Published in final edited form as:
Ecotoxicol Environ Saf. 2008 May ; 70(1): 147–153. doi:10.1016/j.ecoenv.2007.03.012.

Heavy metals in mosquito larval habitats in urban Kisumu and Malindi, Kenya, and their impact

Paul O. Mireji[a,b,*], **Joseph Keating**[c], **Ahmed Hassanali**[b], **Charles M. Mbogo**[d], **Hudson Nyambaka**[e], **Samuel Kahindi**[d], and **John C. Beier**[f]

a*Department of Biochemistry, Kenyatta University, P.O. Box 43844, Nairobi 00100, Kenya*

b*International Center of Insect Physiology and Ecology, P.O. Box 30772, Nairobi, Kenya*

c*Department of International Health and Development, School of Public Health and Tropical Medicine, Tulane University, New Orleans, LA 70112, USA*

d*Center for Geographic Medicine Research—Coast, Kenya Medical Research Institute (KEMRI), Kilifi, Kenya, P.O. Box 4281, Kilifi, Kenya*

e*Department of Chemistry, Kenyatta University, P.O. Box 43844, Nairobi 00100, Kenya*

f*Department of Epidemiology and Public Health, University of Miami, Miami, FL 33177, USA*

Abstract

Concentrations and distribution of cadmium, chromium, copper, iron, lead, manganese and zinc in mosquito larval habitats in urban Kisumu and Malindi, Kenya and their effect on the presence of *Anopheles gambiae*, *Aedes aegypti*, *Culex quinquefasciatus* and *Anopheles funestus* larvae were investigated. Manganese and iron were the most prevalent heavy metals in water of larval habitats in urban Kisumu and Malindi, respectively. Iron was the most prevalent heavy metal in bottom sediments in larval habitats in both cities. The highest concentrations of all heavy metals, except cadmium and iron, were recorded in the poorly planned–well drained stratum in the two cities. All heavy metals were more concentrated in human-made than in natural larval habitats. Copper was positively associated with the presence of *Ae. aegypti*, and lead was associated with the presence of *An. gambiae* and *Ae. aegypti* in urban Kisumu. Absence of significant correlation between the other metals and mosquito species in both cities, despite relatively high concentrations, suggest that the local larval populations, including key malaria vectors have adapted to the detected levels of these metals.

Keywords

Heavy metals; Mosquitoes; Larval habitats; Human-made habitats; Natural habitats; Strata; Tolerance

1. Introduction

Heavy metals such as cadmium, chromium, copper, iron, lead, manganese and zinc are environmentally dangerous substances, and this necessitates their surveillance in aquatic environments. Low concentrations of heavy metals occur in natural aquatic ecosystems, but recent expansions in human population growth, industry, and peri-urban agricultural activities

*Corresponding author. Human Health Division, The International Center of Insect Physiology and Ecology, P.O. Box 30772, Nairobi 00100, Kenya. Fax: +254 20 806330/860110. *E-mail address:* E-mail: mireji@gmail.com (P.O. Mireji)..

in African cities have led to an increase in heavy metal occurrence in excess of natural loads (Biney et al., 1994).

Environmental studies on the distribution of heavy metals have been conducted in water, sediment, fauna, and flora throughout Africa, with an emphasis on sediment in large water bodies such as rivers and lakes (Biney et al., 1994). Most of the studies in Kenya have centered on Winam Gulf of Lake Victoria (Onyari and Wandiga, 1989; Wandiga and Onyari, 1987; Urasa and Onyari, 1986) and on the Indian Ocean shoreline (Kamau, 2002; Rees et al., 1996). Within these environments, significant increases in some heavy metals have been observed and attributed to car washes, ship traffic, and industrial and municipal discharge (Onyari and Wandiga, 1989). However, information is lacking on the association between human activities and the distribution of heavy metals within such environments.

Water quality is rarely monitored in Kenya on a regular basis (JICA, 2002), leading to a lack of reliable information on heavy metal concentrations in areas of urbanization and industrialization. Moreover, only 50% of the Kenyan population has access to adequate sanitation facilities, and no more than 30% of the 142 urban areas in Kenya have functional sewerage systems, which leads to the dumping of sewage and human waste directly into the environment (JICA, 2002). Sewage typically contains high concentrations of heavy metals (Nriagu and Pacyna, 1988). Also common in Kenya are the combustion of fossil fuel (i.e. leaded gasoline) and the un-regulated disposal of used batteries and motor oil, which are also important sources of heavy metal pollution (Chang and Cockerham, 1994). Heavy metal pollutants, irrespective of the source, ultimately end up in aquatic systems (Nriagu and Pacyna, 1988).

