Effect of Using Different Types of Irrigation Water on the Soil-To-Crop-Transfer Factor in Leafy Vegetables Grown Along Peri-Urban Areas of Kiambu County, Kenya

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ABSTRACT

The water used for irrigation has a significant effect on the way heavy elements accumulates in the soil as well as how plants grown on those soils uptake elements. Therefore, this study aimed at establishing the effect of using different types of irrigation water on the soil-to-plant transfer factor for African nightshade (Solanum Scabrum Mill) grown in the peri-urban areas of Kiambu County, Kenya. Randomized complete block design was used to grow the crop samples in the field for a period of 30 days. Four types of water (tap water, borehole water, shallow well water and wastewater) were considered as the four treatments and replicated four times. From the results, the level of Cd^{2+} *and* Pb^{2+} *in the soils which were 2.63 ± 0.10 and 3.77 ± 0.10 ppm respectively was above the World Health Organization (WHO) acceptable limits. For the crop samples that were irrigated using wastewater, a high level of* Fe^{3+} *was recorded 224.59 ±14.59 ppm though not above the WHO limits. The soil-to-crop transfer factor values (TF) for crops grown using shallow wells had a value >1, an indication that this type of water positively influences the uptake of these elements. The TF values for* CD^{2+} *AND* PB^{2+} *IN crop samples grown using tap water were< 1 at 0.95 and 0.97 respectively which signify the ability of tap water to suppress uptake of heavy elements by plants. Based on the results, it is notable that the quality of water used for irrigation affects the way in which plants accumulates elements from the soils. It is recommendable for policy makers in the study area to educate the farmers on the need to carry out phytoremediation as one of the innovative risk-reduction interventions measures in regard to bioaccumulation.*

Key terms: Soil-to-plant transfer factor (TF), World Health Organization (WHO), Tap water, Borehole water, Shallow well water and Wastewater.

INTRODUCTION

Soils from fields that are irrigated using wastewater have high probability of being contaminated with heavy metals, thus posing a threat to humans. This is due to the premise that wastewater irrigation results to increased total and phytoavailable heavy-metal concentrations in the soils. Consequently, heavy-metal elements in the soils are taken up by plants and undergo sequestration in various parts of the plants such as the roots, leaves and stems. Therefore, the heavy elements are able to accumulate on those parts thus readily available for consumption by humans and animals, a factor which results to bioaccumulation. However, it is worth noting that the factors which affects the form and solubility of available species of metal in soil varies significantly depending on the soil properties (mineralogy, endogenous metal concentration, particle size distribution), chemical form of elements that are entering the soil, soil processes (microbial activity, mineral weathering) (Lepp, 2012). By determining the soil-to-crop transfer factor, one can be able to evaluate the amount of elements that are in the soil and readily for uptake by plants. The soil-to-crop transfer factor (TF), or uptake factor, is regarded as one of the most important parameters used for evaluating the transfer potential of a metals and radionuclides from soil to plant. This is based on the fact that plants are the primary recipient of heavy metals and radioactive contamination to the food chain from the abiotic environment through uptake from the atmosphere by above ground parts and sorption from the soil by the root system of plants (Gupta & Walther, 2014). TF is calculated as:

$$TF = \frac{\text{the Metal concentration in the edible part of the vegetable}}{\text{Metal concentration in the media sample}}$$

The metal concentrations in the extracts of the soils and plants are calculated on the basis of dry weight. If the ratios >1, the plants have accumulated elements, the ratios around 1 indicate that the plants are not influenced by the elements, and ratios < 1 show that plants exclude the elements from the uptake. If the plants have higher TF values, they can be used for phytoremediation. Vegetables grown on contaminated soils accumulate high concentrations of heavy metals in their edible parts. This is based on the ability of vegetables to uptake and translocate heavy metal elements in different parts, factor which may lead to more concentration of a particular element in the plant as compared to the leaves (Olowoyo et al. 2010).

It is important also to note that the TF values of heavy metals and radionuclides vary enormously depending on the type of soil, crop as well as the duration a particular element has been in the soil. Other factors are crop variety, agricultural practice (especially applying fertilizer) and differences in the weather during the growing season as summarized by the figure below.

