EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 12(1) (2019) 74-82
DOI 10.14456/ea.2019.9
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Heavy Metal Residue and Potential Human Health Risk Factors of *Celosia argentea* (Lagos Spinach) Planted in a Soil Mixed with Landfill Leachate

Ogunyebi Amos Lanrewaju[1*], Njoku Kelechi Longinus[1], Misbaudeen Quasim Olamilekan[1], Adesuyi Adeola Alex[1], Oludoye Oluseye Olalekan[2] and Balogun Olanrewaju[1]

[1]*Environmental Biology Unit, Department of Cell Biology and Genetics, University of Lagos, Lagos, Nigeria*
[2]*International Program in Hazardous Substance and Environmental Management, Graduate School, Chulalongkorn University, Bangkok, 10330, Thailand.*

*Corresponding Author: lanreyebi@yahoo.com; logunyebi@unilag.edu.ng
Received: May 12, 2018; Accepted: September 23, 2018

Abstract

Landfill leachate could constitute significant health impact on human health due to its penetrating tendency and eventual contamination of nearby groundwater. Therefore, assessment of the leachate probable environmental impact is paramount so as to prevent adverse ill-health to man and other living organisms. This study evaluates the heavy metals residue and the potential human health risk assessment factor of *Celosia argentea* (Lagos spinach) planted on soil mixed with leachate. The concentrations of the heavy metals in the harvested samples were determined with Flame Atomic Absorption Spectrophotometer (AAS). Heavy metals residue in *Celosia argentea* (Lagos spinach) was highest in soil mixed with 40 ml leachate. The daily intake of metals (DIM) of Zn (0.145 – 0.498 mg/kg) and Ni (0.032 – 0.090 mg/kg) were below the recommended limit while that of Cd (0.048 – 0.161 mg/kg) and Pb (0.158 – 0.341 mg/kg) were above the recommended DIM and the upper tolerable daily level. The health risk indexes (HRI) for Cd, Pb, Zn and Ni from this study were far greater than 1 (HRI > 1) except Cr that is less than 1. Thus, findings revealed that inhabitants may be highly exposed to health risks associated to these metals in the order Pb > Cd > Zn > Ni > Cr and as such people should be advised not to grow vegetables and other edible plants around the location of the dumpsite. Government and Policy makers should sensitize the public on the potential danger of eating heavy metal polluted foods.

Keywords: *Celosia argente*; Heavy metals; Risk Assessment; Landfill Leachate

1. Introduction

Landfill leachate is a heterogeneous mixture consisting of refractory organic compounds, inorganic contaminants, heavy metals, humic acids, fulvic acids and high nitrogen concentrations (Wiszniowski *et al.*, 2007). Studies have reported that leachate percolation contaminates nearby groundwater resources (Mor *et al.*, 2006; Pande *et al.*, 2015; Singh *et al.*, 2016). Leachates high load of organic matter, high nitrogen content and mass flux of transported contaminants impact plants heavily and can enter the food chain through vegetation around the site (Weng *et al*., 2011).The high nitrogen levels may contaminate soil and phreatic groundwater (Cheng *et al*., 2011). It is important to note that nitrogen (N) is most imperative element for proper growth and development of plants which significantly increases and enhances the yield and its quality by playing a vital role in biochemical and physiological functions of plant. Soil nitrogen availability has been long known to influence crop and root growth thus to have a direct impact on crop yield, attributing increased death rates for young individuals and leaf yellowing to insufficient nitrogen uptake (Lloyd D., 2003; Niste *et al*., 2013).

The process of leachate formation and subsequent contamination is dependent upon the amount of water which passes through the solid waste. Water which infiltrates the surface of the cover material, assuming daily and final cover is applied, will first be used for soil evaporation and plant transpiration. Any excess water will percolate into the layers of solid waste. Additional surface runoff from surrounding land, moisture contained in the solid or liquid wastes placed in the site, moisture from solid waste decomposition, water entering during waste placement in the site, and ground water entering through the bottom or sides of the site also contribute to the generation of leachate (Fenn *et al*., 2005).

The assessment of the potential impact of leachate is very important in the environment to avoid and prevent both severe and continual toxicity effect on the living organism and man. The phytotoxicity assessment on several test plants, such as *Vicia faba, Zea mays* and *Hordeum vulgare* have been used as receiving medium due to their sensitivity to a wide range of contaminants. Phytotoxicity assays can be used to measure putative environmental risks. They are reliable, cost effective, quick, and simple. The use of plants offers an advantage over other organisms because they can be more sensitive to environmental stresses (Sang and Li, 2004; Sang *et al*., 2010; Srivastava, 2014). Presently, there is paucity of information on the human health risk assessment on the subject matter.

