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Heavy Metal Accumulation Trends for Tsunga, Tomatoes and Rape in Soils from Two Provinces of Zimbabwe

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Abstract: Tomatoes, tsunga (mustard) and rape were sampled from Mashonaland East and Central provinces of Zimbabwe. Aim was to assess hyper accumulative tendency of these towards heavy metals (Cd, Cu, Co, Cr, Ni, and Pb). Most of these heavy metals were noted to be of anthropogenic origin. Co, Mn and Cr were noted to be naturally inherent in Mushimbo, Mutoko soils. Heavy metal levels in irrigation water were within internationally acceptable ranges according to ATSDR. There was no direct reflection of level dependency between the water and plants studied. Bioaccumulation of cadmium and lead levels occurred in all vegetables despite low levels in the soil environment. High heavy metal levels in arable land as compared to virgin land proves contamination at play and also the anthropogenic origin. It was concluded that different vegetables accrue different heavy metals at different rates under the same environment. It was recommended to do more investigations on factors that determine absorption and hyper accumulation tendency of heavy metals in plants. This data could be used as a basis for recommending what crops to grow and in specific areas hence promote food safety in addition to food security for the nation.

Keywords: Heavy Metal Levels, Hyper Accumulation, Bioaccumulation, Anthropogenic, Health Risk.

Research Paper

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1.0.INTRODUCTION

Mineral elements in the soil environment provide the necessary plant nutrition for their well-being. The same mineral elements are a necessity for the normal functions of the various organelles making up plants. Soil nutrition needs be regulated in commercial horticultural systems. This is necessary for the promotion of a positive ecosystem which helps promote positive plant health and that of the food chains on which plants contribute. There are many elements classified as heavy metals, some of which have no known positive contribution to plant nutrition. These are also present in the soil environment in various levels according to Giovanni Dalcosso *et al*., 2019. Plants absorb these elements at varying rates and at different levels of their life cycle. This phenomenon is influenced by a number of factors some of which the plant has no control. Various vegetable species and varieties perform differently towards absorption and accumulation of these metals according to Hailu Reta Gebeyehu, Leta Danno Bayissa, 2020. Plant variety selection is usually centered on characteristics of the commercial variety like plant vigor, fruit characteristics, disease resistance, target market, soil, climate and quality of irrigation water according to InfoAgro.com, 2024. Little attention is taken to consider the performance of these plant varieties on hyperacculation tendencies towards heavy metals hence the intention of this study.

Most of heavy metals observed in horticultural products are of anthropogenic origin with fertilizers playing the biggest contribution. Fertilizers used for tomatoes production are in soluble solid form. These include calcium nitrate, potassium nitrate, ammonium nitrate, monopotassium phosphate, mono ammonium phosphate, potassium sulphate and magnesium sulphate. Phosphates are usually associated with cadmium contamination. There are also complex crystalline solids and liquids existing on the market according to InfoAgro.com, 2024. Chemical treatment for diseases in tomatoes is mostly centered on sprays containing copper and Sulphur. These are used as protectants and help control the spread of diseases according to Lauren Miller, 2012. These chemicals are usually sprayed after every 10-14 days intervals. Copper is one heavy metal which is absorbed in the form of Cu^{2+} or Cu chelate according to Flávio José Rodrigues Cruz (2022). He noted that its safe thresholds, in the dry mass of plants is small and generally ranges from 2 to 20 ppm. Industrial, mining, and agricultural activities usually contribute to accruing copper levels in soil and in particular intensive use of copper-containing agrochemicals or swine manure.

Mining activities are mainly associated with the source of Cu, Zn, Cd and Mn according to Decong Xu *et al*., 2022. Metal concentrations were noted to increase with a decrease in distance from the mine. Major key pathways for heavy metals like Cu, Zn, Pb and Cd translocation to arable land has been attributed to windborne and water runoff including erosion. Bioavailability of these metals is one factor that determines the significance of the presence of these heavy metals in the soil environment. This in some way depends on types of extractants available in the soil environment and nature of metals themselves according to Decong *et al*., 2022. This is dependent on soil properties which has the influence to heavy metal availability, absorption and accumulation in plants. In their paper they also observed that Cu, Zn, Pb, Cd and Mn concentrations on average exceeded the local geochemical background values which is the hyperacumulation phenomenon at play.

