MERCURY CONTAMINATION IN DOMESTIC DUCKS IN GEITA, NORTHWEST TANZANIA

C Kinabo[*1] and H Lyatuu[2]
[1]Department of Geology, University of Dar es Salaam,
P.O. Box 35052 Dar es Salaam, +255 478 48 88 20; Fax +255 22 241 0481;
Email: kinabo_2003@yahoo.co.uk
[2]Keko Pharmaceutical Industries Ltd,
Phone +255 2 22866237 Dar es Salaam, Tanzania

ABSTRACT

*Total mercury concentrations (THg) were determined in domestic ducks (*Anas platyrhncha*) tissues in Mgusu Village, Geita District NW Tanzania. Elevated mercury levels were found in all tissue samples and showed a trend of increasing mercury concentration with weight/age of the poultry. Highest total mercury (THg) levels (mg/kg) in domestic ducks were found in liver (ducklings: 30.5; juvenile: 254.1; mature ducks: 590.2), followed by gizzards (ducklings: 45.9; juvenile: 230.3; mature: 254.6), lungs (ducklings: 12.2; juvenile: 29.1; mature: 46.9) and feathers (ducklings: 0.1; juvenile: 62.1; mature: 198.3). Corresponding THg statistical values (mg/kg) for the tissues increased with age and weight. Highest THg values were found in liver and gizzard suggesting prevalent mercury accumulation in body through ingestion. Low values of THg in lungs were correlated with inhalation of atmospheric Hg, while in feathers they were correlated to THg exposure during bathe in amalgamation pond waters*.

INTRODUCTION

Concerns were raised in 1990s when various research institutions began releasing data showing prevalent, elevated concentrations of mercury in soils, sediments, water (Mutakyahwa *et al*. 1996, MEM 1996) and freshwater fish (Harada *et al*. 1999), from the artisanal and small scale gold mining camps in Tanzania. The camps use amalgamation process to recover gold from gold ores. The ore is initially finely ground then mixed with water to form a pulp. The pulp is then mixed with liquid mercury allowing the gold to amalgamate onto mercury to form spongy amalgam. After a press or filtration process to remove excessive mercury from amalgam, gold is recovered from the amalgam by burning it over a fire, which releases mercury vapour to the atmosphere. The pressing process releases substantial mount to the environment through seepage and leakage. This method is very common in most of artisanal and small scale gold mining camps in Tanzania (MEM 1996, van Straaten 2000, UNIDO 2003). Mercury is of particular apprehension owing to its persistence in the environment, which threatens both ecological and human health. In aquatic environment, it biomagnifies in animal tissues to levels exceeding published safe consumption limits (Cabana *et al*. 1994, Fitzgerald *et al*. 1998, Sweet and Zelikoff 2001). In combating excessive mercury in the environment, scientists have previously looked to studies of persons exposed to high levels. Examples include studies of two poisoning episodes from highly contaminated fish in Japan in the 1960's, and another poisoning incident in Iraq in the 1970's involving contaminated grains. Consequently, a lot of information has been gathered on mercury contamination in fish (Harada 1995). Considering mercury poisoning catastrophe in which an estimated 10,000 people died and 100,000 were severely and permanently brain damaged (Rustam & Hamdi 1974, Amin-Zaki *et al*. 1974), there is a need to establish mercury levels in animals feeding in soils and sediment derived from gold processing activities.