Heavy metal pollution can have a devastating effect on the ecological balance of aquatic environments, limiting the diversity of aquatic organisms and plants. For instance, there are indications that the level of pollution in water bodies directly influences the diversity and abundance of larval stage mosquito species (Chinery, 1984, 1995; Coluzzi, 1993; Coene, 1993). *Anopheles* mosquito populations are typically lower in urban environments as compared to rural environments because of high levels of human pollution and perturbation (Trape and Zoulani, 1987). The level of heavy metal contamination may play a limiting role on *Anopheles* mosquito populations in urban environments. However, no data on concentrations or biological effects of heavy metals in habitats of mosquito larvae located in these urban areas has been published.

This study was initiated to (1) establish a baseline of existing levels of heavy metals in potential mosquito larval habitats in the urban areas of Kisumu and Malindi, Kenya; (2) examine the distribution of heavy metals and potential mosquito larval habitats in relation to drainage and planning in the urban environment; and (3) examine the relationship between heavy metal concentrations and the presence of mosquito larvae in water bodies. Herein we report our findings.

2. Materials and methods

2.1. Study areas

Urban Kisumu (00°06′S 034°45′E) is located on the shores of Lake Victoria, Kenya, with a population of about 329,000 (Kenya National Bureau of Statistics, 1999). Kisumu experiences long and short rain seasons from March to May and September to December, respectively. The mean annual rainfall level is between 1000 and 1500 mm. The species of *Anopheles* mosquitoes in the Kisumu region include *Anopheles arabiensis* Patton 1905, *Anopheles funestus* Giles (Bruhnes 1978) and *Anopheles gambiae* sensu stricto Giles 1902 (Githeko et al., 1993). Urban Malindi (03°21′S 40°10′E) is located on the shore of the Indian Ocean in Kenya with a population of about 120,000 (Kenya National Bureau of Statistics, 1999). Malindi experiences long and short rainy seasons from April to June and October to November, respectively. The mean annual rainfall level is between 750 and 1200 mm. The species of *Anopheles* mosquitoes on the coast of Kenya include *An. arabiensis*, *An. funestus*, *An. gambiae* s.s. and *Anopheles merus* Dönitz 1902 (Mbogo et al., 1995).

2.2. Sampling design and procedure

A survey of cadmium, chromium, copper, iron, lead, manganese and zinc concentrations, and presence of *An. gambiae* sensu lato, *An. funestus*, *Aedes aegypti* Linnaeus 1762, and *Culex quinquefasciatus* Say, 1823 in water bodies was conducted in urban Kisumu (July 7–24, 2002) and Malindi (June 17–24, 2002). The sample frame used in this study has been described in detail elsewhere (Macintyre et al., 2002; Keating et al., 2003). Briefly, the sampling design involved segmentation of each study area into a series of 270 m × 270 m grid cells, which corresponded to a 9 pixel × 9 pixel LANDSAT Thematic Mapper remote sensing satellite imagery (National Aeronautics and Space Administration Goddard Space Flight Center, Greenbelt, MD). A total of 317 grid cells fell within the Kisumu and 244 within the Malindi study areas. District development plans, existing town maps, GIS base maps, house spacing, presence or absence of engineered drainage systems, types and patterns of roads, and community water sources were examined to determine whether an area was planned or unplanned. Well-drained areas versus poorly drained ones were determined by the presence or absence of functional engineered drainage systems and topographic features. The resulting sample frame consisted of four strata: (1) well planned–well drained, (2) poorly planned–well drained, (3) well planned–poorly drained, and (4) poorly planned–poorly drained. The number of grid cells selected for heavy metal and water body sampling in each city was proportional to the size of the strata over the entire city. Ninety-six and 73 grid cells were selected in Kisumu and Malindi, respectively, representing approximately 30% of the total number of grid cells. Well planned–well drained, well planned–poorly drained, poorly planned–well drained, and poorly planned–poorly drained strata were represented by 32, 5, 8 and 51 cells, respectively, in Kisumu, and 17, 20, 4 and 32 cells, respectively, in Malindi.

Once the selected grid cell was identified, the center of the cell was located and a direction was randomly selected from the center. The first water body encountered in this direction was selected for sampling. When no habitat was encountered in the first direction, the search was extended in the opposite direction. All water bodies encountered were considered potential larval habitats, and sampled for mosquito larvae and for heavy metal concentrations. Water bodies were classified as either natural or human-made. Natural habitats were defined as any water body that did not originate from human activities. Natural habitats included ponds, swamps, and springs. Human-made habitats included domestic and industrial drainage ditches, discarded car tires, sewage pools, and water tanks.

