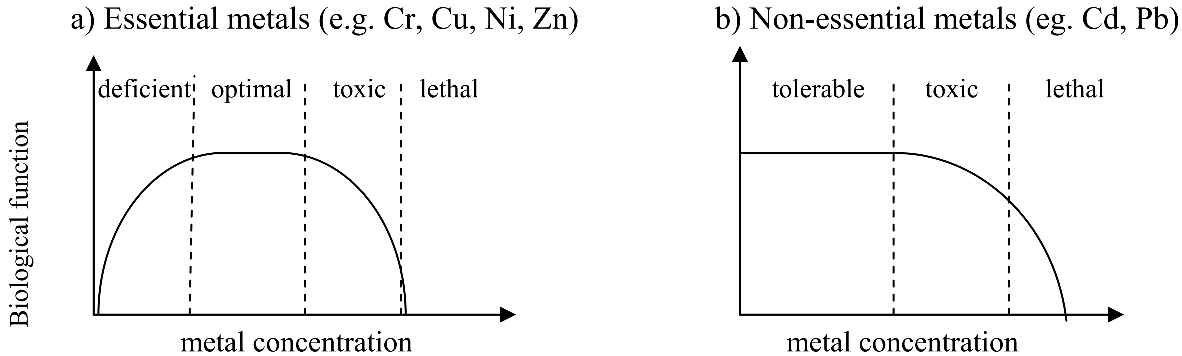


Figure 1.3: Deficiency and oversupply of a) essential and b) non-essential elements (Smith, 1986)

1.4.3.2 Uptake of pollutants

Animals can take up toxicants in many different ways; via the stomach and intestines, via lungs and gills, and in some cases directly into the blood vessels. The absorption of pollutants does not necessarily take place where it is taken up. Some may leave the body, some may be destroyed while others accumulate. Aquatic animals with gills receive the majority of their load of pollutants via the gills. The gills are specialized for taking up oxygen and ions from the water, and hence have a large area of contact with the water. (Kihlström, 1992)

1.4.3.3 Effects on organisms

There are hundreds of effects on organisms due to pollution, but the following will only describe those that entail ecological consequences. In the following sections, a more precise description of the effects of each analyzed metal can be found. A summary of toxic effects on organisms from each metal can be found in Appendix 2.

Principally, all toxic chemicals execute their primary biological effects on the cells and their functions. Slightly elevated metal concentrations in natural waters may cause the following sublethal effects in aquatic organisms: 1) histological and morphological change in tissues; 2) changes in physiology, such as supression of growth and development, poor swimming performance, changes in circulation; 3) change in biochemistry, such as enzyme activity and blood chemistry; 4) change in behaviour; 5) and changes in reproduction. (Water Shedss, 2001)

1.4.3.4 Effects on ecosystems

The majority of the serious environmental pollutants are chemically very stable. Since a number of pollutants of the feed are stable, they will increase with increasing age of the animal. Herbivores therefore accumulate the pollutants and these are further transported to and accumulated in carnivores. This transport of toxicants in the nutrition web causes the concentrations of toxicants to increase from one nutrition level to the next, thereby causing chain effects in ecosystems. The magnification in each step is considered to be 3-5 times in an aquatic nutrition web. (Kihlström, 1992) If water is polluted, it will not only affect water-dwelling organisms, but also terrestrial organisms that feed on aquatic organisms. The animals who in turn feed on these terrestrial animals will also be affected. Thus, pollution can cause effects even to animals that are not directly dependent on the specific water area. These effects include decreased source of food as well as magnified substance level higher up in the nutrition chain which in turn affects reproduction.

1.4.4 Cadmium (Cd)

The most general soil mineral containing Cd is biotite. Cd also occurs naturally in Zn, Pb, Cu and other ores which can serve as sources to ground and surface waters. (EPA, 2001) Compared with other trace metals, Cd is relatively mobile in the aquatic environment and is less readily removed by adsorption and complexion. (Smith, 1986)
Cd is mainly used in:

- Steel industry
- Colour pigment in plastics and paints
- Photography
- Television phosphorus
- Cathode material for Ni-Cd batteries.
- Phosphorus fertilizers

Cd is also present in sewage and storm water containing particles from rubber tyres. Cd is a by-product of Zn and Pb mining and smelting, which are important sources of environmental pollution (Klaassen, 1996).

Cd is released to the environment in wastewater, as well as diffuse pollution from fertilizers and local air pollution. Contaminated drinking-water may also be caused by impurities in the zinc of galvanized pipes and Cd-containing solder in fittings, water heaters, water coolers and taps. Concentrations of Cd could be higher in areas supplied with soft water of low pH, as this would tend to be more corrosive in plumbing systems containing Cd. Cd concentrations in unpolluted waters are usually below 1 $\mu g*l^{-1}$. (WHO, 1993) Another important source of Cd to humans is through smoking of cigarettes.

1.4.4.1 Effects in humans

Acute toxicity may result from the ingestion of relatively high concentrations of Cd, as may occur in contaminated beverages or food. There is evidence for symptoms such as nausea, vomiting, and abdominal pain occuring from consumption of drinks containing approximately 16 mg/l of Cd (Klaassen, 1996). Short-term effects from concentrations greater than 5 ppb include all effects listed above as well as diarrhea, muscle cramps, salivation, sensory disturbances, liver injury, convulsions, shock and renal failure. Long-term effects from lifetime exposure include kidney-, liver-, bone- and blood damage. (EPA, 2001)

About 50 to 75 % of the body burden of Cd is in the liver and kidneys. Its half-life in the body is not known exactly and may be as long as 30 years. (Klaassen, 1996) This means that even small amounts of Cd can accumulate and cause long-term damage. With chronic oral exposure, the kidney appears to be the most sensitive organ. The estimated critical concentration of Cd would be reached after a daily dietary intake of about 175 µg per person for 50 years. (WHO, 1996) Because of the potential for accumulation in the kidneys, there is considerable concern about the concentrations of dietary Cd intake for the general population. (Klaassen, 1996).

Cd toxicity from oral intake affects calcium metabolism. Associated skeletal changes are probably related to calcium loss and include bone pain, osteomalacia, and/or osteoporosis. Cd is also believed to be the cause of itai-itai disease (meaning 'it hurts'). Epidemilogical studies of people chronically exposed to Cd via the diet as a result of environmental contamination have not shown an increased cancer risk. No reliable studies on reproductive, teratogenic, or embryotoxic effects in humans are available. (Klaasen, 1996).

1.4.4.2 Environmental effects

When Cd compounds bind to sediments, they can be more easily bioaccumulated or dissolved when sediments are disturbed, eg. during flooding. Its tendency to accumulate in aquatic species is great in some, and low in others. (EPA, 2001)

Effects of Cd exposure have been observed in all trophic levels at concentrations around 0.2 $\mu g*l^{-1}$. In plankton, reproductivity is known to decrease at Cd concentrations of 0.17 $\mu g*l^{-1}$ in natural fresh water. In fish, chronic effects in the laboratory have been reported at concentrations of 0.9 $\mu g*l^{-1}$ and above, with affected juvenile development stages (Lithner, 1989). Cd can accumulate in plants, particularly in roots, and reach high concentrations without signs of stress (Alloway, 1995)

In fish, Cd primarily accumulates in the liver, kidney and gills, and to a less extent in muscles. The biological half-life in fish is relatively long, over a year. Acute toxicological effects include cellular damage and/or disturbed metabolism. Long-term exposure to Cd concentrations of 5-500 $\mu g*l^{-1}$ affects carbonhydrate-metabolism, ion regulation and blood in fish. There is also evidence of anaemia from chronic exposure, but this symptom disappears if the Cd concentation in the water returns to normal. Cd also causes damage to the gills and changes in gill-membrane have been observed at concentrations of 3 $\mu g*l^{-1}$. Another effect of Cr exposure in fish is deformed spine. (Åhgren & Norrgren, 1996)

1.4.5 Chromium (Cr)

Chromium is widely distributed in the earth's crust and can exist in valences of +2 to +6, but only trivalent and hexavalent forms are of biological significance. The trivalent is the more common form, but hexavalent forms are of greater industrial importance. Sodium chromate and dichromate are the principal substances for the production of all Cr chemicals. (Klaassen, 1996).

The main uses for Cr are in:

- Stainless steel
- Chrome pigments for paints, cement, paper, rubber, composition floor covering and other materials (EPA, 2001).
- Cr salts used for tanning leather, mordant dying, wood preservatives, and as an anticorrosive in cooking systems and boilers.

EPA (2001) has found the two largest sources of Cr emission in the atmosphere to originate from the chemical manufacturing industry and combustion of natural gas, oil and coal. Cement-producing plants are also an important source of atmospheric Cr. When Cr precipitates, its fallout is deposited on land and water, and land fallout is eventually carried to water by runoff. A controllable source of chrome is waste water from chrome-plating and metal-finishing industries, textile plants and tanneries. (Klaassen, 1996)

1.4.5.1 Effects in humans

Total Cr concentrations in drinking water are usually less than 2 $\mu g*l^{-1}$, although concentrations as high as 120 $\mu g*l^{-1}$ have been reported. The absorption of Cr after oral exposure is relatively low and depends on the oxidation state. Cr (VI) is more readily absorbed from the gastrointestinal tract than Cr (III) and is able to penetrate cellular membranes (WHO, 1993) Hexavalent Cr is corrosive and causes chronic ulceration and perforation of the nasal septum. It also causes chronic ulceration of other skin surfaces. Exposure to Cr is associated with cancer of the respiratory tract. The possibility of Cr compounds causing cancer at other sites has been suggested but is not certain. (Klaassen, 1996)

U.S. Environment Protection Agency (EPA) has set a maximum contaminant level of 0.1 ppb Cr. In drinking waters exceeding this limit, they have found short-term effects, including skin irritation or ulceration, and long-term effects including damage to liver, kidney circulatory and nerve tissues as well as skin irritation.

1.4.5.2 Environmental effects

Cr(VI) has a high mobility in water and is more bioavailable than Cr(III), which makes Cr(VI) more toxic. Cr is very toxic to microorganisms in water and there is a high potential for accumulation in aquatic life (EPA, 2001). Chronic and sublethal effects have been observed in certain species of fish and plankton at concentration levels of 8-13 $\mu g*l^{-1}$, but Cr is not known to accumulate in fish to a high extent. In Canada, a maximum level of 20 $\mu g*l^{-1}$ is set for fish, and 2 $\mu g*l^{-1}$ for all other organisms. (Lithner, 1989)

1.4.6 Copper (Cu)
Cu has been used by humans for a very long time and mining is believed to have started over 6000 years ago. In water, Cu exists in different forms such as colloids, free ions and bound to particles. Humus particles bind up to 90% of the total Cu amount in freshwater (Åhgren & Norrgren, 1996).

Cu and its compounds are used in:
- Electrical wiring
- Water pipes
- Cooking utensils
- Electroplating
- Algicides and pesticides
- Food additives.

Cu is an essential nutrient for organisms, required for the proper functioning of many important enzyme systems. In humans, the highest concentrations of Cu are found in the liver, brain, heart, kidney and adrenal glands (WHO, 1998).

1.4.6.1 Effects in humans
Cu utilization is affected by a number of genetic disorders. The genetic abnormalities associated with Menke syndrome (peculiar hair, failure to thrive, severe mental retardation, neurological impairment, and death before three years of age; Klaassen, 1996), Wilson disease (excessive accumultion of Cu in liver, brain, kidneys and cornea; Klaassen, 1996), and aceruplasminaemia are fairly well understood, and there is some evidence to suggest a genetic basis for Indian childhood cirrhosis and idiopathic Cu toxicosis. (WHO, 1998)

Acute gastrointestinal effects may result from exposure to Cu in drinking water, although the concentrations at which such effects occur are not defined with any precision. Long-term intake of Cu in the diet in the range of 1.5-3 mg/day has no apparent adverse effects. Daily intake of Cu below this range can lead to anaemia, neutropenia, and bone demineralization in malnourished children. Adults are more resistant than children to the symptoms of Cu deficiency (WHO 1998).

1.4.6.2 Environmental effects
Effects of Cu have been observed in algae, invertebrates and fish at concentration levels of <5 $\mu g*l^{-1}$ with the lowest level being 2-3 $\mu g*l^{-1}$. Increased intake of Cu causes increased levels of stress hormones in the blood of fish. (Lithner, 1989)

While being an essential nutrient, Cu is also one of the most toxic metals for aquatic organisms. Acute toxicity in fish occurs at levels of 17-1000 $\mu g*l^{-1}$. Sublethal effects include damage to gills, liver and kidney as well as disruption of cellfunctions such as inhibition of enzyme activity. Cu toxicity also affects the olphactory area of the mucosa, stress response, and immune system. (Åhgren & Norrgren, 1996)

1.4.7 Nickel (Ni)
Ni is found in natural deposits as ores containing other elements. Ni is used in a large number of alloys including:
- Stainless steel
- Batteries
- Chemicals
- Catalysts

- and in the electrolytic coating of items such as Cr-plated taps and fittings used for tapwater.

Ni concentrations in drinking water around the world are normally below 20 μg*l^{-1}. The concentration may be increased if raw waters are polluted by natural or industrial Ni deposits or if leaching from Ni-Cr plated taps and fittings occurs. Intake from food exceeds that from drinking-water, which is about 20 μg/day. (WHO, 1998).

1.4.7.1 Effects in humans

Acute Ni intoxications are rare, but symptoms related to heavily contaminated drinking-water (>1.63 g/l) are nausea, vomiting, abdominal discomfort, diarrhoea, giddiness, lassitude, headache, cough and shortness of breath that last from a few hours up to a few days. (WHO, 1996). Long-term exposure to Ni can potentially cause decreased body weight as well as heart and liver damage (EPA, 2001). Ni is also a common skin allergen. Women seem to be more sensitive to allergic reactions from Ni exposure than men, and 50% of Ni-sensitive women develop hand aczema, which in severe cases may cause incapacitation. The allergic reactions are most common from dermal application but oral intake of extremely low doses of Ni may provoke eczema in sensitized individuals. (WHO, 1996)

1.4.7.2 Environmental effects

Ni is one of the most mobile heavy metal when released to water, especially in polluted waters where organic matter will keep Ni soluble. Ni accumulates in aquatic life, but does not become magnified along food chains (EPA, 2001). The toxicity of Ni is less documented than other elements, but concentration levels of 23-50 μg*l^{-1} have shown chronic and sublethal effects in some species of fish and microrganisms. In USA and Canada, environmental standards are set to 23 and 25 μg*l^{-1}, respectively, in soft waters. (Lithner, 1989)

1.4.8 Lead (Pb)

Pb is used:

- Principally in the production of Pb-acid batteries, solder, and alloys.
- Sometimes in household plumbing materials or service water lines.
- As antiknock and lubricating agents in petrol.