van Straaten (2000), Lyimo (2002), Appleton *et al*. (2004) and Taylor et al., (2005) recorded elevated mercury concentrations both in human urine and foodstuffs grown in areas impacted by Hg-contaminated water and sediment derived from mineral processing activities in Geita District, Tanzania. Although human health concerns in Lake Victoria Goldfield have been addressed in several studies (van Straaten 2000, Campbell *et al*. 2003, UNIDO 2003, Appleton *et al*. 2004, Taylor *et al*. 2005), little has been done on the domestic poultry impacts due to mercury pollution. However, it is evident that mercury can be accumulated in plant and domestic animals tissues, and enters human food web (Lyatuu 2002, Lyimo 2002, Dauwe *et al*. 2004, Egler *et al*. 2006). Additionally, Dauwe *et al*. (2004) established that only few studies have analyzed metal concentrations in bird tissue samples and compared these with metal concentrations in food and/or vegetation samples. Domestic ducks can be potentially unsafe to human health because they are ubiquitous in many gold mining camps. Following this, a study on tissue mercury levels was carried out in ducks in 2002 as part of a baseline survey study on the impacts of mercury to the ecosystem. The study area was Mgusu Village in Geita District, which is characterized by artisanal gold mining activities. The objective was to determine the concentrations of mercury in the ducks' lung, gizzard, liver and feathers and investigate whether mercury residues varied with the weight/age of the poultry both in contaminated and non-contaminated sites. The primary assumption underlying the analysis of these tissues was selected on the fact that liver has been reported by many researchers as a preferential organ for mercury accumulation and is the active organ involved in the metabolism process of heavy metals (Elia *et al*. 2003, Storelli *et al*. 2005).

MATERIALS AND METHODS

The Mgusu gold mining area (Figure 1) is located in Geita District, northwestern Tanzania, about 93 km southwest of the city of Mwanza. It lies between latitudes $2^0$06 'S and $3^0$00'S, and longitudes $32^0$04'E and $32^0$00'E. The village hosts estimated population of about 8000 people of which one third engage directly in artisanal gold mining activities (Mwaipopo et. al., 2004). During sample collection, 57 domestic ducks (*Anas platyrhyncha)* were selected, of which 20 weighed between 450 and 600 g which were referred as ducklings; 20 weighed between 1000 to 1250 g which were referred as juveniles and the rest 17 weighed 2000 to 2250 g which were referred as mature ducks. Control subjects, weighing between 400 and 500 g (ducklings), 1000 to 1300 g (juvenile ducks) and 1900 to 2050 g (mature ducks) were collected from Mwanza city.

Prior to sample collection, the sample containers were washed several times with de-ionized water then by soaking them into nitric acid solution for 24 hours followed by rinsing with distilled water in order to remove any trace amounts of metal adhered to the walls of the containers. Samples of liver, lungs, gizzard and feather tissues were excised from each duck, homogenized through grinding and individually stored in clean, glass laboratory ware. Tissue samples were digested by sulphuric acid as described by Lyatuu (2002). Concentrations of total mercury (THg) which include organic and inorganic species of mercury were determined at the Department of Geology, University of Dar es Salaam and the Southern African Mineral Centre (SEAMIC), Tanzania. THg was determined by a cold vapour technique using Varian Atomic Absorption Spetrophotometer model Spectra A55 (Varian, Australia). Laboratory quality control samples included samples collected in Hg-free zones of Mwanza. Sample blank was prepared by introducing all reagents, as used for treating the samples, into de-ionized – distilled Hg–free water.

Instrument calibration and sample digestions were adapted from Lyatuu (2002). Concentrations were presented in mg/kg on a dry weight basis.

Application of SPSS 12.0 software package for analytical evaluation of the results followed standard statistical methods (Gaur et al., 2006). This included determination of the correlation coefficient measuring the strength of linear relationship between THg concentration in tissues and age / weight.

