

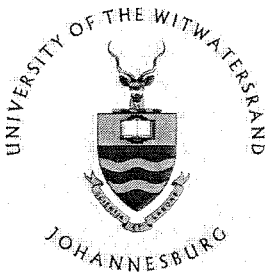
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Assessment of mercury and cadmium concentrations in fish and crocodiles of Mtera Dam, Tanzania

Semanini, Festo Mathew

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University of the Witwatersrand
School of Animal Plant and Environmental Science

ASSESSMENT OF MERCURY AND CADMIUM CONCENTRATIONS IN FISH AND CROCODILES OF MTERA DAM, TANZANIA

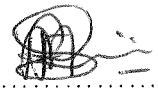
Festo Mathew Semanini

A research report submitted to the Faculty of Science, University of the Witwatersrand, Johannesburg, in partial fulfillment of the requirements for the degree of Master of Science.

Johannesburg, 2010

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the Degree of Masters of Science in Environmental Science in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other university.



.....

Festo Mathew Semanini

...23.....day of ...December2010

ABSTRACT

This study determined total mercury (THg) and cadmium concentrations in tilapia (*Oreochromis urolepis*) catfish (*Clarius gariepinus*) and the Nile crocodile (*Crocodylus niloticus*) representing various trophic levels in Mtera Dam, Tanzania. Accumulation of THg was highest in *C. niloticus* muscle (median: 21 µg/kg) followed by *C. gariepinus* (median: 11.5 µg/kg) and lastly *O. urolepis* (median: 9.5 µg/kg). In the *C. niloticus* tissues, higher THg concentrations were found in the liver (median: 146 µg/kg) than muscle (median: 21µg/kg). Cadmium concentrations were high in *O. urolepis* muscle (range: <0.01-1µg/kg), and were below detection limit (<0.01 µg/kg) in both *C.gariepinus* and the *C. niloticus* muscles. Furthermore, cadmium concentrations were relatively higher in the *C. niloticus* liver (range: 1-3 µg/kg) than in the muscle (under the detection limit of 0.01 µg/kg). In general, THg and cadmium concentrations in Mtera Dam are well below the maximum permissible levels recommended by the World Health Organization (WHO). Based on these data, people around Mtera region could eat up to 1.5 kg of *O. urolepis* or 1.2 kg of *C.gariepinus* or 0.7 kg of *C. niloticus* of Mtera Dam every day and remain safe as per WHO standards. The results from this study are consistent with other THg and cadmium studies conducted in aquatic species in Tanzania. Concentrations of THg and cadmium in the biota of Mtera Dam tend to be lower than those in dams and lakes in tropical and temperate regions. Low THg and cadmium concentrations suggested a relatively clean environment in Mtera Dam.

DEDICATION

For Vida, Shimwe and Colin and everyone looking towards the future

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NOMENCLATURE

$(CH_3)_2Hg$	Dimethylmercury
µg	microgram
µg/day	microgram per day
µg/g	Microgram per gram
µg/kg	microgram per kilogram
µg/kg	Microgram per kilogram
µg/L	Microgram per liter
µmHg	Micrometer of mercury
^oC	Degree Celsius
asl	Above sea level
BDL	Below detection limit
Cd	Cadmium
$Cd(OH)_2$	Cadmium hydroxide
Cd^{2+}	Cadmium cyanide complex
$CdCO_3$	Cadmium carbonate
CdS	Cadmium sulphide
CH_3Hg^+	Monomethylymercury
CIFA	Committee for Inland Fisheries of Africa
cm	Centimeter
CVAAS	Cold Vapour Atomic Absorption Spectrometry
DGO	District Game Officer

DO	Dissolved Oxygen
DR Congo	Democratic Republic of the Congo
E	East
EC	European Commission
EU	European Union
ECO	Environmental Commissioner of Ontario
ETAAS	Electro-thermal Atomic Absorption Spectrophotometer
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
g	Gram
GEF	Global Environmental Facility
H_2SO_4	Sulphuric acid
H_3PO_4	Phosphoric acid
Hg	Mercury
HgS	Cinnabar
HNO_3	Nitric acid
IRUWASA	Iringa Urban Water Supply and Sewerage Authority
JICA	Japan International Cooperation Agency
kg	Kilogram
kg/ha	Kilogram per hectare
L	Length
LVGF	Lake Victoria Goldfields
m	Meter

m^3	Cubic meter
MeHg	Methylmercury
mg/g	Milligram per gram
mg/kg	Milligram per kilogram
mg/L	Milligram per liter
MmHg	Millimeter of mercury
MW	Megawatt
NEMC	National Environmental Management Council
NPK	Nitrogen-Phosphorus-Potassium fertilizer
PO_4^{3+}	Organophosphate
PPM	parts per million
RBWO	Rufiji Basin Water Office
S	South
SD	Standard deviation
SEAMIC	Southern and Eastern Africa Mineral Centre
SMUWC	Sustainable Management of the Usangu Wetland and Catchment
$SnCl_2$	Tin chloride
SWECO	Swedish Consulting Group
TDI	Tolerable Daily Intake
TFC	Tanzania Fertilizers Company
THg	Total mercury
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organisation

URT	United Republic of Tanzania
USEPA	United States Environmental Protection Agency
WCS	Wildlife Conservation Society
Wet wt	Wet weight
Wt	Weight

1 INTRODUCTION

1.1 General Background

Heavy metals occur naturally in the environment and can be a major source of pollution (Foulke, 1994). The definition of heavy metals is that they occur persistently in the environment and have a specific gravity at least five times greater than that of water. Heavy metals can be incorporated into food webs, and their toxic effects on living systems are well known (Evanko and Dzombak, 1997). Tons of heavy metals are released into the atmosphere naturally by degassing from the Earth's crust and ocean. Additionally, a substantial amount is released by human activities, primarily industrial, mining, urbanization and agricultural activities (Clark, 1992). Like all other elements heavy metals are not degraded or destroyed (Davydova, 2005) and they are easily transported and deposited on land and water. Owing to their persistence in soil, water and biota, heavy metals have the potential to cause both acute and chronic impacts on humans and ecosystem health through toxic, mutagenic and carcinogenic effects (Urum *et al.* 2004). If unrecognized or inappropriately treated, heavy metals can result in significant morbidity and mortality of human beings (Levine *et al.* 2006).

Heavy metals pollution is a concern in south central Tanzania and more importantly in Mtera Dam where it threatens both people and wildlife. Considering the geographical position and overall importance of the Mtera Dam and reliance of a

large local population, it is important that heavy metals are monitored to provide early warning of potential toxicity.

1.2 Value of Mtera

Mtera Dam is located midway between Iringa and Dodoma regions of Tanzania about 150 km from Iringa municipality or about three hours travel time from Dodoma on a gravel road. Mtera was built in 1980 for the purpose of regulating water levels at the downstream Kidatu hydroelectric dam and is the biggest hydroelectric dam in Tanzania (SWECO, 1997; Figure 1.1). Mtera Dam (installed capacity of 80MW) together with Kidatu hydro-electric plant downstream (production capacity of 200MW) are currently generating around two thirds of Tanzania's electricity (Coppolillo *et al.* 2006).

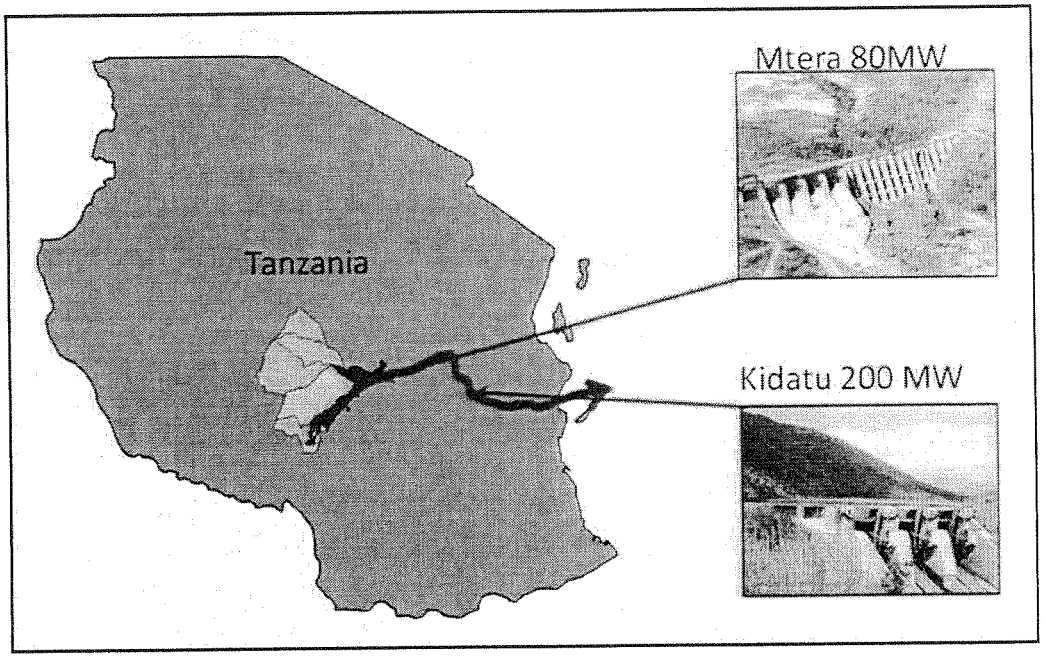


Figure 1.1 Mtera and Kidatu dams location and production capacity

Fishing is another important economic activity in Mtera Dam. For the past two decades or so Mtera Dam has acted as a fish refuge when most rivers empting water into it ceases to flow, especially during dry months of the year (SMUWC, 2002; Mtahiko *et al.* 2006). Fish and other aquatic species migrate to Mtera Dam as water levels in the rivers drop. As a consequence, Mtera harbors most of the fish species present in Great Ruaha River sub catchment. This has attracted fishermen from the central and southern regions of Tanzania and therefore Mtera is a primary source of protein and income for almost 90% of people residing around this dam (Sosovele and Ngwale, 2002). According to URT (1997) statistics, Mtera generated revenue of up to 511 million Tanzanian Shillings (Table 1.1).

Table 1.1 Water levels, fish catch volume, number of vessels and fishermen and revenues in Mtera Dam (after URT, 1997; RBWO, 2006)

Year	Water levels (meters)	Number of fishermen	Number of vessels	Weight in metric tons	Value in 000'Tshs.
1990	697.74	970	713	2779.5	186,737.5
1991	695.78	822	665	3159.2	210,352.21
1992	692.95	722	681	5037.05	511,642.11
1993	694.05	789	316	2346.34	489,124.75
1994	692.10	660	602	128.21	34,611.10
1995	692.37	563	503	98.35	39,056.083

2 HEAVY METALS IN MTERA DAM

2.1 Sources of Heavy Metal

Mtera Dam receives water from the Great Ruaha River (56%), the Little Ruaha River (18%) and the Kizigo River (26%) (Coppolillo *et al.* 2006; Figure 2.1). Unfortunately, ongoing human activities associated with these tributaries are probably the major sources of pollution and heavy metals in Mtera Dam. The Little Ruaha River, for instance, passes through Iringa municipality and receives all domestic and industrial effluents. According to Clark (1992), these effluents contribute to heavy metal pollution, especially mercury. Generally in Tanzania, about 70% of industries are located along lake basins, river banks, flood plains and coastal areas. Therefore these water bodies serve as dumping sites for industrial wastes (UNEP, 1982; Lann, 1985; Lann and Mbagi, 1986; NEMC, 1990; UNIDO, 1991; Yhdego, 1995). Also due to rapid urbanization of towns in Tanzania, urban areas become overcrowded. Water supply and sanitary facilities are increasingly becoming inadequate. Systems for sewage, drainage and waste disposal are inadequate making waste recycling and management almost an impossible task. Over 80% of sewage and wastewater in Tanzanian urban areas is channeled into natural water bodies (Yhdego, 1995; JICA, 1999). Currently only a small portion (<50%) of Iringa town is served by treatment plant on the outskirts of the municipality, and a large portion of untreated sewerage drains into Little Ruaha River (IRUWASA, 2008).

