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*Original Article*

# Assessment of Concentration Levels and Associated Health Risks of Arsenic, Cadmium, Lead, and Mercury in Selected Green Leafy Vegetables Irrigated by Morogoro River Using Atomic Absorption Spectroscopy

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*Toxic elements, AAS, Target Hazard Quotient (THQ), Total Target Hazard Quotient (TTHQ), Cancer Risk.*

**ABSTRACT**

Morogoro River is among the tributaries of Ngerengere River, providing water for some domestic and agricultural activities to the community of Morogoro region. However, as it flows through Morogoro town, the river is increasingly subjected to pollution from various sources and contaminates the water. The contamination is likely due to a combination of industrial activities, agricultural runoff, domestic waste, and natural geological sources. This study aims to investigate the levels of toxic elements, lead (Pb), cadmium (Cd), arsenic (As) and Mercury (Hg) in green leafy vegetables grown near and irrigated by water from Morogoro River by using Atomic Absorption Spectrometry (AAS). Samples of three categories were collected, first category samples were collected before industrial areas, second category samples were collected after industrial effluent were discharged to the river and the third category are samples collected away from the vicinity of Morogoro River. The results were used to calculate Target Hazard Quotient (THQ), Total Target Hazard Quotient (TTHQ) and Cancer Risk for health risk assessment. Both first and second-category samples have TTHQ of 7.4 and 22.6 respectively which indicate a serious health risk and the value for third category is 1 which means no serious health risk. The cancer risk values are very high for second-category samples which are intolerable. This means there is urgent need for immediate interventions, such as stricter regulations on domestic and industrial waste disposal, promotion of sustainable agricultural practices, and establishment of regular environmental monitoring systems.

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## INTRODUCTION

The Morogoro River originating from the Uluguru Mountains is one among the vital watercourse in the Morogoro Region of Tanzania. The river is flowing through the town of Morogoro and providing water for some domestic and agricultural activities. However, as it flows through Morogoro town, the river is increasingly subjected to pollution from various sources, making a significant environmental and public health concern. Morogoro town is one among growing urban centre in Tanzania with an increase in industrial activities. Some of industrial effluents from factories are often discharged into the Morogoro River. This practice has led to the contamination of the river, with pollutants ranging from heavy metals to organic waste. Studies have shown that the water quality in the Morogoro River has deteriorated significantly posing risks to human health and the ecosystem (Mbonaga *et al*., 2024). The contamination of the Morogoro River has been linked to various adverse effects. For instance, the river is a primary source of water for irrigation in the surrounding agricultural areas. The presence of pollutants in the river water not only affects crop yields but also leads to the accumulation of toxins in food products, which can have long-term health implications for consumers (Joseph & Temba, 2019)

Green leafy vegetables are known for their high nutrient content and dietary importance (Aslam *et al*., 2020). However, industrial activities, including mining and manufacturing, are recognized sources of environmental pollution, releasing pollutants such as heavy metals into the air, water, and soil (Duruibe *et al*., 2007). Morogoro River, just like other town-passing rivers in Tanzania, is at high risk of contamination due to industrial activities along its banks (Hellar-Kihampa *et al*., 2014). Studies have shown that heavy metals, including lead, cadmium, arsenic and mercury, can accumulate in green leafy vegetables through processes such as absorption and water uptake (Huang *et al*., 2018).

Green leafy vegetables, among the crops irrigated by water from Morogoro River, are essential components of diets due to their nutritional value and health benefits. However, concerns have been raised regarding the potential contamination of these vegetables with toxic elements, particularly in regions near industrial activities. The proximity of green leaf vegetable farms to the Morogoro River, located near industries raises concerns about the potential contamination of these crops with toxic elements. The discharge of industrial effluents may contain toxic elements and other harmful substances into the river and pose a risk to human health through the consumption of contaminated vegetables. Therefore, there was a critical need to assess the levels of toxic elements such as arsenic, cadmium, lead, and mercury in some selected green leafy vegetables grown in the vicinity of the

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Morogoro River to determine the extent of contamination and its potential impact on public health. This study aimed to assess the levels of toxic elements in green leafy vegetables grown near the Morogoro River by using Atomic Absorption Spectrometry (AAS). By understanding the extent of contamination and its implications for public health, this study seeks to contribute to food safety and environmental protection efforts in the region.