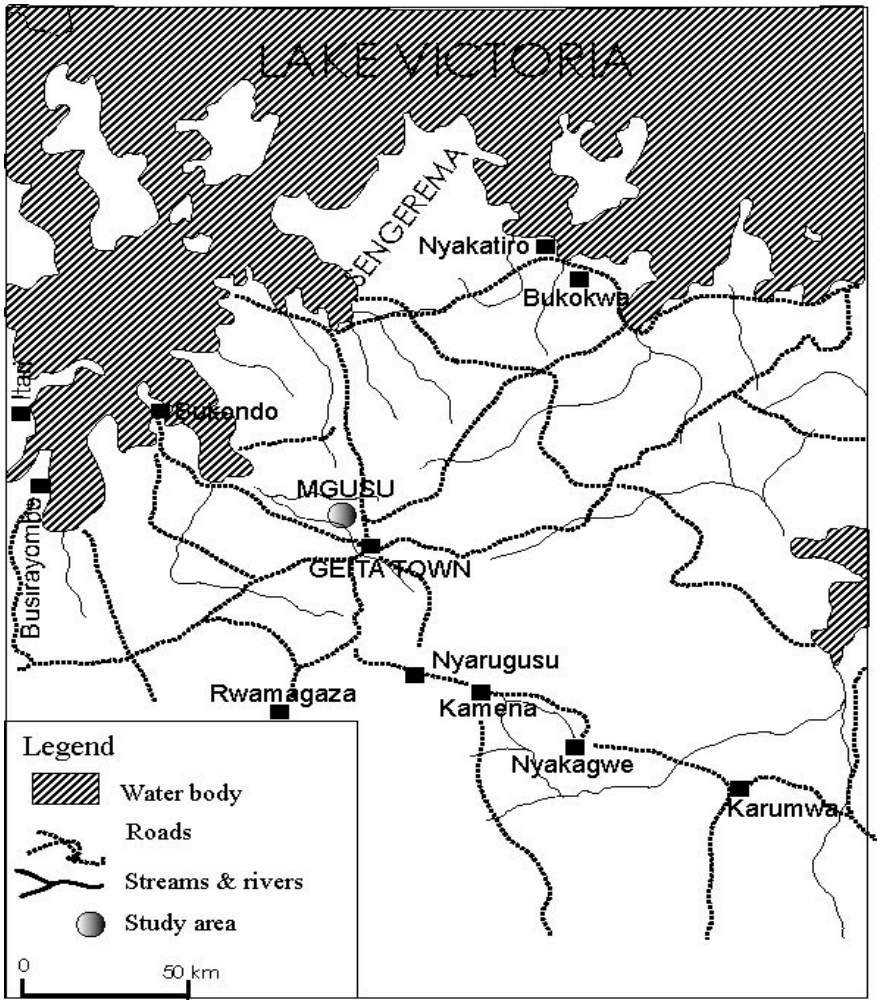

Figure 1: Location of the study area

RESULTS

Duck tissue samples from Mgusu Mining Village

Mercury concentrations in liver tissues of ducks ranged from 8.5 to 590.2 mg/kg (Table 1). In addition, tissues had THg values that ranged from 8.5 to 30.5 mg/kg (50% of samples < 10 mg/kg) for the ducklings, 118.6 to 254.1 mg/kg (45 % of samples < 200 mg/kg) for juveniles. Mature ducks showed mercury concentration of 151.1 to 590.2 mg/kg in liver of which 75%

of the tissue samples had THg concentrations below 400 mg/kg.

On average, a 2-fold increase in weight of the ducklings corresponds to 10-fold concentration of THg in the liver. Furthermore, increase in 2-fold weight of juvenile to mature ducks corresponds to 2-fold increase in THg in the ducks' liver.

Table 1: Mean concentrations of THg (mg/kg) in liver tissue samples from Mgusu

Ducks weight (g)	N	Mean±SD[a]	Std. Error	Lower[b]	Upper[c]	Min/Max[c]	F/sig[d]
450 - 600	20	19.0±5.99	1.33	16.20	21.81	8.5/30.5	116.5/0.00
1000-1250	20	190.0±46.66	10.43	168.19	211.86	118.6/254.1	
2000-2250	17	373.0±118.56	28.75	312.04	433.96	151.1/590.2	

[a] Mean and standard deviation values
[b] 95% Confidence Interval for Mean (lower & upper bound)
[c] Minimum and maximum values
[d] F-value and significance

Table 2: Mean concentrations of THg (mg/kg) in gizzard tissue samples from Mgusu

Ducks weight (g)	N	Mean±SD[1]	Std. Error	lower[2]	Upper[2]	Min/Max[3]	F/sig[4]
450 - 600	20	26.00±8.53	1.90	22.00	29.993	11.5/45.9	150.69/0.00
1000-1250	20	164.01±30.98	6.92	149.50	178.51	98.1/230.3	
2000-2250	17	170.02±40.71	9.87	149.09	190.96	112.5/254.6	

[1] Mean and standard deviation values
[2] 95% Confidence Interval for Mean (lower & upper bound)
[3] Minimum and maximum values
[4] F-value and significance