Water samples (250 ml) were collected in two replicates in plastic bottles and were immediately acidified to pH<2.0, by adding 1 ml of analytical grade concentrated HNO_3. This was done to prevent heavy metal adsorption into the container walls as well as to inhibit the activity of micro-organisms, which might cause changes in trace metal levels in the water samples. Using a sampling corer, bottom sediment samples (up to 12 cm depth), where available e.g. in ponds as opposed to discarded car tires, were collected in two replicates, placed in plastic bags, and immediately stored at 4 °C. Larval samples were collected from the habitats using standard mosquito-sampling dipper (350 ml), and were immediately preserved in absolute ethanol for identification. Larvae were identified using morphological characteristics (Gillett, 1972).

2.3. Water and soil sample processing and heavy metal determination

Water samples were subjected to acid digestion to remove suspended solid particles. Briefly, 100 ml of each sample solution were placed in 50 ml of HNO_3 (Analar grade1:1); digested by gently heating the solutions until the volume was reduced to a third of its original volume. The solution was allowed to cool to room temperature before 20 ml of HCl (1:1) was added and then gently heated for another 10 min to complete the digestion. The solutions were filtered, and the filtrate volume adjusted to 100 ml with distilled water and stored in plastic bottles.

Sediment samples were oven dried at 50 °C for 12 h and ground using a pestle and mortar. The powders were sieved through a 50–75 μm screen. A portion of the sample (1 g) was placed in Teflon beakers, acidified with 2 ml of concentrated HNO_3 and evaporated to dryness at 80 °C. The samples were further digested in a concentrated mixture of HNO_3, $HClO_4$ and HF (30:2:10 by volume) at 60 °C. They were then evaporated to dryness by gradually raising the temperature to 120 °C to remove $HClO_4$. Digestion was completed by the addition of 30% H_2O_2 to remove residual biological material, and the solutions filtered into plastic containers. The residues were rinsed with 0.1 M HCl and the filtrate volume adjusted to 100 ml with distilled water. Procedural blanks and standards were taken through similar processing, storage and digestion. Quantitative determination of cadmium, chromium, copper, iron, lead, manganese, and zinc were conducted separately in the water and soil samples with a Buck Scientific 210VGP atomic absorption spectrophotometer (Buck Scientific, East Norwalk, Connecticut, USA) according to the manufacturer's instructions.

2.4. Data analyses

One-way analysis of variance (ANOVA) was used to compare heavy metal concentrations in water and sediment samples among strata within each town, and Tukey HSD post-hoc test used to determine which strata were significantly different in terms of metal concentrations. ANOVA was also used to compare metal concentrations between Kisumu and Malindi, and between natural and human-made larval habitats. For each metal, analyses were conducted on metal concentrations in water and sediment samples. Pearson correlation coefficient was used to determine if a relationship existed between metal concentrations for both water and sediment samples. The same analysis was used to establish correlations between different metal ions in water and sediment phases. Since some response variants had less than five entries, Fisher's Exact Test was used to identify relationships between metal concentrations and the presence or absence of the respective mosquito larvae species. For Fisher's Exact Test, concentrations of each metal were dichotomized into either low or high category relative to the mean concentrations. In all analyses, P value below 0.05 was considered significant. All analyses were conducted using SPSS statistical software (SPSS Corporation, Chicago, Illinois Statistical Package version 11.5).

3. Results

Fifty-six of the grid cells sampled in Kisumu and 25 in Malindi contained no water bodies. Accordingly, 14, 5, 2 and 19 water bodies in Kisumu and 15, 9, 4 and 27 water bodies in Malindi were sampled from well planned–well drained, well planned–poorly drained, poorly planned–well drained, and poorly planned–poorly drained strata respectively.

3.1. Distribution of heavy metals in habitats in Kisumu and Malindi water

In the comparison of metal concentrations, concentration of manganese in human-made habitats was significantly higher ($F_{(1,81)} = 4.804$, $P<0.05$) in Kisumu than in Malindi (Table 1). Copper, lead and zinc concentrations were higher in natural habitats located in Malindi than those located in Kisumu, while cadmium, chromium and iron concentrations were also similar between the cities (Table 1). With the exception of cadmium in habitats located in Malindi, concentrations of all the other metals were consistently higher in water from human-made than from natural larval habitats located in both Kisumu and Malindi (Table 1). The biggest difference involved copper, where more than a three-fold difference was observed in Malindi.