The Little Ruaha River is intensively used for irrigation of grain crops and vegetables all year round. Unlike other tributaries of Mtera Dam which are

ephemeral, the Little Ruaha River is perennial. Chemical fertilizers and pesticides are used to treat agricultural fields and also contribute to pollution into the river. The slash and burn practice which is common in this region for preparation of fields and establishment of new farms is thought to disturb the natural mercury cycle and results in accumulation of mercury in the soils (Roulet *et al.* 1999). Mercury accumulated in soils can be leached and released into drainage waters and eventually accumulated in Mtera Dam.

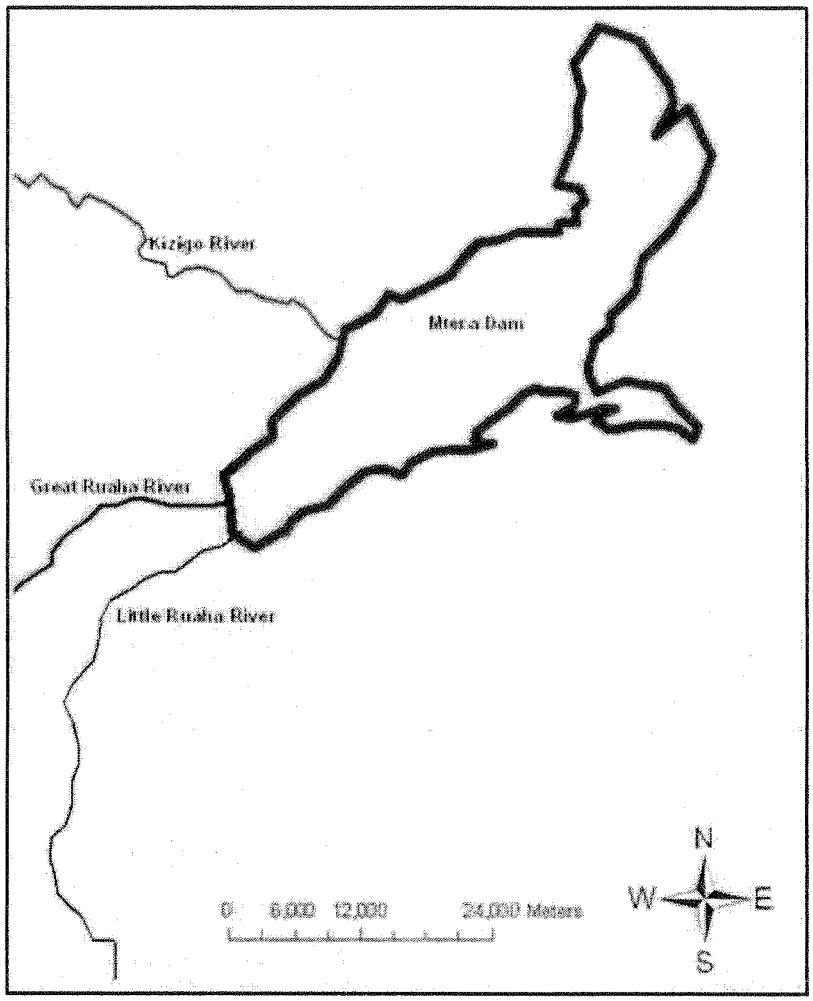


Figure 2.1: Rivers emptying water into Mtera Dam.

The Great Ruaha River originates in Mbarali district of Mbeya region where there are massive irrigation activities currently in practice. Three industrial-scale rice schemes were instituted by the Tanzanian government in the mid /late 80s with the ultimate purposes of 1) growing more rice /ha 2) using water more efficiently 3) promoting more equitable sharing of benefits (Coppolillo *et al.* 2006). This project was coupled with thousands of surrounding satellite rice farms owned by

smallholders, all using pesticides and chemical fertilizers -most notably phosphate (P) fertilizer. According to Mwambete (1991), Tanzania fertilizers company (TFC) is manufacturing almost exclusively triple super phosphate fertilizers and NPK from phosphate rocks mined at Minjingu in Manyara region and therefore these fertilizers are widely available and used by farmers in this region. Phosphate rocks are usually too insoluble to be efficient fertilizer hence they are generally converted to more soluble forms by treatment with sulphuric acid (H_2SO_4) a process known as "wet process" (Slack, 1968; Al-Shawi and Dahl, 1999). Phosphate rock may alternatively be treated with phosphoric acid (H_3PO_4) to produce a pure form of monocalcium phosphate and sold as triple phosphate fertilizer. Fertilizers produced using the wet process contains high amounts of cadmium as compared to "odda process" where phosphate rock is treated with nitric acid (HNO_3) to produce NPK fertilizers (Vermuel *et al.* 1995). Phosphate in fertilizers may contain cadmium concentration of up to 100 mg/kg (Trueman, 1965; Syers *et al.* 1986). Cadmium is a relatively mobile metal in surface and ground water. Cadmium leaching occurs relatively quickly and it is readily absorbed by plants from P-fertilized soils (Dick, 1992; Sharpley *et al.* 1994; Jarvis *et al.* 1995; Mortvedt, 1996; Liebig and Doran, 1999; Gillingham and Thorrold, 2000; Ledgard *et al.* 2000). Due to unknown long-term effects of cadmium additions to soils, some countries, especially in the European Community (EC) have set a tolerance limit for its application to farmlands. Recommended maximum annual and total loading rates for cadmium in agriculture lands in EC countries are 0.1 and 0.15 kg Cd/ha/yr for recommended and mandatory

maximum annual loadings, respectively. Recommended maximum and mandatory annual cumulative limits are 2.4 and 8.4 kg/ha, respectively (Webber *et al.* 1984).

Unsurprisingly, manures also contain cadmium and other heavy metals, but most of the time concentrations are relatively low and no buildup is considered from moderate manure application rates on agricultural land (Mortvedt, 1996). When the Great Ruaha and Kizigo Rivers stop flowing in the dry season, small water holes are left behind (Figure 2.2). This attracts dozens of wildlife species and sometimes domestic animals to congregate on the river bed (Epaphras *et al.* 2007). When they are in the process of utilizing water holes, they drop massive amounts of dung and when the first flush of a new rainy season comes, dung is washed downstream and deposited in Mtera Dam. Animal manure, especially from domestic animals on a farm (pig and poultry) may contain annual cadmium loadings up to 0.007 kg/ha (Chambers *et al.* 1998). Gereta and Wolanski (1998) documented a relationship between animal dung and decreased dissolved oxygen as well as eutrophication of surface waters of Serengeti National Park which could also be the case in Mtera.

When the Great Ruaha stopped flowing for the first time during the dry season of 1993 (SMUWC, 2002; Mtahiko *et al.* 2006), illegal wildlife hunters began poisoning water holes. These poachers dig few centimeters into the river bed or sometimes use small remnant water pools dug by elephants or zebra (Figure 2.3); they added poison to water sources and waited for wildlife to come and drink. According to the report from the Tanzania government chemist who tested the water from one of

the kill sites, the poison used was organophosphate (PO_4^{3-}) (WCS, 2006). Organophosphate is acutely toxic when consumed in large amounts (Costa, 2006). It is unknown how many poisoned holes are dug each year and how frequently poachers are using this approach but the fatality rate of this method is outrageous. One documented poisoning killed over 200 vultures and one giraffe. Additionally an unknown number of carnivores may have consumed poisoned carcasses here and died elsewhere (WCS, 2006; Figure 2.4). Organophosphate and other poisons used in the Great Ruaha River bed will later wash downstream into Mtera Dam where they may affect fish and other aquatic organism. Fertilizer PO_4^{3-} may also contribute to eutrophication.

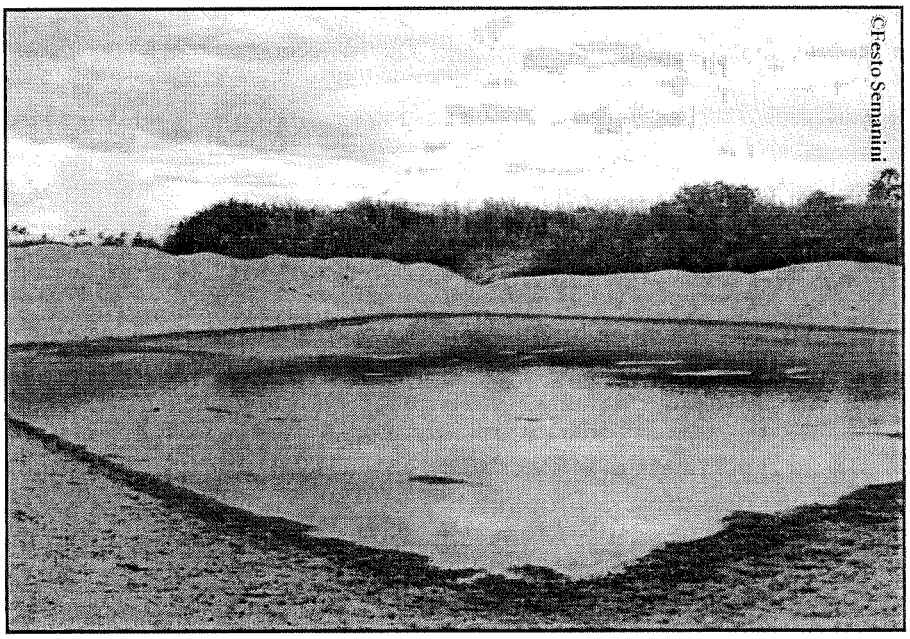


Figure 2.2: Water hole dug by Ruaha National Park on the river bed of the Great Ruaha River

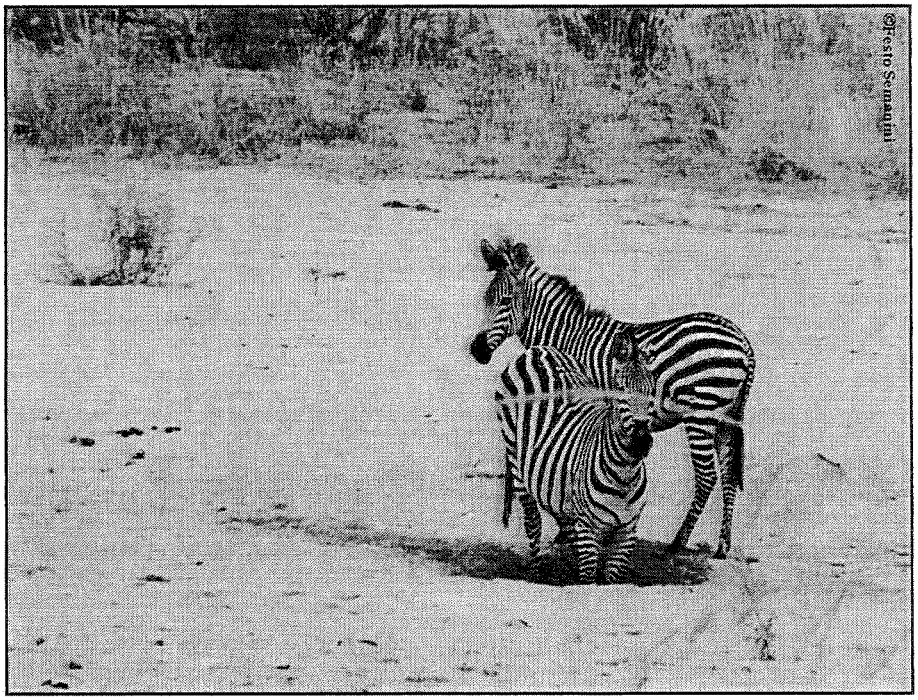


Figure 2.3: Zebra digging holes in search of water

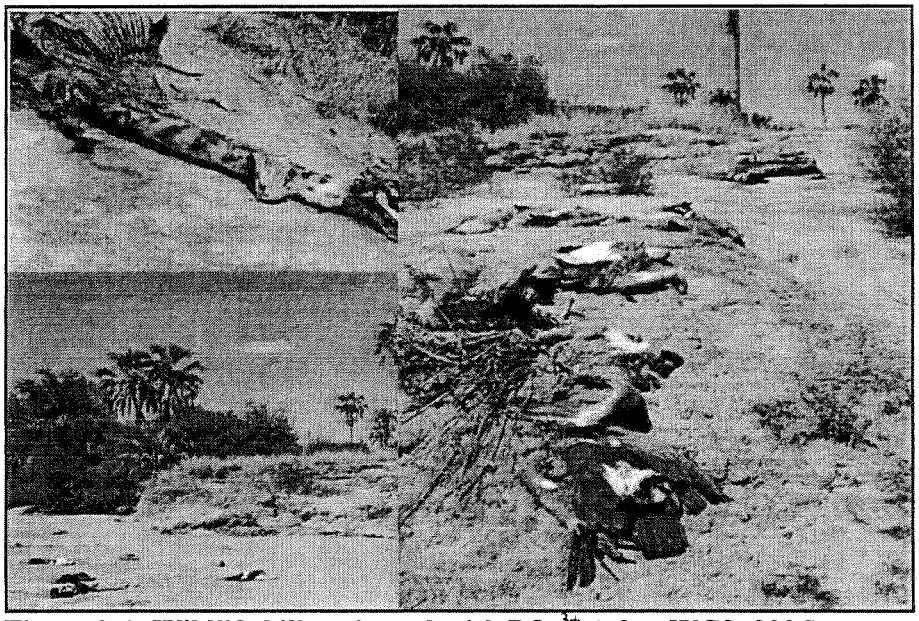


Figure 2.4: Wildlife kills poisoned with PO_4^{3+} (after WCS, 2006)