THg concentration in gizzard tissue samples varied from 11.5 to 45.9 mg/kg in gizzard (80% > 20 mg/kg) for ducklings, 98.1 to 230.3 mg/kg (90% ranged from 100 to 200 mg/kg) for juvenile ducks and 112.5 to 254.6 mg/kg (85% < 200 mg/kg) for mature ducks (Table 2). Correspondingly, a 2-fold increase in body weight corresponded to 6-fold THg mercury rise in the gizzards. However, there was no significant sharp rise in THg concentration in the tissue samples as the juvenile ducks weight doubled the mature ducks. Mature ducks in Mgusu Village showed 212 times more THg concentration in the organ compared to those of Mwanza city.

Lung tissues ranged from 0.8 to 12.2 mg/kg THg (50% of samples < 1 mg/kg) for ducklings and 9.1 to 29.1 mg/kg THg (70% of tissue samples < 10 mg/kg) for juvenile ducks. Similarly, sample showed lowest THg concentration among the groups of tissues analyzed, which ranged from 18.1 to 49.6 mg/kg, (40% of samples < 30 mg/kg) for mature ducks. Mercury concentrations in lungs of mature ducks feeding near the pollution source points were on average 200 times higher than those feeding in mercury free zone. The site difference is also remarkable as lung mercury increased with weight. Mature ducks had on average 8 and 1.7 times higher than the ducklings and juvenile ducks feeding in same locality (Table 3).

Feather samples from ducklings showed THg concentration below detectable limit (0.1 mg/kg), an indicative of non-mercury exposure during feather formation. However, feather samples from juvenile ducklings showed a relatively constant values ranging

from 36.9 to 62.1 mg/kg THg. Mature ducks showed mercury concentration levels in feathers were relatively high ranging from 89.4 to 198.3 mg/kg, of which 90% of samples analyzed had concentrations less than 100 mg/kg (Table 4).

Table 3: Mean concentrations of THg (mg/kg) in lungs tissue samples from Mgusu

Ducks weight (g)	N	Mean±SD[1]	Std. Error	lower[2]	Upper[2]	Min/Max[3]	F/sig[4]
450 - 600	20	4.00±2.85	0.63	2.66	5.34	.8/12.2	94.13/0.00
1000-1250	20	19.03±5.61	1.25	16.40	21.66	9.1/29.1	
2000-2250	17	32.01±9.12	2.21	27.32	36.70	18.1/49.6	

[1] Mean and standard deviation values
[2] 95% Confidence Interval for Mean (lower & upper bound)
[3] Minimum and maximum values
[4] F-value and significance

Table 4: Mean concentrations of THg (mg/kg) in feather samples from Mgusu

Ducks weight (g)	N	Mean±SD[1]	Std. Error	lower[2]	Upper[2]	Min/Max[3]	F/sig[4]
450 - 600	20	0.031±.04	0.01	0.01	0.05	0.0/0.1	224.87/0.00
1000-1250	20	49.01±6.92	1.54	45.77	52.24	36.9/62.1	
2000-2250	17	143.00±37.14	9.01	123.90	162.09	89.4/198.3	

Mean and standard deviation values
[2] 95% Confidence Interval for Mean (lower & upper bound)
[3] Minimum and maximum values
[4] F-value and significance

Duck tissues from Mwanza

In contrast to Mgusu Mining Village, THg concentrations in duck tissues in Mwanza were very low and varied between non-detectable to less than 5 mg/kg. No mercury was detected in the tissue samples from ducklings. Low mercury concentrations were also found in juvenile ducks. 55% of the liver tissues for instance showed THg concentrations of 1.2 to 1.8 mg/kg. The rest of the liver tissue samples were below 1.0 mg/kg. Gizzard and lung tissue samples showed very low concentrations of less than 1.0 mg/kg. Similarly, 90 % of feather tissue samples had THg concentrations less than 1.0 mg/kg. Mature ducks showed mercury concentration of 1.2 to 4.4 mg/kg in all liver tissues analyzed. In contrast, a large proportion of the gizzard samples (65%) showed mercury levels below 1 mg/kg. In the rest, THg concentrations varied from 1 to 1.6 mg/kg only. Lung tissue samples showed low concentrations ranging from 0.1 to 0.3 mg/kg. THg levels in feathers were relatively low, of which 30% of samples analyzed had concentrations varying from 1.0 to 2.5 mg/kg. The rest showed concentrations of THg below 1.0 mg/kg.

