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2016-02-17

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Science Publishing Group

doi: 10.11648/j.ijepp.20160401.13

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International Journal of Environmental Protection and Policy
2016; 4(1): 16-23
Published online February 17, 2016 (http://www.sciencepublishinggroup.com/j/ijepp)
doi: 10.11648/j.ijepp.20160401.13
ISSN: 2330-7528 (Print); ISSN: 2330-7536 (Online)

Review Article

Heavy Metals Contamination in Agricultural Soil and Rice in Tanzania: A Review

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To cite this article:
Fides Simon, Kelvin Mark Mtei, Martin Kimanya. Heavy Metals Contamination in Agricultural Soil and Rice in Tanzania: A Review. *International Journal of Environmental Protection and Policy.* Vol. 4, No. 1, 2016, pp. 16-23. doi: 10.11648/j.ijepp.20160401.13

Abstract: Heavy metals contamination in agricultural soil is a potential environmental threat to the safety of agricultural food crops such as rice which is consumed by majority of Tanzanians. The aim of this review is to put together available information on sources of heavy metals, their extent of contamination in agricultural soil and in rice, the risk of exposure through rice consumption as well as the relationship between heavy metals contamination in agricultural soils and in rice in Tanzania. There are several methods of determining the concentrations of heavy metals in soils and in rice. These include Inductively Coupled Plasma Mass Spectrometer (ICP – MS) and Energy Dispersive X – ray Fluorescence spectrometer (EDXRF). It has been mostly reported that the extent of heavy metals contamination in agricultural soils is influenced by their closeness to mining or industrial areas. The use of river waters in mining areas or wastewater from industries for irrigation has been associated to increasing levels of heavy metals in agricultural soils. The elevated level of heavy metals in agricultural soils leads to their accumulation in crops especially rice which upon consumption poses health effects to human and the ecosystem at large. This review suggests the need for determining the extent of heavy metals contamination in agricultural soils around potential areas such as mining and to link this with exposure assessment on heavy metals through rice consumption in Tanzania. This information is necessary to establish the extent at which rice consumers in Tanzania are at risk of heavy metals exposure.

Keywords: Mining, Contaminated Rice, Exposure Assessment, Industrial Wastes

1. Introduction

Heavy metals contamination in the environment may cause detrimental effects to both plants and animals including human being. This calls for attention from government authorities and the general public at large. Whereas food crops may be exposed to heavy metal through contaminated soil or atmospheric dispersal of such metals from industrial areas, human beings may be exposed to heavy metals through consumption of contaminated foods such as rice [1].

Heavy metals such as copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are considered to be useful micro-nutrients to plants when used in amounts which facilitate the physical growth and development of plants [2]. When these metals exceed maximum acceptable limits they become toxic to the plants [3]. The normal plant growth can be inhibited by high levels of heavy metal in the soil, leading to reduction of crop yield [4, 5]. The heavy metals cadmium (Cd), arsenic (As) and chromium (Cr) have been reported to be more toxic to plants than the others and have no any reported biological functions to plants [6]. Other heavy metals with no reported benefits to plants are lead (Pb), nickel (Ni) and mercury (Hg) [4]. Heavy metals are non degradable and stay longer in the soil [7]. Crops such as rice that are grown in submerged conditions are even more exposed to heavy metal sources both from the soil and water. Rice being the second most consumed crop in the world may in turn expose the majority of its consumers to the heavy metals [8].

Just like in plants - Fe, Cu, Mn and Zn are useful in humans when used in trace amounts. When these metals exceed the acceptable limits in the body, they pose health problems [9]. Some of these health problems are cancer, hypertension, fever,

kidney disorder and DNA damage in living cells [10]. Heavy metals can also cause modifications in DNA methylations resulting to epigenetic silencing of gene expression [10]. Just like in plants, some heavy metals such as Cd, As, Cr, Pb and Hg have no any reported biological functions in humans [6].