Correlations between most metal concentrations in water samples were significant in Malindi, except between cadmium and chromium, lead or manganese and lead and manganese (Table 2). The number of significantly correlated pairs of heavy metals was lower in Kisumu, and included copper and cadmium, lead and cadmium or copper, manganese and copper or lead, and zinc and chromium, iron or manganese (Table 2). Apart from cadmium and iron, highest concentrations of metals in Kisumu, were recorded in the poorly planned–well drained stratum, while in Malindi this was so without exception (Table 3). Concentrations of all the metals in habitats in Kisumu were similar among the strata (Table 3). In Malindi, there was significant variation in the distribution of copper ($F(3,51) = 5.262$, $P<0.01$), iron ($F_{(3,51)} = 6.462$, $P<0.01$) and zinc ($F_{(3,51)} = 9.123$, $P<0.001$) among strata, with poorly planned–well-drained stratum having the highest concentrations (Table 3).

3.2. Sediments

Iron was the most prevalent metal in the sediments of the habitats in both Kisumu and Malindi. Iron ($F_{(1,39)} = 10.444$, $P<0.01$) and manganese ($F_{(1,39)} = 21.781$, $P<0.01$) concentrations were significantly higher ($P<0.05$) in sediments of habitats in Kisumu than in Malindi (Table 4). With the exception of cadmium and lead in Kisumu, concentrations of all the metals in sediment were higher in natural than in the human made habitats in Kisumu, while in Malindi, concentrations of all the metals were lower in natural than in human made habitats (Table 4). In both Kisumu and Malindi, concentrations of each metal in sediment except zinc were similar among strata. In Kisumu the concentrations were 1.489±0.215, 2.524±0.224, 3.035±1.143 and 1.435±0.330 ppm while in Malindi, zinc concentrations were 1.089±0.181, 0.941±0.211, 2.575 ±0.363 and 0.829±0.304 ppm, in well planned–well drained, well planned–poorly drained, poorly planned–well drained, and poorly planned–poorly drained, respectively. In Kisumu, manganese and iron concentrations were significantly correlated, while in Malindi, this was the case between copper and iron, lead and zinc, and between iron and lead and manganese (Table 5). Cadmium and copper concentrations in water and sediments were significantly correlated ($P<0.05$, Pearson correlation) in habitats located in Kisumu; this was the case with cadmium in habitats located in Malindi.

3.3. Mosquito species composition in habitats and association with heavy metal concentrations

Most of the habitats in Kisumu (77%) and Malindi (95%) were human-made. However, mosquito larvae were not present in most of the habitats in Kisumu (71.4%), or Malindi (51.9%). Of the 93 mosquito larvae collected in Kisumu, about 16% were anopheline (*An. gambiae*, 11% and *An. funestus*, 5%) and 2% *Ae. aegypti*. The rest were *Cx. quinquefasciatus*. In Malindi, 4% of all the collected larvae were *An. gambiae* and greater than 95% were culicines (*Ae. aegypti* and *Cx. quinquefasciatus*). No *An. funestus* was collected in any of the habitats sampled in Malindi. In Kisumu, most mosquito larvae (71.2%) were collected from poorly planned–poorly drained stratum. The majority (86.6%) of these were *Cx. quinquefasciatus. Culex quinquefasciatus* species was also dominant (90.1%) in the well-planned and well-drained stratum. No *Cx. quinquefasciatus* larvae were collected in poorly planned–well drained stratum. Similarly, the habitats in the poorly planned–poorly drained stratum had the highest proportion (58.0%) of mosquito larvae in Malindi. Most (98.3%) of these were *Ae. aegypti. Aedes aegypti* larvae were also dominant (>50.0%) in all other strata. The well planned–poorly drained stratum had the least proportion (5.5%) of mosquito larvae. The well planned–well drained stratum had 17.5% of the mosquito larvae population, among which most (87%) were *Ae. aegypti*.

There was significant positive association ($P<0.05$, Fisher's exact test) between the concentration of copper in the water phase and the presence of *Ae. aegypti* larvae in habitats located in Kisumu. Similar association was observed between lead concentration and *An.*

NIH-PA Author Manuscript

NIH-PA Author Manuscript

gambiae or *Ae. aegypti* ($P<0.05$, Fisher's exact test). There were no significant ($P>0.05$, Fisher's exact test) associations between concentrations of the remaining metals and mosquito presence in habitats in Kisumu. In Malindi on the other hand, there was no significant associations between metal concentrations in the water phase and the presence of any of the mosquito species sampled ($P>0.05$, Fisher's exact test).