The Kizigo River, which originates in central region of Tanzania, is believed to be the major source of heavy metals (specifically mercury) to the Mtera Dam. In July 1992 the Dodoma "Madini" Mineral Association reported gold occurrence at several localities of Itigi, particularly along Njombe and Kizigo River. When this news spread, artisanal miners stormed the Iluma area within the Rungwa-Kizigo-Muhesi Game reserve complex (Leader Williams *et al.* 1996). Artisanal and small-scale mining uses the mercury based amalgamation process to recover gold. This method is widely used in African countries such as Sudan, D.R Congo and Zimbabwe (Global Mercury Project, 2007). In Tanzania the most documented mercury-based amalgamation is being practiced in Geita gold mining in Geita district (Taylor *et al.* 2005). By definition "amalgamation is a concentrating process in which metallic gold is mixed with mercury into an amalgam which is then separated by heating into mercury vapour or gold" (GEF, 2001). Mercury amalgamation is a very simple technology, making it a first choice for poor people in the developing world. However mercury is potentially dangerous when it contaminates air, soil and water (Taylor *et al.* 2005). It is estimated that two grams of mercury are released into the river for each gram of gold recovered (Global Mercury Project, 2007). Mercury emissions from gold amalgamation have localized effects depending on the watershed and local conditions. Mercury amalgamation is considered to be the most severe threat to health of miners and individuals living within the area, because of inhaling mercury vapour and consuming fish and other contaminated food (Lechler *et al.* 2000).

Construction of large dams such as Mtera may contribute to the accumulation of mercury in lakes and dams by the phenomenon known as 'reservoir effect' (Anderson *et al.* 1995). Mercury may be released in aquatic systems from two major sources in new dams. First, during construction of dams and hydroelectric power schemes, especially in tropical regions, stored mercury in soils and vegetation is released in aquatic systems during reservoir flooding (Lechler *et al.* 2000). Release of mercury from soils may be controlled by podzolized soils which are widely found in tropical latitudes including the Ivory Coast and Congo (Schwartz, 1988). Podzolization involves the processes of weathering of primary minerals by organic complex acids and translocation of organic matter as well as aluminum (Al) and iron (Fe) complexes. Classically, podzolization was recognized as specific feature of boreal and temperate zone soils (Bravard and Righi, 1990). In the tropics, podzolization is significant as mercury accumulates in soils and organo mercury complexes are leached and released into dams (Roulet *et al.* 1999). According to Forsberg *et al.* (1999), naturally occurring mercury in soils and vegetation is the largest reservoir of mercury in the ecosystem. Second, anoxic condition in sediment created by increased microbial activity may enhance methylmercury production (Rogers *et al.* 1995; Leaner, 2007). Methylmercury bound to soil and organic matter is mobilized during reservoir flooding and results in increased mercury bioavailability in fish in new dams (Morrison and Therien, 1995). Methylmercury is more effectively transferred from water into food chains compared to inorganic mercury. The duration of elevated fish mercury levels in fish is debatable; fish in other reservoirs have reverted to pre –impoundment levels within 5-10 years of flooding (Verdon *et al.*

1991). A study conducted in LaGrande reservoir in Canada suggested that it could take up to 30 years before fish mercury level decreased to background level (Anderson *et al.* 1995). Mtera Dam is fairly young -inundated in 1980, it is the newest of all hydro-electric power generation dams in Tanzania. There is a serious risk of mercury accumulation and methylmercury formulation here (Ikingura and Akagi, 2003).

2.2 Research Motivation

Heavy metals discharged into the environment have been widely reported to harm human health (Otitoloju, 2003; Otitoloju and Don –Pedro, 2004). For example methylmercury pollution caused Minamata disease in Japan and it was described for the first time in 1956. By March of 2001, 2,265 victims had been officially recognized (1784 of whom had died) and over 10,000 had received financial compensation (Kurdland, 1960; Irukayama, 1966). On the other hand Itai-Itai disease which is caused by mass cadmium poisoning was recognized in Toyoma prefecture in Japan in the year 1968. Since the year 1967, 184 victims were legally recognized (Varma *et al.* 1976). These two highly publicized diseases motivated research of acute and chronic biological effects of heavy metals carcinogenicity, kidney diseases and kidney failure (Hatakeyama and Yasuno, 1981; Khangarot *et al.* 1982; Mackie, 1989; Kiffney and Clement, 1993; Levine *et al.* 2006). Published information about the toxicity of heavy metals (mercury and cadmium) and accumulation in water and biota of Africa are still not widely available. Yet these are essential for both ecological and human health monitoring (Boon *et al.* 2002; van der Oost *et al.* 2003;

Don –Pedro *et al*. 2004; Erdogrul *et al*. 2005). There is no doubt that anthropogenic sources of mercury and cadmium could contribute to the pollution of the Mtera Dam but the information about the extent and type of contamination is limited.

3 LITERATURE REVIEW

3.1 Heavy Metals

Heavy metals are loosely defined as metallic chemical elements which have a relatively high density and are poisonous at low concentration (Duffus, 2002). They usually occur naturally in our environment at trace concentrations but human activities frequently elevate their level of occurrence (Clark, 1992). Human activities result in the discharge of heavy metals into the atmosphere and water through industrial, domestic or agricultural waste (Otitoloju, 2003; Otitoloju and Don-Pedro, 2004). Heavy metals are bioaccumulative in nature and enter animals through food, air and drinking water (Davydova, 2005). Heavy metals can cause irreversible brain damage and also can impair natural resources and can hinder people from using them (Otitoloju, 2003; Otitoloju and Don-Pedro, 2004).

3.2 Mercury

Mercury is a chemical element with the symbol Hg 'Hydrargyrum' in Latinized Greek meaning water or liquid silver. In the earth's crust mercury is the 67th most abundant naturally occurring element (Krauskopf and Bird, 1995). Mercury is the only metal that is liquid at standard temperature and pressure but its gas phase is important since some elemental mercury compounds have relative high vapour pressure. For example at 20^{0}C the vapour pressure is 1.2 μmHg but at 100^{0}C, vapour pressure could reach 0.2729 mmHg. Mercury is the densest liquid ever known

(Perelman, 1997). Additionally, mercury has seven stable isotopes which occur in the following proportions; ^{196}Hg, 015%; ^{198}Hg, 16.76%; ^{200}Hg, 23.2%; ^{201}Hg, 13.2%; ^{202}Hg, 29.8%; ^{204}Hg, 6.8% (Friedlander *et al.* 1981). Terrestrial and extraterrestrial material distribution of mercury isotopes is very similar, for example Allende meteorite distribution is 30-300 µg/kg (Lauretta *et al.* 2001). But so far there has been little success in assessing mercury isotopes as an indication of magmatic or biological fractions.

Traditionally mercury and its ore, cinnabar (HgS), have been used in preserving wood, silvering mirrors as well as in medicine. Mercury was also applicable in dentistry and pharmaceuticals, chlor-alkali production and gold and silver refining. For many years, mercury was also used in thermostats, catalyst electrodes, batteries, switches, fluorescent lighting and pesticides (Schülter, 2000).

Natural events such as volcanic eruptions and anthropogenic activities such as mining, chlor-alkali production and the combustion of fossil fuels are the major entrance pathways of mercury to the atmosphere. Currently anthropogenic sources are likely largest contributors of mercury to the atmosphere and surface water (Mason *et al.* 1993). Mercury is persistent, bioaccumulative and toxic especially its organic forms of (Monomethylymercury $CH3Hg^{+}$) and dimethylmercury ($(CH_3)_2Hg$). Monomethylymercury commonly referred as 'Methylmercury' and its chemical formula sometimes written as $MeHg^{+}$ is a bioaccumulative environmental toxicant (Govindaswamy *et al.* 1992) formed during methylation process in anoxic sediments.

Methylation is a natural process and involves the action of anaerobic organisms that live in aquatic systems including lakes, rivers, wetland sediments, soils and the open ocean which convert inorganic mercury to methylmercury (Ullrich *et al.* 2001).

Mercury is not readily eliminated from organisms thus it is biomagnified in aquatic and terrestrial food chains. The concentration of methylmercury in the top level aquatic predator can reach a level of a million times than that of water (Wiener *et al.* 2003).

Human exposure to mercury occurs almost exclusively through consumption of fish and other aquatic organism (USEPA, 1997). Mercury is a mutagen, teratogen, and carcinogen. It also has embryocidal, cytochemical and histopathological effects (Eisler, 1987).

Minamata disease is a poisonous disease in humans that affect mainly the central nervous system. When it was reported to the first time was concluded to be due to consumption of large quantities of fish and shellfish living in Minamata Bay (Kurdland, 1960; Irukayama, 1966; Masazumi, 1972).

Biologically, mercury has no known function in living organism. Several international organizations have established mercury standard limits for human ingestion. For example the limit allowed for interstate commerce in fish muscle tissue is normally 500 or 1000 μg/kg (FDA, 1987; Lange *et al.* 1994). Normally mercury

consumption from food sources is higher than from drinking even highly polluted water sources. The World Health Organisation (WHO) limit for inorganic mercury ingestion in food is 6 µg/kg. Additionally, the tolerable weekly dose for methylmercury consumption in food for people is 1.6 µg/kg (WHO, 2005)

3.3 Cadmium

Cadmium (Cd) is a chemical element with soft bluish –white colour and it is a relatively abundant metal. Cadmium occurs naturally in the form of cadmium sulphide CdS or cadmium carbonate $CdCO_3$ in soils. Cadmium is also a by-product of zinc production as it occurs as a minor component in most zinc ores. Cadmium was used as a pigment and for corrosion resistant plating on steel. It is also currently used to manufacture nickel-cadmium batteries (Schülter, 2000). Plating operations and the disposal of cadmium-containing waste are the most notable sources of cadmium contamination in the environment. Treatment of the waste before disposal and local soil chemistry frequently determine the form of cadmium occurring at a site (LaGrega *et al.* 2001). However the most common forms of cadmium include $Cd(OH)_2$ (solid sludge), or Cd^{2+}, (cadmium-cyanide complexes). Cadmium-cyanide complexes is most dominant in the environment where pH <8. Cadmium hydroxide $Cd(OH)_2$ and cadmium carbonate $CdCO_3$ are dominant in higher pH environments (Luoma *et al.* 1989; LaGrega *et al.* 2001). Cadmium is known to have two possible oxidation states, +1 and +2. The +2 oxidation state is by far the most common one. Furthermore cadmium has five stable isotopes namely $_{108}Cd$, $_{110}Cd$, $_{111}Cd$, $_{112}Cd$ and $_{114}Cd$ with respective natural abundances of 0.89%, 12.49%, 12.80%, 24.13% and 28.73%. The

isotopes made up of the remaining 20.96% vary in half life up to 10 years and more (Parrington *et al.* 1996). Cadmium is classified as a borderline metal, i.e. it is neither hard nor soft, and as such can bond to both hard and soft ligand donors (Webb, 1979).

Like mercury, cadmium has no constructive purpose in human body. Cadmium and its compounds are extremely toxic and can bioaccumulate in organisms and ecosystem even when present in low concentrations. In Japan for instance, environmental exposure to cadmium has been a major problem. Many people that consumed rice grown in cadmium-contaminated irrigation water suffered from Itai-itai disease. Itai-itai (ouch-ouch) is the disease associated with severe pains in the joints and spine. Bone softening and kidney failure are also symptoms of this disease (Gonick, 2008). Worldwide industrial use of cadmium has decreased due to its toxicity and carcinogenicity.