The risk of human exposure to heavy metals through food increases when the food is grown on heavy metals contaminated soils. Agricultural soils may be contaminated by heavy metals through practices such as irrigation and use of heavy metals containing agrochemicals such as pesticides, herbicides and fertilizers [10]. The highest risk of contamination has been reported for soils around mining operations [11]. In Tanzania, artisanal and small scale mining activities are conducted in areas where rice production is also high. Of such areas are Kahama and Geita in the Lake Victoria zone. This suggests that there are high chances for the rice produced from these areas to be contaminated with heavy metals at levels that exceed regulatory limits. Observations made in China by a study conducted around Dabaoshan mine in China reported high levels of Pb (1.44 mg/Kg) and Cd (0.82 mg/Kg) in rice. The study also reported, high concentration of Cu (276 mg/Kg – 703 mg/Kg), Zn (181 mg/Kg – 1100 mg/Kg) and Cd (3.0 mg/Kg – 5.5 mg/Kg) in paddy soils of China [11]. The maximum tolerated level for both Pb and Cd in rice of China is 0.2 mg/Kg as stated by National Food Safety Standard [12].

Heavy metals from mining sites may reach agricultural soils through leaching. Also during the rainy season large quantities of tailing and waste containing heavy metals are carried by runoff to the agricultural fields near the mining sites which lead to the elevated levels of heavy metals in the soils [13]. Due to this reason, protecting the agricultural soils in Tanzania from the heavy metals contamination is an urgent need. However, strategies to protect those areas from heavy metal contamination cannot be formulated when data on heavy metal contamination of agricultural soils in Tanzania are limited and scattered.

The objective of this paper is to review the available literature on extent of heavy metals contamination in agricultural soils, sources of the contamination, extent of heavy metal contamination in rice and the risk of human exposure to heavy metals through consumption of rice, as well as the relationship between heavy metals contamination in agricultural soils and in rice in Tanzania. The reviewed information will be useful to decision makers and other organs responsible for environmental and food safety control to find ways of reducing heavy metals contamination in the environment as well as in food.

2. Heavy Metals Contamination in Agricultural Soil

Extent of contamination

In soil science perspective, heavy metals contamination in agricultural soil refers to the presence of heavy metals of significant toxicity [14]. There are limited data of heavy metal contamination in agricultural soils of Tanzania. Kibassa et al. [15] reported average concentrations of Zn, Pb, Cr, Cd and Cu in agricultural soils collected from six sites in Dar – es – Salaam to be 33.18 mg/Kg, 14.32 mg/Kg, 7.68 mg/Kg, 0.22 mg/Kg and 5.62 mg/Kg, respectively. These sites were chosen based on their proximity to the steel, iron, food and detergents manufacturing industries which drain wastewater into the rivers and streams from which residents draw water for irrigation purposes. The mean concentrations of Cr (0.35 mg/Kg), Pb (8.45 mg/Kg), Cu (1.69 mg/Kg) and Zn (13.9 mg/Kg) were also reported for agricultural soil of Lushoto district [16]. A study by Machiwa [1] in the lake Victoria basin reported mean concentrations of Cd (8.70 mg/Kg), Hg (19.99 mg/Kg), Pb (19.38 mg/Kg), Cr (20.98 mg/Kg), Zn (65.46 mg/Kg) and Cu (14.58 mg/Kg) in paddy soils collected from 18 sites within the basin. The Lake Victoria basin was chosen for the heavy metals investigation based on increasing mining activities, urbanization, industrial and agricultural development. However, all these studies did not assess and report as to whether the levels of heavy metals contamination constitute a significant risk of toxicity in the soils or not. One of the ways to assess the risk of heavy metal toxicity in soils is comparing the contamination levels with the maximum acceptable limits for the metals in soils.