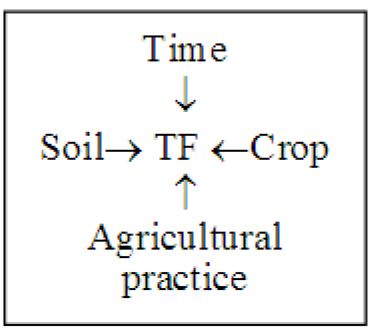

Figure 1: Main factors affecting TF values

In this study on accumulation of heavy metal in the edible parts of some cultivated plants in Southern Turkey, Saglam (2013) established that the TF values of Molybdenum was the highest in all crop samples tested (*R. sativus*, *B. oleracea*, *V. unguiculata* and *P. vulgaris*) with *V. unguiculata and B. oleracea* having a value of 11.67 and 3.90 respectively. Similary, *R. sativus* had a high TF value of 1.345, 1.336 and 0.692 in regard to cadmium, Cobalt and Zinc accumulation as compared to the other vegetables grown in the area. For this study, African nightshade (*Solanum Scabrum*) was selected as the leafy vegetables to evaluate the ways in which soils colloids influence the uptake of elements in vegetables grown around Kiambu County Kenya. The various species of the African nightshade grown in Kiambu County have become popular as they contain high level of proteins, iron among other nutrients as compared to the traditional vegetables such as kales. As noted byMuthomi & Musyimi (2009), the composition of 100g edible portion of *S. Scabrum* Mill is 87.8 g of water, energy 39 kcal (163 kJ), protein 3.2 g, carbohydrate 6.4 g, fat 1.0 g, β-carotene 3.7 mg, Ca 200 mg, ascorbic acid 24 mg, fibre 2.2 g, Fe 0.3 mg and P 54 mg. There are also high

levels of vitamin A, B and C and alkaloids and phenolics in the leaves. Based on this, a diet that incorporates African nightshade is significantly recommendable to nursing or pregnant mothers as well as those having iron deficiencies. It is based on this that this study aimed at establishing the effect of using different types of irrigation water on the soil-to-plant transfer factor for African nightshade (*Solanum Scabrum* Mill) grown in the peri-urban areas of Kiambu County, Kenya. The four types of water used for this study were wastewater, water from borehole water, water from the shallow wells and municipal water (tap water).
Borehole- It is a narrow shaft bored in the ground, horizontally or vertically and having a depth of between 25 to 1000 feet (Preene, 2012).

Tap water- Tap water also referred to as municipal water, city water, running water or town water is water supplied to a tap (valve) (Salzman, 2013).

Wastewater- Any type of water whose quality has been adversely affected by anthropogenic influence (World Health Organization, 2016)

Shallow well –A well that has a depth of 25 feet and below (Preene, 2012).

MATERIALS AND METHODS

Study area
The study area, located in Kiuu Ward Githurai area, lies between 1°11'59.43"S and 36°56'00.03"E. The area was selected due to accesibility as well as availability of land for carrying out the experiment. It is notable that the area is rapidly growing as it is has an elabotate means of transport, both the Kenya-Uganda Railway and Thika Road Super Highway, a factor which has attracted many people to invest in this area. Majority of people residing in this area work for the City of Nairobi (Chege, 2011). The area has around 100 farmers mainly growing *S. Scabrum* among other leafy vegetables. There is also availability of market along the study area due to its proximity to the Githurai open air market located between 36º54′49.77″E, 1º 12′10.07″S and 36º55′10.62″E, 1º12′10.21″S , thus encouraging increased farming of *S.Scabrum*. In the study area, there are two rainy seasons: the long rains which fall between April and mid-June and short rains in which fall in November and early December. According to the Kenya Meteorological Department, in Githurai area, the avarage annual rainfall is approximate 900 mm, although this varies from one year to the other. Due to its proximity to the equitor, the avarage datime temperature varies slightly from 29°C (85°F) in dry seasons and 24°C (75°F) during the rest of the year. The strongest winds take place during the dry season just before the "Long Rains" at a speed of between 20 and 25 m.p.h (Kenya Meteorological Department).

According to the 2009 Kenya Population and Housing Census, the total population in Githurai Location was 103,045 and was projected to rise to 120,906 by 2015. Similarly, the total number of households was 33,185 by 2009, all in an area of 32.2 sq.km. Since Githurai came up as a result of land being subdivided without following any guidelines, the area is highly unplanned in regards to sewerage system, road reserves and a system to manage solid waste. The area is congested as a result of huge number of tenements that are being built with the aim of taking advantage of increasing population (Chege, 2011). In regard to soils and geological formation, the area contains tertiary volcanic rocks, the most critical one being what is regarded as Nairobi Stone. Nairobi Stone, mostly used for building, is a tertiary volcanic rock, which gives to soils that are dark reddish brown, friable, well drained and highly calcareous. In geological terms, soils in the study area are youthful soils, with patches of black cotton soils. However, majority of the soils possess a high safe-bearing capacity, thus being able to support foundations for buildings at even shallow depths. As a result, the vegetation in Githurai area is mainly comprised of shrub vegetation as this is what the soils can support (Kamau, 2012).