4 AIMS AND OBJECTIVES

4.1 Aim

The aim of this study is to assess the heavy metal (mercury and cadmium) concentrations in Mtera Dam biota and calculate dietary intake maxima for residents around Mtera region. Mercury and cadmium concentrations in the Rufiji tilapia (*Oreochromis urolepis*), the catfish (*Clarius gariepinus*), and the Nile crocodile (*Crocodylus niloticus*) will be quantified according to trophic level.

4.2 Objectives

- Determine concentrations of mercury in the muscle tissue of *C. gariepinus*, *O. urolepis* and the muscle and liver tissues of *C. niloticus* in Mtera Dam.
- Determine concentrations of cadmium in the muscle tissues of *C. gariepinus*, *O. urolepis* and the muscle and liver tissues of *C. niloticus*.
- Characterize heavy metal concentrations in fish and crocodiles with the long-term goal of mitigation.
- Use results of this study to calculate recommended fish intake for local human population.

4.3 Hypotheses

1. Fish and crocodile tissues collected in Mtera Dam contain relatively high mercury and cadmium concentration as a result of reservoir effect and

pollutants from human activities upstream (domestic, agriculture and mining effluents).

2. Mercury and cadmium concentrations will be highest in *C. niloticus* as they are top predators. *Clarius gariepinus*, which are omnivorous, will have lower concentration and *O. urolepis* as primary consumers will have the lowest concentrations.
3. People around Mtera Dam will be in a high risk of contacting mercury and cadmium associated diseases as a result of eating fish and crocodiles with elevated concentrations.

5 METHODOLOGY

5.1 Study Area

The study was carried out in Mtera Dam which is in Southern Central Tanzania (Figure 5.1). Mtera Dam lies between latitude $7^0$08'96"S and longitude $35^0$59'16"E and it is shared by Iringa and Dodoma regions. Mtera Dam was constructed in 1980 for the purpose of providing adequate water for the Kidatu power plant during prolonged periods of low rainfalls and drought (SWECO, 1997). It measures 660 square kilometers with a storage capacity of 3200 million m^3 and therefore is the biggest hydroelectric dam in Tanzania. The dam is 698.5 m above sea level (a.s.l) when operating at full supply level and 690 m a.s.l is the minimum supply level. Mtera has a maximum depth of 30 m at the dam site and 13 m in the central basin of the dam at full supply level (Ekstrand *et al.* 1997). Vegetation characteristics of the area surrounding Mtera Dam are typical of semi-arid savanna and the estimated potential evaporation is 3200 mm/year which is far higher than precipitation (450 mm/year; Ekstrand *et al.* 1997). Mtera Dam is recharged by the Great Ruaha River, the Little Ruaha River and the Kizigo River.

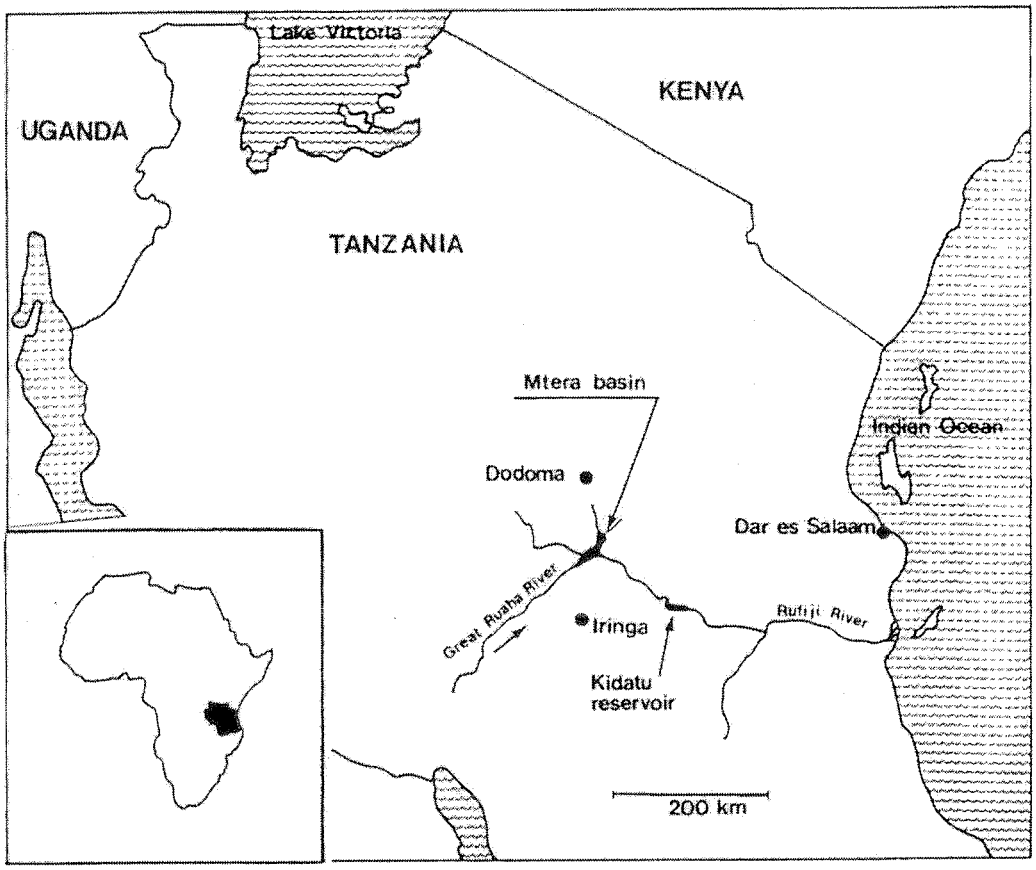


Figure 5.1: Location Map of Mtera Dam (Adapted from: SWECO, 1997)

During the surveys five fish landing sites were visited: Migori, Mnadani, Makuka, Chungu and Chamdubwi. These landing sites are situated in the villages around Mtera Dam. Three of them are in Iringa region while two are in Dodoma region (Figure 5.2).

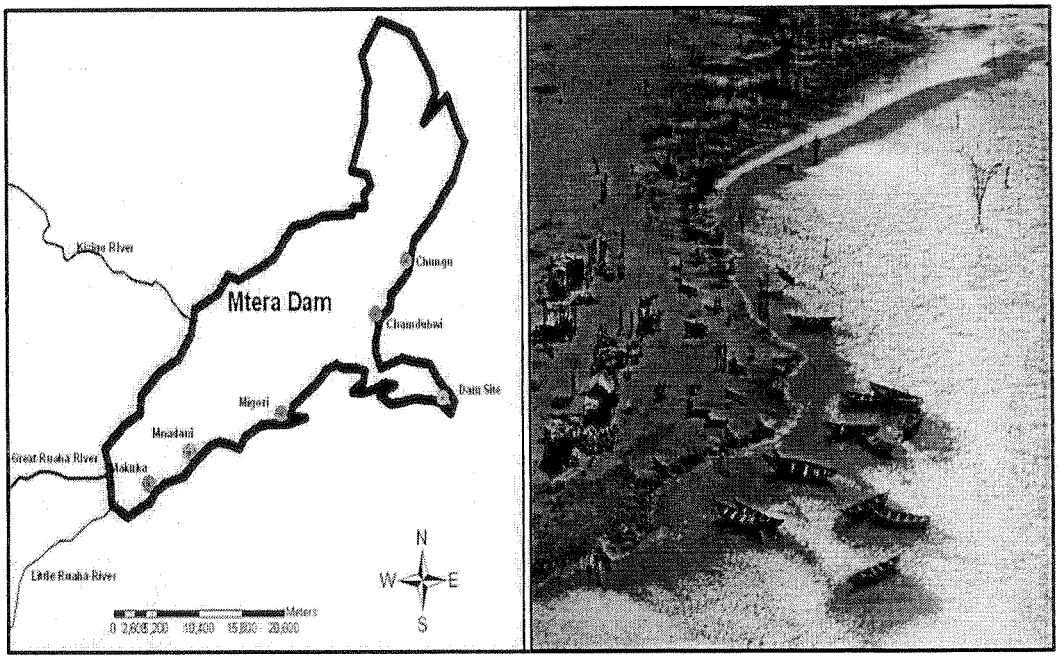


Figure 5.2 Sampling sites at Mtera Dam (on the left) Migori fish landing site (on the right)

5.2 Methods

Samples were collected at fish landing sites in Migori, Mnadani, Chungu and Chamdubwi (Figure 5.2). At each site 2- 5 fishermen were approached and *O. urolepis* and *C. gariepinus* tissue samples were collected from fish either donated or purchased from fishermen. However, most fish samples were purchased from fishermen. Normally the biggest fish in the catch was selected. During this survey, the approximate weight of *O. urolepis* was 500 g and *C. gariepinus* was 1000 g. A total of 36 samples (26 *O. urolepis* and 10 *C. gariepinus*) were collected. Fish samples were collected three times over a period of one year in 2008. The first set of samples was collected in April during the wet season, the second and the third were collected during the months of September and November. Twenty six specimens of *O. urolepis*

were collected in Migori (8), Mnadani (6), Chungu (6) and Chamdubwi (6) fish landing sites in 2008.

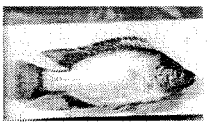
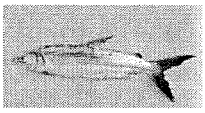
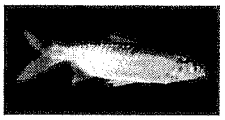
Muscle (5-10 g) was cut from each specimen below the dorsal fin, above the midline just caudal to the pectoral fins. Ten samples of *C. gariepinus* were collected in Migori (5) and Chungu (5) fish landing sites. As in *O .urolepis*, 5-10 g of muscle was cut from each catfish. Muscle samples were analysed in both *O. urolepis* and *C .gariepinus* because this is consumed most by humans. *Oreochromis urolepis* and *C. gariepinus* are the most numerous although surveys revealed that there are eight important species targeted by fisheries (Table 5.1). Due to their reasonable size, *Oreochromis urolepis* and *C. gariepinus* are gutted and dried in the sun or smoke during preparation. Sometimes these fish are eaten fresh by simply boiling or frying. Indeed, much smaller fish (commonly known as dagaa) are eaten without removing their internal organs which includes the liver (Sosovele and Ngwale, 2002).

Crocodylus niloticus tissue sample collection occurred between July-December 2008. According to Tanzania hunting regulations wildlife is hunted from July –December. It should be noted that Mtera Dam does not fall into any sort of protected area and *C. niloticus* hunting in the dam is not regular. However there was public outcry about *C .niloticus*' number and general safety. This prompted the District Game Officer (DGO) for Iringa district to grant licenses to *C. niloticus* skin hunters. *Crocodylus niloticus* has been legally hunted in Mtera Dam since 2007.

Seven *C. niloticus* samples were collected in Makuka village where most hunters camp. Makuka village is far from the deepest point of the dam and *C .niloticus* tends to concentrate there to take advantage of shallow water when hunting. Thus *C. niloticus* which was hunted everywhere else in the dam was also brought to Makuka. It was therefore assumed that samples collected in Makuka village represent the entire dam. Muscle and liver (5-10 g) were collected from each *C. niloticus*. Around Mtera Dam, *C. niloticus* tail is the only part which is known to be eaten by people. The abdomen is completely avoided due to its associated toxic bile which can be fatal if poorly handled. Reportedly, villagers in Mtera Dam have used toxic powder from *C. niloticus* bile to poison their colleagues/enemies in local liquor clubs.

While in the field, all tissue samples were kept in plastic vials and temporarily stored in cool boxes filled with ice packs (Stojchev *et al.* 2006). Samples were transported to Iringa station and stored at -20^{0}C for several months until they were analysed.