This study focused on assessing the levels of toxic elements (lead, cadmium, arsenic and mercury) in green leafy vegetables grown near the Morogoro River particularly in areas before reaching the industrial areas and adjacent to industrial areas and compares it with other vegetables of the same species grown in Morogoro town but does not irrigate by water from Morogoro River. Heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) are common pollutants found in industrial areas (Huang *et al*., 2018). These metals are known for their toxicity and persistence in the environment. When vegetables are irrigated with water containing heavy metals, these elements can be absorbed by the plants and accumulate in their edible parts. Chronic exposure to heavy metals through food consumption can lead to various health issues, including kidney damage, neurological disorders, and an increased risk of cancer. For instance, a study conducted by Jalil *et al*., (2022) found elevated levels of heavy metals in vegetables irrigated with contaminated water indicating a significant public health concern.

The study provide valuable insights into the levels of toxic elements in green leafy vegetables grown near the Morogoro River, highlighting potential health risks for local communities exposed to contaminated vegetables, also provides awareness about the potential dangers of consuming vegetables grown in areas with industrial pollution. The study can empower residents to make informed decisions about their food choices and advocate for environmental protection measures. Findings from this study can inform policymakers and regulatory agencies about the need for stricter environmental regulations and enforcement measures to mitigate contamination from industrial activities and safeguard public health. Also, the study can contribute to the development of targeted public health interventions aimed at reducing exposure to toxic elements and improving food safety in communities living near industrial zones and water bodies, it can also guide future studies and interventions focused on understanding and mitigating the environmental and health risks associated with industrial pollution. By promoting sustainable agricultural practices and environmental management strategies, the study can support efforts towards achieving sustainable development goals related to environmental protection, food security, and public health.

## MATERIALS AND METHODS

### Description of the Study Area

This study was conducted in Morogoro town near the banks of the Morogoro River, which is located in the Morogoro region of Tanzania. This area is known for its agricultural activities whereby Morogoro River is a vital water source for irrigation of the crops especially green leafy.

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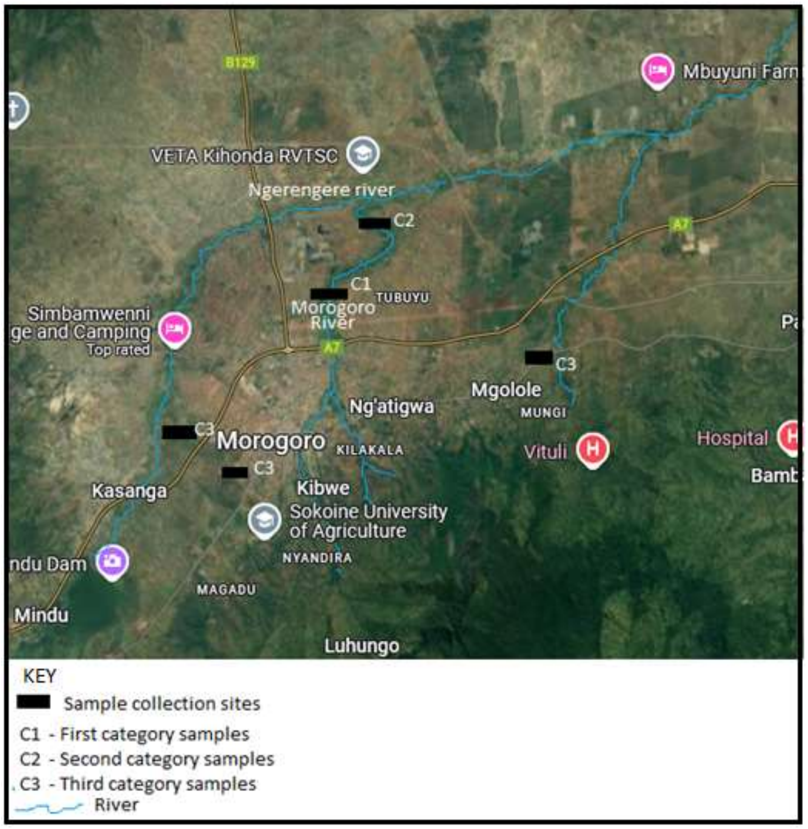
**Figure.1 Map showing Morogoro River and sample collection sites (created with the help of Google map)**