Consequently, this study evaluated the heavy metals residue and the potential human health risk assessment factor of *Celosia argentea* (Lagos spinach) planted on soil mixed with leachate.

2. Marerials and Methods

This experiment was conducted in the Botanical and zoological garden of the Faculty of Science, University of Lagos, Akoka, and Lagos. University of Lagos is located in Lagos, Nigeria between the magnitudes of 6031´0´´N 3023´10´´E/ 6.516670N 3.386110E (Fig.2)

2.1 Sample Location and Collection

The Olusosun landfill located at Ojota, Lagos State, Nigeria was used as a case study for this experiment. Landfill leachates samples

Figure 2. University of Lagos geographical coordinates showing the botanical and zoological garden of the University of Lagos.

Figure 3. A map showing Olusosun landfill.

were collected from the dumpsite at random. The samples were collected in a 20 litres container.

2.2 Data Collection

This experiment followed the design of Hang *et al.* (2016). Soil contaminated with leachate was analyzed to determine its heavy metal and physico-chemical properties of the soil. 5 bowls were filled with 2 kg of soil mixed with leachate of different volumes (20ml, 40ml, 60ml, 80ml, 100ml) and the control (soil sample from botanical garden), the soil were marked properly. The seeds were sourced from the Lagos State Agricultural Farm Settlement, Odongunyan Ikorodu, Lagos were sown directly in different concentrations and in the control soil sample. The seeds planted in each concentration were in two replicates. After six weeks of planting (AWP), whole plants from each replicates and the control were harvest for laboratory.

2.3 Data Analysis

Twenty grams (20 g) of soil sample mixed with leachate, control soil, plants grown in contaminated soil and control plants were analyzed for metal extraction. The samples were weighed into a conical flask; distilled water and Nitric acid was added in ratio (1:3), heated on a Burner until all the reddish-yellow flames were expelled, allowed to cool and filtered into a 10ml standard flask. The concentrations of the metallic elements in the harvested sample were determined with the use of Flame Atomic Absorption Spectrophotometer (AAS). A suitable standard curve was generated on the AAS using standard solution of the metal. Standard concentration of 6, 12, 18, 24, 30 μg/g were utilized. A digital concentration read-out (meter) indicates the concentration of the metal contained in the samples (Quevauviller *et al.*, 2007). The potential health risks of heavy metal consumption through vegetables were analyzed based on the daily intake of metal (DIM) (Chary *et al.*, 2008), health risk index (HRI) (Jan *et al.*, 2010), and the target hazard quotient (THQ) (Wang *et al.*, 2005; Storelli, 2008). The estimated daily intake was calculated based on the formula:

$$DIM = \frac{C_{metal}\, x\, C_{factor}\, x\, C_{food\ intake}}{B_{averageweight}} \quad (1)$$

Where, C_{metal} is the heavy metal concentration in vegetables (mg/kg), C_{factor} is the conversion factor, $C_{foodintake}$ is the daily intake of vegetables. The conversion factor of 0.085 used to convert fresh vegetable weight to dry weight (Sajjad *et al.*, 2009), daily vegetable intake of 65 g/day (Oguntona, 1998) while the average body weight used was 65 kg (Oguntona, 1998).

The health risk index (HRI) was calculated using the formula:

$$HRI = \frac{DIM}{RFD} \quad (2)$$

The THQ was calculated using the formula:

$$THQ = \frac{EF\ x\ ED\ x\ FIR\ x\ C\ x\ 10^{-3}}{RfD\ x\ WAB\ x\ TA} \quad (3)$$

Where;
EF = Exposure Frequency (350 days/year)
ED = Exposure duration (54 years, equivalent to the average lifetime of the Nigerian population);
FIR = Food Ingestion Rate (vegetable consumption values for south western adult Nigerian is 65 g/person/day) (Oguntona, 1998);
C = Metal Concentration in the edible parts of vegetables (mg/kg);
RFD = Oral Reference Dose (Pb, Cd, Zn, Cr and Ni values were 0.0035, 0.001, 0.300, 1.5 and 0.020 mg/kg/day, respectively) (USEPA IRIS, 2006),
WAB = The Average Body weight (65 kg for adults vegetable consumer in South western Nigeria) (Oguntona, 1998);
TA = Average Exposure time for non-carcinogens (ED x 365 days/year). If the THQ value is greater than 1, the exposure is likely to cause obvious adverse effects.