Table 5.1 Checklist for dominant fish species caught in Mtera Dam (WCS survey, 2007)

S/N	COMMON NAME	SCIENTIFIC NAME	PHOTO
1	Tilapia	*Oreochromis urolepis*	
2	Dogfish	*Hydrocynus vittatus*	
3	Catfish	*Clarius gariepinus*	
		Clarius theodore	
4	Rufiji mudsucker	*Labeo cylindicus*	
		Labeo congoro	
5	Synodontis	*Synodontis maculpinna*	
6	Alestes	*Brycinus affinis*	

Daily THg intake for residents of the Mtera region was also calculated. The tolerable daily intake was determined based on the assumption that an average body weight for a person in Mtera region is 60 kg. THg consumption recommended by WHO (2006) is 0.23 µg/kg of body weight per day. The tolerable daily intake was determined using the equation

$$\text{Daily portion size (kg)} = \frac{\text{WHO limit (µg/kg/day)} \times \text{body weight (kg)}}{\text{Average THg conc. in species (µg/kg)}}$$

5.3 Sample analyses

All tissue samples were analysed for total mercury (THg) and cadmium at the Southern and Eastern African Mineral Centre (SEAMIC) in Dar es Salaam, Tanzania. THg was chosen due to high cost of analyzing compound specific mercury (e.g. methylmercury) and because it is the most commonly measured component (Morel *et al.* 1998). Total mercury is the sum of all mercury compounds including methylmercury. All samples were homogenized and treated with nitric acid and hydrogen peroxide and digested by microwave (milestone, Ethos Plus) under pressure at 180^{o}C, a standard rapid sample preparation for trace metals. The homogenate was diluted with deionised water to 25 ml. Samples for cadmium were analysed using a graphite furnace atomic absorption spectrophotometer (ETAAS) and for THg using a cold vapour generation system (CVAAS) with $SnCl_2$-reduction. Modifiers that include mixtures of palladium/magnesium nitrate for cadmium analysis were used. Both elements were analysed using an L'VOV platform on Varian instrument (Spectr AA600 Varian) which was equipped with deuterium background compensation. THg

was analysed using the same instrument, but equipped with a continuous flow system through a quartz cell.

THg and cadmium in this study are expressed in micrograms per kilogram of fish and crocodile muscle on wet weight basis (µg/kg wet wt). For the sake of consistency while comparing published data, THg and cadmium concentrations were converted to standard units. Concentrations in aquatic biota from literature were expressed as microgram per kilogram (µg/kg), sediment concentrations as microgram per kilogram (µg/kg), while water concentrations were presented as microgram per liter (µg/L)

5.4 Statistical analysis

Few statistical comparisons were possible due to the limited number of samples analysed. The Kruskal-Wallis test for nonparametric multiple comparison was used to compare the concentration of THg and cadmium between *O. urolepis, C. gariepinus* and *C. niloticus.* The Wilcoxon Mann-Whitney test for independent samples was used to compare the concentrations of THg and cadmium in *C .niloticus* muscle and liver tissues. STATISTICA software version 6.0 of 2001 was used and tests were run at 5% level of significance.

6 RESULTS

6.1 Mercury

Orechromis urolepis had the lowest THg concentration (2-26 µg/kg) followed by *C. gariepinus* with the THg concentration ranging from 8-20 µg/kg and *C. niloticus* had the highest THg concentration of 7-29 µg/kg wet wt (Table 6.1). Concentrations increased with trophic level and support the hypothesis proposed earlier. Accumulation of THg was significantly different between the three species (P=0.02). There was significant difference in THg between *C. gariepinus* and *O. urolepis* (P=0.00). No significant difference in THg concentration was observed between *C. gariepinus* and *C. niloticus* (P=1.00), while THg concentration between *C. niloticus* and *O. urolepis* differed significantly (P=0.00). THg concentrations in *C. niloticus* liver were significantly higher than those in muscle (P=0.00)

Generally, THg concentrations in *O. urolepis, C. gariepinus* and *C. niloticus* from this study are lower than concentrations found in other studies in Tanzania, Sub-Saharan Africa and other tropical and temperate regions (Table 6.1).

Table 6.1: Mercury concentrations at Mtera Dam with comparison with worldwide mercury concentrations in biota.

Site	Trophic Level		Tissue	THg (µg/kg wet wt)				Data Source
	Level	Species		Range	Median	Mean	SD	
Mtera Dam	1°Consumer	*O. urolepis*	Muscle	2-26	9.5			Current study
	2°Consumer	*C. gariepinus*	Muscle	8-20	11.5			
	3°Consumer	*C. niloticus*	Muscle	7-29	21			
			Liver	84-238	146			
Mindu Dam	1°Consumer	*M. rude*	Muscle	1-200		20	12.97	Mdegela *et al.* 2009
	1°Consumer	*O. urolepis*	Muscle	BDL-30				
	2°Consumer	*C. gariepinus*	Muscle	10-200		50	23.80	
Nungwe Bay	1°Consumer	Soga	Muscle	7.8-16.9		13.7	5.12	Ikungura and Akagi, 1996
	1°Consumer	*O. niloticus*	Muscle	1.8-2.9		2.4	0.42	
	1°Consumer	*C. gariepinus*	Muscle	2.1-2.3		2.2	0.06	
	3°Consumer	*L .niloticus*	Muscle	6.9-11.7		9.7	2.50	
Rwamagasa area	1°Consumer	*Haplochromis spp*	Muscle	995-2900		2060	849.89	Taylor *et al.* 2005
	1°Consumer	*O. niloticus*	Muscle	2-31		9	13.44	
	2°Consumer	*C. gariepinus*	Muscle	138-1970		1036	773.96	
Kidatu Dam	1°Consumer	*O. urolepis*	Muscle	7.0-16.9		12.1	3.62	Ikungura and Akagi, 2003
	2°Consumer	*B. orientalis*	Muscle	13.4-57.7		38.0	22.55	
	2°Consumer	*H. vittatus*	Muscle	21.8-119		51.8	45.81	
LaGrande - Canada	1°Consumer	*C. clupeaformis*	Muscle	480-570				Verdon *et al.* 1991
	3°Consumer	*E. lucius*	Muscle	1310-2990				
Guri -Venezuela	2°Consumer	*H. scomberoides*	Muscle	170-8250		2700		Veiga and Hinton, 2001
Hirvijari-Finland	3°Consumer	*E. lucius*	Muscle	1600				Porvari, 1998

6.2 Cadmium

Cadmium concentrations in *O. urolepis* samples range from <0.01-1 µg/kg. *C. gariepinus* and *C. niloticus* both had concentrations lower than detection limit (<0.001). There was no significant difference in cadmium concentrations between *O. urolepis C. gariepinus* and *C. niloticus* (P=0.51)

Muscle and liver tissues of *C .niloticus* were also compared for cadmium concentrations. Cadmium concentrations in muscles were below detection limit (<0.01 µg/kg). But for the liver tissues, cadmium ranged from 1-3 µg/kg, again suggesting the importance of the liver for the detoxication of ingesta. Generally, there was significant difference in cadmium concentration between muscle and liver tissues of *C. niloticus* (P=0.00).

Cadmium concentrations in *O. urolepis, C. gariepinus* and *C. niloticus* from this study are generally lower than concentrations found in other studies in Tanzania, and Sub-Saharan Africa (Table 6.2).

Table 6.2: Cadmium concentration at Mtera Dam with comparison with worldwide mercury concentrations in biota.

Site	Trophic Level		Tissue	THg(µg/kg wet wt)				Data Source
	Level	Species		Range	Median	Mean	SD	Current study
Mtera Dam	1°Consumer	*O. urolepis*	Muscle	<0.01-1				
	2°Consumer	*C. gariepinus*	Muscle	<0.01				
	3°Consumer	*C .niloticus*	Muscle	<0.01				
			Liver	1-3	1			
Mindu Dam	1°Consumer	*M. rude*	Muscle	90				Mdegela *et al.* 2009
	2°Consumer	*O. urolepis*	Muscle	BDL-10				
	3°Consumer	*C .gariepinus*	Muscle	BDL-10				
Azuabie creek (Nigeria)	1°Consumer	*T .mariae*	Muscle	54-56		55	0.001	Daka *et al.* 2008
	1°Consumer	*C. nigodigitatus*	Muscle	43-79		61	25	

7 DISCUSSION

7.1 Mercury

7.1.1 Total mercury in Mtera Dam

THg concentrations in *O. urolepis*, *C. gariepinus* and *C .niloticus* of Mtera Dam were below World Health Organization (WHO, 1990) reference standards. Total mercury of 500 µg/kg in aquatic species is the international limit for export markets which is followed by the United States, Canada and European Union (European Community, 1993; USEPA, 1997). World Health Organization (1990) recommend a lower guideline of 200 µg/kg for THg in aquatic species to protect vulnerable people including frequent fish consumers, pregnant women and children under the age of 15 years. Mtera Dam median THg concentrations in muscle tissues were 9.5 µg/kg, 11.5 µg/kg and 21 µg/kg for *O .urolepis*, *C. gariepinus* and *C .niloticus* respectively. Median THg concentration of *C. niloticus* liver samples was 146 µg/kg. None of the samples analysed from Mtera Dam was ≥500 µg/kg nor did they exceeded the WHO permissible limit. Only one sample from *C. niloticus* liver had a concentration of 238 µg/kg which is slightly higher than the limit set for vulnerable people. Additionally, Chvojka *et al.* (1990; Table 7.1), categorized THg concentrations as *very low*, *low*, *medium*, *high*, and *very high* depending on distribution of the values. In this regard, Mtera Dam *O .urolepis*, *C. gariepinus* and *C .niloticus* THg concentration values from muscle and liver tissues fall under *very low* category.

Table 7.1 THg concentration categories on fish (after: Chvojka *et al.* 1990)

THg (µg/kg wet wt)	Category
50-150	Very low
150-250	Low
250-350	Medium
350-450	High
>450	Very high

7.1.2 Comparison of THg concentration at Mtera Dam with other lakes

Total mercury concentrations in Mtera Dam are low and are within range with other THg concentrations in dams and lakes elsewhere in Tanzania (Bootsma and Hecky, 1993). Results of the study conducted by Mdegela *et al.* (2009) in Mindu Dam which is situated in Morogoro municipality show THg concentrations of (10-200 µg/kg) for *C. gariepinus*, 200 µg/kg for *Macrobranchium rude* and (BDL-30 µg/kg) for *O. urolepis* (Table 6.1). According to Mdegela *et al.* (2009), these THg concentrations were below the permissible limit for aquatic species set by WHO (1990).

Along the Lake Victoria Goldfields (LVGF) north of Tanzania, Ikungura and Akagi (1996) and Taylor *et al.* (2005) conducted research in Nungwe Bay and

Rwamagasa area respectively. THg concentrations in LVGF (which is occupied by artisanal miners practicing mercury-based amalgamation to separate gold) were slightly higher than those of Mtera Dam. In Rwamagasa area, *Haplochromis spp* were found to have higher THg than other species regardless of the fact that they are primary consumers (Table 6.1). In Nungwe Bay, Ikungura and Akagi, (1996) found low THg concentrations in fish. The THg concentrations found were below those found in non polluted fresh water lakes as documented by WHO (1976). THg concentrations found in finfish from Africa inland waters range from 10-53 µg/kg (mean: 35 µg/kg) (Biney *et al.* 1994).

East African fish THg concentrations tend to be lower than concentration in fish from the Trapajós River in Brazil (which is also polluted by artisanal miners) with THg concentrations ranging from 40-3800 µg/kg (Maim *et al.* 1995). Additionally, in Guri Reservoir, Venezuela, carnivorous fish had THg concentrations ranging up to 8250 µg/kg (Bermudez *et al.* 1999).

THg concentration from fish in temperate regions also had concentration values which are much higher than found in Tanzania. In both Canada and Finland, fish species like lake white fish (*Coregonus clupeaformis)* and northern pike (*Esox lucius*) exhibited high THg concentrations (Table 6.1).

7.1.3 Understanding low THg concentration values in Tanzanian waters

Ikungura and Akagi (2003) observed low THg concentrations (1-140 μg/kg) in fish found in hydroelectric reservoirs and suggested that the dynamics of mercury cycling could be the underlying factor for the slow THg bioaccumulation in fish. Mercury cycling is determined by trophic dynamics (community composition and feeding relation) in reservoirs. Total mercury concentrations in forage and predatory fish are strongly related to the amount of dissolved organic carbon. In Tanzanian reservoirs Ikungura and Akagi (2003) documented very low organic matter, intense sunlight and iron-rich laterite soil which binds THg and decreases its mobility and bioavailability. According to Campbell *et al.* (2003) THg concentrations in Lake Victoria are limited by 1) a short food-chain length, 2) increased growth dilution in fast- growing fish including higher tissue turnover in tropical biota, 3) biomass dilution in eutrophic water and 4) the biogeochemistry of the lake. Biogeochemistry of the lake is largely influenced by the intense solar radiation which penetrates the photoactive zone (top 2 meters of the lake) and rapidly cause photodegradation of THg which is then lost from the lake by volatilization.

