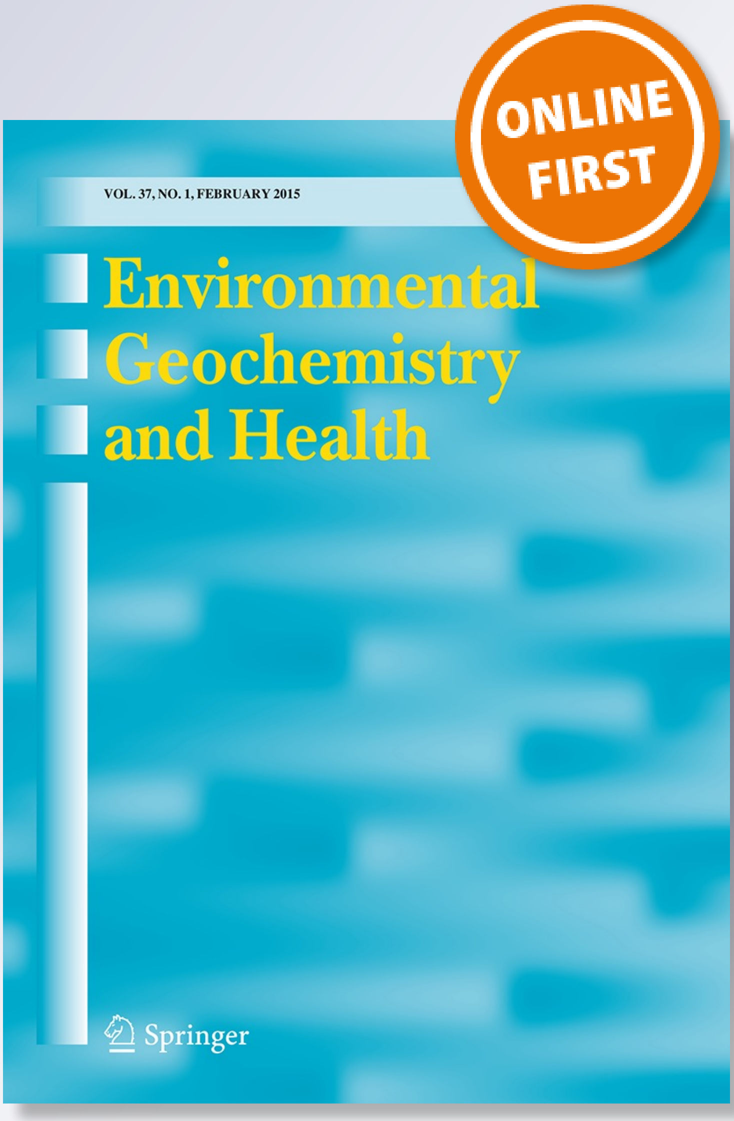
Heavy metals and parasitic geohelminths toxicity among geophagous pregnant women: a case study of Nakuru Municipality, Kenya

A. O. Odongo, W. N. Moturi & E. K. Mbuthia

Environmental Geochemistry and Health
Official Journal of the Society for Environmental Geochemistry and Health

ISSN 0269-4042

Environ Geochem Health
DOI 10.1007/s10653-015-9690-3



Springer

Environ Geochem Health
DOI 10.1007/s10653-015-9690-3

ORIGINAL PAPER

Heavy metals and parasitic geohelminths toxicity among geophagous pregnant women: a case study of Nakuru Municipality, Kenya

A. O. Odongo · W. N. Moturi · E. K. Mbuthia

Received: 25 October 2014 / Accepted: 25 February 2015

Abstract Geophagia is defined as deliberate consumption of earths' materials, e.g. soil, clay and soft stones. The practice is widespread among pregnant women, and there are conflicting views as to whether it is beneficial to health or not. Geophagic materials may be a source of micronutrients though the materials may bind the micronutrients thus reducing or hindering their bioavailability in the body. Geophagia is closely associated with geohelminthic infections among pregnant women and heavy metal poisoning, which constitute significant public health problem in many developing countries such as Kenya. In our research, the geophagic materials consumed by the pregnant women were studied. A total of 38 geophagic materials in the possession by different pregnant women were analysed. The collected samples were subjected to standard digestion procedures and analysed for zinc, lead and iron by atomic absorption spectroscopy. Results indicated that the geophagic materials contained elevated levels of Fe at mean concentration value of 80.10 ppm, Pb at 3.28 ppm and Zn 1.81 ppm for a 1.00 g sample. An average of 20 g of the geophagic materials was being consumed per day. Based on the average consumption, the pregnant women were exposed to 65.52 ppm Pb per day, 36.2 ppm Zn per day and 1602 ppm Fe per day. Lead exceeded the WHO-lead exposure limits of 25 ppm/day for pregnant women. The materials were also subjected to microscopic examination for *Ascaris lumbricoides, Trichuris trichiura, Taenia* Spp., *Necator americanus* and *Ancylostoma duodenale*. In conclusion, the women were exposed to heavy metals—iron, zinc and lead, but there was no observable eggs, larvae or adult species of the geohelminths. The key recommendation was that there is need to integrate public health education on geophagia, lead screening and testing with antenatal support care systems. This will enhance maternal and child health, thus reducing infant and maternal morbidity and mortality rates.