## Sample Collection

Green leafy vegetable samples were collected in three categories. The first category is from farms located near the Morogoro River before the industrial areas. The second category are samples collected from farms located near the Morogoro River just after the industrial areas where the effluent from industrial areas has entered the river and the third category are samples collected from areas located far from Morogoro River and does not use water from Morogoro River for Irrigation but within Morogoro municipal. All samples were collected during the peak growing season to ensure the vegetables are at their optimal stage of development. The size of the samples used were three first category samples, collected from areas at a place known as *mafisa kwa mambi*. Three second category samples, collected from the areas at a place known as *mafisa maji machafu* and lastly are three third category samples, collected at three places known as *kasanga*, *bigwa mchichani*, and *mafiga.*

## Sample Preparation

All samples were thoroughly washed with distilled water to remove surface contaminants, and then dried by using clean paper towels to remove excess moisture. The samples were then cut into small, uniform pieces to facilitate homogenization and digestion. Then the samples were homogenized to ensure uniform distribution of elements throughout the sample using a well cleaned blender (Skoog *et al*, 2007).

Homogenized samples were digested to break down organic matter and release the elements of interest for analysis. For this study, dry ashing was performed by heating the samples in a muffle furnace at high temperatures until a powder form was obtained (Ismail, 2017, Liu, 2019). The powdered vegetable samples digested using a

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mixture of nitric acid ($HNO_3$) and perchloric acid ($HClO_4$) in a microwave digestion system. The digested sample was diluted in solution with acid, to achieve a concentration range suitable for AAS analysis.

**Measurement with AAS**

The digested samples were analyzed for the presence of toxic elements, lead (Pb), cadmium (Cd), arsenic (As) and mercury (Hg) by using atomic absorption spectrometer (AAS). Calibration standards were prepared by diluting standard stock solutions of the toxic elements to various concentrations. These standards were used to generate a calibration curve relating absorbance readings to the concentration of each element (Skoog *et al.*, 2007). Absorbance of the digested sample solutions were measured using an AAS instrument, PerkinElmer Analyst 800. Absorbance values were compared to the calibration curve to determine the concentration of toxic elements in the samples.

## RESULTS AND DISCUSSION

The concentrations of the measured heavy metals were presented in Table 1. During measurement, mercury was not detected in all samples; this means the concentration of the mercury is below the detection limit of the machine used.

**Table 1: Concentration of Arsenic, Cadmium, Lead and Mercury in the samples**

| Category | Sample | Arsenic (As) (mg/Kg) | Cadmium (Cd) (mg/Kg) | Lead (Pb) (mg/Kg) | Mercury (Hg) (mg/Kg) |
|---|---|---|---|---|---|
| First Category | 1A | 1.561 | 0.811 | 1.81 | BDL |
| | 1B | 1.598 | 0.799 | 1.81 | BDL |
| | 1C | 1.572 | 0.823 | 1.819 | BDL |
| Second Category | 2A | 4.681 | 2.432 | 5.43 | BDL |
| | 2B | 4.791 | 2.52 | 5.769 | BDL |
| | 2C | 4.672 | 2.511 | 5.423 | BDL |
| Third Category | 3A | 0.201 | 0.103 | 0.298 | BDL |
| | 3B | 0.213 | 0.121 | 0.288 | BDL |
| | 3C | 0.219 | 0.101 | 0.279 | BDL |
| Detection Limit | | 0.02 | 0.01 | 0.05 | |