Mdegela *et al.* (2009) suggested that mercury detection at comparable levels in different sites in Mindu Dam could entail common background sources such as soil erosion, weathering of rocks and deposition from air and not the anthropogenic sources. In Lake Victoria, van Straaten (2000) ruled out gold mining as a major contributing factor for mercury pollution in the lake pointing out that it only affects localities near mercury amalgamation sites. Bootsma and Hecky (1993) proposed that

burning of organic materials both for fuel and to clear agriculture land is linked to mercury pollution in Lake Victoria.

Campbell *et al.* (2003) associated shallow, clear water coupled with rapid photo-degradation under intense sunlight in Lake Victoria as limiting factors for THg bioaccumulation in aquatic species. Though there are no hotspots for THg in the study area, low THg concentrations in Mtera Dam biota can also be associated with the following factors. Firstly, Mtera Dam is generally shallow with an average depth of 8.5 m, and over the last ten years the dam had experienced periods of extensive water level fluctuations due to excessive water extraction for both agriculture and electricity production (Coppolillo *et al.* 2006). As a consequence, especially in the year 2006, the water level dropped below the 'dead storage' (minimum water level below which power production turbines are shut down) and it remained so for several months (Figure 7.1). Secondly, in Mtera fire is probably playing a major role in mercury pollution. As Dwyer *et al.* (2000) observed, burning of plant materials and animal waste as fuel is prevalent in African countries. Around Mtera Dam numerous fire incidences were recorded from 2000-2007 (Erickson, 2008; Figure 7.2). As it was in the case for Lake Victoria, here fire could have the similar effect in THg pollution in Mtera Dam.

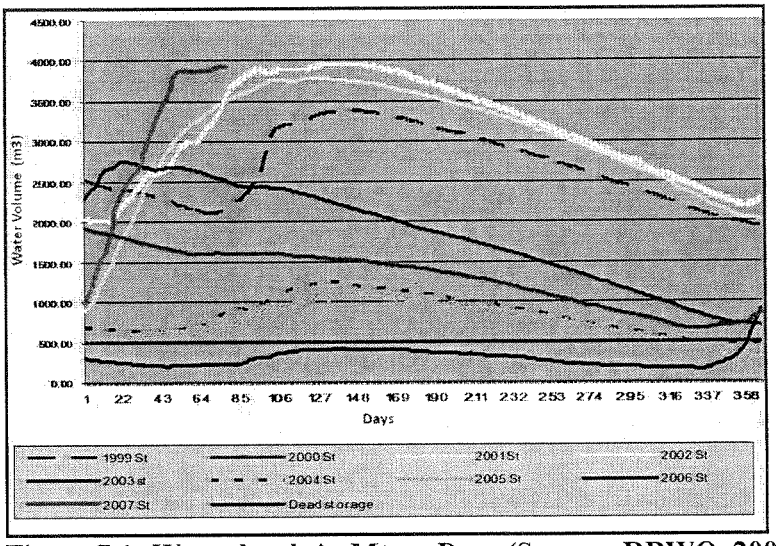


Figure 7.1: Water levels in Mtera Dam (Source; RBWO, 2006)

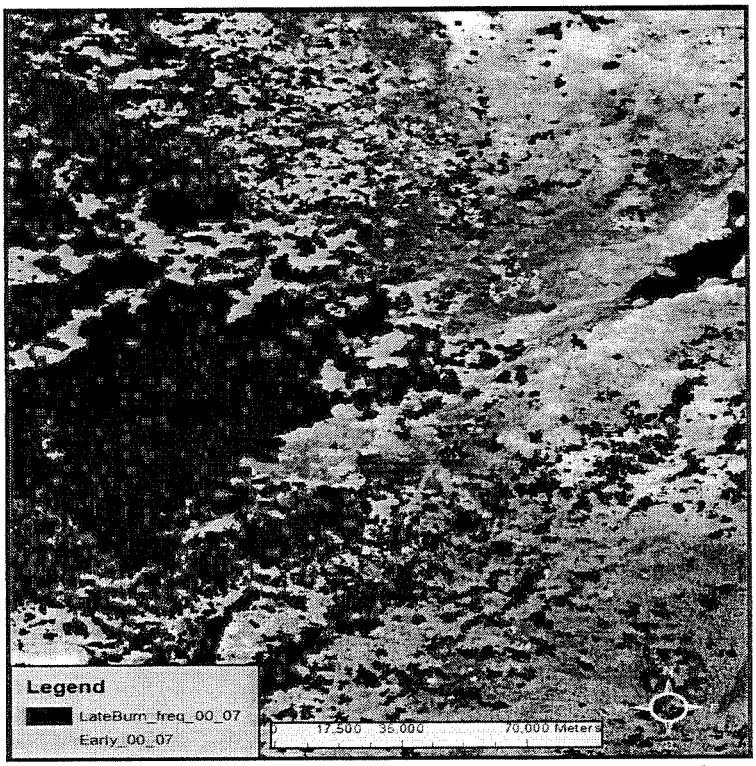


Figure 7.2: Fire sightings in areas around Mtera Dam from 2000-2007; yellow colour indicates early burn (April-July) and red colour indicates late burn (August-November) (Source; Erickson, 2008)

7.1.4 Daily THg intake guidelines for residents of the Mtera region

Tolerable daily THg intake was determined for residents of Mtera region regarding maximum daily consumption according to WHO (2006) safety limit standards (Table 7.2). Based on TDI calculation, an average person of 60 kg body weight could eat up to 1.5 kg of *O .urolepis* or 1.2 kg of *C. gariepinus* or 0.7 kg of *C. niloticus* muscles everyday in Mtera region without exceeding THg consumption guidelines.

Table 7.2: Tolerable daily intake based on THg

Species	Median THg (µg/kg)	Maximum daily consumption (kg)
O. urolepis	9.5	1.5
C .gariepinus	11.5	1.2
C. niloticus	21	0.7

7.2 Cadmium

7.2.1 Cadmium in Mtera Dam in comparison with worldwide concentrations

Different countries and regions have set their own limit standards to be followed in their respective countries and /or regions as there is no agreed international limit standard for cadmium intake (Ashraf, 2006; Mdegela *et al.* 2009). As a country Tanzania has not yet established limits governing cadmium intake (Mdegela *et al.* 2009). Therefore European Union (EU) limits will be used for comparison. Current EU legislation specifies the maximum cadmium limits in fish meat as 50 µg/kg.

Cadmium concentrations in *O .urolepis*, *C. gariepinus*, and *C. niloticus* in Mtera Dam were extremely low compared to the limits set by EU (2005). In Mtera, cadmium concentrations in muscle tissues were a little inconsistent as higher concentrations were found in *O. urolepis* (range 0.01-1 µg/kg) despite it being at a low trophic level. *Oreochromis urolepis* with highest concentrations came from Chamdubwi landing site. In both *C. gariepinus*, and *C. niloticus* muscle, cadmium concentrations were below 0.01 µg/kg which was the detection limit. Livers contained higher cadmium concentrations among *C. niloticus* tissues ranging from 1-3 µg/kg. Cadmium was undetectable in muscle tissues of *C. niloticus*.

Mdegela *et al.* (2009) observed similar findings from Mindu Dam in Morogoro region, Tanzania. Although cadmium concentrations in Mindu Dam biota were slightly higher than those of Mtera Dam (Table 6.2), Mdegela *et al.* (2009) concluded that cadmium does not pose any threat to consumers in urban and peri-urban areas in Morogoro municipality based on the levels found.

Results from the study conducted in Rwamagasa area in LVGF show slightly elevated cadmium concentrations in sediment and soils (Taylor *et al.* 2005). No significant risk was evident for people eating produce grown in the Rwamagasa artisanal gold mining center since cadmium concentrations in sediment and soils ranged from <500-700 µg/kg and are below the toxic threshold of 3000 µg/kg (Environment Canada, 1992 quoted in Haines *et al.* 1994).

In Nigeria, cadmium concentrations in *Tilapia mariae* ranged from 54-56 µg/kg (mean: 55 µg/kg) and *Chrysichtyses nigodigitatus* ranged from 43-79 µg/kg (mean: 61 µg/kg). Unlike the case for Tanzania, these concentrations were above the EU limit of 50 µg/kg for fish meat (Ashraf, 2006; Şireli *et al.* 2006; Daka *et al.* 2008).

7.2.2 Daily cadmium intake in Mtera

A provisional tolerable intake of cadmium for humans is 400-500 µg per week. This limit was suggested by the joint Food and Agricultural Organization/ World Health Organization (FAO/WHO) Expert Committee on Food Activities (CIFA, 1992). Cadmium concentrations found in *O. urolepis, C. gariepinus* and *C. niloticus* were mostly below the detection limit of 0.01 µg/kg making the calculation for maximum daily cadmium intake impossible. But the cadmium concentrations in aquatic biota of Mtera suggest that the likelihood of obtaining high cadmium dosage from eating fish and/or crocodiles is low. Since consumption limits for THg were much lower, same limits can be used as threshold for cadmium tolerable daily intake.

8 CONCLUSION AND RECOMMENDATIONS

In Mtera the highest median THg concentrations were found in *C. niloticus* (21 µg/kg) for the muscles and (146 µg/kg) for the liver tissues. *Oreochromis urolepis*, the most important commercial fish in Mtera Dam contained the lowest THg concentration of (9.5 µg/kg) while *C. gariepinus* contained THg concentrations of (11.5 µg/kg).

Cadmium concentrations in muscle tissues of *O. urolepis* range from < 0.01-1 µg/kg and were below the detection limit of 0.01 µg/kg in both *C. gariepinus* and *C. niloticus* muscles. In *C. niloticus* liver tissues cadmium concentrations ranged from 1-3 µg/kg.

THg concentrations in Mtera are below the limit standard of 500 µg/kg set by WHO for aquatic species. Also cadmium concentrations in Mtera are below the USEPA limit of 200 µg/kg for aquatic species.

Generally, THg and cadmium concentrations in *O. urolepis C. gariepinus* and *C. niloticus* in Mtera Dam appeared to be lower than natural concentrations documented from unpolluted freshwater lakes around the world. For example THg concentrations in Mtera were three to 24 times lower than the average concentration reported in top predator fish species in Brazil (Tucurui) and Venezuela (Guri) reservoirs (20-6040 µg/kg) which are also situated in tropical regions and have similar sources of pollution including artisanal mining. Lower THg and cadmium

concentrations in Mtera could possibly reflect a clean dam environment that has not been severely impacted by anthropogenic sources; rather the pollution might have resulted from natural sources or human mediated natural causes e.g. fire.

In view of the present low THg and cadmium concentrations levels in *O. urolepis, C. gariepinus* and *C. niloticus* in Mtera Dam, it is safe to say that consumption of these aquatic species do not seem to pose any significant human health risks in terms of THg and cadmium exposure. Therefore people can safely eat up to 1.5 kg of *O. urolepis* or 1.2 kg of *C. gariepinus* or 0.7 kg of *C. niloticus* everyday and remain within WHO standards for THg and cadmium consumption based on the levels found.

However in order to ensure the clean Mtera Dam persists, then it is worth making sure that sources of pollution are addressed most notably fire. Fire may contribute in heavy metal (THg) pollution in Mtera Dam though so far its magnitude and extent is not known. It is however recommended that thorough study is conducted to determine the impact of current fire practices around the Mtera Dam.

Generally, it is recommended that future studies should focus on:

- Assessing why heavy metal concentration levels in Tanzanian waters are so low compared to other countries
- Including samples from water, sediment, biota, and human to obtain a broader picture of heavy metal concentrations and their sources (natural or anthropogenic)

- Comparing metal concentrations in Mtera Dam with concentrations in upstream rivers and describing the concentration trend whether it is increasing or decreasing towards Mtera Dam.