Keywords Geophagia · Geohelminths · Heavy metal poisoning · Pregnancy · Antenatal care

A. O. Odongo (✉) · W. N. Moturi
Department of Environmental Science, Egerton University, Box 536, Njoro, Kenya
e-mail: alfredodongo.owino@gmail.com

E. K. Mbuthia
Department of Human Nutrition, Egerton University, Box 536, Njoro, Kenya

Introduction

Geophagia is the habit of eating earth including clay and other types of soil (Halsted 1968). It is a form of pica that has been observed in many parts of the world (Abrahams and Parsons 1996), but is especially widespread in sub-Saharan Africa. Soil or clay is mostly consumed by pregnant or breast-feeding women and also by children (Luoba et al. 2004).

Studies suggest that in African regions where geophagia occurs, between 46 and 73 % of pregnant or breast-feeding women consume soil regularly. The amounts differ considerably, with average values from 1 to 100 g/day (and more) being reported (Luoba et al. 2004). The practice of geophagia is deeply embedded in cultural traditions, and in many cultural contexts, it is seen as normal.

The aetiology of geophagia remains unclear. There may be several major contributing factors to geophagia, including nutritional, sensory, physiological, neuropsychiatric, cultural, or psychosocial factors (Sayetta 1986). Geophagia can have serious medical implications which may include metabolic abnormalities such as heavy metal poisoning (Patrick 2007), electrolyte disturbances, vitamin deficiencies and iron and zinc deficiencies. It can also lead to soil-borne parasitic infection, dental injury, and achlorhydria (Patrick 2007). Furthermore, it has been associated with gastric and intestinal obstruction from bezoars, foreign bodies, faeces or parasites (Patrick 2007). In addition, geohelminthic infections in pregnancy have been associated with increased iron deficiency, maternal anaemia, and impaired nutritional status, as well as decreased infant birth weight and intra-uterine growth retardation (Villar et al. 1989; WHO 2002). All these can result in both increased infant and maternal morbidity and mortality. Some hypotheses suggest that geophagia may be beneficial in that it can provide the much-needed micronutrients among people with deficiencies and protection from toxins and pathogens (Young et al. 2007). Geophagic substances protect either by adsorbing pathogens and toxins within the gut or by coating the surfaces of the intestinal endothelium rendering the gut less permeable to toxins and pathogens.

In Africa, the habit is widespread and is passed from one generation to another because of cultural beliefs and genuine enjoyment of the habit (Giessler et al. 1997). In Kenya, previous studies on geophagia among school children and pregnant women in Western Kenya have been described by Giessler et al. (1997). They found out that over 70 % of the sampled school-going children in Nyanza province consume soil at an average rate of approximately 30 mg daily. The eaten soils were mainly from termite nests, weathered stones and walls of huts. Another study conducted by Moturi and Shivoga (2009) in Mauche division Nakuru County showed that the geophagia among children in this region of Kenya was a risk factor for diarrhoea. It is thus evident that the periodic consumption of geophagia materials might adversely affect the health of the mother and infant during pregnancy. This study aimed at determining heavy metals—lead, zinc and iron—exposure and geohelminths exposure among geophagous pregnant women in Nakuru Municipality.

Materials and methods

Nakuru Municipality is located 160 km northwest of Nairobi, along the Kenya–Uganda highway. It is the headquarters of Nakuru County and the fourth largest town in Kenya. It is a cosmopolitan town with its population originating from all the 42 ethnic groups around the country. Nakuru's population has been growing at the rate of 5.6 % per annum. From a population of 38,181 in 1962, the population reached 163,927 in 1989 and 289,385 in 1999 and 473,288 in 2009 population and housing census reports (GOK 2000; KNBS 2010). By the year 2015, the population is projected to rise to 760,000 (MCN 1999), which is approximately 50 % above the present levels.