4. Discussion

In the present study, concentrations of most of the metals examined were several folds higher than those previously reported in water bodies in some African cities such as lake Nakuru in Kenya (Greichus et al., 1978), Hartbeespoort and Voëlvlei dams in Cape Province, South Africa (Greichus et al., 1977), Gwebi and Mukuvisi rivers in Harare, Zimbabwe (Moyo and Phiri, 2002), while the reverse was found in the sediment samples. The factors underlying these differences may be complex and detailed comparative studies are needed on the sources of pollutants, soil composition in specific topologies and particularly their physical and chemical characteristics, precipitation patterns, and composition of flora growing in the areas.

Elevated levels of the heavy metals observed in human-made, as compared to natural habitats, underscores the anthropogenic nature of heavy metal pollution in the cities. The positive correlations observed between most of the metals in water, especially in Malindi, suggest relative uniformity of the sources of the metal pollutants, as previously reported (Onyari and Wandiga, 1989). However, lack of a similar degree of correlation among metals in the sediments of the habitats suggests that the metals are retained differentially in the sediments. Levels of planning and draining seem to have an incremental impact on the levels of heavy metal pollution in the habitats, especially in Malindi. In particular, activities taking place in poorly planned–well-drained stratum appears to contribute to heavy metal pollution of the habitats or predispose these habitats to pollution by such metals. The existence of correlation between iron and manganese concentrations in the sediments in the two cities is interesting and has previously been observed in sediments of the Lagos lagoon in Nigeria (Okoye et al., 1991). This may indicate an underlying similarity in the sources and mechanism of the build up of these metals.

The observed absence of significant correlation between concentrations of most heavy metals and the presence of *An. funestus*, *An. gambiae*, *Ae. aegypti* and culicine larvae suggests relatively high tolerance of the larvae to these metals in the habitats in Malindi and/or beneficial and compensatory effects of high nutrient levels generally associated with sewage or domestic waste present (Clements and Kifney, 1994; Renoldi et al., 1997). Aquatic insects chronically exposed to heavy metals exhibit increased tolerance relative to naïve populations (Klerks and Weis, 1987; Krantzberg and Stokes 1990; Hare, 1992; Clements and Kifney, 1994; Dallinger, 1994). Previous studies have demonstrated greater tolerance of culicines and *Ae. aegypti* to elevated levels of heavy metals in different habitats (Subra, 1981). However, anophelines are normally known to proliferate almost exclusively in relatively unpolluted environments (Eldridge, 2005). Our observations suggest that these species, which include important Afro-tropical malaria vectors, may have adapted to higher concentrations of most of the heavy metals analyzed in the habitats. Further studies are needed to investigate the underlying mechanisms.

5. Conclusions

Concentrations of most heavy metals in aquatic larval habitats in urban Kisumu and Malindi are relatively high and anthropogenic factors, and particularly poor planning and drainage, are associated with the accumulation of the heavy metals. Most mosquito species examined, including anopheline malaria vectors, appear to perform well in these habitats, and further studies are needed to elucidate the underlying mechanisms.

Acknowledgments

We would like to thank Dr. John Githure and Dr. Andrew Githeko for facilitating this work. We would also like to thank Mr. Salim Mwatsahu of the Department of Chemistry, Kenyatta University, Nairobi, Kenya, for his technical assistance with Atomic absorption spectroscopy analysis of the samples and to both Prof. Lev Vladimirovich Nedorezov, and Mr. Anthony Wanjoya of the Biometry Department of ICPE for their assistance with statistical analyses.

This study was funded by National Institutes of Health (NIH) grant NIH ICIDR U19 A145511 and NIH Fogarty ABC grant D43 TWO1142. This study did not involve humans or experimental animals. National and institutional approval regarding protection of human subjects and animal welfare was not required.

References

Biney C, Amazu AT, Calamari D, Kaba N, Mbome IL, Naeve H, Ochumba PBO, Osibanjo O, Radegonde V, Saad M. Review of heavy metals in the African aquatic Environment. Ecotoxicol. Environ. Saf 1994;28:134–159. [PubMed: 7525211]

Chang, LW.; Cockerham, L. Toxic metals in the environment. In: Cockerham, LG.; Shane, BS., editors. Basic Environmental Toxicology. CRC Press Inc; Florida: 1994. p. 109-132.

Chinery WA. Effects of ecological changes on the malaria vectors *Anopheles funestus* and *Anopheles gambiae* complex of mosquitoes in Accra, Ghana. J. Trop. Med. Hyg 1984;87:75–81. [PubMed: 6748132]

Chinery WA. Impact of rapid urbanization on mosquitoes and their disease transmission potential in Accra and Tema, Ghana. Afr. J. Med. Sci 1995;24:179–188.

Clements WH, Kifney PM. Integrated laboratory and field approach for assessing impact of heavy metals at the Arkansas River, Colorado. Environ. Toxicol. Chem 1994;7:715–722.