9 REFERENCES

Al-Shawi, A. W. and Dahl, R., 1999: The determination of cadmium and six other heavy metals in nitrate/phosphate fertilizers solution by ion chromatography, *Analytica Chimica Acta*, 391:35-42.

Anderson, M.R., Scruton, D.A., Williams, U.P. and Payne, J.F., 1995: Mercury in fish in the Smallwood Reservoir, Labrador, twenty one years after impoundment, *Water Air Soil Pollution*, 80: 927-930.

Ashraf, W., 2006: Levels of selected heavy metals in tuna fish, *Arabian Journal of Science and Engineering*, 31: 89-92.

Baker, D., 2009: Mercury detoxication. http://www.y2khealthanddetox.com/mercdetox.html accessed on the 10th September 2009.

Bermudez, D., Gali, G., Carneiro, F., Paolini, J., Venegas, G. and Marquez, O., 1999: *Mercury exposure through fish consumption in riparian populations at reservoir Guri, using nuclear techniques*, Bolivar State, Venezuela. IAEA CRP Report VEN-10882 (p10).

Biney, C., Amuzu, A.T., Calamari, D., Kaba, N., Mbome, I. L., Naeve, H., Ochumba, P.B.O., Osibanjo, O., Radegonde, V. and Saad, M.A.H., 1994: Review of heavy metals in the African aquatic environment, *Ecotoxicology and Environmental Safety*, 28: 134-159.

Boon, J.P., Lewis, W.E., Tjoen-A-Choy, M.R., Allchin, C.R., Law, R.J., De Boer, J., Ten Hallers-Tjabbes, C.C. and Zegers, B.N., 2002: Level of polybrominated diphenyl ether (PBDE) flame retardants in animals representing different trophic levels of the North Sea food web, *Environmental Science and Technology*, 36: 4025-4032.

Bootsma, H. A. and Hecky, R. E., 1993: Conservation of the African Great Lakes: A limnological perspective, *Conservation Biology*, 7:644–656.

Bravard, S. and Righi, D., 1990: Podzols in Amazonia, *An Interdisciplinary Journal of Soil Science- Hydrology- Geomorphology focusing on Geocology and Landscape Evolution*, 17:461-475.

Campbell, L.M., Dixon D.G. and Hecky, R.E., 2003: A review of mercury in Lake Victoria, East Africa: implications for human and ecosystem health, *Journal of Toxicology and Environmental Health Part B*, 6:325-356.

Chambers, B.J., Nicholson, F.A. and Soloman, D.R., 1998: *Heavy metal loadings from animal manures to agricultural land in England and Wales*. ADAS Gleathorpe Research Center, Meden Vale, Mansfield, Notts. NG20 9PF, UK, 475-483.

Chvojka, R., Williams, J. and Fredrickson, S., 1990: Methlymercury, total mercury and selenium in snapper from two areas of the New South Wales coast, Australia, *Marine Pollution Bulletin*, 21: 570-573.

CIFA , (1992) *Report of the third session of the working party on pollution and fisheries.* (FAO Fisheries report No.471). Rome: United Nations.

Clark, R. B., 1992: *Marine Pollution*, 3rd edn. Oxford University Press, New York, NY, USA.

Coppolillo, P., Demment, M. and Mbano, B., 2006: *Current wetland management practices in the Usangu sub catchment: A review of drivers, pressures, state, impacts and responses*. Report p 03.

Costa, L.G., 2006: Current issues in organophosphate toxicology, *Clinica Chimica Acta*, 366(1-2):1-13.

Daka, E.R., Ekeh, C.A. and Molsen, M., 2008: Cadmium and lead levels in some fish species from Azuabie creek in the Bonny Estuary, Nigeria, *African Journal of Biotechnology*, 7(1): 063-064.

Davydova, S., 2005: Heavy metals as toxicants in big cities, *Micro-chemical Journal*, 79: 133-136.

Dick, R.P., 1992: A review: long term effects of agricultural systems on soils biochemical and microbial parameters, *Agriculture Ecosystem and Environment*, 40:25-36.

Don-Pedro, K.N., Oyewo, E.O. and Otitoloju, A.A., 2004: Trend measurement of heavy metals in Lagos lagoon ecosystems, Nigeria, *West Africa Journal of Applied Ecology*, 5: 103–114.

Duffus, J.H., 2002: "Heavy metals" a meaningless term? (IUPAC Technical Report)", *Pure and Applied Chemistry*, 74:793-807.

Dwyer, E., Pinnock, S., Grégoire, J.M. and Pereira, J. M. C., 2000: Global spatial and temporal distribution of vegetation fire as determined from satellite observations, *International Journal of Remote Sensing*, 21:1289–1302.

Eisler, R., 1987: Mercury hazards to fish wildlife and invertebrates: a synoptic review, *U.S. Fish and Wildlife Service Biological Report*, 85:1-10.

Ekstrand, G., 1997: *Great Ruaha River and river basin upstream of the Mtera Reservoir. Environmental Assessment of the Mtera Reservoir, Tanzania, in a 20- year Perspective Stockholm*: SWECO p 25-27.

Epaphras, A.M., Gereta E., Lejora I.A., Ole Meing'ataki, G.E., Ng'umbi G., Kiwango, Y., Mwangomo, E., Semanini, F., Vitalis, E., Balozi, J. and Mtahiko, M.G.G., 2007: Wildlife water utilization and importance of artificial waterholes during dry season at Ruaha National Park, *Wetlands Ecology and Management*, 16 (3): 183-188.

Erdogrul, Ö., Covaci, A. and Schepens, P., 2005: Levels of organochlorine pesticides, polychlorinated biphenyls and brominated diphenyl ethers in fish species from Kahramanmaras, Turkey, *Environmental International*, 31:703-711.

Erickson, D., 2008: *Ruaha Landscape Program Preliminary Fire Analysis*, WCS Ruaha Landscape Program, Iringa, Tanzania.

EU, 2005: Commission Regulation (EC) No: 78/2005 of 16 January 2005 amending Regulation EC No: 466/2001 as regards heavy metals, *Official Journal L* 16/43. 20/1/2005, p. 43-45.

European Economic Community, 1993: *Commission decision of 19 May 1993 determining analysis methods, sampling plans and maximum limits for mercury in fishery products*. 16 June. Brussels, Belgium: EEC. 393D0351 93/351/EEC. http://europa.eu.int/eur-lex /en/lif/dat/1993/en_393D0351.html.

Evanko, C.R. and Dzombak, D.A., 1997: Remediation of Metals-Contaminated Soils and Groundwater, Technology Evaluation Report.

FDA, 1987: Compliance Policy Guide. Food and Drug Administration, Washington D.C.

Forsberg, B.R., Jardim, W.F., Zeidemann, V.K., Fadini, P.S., Carneiro, A., Padovani, C.R., Silver-Forsberg, M.C., Roulet, M., Lucotte, M., Nakazono, E.M., Martins, A.E. and Chaagas, E.C., 1999: The biogeochemistry of mercury in the Negro River basin (Brazilian Amazon) Proceedings of the 5th International Conference on Mercury as a Global Pollutant Rio de Janeiro: 153.

Foulke, J.E., 1994: Mercury in Fish: Cause for Concern, Food and Drug Administration Consumer, September 1994.

Friedlander, G., Kennedy, J.W., Marcias, E.S. and Miller, J.M., 1981: *Nuclear and Radiochemistry*, Wiley, New York, 640-641.

GEF, 2001: Feature: Artisanal gold mining without mercury pollution, Vienna Austria. Feb 2001.

Gereta, E. and Wolanski E., 1998: Wildlife –water quality interactions in the Serengeti National park, Tanzania, *African Journal of Ecology*. 36(1):1-14.

Gillingham, A.G. and Thorrold, B.S., 2000: A review of New Zealand research measuring phosphorus runoff from pasture, *Journal of Environmental Quality*, 29:88-96.

Global Mercury Project, 2007: Report to the UNEP Governing Council Meeting; Nairobi, Feb. 2007.

Gonick, H. C., 2008: Nephrotoxicity of cadmium and lead: Division of nephrology, West Los Angeles healthcare center, Los Angeles, California, USA, *Indian Journal of Medical Research*, 128: 335-552.

Govindaswamy, N., Moy, J., Millar, M. and Koch, S. A., 1992: "A distorted mercury $[Hg(SR)_4]^{2-}$ complex with alkanethiolate ligands: the fictile coordination sphere of monomeric [Hg(SR)x] complexes", *Inorgarnic. Chemistry*, 26: 5343.

Haines, M.L., Brydges, K., MacDonald, M.J., Smith, S.L. and MacDonald, D.D., 1994: A review of environmental quality criteria and guidelines for priority substances in the Fraser River Basin. Supporting Documentation. DOE FRAP 1994-31. Vancouver7 Environment Canada.

Hatakeyama, S. and Yasuno, M., 1981: A method for assessing chronic effects of toxic substances on the midge Paratanytarsus parthenogeneticus – effects of copper, *Archive of Environmental Contamination and Toxicology*, 10: 705–715.

Ikingura, J.R. and Akagi, H., 1996: Monitoring of fish and human exposure to mercury due to gold mining in the Lake Victoria goldfields, Tanzania, *Science of the Total Environment*, 191(1–2):59–68.

Ikingura, J.R. and Akagi, H., 2003: Total mercury and methylmercury levels in fish from hydroelectric reservoirs in Tanzania, *Science of the Total Environment*, 304: 355-368.

Irukayama, K., 1966: The Pollution of Minamata Bay and Minamata Disease. In Proceedings: Third International Conference, Water Pollution Resources, Water Pollution Control Federation, Washington D.C. 430–438.

IRUWASA, 2008: Urban Water Supply Project in Iringa, Tanzania http://madeingermany.de/en/africa/2010/report/show/id/331/title/Urban+Water+Supply+Project+in+Iringa,+Tanzania/ accessed on the 13th October 2009.

Jarvis, S.C., Schofield, D. and Pain, B., 1995: *Nitrogen cycling in grazing systems*. In: Bacon P.E (ed), Nitrogen fertilization in the Environment. Marcel Dekker Inc, New York, p. 381-419.

JICA, 1999: Country profile on environmental- Tanzania. JICA report.

Khangarot, B.S., Mathur, S. and Durve, V.S., 1982: Comparative toxicity of heavy metals and interaction of metals on a freshwater pulmonate snail, Lymnaea acuminata L. *Acta Hydrochimica et Hydrobiologica*, 10, 367–375.

Kiffney, P.M. and Clement, W.H., 1993: Bioaccumulation of heavy metals by benthic invertebrates at the Arkansas River, Colorado, *Environmental Toxicology and Chemistry*, 12: 1507–1517.

Krauskopf, K.B. and Bird, D.K., 1995: *Introduction to Geochemistry*, Mc Graw-Hill, Inc., 647.

Kurdland, L., 1960: Minamata disease, *World Neurology*, 1:370.

LaGrega, M.D., Buckingham, P.L. and Evans, J.C., 2001: *Hazard waste management*, Environmental Resource Management, MC Graw Hill, New York, 2nd Edition, 1202p, ISBN 0-07-039365-6.

Lange, T. R., Royals, H.E. and Connor, L.L., 1994: Mercury accumulation in largemouth bass (Micropterus *salmoides*) in a Florida lake, *Archive of Environmental Contamination and Toxicology*, 27: 266-471.

Lann, H., 1985: Is environmental pollution a problem in Tanzania? A paper presented at the media workshop on environment and development, Arusha, Tanzania.

Lann, H. and Mbagi, Y., 1986: *The river Msimbazi, Dar es Salaam: Investigation of water quality and discharge of wastewater into the river and its tributaries (1984-1986).*

Report to the ministry of Lands, Water, Housing and Urban Development. Environmental Protection and management Section, Dar es Salaam, Tanzania.

Lauretta, D.S., Klaue, B., Blum, J.D. and Buseck, P.R., 2001: Mercury abundances and isotopic compositions in the Murchison (CM) and Allende (CV) carbonaceous chondrites, *The Journal of both the Geochemical Society and the Meterioritical Society*, 65(16): 2807-2818.

Leader Williams, N., Kayera J.A. and Overton, G.L., 1996: *Mining in Protected Areas in Tanzania;* International Institute for Environmental and Development. Wildlife and Development Series No. 9

Leaner, J., 2007: http://www.waternet.co.za/samercury/facts.html accessed on 5th September 2009.