Alessio Aprile and Luigi De Bellis, 2020 used the term "bio magnification (or bioaccumulation)", to describe the rate of elimination of heavy metals from an organism. They defined it in ecological and biological terms, as the process whereby the accumulation of toxic substances in living organisms' increases in concentration following a rise in the trophic level. They noted that the higher the trophic level, the stronger the concentration of heavy metals. Biomagnification was also expressed as the concentration increase of a pollutant in a biological systems over time. This displays the detrimental effects of heavy metals within the food chains involving humans. Humans as having the highest trophic level in the food chain become the major victims of the phenomenon. This calls for a need to regulate the horticultural environment on the basis of heavy metal levels.

Temperature, precipitation, soil type and pH, oxygen content, and the presence or absence of other inorganic and organic compounds are some factors that may affect fluctuation of heavy metal availability in soils according to Giovanni Dalcosso *et al*., 2019. These heavy metals are absorbed by plants either through roots or foliar and taken to various organelles for metabolism. Homeostatic processes ensure metal requirement, storage, and re-mobilization under different environmental conditions is enhanced. There is a complementarity in cadmium and zinc uptake by plants according to Agritopic 2021. If one is low the other increases in concentration through uptake from the soil solution. It is recommended that in order to suppress cadmium uptake by plants, applying zinc to some arable land to depress plant uptake of cadmium.

This study intends to look into an assessment of the behaviour of tsunga (mustard), rape and tomatoes on hyper accumulation of heavy metal. It tends to look into the soil on arable and virgin land, and water, compare their elemental composition with reference to heavy metals. A comparison of high levels of heavy metals in virgin land as compared to arable land indicates inherent traits within the soil environment, somehow reflecting on what has been and what it is now between the two environments. If there is more of the heavy metals in arable land than in the virgin land and water then it proves anthropogenic nature of the metals. The study intends to make an assessment of hyper accumulative tendencies of three vegetables for the same heavy metals under the same environmental conditions. This can be used as a basis for making recommendations on what vegetables to grow under certain heavy metal level environments so as to uphold the principle of food safety promotion.

2.0.METHODOLOGY

Sampling was done from gardens in various parts of the country for three vegetables commonly grown and eaten by the general populace around the country. The vegetables are tsunga, rape and tomatoes. These vegetables were sampled together with soils and irrigation water in situ. A sample was also taken from untampered with portion of the field here classified as virgin land. This land had not been tampered with in horticultural terms and there was free growth of the local wild flora to prove its virginity.

Random sampling of the vegetables was done. These were picked by plucking the edible parts of the plant for a number of plants representing the population present. These were placed in khakhi envelops and taken to the laboratory for preparation for chemical analysis. At the laboratory these were coded with unique identification, weighed, dried in oven and reweighed to determine moisture content. After weighing, these were put in a mill and ground. These were placed in sample bottles tagged with the unique identity code for the sample, taken to the laboratory and analyzed for chemical composition using the atomic absorption spectrophotometer.

The soil was sampled by digging a trench at least 20cm deep, scooping a slab of soil parallel to the hole. A number of sports were sampled to represent the area in question and put on a clean plastic bag for composite sample making. Once made, this was placed to dry naturally until a constant mass was observed from the sample. This was then ground and a representative sample placed in a sampling bottle for chemical laboratory analysis. Extraction of the elemental constituents of the soil was done using aqua regia and samples analyzed using the atomic absorption spectrophotometer (AAS) Varian A734. Results were reported in unit of parts per million (ppm).