2.4 Statistical Analysis

Statistical Package for Social Science (SPSS) version 20 was used for data analysis. Independent two sample t-test was used to determine if there is significance difference among the measured parameters.

3. Results and Discussions

The heavy metal was higher in the soil mixed leachate than that of the control soil samples. The two sample t-test for the metals revealed that the concentrations of lead, chromium, zinc were higher in the soil contaminated with leachate than in the control soil. Nickel and chromium were not detected in the control soil samples. The leachate has the highest concentration of metals, followed by the soil mixed with leachate and lowest was recorded in the control soil sample. There was a significant difference in the concentrations of zinc, chromium, lead, cadmium and nickel between the soil contaminated with leachate and the plant samples at 20ml, 40ml and 60ml volumes ($P < 0.05$).

The highest metals concentrations was recorded in plants grown in soil mixed with leachate at 40 ml concentration. These findings corroborate the study of Abdul-Qadir *et al*., 2015. A significant difference was observed when *C. argentea* planted on soil contaminated with leachate and control plants were compared at 0.43, 0.12 and 0.23 respectively at ($P < 0.05$) significant levels. Heavy metals accumulation increases with soil mixed with leachate volume of 20 ml, 40 ml and 60 ml. respectively. The level of accumulation at 80 ml and 100 ml were insignificant and this is because of excessive accumulation of heavy metal which resulted in stunted growth of *Celosia argentea*. The health risk of the inhabitants of Lagos and the environments due to heavy metal intake from vegetables consumption i.e., the daily intake of metals (DIM), health risk index (HRI), and target hazard quotient (THQ) were presented in Tables 6 and 7. The DIM in *Celosia argentea* species for Zn (0.145 – 0.498 mg/kg) and Ni (0.032 – 0.090 mg/kg) were significantly lower than the recommended daily intake of metals and the upper tolerable daily intake level (UL).

However, DIM of Cd (0.048 – 0.161 mg/kg) and Pb (0.158 – 0.341 mg/kg) exceed the recommended DIM and the upper tolerable daily level. Cr (0.142 – 0.236 mg/kg) is lower than the recommended oral reference dose (RFD) of 1.5 mg/kg (USEPA, 2010). The HRI in *Celosia argentea* the leachates concentration ranges as follow; Cd (48.440 – 160.650), Pb (45.143 – 97.429), Zn (0.483 – 1.190) and Cr (0.095 – 0.158). The HRI for Cd, Pb, Zn and Ni from this study were far greater than 1 ($HRI > 1$) except Cr. Generally, $HRI < 1$ meaning that the exposed population is safe of metals health risk while $HRI > 1$ means the reverse (Khan *et al*., 2008). The population in the study area is therefore at greater risk of Cd, Pb, Zn, Ni and Cu as also reported by Tsafe *et al*. (2016). The THQ

Table 2. Heavy metals concentration of leachate sample

Leachate Heavy metals	Concentration (mg/L)
Zinc	4.07±0.003
Nickel	0.90±0.002
Lead	3.00±0.002
Cadmium	1.08±0.001
Chromium	1.04±0.002

Table 3. Heavy metals concentration of the soil contaminated with leachate and the control soil (soil sample from University of Lagos botanical and zoological garden)

Heavy metals	Concentration (mg/kg)	Control soil concentration (mg/kg)
Zinc	3.87±0.001	2.20±0.001
Nickel	0.04±0.000	ND
Lead	1.97±0.001	1.37±0.002
Cadmium	1.00±0.002	0.98±0.002
Chromium	0.68±0.002	ND

ND: Not detected

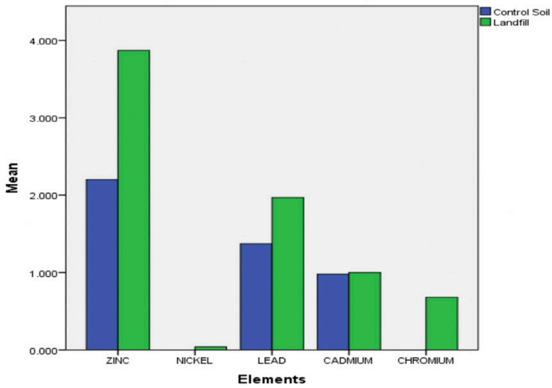

Figure 5. A graph showing the heavy metal concentration of soil contaminated with leachate and the control soil sample