Owing to the decreasing use of Pb-containing additives in petrol and Pb-containing solder in the food processing industry, concentrations in air and food are declining, and intake from drinking water constitutes a greater proportion of total intake. (WHO, 1993) Pb is toxic to most organisms at high exposures and there is no demonstrated biological need for it. (Klaassen, 1996)

In Uganda, Pb-containing petrol is common and therefore should be considered a major source of Pb to the environment. There is also no organised collection of used-up Pb-acid batteries. The batteries are usually dumped or repaired with used parts poured out or thrown away. (Sentongo, 1998)

Pb is present in tapwater to some extent as a result of its dissolution from natural sources, but primarily from household plumbing systems containing Pb in pipes, solder, fittings or the service connections to homes. The amount of Pb dissolved depends on several factors, including pH, temperature, water hardness and standing time of the water, with soft acidic water being the most plumbosolvent. (WHO, 1993)

1.4.8.1 Effects in humans

Pb is transported in the blood and is first accumulated in the liver, kidneys and spleen. It is then relocated and accumulated in the skeletal bones. Pb also has effects on the gastrointestinal system, cardiovascular system, thyroid glands and foetus. (Birgersson, 1995) Pb is also toxic both to the central and peripheral nervous system. (WHO, 1993) This is of special concern since neurophysiological effects influence learning ability, hearing, attention span and general behaviour in children. (Harrison, 1990) Young children absorb 4-5 times as much Pb as adults, and the biological halflife may be considerably longer in children than in adults. Infants, children up to six years of age, and pregnant women are most susceptible to its adverse health effects. Pb is also classified as a possible human carcinogen and there is evidence of adverse neurotoxic effects other than cancer occurring at very low Pb concentrations and a guideline value for drinking-water derived on this basis would also be protective against carcinogenic effects (WHO, 1993). Other long-term effects than cancer include stroke and kidney disease. (EPA, 2001)

1.4.8.2 Environmental effects

The pH and hardness of the water affect the availability of Pb to organisms. This is because an increase in pH and hardness results in an increase in the number of Pb ions binding to carbonates and hydroxides, which are less bioavailable. Pb is therefore less toxic in neutral, humus-rich waters, especially to fish. (Lithner, 1989) The accumualation of Pb in fish does not seem to be organ-specific. Several studies show no connection between the concentration of Pb in organs and age or size of the fish. A sub-lethal effect of Pb uptake in fish is anaemia. Other effects include skeletal changes and neurotoxicity. A common symptom of Pb poisoning is the black-tail syndrome. These effects have been observed at Pb concentrations of 5-15 $\mu g*l^{-1}$ or above (Lithner, 1989). The function of mitochondria is also affected (Åhgren & Norrgren, 1996). In microorganisms, chronic effects have been observed at Pb concentrations of 19-30 $\mu g*l^{-1}$ (Lithner, 1989).

1.4.9 Zinc (Zn)

Zn is used as an anticorrosive in plumbing systems. In Uganda, old plumbing material is in Uganda used in the production of locally made metal products (Sentongo, 1998). Zn is also used in brass, glass, glazing, manufacturing of batteries, pigment, powder and creams (Birgersson, 1995) as well as in wood preservatives (Naturvårdsverket, 1988).

Zn is an essential trace element found in virtually all food and potable water in the form of salts or organic complexes. Food is principally the source of Zn. Concentrations of Zn in surface and ground water normally do not exceed 0.01 and 0.05 mg/l, respectively, but concentrations in tapwater may be higher as a result of dissolution of Zn from pipes (WHO, 1993)

1.4.9.1 Effects in humans

Excessive exposure to Zn is relatively uncommon and requires heavy exposure. The halflife for Zn in a healthy body is about a year (Naturvårdsverket, 1988) and Zn does not accumulate with continued exposure, but body content is modulated by mechanisms that act principally on absorption and liver concentrations. Although uncommon, gastrointestinal distress and diarrhea have been reported following ingestion of beverages standing in galvanized cans or from use of galvanised utensils. (Klaassen, 1996) Other symptoms of Zn toxicity are slow reflexes, shakes, paralyzation of extremities, anaemia, metabolic disorder, terratogenic effects and increased mortality. It should be noted that these symptoms are very rare and are due to large overdoses (Naturvårdsverket, 1988). There is no health-related guideline value for Zn in drinking water from WHO, but consumers may complain about the appearance and taste of the water if the concentration exceeds 3 mg/l (WHO, 1996).

1.4.9.2 Environmental effects

Zn is part of several enzymes and is therefore essential, but may be toxic to aquatic organisms. Fish in freshwater respond quickly to Zn exposure. High concentrations in water can cause death and lower concentrations can inhibit growth, sexual maturity and reproduction. The acute cause of death in fish seems to be anoxia due to serious gill damage. (Åhgren & Norrgren, 1996) Effects on algae have been observed at concentrations of 15 $\mu g*l^{-1}$. Increased Zn concentrations in green algae increase the need for phosphorus which, in turn, indirectly causes a decrease in production. Lethal and sub-lethal effects such as decreased growth have been observed in invertebrates, but the symptoms seem to vary between species. (Naturvårdsverket, 1988)

1.4.10 Synergism and antagonism

The biological function of a metal can be affected by the presence of other metals. Through synergism, the negative environmental effect of an element increases when in presence of another element. The environmental effect may thereby be greater than the effects caused by each isolated element. Presence of more than one element may also have the opposite effect, where presence of one element inhibits the uptake of another (Zink i Miljön, 1988). An example of negative effects of synergism, though, is when presence of Cd inhibits uptake of Ca, thereby causing skeleton changes. (Klaassen, 1996)

1.5 Objectives of the study

1) To evaluate heavy metal discharge into Lake Victoria from the largest Ugandan cities located on the shores of the lake.

2) To determine whether or not wetlands impact on the magnitude of metal discharge into the lake.

3) To determine heavy metal levels in 1) drinking water taken from different residential areas in Jinja, Kampala and Entebbe, 2) irrigation water from farmland.

4) To compare the results with Swedish environmental guidelines to evaluate whether the discharge of heavy metals into Lake Victoria has negative environmental effects.

2 Methods

2.1 Methods in the field

2.1.1 Selection of sampling sites

Selection of sampling sites was done by viewing maps in order to evaluate where pollution from the towns was most likely to enter Lake Victoria. Help was recieved from Dr. Aniku, supervisor in the field. Not all the planned sampling sites could be visited due to transportation and access problems.

2.1.2 Collection of samples

Five samples of 0.5 litres each were collected using a common plastic beaker of 1 litre. These samples were poured into a bucket and then mixed. All of the equipment used was made of plastic. A 100 ml sample was then taken from the mixture. The procedure was repeated once which gave a total of two 100 ml samples from each sampling site and both 100 ml samples were put in an ice chest for field storage. The two samples were later mixed, giving one analyzed sample from each site.

2.1.3 Preparation and storage

The water samples were put in an ice chest during the completion of the field work. They were then moved into a freezer and kept deep-frozen until the day of departure from Uganda. Then the samples were put back in the ice chests, and transported in that manner to Sweden.

2.2 PREPARATORY LABORATORY WORK

From each sample, 20 ml of water was put into a test tube of glass. The samples were then put in a water bath for evaporation until about 5 ml of water was left in the test tube. 5 ml 2 M HNO_3 was added to the samples in order to dissolve organic matter and get a total amount of the substances of interest. The samples with nitric acid were put in a digestor (2140 digestor, Foss Tecator) at a temperature of 20 °C for three hours. The samples were then clear in colour and transferred to 25 ml volumetric bottles. Distilled water was added to make the sample a total of 25 ml for analysis. The samples were then poured into 25 ml plastic containers and labelled. There were two samples that were not completely clear, and these were therefore filtered into the plastic containers. All samples were stored at +4 ^{o}C until analysis.

2.3 ANALYSIS

The water samples were analyzed at the Department of Soil Science at the Swedish University of Agricultural Sciences. Pb and Cd were analyzed at the Division of Soil Chemistry and Pedology using atomic absorption with graphite oven (model Perkin Elmer, Zeeman 4110ZL). Ni, Cr, Cu and Zn were analyzed by the Division of Soil Fertility and Plant Nutrition using an ICP spectrometer (Perkin Elmer Optima 3000DV).

Since the samples were diluted, all results were multiplied by a factor of 1.25 in order to calculate the concentration of each metal in the original water sample.

3 MATERIALS

3.1 THE CITIES INVESTIGATED AND SITE DESCRIPTION

The sampling sites were chosen through the studying of maps of the areas and through consultation with Dr. Aniku, supervisor in the field and with great knowledge of the chosen areas. Sampling was carried out between February and April 2001. The samples in swamps were collected before the heavy rains started in March.

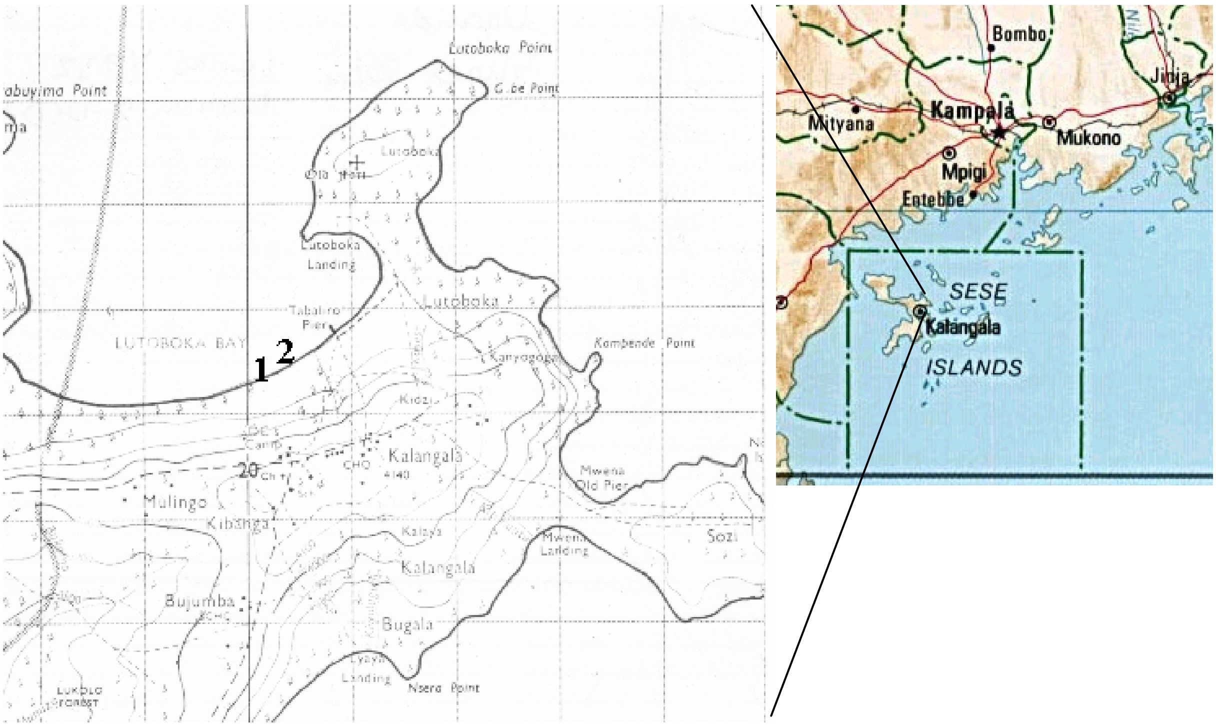
Samples of surface water were collected from three major towns on the Ugandan shores of Lake Victoria, namely Kampala, Jinja and Entebbe. In these towns, the chosen sampling sites are suspected of receiving polluted discharge from municipal and industrial wastewater. By analyzing these samples, an idea of the amount of discharge containing heavy metals that enters Lake Victoria from these towns can be identified. Samples of surface water have also been collected off the shore on Ssese Islands, which have no point sources of pollution through industries, etc., and were therefore an appropriate site for background values.

3.1.1 Ssese Islands

The Ssese archipelago consists of 84 islands some 30 km south of Entebbe. The islands do not have any industries and have not been significantly affected by human activities. They are inhabited by the Basese people – a distinct ethnic group with their own language, culture and folklore. Primarily fishermen, the Basese also farm coffee, sweet potato, cassava, yams and bananas (Camerapix, 1998).

The islands are lush and well-watered, with an average rainfall of more than 2000 mm/year. The main islands are hilly and forested with a large variety of trees. (Camerapix, 1998) Due to the lack of polluting factors on the islands, they were chosen as a site of interest for control samples.

3.1.1.1 Sampling sites



Map 1. Sampling sites on Ssese islands

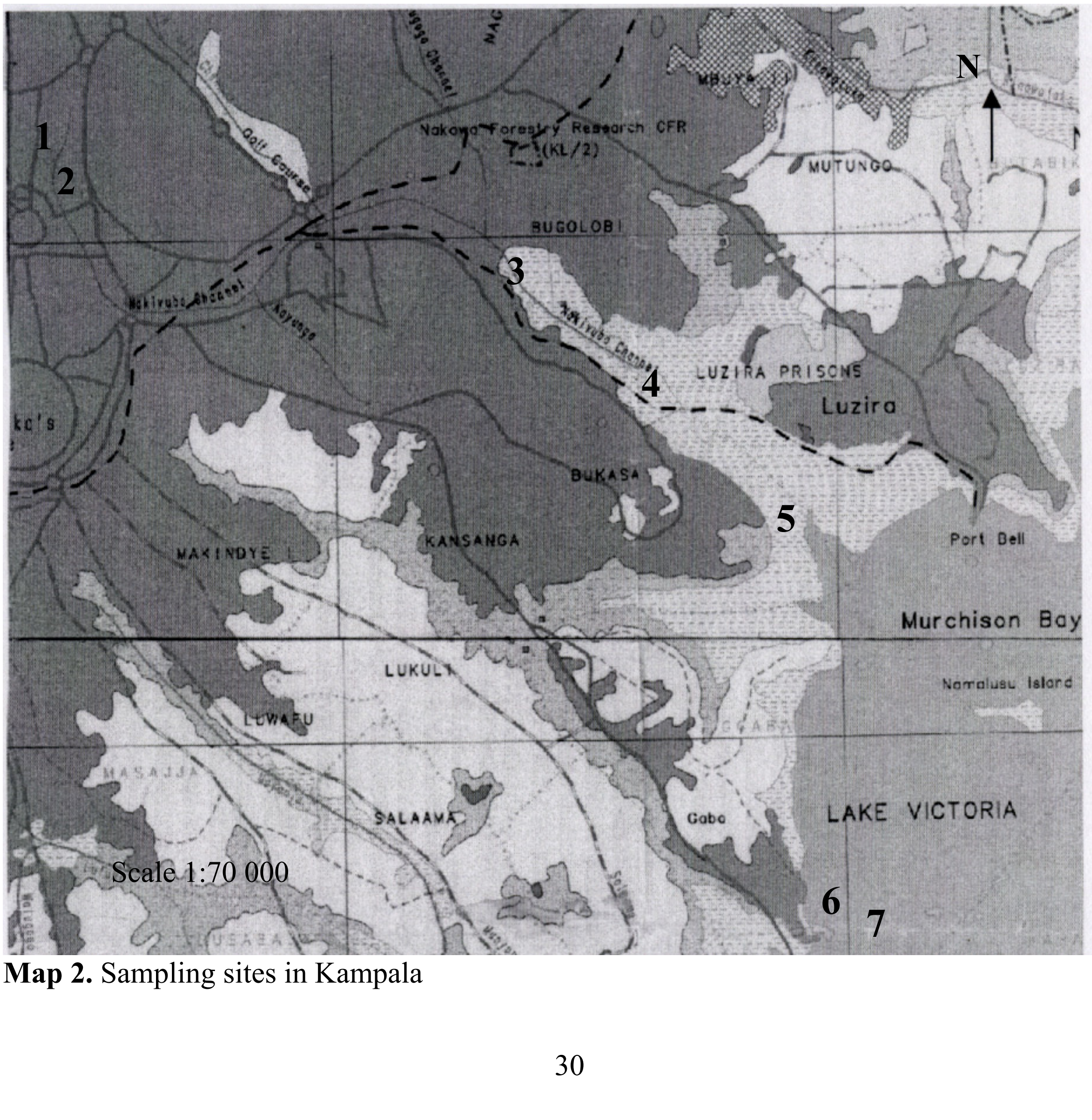
1) *Ssese Island Club* and 2) *Ssese Island*: Two locations were chosen as sampling sites on Ssese Islands, and two samples were collected at each site. The sites were located off Bukwanyo Beach on the main island of Kalangala. Samples were collected just off the inner shore of Kalangala Bay. A few campsites were present nearby, but in all it was a quiet place with hardly any inhabitants. Above the shoreline was rainforest, with a rich and varied birdlife. The beach at the site was narrow and reached 0.5 – 1 m from the water at the sampling sites with a vegetation of mostly grass and polygonum. The water was shallow and quite clear. No large amount of organic matter was visible.