3.0. RESULTS AND DISCUSSION

From Figure 1, copper levels were 37% higher in tsunga than rape. This showed a hyperaccumulative tendency towards the element despite lower levels in the soil within the arable land. This may be due to some preferential absorption and accummulation of the metal in tsunga as conmpared to rape. opper compounds are sprayed as fungicides on tomatoes during their production period. The copper might have remained as a residue in the arable soil from a rotation with tomatoes since it did not show in the virgin land hence proving its anthropogenic origin. Cadmium. According to ATSDR (1999a) in the USA, leafy vegetables contain high levels of cadmium, approximately 0.05 –0.12 mg cadmium/kg. Both samples of tsunga and rape exceeded this recommended maximum threshold on cadmium. All vegetables exceeded the maximum threshold acceptable for lead concentration of 0.3ppm according to ATSDR.

There was some elevated cadmium levels on the virgin land as compared to the arable land. This may prove tendencies of environmental degradation through erosion and also results of mining by the various vegetables put in rotation on the arable land. With lead, tsunga displayed high hyperaccumulation tendencies towards the element than rape. No nickel was detected in any of the samples implying safety from nickel contamination within the environment. Zn, Co, Mn and Cr are a necessity in minute quanties for promoting positive plant health and are within acceptable range for human consumption. No water was available since weirs in the area were dry during sampling period.