Preparation, Collection and Laboratory Analysis of the Crop Samples

Randomized complete block design was used to grow the crop samples in the field for a period of 30 days. The four types of water (tap water, borehole water, shallow well water and wastewater) were considered as the four treatments and replicated four times as shown by figure 2. After the 30th day, complete harvest was done where only the mature leaves were randomly selected and placed in brown papers bags and transported to the laboratory for analysis.

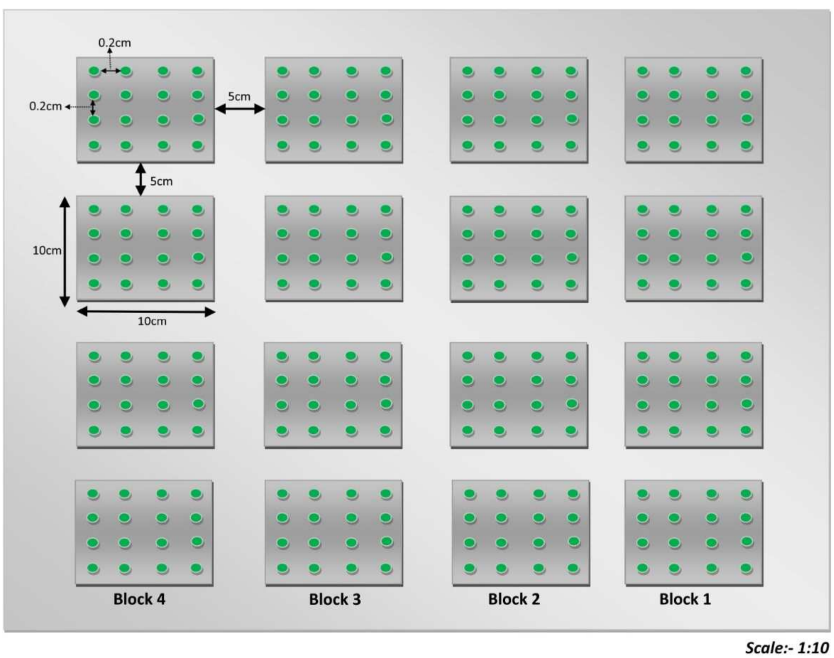

Figure 3.3: Layout Of The Experimental Area*Source*: (Author)

In the laboratory, all the crop samples were first washed under running tap water with the aim of removing dust particles that may interfere with the results from analysis. Subsequently, the samples were washed with acidified distilled water (1ml Conc. HCL/Liter), and then rinsed thoroughly with distilled water (Masabni, 2015). An oven was used to dry all the samples at approximately 70^{o} C for a period of 24-48 hours. Since the water content in each sample varies significantly, their weights were noted throughout. They were regarded as dry when the weight was constant for two consecutive readings. After drying, the plant samples were ground in order to pass a 1.0-mm screen (20 mesh), as the sample aliquot assayed was >0.5 g (Molina, 2011). The samples were then mixed thoroughly and transferred to polythene bags, labeled clearly and stored.

One gram of plant tissues from every sample was carefully weighed and put in 100 ml volumetric flask. 5 ml of acid mixture (HNO_3 and $HCLO_4$) and mixed in the ratio of 2:1 respectively) were added to the each crop sample. The solution was then heated by the use of hot plates for 15 minutes in a fume chamber at 60 ºC until the reaction was complete. Thereafter, the samples were heated at 120 ºC for 75 minutes until the liquid turned colorless. They were then removed from the hot plates, cooled, transferred to a volumetric flask (100 ml) and distilled water used to fill it to the mark and filtered using Whatman No. 1 filter paper. Through use of the Atomic Absorption Spectrophotometer (AAS), the level of concentration of copper, lead, iron, zinc, manganese and cadmium were obtained from the samples.

Preparation, Collection and Laboratory Analysis of the Soil Samples

Soil samples were collected from all the four blocks by the use of a soil auger. The samples were randomly collected in triplicates at a depth of between 10 and 25 cm and stored in brown sugar bags each weighing 0.5 kg. They were clearly labeled by the use of a marker pen and transported to the laboratory, where they were air dried for two days. All the samples were then crushed to pass a 2mm sieve prior to various laboratory tests.