3.1.2 Kampala

Like the city of Rome, Uganda's capital Kampala was originally built on seven hills, around which was a mixture of valleys, swamplands, and streams. The area had long been an area of Baganda activity, with the Kabaka (king) having his capital here. The name comes from *Kasozi ka Impala*, or 'hill of antelopes', because the Impala antelopes were abundant on the hills. These days, the city has extended to cover about 20 hills in the area. The population is estimated to be somewhere near one million on an area of more than 300 km^2, with Greater Kampala having a radius of about 20 km (Camerapix, 1998). Kampala has six industrial areas with over 400 firms. Four of these areas discharge waste water into streams and swamps which drain into Lake Victoria. (The Lake Victoria Basin, 1998)

3.1.2.1 Sampling Sites in Kampala

Sampling sites in Kampala were selected along Nakivubo channel (samples Makerere, Lugogo and Mpanga) as well as at its discharge point in Lake Victoria (sample Lake Victoria). Samples were also taken at the two intake points of the Water Treatment Plant (samples Old Gaba and New Gaba) which provides drinking water for the city's inhabitants as well as at three different drinking water taps in the city (samples Makerere Well, Kololo and Kamwokya). Nakivubo channlarge parts of the city, collecting wastewater from both central and industrial areas. Samples were selected so as to show the additional pollution to the channel as it runs through the city. Before the channel enters Lake Victoria, it runs through a farming area which is flooded during the wet seasons, as well as a papyrus swamp. Sample collection was made at sites listed below.



Map 2. Sampling sites in Kampala

1) *Makerere (Feb 21):* The site was located near Makerere University, in a valley about 400 m from where Nakivubo channel reemerges above ground. The channel ran in a ravine with a depth of about two m. There was little water in the channel at the time of sampling and the banks consisted mainly of sand. During the wet season, water runoff from the surrounding slopes is collected in the channel. The ravine had a rich natural flora and household farming with crops such as bananas and yams was practiced on the slopes. On the hill above the sampling site there was a Shell petrol station. There was also a KCC dumping site nearby. The channel drained a residential area with poor or no sewage systems and garbage piles. The water had a strong smell, a greyish colour and contained suspended organic material. No biological activity was noticed at the time of sampling.
2) *Makerere Well (Feb 21):* A few metres from Makerere sampling site, there was a natural spring where drinking water was collected. One sample was collected from this spring.
3) *Lugogo (Feb 19):* The Lugogo site was located after the junction of Nakivubo and Lugogo channels. These channels pass through Kampala picking up city and industrial waste water in the form of discharge, sewage, garbage and runoff. Kampala's sewage treatment plant, which was located just upriver from the site, was another source of polluted water. The area is flooded 9 months a year (March-June and mid August-December). During the dry season it is used for growing crops because of its high fertility. The site used to be a swamp but the area has been drained in order to obtain better growing conditions. The site was located in an industrial area on the outskirts of Kampala, between the city districts of Bugolobi and Namuwongo. Some of the closest industries were a plastic factory and a metal producer. Other industries include manufacturers of paper, metal, meat, leather as well as small-scale manufacturers. The water was brown, smelly and full of solid waste. The depth of the channel was approximately 1 m and its width 2 m. No sign of biological activity was observed on the site.
4) *Mpanga (Feb 20):* At this point, Nakivubo channel has passed through a rather large area of small-scale, household farming. The area was flat with a 0-1% slope and flooded during the heavy rains. During the dry season, water only flows in the channel. Bananas, yams and sugarcane were grown around the site for household and market use. The water had a strong smell but the amount of solid waste in the channel was less than upstream at Lugogo and also seemed to be cleaner. At this point the channel had a width of about 3 metres. Algae and larvae were present as well as a rather large amount of organic material.
5) *Lake Victoria (Feb 19):* At this point, Nakivubo channel enters Lake Victoria. The water has now passed through a papyrus swamp as well as a farming area and the city. The area had a floating flora of papyrus, water hyacinth, and water lettuce. The water was open towards the lake, but no shoreline was visible from the sampling site due to thick vegetation of water hyacinth, papyrus, reed grass and other aquatic vegetation. The water had a strong smell of sewage and was brown with plenty of algae and organic material. Bilharzia shells were noted and there were plenty of birds.
6) *Old Gaba (Feb 19, March 16):* Samples were collected at the intake point of the first and older water pumping station, which delivers water to the city of Kampala. At this point the water has been diluted in Lake Victoria and the intake points were situated on the opposite side of the bay from where Nakivubo channel enters Lake Victoria. The samples were collected approximately 40 meters from the shore at the end of a long metal construction. There was no vegetation and the water was brown and muddy with some algae and small insects. At the second visit (March 16), algae were seen in green clusters.
7) *New Gaba (Feb 19, March 16):* Samples were also collected at the intake point of the newer pumping station. This station was situated a bit further away from the discharge point of Nakivubo channel than Old Gaba. The water quality was similar to the site of Old Gaba. This pump station was situated on small peninsula further out in the lake and there

was some water hyacinth present. The water seemed to contain less algae, but was also more turbid than at Old Gaba.

8) *Kamwokya (March 22):* One water sample was collected in a residential area in the district of Kamwokya. This is an area mostly populated by low income households and the sample was collected from a common well used by several families for drinking and cooking water.
9) *Kololo (Apr 2):* This sample was collected from a tap in a residence situated in an area populated by mostly wealthy people.

Larsson (2001) has investigated heavy metal content in soil and crops grown at sites Makerere, Lugogo and Mpanga.

3.1.3 Jinja Town

Jinja lies 80 km east of Kampala on the shores of Lake Victoria and is a major market centre for central, southern and eastern Uganda (Lonely planet, 2000). Jinja lies north of the equator at an altitude of 1 143 metres and its temperature ranges from 17°C to 28°C. Jinja is Uganda's largest town after Kampala and the municipality covers an area of 30 km^2 and is estimated to have a population of 61 000 (Africa Water Network, 1998). Jinja is known to be the source of the Nile, the point where the Nile flows out of Lake Victoria on its 6 400 km long journey to the Mediterranean Sea. (Camerapix, 1998)

The earliest industries in Jinja were based primarily on agricultural production, particularly cotton, sugar, timber and their by-products. In the sixties, a steel smelter and rolling mill was developed and is today one of the largest in East Africa, with a capacity to produce more than 24 000 metric tonnes of finished steel a year. Jinja also has large sugar and tea industries. (Camerapix, 1998)

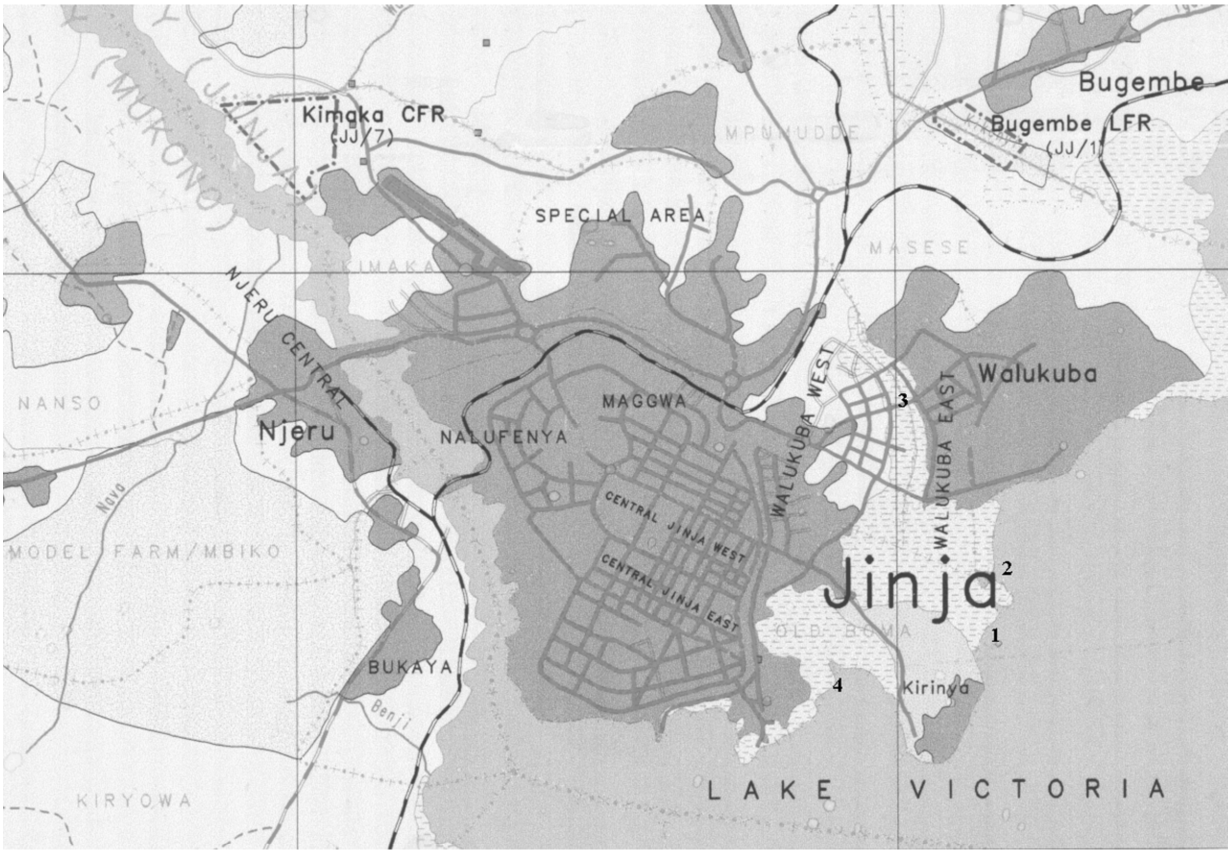
In 1952, the Owen Falls Dam was opened in Jinja to harness the water of the Nile to generate electricity for Uganda, as well as Kenya, Tanzania and Rwanda. Jinja is also the home of the Nile Breweries Industries, which brew beer using the waters of the Nile. In addition to the steel rolling mill and the major sugar operations, industries represented in Jinja include textile producers, a flour mill, a paper bag manufacturer, a modern printing works, a cigarette and match manufacturer, a soap and oil producer, a sawmill, a furniture maker, and a steel tubing manufacturer. Several multinational companies represented here include Dunlop, who have a tyre and tube factory in Jinja, the Chillington Tool Company of Wolverhampton, England; and the British-American Tobacco Company (BAT). The government-owned Kilembe Mines Ltd is situated on Walukuba Hill and explores, processes and exports minerals like Cu and Co. Kilembe Mines has been closed since 1977 when Cu smelting was halted. (Camerapix, 1998)

Jinja remains an agricultural trade centre, with the potential of producing more than 90 000 bales of cotton a year – more than all the rest of Uganda. Other crops grown here include sugar, coffee and groundnuts. The Uganda Fish Enterprises Limited factory was set up here in the 1980s to process fish for export – just one of more than ten fish factories located on the shores of Lake Victoria involved in the processing and exporting of fish. (Camerapix, 1998) Jinja town has two industrial areas, one situated on the banks of the Nile and the other in central Jinja. Most of these industries are connected to the public sewage system but the wastes are not treated for heavy metals. The sewage treatment plant uses oxidation ponds and discharges into Kirinya Swamp (see map below). (The Lake Victoria Basin, 1998). Due to

Jinja being an industrial and agricultural centre, the shores and swamps of the town were considered to be interesting sampling sites.

3.1.3.1 Sampling sites in Jinja

Since Jinja has large industrial areas, sampling sites were chosen to try to show the amount of pollution generating from these industries that reach the waters of Lake Victoria.



Map 3. Sampling sites in Jinja

1) *Kirinya (March 8):* The site was located at the southern part of Walukuba swamp and north-east of Kirinya Prison. The water was brownish, with some algae and a lot of small aquatic insects. The sampling site was very shallow with a depth of approximately 1 meter.
2) *Walukuba (March 8):* This sampling site was located in the waters outside the same swamp as above, but further north towards the mainland. The swamp consisted of papyrus and further inland, the area was used for household farming. North of the site, Kilembe Mines was situated on the hillside. Apart from the mine, no other bulding was located on the hill. The open water was quite clear, but got muddier closer to the vegetation of papyrus. The number of insects and algae also increased. Further north-east along the shore, Jinja's water intake was situated.
3) *Walukuba North (March 19):* The site was located where Walukuba Road crossed the stream that runs southwards from Walukuba to Lake Victoria. The natural swamp habitat of the area has been drained for farming purposes. Crops grown here include maize, cassava, yams, maniok and kidney beans.
4) *Old Boma (March 8):* The site was located at the edge of Kirinya swamp. Kirinya Prison was situated east of the swamp. The prisoners practiced small-scale farming on the eastern edge of the swamp which, besides farmland consisted mainly of papyrus. The water was rather clean with no smell but there was some organic material visible at the time of

sampling. Fishermen go into the specific bay for fish and there were a lot of birds and fish in the water.