BDL = Below Detection Limit

**Health risk assessment**

Health risk assessment in this study can be categorized into two categories, carcinogenic and non-carcinogenic risk. According to USEPA (1991) carcinogenic risk is the probability or likelihood of person to get cancer after being exposed to certain substance, environmental factor or lifestyle behaviour and non-carcinogenic risk is the potential harm or adverse health effect caused by exposure to a substance, environmental factor or lifestyle behaviour but does not involve cancer. Health risk, associated with heavy metals, is estimated through calculation of the level of human exposure for a particular metal by identifying the exposure route of a pollutant to the body (Koleleni & Tafisa 2019)

**Non-carcinogenic risk**

Consuming vegetables contaminated with heavy metals can cause non-carcinogenic risk which can be estimated in terms of target hazard quotient (THQ) and total target hazard quotient (TTHQ) (Antoine et al., 2017)

***Target Hazard Quotient (THQ)***

Target Hazard Quotient (THQ) is a risk assessment metric used to evaluate the potential health risks from long-term exposure to a chemical substance

 

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through ingestion. It is a comparison of the estimated exposure level to the chemical and reference dose that is considered safe. The THQ is expressed as:

$\text{THQ} = \frac{\text{Estimated Daily Intake (EDI)}}{\text{Reference dose (RfD)}}$ (Antoine et al., 2017)

Where $\text{Estimated Daily Intake (EDI)} = \frac{\text{MC} \times \text{IR}}{\text{BW}}$

**EDI** is the estimated daily intake of the substance (mg/kg/day). **RfD** is the reference dose for the substance (mg/kg/day), which represents the maximum safe daily exposure, **MC** is the metal concentration in vegetables (mg/kg), **IR** (g/day/person) is the ingestion rate of vegetables which is taken to be 240 g/day according to FAO/ WHO (WHO 2004) and **BW** is a body weight in Kg which is taken to be 60 Kg as given by Agrawal *et al.*, (2007).

When **THQ > 1**it indicates a potential health risk, meaning that the exposure level exceeds the RfD and could pose a hazard and when **THQ ≤ 1**it indicates that the exposure level is below or equal to the RfD, meaning that no significant risk is expected. RfD refers to oral reference dose which was taken as 3 ×10 E–3 for As, 1 ×10 E–3 for Cd and 3.5 × 10E–3 for Pb (USEPA, 2021).

***Total Target Hazard Quotient (TTHQ)***

TTHQ for individual is the sum of THQs and expressed as the sum of the hazard quotients.

TTHQ = THQ (As) + THQ (Pb) + THQ (Cd)

When TTHQ ≤ 1 is considered as safe and when TTHQ > 1 is considered as hazardous (USEPA, 2011)

**Carcinogenic risk**

According to USEPA (1991) Carcinogenic risk assessment is a method of estimating the incremental probability of developing cancer over an individual's lifetime due to exposure to a potential carcinogenic substance. As, Pb and Cd contribute to both non-carcinogenic health risk and carcinogenic health risk depending on how long the individual is exposed and the exposure dose. This study estimated the Cancer Risk values of Pb, Cd and As due to exposure from vegetables. The carcinogenic risk is evaluated by using the formula:

Cancer Risk (CR) = EDI×CPSo

Where EDI is the estimated daily intake, CPSo is the carcinogenic potency slope for oral route which is 0.0085 $(\text{mg/kg-day})^{-1}$ for Pb, 1.5 $(\text{mg/kg-day})^{-1}$ for As, and 0.38$(\text{mg/kg-day})^{-1}$ for Cd. In general, there is probability of carcinogenic risk when Cancer Risk value is above 1.0E−06, lower than 1.0E−06 is considered to be negligible, 1.0E−06 to 1.0E−04 is considered as tolerable range and above 1.0E−04 is considered unacceptable/intolerable (USEPA, 1989 and USEPA, 2010)

***Arsenic (As)***

High levels of arsenic in vegetables can lead to prolonged consumption of it by the people especially those who live near Morogoro River. Figure 2 shows the concentration of arsenic from the tested samples.