Figure 2: Air drying the soil samples

In testing the seven selected elements Melich Double acid extraction method was used. By use of this method, the soil samples collected before transplant (T_0) and at the time of complete harvest

(T_1) were extracted with a double acid extracting solution (0.1 N HCl and 0.025 N H_2SO_4). The soil samples were dried crushed and sieved using a 2 mm sieve. 5g of each soil sample was separately treated with the double acid solution, a mixture of 0.1 N HCl and 0.025 N H_2SO_4 solutions in a 1:5 ratio (w/v). The mixture was then shaken using a mechanical shaker for 30 minutes and filtered using Whatman No. 1 filter paper. The extracts were used for analysis of cadmium, magnesium, manganese, iron, lead, copper and zinc by the use of the Atomic Absorption Spectrophotometer (AAS).

RESULTS AND DISCUSSION

The following section will offer and discuss the results obtained from the experiment conducted above as summarized in table 1.

Table 1: Mean concentration of heavy metals in soil samples and plant samples by using four sources of water (July 2017-September 2017)

	Conc. in Soil Samples	Mean Conc. In Plants grown using Wastewater	Mean Conc. In Plants grown using Shallow Well	Mean Conc. In Plants grown using Borehole Water	Mean Conc. In Plants grown using Tap Water
Cd^{2+}	2.63 ± 0.10	2.95 ± 0.13	3.62 ± 0.11	3.60±0.13	2.09±0.12
Mn^{2+}	3.58 ± 0.22	8.92 ± 0.19	9.38± 0.96	10.63±0.48	8.58±0.58
Fe^{3+}	113.06 ± 1.88	224.59 ±14.59	259.42 ±17.58	221.31±10..92	170.69±8.18
Zn^{2+}	19.01± 0.09	32.31 ±0.79	26.41 ± 1.74	37.17±3.70	30.06±1.42
Mg^{2+}	113.40 ± 1.22	114.30 ±10.87	170.87± 8.37	151.16±5.72	119.84±24.53
Pb^{2+}	3.77 ± 0.10	7.78 ±0.7	7.65 ± 0.31	8.49 ±0.35	4.36±0.40
Cu^{2+}	1.99 ± 0.12	4.77 ±0.29	4.08± 0.25	4.05 ±0.28	3.98±0.20

As indicated on table 1, it is clear that the soils along the study area exceed the tolerance limit values as recommended by the World Health Organization, thus acting as the main source of contamination in the edible leafy parts of the African nightshade grown along the river. The level of Cd^{2+} and Pb^{2+} in the soils which were 2.63 ± 0.10 and 3.77 ± 0.10 ppm respectively were above the World Health Organization acceptable limits. The WHO limit for Cd^{2+} and Pb^{2+} are < 0.1 ppm and < 2.00 ppm respectively in soils. Therefore, the continuous irrigation of the farms around the study area has resulted to the high accumulation of the lead and cadmium in the soils.

For the crop samples that were irrigated using wastewater, a high level of Fe^{3+} was recorded 224.59

±14.59 ppm though not above the WHO limits. Cd^{2+} and Pb^{2+} were 2.95 ± 0.13 and 4.77 ±0.29 ppm which was above the standards. The soil-to-crop transfer factor for CD^{2+}, MN^{2+}, FE^{3+}, ZN^{2+}, MG^{2+}, PB^{2+} AND CU^{2+} WAS 1.12, 2.49, 1.99, 1.70, 1.01, 2.06 AND 2.40 RESPECTIVELY. THIS IS AN INDICATION THAT THE MOBILITY OF MG^{2+} AND CD^{2+} WHICH HAD A TF VALUE OF 1.12 AND 1.01 DID NOT INFLUENCE THE GROWTH OF *S. SCABRUM*.

FOR CROP SAMPLES GROWN USING WATER FROM THE SHALLOW WELLS, A HIGHEST VALUE OF MG^{2+} ANDCD^{2+} WAS RECORDED AT170.87± 8.37 and 3.62 ± 0.11ppm respectively was recorded as compared to the other treatments. The TF values for CD^{2+}, MN^{2+}, FE^{3+}, ZN^{2+}, MG^{2+}, PB^{2+} AND CU^{2+} FROM THIS TREATMENT WERE 1.56, 2.50, 2.35, 1.73, 1.52, 1.50 and 1.84. This is an indication that CROP SAMPLES GROWN USING WATER FROM THE SHALLOW WELLS ARE influenced by the all the elements that were measured, thus all had TF value of >1.