As guidance to farmers and agricultural extension officers, Tanzania Bureau of Standards (TBS) sets the maximum acceptable limits for heavy metals in agricultural soils. The maximum acceptable limits set by the TBS [17] for Cr, Cu, Zn, Pb, Ni, As and Cd are 100 mg/Kg, 200 mg/Kg, 150 mg/Kg, 200 mg/Kg, 100 mg/Kg, 1 mg/Kg and 1 mg/Kg, respectively. There is an urgent need to determine the extent at which heavy metal contaminations in agricultural soils of Tanzania comply with the TBS set limits. Additionally, a need exist to determine the heavy metal contamination in as many farms as possible to avail sufficient data for risk assessment which will inform policy makers in formulation of strategies to prevent agricultural soils from contamination. In other countries data are available for a considerable part of their farm lands. For instance, in Bulgaria 19360 ha of agricultural soils are known to be contaminated with heavy metals, in Poland, 0.5% of the total agricultural areas is known to be contaminated with heavy metals, in France, approximately 800,000 agricultural sites are known to be contaminated with heavy metals, whereas in Western Europe, up to 1,200,000 agricultural sites are reported to be potentially contaminated with heavy metals [18].

2.1. Sources of Contamination

There are several sources of heavy metals contamination in agricultural soil. These include the parent material from which the soil is derived as well as anthropogenic activities [19]. Although most farms in Tanzania are located in contamination prone areas, there are very limited reports on influence of the sources in heavy metal contamination status. Machiwa [20] reported that many agricultural fields located near mining site in Geita and Tarime districts are contaminated with heavy metals. In Tanzania, major gold mines are located in Geita, Musoma, Kahama, Tarime, Chunya and Mpanda [21] which

are also main food crops producing areas. Therefore, food crops cultivated near these gold mines are vulnerable to contamination with heavy metals. For instance, it has been reported that the level of Hg in agricultural soils in Mugusu gold mining in Geita district of Tanzania is high due to the mining activities taking place near the agricultural soils [22].

Concentrations of heavy metals in areas close to mining operations can exceed maximum limits [22]. It has been recorded that the average concentrations of Cu (502 mg/Kg), Zn (498 mg/Kg) and Cd (3.92 mg/Kg) in Dabaoshan mines in South China were above grade II of environmental quality standards values [11] which are 100 mg/kg, 300 mg/Kg and 0.60 mg/Kg for Cu, Zn and Cd respectively for agricultural soils in China [23].

According to Escarré *et al*. [24] and Duruibe *et al*. [25], the levels of heavy metals in the agricultural soils depend on the distance from the source of contamination. Escarré *et al*. [24] reported that levels of heavy metals in agricultural soils decrease as the distance from the mining sites increase, and proved that high levels of heavy metals were concentrated within 0 – 1.5 Km from the mining sites. In Tanzania, the extent at which distances from certain mining operations to agricultural sites affect heavy metal contamination is not known. This information is indeed necessary to provide advice to farmers on where to locate their farms in order to prevent heavy metals contamination in the soils.

Another source of heavy metals contamination to the environment is industries. Industries emit heavy metals to the atmosphere which may be deposited on the agricultural soils. The heavy metals originate from uses of different heavy metals as raw materials during the industrial processes [26]. The disposal of industrial waste on or near the agricultural land may lead to the heavy metals concentration on the agricultural soil, beyond the acceptable limits [1, 27, 28]. The study by Machiwa [1] reported that Lake Victoria basin wetlands are highly contaminated with heavy metals through runoff from the industrial waste disposals. Similar observations were made in China, where heavy metals such as Cu, Pb and Zn in the agricultural soil of Xuzhou, Guangzhou and Wuxi were reported to be due to industrial activities such as electroplating plants, spring factory, band steel factory, leather factory and petrochemical complex [29].

The use of waste water from industries for irrigation may lead to high level of heavy metals in the agricultural soil [8]. For examples, the Msimbazi valley in Da es Salaam-Tanzania is highly contaminated with heavy metals from industrial wastewater draining into the valley. Small farmers use this contaminated water from the valley to irrigate vegetable gardens. This may influence the elevated levels of heavy metals in the soils [15] and ultimately in the plants. To reduce the effects of heavy metals in agricultural soils, industries and mines operators should adhere to the environment protection standards set by bodies such as TBS in the case of Tanzania.