 

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**Figure 2: The concentration of Arsenic in the samples**

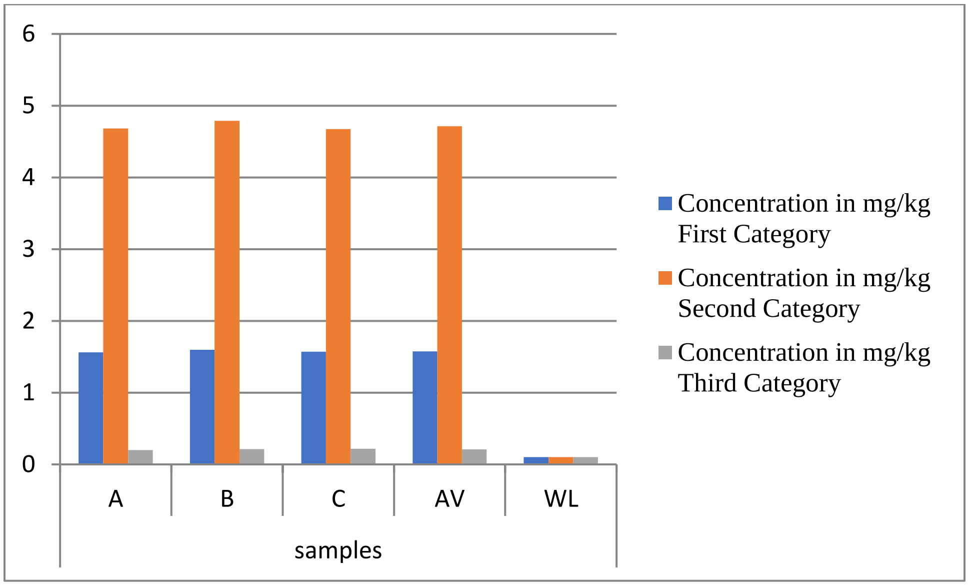


**Table 2: EDI and THQ calculated from concentration of Arsenic in the samples**

| | A(mg/Kg) | B(mg/Kg) | C(mg/Kg) | Average | EDI | THQ |
|---|---|---|---|---|---|---|
| First Category | 1.561 | 1.598 | 1.572 | 1.577 | 0.00631 | 2.10267 |
| Second Category | 4.681 | 4.791 | 4.672 | 4.715 | 0.01886 | 6.28622 |
| Third Category | 0.201 | 0.213 | 0.219 | 0.211 | 0.00084 | 0.28133 |

From figure 2 the concentration of arsenic is very high in the second category sample than in the first category. This means that the effluent from industrial areas inject some significant amount of arsenic in the river. Also, the concentration in the first category is very high compared to that of the third category which is slightly higher than the world Limit. It is clear that there is high contamination of arsenic in the Morogoro River than other part of Morogoro municipal. High concentration of Arsenic in the vegetable is associated with several serious health problems due to its toxicity, particularly when ingested over long periods (Hong *et al*. 2014).

Table 2 shows that Target Hazard Quotient (THQ) for first and second category samples is greater than 1, which indicates a potential health risk. Second category samples have high THQ which means high potential health risk. A study done by Navas-Acien*et al*. (2005) shows that, cardiovascular problems such as hypertension and atherosclerosis are associated with chronic arsenic exposure. In children, exposure to arsenic can cause neurodevelopment effects such as cognitive impairments, reduced IQ and brain function (Wasserman *et al*., 2004). Other health problems include diabetes (Navas-Acien *et al*., 2006) and respiratory problems (Chen *et al*., 1985). Third category samples have low THQ, which is less than one indicating no potential health risk is expected.