Pearson correlation coefficient between weight and THg concentration in all tissue samples showed linear relationships. The weight showed a positive correlation (ρ>0.05) with THg of all analyzed tissues in Mgusu Mining Village.

Overall THg concentration difference between mature ducks from Geita and Mwanza is evident as geometric means were 373±118.5 mg/kg (N = 17) versus 3.2±1.2 mg/kg (N = 20) for mature ducks and

190±46.6 mg/kg versus 1.2±1.8 mg/kg (N=20) for juvenile ducks. Similar trend of elevated THg values in Mgusu Mining Village was also observed firm gizzard and liver tissues. The geometric mean for THg in gizzard was 170±40.7 mg/kg (N = 17) versus 0.8±0.5 mg/kg (N = 20) for mature ducks and 164±30.9 mg/kg versus 0.5±0.46 mg/kg (N=20) for juvenile ducks. The lung tissues showed geometric mean of 32±9.1 mg/kg (N = 17) versus 0.8±0.4 mg/kg (N = 20) for mature ducks and 19±5.6 mg/kg versus 0.5±0.3 mg/kg (N=20) for juvenile ducks. The feather tissues showed geometric mean of 143±37 mg/kg (N = 17) versus 0.8±0.8 mg/kg (N = 20) for mature ducks and 49±6.9 mg/kg versus 0.5±0.46 mg/kg (N=20) for juvenile ducks. There were no elevated mercury levels in duckling feathers in Mwanza areas.

DISCUSSION

In all tissues analyzed, liver appears to be most the preferred organ for mercury accretion. Frodello et al., (2000) and Storelli et al., (2005) reported similar results of which the liver appears to be the preferential organ for mercury accumulation, followed by kidney and lung. High THg concentrations account possibly for the role played by the liver in terms of biotransformation, of which the organ demethylates organic mercury into less toxic compounds. Similar results reported indicates that a whale liver transforms organic mercury into less toxic inorganic form of insoluble mercury selenide (Wagemann 1998, Boening 2000, Kehrig, 2008). Frodello *et al*. (2000) found elevated THg concentration in lung tissues of a five toothed-whale species of the Mediterranean and Augier *et al*. (1993) suggested organisms can inhale atmospheric Hg, which could also explain relatively high values found in lung samples of the ducks at Mgusu. The finding of this study suggests that the other alternative is the diffusion of gaseous THg from sediments and soils into the respiratory system of the ducks. The average THg concentrations in the tissues were generally higher in samples from Mgusu than in samples from Mwanza area. The distribution of THg concentrations is commonly affected by many factors, such as location, weight (age) and poultry tissues.

The first pattern is high concentration of THg in ducks tissues in Mgusu gold Mining Village. THg concentrations in all tissue types in Mgusu were higher than those of ducks tissue samples from mercury free zone of Mwanza city. Mutakyahwa *et al*. (1996) identified Mgusu Mining Village as a "hot spot" where levels of THg in soils and sediments were anomalously high. Similarly, Kahatano and Mnali (1995) presented comparable data on mercury level in soils and sediments in Mgusu Mining Village, of which amalgamation process attributed to elevated levels in the environment. THg values for duck tissues from Mgusu Village were consistent with the spatial patterns of THg distribution previously observed in river water, soils sediments and mine tailings in gold mining camps. For instance, duck tissue samples from Mgusu showed highest THg concentration values which are correlated with those values reported from sediments, soils and water (Kahatano and Mnali 1995; Mutakyahwa *et al*. 1996).