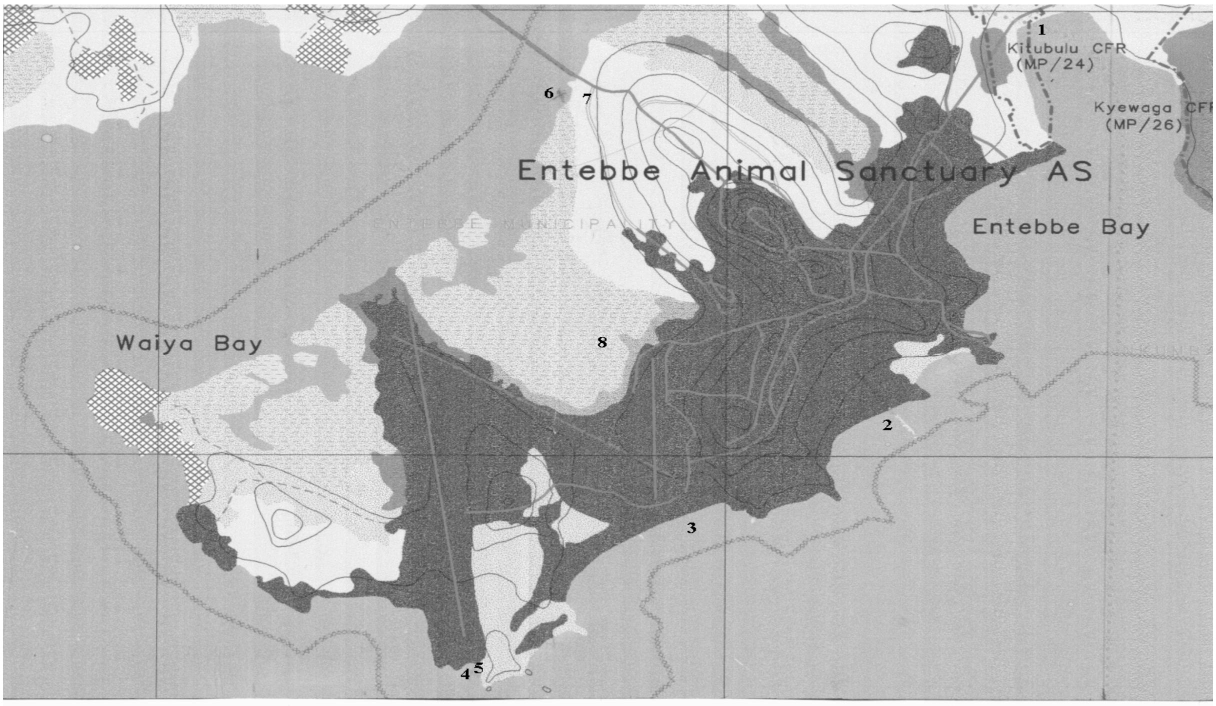
3.1.4 Entebbe Town

The town of Entebbe is situated 34 km south of the country's capital and lies on the north-western shores of Lake Victoria. The peninsula on which it lies is situated 1 158 metres above sea level. Entebbe was initially the capital of Uganda but, after independence in 1962, the capital moved to Kampala. The beginnings of present-day Entebbe go back to the 19th century when colonialists built a major administrative centre here. Today, a number of government offices are located here. (Camerapix, 1998) Entebbe is a small town with an estimated population of 42 000 (Africa Water Network).

Entebbe has a botanic garden which covers 2.6 km^2, with a wide variety of East African flora (Camerapix, 1998). Entebbe International Airport, Uganda's sole international airport, is also located here. The airport is situated on the southern part of the peninsula and aeroplanes fly close above the waters of Lake Victoria during take-offs and landings. Airports and aircraft are known to generate heavy metal pollution to the surrounding environment. Leaded petrol is often used in smaller aircraft leading to emissoins of Pb to the surrounding area. The landinggear of the aircraft is painted with Cd, which is released to the environment during washing or heavy rains, and Cu is found in the brake system of the aircraft. Heavy metals are also known to be picked up from the atmosphere during flights and released when the planes are washed. Most of this pollution spreads into the environment by run-off water. (Ljung, 2002) Due to the high rate of pollution originating from the airport and aircraft in comparison with the rest of the town, the shores of Entebbe were of interest to the study.

3.1.4.1 Sampling sites in Entebbe

The largest source of pollution in Entebbe is the international airport. Sampling sites were therefore chosen to analyze how this pollution spreads over the Entebbe area, and to establish how far from the point source there was evidence of high concentrations of heavy metals. Well samples were also collected for analysis.



Map 4. Sampling sites in Entebbe

1) *Kitubulu (Feb 26):* The site was located at the bay closest to main land on Entebbe peninsula. The bay was rather closed off and carved quite a bit into the mainland and was located close to the mainroad leading to the airport. The beach was rather long with a small beach resort located on the north-eastern part. There were no houses on the shore but people were seen collecting drinking water in the morning. The vegetation on the shore was low with mostly different kinds of grass. Some reed grass was seen. The sand on the beach was brownish-yellow with larger particles. The water was not clear by the shore. Up to 1.5 m out, there was a lot of organic material, that probably had floated in with the waves. At the time of sampling the N-W wind was quite strong. On both sides of the beach, small-scale, non-uniform farming was present.
2) *Bugonga (Feb 26):* The site was located on the peninsula close to the golf club. The area was a rather large open space covered with sand and grass. There were a few houses situated about 200 m from the beach, and there was also a house on the north eastern side along the shore. Plenty of bilharzia shells were present on the beach at the time of collecting. The N-W wind was rather strong and there were also waves. The sand was brownish-yellow and coarse. The water was clear with no organic material.
3) *Kitoro (Feb 26):* The site was located on the peninsula close to the airport area and the flight control tower was seen from the site. The area was open and covered with sand and grass. The beach was covered with low beach vegetation, mostly grass and polygonum. Plenty of bilharzia shells were present and due to the rather strong N-W wind there were also water hyacinth and other floating plants on the beach. The sand at this site was white and consisted of fine particles. To the north east there was a small fishing harbour and to the south west there was a company situated called "Clovergem Fish and Food Ltd". A woman passing by informed us that this site was used for fetching of drinking water. The shore was situated about 100 m from the main road to the airport.
4) *Airstrip (Feb 26):* The site was located in a bay just outside the fence of the airstrip where aeroplanes take off and land (about 100 meters). The bay was small but cut quite deep into the coastline which resulted in it being rather protected from the wind. There was a large amount of bilharzia shells and also plenty of shrubs. The vegetation reached down almost to the shoreline which left a very thin string of sandy beach. The sand was brownish-yellow and rather coarse. The water was clear with no organic material. There were no people living on this beach, but there seemed to be human activity on the western side of the bay. One small fishing boat was pulled up on the shore and two others (larger) were seen just outside the bay.
5) *Airstrip run-off (Feb 26):* This sample was collected from a small stream coming from the airport area and entering Lake Victoria. It is believed to be partly the run-off water from the airstrip.
6) *Nakiwogo (Feb 26):* The site was located on the opposite side of the Entebbe peninsula from where the other sampling sites were located. The area had a population of 600 living in low-standard houses on the north eastern part. In the same direction there was also a small harbour which received boats carrying cassava flour and timber from Tanzania. The people living in this area grew pineapple, tomatoes, cassava and sweet potatoes on the other side of the bay, in Buzi. Buzi is also used for collecting charcoal and wood. The people in the village consume the crops collected from Buzi, as well as tilapia and lungfish, and sometimes Nile Perch. People did not use the lake as a source of drinking water at this site since there was a well present. The fishermen informed us that they usually did not bring drinking water along with them, but drank water straight from the lake. The beach was sandy with some organic material present in the water.
7) *Nakiwogo Well (Feb 26):* A water sample was taken from the well of the fishing village in Nakiwogo.

8) *Kinarwanda Well (Feb 26)*: A well sample was also collected from a household farming area bordering one of the swamps in Entebbe.

3.2 SOURCES OF POLLUTION

3.2.1 Point sources

3.2.1.1 Municipal wastewater

The sewer systems in Kampala, Jinja and Entebbe do not combine domestic wastewater collection with stormwater collection. The sewer lines are found only in the central business areas, covering an estimated 15% of the population of the towns, whilst newly created business districts and adjacent peri-urban areas are served by septic tanks (10%) and pit latrines (40%). The rest of the population has no adequate sanitation facilities (Ehlin Consulting, 1997). All facilities operate below design capacity and are estimated to collect less than 38% of wastes generated in the municipalities. Only Kampala employs conventional treatment methods, with sedimentation, trickling filters and sludge digester. The other towns use oxidation ponds. The works are in a poor to moderate state of functionality, although the Kampala plant is currently undergoing major rehabilitation (Africa Water Network, 1998).

Table 3.1 Wastewater generation and collection in Kampala, Jinja and Entebbe (Africa Water Network, 1998)

Town	Population	Estimated Wastewater Production (m^3/day)	Current Wastewater Collection (m^3/day)	Percentage Coverage
Kampala	775 000	116 300	20 000	17%
Jinja	61 000	9 200	7 650	83%
Entebbe	42 000	6 300	835	13%
Mean				38%

The effluent from the plants is discharged into Lake Victoria or led into nearby swamps and streams draining into the lake. The sewerage plant in Kampala releases its effluents into Nakivubo channel which drains into Lake Victoria. In Jinja, there are two treatment works which drain into the Nile, and one discharging into a swamp draining into Lake Victoria. The effluent from Entebbe is discharged into a swamp which drains into Lake Victoria. The total loading from the municipalities is probably higher than these estimates, considering the low present coverage. Apart from effluent from sewerage plants, there are also many homes that are not connected to the public sewer. There are large areas with unplanned settlements which have no sanitation facilities while other homes located where facilities are available refuse to connect so as to avoid paying service fees. Domestic wastes from such homes and from peri-urban areas eventually enter Lake Victoria from diffuse points. (Africa Water Network, 1998)

3.2.1.2 Industrial wastewater

Most industries in the catchment area of Uganda are located in the towns of Kampala, Jinja, Mbarara, Masaka and Entebbe (Africa Water Network, 1998). Below is a list of industries with discharge into Lake Victoria and its connecting streams.

- Two major breweries produce 5 000 m^3 of toxic waste per day which is discharged into the lake untreated.
- Four textile factories that produce over 2 000 m^3 waste per day from the printing and dyeing processes, discharge it untreated into the lake.

- Three crystal sugar manufacturing factories, each producing 500 m^3 waste water per day.
- One tanning facility discharging 420 m^3 waste water per day containing arsenic, DDT, zink choride and various chlorobenzenes. This highly corrosive waste is discharged into the public sewer system which does not render it inert. Several new leather tanning factories are planned for the Lake Victoria area.
- Kilembe Cu mines. The tailing lagoons at Kasese have not been consolidated, capped or vegetated and leakage of waste containing Fe, Co, Cu, Cd and Zn into nearby water is taking place.
- Small-scale gold mining and refining using mercury is carried out in several parts of the country.

(Ministry of Natural Resources, 1995)

Until recently, solid waste and other waste in dumping sites in Kampala was spread out by bulldozers and some of those areas are now fertile land where some of the city's vegetables are grown, without any regard to chemical absorption by plants. A chemical profile of the garbage in selected residental areas of Kampala shows high concentrations of heavy metals derived from used batteries and other sources. Recently, the management of some dumping sites has improved. Excavations similar to landfills have been made and the garbage is periodically covered with sand and soil to minimize the smell. But the problem of chemicals getting into water still persists. The landfills are not constructed with channels to collect the effluent, which drains either into swamps or into underground water. (Kiremire, 2001)

3.2.1.3 Urban stormwater

Kampala, Jinja and Entebbe are located within the Lake Victoria climatic zone where rainfall (above 1200 mm) is received throughout the year with twin peaks in March-May and October-December. The collection and disposal of stormwater in the towns is made difficult by four factors, namely (1) devegetation for housing expansion, road construction and urban agriculture, (2) poor solid waste management, (3) inadequate facilities for management of industrial waste water, and (4) poor sanitation especially in newly created business districts and peri-urban areas. The existing drains are unable to handle the increased volume of runoff resulting from creation of more impervous surfaces. Flooding therefore occurs following downpours. Due to improper design and sitings of pit latrines, there is overland flow of sewage from the pit latrines during heavy rains, and this sewage, together with other debris littering the land surface ends up in surface waters, storm water drains and ultimately the lake. The biggest and most polluted stream entering Lake Victoria in Kampala is Nakivubo channel. (Africa Water Network, 1998)

3.2.2 Non-point sources

Non-point sources in the Lake Victoria basin include soil erosion, run-off from agricultural activities and wetland degradation. Uganda's agriculture is characterised as low-input low-technology. There is little use of modern inputs such as tractors, herbicides, pesticides and irrigation. The only areas which use such techniques are today the tea, sugarcane, vanilla, flower and vegetable plantations in the districts of Jinja, Mpigi and Mukono. These plantations are known to use herbicides and pesticides which end up in the lake. (Africa Water Network, 1998)

3.2.2.1 Soil erosion

Soil erosion is a large problem in the catchment area. The growing population puts pressure on the land for wood fuel, building material, farm land, grazing, mining, pitsawing and brickmaking. In 1995, 94-96% of Uganda's population depended on woodfuel as their only energy source. Uganda uses 10.8 million m^3 of wood per annum for energy purposes, which is 17% of the sustainable yield. There are at present few alternative energy sources considering the widespread poverty of the country. Deforestation and soil erosion as processes are described in 1.4.1.2. The problems of this in relation to the topic of this study are mainly transport of toxic material to the lake, and silting in wetlands, reducing their storage and purifying capacity. The problem of soil erosion is largely complicated by poverty. Cultivation of more and more land is carried out in order to meet basic needs such as hunger and housing. These needs are met in the short run, but the practice leads to destruction of the sources supplying them. (Ministry of Natural Resources,1995)

3.2.2.2 Agriculture and agrochemicals

Agriculture employs more than 80% of the population, and more than 70% of the farms practice crop production. The farmers grow both food and cash crops on their mainly small-scale holdings and poverty often causes the farmers to open more land for cultivation. The environmental problems that arise from rural agriculture include absence of fallow periods, soil degradation in unprotected areas such as cultivated hillsides, decline in soil fertility, deforestation and wetland drainage. These problems result in increased exportation of silt, organic material and nutrients from land to surrounding water areas (Africa Water Network).