Lechler, P.J., Miller, J.R., Lacerda, L.D., Vinson, D., Bonzogo, J.-C., Lyons, W.B. and Warwick, J.J., 2000: Elevated mercury concentrations in soils, sediment, water and fish of the Madeira River basin, Brazilian Amazon: a function of natural enrichments? *Science of the Total Environment*, 260 (2000): 87-96.

Ledgard, S.F., De Klein, Crush, J.R. and Thorrold, B.S., 2000: Dairy farming, nitrogen losses and nitrate-sensitive areas. Proceedings, *New Zealand Society of Animal Production*, 60: 256-260.

Levine, M.B., Hall, A.T., Barrett, G.W. and Taylor, D.H., 2006: Heavy Metal Concentrations during Ten Years of Sludge Treatment to an Old-field Community, *Journal of Environmental Quality*, 18:411-418.

Liebig, M.A. and Doran, J.W., 1999: Impact of organic production practices on soil quality indicators, *Journal of Environmental Quality*, 28:1601-1609.

Luoma, S.N and Lee B.G., 1998: *Influence of microalgal biomass on absorption efficiency of Cd, Cr and Zn by two bivalves from San Fransico Bay* .US Geological Survey, Middlefield Rd. Menlo Park, Calfornia.

Mackie, G.L., 1989: Tolerances of five benthic invertebrates to hydrogen ions and metals (Cd, Pb, Al), *Archive of Environmental Contamination and Toxicology*, 18: 215–223.

Maim, O., Branches, F.J.P. , Akagi, H., Castro, M.B., Pfeiffer, W.C., Harada, M., Bastos, W.R. and Kato, H., 1995: Mercury and methylmercury in fish and human hair from the Tapajos river basin, Brazil, *Science of the Total Environment*, 175:141-150.

Masazumi, H., 1972: *Minamata Disease*, Kumamoto Nichinichi Shinbun Centre & Information Center/Iwanami Shoten Publishers. ISBN 4-87755-171-9 C3036.

Mason, R.P., Fitzgerald, W.F., Hurley, J.P., Hanson, A.K., Jr., Donaahay, P.L and Sieburth J.M., 1993: Mercury biogeochemical cycling in a stratified estuary, *Limnology and Oceanography*, 38: 1227-1241.

Mdegela, R.H., Braathen, M., Pereka, A.E., Mosha, R.D., Sandvik, M. and Skaare, J.U., 2009: Heavy metals and organochlorine residues in water, sediment and fish in aquatic ecosystems in urban and peri-urban areas in Tanzania, *Water, Air and Soil Pollution*, 203: 369-379.

Morel, F. M. M., Kraepiel, A. M. L. and Amyot, M., 1998: The chemical cycle and bioaccumulation of mercury, *Annual Review of Ecology and Systematics*, 29:543–566.

Morrison, K.A. and Therien, N., 1995: Changes in mercury levels in lake whitefish (*Coregonus clupeaformis*) and northen pike (*Esox lucius*) in the LG-2 reservoir since flooding, *Water Air Soil Pollution*, 80: 819-828.

Mortvert, J.J., 1996: *Heavy metal contamitants in inorganic and organic fertilizers.* Department of Soil and Crop Sciences, Colorado State University, Fort Collins, CO 80523 USA.

Mtahiko, M.G.G., Gereta, E., Kajuni, A.R., Chiombola, E.A.T., Ng'umbi, G.Z., Coppolillo, P. and Wolanski, E., 2006: Towards an ecohydrology-bssed restoration of the Usangu wetlands and the Great Ruaha River, Tanzania, *Wetlands Ecology and Management*, 14:489-503.

Mwambete, I., 1991: Tanzania fertilizer mineral deposits, *Fertilizer Research*, 30: 181-185.

NEMC, 1990: National environment management council, programme on purification of industrial wastewaters (phase 1). UNIDO country paper, Dar es Salaam, Tanzania.

Otitoloju, A.A., 2003: Relevance of joint action toxicity evaluations in setting realistic environmental safe limits of heavy metals, *Journal of Environmental Management*, 67: 121–128.

Otitoloju, A.A. and Don-Pedro, K.N., 2004: Integrated laboratory and field assessments of heavy metals accumulation in edible periwinkle, Tympanotonus fuscatus var radula (L), *Ecotoxicology and Environmental Safety*, 57: 354–362.

Parrington, J.R., Knox, H.D., Breneman, S.L., Baum, E.M. and Feiner, F., 1996: Nuclides and Isotopes Chart of the Nuclides; 15 ed; GE Nuclear Energy Lockheed Martin

Perelman, A.I., 1977: *Geochemistry of Elements in Supergene zone*, Keter, eds. Publishing House Jerusalem Ltd.

Porvari, P., 1998: Development of fish mercury concentrations in Finnish reservoirs from 1979 to 1994, *Science of the Total Environment*, 213:279 –290.

RBWO, 2006: Annual reservoir levels from Mtera Dam. Rufiji Basin Water Office report: December 2006, Iringa, Tanzania.

Rogers, D.W., Dickman, M. and Han, X., 1995: Stories from old reservoirs: sediment Hg and Hg methylation in Ontario hydroelectric developments, *Water, Air and Soil Pollution*, 80: 829-839.

Roulet, M., Lucotte, M., Farella, N., Serique, G., Coelho, H., Sousa Passos, C.J., De Jesus Dasilva, E., Scavone De Andrade, P., Mergler, D Guimaraes, D. and Amorin, M., 1999: Effects of recent human colonization on the presence of mercury in Amazonian ecosystems, *Water, Air and Soil Pollution*, 112: 297-313.

Schülter, K., 2000: Review evaporation of mercury from soils. An intergration and synthesis of current knowledge, *Environmental Geology*, 39:3-4

Schwartz, D., 1988: Some podzols on Bateke sands and their origin, Peoples Republic of Congo, *Global Journal of Soil Science*, 43: 229-248.

Sharpley, A.N., Chapra S.C., Wedepohl R., Sims J. T., Daniel T.C. and Reddy K.R., 1994: Managing agricultural phosphorus for protection of surface waters: issues and options, *Journal of Environmental Quality*, 32: 437-451.

Şireli, U.T., Göncüoğlu,M., Yıldırım,Y., Gücükoğlu, A. and Çakmak,Ö., 2006: Assessment of Heavy Metals (Cadmium and Lead) in Vacuum Packaged Smoked Fish Species (Mackerel, *Salmo salar* and *Oncorhynhus mykiss*) Marketed in Ankara (Turkey) E.U., *Journal of Fisheries and Aquatic Sciences*, 23(3-4): 353–356.

Slack, A.V., 1968: Phosphoric acid, Part II, chapter 6-8 Marcel Dekker, New York.

SMUWC, 2002: The Sustainable Management of the Usangu Wetland and its Catchment , September 1998- March 2003, vol 20, UK Department of International Development and Ministry of Water and Livestock, Dar es Salaam.

Sosovele, H. and Ngwale, J.J., 2002: Socio-Economic Root Causes of the Loss of Biodiversity in the Ruaha Catchment Area, WWF- Tanzania.

Stoichev, T., Amouroux, D., Wasserman, J.C., Point, D., De Diego, A., Bareille, G. and Donard, O.F.X., 2004: Dynamics of mercury species in surface sediments of amacrodital estuarine-coastal system (Adour River, Bay of Biscay), *Estuaries, Coast and Shelf Science*, 59: 511-521.

SWECO, 1997: Environmental Assessment of the Mtera Reservoir, Tanzania, in a 20 –year Perspective. Stockholm: SWECO, 1997. (p 247)

Syers, J.K., Mackay, A.D., Brown, M.W. and Currie, C.D., 1986: "Chemical and physical characteristics of phosphate rock materials of varying reactivity". *Journal of the Science of Food and Agriculture* 37: 1057–1064.

Taylor, H., Appleton, J.D., Lister, R., Smith, B., Chitamweba, D., Mkumbo, O., Machiwa, J.F., Tesha, A.L. and Beinhoff, C., 2005: Environmental assessment of mercury contamination from the Rwamagasa artisanal gold mining centre, Geita District, Tanzania, *Science of the Total Environment*, 343(1-3): 111-133.

Trueman, N.A., 1965: "The phosphate, volcanic and carbonate rocks of Christmas Island (Indian Ocean)", *Journal of Geological Society of Australia*, 12: 261–286.

Ullrich, S.M., Tanton, T.W. and Abdrashitova, S.A., 2001: Mercury in the aquatic environment: a review of factors affecting methylation, *Critical Reviews in Environmental Science and Technology*, 31(3): 241-293.

UNEP, 1982: Industrial sources of marine and costal pollution in the East African Region. UNEP Regional Seas Report and Studies No 7.

UNIDO, 1991: Leather industry. A paper presented at the conference on ecological sustainable industrial development, Copenhagen, Denmark, 14-18 October, 1991.

URT, 1997: Iringa region Socio-economic profile. Planning Commission and Regional Commissioners Office, Iringa, Tanzania.

Urum, K., Pekdemir, T. and Copur M., 2004: Surface treatment of crude oil contaminated soils, *Journal of Colloid and Interface Science*, 276: 456-464.

USEPA, 1997: Mercury study report to congress (Vol.III): Fate and transport of Hg in the environment.

Van der Oost, R., Beyer, J. and Vermeulen, P.E., 2003: Fish bioaccumulation and biomarkers in environmental risk assessment: a review, *Environmental Toxicology and Pharmacology*, 13:57-149.

Van Straaten, P., 2000: Mercury contamination associated with small scale gold mining in Tanzania and Zimbabwe, *Science for Total Environment*, 259:105–113.

Varma, M.M., Serdahely, S.G. and Katz, H.M., 1976: Physiological effects of trace elements and chemicals in water, *Journal of Environmental Health*, 39: 90–100.

Veiga, M. M. and Hinton, J.J., 2001: Mercury bioaccumulation by aquatic biota in hydroelectric reservoiurs: Review and consideration of the mechanisms. Paper presented at the 1st International forum of mercury problem in hydro electric reservoir: The Guri case Boliver state, Venezuela, Org. IAMOT/UNEG, Ciudad Bolivar.

Verdon, R., Brouard, D., Demers, C. and Lalumiere, R., 1991: Mercury evolution (1978-1988) in fishes of the La Grande Hydroelectric Complex, Quebec, Canada, *Water Air and Soil Pollution*, 56:405-417.

Vermeul, R.M., van Ede, C.G.H., Mutsaers, P.C.M. and Kolmeijer, N.W., 1995: Phosphorus and Potassium, Jan-Feb (1995):27.

WCS, 2006: Water poisoning report, Iringa, Tanzania October 2006.

WCS, 2007: Fish survey report for the Great Ruaha River Catchment Area, Iringa Tanzania November 2007.

Webb, M., 1979: Interaction of Cadmium with cellular components. In Webb M (ed) *The Chemistry, Biochemistry and Biology of Cadmium*. Elsevier/ North Holland Biomedical Press, New York, p 285-340.

Webber, M.D., Kloke, A. and Tjell J., 1984: A review of current sludge use guidelines for the control of heavy metal contamination in soils. In Hermite PL and Ott H (eds) *Processing and use of Sewage Sludge* Reidel Publishing Co., Dordrecht, The Netherlands.

WHO, 1976: Environmental Health Criteria 1: Mercury, World Health Organisation, Geneva.

WHO, 1990: World Health Organization. Environmental Health Criteria No. 101: Methylmercury.Geneva.

WHO, 2005: Mercury in Drinking-water. Background document for development of WHO *Guidelines for Drinking-water Quality*. WHO/SDE/WSH/05.08/10, World Health Organization, Geneva.

WHO, 2006: Chemical aspects. In: World Health Organization.Guidelines for Drinking-Water Quality Standards. Incorporating First Addendum. Vol. 1, Recommendations.3rd ed, 145–196.

Wiener, J.G., Krabbenhoft, D.P., Heinz, G.H. and Scheuhammer, A.M., 2003: "*Ecotoxicology of mercury*," Chapter 16 *in* Hoffman, D.J., B.A. Rattner, G.A., Burton, Jr., Cairns, J. Jr., eds., Handbook of Ecotoxicology, 2nd edition.: Boca Raton, Florida, CRC Press, p. 409-463.

Yhdego, M., 1995: Environmental pollution management for Tanzania: towards pollution prevention, *Journal of Cleaner Production*, 3:143-151.