More recent sampling of food crops growing in abandoned amalgamation ponds in Mgusu Mining Village has confirmed continued presence of these THg "hot spots". Kinabo and Lyimo (2002) reported elevated levels of THg as high as 462 mg/kg in sweet potatoes (*Iponea batatus*) and 412 mg/kg in beans (*Phaseolus vulgaris*) collected from Mgusu "hot spot" areas where ducks feed and bathe. THg concentrations in ducks from Mwanza were significantly low as expected based on the low background levels of THg in soils and sediments. On average, Mgusu ducks had concentrations of THg that were 10 to 100-fold higher than Mwanza-wide averages. Similar study conducted by Burger (1993) has shown that levels of lead and cadmium in the feathers of adult great tits (*Palus major*) from the site

closest to the pollution source are among the highest reported in literature. Heavy metal levels in great tit feathers feeding in contaminated sites were on average 2–40 times higher compared to a presumably non-polluted reference site (Janssens *et al*. 2001). Comparable results were reported by Dauwe et al., (2004), of which metal levels in excreta and feathers of Great tit nestlings were significantly higher at the polluted site than non-polluted areas. Great Tit for instance from the site closest to the pollution source had 11 to 200 times higher concentrations of silver, arsenic and lead in their feathers, than nestlings in other non polluted sites. The results are comparable with current findings, that on average, ducks feeding in Mgusu Mining Village had 120 (liver), 215 (gizzard), 214 (lung) and 286 (feathers) times higher concentration of THg than ducks in Mwanza Town.

The second pattern observed showed increasing THg concentration with the weight (aging) of the poultry. Consequently, concentrations of THg in all duckling tissue samples were lower than the juveniles or the mature ducks. Storelli *et al*. (2005) reported that mercury concentrations in fish increase with body size. In this study, significant positive relationships between THg levels and body weight (age) were observed for all tissue samples analyzed suggesting that THg increases as the ducks grow. As the weight of the duckling doubles, THg in liver increases 10-fold while THg at the mature age increases 19-fold. In comparison, these findings are consistent with other previous works (Storelli *et. al*. 2005) that highest mean levels of mercury in analyzed samples are found in liver, therefore this organ can be used as target tissue when monitoring metal concentrations in animals (Elia et al., 2003). Similar trend is also observed in the gizzard samples of which ducklings had 26.00±8.53 mg/kg THg, which rises to 164.01±30.98 and 170.02±40.71 mg/kg THg for the juvenile ducks and mature ducks, respectively. This is an equivalent of 2-fold increase in weight, which increases THg concentration to 6-fold. There was no significant further increase in THg between juveniles and mature ducks, indicating saturation of THg in the gizzard. The lungs showed similar trend as liver. The duckling samples averaged 4.00±2.8 mg/kg THg, which increases to 19.03±5.6 mg/kg THg for juvenile ducks and 32.01±9.12 for mature ducks. This corresponds and increases of 5-fold in THg as the weight of duckling doubles and an increase factor 8 at the maturity stage. Low mercury levels measured in lungs could be explained by inhalation of organic mercury from atmosphere. The feather THg concentrations were 0.031±0.04 for ducklings, 49.01±6.92 for juvenile and 143.00±37.14 for mature ducks. The results show that low mercury concentrations in ducklings' feathers are a sign of low THg exposure during the formation of feathers. High THg concentration in mature ducks is an indication of high external mercury exposure, possibly in bathe areas such as amalgamation water ponds in which the sediments have high THg, exceeding 10^4 mg/kg (Mutakyahwa *et al*. 1996). This factor is important since feathers could be used as biomonitor of THg in the mining camps without butchery of the poultry. High THg in feathers can be used as an indicator of mercury "hot spots" in artisanal gold mines.

In summary, in evaluating these results in terms of community health concerns, one must consider the age/size of the poultry and its spatial distribution. While Mgusu ducks continue to pose health risk to human consumers, levels do not appear to be a threat in Mwanza City. For instance, children and pregnant women eat gizzards and liver which have high THg values (Table 1) that exceed the American Food and Drug Administration (FDA) action level of 1.0 mg/kg (UNEP Report 1990). Poultry however is not a frequent diet in many artisanal gold mines.