Table 4. Physico-chemical content of the soil mixed with landfill leachate sample

Parameters	Soil mixed with landfill leachate sample
pH	8.1
Conductivity (µs/cm)	15,008
Salinity (mg/l)	12.69
Total Dissolve Solute (mg/l)	6,718.60
Biological Oxygen Demand (mg/l)	122
Chemical Oxygen Demand (mg/l)	259.2
Nitrate (mg/l)	1.23
Phosphate (mg/l)	0.82
Chloride (mg/l)	1,065.00

Table 5. Heavy metal concentration of *Celosia argentea* (mg/kg) after six weeks of planting

Element	Leachate volume				
	20ml	40ml	60ml	80ml	100ml
Zinc	4.751±0.004	5.855±0.004	5.301±0.005	4.202±0.003	1.708±0.001
Lead	3.314±0.003	4.011±0.003	3.668±0.003	2.968±0.004	1.864±0.001
Chromium	2.482±0.003	2.784±0.003	2.635±0.003	2.338±0.002	1.674±0.001
Cadmium	1.594±0.002	1.890±0.003	1.740±0.02	1.440±0.003	0.570±0.000
Nickel	0.870±0.001	1.055±0.001	0.960±0.000	0.784±0.003	0.375±0.000

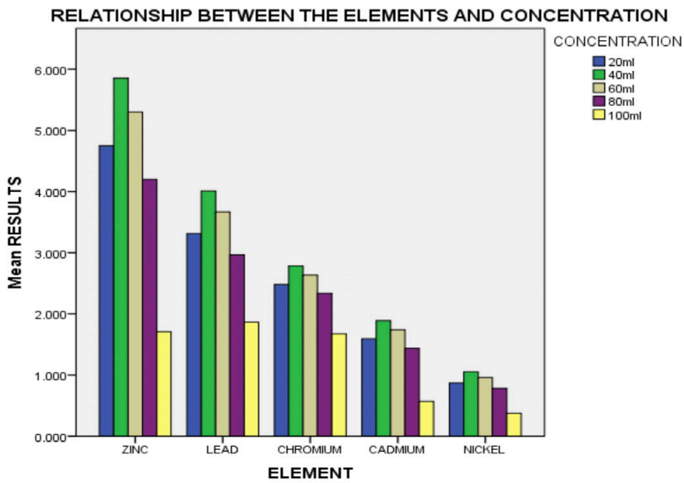

Figure 6. Graphical representation of heavy metals residue concentration in *Celosia argentea* (Lagos spinach) planted on soil contaminated with leachate after six weeks of plantation.

Potential human health risk assessment parameters of heavy metals

Table 6. Daily intake rate (mg person^{-1}day^{-1}) of heavy metals in *Celosia argentea* grown on soil mixed with leachate

Leachate volume	Heavy metals Element				
	Zinc	Lead	Chromium	Cadmium	Nickel
20 ml	0.404	0.282	0.211	0.135	0.074
40 ml	0.498	0.341	0.236	0.161	0.09
60 ml	0.451	0.312	0.223	0.148	0.0816
80 ml	0.357	0.252	0.199	0.122	0.067
100 ml	0.145	0.158	0.142	0.048	0.032
*DL (mg day^{-1} person^{-1})	8	0	0	0	0.5
*UL (mg day^{-1} person^{-1})	40	0.24	0	0.064	1

* Recommended daily intake (DL) and upper tolerable daily intake (UL) levels of heavy metals in foodstuffs (FDA, 2001; Garcia-Rico, 2007)

Table 7. Calculated values of health risk index (HRI) and target hazard quotient (THQ) for heavy metals in *Celosia argentea* planted on a soil mixed with leachate

Leachate Volume	Heavy metal element									
	Zinc		Lead		Chromium		Cadmium		Nickel	
	HRI	THQ	HRI	THQ	HRI	THQ	HRI	THQ	HRI	THQ
20 ml	1.347	0.015	80.571	0.908	0.141	0.016	135.49	1.528	3.7	0.042
40 ml	1.66	0.019	97.429	1.099	0.158	0.018	160.65	1.812	4.45	0.051
60 ml	1.503	0.017	89.143	1.005	0.149	0.017	147.9	1.668	4.1	0.046
80 ml	1.19	0.013	72	0.813	0.133	0.015	122.4	1.381	3.35	0.038
100 ml	0.483	0.055	45.143	0.511	0.095	0.011	48.45	0.547	1.6	0.027

values range showed that Cd was 0.547 – 0.812, Pb was 0.511 – 1.099, Zn was 0.013 – 0.055, Cr was 0.011 – 0.018 and Ni was 0.027 – 0.051 respectively.