Geological foundations of the municipality are related with the volcanic eruptions and tectonic activities associated with the formation of the Great Rift Valley. Situated within the municipality is Menengai Crater that is a dormant volcano. The soils are loose volcanic soils with volcanic rocks associated with a host of minerals and construction materials. These volcanic-sedimentary accumulations have deposits of clays, trona, diatomite, gypsum and other minerals. There are a number of sand, gravel and stone quarries within the municipality (Kibet 2004). The products from these quarries are not only utilized in the construction industry in the town but also exported to other regions outside the municipality (Kibet 2004).

The study sites comprised public government health facilities within the Nakuru Municipality. This covered twelve level two and three healthcare facilities which included: Langa Langa, Lanet, Bondeni Maternity, Bondeni clinic, Kapkures, Barut, Kenya Industrial Training Institute (KITI), Forest Institute Training College (FITC), Viwanda, Nakuru West, Mirugi Kariuki and Kenya Prisons Clinic.

Ethical clearance

Ethical approval was obtained from Egerton University Ethical committee, and research permit from National Commission for Science, Technology and Innovation (NACOSTI), Ministry of Health and the healthcare facilities. Recruitment and consent of the participants was done in the presence of the clinical officers, nurses and nutritionists in the respective health centres.

Sampling

A cross-sectional, descriptive study was adopted for the study. Purposive sampling was used to select public health centres and dispensaries within the municipality. To determine the sample size in each of the selected health centres, data from prenatal health care were evaluated which included the number visiting per health centre, age and stage of pregnancy. These data guided the total number of recruits targeted and other criteria for clustering, e.g. trimester of pregnancy. The pregnant women were sampled from the twelve healthcare facilities, and a total of 431 pregnant women in different trimesters (1st, 2nd and 3rd) of pregnancy accepted to be part of the study. The information on sources, types and daily amount of consumption of geophagia materials were collected using a questionnaire. All the geophagic materials consumed by 151 geophagous pregnant women in their possession were collected. One hundred and fifty-one samples were collected and 25 %, i.e. 38 samples subjected to both biological and chemical laboratory analysis.

Sample analysis

For chemical analysis of heavy metals—zinc, iron and lead, 1.00 g of each sample was crushed, weighed in duplicate and transferred into a 125-ml conical flask. In each conical flask, 30 ml of Aqua regia ($3HCl:1NO_3$) digestion mixture was added and left overnight for cold digestion to take place. Further digestion was done by heating at 300–370 °C on a hot plate for 30 min. The samples were then filtered into 125-ml plastic containers and the eluent solution topped to 50 ml. Standard procedure for the preparation of stock solutions (1000 ppm) for Fe, Zn and Pb were employed. Serial solutions for the determination of the elements in the samples using AAS were then prepared (Okalebo et al. 2002).

Within 24 h of collection, the samples for geohelminths (*Ascaris lumbricoides, Trichuris trichiura, Taenia* Spp. and hookworm—*Necator americanus* and *Ancylostoma duodenale*) examination were preserved in 5 % formalin. Simple flotation method with the use of McMaster technique (Hansen and Perry 1987) was employed for the examination. In the method, 4 g of each crushed sample was weighed and mixed with 56 ml distilled water. The mixture was stirred, filtered and subjected to centrifugation at 1500 rpm for 5 min. The supernatant was discarded, and 40 ml of the flotation fluid added to 10 ml of the sub-sample sediments. The McMaster counting chambers were filled with the sub-sample and examined under a light microscope at 10 × 10 magnifications.

Data analysis

A standard calibration curve of absorbance versus concentration was obtained and used to calculate the concentrations for each metal in the various samples. Statistical package for social sciences (SPSS) and Microsoft excel were used to analyse the data. Descriptive statistics was used in data analysis, and results presented in frequencies, percentages, statistical charts, tables and means were employed to present results from the field survey and laboratory analysis. This gave the prevalence rates of geophagia, the geohelminths exposure and the concentrations and exposure to iron, zinc and lead. Based on the amount of consumed geophagic materials and concentrations obtained after laboratory analysis, lead exposure levels were compared with the WHO standard to determine the health risk (Fig. 1).