CONCLUSION

The difference between ducks feeding in Mwanza and Mgusu was significant, indicating that ducks feeding in contaminated sites have significantly higher mercury concentrations than ducks feeding in non-contaminated sites. The results suggest that mercury may accumulate in the tissues as the poultry grows since mercury is not an essential element in their bodies. Ducks are an extreme example in terms of its habit to feed in mud; however they can be bio-indicators of mercury "hot spots" in mines. In terms of its use as a dietary item, ducks feeding in artisanal gold mining camps appear to accumulate excessively high concentrations of mercury in its edible tissues and therefore appear to be an unacceptable food item with respect to Hg. However, concentrations of Hg of dietary concern at present are not relevant as ducks in camps are not consumed on a regular basis. Nevertheless, ducks continue to serve as a potentially significant exposure route to humans especially pregnant women, nursing mothers and children. It is therefore recommended that further monitoring, possibly on a 2-year frequency, should be done to determine whether mercury concentrations in "hot spot" areas will continue to be a long-term threat to health.

ACKNOWLEDGEMENT

The authors would like to thank all the people who enabled the study to be completed. Specifically, we are grateful to Mgusu artisanal gold miners, University of Dar es Salaam and German Academic Exchange Service (DAAD) for their kind assistance.

REFERENCES

Amin-Zaki L, Elhassani S, Majeed MA, Clarkson TW, Doherty RA and Greenwood M 1974 Intra-uterine Methylmercury Poisoning in Iraq *PEDIATRICS* **54**(5): 587-595.

Appleton JD Taylor H Lister TR Smith B Drasch G and Reilly SB 2004 British Geological Survey Final Report for an assessment of the Environment and Health in Rwamagaza area, Tanzania. UNIDO Project EG/GLO/01/G34. 128 p.

Augier H, Park WK, Ronneau C 1993 Mercury contamination of the stripped dolphin *Stanella coeruleoalba* Meyen from the French Mediterranean coasts. *Mar. Pollut. Bulll.* **26**: 306-311.

Boening, DW 2000 Ecological effects, transport, and fate of mercury; a general review. *Chemosphere* **40**: 1335- 1351.

Burger J 1993 Metals in avian feathers: bioindicators of environmental pollution. *Environ. Toxicol.* **5 :** 203–311.

Cabana G, Tremblay A, Kalff J and Rasmussen JB 1994 Pelagic food chain structure in Ontario lakes; A determination of mercury levels in Lake Trout. *Can. J. Aquat. Sci.* **51**: 381-389.

Campbell LM, Dixon DG and Hecky RE 2003 Review of mercury in Lake Victoria, East Africa: Implications for human and ecosystem health. *J. Toxicol. Environ. Health* **B 6**: 325-356.

Dauwe, T Janssens E, Bervoets L, Blust R and Eens M 2004 Relationships between metal concentrations in great tit nestlings and their environment and food *Environ. Pollut.* **131**(3): 373-380.

Egler SG, Rodrigues-Filho S, Roberto C, Villas B and Beinhoff C 2006 Evaluation of mercury pollution in cultivated and wild plants from two small communities of the Tapajós gold mining reserve, Pará State, Brazil. *Sci. Total Environ*. **368**(9): 424-433.

Elia AC, Galarini R, Taticchi MI, Dorr AJM and Mantilacci 2003 Antioxidant responses and bioaccumulation in *Ictalurus melas* under mercury exposure. *Ecotoxicol. Environ. Safety* **55**(2): 162-167.

Fitzgerald WF, Engstrom DR, Mason RP and Nater EA 1998 The case of atmospheric mercury contamination in Remote areas. *Environ. Sci. Technol.* **32**: 1-7.

Frodello JP, Romeo M and Viale D 2000 Distribution of mercury in the organs and tissues of five toothed-whale species of the Mediterranean. *Environ. Pollut.* **108**(3):447- 452.

Gaur SS and Gaur AS 2006 Statistical Methods for Practice and Research: A Guide to Data Analysis Using the SPSS. Sage Publications, ISBN: 10: 0761935029, pp: 208.

Harada M 1995 Minamata disease: Methylmercury poisoning in Japan caused by environmental pollution. *Crit. Rev. Toxicol.***25**: 1-24.

Harada M, Nakachi S, Cheu T, Hamada H, Ono Y, Tsuda T, Yanagida K, Kizaki T and Ohno H 1999 Monitoring of mercury pollution in Tanzania: relation between head hair mercury and health. *Sci. total Environ.* **227**: 249-256.