IARC (2012) classifies arsenic as among carcinogenic and that long term exposure to high levels of arsenic has been associated with an increased risk of liver, skin, kidney, and lung cancers.

 

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**Table 3. Estimated Total Cancer Risk**

| | Cancer Risk | | |
|---|---|---|---|
| | **Arsenic (As)** | **Cadmium (Cd)** | **Lead (Pb)** |
| 1 Category | 0.0095 (9.5E-3) | 0.001233 (1.2 E -3) | 0.000062 (6.2 E -5) |
| 2 Category | 0.0283 (2.8 E-2) | 0.003781 (3.8 E-3) | 0.000188 (1.8 E -4) |
| 3 Category | 0.0013 (1.3E-3) | 0.000165 (1.7 E-4) | 0.000010 (1.0 E -5) |

Table 3 shows that the probability of cancer is 0.95% from first category samples, 2.8% from second category samples and 0.13% from third category samples. The value from second category samples is high and raises concern since from 1000 people, 28 are in danger of developing cancer. According to Smith *et al*. (2012), skin conditions such as hyperpigmentation, depigmentation, and the development of skin lesions can also be associated with prolonged arsenic exposure.

***Cadmium (Cd)***

Cadmium was another heavy metal of interest during this study because it is commonly found in industrial effluents and phosphate fertilizers. Figure 3 shows the concentration of Cadmium from the tested samples.

**Figure 3: The concentration of Cadmium in the samples**

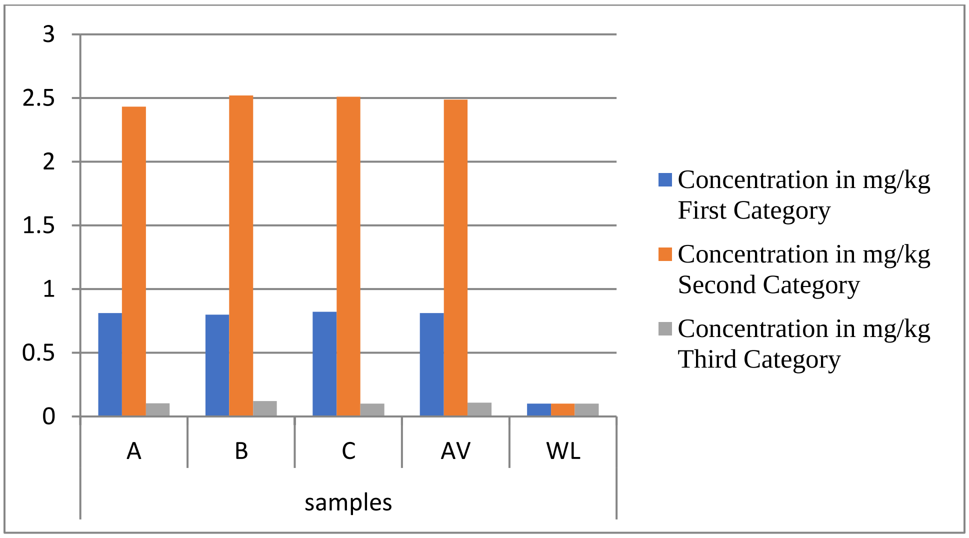


**Table 4. EDI and THQ Calculated from Concentration of Cadmium in the samples**

| | A(mg/Kg) | B(mg/Kg) | C(mg/Kg) | Average | EDI | THQ |
|---|---|---|---|---|---|---|
| First Category | 0.811 | 0.799 | 0.823 | 0.8110 | 0.00324 | 3.24400 |
| Second Category | 2.432 | 2.52 | 2.511 | 2.4877 | 0.00995 | 9.95067 |
| Third Category | 0.103 | 0.121 | 0.101 | 0.1083 | 0.00043 | 0.43333 |

The presence of agricultural runoff, industrial effluents, and other pollutants from the town in the Morogoro River has led to the accumulation of cadmium and its level in green leaves irrigated by the river is of significant concern. As figure 3 shows, the concentration of the cadmium in the sample is much greater than the recommended world limit. The samples collected after Industrial discharge, second category samples, shows much higher concentrations of cadmium three times more than the first category samples. These levels pose a serious potential health risk to consumers.