This showed the risk associated with Cd, Pb, Zn, Cr and Ni exposure for the period of life expectancy considered, and the inhabitants are highly exposed to health risks associated to these metals in the order Pb > Cd > Zn > Ni > Cr. Generally, Zn, which is an important nutrient for humans, is considered a much lower health risk to humans than Pb, Cd, and As (Alexander *et al.*, 2006). In this study, the THQ in all heavy metals except Pb is far less than 1 in *Celosia argentea* in all the concentration; therefore, it does not pose health risk concern. Higher THQ for Cd, Pb, and Ni were reported by Singh *et al.* (2010) in vegetables from waste water irrigated area. Higher THQ for Cd and Pb in an area near a lead (Pb) and antimony (Sb) smelter in Nanning, China, was also reported by Cui *et al.* (2004) and Zhou *et al.* (2016) in vegetable species planted in contaminated soils. However, for special populations, such as those with a weak constitution, those that were sensitive, and women that were pregnant, the potential health risks of heavy metal accumulation through vegetable consumption were likely to be higher than for the normal population. Moreover, vegetable consumption was just one part of food consumption. Other foods like fishes, meat, tobacco, rice, and cassava (Osu *et al*, 2015; Iwegbue, 2015; Jolaoso *et al.*, 2016). For Lagos populace, food consumption, air pollution, drinking water are the important pathways for human exposure to toxic metals (Jolaoso *et al.*, 2016; Njoku *et al.*, 2016).

4. Conclusion

This study provides data on heavy metal pollution in Olusosun landfill and the heavy metal residue present in *Celosia argentea*. From the findings, it is evident that the landfill leachate is significantly polluted with heavy metals especially in the case of Zinc although the concentrations of the heavy metals in the plant tissues were quite low. While these vegetables are not considered hyper accumulators, they are still capable of accumulating these metals and if they are grown on soils with severe heavy metal pollution they will be very toxic to human health. Locations with higher heavy metal concentration produced plants with higher heavy metal concentrations. People that reside near Olusosun dumpsites should be discouraged from eating vegetables growing around the location of the dumpsite.

References

Abdul Qadir A, Qudsia K, Ruqia B, Balal Y. Accessing potential bioaccumulation of heavy metals in selective vegetables from Gujranwala district, Pakistan. Journal of Environment and Earth Science 2015; 8: 58-70.

Alexander P, Alloway B, Dourado A. Genotypic variations in the accumulation of Cadmium, Copper, Lead and Zinc exhibited by six commonly grown vegetables. Environmental Pollution 2006; 144:736–745.

Chary NS, Kamala CT, Raj DS. Assessing risk of heavy metals from consuming food grown on sewage irrigated soils and food chain transfer. Ecotoxicology and Environmental Safety 2008; 69: 513–524.

Cheng C, Tsang C, Wong R, Chu L. Is landfill leachate a potential source of nitrogen for plant growth? International Conference on Environment and Industrial Innovation Press, Singapore. 2011.

Cui YJ., Zhu YG, Zhai RH, Chen DY, Huang YZ, Qui Y, Liang JZ. Transfer of metals from near a smelter in Nanning, China. Environmental International 2004; 30: 785-791.

FDA (Food and Drug Administration). Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Report of the Panel on Micronutrients. National Academy Press, Washington, DC Food and Drug Administration, Dietary supplements, Center for Food Safety and Applied Nutrition. 2001.

Fenn D, Hanley K, Degeare T. Use of water balance method for predicting leachate generation from solid waste disposal sites. U.S Environmental Protection Agency 2007; 168: 1-10.

Garcia-Rico L, Leyva-Perez J, Jara-Marini ME. Content and daily intake of copper, zinc, lead, cadmium, and mercury from dietary supplements in Mexico. Food Chemistry and Toxicology. 2007; 45:1599-1605.

Hang Z, Wen-Tao Y, Xin Z, Li L, Jiao-Feng G, Wen-Lei W, Jia-Ling Z, Tao T, Pei-Qin P, Bo-Han L. Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. International Journal of Environmental Research and Public Health 2016; 13(3): 289-294.

Iwegbue CMA. Metal concentrations in selected brands of canned fish in Nigeria: Estimation of dietary, intakes and target hazard quotients. Environmental Monitoring Assessment. 2015, 187: 1–15.