Results

The most preferred type of geophagia material for consumption was the soft earth stone also called "monyo" or "odowa" in local dialects. Majority of the respondents obtained the materials from kiosks/shops and others from open-air markets (Fig. 2). The substances and their sources reported to be ingested are consistent with most of the commonly reported in the literature. A study done by Ngozi (2008) in Nairobi reported that 89.9 % of the respondents ingested soft

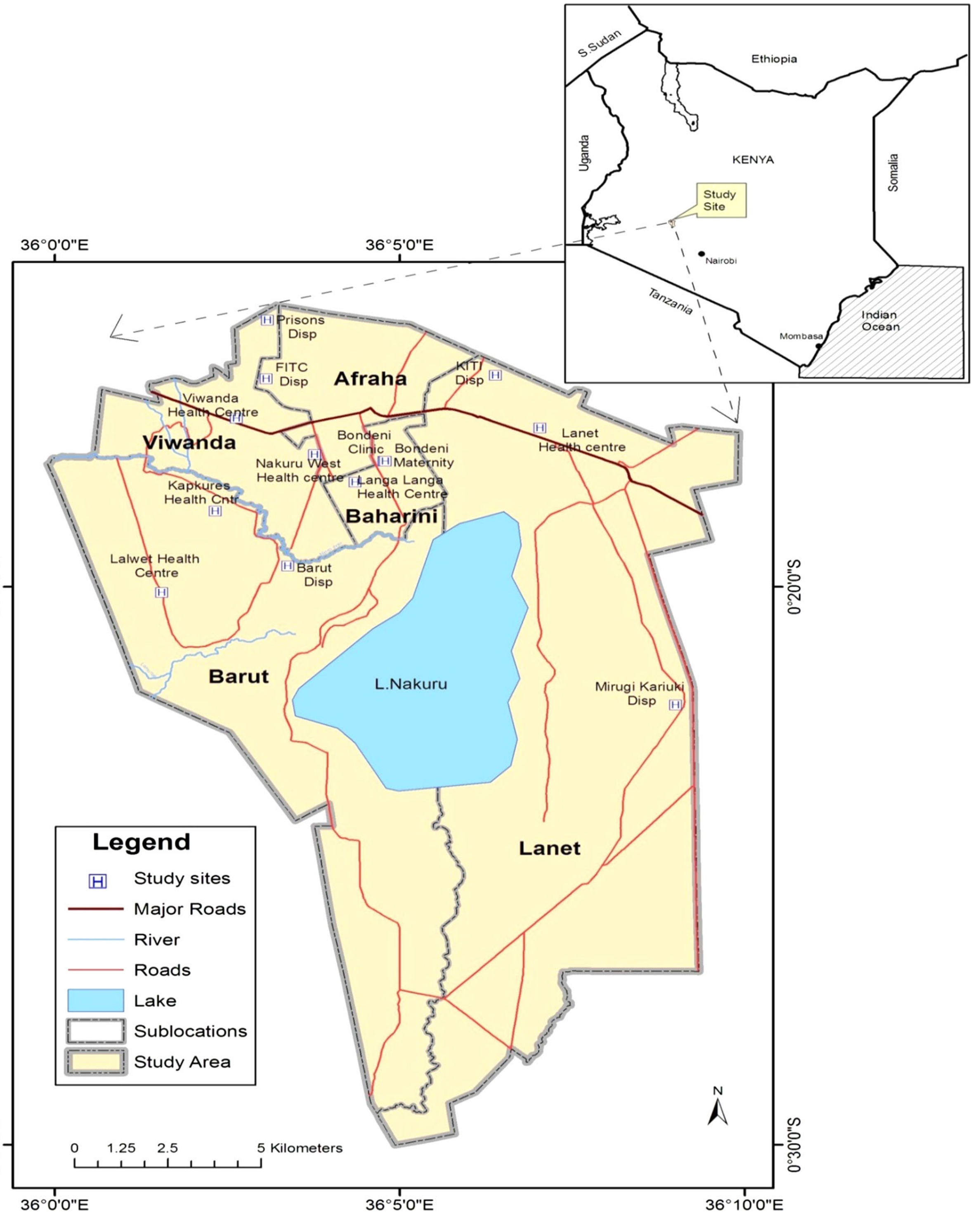


Fig. 1 Map showing Nakuru municipality and the locations of the health centres. Maina G and Odongo A, Department of Environmental Science, Egerton University