It has also been found that the sources of Cd, Hg and As in agricultural soil of many locations in China are influenced by excessive use of pesticides and fertilizers [6, 14, 29]. Phosphate fertilizers which are widely used in agricultural production in Tanzania are reported to be rich in Hg, Cd, As, Pb, Cu and Ni [30]. The use of this kind of fertilizer on agricultural land may act as another source of heavy metals in the soils. Malidareh *et al*. [31] investigated the levels of As, Cd and Pb on paddy soils in North of Iran before and after phosphate fertilizer application. The author reported the ranges of these heavy metals in paddy fields before application of fertilizers to be from 0.001 mg/Kg – 0.007 mg/Kg (As) and 0.066 mg/Kg – 0.103 mg/Kg (Pb) whereas after applying fertilizers, the level of As ranged from 0.10 mg/Kg – 0.30 mg/Kg and the level of Pb increased at the range of 0.201 mg/Kg – 0.447 mg/Kg. Before application of fertilizers, the level of Cd in paddy soils was recorded below the detection limit whereas after application of fertilizers the level of Cd was detected at the range of 0.045 mg/Kg to 0.052 mg/Kg. These studies proved that the excessive use of fertilizers may increase the levels of heavy metals in agricultural soils. The summary of facts and finding of heavy metals contamination in agricultural soils is presented in Table 1.

Table 1. *The summary of facts and findings of sources of heavy metals contamination in agricultural soils.*

FACT	FINDING
Mining activities contribute to the increase of levels of heavy metals in the agricultural soils [22]	High level of Hg in agricultural soils in Mugusu gold mining in Geita District is influenced by mining activities [21]
Deposition of industrial waste on the agricultural soils leads to the increase of heavy metals on the agricultural soils [1]	Lake Victoria basin wetlands in Tanzania are highly contaminated with heavy metals through runoff from industrial waste disposal [1]
Phosphate fertilizers produced in Tanzania consists of Hg, Cd, As, Pb, Cu and Ni, these may increase levels of these heavy metals to the soils [30]	Application of phosphate fertilizers increased levels of As, Cd and Pb on paddy soils of North of Iran [31]

2.2. Minimizing the Extent of Heavy Metals Contamination in Agricultural Soils

In order to reduce the levels of heavy metals contamination in agricultural soils, the National environmental policies should be reinforced. Heavy metals in industrial effluents should not exceed the maximum allowable limits which are 0.1 mg/l, 0.2 mg/l, 1.0 mg/l, 0.1 mg/l, 1.0 mg/l, 2.0 mg/l, 5.0 mg/l, 0.1 mg/l, 5.0 mg/l, 0.005 mg/l and 5.0 mg/l for Cd, As, Cr total, Cr VI, Co, Cu, Fe, Pb, Mn, Hg and Zn respectively [32].

Mining tax policy should be reinforced for the purpose of encouraging proper exploitation of the mining areas. This may help to regulate the environmental conditions since as the mining cost increases, only few people will be able to exploit the mining areas and hence reducing aggressive mining activities which may be the source of destroying environmental natural condition [33].

Polluter pay principle is a tool which is implemented in Tanzania, whereby a polluter has to pay a cost for the pollution he or she has imposed in the environment. As the cost for pollution becomes high, a polluter will be very serious in adopting ways to decrease the contamination [33].

3. Heavy Metals Contaminations in Rice Grains

In Tanzania, rice is considered as the seventh most important agricultural crop contributing to about 5% of total crop production and is consumed by large population. Rice production in Tanzania has increased from 781,538 tons to 1,341,846 tons from year 2000 to 2007 [34]. Rice is a very important crop in Tanzania as it provides about 8% of the Tanzanian's calories intake [34]. Although, this is the third energy supplier crop after maize (24.3%) and cassava (10.5%) [35], it is mostly consumed by large number of people in Tanzania, especially in urban areas than other foods [36]. Rice is considered as one of the important agricultural crop in different parts of the world as well [37].

Rice can be contaminated by heavy metals when grown in contaminated paddy soils or through irrigating using groundwater and municipal wastewater containing heavy metals [7]. Heavy metals from the contaminated paddy soils may be taken-up by the rice plant and accumulate in the grains [38, 39].