Of the chemicals investigated in this study, Cd, Cu and Pb are present in agrochemicals used in Uganda. The use of agrochemicals in Uganda is today not widespread, but with the country's crop diversification policy, especially encouragement of high value export crops is likely to contribute to greater use of agrochemicals. The major users of these agrochemicals are smallholders who have had little, if any training or skills in application/use, storage or disposal. The amount of chemicals entering the environment is thereby significant regarding the additional source from chemicals used for livestock and protection of humans (eg. tse-tse fly control). (Ministry of Natural Resources, 1995)

3.2.2.3 Wetland degradation

Large unplanned settlements with no or poor sanitation and waste disposal systems result in polluted run-off into the lake. These settlements also bring pressure on fuel wood and building material. The problems that arise from these areas include deforestation and wetland degradation. This degradation is alarming since wetlands in many areas are the only purifying system for polluted streams leading to Lake Victoria. Wetlands are also threatened by increased cultivation, brick-making, sand mining and by residential and industrial estate development. When the protective functions of the wetlands decrease, it leaves Lake Victoria and the catchment rivers more vulnerable to pollution. In Kampala, wetland which has been drained for house construction now causes a problem of poor flood storage and moderation. This results in more and more areas being flooded during heavy rains and therefore more material being washed into streams and eventually into Lake Victoria. (Africa Water Network)

3.3 Guideline Values

The results from this study have been compared with guideline values regarding drinking water (WHO), irrigation water (EPA) and environmental stability (Swedish Environmental Protection Agency). The different tables of guidelines can be found in Appendix 3.

3.3.1 Drinking Water

The World Health Organisation has published guidelines and standards for drinking water since 1958, with the latest edition being published in 1993-97. The basic concept of the guidelines is that “they be used by national and regional authorities as a basis for the development of drinking water standards and regulations appropriate to their own socio-economic and exposure situation” (WHO, 2001). The importance of good quality drinking water can not be stressed enough since water is essential to life. In 1992, the United Nations Conference on Environment and Development (UNCED) estimated that “80% of all diseases, and over one-third of deaths in developing countries are water-associated, and on average as much as one-tenth of each person’s productive time is sacrificed to water-related diseases” (UNCED, 1992).

The results from this study are compared with the drinking water guidelines recommended by WHO. These guideline values represent the concentration of a chemical constituent that does not necessarily mean that the water is unsuitable for consumption. At the same time, one has to take into account the possibilty of intake of substances from other sources. (WHO, 2001)

3.3.2 Irrigation guidelines

Water from Nakivubo channel in Kampala and Walukuba North in Jinja is used by crops grown in the areas. This water is not irrigated, but is the main source of water to the crops during the dry season. It was therefore seen as relevant to compare these guidelines with the results found. Guidelines are taken from EPA (1973) through Smith (1986).

3.3.3 Environmental guidelines

No standards were found regarding tropical lakes, so the guidelines used in this study are derived from the Swedish Environmental Protection Agency (Naturvårdsverket). The guidelines regard total concentrations of each metal in lake waters.

4 RESULTS

This report complements the one published separately by Larsson (2001) on concentrations of Cd, Cr, Cu, Ni, Pb and Zn in soil- and plant samples collected at the same sites as presented in this study.

4.1 SSESE ISLANDS

Water samples taken on Ssese Islands were intended to be used as the controls. These islands are situated off the coast and do not have any point source of pollution in the form of industries and agricultural chemicals. There are a few cars and engine-driven boats present, but these are not believed to contribute significantly to the concentrations of heavy metals in the lake. It was assumed in this study that the metals present in water on Ssese Islands originate from natural sources, such as geology and rock weathering.

4.1.1 Comparison with estimated natural concentrations

Data on estimated natural concentrations of the metals investigated in this study were published by Borg (1984) and Forstner and Wittman (1983). Their studies give background values on freshwater unaffected by anthropogenic activities. These data are presented in Table 4.1 together with data obtained from the Ssese Island samples.

Table 4.1 Heavy metal concentrations at Ssese Islands in comparison with estimated natural concentrations

Site	Cd $\mu g*l^{-1}$	Cr $\mu g *l^{-1}$	Cu $\mu g*l^{-1}$	Ni $\mu g*l^{-1}$	Pb $\mu g*l^{-1}$	Zn $\mu g*l^{-1}$
Ssese Island Club	0.13	2.15	2.76	1.01	3.40	27.50
Ssese	0.09	2.14	5.06	2.83	3.56	31.90
Borg 1984	0.005-0.05	0.1-0.5	0.2-2	0.01-1	0.05-0.5	0.5-5
Forstner & Wittman 1983	0.07	0.5	1.8	0.3	0.2	0.5

From Table 4.1 it can be seen that the metal concentrations measured in lake water from Ssese Islands exceeded the background data reported by Borg (1984) and Forstner and Wittman (1983). The analysed concentrations of Ni, Cu and Cd were 1, 2 and 2.5 times as high as the highest corresponding background values, respectively. Cr exceeded the background value by about four-fold, while the concentrations of Pb and Zn were seven- and six-fold higher, respectively.

The actual source of the metals is difficult to identify. One possibility is that the high concentrations of Cr, Pb and Zn were associated with the erosion and weathering of soils and parental rocks in the surrounding catchment as well as mobilisation of metals from the sediments. This is not supported by the findings of Larsson (2001), who found the soils of Ssese Islands to contain rather low concentrations of each metal. The metal concentrations in the water of Lake Victoria could also be affected by anthropogenic activities. Since Ssese Islands do not have any point sources, this pollution might have originated from the riparian countries via air and/or in-flowing streams carrying wastes, which slowly spread over the lake. There is also the possibility of wastes containing heavy metals having been dumped near the sampling sites.

In comparing the results from Ssese Islands with results from Kampala, Jinja and Entebbe, it was found that 9% of the Cd samples, 55% of the Cr samples, 45% of the Cu samples, 18% of the Ni samples, 55% of the Pb samples and 18 % of the Zn samples from the cities actually had lower concentrations than at Ssese Islands. Since the samples from Ssese Islands contained rather high concentrations of the different metals, it can be concluded that Ssese Islands are not suitable sites for control samples. The Ssese Island samples were then compared to the guidelines for drinking water and environmental quality.

4.2 DISCHARGE INTO LAKE VICTORIA

4.2.1 Kampala

Nakivubo channel, after draining large parts of Kampala, discharges into Lake Victoria. Samples were taken along the course of the channel and at its discharge point in the lake as well as in the open water away from the discharge point. The results are shown in Table 4.2. Sampling sites at Makerere, Lugogo and Mpanga are situated along the channel, while Lake Victoria (discharge point), Old Gaba and New Gaba are situated in the lake.

Table 4.2 Heavy metal concentrations at different sampling sites in Kampala

Site	Cd $\mu g*l^{-1}$	Cr $\mu g*l^{-1}$	Cu $\mu g*l^{-1}$	Ni $\mu g*l^{-1}$	Pb $\mu g*l^{-1}$	Zn $\mu g*l^{-1}$
Makerere	2.71	10.96	1.06	4.01	14.75	170.00
Lugogo	2.11	147.50	153.75	92.63	525.00	1233.75
Mpanga	0.36	18.63	8.03	11.15	46.80	242.50
Lake Victoria	0.08	1.86	0.05	2.91	2.81	31.25
Old Gaba	0.14	1.22	2.46	5.34	3.58	35.88
New Gaba	0.18	1.94	3.45	1.80	3.38	25.75

The table shows generally higher concentrations of each metal at sampling sites along Nakivubo channel than at sampling sites in the lake. Makerere, being situated at the beginning of Nakivubo channel, contained higher concentrations of Cd, Cr, Pb and Zn than the sites in the lake. This could be due to the nearby petrol station as well as the KCC dumping site. The concentrations of all metals were particularly high at Lugogo. At Mpanga, concentrations of all metals except Cd were markedly high. The increase of metal concentrations along Nakivubo channel and the apparent decline in the lake is illustrated in Figure 4.1.

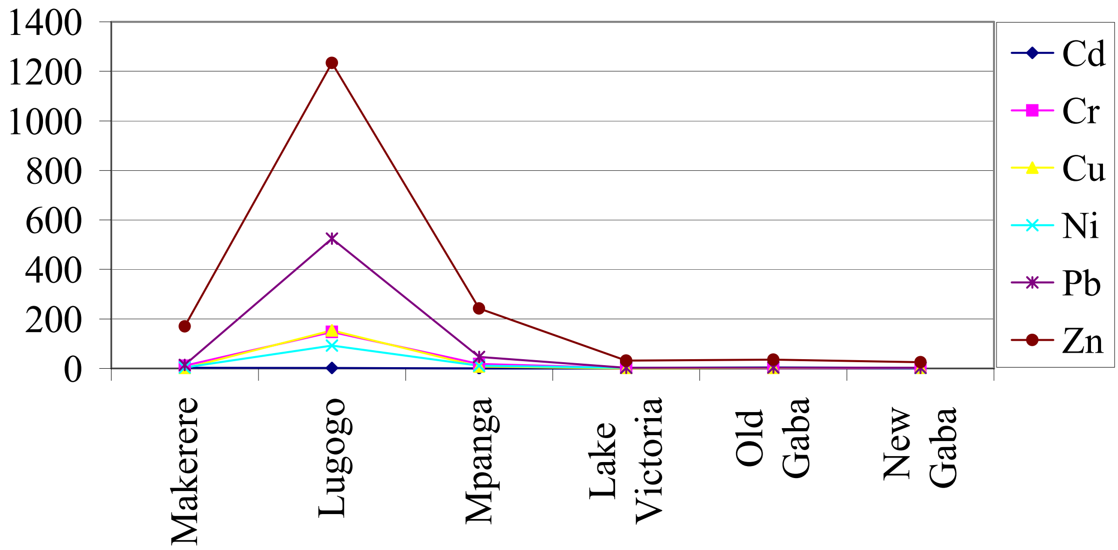


Figure 4.1 Heavy metal concentrations in Nakivubo channel and Lake Victoria

As shown in the figure, the metal concentrations increased downstream from Makerere to Lugogo, i.e. as the channel passed through the city (Makerere – Lugogo). This indicated metal inputs by wastewater discharged along the channel as it passes through central and industrial parts of Kampala. Between the sites Lugogo and Mpanga, there was a large urban farming area. The decrease of metal concentration down stream towards Mpanga could be due to sorption of metals in the soil and uptake by plants including crops in the area. This conclusion is supported by Larsson's MSc degree project (2001) in which she observed increased metal contents in samples of soil and plants taken from this area.

Between the Mpanga and Lake Victoria sites, the channel passes through another farming area, adjacent to a papyrus swamp bordering Lake Victoria. In these two areas, metals seemed to have been retained by soil and vegetation growing in the swamp. The swamp could have retained wastes and eroded soils, thereby preventing them from reaching the lake. Metal concentrations at the Lake Victoria site, the channel's discharge point, were considerably reduced relative to sites along the channel. On one hand, the wetland and farming areas bordering the lake are of importance regarding reduction of heavy metal discharge into Lake Victoria. On the other, high metal contents in crops and soil may cause health and environmental problems.

4.2.2 Jinja

In Jinja, there were two major swamps through which wastewater passed before reaching Lake Victoria. The Walukuba and Kirinya sites were located near the same swamp, while the Old Boma site was located near another swamp. One sample (Walukuba North) was collected from a small stream running through a farming area before entering the Walukuba swamp. This stream sample was used to determine the difference between metal concentrations in the water before it entered the swamp and concentration in the water at the site where it left the swamp. Analytical data are summarised in Table 4.4.

Table 4.3 Heavy metal concentrations at different sampling sites in Jinja

Site	**Cd** $\mu g*l^{-1}$	**Cr** $\mu g*l^{-1}$	**Cu** $\mu g*l^{-1}$	**Ni** $\mu g*l^{-1}$	**Pb** $\mu g*l^{-1}$	**Zn** $\mu g*l^{-1}$
Walukuba N	0.35	6.03	11.94	13.13	5.44	125.00
Walukuba	0.69	3.99	10.40	8.71	3.86	66.38
Kirinya	0.43	1.76	5.51	2.04	5.33	43.63
Old Boma	0.39	2.41	11.05	3.60	3.83	48.63

Table 4.3 shows generally higher metal concentrations in Walukuba North, i.e., before the water passes through the wetland, than after it has passed through it. The pattern of changes is illustrated in Figure 4.2.

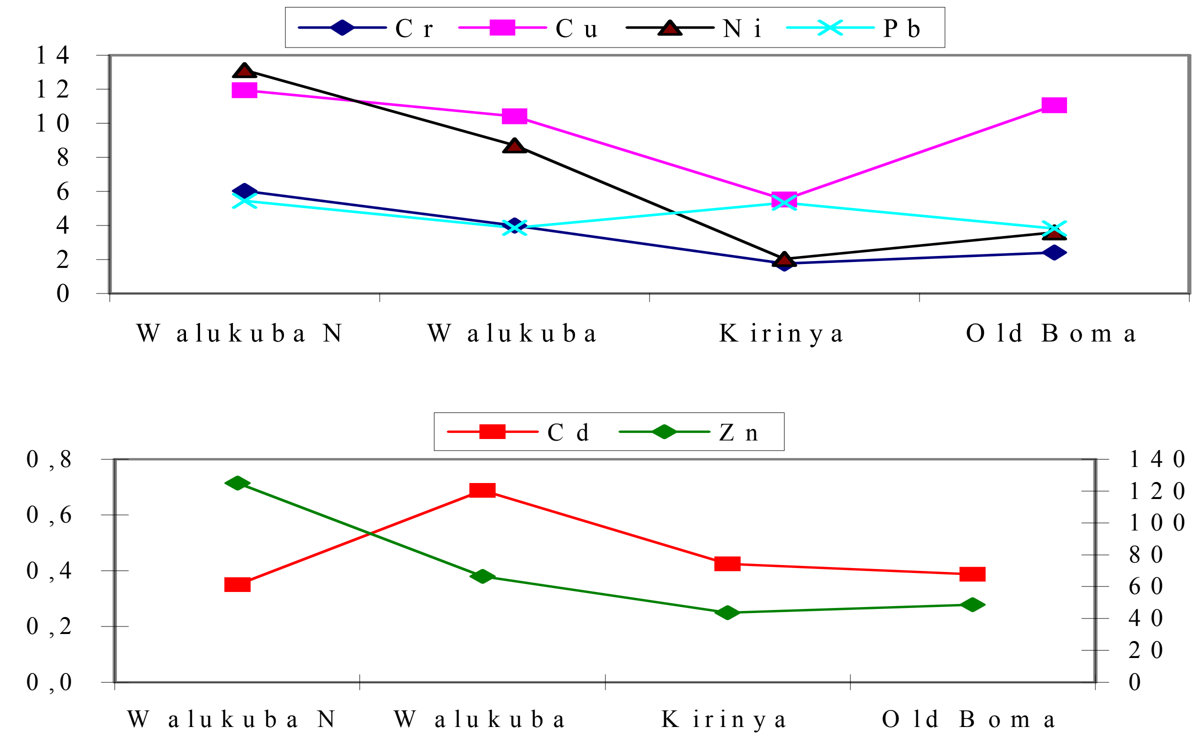


Figure 4.2 Heavy metal discharge into Lake Victoria from Jinja

In the figure, it can be seen that all concentrations of the heavy metals, with the exception of Cd, were higher at Walukuba N, i.e. before the stream entered the swamp, than at Kirinya and Walukuba, when the water left the swamp. This showed some evidence of absorption of metals by the swamp. The difference in metal concentrations at Walukuba compared with Kirinya might have been due to how close to mainland the sites lay. The Walukuba site probably received pollutants carried by run-off and eroded soil to a higher degree than Kirinya. Thus Walukuba, which was closer to the mainland, had higher concentrations than Kirinya. Walukuba site is also closer to the closed-down Cu mine at Kilembe. The elevated Cd concentrations recorded might also be associated with the Kilembe Mines. Old Boma had higher concentrations of Cu, the source of which was not established.