FOR CROP SAMPLES GROWN USING WATER FROM THE BOREHOLE, THE HIGHEST VALUE OF ZN^{2+} AND MG^{2+} WAS RECORDED AT37.17±3.70 and 8.49 ±0.35 ppm respectively in comparison to the other treatments. The TF value for CD^{2+}, MN^{2+}, FE^{3+}, ZN^{2+}, MG^{2+}, PB^{2+} AND CU^{2+} was 1.55, 2.78, 0.99, 1.97, 1.29, 2.32 and 1.84 respectively. This is an indication that crops grow using water from borehole has the ability to exclude the uptake of FE^{3+} SINCE THE TF VALUE WAS < 1.

For crops samples grown using tap water, the lowest values of CD^{2+}, AND PB^{2+} was recorded at 2.09±0.12 and 3.98±0.20 ppm as compared to the other treatments. This is an indication that tap water has the ability to lower the mobility of these harmful elements from the soil to the plants. This can be affirmed by the fact that the TF values of CD^{2+}, AND PB^{2+} were< 1 at 0.95 and 0.97 respectively.

From the above, it is clear that in all the treatments, the level of cadmium in the crop samples ranges from 2.20 to 2.60 ppm which is above the tolerance limit of <0.1 ppm. Similarly, for lead, the value ranges from 3.50 to 5.00 ppm where as the WHO tolerance limit is < 2.00 ppm. For copper, magnesium and manganese, zinc and iron, the concentration in the soil was within the allowed limits, thus low chances of bioaccumulation.

CONCLUSION

From the results, it is notable that the value of CD^{2+}, AND PB^{2+} from crop and soil samples from all the treatments were above the required limits by the WHO. For crop samples grown using tap water, the concentration of CD^{2+} PB^{2+} ANDCU^{2+} were lowest as compared to all the other treatments. This is an indication that the uptake of these toxic elements from the soil were reduced thus a lower level of sequestration in the edible parts of *S. Scabrum*.

RECOMMENDATION

Based on the results, it is clear that high level of Pb^{2+} and Cd^{2+} concentration in the soils resulted to high accumulation of these elements in the edible parts of *S.Scabrum*. Consequently, policy makers should educate the farmers on the need to carry out phytoremediation as one of the innovative risk-reduction interventions measures in regard to bioaccumulation. This is based on the fact that unlike other methods of reducing toxicity in the soils, phytoremediation is relatively affordable and effective hence can be quickly adopted by the farmers.

REFERENCES

Chege N. (2011). Living in a business hub. *Standard Digital*

Gupta, D., & Walther, C. (2014). *Radionuclide Contamination and Remediation Through Plants*. Springer

Kamau, J. (2012). *Environmental Impact Assessment Report; Construction of Sewerage System For Ruiru Municipality*. Accessed From Athi Water Services Board Website: http://ardhi.go.ke/nairobi-metro/eisaseruiru.pdf

Khan S, Rehman S, Khan AZ, Khan AM, Shah MT (2010) Soil and vegetables enrichment with heavy metals from geological sources in Gilgit, northern Pakistan. Ecotoxicology and Environmental Safety 73:1820-1827.

Kenya Meteorological Department (2017). *Retrieved from the Kenya Meteorological* Department Website: www.meteo.go.ke

Lepp, N. (2012). Effect of Heavy Metal Pollution on Plants: Effects of Trace Metals on Plant Function. Springer Science & Business Media

Preene, M. (2012). *Groundwater Lowering in Construction: A Practical Guide to Dewatering*, Second Edition. CRC Press

Masabni, J. (2015). *Texas Home Vegetable Gardening Guide*. Retrieved from Agrilife Extension website: http://cityofirving.org/DocumentCenter/View/11137

Muthomi, J. and Musyimi, D. (2009). Growth Responses of African Nightshades (*Solanum Scabrum* MILL) Seedlings to Water Deficit. *ARPN Journal of Agricultural and Biological Science*. Vol. 4, No. 5.

Olowoyo JO, van Heerden E, Fischer JL, Baker C (2010) Trace metals in soil and leaves of *Jacaranda mimosifolia* in Tshwane area, South Africa. Atmospheric Environment 44: 1826-1830.

Saglam, C. (2013). Heavy Metal Accumulation in the Edible Parts of Some Cultivated Plants and Media Samples from a Volcanic Region in Southern Turkey. *Ekoloji* 22, 86, 1-8 (2013). doi:10.5053/ekoloji.2013.861

Salzman, J. (2013). Drinking Water: A History. Gerald Duckworth & Co World Health Organization (2016). *WHO Guidelines for the Safe Use of waste water, Excreta and Greywater - Volume IV: Excreta and grey water use in agriculture.* World Health Organization (WHO), Geneva, Switzerland