The heavy metals contaminated atmosphere can also be the source of heavy metals to rice. Heavy metals e.g Pb, Cr, Mn and Cd from the industries such as Hg from paper industries and vehicle exhaust can pollute air which then can be absorbed directly by the rice grains [16, 40, 41]. Just like in the case of agricultural soils, the levels of heavy metals in rice may be influenced by factors such as distance from the source of metals e.g mining operations, use of pesticides and fertilizers in rice cultivation and distances to the farm from heavy metal waste discharging industries [42].

Rice crop is widely grown in wetlands which makes it more susceptible to heavy metals contamination than other food crops. Heavy metals from mining areas and industries may be taken by runoff to the wetlands. Wetlands have high capacity of accumulating heavy metals [1].

Buzwagi and Bulyanhulu gold mines in Kahama district and Geita gold mine in Geita district are the largest gold producing mines in Tanzania [43]. Besides Geita and Kahama being largest mining areas, they are among the main rice producing districts in Tanzania [36]. As it has been reported that mining operations near the agricultural sites may influence the increase of heavy metals in soils as well as in food crops [44], rice grown near mining areas in Geita and Kahama districts may be at risk of being contaminated with heavy metals. Therefore there is a need to research on heavy metals contamination in rice grown near the mining areas in Tanzania.

According to the Codex Alimentarius Commission [45], heavy metal contamination in rice should not exceed the maximum limits of; 0.4 mg/Kg and 0.2 mg/Kg for Cd and Pb, respectively. It is recommended that the levels of As in polished rice should not exceed 0.2 mg /Kg [46].

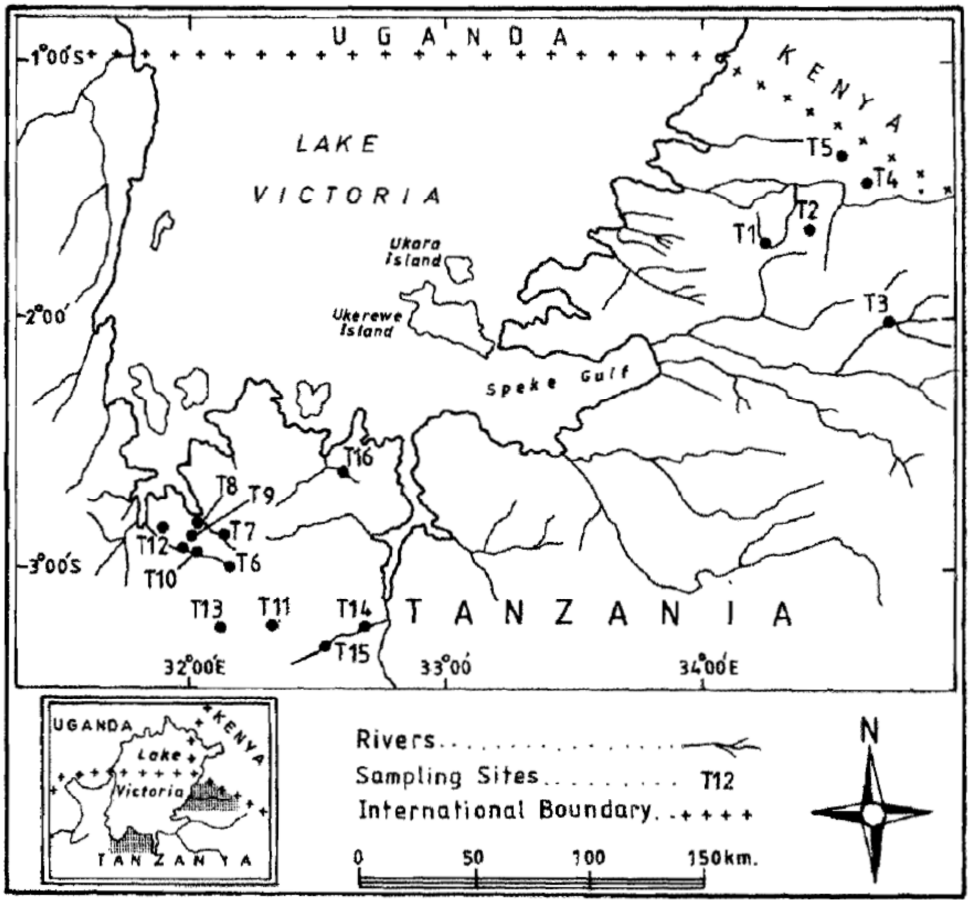

Figure 1. Map of Lake Victoria basin, Tanzania showing rice cultivating areas near the mining areas within lake Victoria Basin. Source: Machiwa [20].