Coene J. Malaria in urban and rural Kinshasa: the entomological input. Med. Vet. Entomol 1993;7:127–137. [PubMed: 8481529]

Coluzzi M. Advances in the study of Afrotropical malaria vectors. Parasitologia 1993;35:23–29.

Dallinger R. Invertebrate organisms as biological indicators of heavy metal pollution. Appl. Biochem. Biotechnol 1994;48:27–31. [PubMed: 7979349]

Eldridge, BE. Mosquitoes, the culicidae. In: Marquardt, WC., editor. The Biology of Disease Vectors. Elsevier Academic Press; London: 2005. p. 95-112.

Gillett, J. Common African Mosquitoes and their Medical Importance. William Heinemann Medical Books Limited; London: 1972.

Githeko AK, Service MW, Mbogo CM, Atieli F, Juma FO. *Plasmodium falciparum* sporozoite and entomological inoculation rates at the Ahero Rice Irrigation Scheme and the Miwani Sugar-belt in western Kenya. Ann. Trop. Med. Parasitol 1993;87:379–391. [PubMed: 8250629]

Greichus YA, Greichus A, Ammann DB, Call DJ, Hamman DCD, Pott RMJ. Insecticides, polychlorinated biphenyls and metals in African lake Ecosystems. I. Hertbeespoort Dam, Transvaal and Voëlvlei Dam, Cape Province, Republic of South Africa. Arch. Evironm. Contam. Toxicol 1977;6:371–383.

Greichus YA, Greichus A, Ammann DB, Hopcraft J. Insecticides, polychlorinated biphenyls and metals in African lake Ecosystems. III. Lake Nakuru, Kenya. Bull. Environ. Contamin. Toxicol 1978;19:454–460.

Hare L. Aquatic insects and trace metals: bioavailability, bioaccumulation and toxicity. Crit. Rev. Toxicol 1992;22:327–369. [PubMed: 1489510]

JICA. Country Profile on Environment: Kenya. Japan International Cooperation Agency; 2002. p. 18-29. 〈http://www.jica.go.jp/english/global/env/profiles/pdf/14.pdf〉

Kamau NJ. Heavy metal distribution and enrichment at Port-Reitz Creek, Mombasa, Western Indian Ocean. J. Mar. Sci 2002;1:65–70.

Keating J, Macintyre K, Regens JL, Swalm C, Mbogo CM, Githeko A, Ndenga B, Steinberg L, Kibe L, Githure JI, Beier JC. A geographic sampling strategy for studying relationships between human activity and malaria vectors in urban Africa. Am. J. Trop. Med. Hyg 2003;68:357–365. [PubMed: 12685645]

Kenya National Bureau of Statistics. Executive Report: Summary Statistics. Nairobi, Kenya: 1999.

Klerks PL, Weis JS. Genetic adaptation to heavy metals in aquatic organisms: a review. Environ. Pollut 1987;45:173–205. [PubMed: 15092750]

Krantzberg G, Stokes PM. Metal concentrations and tissues distribution in larvae of *Chironomus* with reference to X-ray microprobe analysis. Arch. Environ. Contam. Toxicol 1990;19:84–93.

Macintyre K, Keating J, Sosler S, Kibe L, Mbogo C, Githeko A, Beier J. Examining the determinants of mosquito-avoidance practices in two Kenyan cities. Malaria J 2002;1(14):1–10.

Mbogo CM, Snow RW, Khamala CP, Kabiru EW, Ouma JH, Githure JI, Marsh K, Beier JC. Relationships between of *Plasmodium falciparum* transmission by vector populations and the incidence of severe disease at nine sites on the Kenyan coast. Am. J. Trop. Med. Hyg 1995;52:201–206. [PubMed: 7694959]

Moyo NAG, Phiri C. The degradation of an urban stream in Harare, Zimbabwe Afr. J. Ecol 2002;40:401–406.

Nriagu JO, Pacyna J. Quantitative assessment of worldwide contamination of air, water and soils by trace metals. Nature 1988;333:134–139. [PubMed: 3285219]

Okoye BCO, Afolabi OA, Ajao EA. Heavy metals in the Lagos lagoon Sediments. Int. J. Environ. Stud 1991;37:35–41.

Onyari JM, Wandiga SO. Distribution of Cr, Pb, Cd, Zn, Fe and Mn in Lake Victoria sediments, East Africa. Bull. Environ. Contam. Toxicol 1989;42:807–813. [PubMed: 2743013]

Rees JG, Williams TM, Nguli MM, Kairu KK, Yobe AC. Contaminant transport and storage in the estuarine creek systems of Mombasa, Kenya. British Geological Survey Overseas Geology Series. 1996Technical Report WC/96/ 42

Renoldi M, Camusso M, Tartari G. The highly polluted Lambro river (N. Italy): Dissolved and solid transport of Cu, Cr and Fe. Water Oil Soil Pollut 1997;95:99–118.