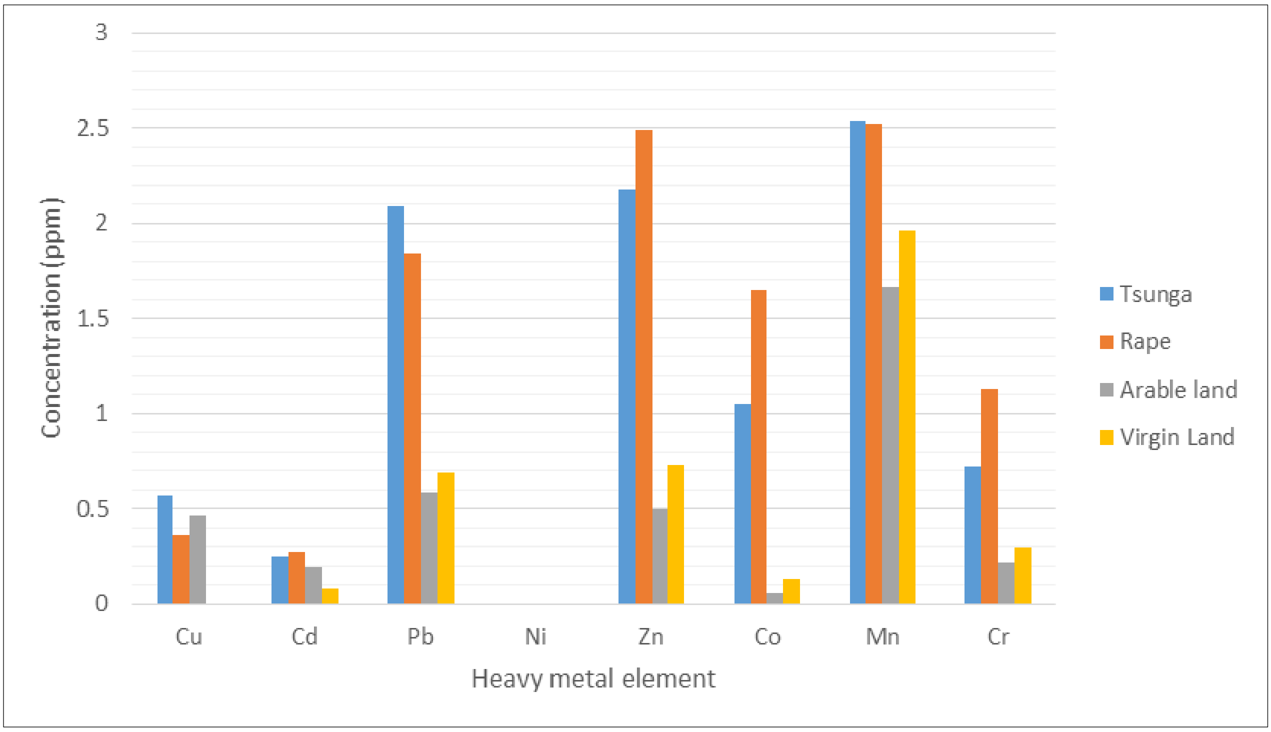

Figure 1: Comparison of soil heavy metal present against hyper accumulation tendency of tsunga and rape in Macheke, Village 4. (Source: Authors Data)

There is no direct linear relationship between heavy metal levels in arable land and levels in rape as a vegetable. There is however a hyperaccumulation of cadmium, zinc, nickel and lead despite their low levels in irrigation water and soil as depicted in Figure 2. Rape has a fast growth rate as a commercial vegetable hence rate at which it absorbs and accrues these heavy metals is also astronomic by virtue of its short life cycle. Zinc, cobalt, manganese and copper have known biological functions in the human body and are needed up to certain thresholds in the human diet. They were within recommended maximum thresholds in the rape vegetable according to ATSDR. Cadmium, lead and nickel have no known biological functions in plants and humans and considering their presence in the rape, it is advised to tread with care in growing and consumption of this vegetable without giving prior soil ammendments hence the rape from this environment may not be recommended for human consumption.

The level of heavy metals within the virgin land are within acceptable maximum thresholds for the elements under study in agricultural soils according to WHO / FAO standards. There is an acceptable elemental composition for all heavy metals under study in the weir water with the exception of chromium, that is way above the maximum threshold of 0.55ppm. This might point out to some form of pollution or contamination to irrigation water hence source can be attributed to that.