In Tanzania, Machiwa [1] reported mean concentration of Cu and Zn in rice collected from four different locations of Mwanza, Geita, Bunda and Magu within the Lake Victoria Basin to be 3.7 mg/Kg and 21.7 mg/Kg, respectively. These levels were associated with the effects of industrialization in that basin. Furthermore, Tungaraza *et al*. [21] reported average level of Hg (0.026 mg/Kg) in rice grown in Mugusu mining area in Tanzania. These data on heavy metal contamination in rice are essential for food safety control organs to be able to perform risk assessments which inform food safety managers on strategies to prevent contamination in rice. However, the available data are insufficient and inadequate for such risk assessments. This implies that more studies on heavy metals contamination in rice grown in different regions of Tanzania are needed. Figure 1 shows the rice cultivating villages near the mining areas within lake Victoria Basin. T9 (Saragurwa), T10 (Mugusu), T11 (Nyarugusu), T12 (Buseresere) and T13 (Lwamgasa) are currently active mining areas in Geita district and are considered to be rice producing areas as well. T7 (Nungwe) is also rice cultivating area located near T10 (Mugusu) [20].

Other food crops may also be contaminated with heavy metals when grown on contaminated soils [21]. Lugwisha and Othman [16] reported the concentration of Cd of 0.09 mg/Kg in both onions and tomatoes collected in Lushoto district in Tanzania to be above the Codex Alimentarius Commission limit of 0.05 mg/Kg. Dumitru *et al*. [47] reported the levels of Pb and Zn in maize grains collected from Târnava Mare River bottomland to be above the maximum allowable limits in foods. This indicated that the consumption of maize grains products cultivated in that site may result to the human health problems.

3.1. Exposure Assessment for Heavy Metals in Rice

The consumption of heavy metal contaminated rice has detrimental effects to human health [16]. The risk of exposures of humans and the associated health effects depend on the extent of heavy metal contamination in rice and the amount of the rice consumed by an individual. In Tanzania, rice is increasingly becoming a staple food for majority of the people. It has been reported that from the year 2000 to 2007, annual rice consumption per capita has increased from 28 Kg to 29 Kg [34]. Similar consumption rates were reported by Mghase *et al*. [48] who showed that the average rice consumption in Tanzania is about 68.5 – 82.2 g.

Based on the Joint FAO/WHO Expert Committee on Food Additives (JECFA) [49], the tolerable daily intake (TDI) for Cd, Hg and As are recommended to be 1.0 µg/Kg body Body weight (Bw)/day, 0.57 µg/Kg body Bw/day and (2 - 7 µg/Kg body Bw/day), respectively. Tungaraza *et al*. [21] reported the estimated daily intake (EDI) for Hg in rice grown around Mugusu artisanal gold mining areas in Tanzania to be 4.0 µg/day / person of 68 Kg weight which is equivalent to 0.06 µg/ Kg body weights/day. Although this value is lower when compared with the TDI for Hg set by the JECFA which is 0.57µg/Kg Bw/day [50], the growing rice consumption patterns in Tanzania can lead to higher intakes. This implies that the available information is not enough to conclude that Tanzania is not at high risk of heavy metals exposures exceeding the TDIs. Thus; more studies should be conducted on risk assessment for heavy metals in rice in Tanzania, particularly in areas around the mining sites.