4.2.3 Entebbe

Water samples were taken from different sites around the peninsula of Entebbe. At the time of writing, little was known about industries in Entebbe, but their impact on the environment regarding heavy metals is not suspected to be greater than the impacts from the airport. Heavy metal pollution is spread to the surrounding environment mostly through run-off water from the airport. The sampling was therefore done in order to show the magnitude of pollution, mainly from the airport, and to see how far it spreads around the peninsula of Entebbe. Many of these sites supply water for household purposes. Samples were also taken from two wells. The analytical data are shown in Table 4.5.

Table 4.4. Heavy metal concentrations at different sampling sites in Entebbe

Site	Cd $\mu g*l^{-1}$	Cr $\mu g*l^{-1}$	Cu $\mu g*l^{-1}$	Ni $\mu g*l^{-1}$	Pb $\mu g*l^{-1}$	Zn $\mu g*l^{-1}$
Kitubulu	0.19	6.03	3.06	3.15	5.04	45.88
Bugonga	0.19	2.14	7.85	1.00	2.98	31.25
Kitoro	0.45	2.70	14.63	3.84	3.28	99.63
Airstrip	0.39	1.91	8.86	3.91	2.81	41.88
Airstrip runoff	0.36	2.41	6.89	3.11	4.59	74.63
Nakiwogo	0.18	2.60	3.90	6.40	2.65	22.25
Nakiwogo Well	0.04	1.31	2.96	1.70	8.46	150.00
Kinyarwanda Well	0.21	2.41	1.43	5.98	2.08	44.75

The airport was believed to contribute greatly to the level of pollution in Entebbe. In general, the concentrations of the metals were not high in the area located close to the take-off and landing route of the aircraft (Airstrip). The results are also depicted in Figure 4.3.

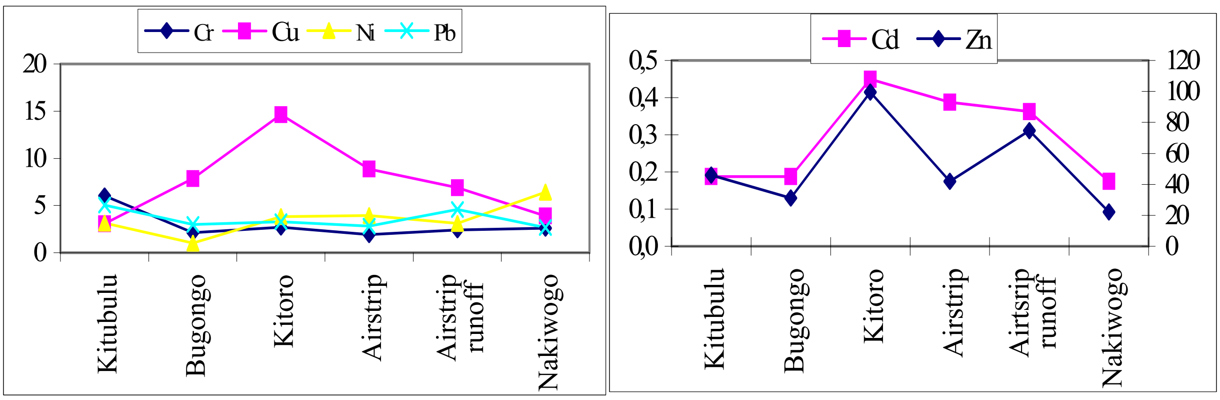


Figure 4.3 Heavy metal discharge into Lake Victoria from Entebbe.

High levels of Cd, Pb and Zn in the runoff water from the airstrip are not surprising, nor is the high concentration of Cd at Airstrip, located below the landing and take-off route of the aircraft. These increased concentrations are probably explained by the closeness of the sites to the airport. Site Kitoro, being close both to the airport and to the mainroad leading to it had the highest Cd-, Cu- and Zn concentrations of the sampling sites in Entebbe. Since both Cu and Cd are common pollutants in runoff water from aircraft wash, it is possible that the runoff-water from the airport ends up near this site. The rather high concentrations of Pb and Cr which were found in the water in Kitubulu, is of concern since tyhis site is siruated quite a distance from the airport. It is possible that this pollution originates from the Entebbe mainroad, running close to this site.

5 DISCUSSION

5.1 DRINKING WATER QUALITY

Good quality drinking water is a prerequisite of good health. In Kampala, water samples were taken from a few wells and public taps (Makerere Well, Kololo, Kamwokya) as well as at the intake points of the two pumping stations distributing water to Kampala's citizens (Old Gaba and New Gaba). The sites at Lugogo, Mpanga and Makerere are not known sites for collecting drinking water, but this water is consumed indirectly, through crops grown in the area. The sampling sites in Jinja were not specific locations for fetching drinking water, but fishermen do drink water straight from the lake. The locations selected for water quality investigations in Jinja were Old Boma, Kirinya and Walukuba. Water from Walukuba North is consumed indirectly through crops. In Entebbe, drinking water is known to be collected at sites Kitubulu, Bugonga, Kitoro, Nakiwogo Well and Kinarwanda Well. The water at Nakiwogo and Airstrip could be consumed, but this is not confirmed.

Table 5.1 Comparison of metal concentrations in drinking water and WHO's drinking water guidelines

Site	Cd $\mu g*l^{-1}$	Cr $\mu g*l^{-1}$	Cu $\mu g*l^{-1}$	Ni $\mu g*l^{-1}$	Pb $\mu g*l^{-1}$	Zn $\mu g*l^{-1}$
Kampala						
Makerere Well	0.16	0.81		1.79	1.99	19.63
Makerere	2.71	10.96	1.06	4.01	**14.75**	170.00
Lugogo	2.11	**147.50**	153.75	**92.63**	**525.00**	1233.75
Mpanga	0.36	18.63	8.03	11.15	**46.80**	242.50
Lake Victoria	0.08	1.86	0.05	2.91	2.81	31.25
Old Gaba	0.14	1.22	2.46	5.34	3.58	35.88
New Gaba	0.18	1.94	3.45	1.80	3.38	25.75
Kololo	0.11	0.79	6.03	1.58	3.44	422.50
Kamwokya	0.14	1.09	1.41	3.28	3.53	193.75
Jinja						
Old Boma	0.39	2.41	11.05	3.60	3.83	48.63
Kirinya	0.43	1.76	5.51	2.04	5.33	43.63
Walukuba	0.69	3.99	10.40	8.71	3.86	66.38
Walukuba N	0.35	6.03	11.94	13.13	5.44	125.00
Entebbe						
Kitubulu	0.19	6.03	3.06	3.15	5.04	45.88
Bugonga	0.19	2.14	7.85	1.00	2.98	31.25
Kitoro	0.45	2.70	14.63	3.84	3.28	99.63
Airstrip	0.39	1.91	8.86	3.91	2.81	41.88
Airstrip runoff	0.36	2.41	6.89	3.11	4.59	74.63

Nakiwogo	0.18	2.60	3.90	6.40	2.65	22.25
Nakiwogo Well	0.04	1.31	2.96	1.70	8.46	150.00
Kinarwanda Well	0.21	2.41	1.43	5.98	2.08	44.75
Ssese Islands						
Ssese	0.13	2.15	2.76	1.01	3.40	27.5
Ssese Island Club	0.09	2.14	5.06	2.83	3.56	31.90
WHO	**3**	**50**	**2000**	**20**	**10**	**---**

The values marked in bold are exceeding the guidelines set by WHO. High concentrations of Pb were determined in drinking water from Makerere, Lugogo and Mpanga. Similarly, the Lugogo concentrations of Cr and Ni exceeded the guideline values. Despite the high concentrations, there is no great cause for concern for drinking water quality, since this water is not believed to be used by consumers directly. At Makerere, drinking water is collected at a natural spring, Makerere Well, with safe concentrations of each metal, and not at the sampling site Makerere. There is, however, cause for concern for an indirect consumption. Larsson (2001) recorded high concentrations of Cd, Cu, Pb and Zn in crops grown at Lugogo and Mpanga.

The water from Kololo and Kamwokya is supplied by public facilities. This water is pumped from two stations in Gaba. Table 5.1 shows rather elevated concentrations of Zn in the drinking water supplied by these facilities, compared with the intake points at Gaba. This was probably due to dissolution of the metals in the plumbing system and the concentrations were lower than the set guideline value.

All sites in Jinja and Entebbe had satisfactory metal concentrations for human consumption. Although concentrations of the metals in the water from most sites did not exceed the given guidelines, one should consider the daily intake from sources other than drinking water. A person who drinks water from the Lugogo and Mpanga areas in Kampala or from Walukuba North in Jinja and at the same time consumes the crops grown in the same areas (see Larsson, 2001), could consume greater quantities than recommended.

5.2 IRRIGATION WATER

Comparison of results and guidelines for irrigation is only of significance along Nakivubo channel in Kampala and at site Walukuba North in Jinja. These are the only sites at which crops are grown and the analyzed water constitutes the main water source of these crops during the dry season. The samples were taken in streams running through these areas and the water therefore passes through soil before it is taken up by plants. This process means that the water actually reaching the plant does not contain as high concentrations of the metals as the water in the stream.

Table 5.2: Guideline values for irrigation water compared with sites watering crops

Site	**Cd** $\mu g*l^{-1}$	**Cr** $\mu g*l^{-1}$	**Cu** $\mu g*l^{-1}$	**Ni** $\mu g*l^{-1}$	**Pb** $\mu g*l^{-1}$	**Zn** $\mu g*l^{-1}$
Makerere	2.71	10.96	1.06	4.01	14.75	170.00
Lugogo	2.11	**147.50**	153.75	92.63	525.00	1233.75
Mpanga	0.36	18.63	8.03	11.15	46.80	242.50
Walukuba North	0.35	6.03	11.94	13.13	5.44	125.00
Guideline value	10	100	200	200	5000	2000

The only site exceeding the guideline values was at Lugogo, which had high values of Cr. This result is supported by Larsson (2001) who found high concentrations of Cr in yam tubers and doodo grown at this site.

5.3 Environmental Quality

As described in sections 1.4.4 – 1.4.9, heavy metals are harmful to biological life at high concentrations. Below is a comparison of the findings of this study and Swedich environmental guidelines. The guidelines are divided into three ckasses, each representing different degrees of environmental disturbance.

Table 5.3 Heavy metal concentrations compared with Swedish environmental guidelines

Site	**Cd $\mu g*l^{-1}$**	**Cr $\mu g*l^{-1}$**	**Cu $\mu g*l^{-1}$**	**Ni $\mu g*l^{-1}$**	**Pb $\mu g*l^{-1}$**	**Zn $\mu g*l^{-1}$**
Kampala						
Makerere	2.71	10.96	1.06	4.01	14.75	170.00
Lugogo	2.11	147.50	153.75	92.63	525.00	1233.75
Mpanga	0.36	18.63	8.03	11.15	46.80	242.50
Lake Victoria	0.08	1.86	0.05	2.91	2.81	31.25
Old Gaba	0.14	1.22	2.46	5.34	3.58	35.88
New Gaba	0.18	1.94	3.45	1.80	3.38	25.75
Jinja						
Old Boma	0.39	2.41	11.05	3.60	3.83	48.63
Kirinya	0.43	1.76	5.51	2.04	5.33	43.63
Walukuba	0.69	3.99	10.40	8.71	3.86	66.38
Walukuba N	0.35	6.03	11.94	13.13	5.44	125.00
Entebbe						
Kitubulu	0.19	6.03	3.06	3.15	5.04	45.88
Bugonga	0.19	2.14	7.85	1.00	2.98	31.25
Kitoro	0.45	2.70	14.63	3.84	3.28	99.63
Airstrip	0.39	1.91	8.86	3.91	2.81	41.88
Airstrip runoff	0.36	2.41	6.89	3.11	4.59	74.63
Nakiwogo	0.18	2.60	3.90	6.40	2.65	22.25
Ssese Islands						
Ssese Island Club	0.13	2.15	2.76	1.01	3.40	27.50
Ssese	0.09	2.14	5.06	2.83	3.56	31.90

SNV* Class 3	0.1-0.3	5-15	3-9	15-45	1-3	20-60
SNV* Class 4	0.3-1.5	15-75	9-45	45-225	3-15	60-300
SNV* Class 5	>1.5	>75	>45	>225	>15	>300

SNV* - Values derived from Swedish guidelines regarding environmental concentrations. For further details, refer to Table 3 in Appendix 3. Concentrations exceeding the guideline values are believed to cause negative effects on aquatic organisms.

Class 3: Values marked in light grey are believed to cause environmental disturbance. If the level is close to the guideline value, there is no great cause for concern.
Class 4: Values marked in dark grey indicate an increased risk of environmental disturbance.

Class 5: Values marked in red indicate a high risk of environmental disturbance even at short exposures.

Kampala

Concentrations of all metals widely exceeded the guideline at Lugogo. Similarly, the Mpanga samples had high concentrations of all elements but Ni. Pb and Zn concentrations were higher than the guideline values at all sites in Kampala. The high concentrations of Cd, Pb and Zn recorded in Makerere were surprising since the water sample was taken from a site at the beginning of Nakivubo channel. The water is believed to have passed underground up to a point about 100 m from the sampling site. Since the water passes through soil, it ought to have been filtered. High concentrations at Makerere might mean even higher concentrations at the location before the channel is diverted underground. The nearby petrol station and KCC dumping site are also believed to add to the concentrations via surface runoff and/or leakage.

The lower concentrations at Nakivubo channel's discharge point in Lake Victoria could be explained by the absorption of metals in the farming areas and wetland as well as dilution in the lake. The guideline values are, however, still exceeded for Pb and Zn at this point. Sites Old Gaba and New Gaba are also located in the lake. Here, concentrations of Cd, Cu, Pb and Zn were above guideline values. This might suggest that some metal pollution originates from sources other than Nakivubo channel.

Jinja

All sites in Jinja were enriched with Cd, Cu, Pb and Zn. Increased levels of Cu are most likely the result of former Cu mining activities in the area. None of the sites had values that exceeded Class 5 of SNV's guideline and most sites have heavy metal levels that did not markedly exceed Class 3. The sites of concern were Walukuba for Cd and Walukuba North for Zn.

Entebbe

Cd and Pb were present at all sites in Entebbe at concentrations that could cause concern for biological life. At the Kitoro and Airstrip sites, Cd concentrations were rather high (Class 4, see table 5.3). Cr and Ni concentrations were lower than levels known to harm biological life at all sites.

Ssese Islands

Moderately to high concentrations of Cd, Cu, Pb and Zn were present in the waters of Lake Victoria on Ssese Islands. For most of these elements, the concentrations at which they exceeded the given guideline is not of great significance. The levels are of concern, though, since there are no known sources in the nearby area. The level of Pb is of special concern, since its toxic effects are among the most serious, and indicates elevated concentrations due to unknown sources.