 

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Consumption of vegetables with high level of cadmium exposes individuals to a range of health hazards (Godt *et* al., 2006)

Table 4 shows THQ of 3.244 for first category samples, which indicates a potential health risk, and THQ of 9.951 for second category samples which indicates high potential health risk. According to study done by Watanabe et al (2014), cadmium exposure can course bones problems such as skeletal damage and bone demineralization which increases the risk of fractures. In Japan, Itai-Itai disease associated with cadmium poisoning is a disease led to weakened bones and can result in fractures. Cadmium exposure can cause damage to the cardiovascular system (Tellez-Plaza *et al.*, 2012), can affects organs like the kidneys and liver (Wu & Hentz 2010) and can accumulates in the liver leading to hepatotoxicity (Järup & Åkesson 2009).

There is probability of carcinogenic risk of 0.12% for first-category samples, 0.38% for second category samples and 0.02% for third category samples as can be seen on Table 3. The value from third category samples is slightly higher than tolerable limit which means 2 people out of 1000 are at risk. For second category samples 38 people out of 1000 are at risk which is a concern. According IARC (2012) prolonged cadmium exposure has been associated with an increased risk of developing lung cancer, prostate cancer, and kidney cancer

***Lead (Pb)***

Lead is known for its toxicity and persistence in the environment and prolonged exposure to lead through food can affect a lot of organs in the human body. Figure 4 shows the concentration of lead from the tested samples and all samples of green vegetables irrigated by water from Morogoro River have higher concentration of lead. Industrial effluent still shows large impact as concentration of lead in the second category samples is very high compared to the first category samples. All samples collected away from the vicinity of Morogoro River have shown lower lead concentration which lies within the world recommended limit.

**Figure 4. The concentration of Lead in the samples**

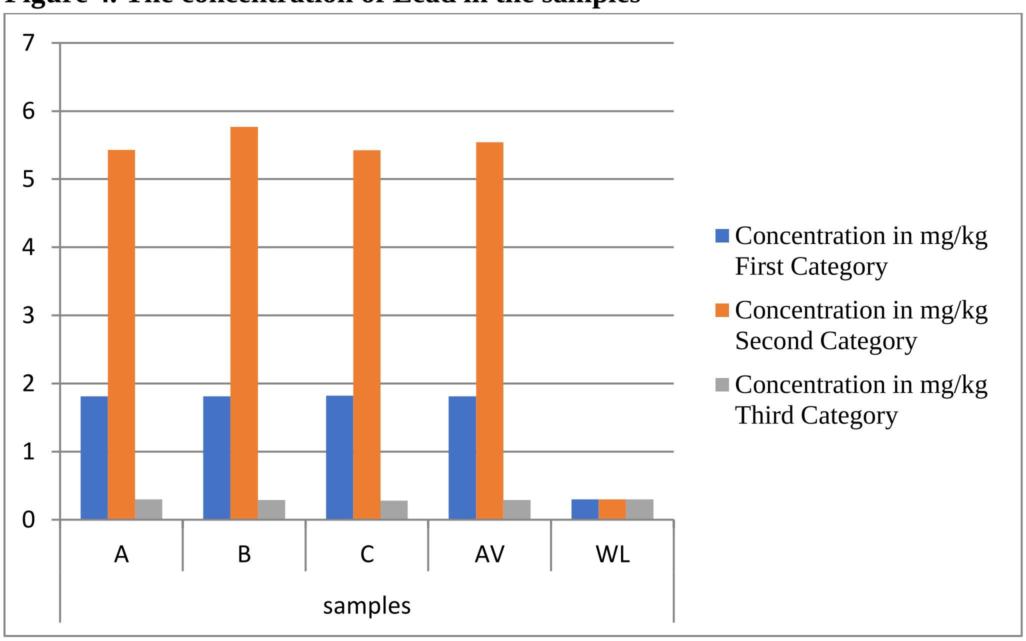


 