3.2. The Influence of Processing on Heavy Metal Contamination in Rice

Rinsing and cooking rice using uncontaminated water may decrease the levels of heavy metals in rice. Naseri *et al*. [51] studied the effects of rice cooking process on the concentrations of heavy metals and found that the raw polished rice had the mean concentrations of Cd (0.33 mg/Kg), Pb (1.75 mg/Kg), Cr (0.38 mg/Kg), Ni (0.89 mg/Kg) and Co (0.2 mg/Kg) which were higher compared to the levels of heavy metals Cd (0.1 mg/Kg), Pb (1 mg/Kg), Cr (0.29 mg/Kg), Ni (0.19 mg/Kg) and Co (0.03 mg/Kg) in cooked rice. Therefore, it is advisable that in order to minimize exposure of heavy metals, one should not consume uncooked rice. However, it has been observed that polished rice can accidentally be contaminated with heavy metals during the polishing and cooking process. In the study done by Ziarati and Azizi [52], arsenic was detected in raw and cooked polished rice while it was not detected in rice husk. This might be due to the unintentionally use of arsenic contaminated water in the cooking or the leakage of arsenic from the equipment used during the polishing process. In Tanzania, there is no any information about the extent traditional rice processing and cooking practices can reduce heavy metal contamination. Data on the influence of the practices in heavy metal contamination of rice are important to advise organs responsible for water treatment on whether or not there is need to improve the treatment procedures to ensure that heavy metals in potable water are within the acceptable limits.

4. Relationship Between Heavy Metals Contamination in Agricultural Soils and Rice

Elevated levels of heavy metals in agricultural soils may influence the uptake of heavy metals in rice plant system [49]; although there are factors such as high pH of the soil that may hinder availability of heavy metals in soils to be absorbed by plant roots [16]. Moradi *et al*. [53] reported a positive correlation ($p < 0.01$) between the levels of Zn in agricultural soil and in rice collected in industrial sites in Iran. Payus and Talip [37] reported that the concentration of Cd in rice was influenced by the concentration of Cd in paddy soils collected from Kompipinan, Papar district, Sabah. The concentrations of Cd and Pb in rice collected from Yangtze river region of China were positively correlated with the concentrations of Cd and Pb in the corresponding agricultural soils as reported by Liu *et al*. [54]; whereas Chanda *et al.* [55] reported that the elevated level of heavy

metals contamination in agricultural soil may not necessary lead to the elevated levels of heavy metals in rice. These authors further reported the mean levels of heavy metals in agricultural soils to be 72.03 mg/kg, 38.7 mg/Kg and 3.0 mg/Kg for Cr, Pb and Hg, respectively, while the concentration of Pb and Cr in rice grown in the same soil were found to be below the detection limits. In Tanzania, there is no adequate information which shows correlation of heavy metals between agricultural soil and rice. There is a need to investigate the correlation of heavy metals levels in agricultural soils with levels in rice produced from these soils.

5. Conclusion

Heavy metal contamination in the environment is of more concern worldwide. The knowledge on the sources of heavy metals contamination in agricultural soils and rice is necessary in order to improve food safety by minimizing the possibility of food insecurity as well as human health problems. The review revealed that the increase of heavy metals in agricultural soils and rice may be influenced by mining activities done close to the agricultural fields, heavy metals emitted from industries which may be directly absorbed by rice grain as well as improper disposal of industrial wastes rich in heavy metals on the agricultural land. The use of phosphate fertilizers may increase the levels of heavy metals in the soils and rice as they may consist of heavy metals such as Hg, Cd, As, Pb, Cu and Ni. High levels of heavy metals in rice lead to high exposures for heavy metals which may pose human health problems. Therefore the levels of heavy metals in rice should be monitored as rice is considered a source of energy for the large population in Tanzania. The present National environmental policies should be reinforced to ensure that heavy metals contaminations in agricultural soils and in food crops are minimized. This will help in reducing health risk to the population at large. This review work concludes that, in Tanzania, there is insufficient information on the heavy metals contamination in agricultural soils and rice. Moreover, it suggests that more researches need to be conducted in areas around the probable sources of heavy metals contamination to investigate the extent of heavy metals contamination in agricultural soils and rice as well as conducting the exposure assessment for heavy metals through rice consumption.

Acknowledgment

The authors would like to acknowledge the Government of Tanzania and the Nelson Mandela African Institution of Science and Technology for financing this study.

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