5.3.1 Environmental effects

A more specific evaluation of effects on the ecosystems of the sampling sites caused by the analysed metals is given below. The concentration levels refer to sections 1.4.4-1.4.9 above. The effects on different organisms vary with species and the evaluation is carried out in order to get an overview of possible chronic, sublethal and acute effects at different concentrations. Acute effects (usually death) in organisms are known to occur at concentrations 3-10 times as high as the lowest harmful concentration. These calculated concentrations are shown in Table 5.4.

Table 5.4 Critical concentrations for acute effects in microorganisms

	Cd	Cr	Cu	Ni	Pb	Zn
	$\mu g*l^{-1}$	$\mu g*l^{-1}$	$\mu g*l^{-1}$	$\mu g*l^{-1}$	$\mu g*l^{-1}$	$\mu g*l^{-1}$
*Lowest harmful concentration**	*0.1-0.3*	*5-15*	*3-9*	*15-45*	*1-3*	*20-60*
Multiplied by 3	0.3-0.9	15-45	9-27	45-135	3-9	60-180
Multiplied by 10	1-3	50-150	30-90	150-450	10-30	200-6000

*according to Naturvårdsverket, 2001

These estimated concentrations differ greatly in terms of highest and lowest concentration causing acute effects. This is due to how well different species and organisms cope with pollution. Nonetheless, they may provide an indication of the environmental conditions of the sampling sites. In the text below, it is assumed that acute effects would occur at the lowest given concentration.

5.3.1.1 Cadmium

Cd concentrations around 0.2 $\mu g*l^{-1}$ are known to have negative effects on organisms at all trophic levels. Sites of concern in the actual lake regarding this include all sites in Jinja as well as Kitoro, Airstrip and Airstrip runoff in Entebbe. All other sites in Entebbe had concentrations close to this limit. In Kampala, all sites along Nakivubo channel exceeded the set limit whereas New Gaba was just under the limit.

The juvenile development stages in fish have been observed to be affected at concentrations of 0.9 $\mu g\ Cd*l^{-1}$. Two sampling sites exceeded this value, namely Makerere and Lugogo in Kampala. Reproduction in plankton is known to decrease at concentrations above 0.17 $\mu g*l^{-1}$, which includes all sites listed above as well as Kitubulu, Nakiwogo and Bugonga in Entebbe. All sites along Nakivubo channel and in Jinja as well as Kitoro, Airstrip and Airstrip runoff in Entebbe had concentrations that greatly exceeded these values. These sites also exceeded the lowest concentrations for acute effects. None of the sites exceeded the highest concentration for acute effects.

5.3.1.2 Chromium

Chronic and sublethal effects are known to occur in fish and plankton at concentrations between 8-13 $\mu g\ Cr*l^{-1}$. All sites along Nakivubo channel in Kampala had concentrations that exceeded this limit. Especially Lugogo, which exceeded this by about 18 times, is of great concern. Mpanga and Lugogo also exceeded the lowest limit for acute effects (15 $\mu g*l$-^{1}) wheras Lugogo's concentration of 147.5 $\mu g*l^{-1}$ was close to the highest limit (150 $\mu g*l^{-1}$).

5.3.1.3 Copper

Effects on algae, invertebrates and fish are known to occur at Cu concentrations of 2-5 $\mu g*l^{-1}$. Sites with these concentrations or higher include all lake sites in Jinja, Entebbe and Ssese Islands. In Kampala, all sites except Makerere and Lake Victoria exceeded this criterion. Lugogo also exceeded the highest limit for acute effects. Walukuba North, Walukuba and Old Boma in Jinja as well as Kitoro in Entebbe all exceeded the lowest limit for acute effects.

5.3.1.4 Nickel

Concentrations of Ni of 23-50 $\mu g*l^{-1}$ have shown chronic and sublethal effects on some species of fish as well as microorganisms. The only site exceeding this limit was Lugogo in

Kampala, with a concentration of 92.63 $\mu g*l^{-1}$. Lugogo also exceeded the lower limit for acute effects on organisms (45 $\mu g*l^{-1}$).

5.3.1.5 Lead

Concentrations of Pb between 5-15 $\mu g*l\text{-}^{1}$ in fresh water are known to cause 'blacktail syndrome' in some species of fish as well as skeletal changes, anaemia and neurotoxicity. Sites Walukuba North and Kirinya in Jinja as well as Kitubulu in Entebbe all had concentrations just above 5 $\mu g*l^{-1}$. In Kampala, it was the sites along Nakivubo channel that exceeded this concentration (5-15 $\mu g*l^{-1}$), where Lugogo and Mpanga had concentrations exceeding 15 μg $Pb*l^{-1}$ by 35 and 3 times, respectively. Concentrations of 19-30 $\mu g*l^{-1}$ cause chronic effects in microorganisms. Lugogo and Mpanga sites also exceeded this concentration (19-30$\mu g*l^{-1}$) by 28 and almost 2.5 times, respectively.

As for acute effects, Lugogo and Mpanga exceeded the highest given limit (30 $\mu g*l^{-1}$) with 17.5 and 1.5 times, respectively. Makerere's concentration of 14.75 $\mu g*l^{-1}$ lies in between the highest limits for acute effects (10-30 $\mu g*l^{-1}$). All other sites in Kampala except the discharge point of Nakivubo channel had concentrations just above the lowest given concentration for acute effects (3 $\mu g*l^{-1}$). In Jinja and Ssese Islands, all sites exceeded this limit. In Entebbe, Kitubulu, Kitoro and Airstrip runoff exceeded the given limit.

5.3.1.6 Zinc

Production of algae is known to decrease at Zn concentrations above 15 $\mu g*l^{-1}$. This concentration was exceeded at all sampling sites in Jinja, Entebbe, Kampala as well as Ssese Islands. As for acute effects, Walukuba North and Walukuba in Jinja exceeded the lower limit of 60 μg $Zn*l^{-1}$. Kitoro and Airstrip runoff in Entebbe as well as all sites along Nakivubo channel in Kampala also exceeded this limit. None of the sites exceeded the highest limit for acute effects.

6 CONCLUSIONS

In general, the concentrations of Ni and Cr were satisfactory regarding environmental quality at all sites investigated. At most sites, the concentrations of Cd, Cu, Pb and Zn were too high to ensure environmental stability. Of special concern were Pb and Cd, which are non-essential elements, and known to be most harmful to aquatic organisms, as well as to humans.

6.1 DISCHARGE INTO LAKE VICTORIA

The discharge from the cities that reached the waters of Lake Victoria often contained increased concentrations of the investigated metals, especially Cd, Cu, Pb and Zn. In Kampala, it was obvious that the wetland areas had a large impact on the pollution reaching the lake. The discharge is believed to largely originate from industries, but also from households. In Entebbe, the airport and the main road leading to it seemed to be the greatest sources of heavy metals to the lake.

6.2 IRRIGATION AND DRINKING WATER QUALITY

As shown in Table 5.1, sites with metal concentrations exceeding the drinking water guideline set by WHO were sites that are not specific for fetching of water. Therefore, there is no great cause for concern about human health from direct water consumption from any of the investigated sites. As mentioned above, the Kampala site Lugogo, which exceeded the guideline for Pb by over 5000%, but also exceeded Cd and Ni guidelines, is a farming area with crops such as bananas, yams, cassava, cabbage and sugarcane. The risk of indirect consumption of heavy metals in this area is great, especially since these crops seem to absorb 80-95% of the metals passing through the area. Crops grown at Makerere, Mpanga (Kampala) and Walukuba North (Jinja) were found by Larsson (2001) to contain increased concentrations of Cd, Cu and Pb. The only site exceeding the guideline for irrigation was Lugogo, where Cr was in excess.

6.3 Environmental Quality

In the three investigated cities, concentrations of Cd, Cu, Pb and Zn were exceeding the guideline for ensuring biologial wellbeing to various degrees. The most alarming sites included Makerere, Lugogo and Mpanga in Kampala, which exceeded guidelines concerning high risks of environmental disturbance, even at a short time of exposure. All sites exceeded concentrations regarding sub-lethal and chronic effects, while 12 out of 17 sites exceeded concentrations regarding acute effects. Table 6.1 shows which sites exceeded concentrations for sub-lethal and chronic effects as well as acute effects.

Table 6.1 Sites exceeding heavy metal concentrations for different environmental effects.

Site	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
Kampala						
Makerere	S A	S			S A	S A
Lugogo	S A	S A	S A	S A	S A	S A
Mpanga	A	S A	S		S A	S A
Lake Victoria			S			
Old Gaba			S		A	S
New Gaba			S		A	S
Jinja						
Old Boma	S A		S A		A	S
Kirinya	S A		S		A	S
Walukuba	S A		S A		S A	S A
Walukuba N	S A		A		S A	S A
Entebbe						
Kitubulu	S				S A	S
Bugonga	S					S
Kitoro	S A		A		A	S A
Airstrip	S A				A	S A
Nakiwogo	S					S
Ssese Islands			S		A	S

S= sub-lethal or chronic effects
A= acute effects

6.4 Sites of Further Interest

6.4.1 Ssese Islands

A puzzling outcome of this study is the high concentration of Pb at Ssese Islands. It would be of interest to study the Pb concentrations in different parts of Ssese Islands and other islands, such as Kome Islands, to see if this pattern is repeated. What is the source of this phenomenon? Is it caused by man and how? Unlawful dumping of hazardous waste may not be ruled out.

6.4.2 Kampala

High concentrations of Cd, Pb and Zn determined in samples taken from Makerere are a cause for concern since the site is situated at the beginning of Nakivubo channel and already contained these high concentrations. It would be of interest to investigate where these metals originate. Is there a point source which can be attended to, or are the concentrations of these metals also high before Nakivubo channel goes underground? If the latter is the case, then where and which are the sources? Mpanga and Lugogo, having concentrations of all metals exceeding the environmental guidelines are of great concern, especially since these sites are used for household farming.

6.4.3 Jinja

In Jinja, there are increased concentrations of Cd, Pb, Cu and Zn. The high concentrations at sites Walukuba and Kirinya may be explained by the Kilembe Mines. It should be necessary to control the leakage from the refinary and to take measures so as to prevent heavy metal discharge into the waters of Lake Victoria. The Old Boma site is situated away from these two sites, but concentrations of Cd, Cu and Pb were still high. These metals, especially Cd and Pb, accumulate in fish, and the concentrations are therefore of concern since local fishermen are known to fish at and near these sites.

The high concentrations of Cd, Cu, Pb and Zn at Walukuba North, a smallscale farmland, are alarming since edible crops are grown at this site. In spite of the high concentrations in the water, only high concentrations of Pb were found in crops grown here (see Larsson, 2001). This site is also located close to the refinery, and preventive steps against leakage should bring about a decrease in metal concentrations.

6.4.4 Entebbe

The heavy metals determined at Entebbe sites were believed to originate from the airport and aircraft runoff as well as leaded petrol used by some aircraft. An investigation of the amount of pollution generated from the airport would be of interest, and also to see which areas around the peninsula that are most affected by the runoff. This could help to evaluate suitable measures and treatment methods needed in order to reduce the discharge in the future.

6.5 THE IMPORTANCE OF WETLANDS

The wetlands bordering Lake Victoria seem to play a major role in determining the quality of water entering the lake from the cities. However, continued deposition of peat (forming of dead plants) and sediment from waste water and runoff, as well as the availability of binding chemical compounds, sets a limit to a wetland's retention abilities. Ultimately, this will lead to decreased or stopped purification and an increased amount of pollutants will enter the lake. As can be seen from the results from Kampala, farming land and wetlands reduce the heavy metal concentration of the water in Nakivubo. Table 6.2 shows the percentage of heavy metal retention as Nakivubo channel passes through the different land types.

Table 6.2 Heavy metal retention (%) in different land types

Location	Cd (%)	Cr (%)	Cu (%)	Ni (%)	Pb (%)	Zn (%)
Lugogo – Lake Victoria	96	99	100	97	99	97
Lugogo – Mpanga (farmland)	83	87	95	88	91	80
Mpanga – Lake Victoria (wetland)	78	90	99	94	94	87

The decrease in metal concentrations as shown in Table 6.2 may be due to several factors. A combination of soil and sediment sorption in the channel bed, plant uptake, retention by wetlands and dilution, all cause a decrease of metal concentration in the water. Table 5.1 demonstrates heavy metal retention as Nakivubo channel passes through farmland and wetland. The farmland and wetland together retain between 96 and 100% of the heavy metal load in Nakivubo channel. Since the farmland absorbs around 90% of the pollution, the heavy metal concentrations are greatly decreased when the channel reaches the actual wetland. This takes pressure off the wetland but, at the same time, is alarming since the edible crops accumulate the metals. For further data on crops from Lugogo and Mpanga, see the work published by Larsson (2001). Research on concentrations of different heavy metals, particularly Pb and Cd, targeting the wet season when the farmland is flooded, would be of great interest.

It is of great importance to ensure the conservation of wetlands bordering Lake Victoria, since their role as purifying media is obvious. Admittedly, wetlands cannot retain the metals indefinitely, Therefore, more studies are warranted to predict their retention capacities. However, it is also necessary to limit the amount of pollution reaching the wetlands in order to ensure their purification capacity in the future. The importance of good quality water in the lake speaks for itself, since 26 million people (in Kenya, Tanzania and Uganda) depend on the lake for their livelihood. With deteriorated water quality, the fishing industry, human health and the environment will suffer.

6.6 Recommendations

In order to tackle the problem of heavy metal pollution reaching the waters of Lake Victoria, and thereby becoming a health and environmental hazard, it is necessary to introduce measures both at the sources and in the use of proper treatment methods. It is also necessary to inform people on proper use of the environment as well as to raise awareness and a common concern for the environment.

What one must have in mind is the state of poverty in Uganda. This greatly complicates the relationship between humans and the environment, and the government's ability to properly protect and manage the country's natural resources. Since 1986, terms of trade for Uganda have been declining. In the case of coffee, for example, earnings in 1995 were four times below the 1986 level due to falling coffee prices. The national debt of $2.8 billion in the same year was greater than the annual GDP, and the foreign exchange paid, excluding interest, was more than 60% of the country's earnings in foreign exchange. This, of course, limits the government's ability to mobilise funds for environmental protection and investment. (Ministry of Natural Resources, 1995)

A rising population increases pressure on a country's natural resources, regardless of the wealth of the country in question. But the addition of the rising population being poor, means that natural resources are used to satisfy basic needs such as hunger, energy demand and house-building. This leads to a misuse of land and waters and this practice, though seemingly necessary in the short run, destroys the very sources on which people depend in the long run.

Another problem, which is not directly related to poverty, concerns people's perception of nature. A negative perception and its consequences are usually regarded as the "Tragedy of the Commons". This has been, and still is, a great problem also in western countries. In order for people to care about their environment, it is necessary that they feel that common land is their land. By feeling a responsibility for the common areas, there is an incentive not to pollute it. This is, of course, difficult due to the poverty situation.