Subra R. Biology and control of *Culex pipiens quinquefaciatus** Say, (Diptera, Culicidae) with special reference to Africa. Insect. Sci. Appl 1981;1:319–338.

Trape JF, Zoulani A. Malaria and urbanization in central Africa: The example of Brazzaville. Part II: Results of entomological surveys and epidemiological analysis. Trans. R. Soc. Trop. Med. Hyg 1987;81:10–18. [PubMed: 2901796]

Urasa, IT.; Onyari, JM. Element content of lakes in the great Rift Valley of East Africa; 43rd Joint Annual Meeting of the National Institute of Science BKK/BSP; Norfolk, Virginia. March 26–29; 1986. National Convention

Wandiga SO, Onyari JM. The concentration of heavy metals: Manganese, iron, copper, zinc, cadmium, and lead in sediments and fish from the Winam Gulf of Lake Victoria and fish bought in Mombassa town markets. Ken. J. Sci. A 1987;8(1–2):5–18.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 1

Mean heavy metal concentrations (ppm±SE) in water of larval habitats in urban Kisumu and Malindi

Metal	Kisumu			Malindi		
	Natural	Human-made	Overall	Natural	Human-made	Overall
Cadmium	0.005±0.003	0.009±0.002	0.010±0.002	0.014±0.006	0.007±0.001	0.010±0.001
Chromium	1.389±0.326	1.935±0.258	1.813±0.214	0.000±0.000	1.755±0.207	1.682±0.201
Copper	0.048±0.008	0.129±0.032	0.111±0.025	0.059±0.000	0.206±0.066	0.201±0.063
Iron	5.627±2.348	6.350±1.347	6.188±1.157	2.465±0.036	6.170±2.524	6.018±2.387
Lead	0.231±0.097	0.496±0.159	0.440±0.126	0.386±0.267	0.628±0.153	0.610±0.145
Manganese	5.302±1.581	9.135±3.458*	8.270±2.703	2.015±1.461	2.931±0.748	2.850±0.710
Zinc	0.316±0.062	0.421±0.106	0.397±0.083	0.187±0.026	0.520±0.185	0.505±0.175

Number of natural habitats in Kisumu and Malindi are 12 and 3 respectively.

Number of human made habitats in Kisumu and Malindi were 45 and 74 respectively.

* Significantly different at the 0.05 level (2-tailed) of *P* across the row on similar column in Malindi.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 2

Pearson correlation coefficients (r) for correlations between various heavy metals in water of various larval habitats in urban Kisumu (n = 40) and Malindi (n = 55)

Metal	Kisumu						Malindi					
	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Cadmium	Chromium	Copper	Iron	Lead	Manganese
Chromium	−0.08						0.14					
Copper	0.48**	0.08					0.33*	0.55**				
Iron	0.31	0.08	0.04				0.27*	0.34*	0.91**			
Lead	0.44**	−0.13	0.82**	0			0.19	0.29*	0.51**	0.45**		
Manganese	0.22	0.22	0.52**	0.31	0.35*		0.14	0.48**	0.60**	0.46**	0.26	
Zinc	0.11	0.42**	0.26	0.46**	0.05	0.79**	0.34*	0.45**	0.93**	0.94**	0.46**	0.56**

** Correlation is significant at the 0.01 level (2-tailed) of *P*.

* Correlation is significant at the 0.05 level (2-tailed) of *P*.

Table 3

Mean concentrations of heavy metal (ppm) in water of larval habitats in various strata in urban Kisumu and Malindi