Janssens E, Dauwe T, Bervoets L and Eens M 2001 Heavy metals and selenium in feathers of great tits (*Parus major*) along a pollution gradient. *Environ. Toxicol. Chem.* **20:** 2815–2820.

Kahatano JM, Mnali SR 1995 Heavy metal contamination due to artisanal gold mining in Lake Victoria Goldfields. In: Landner L. (ed). *Environment and Mining in Eastern and Southern Africa*. 66-81 pp.

Kehrig HA, Seixas TG, Palermo EA, Di Beneditto APM, Souza CMM and Malm O 2008 Different Species of Mercury in the Livers of Tropical Dolphins. *Anal. Lett.* **41**(9): 1691 – 1699.

Kinabo C and Lyimo E 2002 Preliminary studies of mercury contamination in various food crops cultivated at Mgusu Artisanal Mining Village in Geita, Tanzania. Proceedings, International Workshop on Health and Environmental Effects of Mercury. National Institute for Minamata Disease (NIMD) / University of Dar es Salaam (UDSM), Dar es Salaam, Tanzania. November, 2002. 204-214 pp.

Lyatuu HD 2002 A study of mercury levels in some selected animal tissues at Mgusu Mining area, Geita in Mwanza Tanzania. M.Sc. Environmental Science Dissertation, University of Dar es Salaam, Tanzania 58 p.

Lyimo EN 2002 *Evaluation of mercury content in selected food crops grown at Mgusu Mining Area, Geita in Mwanza Tanzania*. M.Sc. Dissertation, University of Dar es Salaam, Tanzania 60 p.

MEM 1996 Ministry of Energy and Minerals, United Republic of Tanzania. Report on Baseline Survey and Preparation of Development Strategy for Small scale and Artisanal Mining Program in Tanzania. Tan Discovery Consulting Company / World Bank Project 1996.

Mutakyahwa MKD Ikingura JR Kinabo CP Kahatano JM Kaaya CZ 1996 Environmental aspects of mining and industrialization in Tanzania. Environmental map of artisanal mining in Tanzania. Unpublished Report. University of Dar es Salaam, Tanzania. 8pp.

Mwaipopo R, Mutagwaba W, Nyange D and Fisher E 2004 Increasing the contribution of artisanal and small-scale mining to poverty reduction in Tanzania. Based on Analysis of Mining livelihoods in Misungwi and Geita Districts, Mwanza Region. Report, for Department for International Development – DFID UK.

Rustam & Hamdi 1974 Methyl mercury poisoning in Iraq. A neurological study. Brain *J. Neorol.* **97**: 499-510.

Storelli MM, Giacominelli-Stuffler R, Storelli A and Marcotrigiano GO 2005 Accumulation of mercury, cadmium, lead and arsenic in swordfish and bluefin tuna from the Mediterranean Sea: A comparative study *Mar. Pollut. Bull.* **50**(**9**): 1004-1007.

Sweet LI and Zelikoff JT 2001 Toxicology and immunotoxicology of mercury: A comparative review in fish and humans. *J. Toxicol. Environ. Health B.* **4**: 161-205.

Taylor H, Appleton JD, Lister R, Smith B, Chitamweba D, Mkumbo O, Machiwa JF, Tesha AL and Beinhoff C 2005 Environmental assessment of mercury contamination from the Rwamagasa artisanal gold mining centre, Geita District, Tanzania. *Sci. Total Environ*. **343**(1/3): 111-133.

UNEP Report 1990 Methylmercury - Environmental Health Criteria 101: International Programme on Chemical Safety. Publ. ILO, WHO and UNEP. Geneva.

UNIDO 2003 Programme for introducing cleaner artisanal gold mining and extraction technologies and assessing the impact of the activity on health and the environment http://www.natural-resources.org/minerals/cd/unido.htm.

van Straaten P 2000 Mercury contamination associated with small scale gold mining in Tanzania and Zimbabwe. *Sci. Total Environ.* **259**: 45-53.

Wagemann R Trebacz E Boila G Lockhart WL 1998 Methylmercury and total mercury in tissues of arctic marine mammals. *Sci. Total Environ*. **218**: 1931.