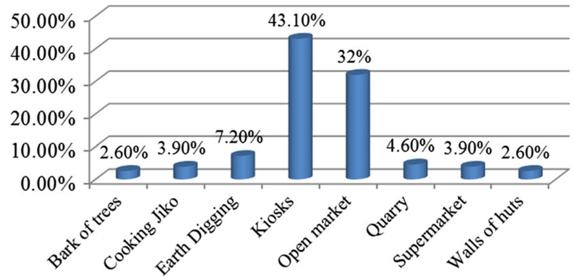


Fig. 2 Sources of the geophagia materials

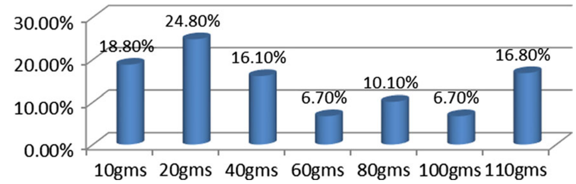


Fig. 3 Percentage frequencies of quantity of the geophagia material consumed per day

stones (odowa) regularly during pregnancy. Luoba et al. (2004) observed in his study that the preferred type of earth eaten by Kenyan women was soft stone, known locally as odowa and earth from termite mounds.

In this study, 26.8 % of the respondents treated the geophagia materials before consumption. The methods of pre-treatment included: 12.4 % burning in charcoal cooker, i.e. "Jiko", 11.8 % drying on the sun and 2.6 % addition of salt to the material (Table 1). The pre-treatment methods may render the biological contaminants such as geohelminths harmless and thus could influence the practice before consumption.

Majority (24.8 %) of the women consumed an average amount of 20 g of the geophagia materials per day, while 16.8 % consumed 110 g and above per day (Fig. 3).

Table 2 shows the approximate average total amount of the materials consumed by the pregnant women in a day at different trimesters of their pregnancy. Women in the third trimester of pregnancy consumed large amount of the materials. However, it was observed that there was no statistical significant difference on the quantities of the material consumed at different trimesters of pregnancy, ($\rho = 0.84$, $x^2 = 7.21$).

Table 1 Pre-treatment methods done to geophagic materials before consumption

	Frequency	Percent (%)
Burning in a charcoal cooker (Jiko)	19	12.4
Drying in the sun	18	11.8
Addition of salt	4	2.6
No pre-treatment	112	73.2

Concentrations of heavy metals in the geophagic materials

Table 3 shows the mean concentrations of the heavy metals in various sampled geophagic materials collected from the geophagous women at different health facilities. Lead concentrations in 1 g of the sampled geophagia materials at the various health centres ranged from 0.20 to 5.50 ppm with mean of 3.28 ppm (SE $\pm$ 0.59) ppm. Considering all the health centres, the concentration of zinc in 1 g of the samples ranged from 1.15 to 2.35 ppm with mean concentration of 1.811 (SE $\pm$ 0.13) ppm. The samples at Barut had the highest zinc concentration of 2.35 ppm with samples at Bondeni Maternity having the least zinc concentration of 1.15 ppm. The relationship between zinc concentration in the geophagic materials with the sources and types of the materials was analysed by use of analysis of variance (ANOVA). The results of the analysis showed that there was no statistical significant difference in zinc concentrations among the different sources of geophagic materials (F-cal $= 0.43$, $p = 0.95$) and also that there was no statistical significant difference in zinc concentrations in the different types of geophagic materials (F-cal $= 0.134$, $p = 0.94$).

The overall results showed that the sampled geophagia materials in the study area had high average concentrations of iron of 80.096 (SE $\pm$ 5.50) ppm per gram of sample. Considering all the centres, the concentration of iron in the samples ranged from 58.21 to 112.5 ppm. The relationship between Fe concentrations and the type and sources of the geophagic materials was analysed by use of ANOVA. The computed statistical results showed that neither was there statistical significant difference in iron concentrations among the different sources of geophagic materials (F-cal $= 0.86$, $p = 0.61$) nor was there statistical significant difference in iron concentrations

Table 2 Trimester of Pregnancy * Total quantity of geophagia material consumed per day Cross tabulation

Trimester of pregnancy	Total quantity consumed per day						
	Below 10 g	10–30 g	30–50 g	50–70 g	70–90 g	90–110 g	110 g and above
1st trimester (1–3 months)	1	1	0	0	0	1	2
2nd trimester (3–6 months)	10	9	7	4	4	2	6
3rd trimester (6–9 months)	17	27	17	5	11	7	17