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**Table 5. EDI and THQ calculated from concentration of Lead in the samples**

| | A(mg/Kg) | B(mg/Kg) | C(mg/Kg) | Average | EDI | THQ |
|---|---|---|---|---|---|---|
| First Category | 1.81 | 1.81 | 1.819 | 1.8130 | 0.00725 | 2.07200 |
| Second Category | 5.43 | 5.769 | 5.423 | 5.5407 | 0.02216 | 6.33219 |
| Third Category | 0.298 | 0.288 | 0.279 | 0.2883 | 0.00115 | 0.32952 |

Table 5 shows THQ greater than 1 for first and second category samples which indicate potential health risk. A study done by Needleman (2004) shows that high level of Lead accumulated in the body can cause irreversible damage to the brain and nervous system leading to cognitive deficits, decreased IQ, and learning disabilities especially among children, and for adults' memory loss, headaches, and depression are associated with long term lead exposure. Chronic kidney disease or even kidney failure is also associated with long term lead exposure whereby lead accumulates in the kidneys leading to decreased kidney functions (Weaver *et al*., 2007). Lead can also interfere body's ability to produce haemoglobin which can lead to anaemia. Anaemia is known for causing fatigue, weakness, and pallor (Kosnett, 2006). Heo *et al*. (1996) shows that long term lead exposure can lead to Immune System Suppression which causes reduction of the body ability to fight infections and recover from illnesses. Lead exposure is also associated with bone damage (Silbergeld *et al*., 2003), cardiovascular disease (Navas-Acien et al., 2007) and harmful effects on reproductive health for both men and women (Wu *et al*., 2010).

The probability of carcinogenic risk is slightly higher than the tolerable value for second category sample only as shown in table 3. Cancer risk value for other samples lies within tolerable value though they are not negligible.

**Table 6. TTHQ calculated from THQ**

| | Arsenic (As) | Cadmium (Cd) | Lead (Pb) | TTHQ |
|---|---|---|---|---|
| 1 Category | 2.103 | 3.244 | 2.072 | 7.4 |
| 2 Category | 6.286 | 9.951 | 6.332 | 22.6 |
| 3 Category | 0.281 | 0.433 | 0.330 | 1.0 |

People who consume vegetables of first category sample or second category sample will be exposed to high level of arsenic, cadmium and lead at the same time. The sum of the hazard quotients is greater than one for first and second category samples which indicate a potential health risk as shown on table 6. TTHQ value is very high for second category samples which indicate a very high potential health risk.

## CONCLUSION

This study reveals a crisis issue concerning the contamination of green leafy vegetables grown near the Morogoro River, especially in areas close to industries, by using Atomic Absorption Spectrometry (AAS). The levels of toxic elements, lead (Pb), cadmium (Cd) and arsenic (As) in the vegetables irrigated by Morogoro River are very high compared to vegetable irrigated by other sources. The results showed that the concentrations of these harmful elements are significantly above the safety limits set by the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) on sample. This poses a serious health risk to people who consume these vegetables regularly as the calculated TTHQ are all above one for the samples irrigated by the river. This means the river is highly polluted and the use of its water in irrigation of vegetables is not safe.

 

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## Recommendation

This study recommends urgent actions such as education to the community on the dangers of consuming contaminated products, implementation of strategies to provide clean water sources for irrigation and promotion of sustainable agricultural practices. Also, immediate interventions, such as stricter regulations on industrial and domestic waste disposal and establishment of regular environmental monitoring systems should be considered.

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## Competing Interests

Author has declared that no competing interests exist.

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