Metal	Strata	Kisumu		Malindi	
		n	Mean±SE	*n*	Mean±SE
Cadmium	Well planned–well drained	14	0.006±0.003[a]	15	0.006±0.002[a]
	Well planned–poorly drained	5	0.010±0.004[a]	9	0.005±0.002[a]
	Poorly planed–well drained	2	0.008±0.008[a]	4	0.016±0.006[a]
	Poorly planned–poorly drained	19	0.009±0.003[a]	27	0.007±0.002[a]
Chromium	Well planned–well drained	14	1.786±0.340[a]	15	1.00±0.250[a]
	Well planned–poorly drained	5	1.750±0.500[a]	9	1.528±0.455[a]
	Poorly planed–well drained	2	3.125±1.875[a]	4	2.813±0.786[a]
	Poorly planned–poorly drained	19	1.711±0.320[a]	27	1.944±0.315[a]
Copper	Well planned–well drained	14	0.084±0.023[a]	15	0.076±0.014[b]
	Well planned–poorly drained	5	0.139±0.060[a]	9	0.123±0.049[b]
	Poorly planed–well drained	2	0.154±0.095[a]	4	1.041±0.738[a]
	Poorly planned – poorly drained	19	0.118±0.047[a]	27	0.172±0.050[b]
Iron	Well planned–well drained	14	5.939±2.445[a]	15	2.931±0.479[b]
	Well planned–poorly drained	5	6.819±4.293[a]	9	3.242±0.725[b]
	Poorly planed–well drained	2	5.358±2.572[a]	4	38.9±31.7[a]
	Poorly planned–poorly drained	19	6.292±1.341[a]	27	3.794±0.426[b]
Lead	Well planned–well drained	14	0.340±0.087[a]	15	0.444±0.091[a]
	Well planned–poorly drained	5	0.391±0.187[a]	9	0.300±0.093[a]
	Poorly planed–well drained	2	0.870±0.000[a]	4	1.629±0.889[a]
	Poorly planned–poorly drained	19	0.473±0.255[a]	27	0.657±0.254[a]
Manganese	Well planned–well drained	14	3.954±1.688[a]	15	1.366±0.997[a]
	Well planned–poorly drained	5	4.535±1.470[a]	9	2.965±2.152[a]
	Poorly planed–well drained	2	13.5±5.1[a]	4	6.813±4.605[a]
	Poorly planned–poorly drained	19	12.1±5.4[a]	27	3.058±0.926[a]
Zinc	Well planned–well drained	14	0.347±0.099[a]	15	0.245±0.107[b]
	Well planned–poorly drained	5	0.419±0.155[a]	9	0.218±0.083[b]
	Poorly planed–well drained	2	0.831±0.433[a]	4	3.206±2.055[a]
	Poorly planned–poorly drained	19	0.388±0.150[a]	27	0.344±0.088[b]

Means with different superscripts are significantly different from each other at 0.05 levels of *P* (Tukey HSD).

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Mean heavy metal concentrations (mg/kg±SE) in sediments of larval habitats in urban Kisumu and Malindi

Metal	Kisumu			Malindi		
	Natural	Human-made	Overall	Natural	Human-made	Overall
Cadmium	0.003±0.002	0.013±0.004	0.009±0.003	0.012±0.012	0.003±0.001	0.004±0.002
Chromium	8.750±2.989	4.643±0.952	6.012±1.214	1.875±0.625	4.352±1.006	4.104±0.919
Copper	0.461± 0.259	0.452±0.167	0.455±0.137	0.248±0.036	0.886±0.439	0.822±0.396
Iron	949.2±221.3	676.8±74.7	767.6±90.2*	398.6±143.1	363.0±93.8	366.5±84.8
Lead	0.728±0.178	1.510±0.525	1.249±0.360	1.250±0.000	2.121± 0.758	2.034±0.683
Manganese	109.7±24.01	93.7±14.2	99.0±12.2*	2.596±0.878	24.4±12.1	22.2±11.0
Zinc	2.218±0.613	1.561± 0.242	1.780±0.260	1.420±0.522	1.242±0.228	1.260±0.208

Number of natural habitats in Kisumu and Malindi are 7 and 2 respectively.

Number of human made habitats in Kisumu and Malindi were 14 and 18 respectively.

* Significantly different at the 0.05 level (2-tailed) of *P* from across the row on similar column in Malindi.

Table 5

Pearson correlation coefficients (r) of correlations between various heavy metals in sediments of various larval habitats in urban Kisumu ($n = 21$) and Malindi ($n = 20$)

Metal	Kisumu						Malindi					
	Cadmium	Chromium	Copper	Iron	Lead	Manganese	Cadmium	Chromium	Copper	Iron	Lead	Manganese
Chromium	−0.16						0.07					
Copper	0.39	−0.06					−0.14	0.06				
Iron	0.07	0.38	0.24				−0.07	0.28	0.72**			
Lead	−0.02	0.03	0.15	0.29			−0.13	0.15	0.92**	0.82**		
Manganese	0.18	0.4	0.35	0.62**	0.39		0.15	0.3	−0.04	0.45*	−0.03	
Zinc	−0.24	0.01	−0.13	0.15	0.05	0.11	0.16	0.09	0.51*	0.44	0.35	0.33

** Correlation is significant at the 0.01 level (2-tailed) of *P*.

* Correlation is significant at the 0.05 level (2-tailed) of *P*.