Table 3 Heavy metals concentrations in geophagic materials in ppm

S/no.	Health facility	Lead (Pb)		Zinc (Zn)		Iron (Fe)	
		$\bar{x}$	S.E	$\bar{x}$	S.E	$\bar{x}$	S.E
1	Langa Langa	1.38	±0.34	1.91	±0.27	79.68	±39.95
2	Kapkures	0.20	±0.12	2.14	±0.11	76.43	±4.24
3	FITC	1.00	±0.27	1.78	±0.41	68.39	±16.51
4	Lanet	2.80	±0.68	1.88	±0.08	66.43	±5.82
5	Bondeni Maternity	3.13	±0.43	1.15	±0.52	58.21	±22.58
6	Bondeni clinic	4.50	±0.50	2.19	±0.19	90.48	±22.04
7	Mirugi Kariuki	4.25	±0.25	1.90	±0.52	100.45	±38.84
8	Nakuru West	5.00	±0.50	1.17	±0.92	112.5	±33.93
9	KITI	5.00	±1.00	1.64	±1.01	62.68	±55.18
10	Barut	5.50	±0.50	2.35	±0.28	85.71	±14.28

in the different types of geophagic materials consumed (F-cal $= 1.67$, $p = 0.19$).

Discussion

The observed high mean iron concentrations of 80.096 ppm per gram sample compared with other metals could be attributed to high iron oxides in the geophagia materials. High lead concentrations were observed in samples from the open-air markets, kiosks and quarry an indication of high pollution of these geophagic substances with either vehicular substances or pollution from industries in the study area. The samples at Barut had the highest mean lead concentration of 5.50 ppm with samples at Kapkures having the least lead concentration of 0.20 ppm. It was observed that there is a lot of quarrying activities that involve sand harvesting at Barut. These quarries are some of the sources of the geophagia materials in the study site. The quarries might be polluted with vehicular substances and water run-off from industries that could contribute to the high lead concentrations. Small-scale agriculture is a major activity in Kapkures. Low lead content on the geophagic materials at the site implies minimal lead contamination of the sources of these materials at the site.

Lead exposure

The mean daily lead exposure ranges calls for concern (Table 4). Ingesting any of the geophagia material at that rate could lead to serious health problems and complications which may include premature birth, low birth weight, miscarriage and stillbirth. Other health problems may include impaired neurobehavioral development, decreased intelligence and impaired hearing acuity to the growing foetus. “Lead is an undisputed neurotoxin; it is poisonous to the foetus growing and developing brain” (CDC 2005). The average amount of 20 g geophagia materials consumed per day is equivalent to 65.52 ppm daily lead exposure (Table 4). This exposure exceeded the World Health Organization-recommended daily tolerable intake of 25 ppm per day for pregnant women (WHO 2000). Computed results of one-sample *t* test

Table 4 Daily exposure to lead, zinc and iron

Pb conc. = 3.27 ppm per gram of sample
Zn conc. = 1.811 ppm per gram of sample
Fe conc. = 80.096 ppm per gram of sample

Daily consumption of the geophagia material (g)	Exposure per daily consumption (ppm)			
Range	Mean	Pb	Zn	Fe
Below 10 g	10	32.76	18.11	800.96
10–30 g	20	65.52	36.22	1601.92
30–50 g	40	131.01	72.44	3203.84
50–70 g	60	196.56	108.66	4805.76
70–90 g	80	261.82	144.88	6407.68
90–110 g	100	327.6	181.1	8009.6
110 g and above	110	360.36	199.21	8810.56
World Health Organization daily tolerable intake value		25	11,000	27,000

showed that there was a statistical significant difference in the mean daily lead exposure compared with the WHO daily tolerable limits, (t-cal = 3.58, $p = 0.012$). Lead is toxic at very low exposures and even the lowest doses can impair the nervous system.

Considering the mode in Table 2, the total average daily lead exposure across the three trimesters exceeded the WHO safety limits on lead, for example two pregnant women in their first trimester consumed an average of 110 g per day which was equivalent to daily lead exposure of 360.36 ppm. It is thus evident from the study that a significant number of pregnant women, and presumably their infants, are being exposed to high lead concentrations in the study area. Chronic lead exposure may cause irreversible dysfunction and morphologic changes, resulting in eventual renal failure and death (Middendorf and Williams 2000). Besides, lead intoxication has adverse effects in the first trimester of pregnancy. A period during which there is extensive cell division and development of primitive central nervous system and major organs (Middendorf and Williams 2000). Geophagia therefore increases the risk of lead exposure. The findings on the lead exposure are of concern since lead exposure is estimated to account for 0.6 % of the global burden of disease, with the highest burden in developing regions (WHO 2009).

Zinc exposure

Adequate zinc is extremely important during the first trimester when organs are formed and may play a role in assisting in immune system development. The tolerable daily zinc intake during pregnancy is 11,000 ppm (Shah and Sachdev 2006).