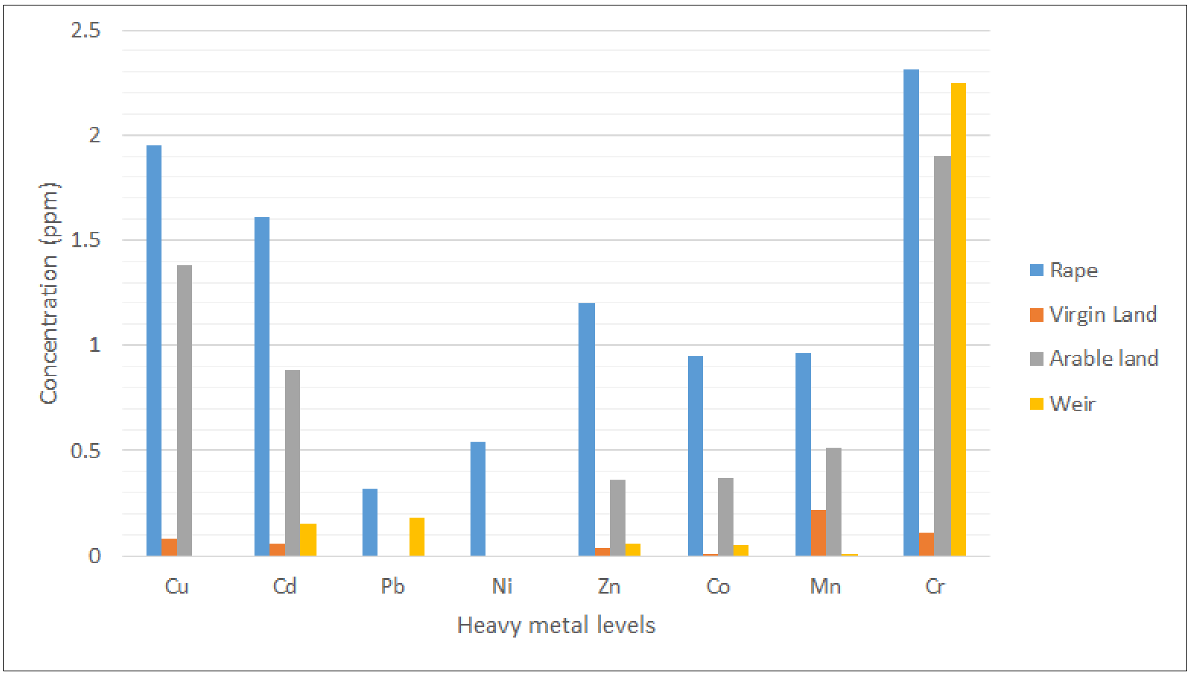

Figure 2: Relating soil heavy metal concentration to rape as a vegetable in Murehwa, Jakopo Village. (Source; Authors data)

Tsunga is a leafy vegetable and follows the same growth pattern like rape contrary to tomato which is a fruit vegetable. Figure 3 shows that tsunga tops the charts in accruing high levels of heavy metals under study especially on lead, zinc, cobalt and manganese. Tomatoes showed a hyperaccumulative tendency for copper, cadmium, zinc, manganese and chromium. Comparing tsunga and tomato field elemental composition of the heavy metals, there is more of copper, lead and chromium in the tsunga field. This might result from less absorption of these by the tsunga but a hyper absorption by the tomatoes. This implies a health risk assessment may reveal poor rating on consumability of tomatoes grown in this environment. Cobalt, manganese and chromium tend to be naturally inherent in the soils as depicted in the levels showing on virgin land soil in Figure 3.

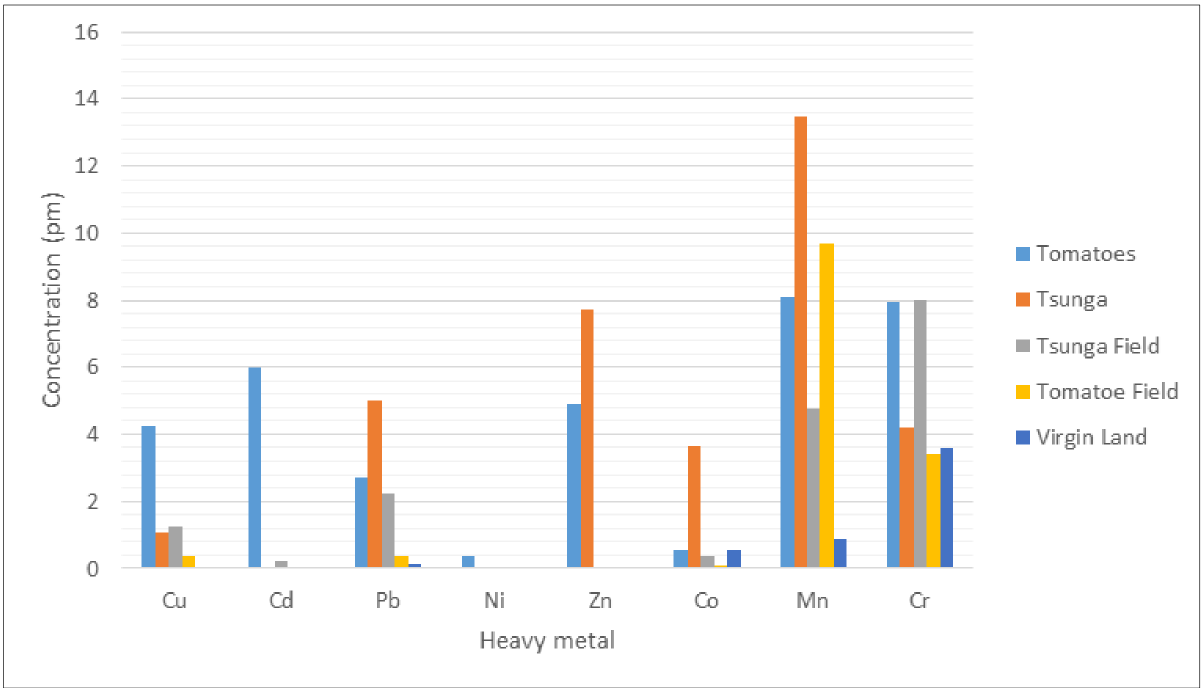

Figure 3: Comparison of tomato and tsunga demands from the environment showing hyperaccumulative tendencies in Mushimbo Village, Mutoko. (Source: Authors data)