With urbanization and industrialization, people have drawn away from traditional systems of agriculture and land management. Today, old-fashioned sustainable practices, adapted to the soil and conditions of the land in use, are only known to a few people in the villages. This indigenous knowledge must be recognized and valued when evaluating proper land use.

6.6.1 Treatment methods

6.6.1.1 Wetlands

As stated numerous times above, wetlands have excellent purification capacities. In order to retain this capacity in the future it is necessary to:

- Reduce siltation – by reducing deforestation and thereby soil erosion. This is difficult considering the poverty situation, but in the long run, education on sustainable land use as well as development of alternative energy sources can reduce siltation in wetlands, rivers and lakes.
- Decrease conversion of wetlands – by town and land use planning, the conversion of wetlands to housing and farming areas can be controlled.

6.6.1.2 Treatment Plants

Treatment methods

At present, the following methods are practiced in treatment plants in Uganda and the investigated cities: Kampala – sedimentation, trickling filters, sludge digestors; Jinja – oxidation ponds; Entebbe – oxidation ponds (Ehlin Consulting, 1997). Table 5.1 lists relevant treatment methods for each investigated metal.

Table 6.3 Treatment methods for different heavy metals

Treatment Method	Cd	Cr	Cu	Ni	Pb
Coagulation/Filtration	X	X			
Lime Softening	X	X		X	
Ion exchange	X	X		X	
Reverse Osmosis	X	X		X	
Corrosion Control			X		X

Connection of industries and households

In order to decrease the concentration of heavy metals reaching Lake Victoria, it is not only necessary to introduce relevant treatment methods, but also to make sure that the discharge of the various cities is being treated. Sewage treatment plants are only present in the larger cities of Kampala, Jinja, Entebbe, Masaka, Mbarara and Kabale. But in these cities, the majority of households and industries are not connected to the sewage system. In order to decrease the amount of untreated sewage discharging into Lake Victoria, it is necessary to provide the public with connection to the sewage system. Most discharge is generated in the urban areas, which expand quickly and in the absence of town planning. Considering the fast expansion of these areas, it is critical to renovate and increase the capacity of sewage systems and treatment plants. Town planning can help to keep the public facilities properly capacitated in the future.

Treatment of airport runoff in Entebbe

Heavy metals in runoff water from the airport can be reduced by treating the waste water generated from runways and hangars.

6.6.2 Recommended measures at heavy metal sources

6.6.2.1 Legislative-related measures

Monitoring and evaluation, construction of environmental standards

There is a lack of knowledge of the environmental status in Uganda today. Environmental standards are necessary in order to implement legislation on pollution, and to regulate discharge of chemicals into the environment. In order to construct relevant environmental standards, it is necessary to monitor and evaluate the following:

- Wetland purification capacity – so as to set standards that reassure the sustainability of the wetlands
- Treatment plant capacity and efficiency – so as to evaluate the need for more plants as well as additional treatment methods in existing plants. This is necessary in order to keep metal concentrations in discharge water in line with environmental standards.
- Discharge from industries – Present discharge containing heavy metals from industries that are not connected to a treatment plant in order to evaluate the need for improved treatment facilities.
- Discharge from households – Since only a minority of households are connected to the public sewer system, it is necessary to evaluate the true amount of discharge from a specific area in order to ensure satisfactory treatment capacity. Evaluation of the contents of the discharge will provide information on which treatment methods are necessary. It is also important to evaluate the sources of household chemicals, so that efforts can be put in to diminish these sources.

Enforcement of environmental legislation

Enforcement of environmental legislation is of great importance when developing a sustainable use of natural resources. One way to enforce legislation is by applying relevant environmental standards. In Uganda's National Environment Action Plan of 1995, there are several strategies introduced in order to ensure legislative enforcement. These include:

- Strengthening criminal law by: introduction of pollution licences; increasing terms of imprisonment and fines; creating new criminal offences
- Environmental restoration orders, for eg. reafforestation
- Community service orders as an alternative to fines and imprisonment.
- Performance reports from all users and manufacturers.
- Chemical status – control through licensing, classification, labelling and registering of all hazardous processes, inputs, products and by-products.

6.6.2.2 Actual measures

Decrease of heavy metal content reaching treatment facilities

Although heavy metals can be extracted from discharge, this still means that the metals will end up somewhere else. Treatment of heavy metals is also an additional cost to the treatment plants and to the sewage system. It is therefore necessary to regulate the heavy metal content reaching the sewage system in the first place. This can be done by:

- identifying the sources of household chemicals and possible substitute goods. In the long perspective, one should consider recycling of goods containing large amounts of metals, such as batteries.
- informing manufacturers and users of chemicals of proper disposal methods

Conversion to unleaded petrol
Leaded petrol is a big source of Pb to the environment. By eliminating the Pb, this source can be dealt with.

Proper management of dumping sites
Unless the public can identify proper dumping sites, one cannot expect these to be used exclusively, which results in garbage, including chemicals, being dumped anywhere in the environment. It is necessary to provide a satisfactory number of dumping sites that are available to the public. These have to be emptied regularly to avoid spreading of garbage with people and animals. It is also of great importance that the runoff and leakage water from dumping sites is collected and treated.

Proper management of leakage from mining activities
There were implications of heavy metal leakage from Kilembe Mines. There are several methods to prevent this kind of leakage. By eliminating this source, a significant reduction in heavy metals reaching Lake Victoria can be sustained.

6.6.3 Public awareness and knowledge

Environmental education in Uganda is greatly aggravated by lack of inadequate teaching materials and resources as well as implementation. The years of instability in the country have had negative effects on cultural values as well as community centres and rural training centres established in the sixties. As a result, the general public today is not well informed about environmental issues which affect their lives (Ministry of Natural Resources, 1995). In order to raise public awareness, it is necessary to provide the public with relevant learning material as well as educate teachers. Useful actors regarding this issue are NGOs and international organisations.

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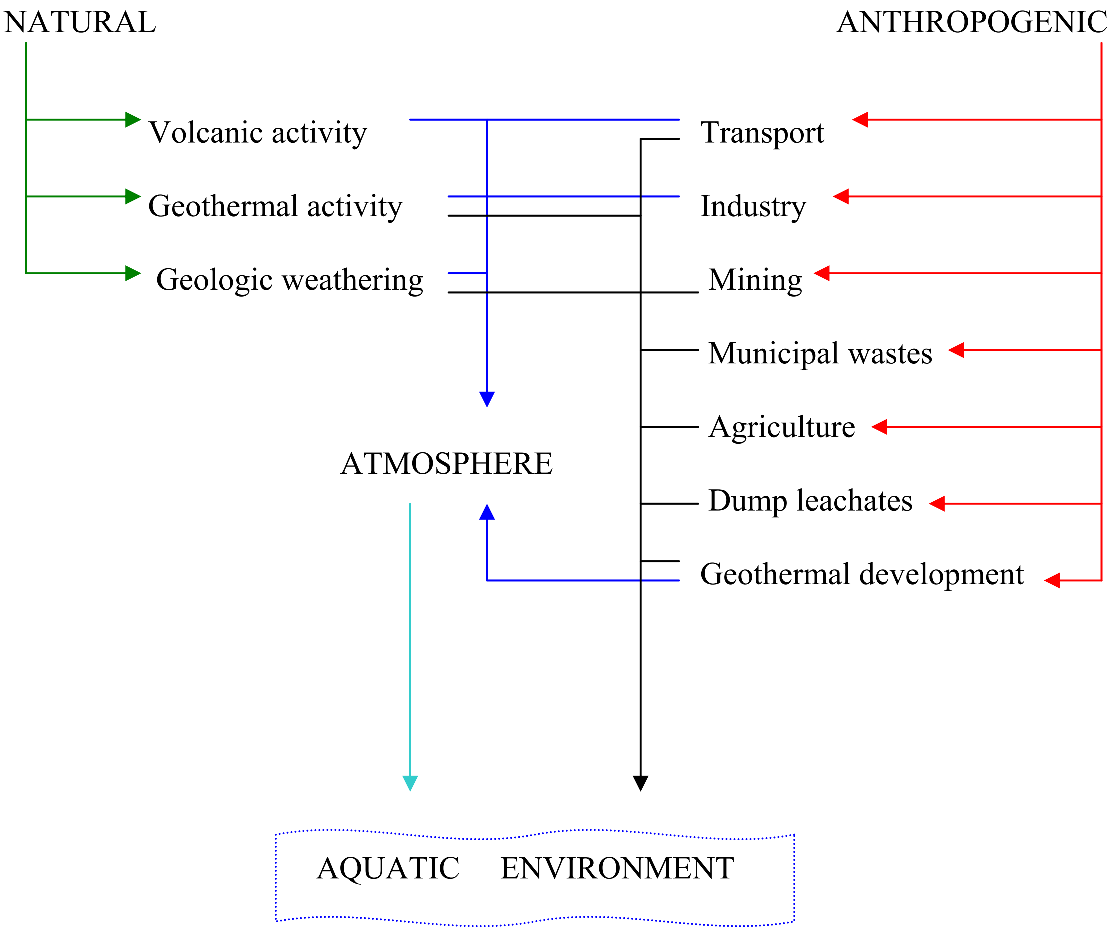
APPENDIX 1

SOURCES OF METAL INPUT TO THE AQUATIC ENVIRONMENT (SMITH, 1986)



This figure summarises the main sources, and their interrelationships, and is briefly amplified by the following points:

1. Geologic weathering includes natural erosion with subsequent loss from the land of material either directly to water or indirectly via the atmosphere as dust, and dissolvation of metals from rocks
2. Geothermal activity will normally result in fluid passing directly into a watercourse with only a small contribution venting to the atmosphere. Man's development of geothermal energy amplifies both processes.
3. Transport contributes metals, e. g. Pb and vehicle corrosion products, to the roadside environment and atmosphere which can end up in stormwater runoff to a waterbody.
4. Industry can discharge directly to a water or may vent metals to the atmosphere, e. g. as fly-ash from the burning of coal.
5. Mining can be a source of pollution by exposing and processing metal-containing rock.
6. Municipal wastes are made up of sewage and posibly industrial waste discharges.
7. Agricultural inputs would include animal dietary additives, pesticide residues and fertilizer runoff.
8. Dump leachetes can be as a point source if the dump is well managed, and a diffuse source if not well managed.
9. The atmosphere is a major source of metal to the aquatic environment, but one which is frequently overlooked. Man-made additions to the atmosphere are most noticeable since natural inputs are usually small.

APPENDIX 2

TABLE OF EFFECTS ON HUMANS AND ENVIRONMENT FROM DIFFERENT HEAVY METALS

Element	**Effects in humans**		**Environmental effects**	
	Acute effects	*Chronic effects*	*Acute effects*	*Chronic effects*
Cd	Nausea Vomiting Abdominal pain	Effects on kidneys and calcium metabolism Skeletal changes	Cellular damage Disturbed metabolism in fish	Reproductivity in plankton Juvenile development in fish Anaemia in fish Damage to gills and gill-membrane Deformed spine
Cr		Ulceration and perforation of nasal septum Ulceration of other skin surfaces Cancer of respiratory tract		Effects in certain species of fish and plankton (8-13$\mu g*l^{-1}$)
Cu	Gastrointestinal effects	Genetic disorders: Menke syndrome Wilson disease Indian childhood cirrhosis	Acute effects in fish at 0.017-1.0 mg/l	Effects in algae, invertebrates and fish at <5 $\mu g*l^{-1}$ Damage to gills, liver and kidney Disruption of cell functions Decreased immune systems Olfactory mucous membranes Stress response
Ni	(rare) Nausea Vomiting Abdominal discomfort, etc	Skin allergy		Effects in some species of fish and microorganisms at 23-50 $\mu g*l^{-1}$
Pb		Accumulates in skeleton Central and peripheral nervous system Possible carcinogen		Anaemia Skeletal changes Neurotoxicity Balck-tail symptoms
Zn		(rare) Gastrointestinal distress Diarrhea	Death due to anoxia	Inhibition of growth, sexual maturity and reproduction Serious gill damage Effects on plankton at 15 $\mu g*l^{-1}$

APPENDIX 3

GUIDELINE VALUES

1. Drinking water:

Metal	G.V. ($mg*l^{-1}$) (health)	$\mu g*l^{-1}$	G.V ($mg*l^{-1}$) (complaints***)	Natural content surface water	Usual content Drinking water
Cd	0.003	3	---	below 1 $\mu g*l^{-1}$	below 1$\mu g*l^{-1}$
Cr	0.05 (P)	50	---	0.5-2$\mu g*l^{-1}$	1-10$\mu g*l^{-1}$
Cu	2** (P)	2000	1	1-2 $mg*l^{-1}$	---
Ni	0.02	20	---	---	below 20$\mu g*l^{-1}$
Pb	0.01	10	---	---	---
Zn	-	-	3	---	---

(WHO, 1998)

G.V – Guideline value

(P) – Provisional guideline value. This term is used for constituents for which there is some evidence of a potential hazard but where the available information on health effects is limited, or where an uncertainty factor greater than 1000 has been used in the derivation of tolerable daily intake (TDI). Provisional guideline values are also recommended: (1) for substances which the calculated guideline value would be below the practical quantification level, or below the level that can be achieved through practical treatment methods, or (2) where disinfection is likely to result in the guideline value being exceeded. (WHO, 2001)

** - The U.S. EPA maximum contaminant level for Cu in drinking water, proposed in 1985 and adopted in 1991, is 1.3 mg/l

*** - concentrations at which consumers have complained over taste and/or appearance of the drinking water

2. Irrigation

Metal ($\mu g*l^{-1}$)	Irrigation
Cd	10
Cr	100
Cu	200
Ni	200
Pb	5000
Zn	2000

(Smith, D. G., *Heavy Metals in the New Zealand Aquatic Environment: A Review*, Water Quality Centre, Ministry of Works and Development, Wellington, New Zealand, 1986)

3. Biological life

Metal	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**
$\mu g*l^{-1}$	Very low	Low	Moderate	High	Very High
Cd	<0.01	0.01-0.1	0.1-0.3	0.3-1.5	>1.5

Cr	<0.3	0.3-5	5-15	15-75	>75
Cu	<0.5	0.5-3	3-9	9-45	>45
Ni	<0.7	0.7-15	15-45	45-225	>225
Pb	<0.2	0.2-1	1-3	3-15	>15
Zn	<5	5-20	20-60	60-300	>300

Class 1: Metal concentrations in waters absent of human activities
Class 2: Concentrations affected by local sources or by long distance atmospheric pollution. This class may also represent natural deviations. This level is not believed to significantly affect biological life.
Class 3: Concentrations are believed to have some biological effect. Levels close to the given guideline causes no great concern.
Class 4: Risk of negative effects on biological life are increased.
Class 5: High risk of negative effects on biological life even at short time exposure
(Naturvårdsverket[a], 2001)