The daily zinc exposure levels Table 4 were of no toxic concern to the study population, for example considering the modes in Table 16, two pregnant women in their first trimester consumed an average of 110 g per day, which is equivalent to zinc concentration of 199.21 ppm per day. Depending on the bioavailability, this may supplement the dietary intake; however, if there is sufficient dietary intake, this can lead to zinc toxicity. The human health effects associated with zinc deficiency are numerous and include neurosensory changes, impaired neuropsychological functions, growth retardation, delayed wound healing, immune disorders and dermatitis. These conditions are generally reversible when corrected by zinc supplementation (Shah and Sachdev 2006).

Zinc is not stored in the body and excess intakes result in reduced absorption and increased excretion. Nevertheless, if usual zinc intake is above the upper levels of intake (UL of 25,000 ppm zinc per day), an individual may be at risk of adverse effects from excessive nutrient intake (Cousins and Hempe 1990). An excess of zinc can result in a decreased availability of dietary copper and the development of copper deficiency. Prolonged intakes of zinc supplements ranging from 50,000 ppm/day up to 300,000 ppm/day have been associated with a range of biochemical and physiological changes. These include hypocupraemia, leucopaenia, sideroblastic anaemia, altered lipoprotein metabolism and impaired immune function (Sandstead 1995).

Iron exposure

Pregnant women in the third trimester of pregnancy consumed a large amount of geophagic materials, for example 17 out of 25 pregnant women who consumed an average total quantity of 110 g and above were in their third trimester of pregnancy (Table 2). This corresponds to high nutrient requirements, for example iron at this period of pregnancy. The daily exposure limits for iron during pregnancy is 27,000 ppm/day (Beard 2008). Considering the modes in Table 2, 27 pregnant women in their third trimester consumed an average of 20 g per day an equivalent of 1601.92 ppm per day. The observed iron exposure levels were therefore of no toxic concern among the study population. Pregnant women require increased amounts of iron, and absorption of dietary iron from the gut is normally increased (Baker 2006). If bioavailable, the observed concentrations may supplement the dietary intake; although in cases where medicinal iron supplement is used by the pregnant women, this might result to excessive intakes. It has been theorized although never proved that geophagia may signal iron deficiency (Mills 2007). Though too much geophagic material can result in blocked bowels and crowd out, preventing absorption of the nutrients such as iron needed by the baby.

Geohelminths exposure

Geophagia may be a risk factor for parasitic infections. In this study, there were no observable eggs, larvae or adult *A. lumbricoides*, *T. trichiura, Taenia* Spp. and hookworm—*N. americanus* and *A. duodenale* in the sampled geophagia materials examined in the laboratory. This might have been as a result of pre-treatment of the materials before consumption or as a result of storage and transportation. The results might also imply that there was no contamination of the materials from their various sources. The pre-treatment, storage and transportation might hinder their survival. The finding supports a parasitological study done by Shinondo and Mwikuma (2008) in Lusaka, Zambia, and the study indicated that the types of soil ingested by geophagous pregnant women did not contain helminth ova. Geohelminths ova of *A. lumbricoides* and *T. trichiura* require moisture to survive and embryonate (Shinondo and Mwikuma 2008). The pre-treatment, storage and transportation might hinder their survival. The findings in this study also corroborates a similar study among school children in Western Kenya, which showed that geophagia does not directly contribute substantially to the infections with soil-transmitted helminths at least in the dry season (Giessler et al. 1997).

Conclusions

The major source of the geophagic materials was open-air markets and kiosks/shops. An average of 20 g was being consumed per day by the majority of the pregnant women. This was preferably after pre-treatment by burning in a charcoal cooker "Jiko". The study also showed that the geophagic materials consumed contained heavy metals—iron, zinc and lead, and thus the women were exposed to these heavy metals. High concentrations of Fe were observed compared with the other heavy metals. The daily lead exposure exceeded the WHO-recommended daily tolerable intake of 25 ppm per day for pregnant women; however, the daily exposure levels for iron and zinc were of no toxic concern since they were below the WHO tolerable daily intake limits of 27,000 and 11,000 ppm respectively. There were no ova or adult geohelminths—*A. lumbricoides*, *T. trichiura, Taenia* Spp. and hookworm—*N. americanus* and *A. duodenale*—recovered from any of the soil types preferred by the pregnant women, and as such geophagia was an unlikely risk of geohelminthic infections. There is a need to integrate public health education on geophagia, lead screening and testing with antenatal care systems.