The trend in increasing hypeaccumulative tendency varies from element to element and from crop to crop as depicted in Figure 4. For copper and chromium, the ranking increased in the order tomatoe > rape > tsunga. For cadmium, all vegetables exceeded the tolerance limit for human consumption and increases in the same order like in copper. Lead, cobalt and manganese had a different pattern altogether with the order ranking from rape > tsunga > tomatoe. It looks like there are a number of factors that determine the rate of accumulation of these heavy metals in vegetables. These factors can be inherent in the vegetable variety and type and also in the environment in which the plants grow. There is the mutual contrary between presence and absorption rate of certain elements within the same vicinity where when one is present in the vicinity of another in excess, it suppresses the absorptiuon of the element that is lacking in quantity. This usually happens between zinc and cadmium in certain species of plants.

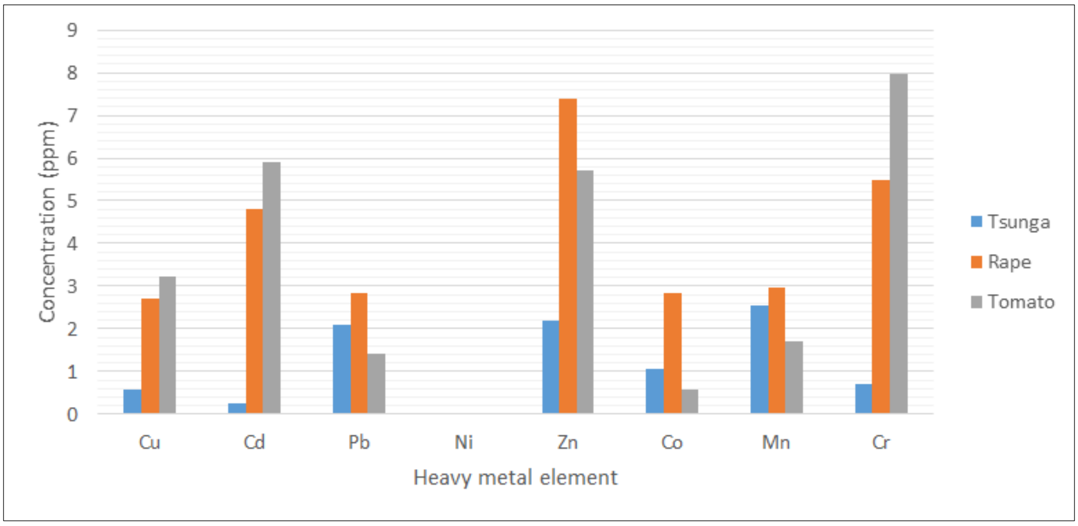

Figure 4: Comparison of tomatoes and Rape hyperaccumulative tendencies towards heavy metals from the same environment. (Source: Authors Data)

The trend in heavy metal content of soils and irrigation water at the farm under study in Mashonaland Central Province of Zimbabwe show that these heavy metals are anthropogenic in origin. This is reflected in low levels of heavy metals in the virgin land as compared to all arable lands. This discrepancy might be due to an input of many fertilizers and other chemicals to boost production of the various vegetables under study. Accumulation of copper, cadmium and chromium in tomatoes may be due to chemicals used during growth period before harvesting. The various elements have proved to be within acceptable tolerance levels in the various soils and weir water used for irrigation. Weir water had high copper levels proving signs of copper contamination as depicted in Figure 5. This reflects the need to check on the environment and make recommendations on what kind of crops to grow within this particular area.