Acknowledgments The authors are grateful to the Departments of Chemistry and Environmental Science Egerton University for their technical assistance. They are also grateful to the Division of Research and Extension Egerton University for partially funding the project.

References

Abrahams, P., & Parsons, J. (1996). Geophagy in the tropics, a literature review. *Geographical Journal, 162*, 63–72.

Baker, P. N. (2006). *Obstetrics by ten teachers*. Manchester: BookPower.

Beard, J. L. (2008). Why Iron deficiency is important in infant development. *Journal of Nutrition, 138*(12), 2534–2536.

CDC. (2005). Blood lead levels-united states, 1999–2002 CDC, Weekly May 2005/54, pp. 513–516.

Cousins, R. J., & Hempe, J. M. (1990). Zinc. In M. L. Brown (Ed.), *Present knowledge in nutrition*. Washington: International Life Sciences Institute.

Giessler, A., Mwaniki, D., Thiongo, F., & Friis, H. (1997). Geophagy among school children in Western Kenya. *Tropical Medicine & International Health, 2*, 624–630.

Government of Kenya, KNBS. (2000). *Demographic survey*. Nairobi: Government of kenya Press Service.

Government of Kenya, KNBS. (2010). *Population and housing census*. Nairobi: Government of kenya Press Service.

Halsted, J. (1968). Geophagy in man; its nature and nutritional effects. *American Journal of Clinical Nutrition, 21*, 1384–1393.

Hansen, J., & Perry, B. (1987). *The epidemiology, diagnosis and control of helminth parasites of ruminants*. Addis Ababa: International Laboratory for Research on Animal Diseases.

Kibet, L. (2004). *Use of environmental accounting to estimate optimal extraction levels for quarries: Case of Nakuru Municipality*. Addis Ababa: Beijer Institute of Ecological Economics.

Luoba, A., Giessler, P., Estambale, B., Ouma, J. H., Magnussen, P., & Alusala, D. (2004). Geophagy among pregnant and lactating women in Bondo District, western Kenya. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 98*, 734–741.

Middendorf, F., & Williams, P. (2000). *Nephrotoxicity: Toxic responses of the kidney*. New York: Wiley.

Mills, M. (2007). Craving more than food: The implications of pica in pregnancy. *Nursing for Women's Health, 11*(3), 266–273.

Moturi, W. N., & Shivoga, W. A. (2009). Geophagia, a risk factor for diarrhoea in home environment: Study of Mauche division, Molo, Kenya. *Journal of Infection Developing Countries, 3*(2), 94–98.

Municipal Council of Nakuru. (1999). *Census*. Nairobi: Kenya National Bureau of Statistics.

Ngozi, P. O. (2008). Pica practices of pregnant women in Nairobi Kenya. *East African Medical Journal, 85*(2), 72–79.

Okalebo, J. R., Gathua, K. W., & Woomer, L. P. (2002). *Laboratory methods of soil and plant analysis. A working Manual* (pp. 22–24). Nairobi: TSBF-CIAT and Sacred Africa.

Patrick, Y. (2007). *A case of geophagia* (pp. 1–3). London: University College London, Clinical Vignette.

Sandstead, H. H. (1995). Is zinc deficiency a public health problem? *Nutrition, 11*, 87–92.

Sayetta, R. (1986). Pica: An overview. *American Family Physician, 33*, 181–185.

Shah, D., & Sachdev, H. P. (2006). Zinc deficiency in pregnancy and foetal outcome. *Nutrition Reviews, 64*(1), 15–30.

Shinondo, Cecilia, & Mwikuma, G. (2008). Geophagy as a risk factor for helminth infections in Lusaka, Zambia. *Medical Journal of Zambia, 35*(2), 50–51.

Villar, J., Klebanoff, M., & Kestler, E. (1989). The effect on foetal growth of protozoan and helminthic infection during pregnancy. *Obstetrics and Gynecology, 74*, 915–920.

WHO. (2000). *Lead in: Safety evaluation of certain food additives and contaminants. Joint FAO/WHO expert committee on food additives, food additives Series: 44*. Geneva: World Health Organization.

WHO. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. Geneva: World Health Organization.

World Health Organization. (2002). *Prevention and control of schistosomiasis and soil-transmitted helminthiasis*. Geneva: WHO.

Young, S. L., Goodman, D., Farag, T. H., Ali, S. M., & Khatib, M. R. (2007). Association og geophagia with Ascaris, Trichuris and Hookworm transmission in Zanzibar, Tanzania. *Transactions of the Royal Society of Tropical Medicine and Hygiene, 101*, 766–772.