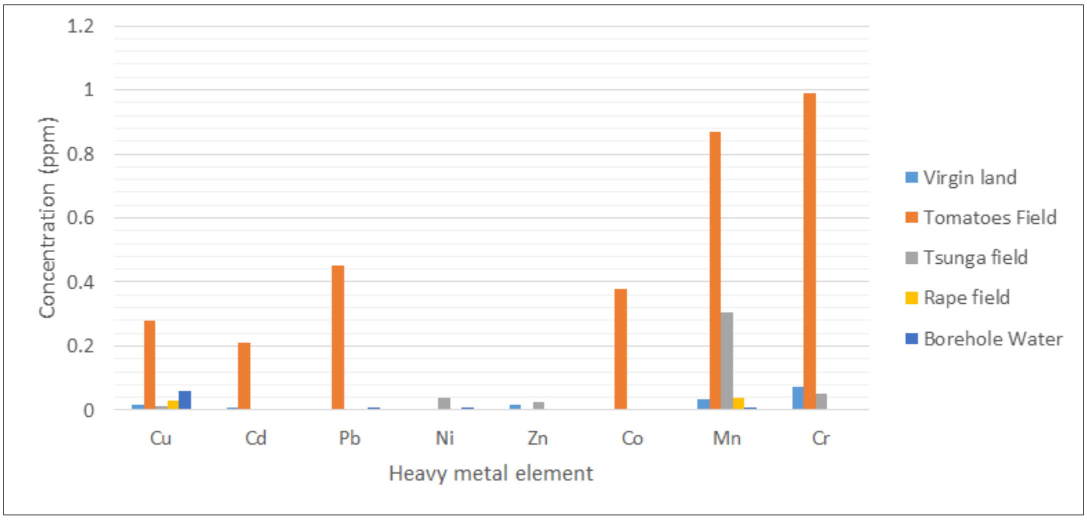

Figure 5: Comparison of inputs to the horticultural system as sources of heavy metal contamination to vegetables sampled in Mashonaland Central Province of Zimbabwe. (Source: Authors data)

4.0.CONCLUSION

Leafy veggetables with shorter life cycles grow fast and actively absorb nutrients at a faster rate than the other vegetables with longer life cycles. Hyperaccumulation of heavy metals occurs to all vegetables and differs with type and variety. There are many other uninvestigated factors in this study that determine heavy metal absorption by plants. Most of the heavy metals causing a concern are anthropogenic in origin in horticultural systems. Ranking in copper, cadmium and chromium affiliation by study vegetables have shown the heirachy in hyperaccumulation tendency in the order that tomatoe > rape > tsunga. The rest of the study elements have demonstrated that hyperaccumulative tendencies accrue in the order tomatoes < tsunga < rape. This study necessitates promotion of food safety basing on the various behaviour of the various vegetables under study in different environments. Certain vegetables can be discouraged growing under certain soils after carrying out soil analysis so as to grow plants that behave normally under specified environments.

5.0. RECOMMENDATIONS

This kind of studiy should be conducted under controlled environments like in green houses. Ranking in heavy metal hyperaccumulative tendency should be used in recommending growing certain crops in certain areas with known inherent heavy metal traits. Sampling was done in different times of the year hence discrepancies in finding certain vegetables in some areas and not others. It is recommend that the three vegetables could have been grown in experimental plots within the same environment so that a distinct trend could be noted that is concretely conclusive.

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Conflict of Interest

The authors declare that there is no conflict of interest with regard to date here presented and final presentation of the study hence any criticisms both positive and negative can be nailed to the author's door.

Abbreviations

AAS – Atomic Absorption Spectrophotometer
ATSDR - Agency for Toxic Substances and Disease Registry
Cd - cadmium
Co - cobalt
Cr - chromium
Cu - copper
Mn - manganese
Ni - nickel
Pb - lead
WHO / FAO – World Health Organization / Food and Agricultural Organization of the US.
Zn - zinc

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