Jan FA, Ishaq M, Khan S, Ihsanullah I, Ahmad I, Shakirullah M. A comparative study of human health risks via consumption of food crops grown on wastewater irrigated soil (Peshawar) and relatively clean water irrigated soil (lower Dir). Journal of Hazard Materials 2010; 179: 612–621.

Jolaoso AO, Njoku KL, Akinola MO, Adesuyi AA, Adedokun AH. Heavy Metal Analyses and Nutritional Composition of Raw and Smoked Fishes from Ologe and Lagos Lagoon, Lagos, Nigeria, Journal of Applied Science and Environmental Management. 2016; 20(2):101-110.

Khan S, Lin A, Zhang S, Huc Q, Zhu Y. Accumulation of polycyclic aromatic hydrocarbons and heavy metals in lettuce grown in the soils contaminated with long-term waste water irrigation. Journal of Hazardous Material 2008; 152: 506-515.

Lloyd D. Aerobic denitrification in soils and sediments: From fallacies to facts. Trends in Ecology Evolution 2003; 8: 352-356.

Mor S, Ravindra K, Dahiya R, Chandra A. Leachate characterization and assessment of ground water pollution near municipal solid waste landfill site. Environmental Monitoring Assessment 2006; 118: 435-456.

Niste M, Vidican R, Pop R, Rotar I. Stress factors affecting symbiosis activity and nitrogen fixation by Rhizobium cultured in vitro. Environment 2013; 6: 42 - 45

Njoku KL, Rumide TJ, Akinola MO, Adesuyi AA, Jolaoso AO. Ambient Air Quality Monitoring in Metropolitan City of Lagos, Nigeria. Journal of Applied Science and Environmental Management 2016; (1): 178-185.

Oguntona T. Green Leafy Vegetables. In: Osagie AU and OU Eka (Eds.). Nutritional Quality of Plant Foods. Post-Harvest Research Unit, Department of Biochemistry, University of Benin, Benin City, Nigeria, pp: 120-133. ISBN: 978-2120-02-2. 1998.

Osu SR, Solomon MM, Abai EJ, Etim IG. Human health risk assessment of heavy metals Intake via cassava consumption from crude oil impacted soils with and without palm bunch ash additive. International Journal of Technical Research and Applications

2015; 3(4):140-148.

Pande G, Sinha A, Agrawal S. Impacts of leachate percolation on ground water quality: A case study of Dhanbad city. Global Nest Journals 2015; 17: 162-174.

Quevauviller P, Rauret G, Lopez-Sanchez J, Rubio R, Ure A, Muntau H. Certification of trace metal extractable contents in a sediment reference material (CRM 601) following a three-step sequential extraction procedure. Science of the Total Environment 2007; 205:223-234.

Sajjad K, Robina F, Shagufta S, Mohammed A, Maria S. Health risk assessment of heavy metals for population via consumption of vegetables. World applied sciences journals. 2009; 6(12): 1602-1606.

Sang N, Li G. Genotoxicity of municipal landfill leachate on root tips of Vicia foba. Mutation Resistance. 2004; 560: 159 – 165.

Sang N, Han M, Li G, Huang M. Landfill leachate affects metabolic responses of Zea mays seedlings. Waste Management. 2010; 30: 856-862.

Singh S, Raju N, Gossel W, Wycisk P. Assessment of pollution potential of leachate from the municipal solid waste disposal site and its impact on groundwater quality. Varanasi environs India. Arab Journals of Geoscience. 2016; 9: 131-135.

Srivastava A, Kumar R, Singh A. Cell cycle stage specific application of municipal landfill leachates to assess the genotoxicity in root meristem cells of barley (Hordeum vulgare). Environmental Science and Pollution Resistance. 2014; 21: 13979-13986.

Storelli MM. Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption: Estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). Food Chemistry and Toxicology. 2008; 46: 2782–2788.

Tsafe AI, Hassan LG, Sahabi DM, Alhassan Y, Bala BM. Evaluation of Heavy Metals Uptake and Risk Assessment of Vegetables Grown in Yargalma of Northern Nigeria. Journal of Basic and Applied Science Research. 2012; 2(7): 6708-6714.

Tsang C. Landfill Leachate Irrigation: Evaluation of Plant Productivity and Soil Toxicity, MPhil Thesis, The Chinese University of Hong Kong, Hong Kong. 2006.

US EPA IRIS. United States, Environmental Protection Agency, Integrated Risk Information System. 2006.

US EPA. Integrated Risk Information System (IRIS), United States Environmental Protection. 2010.

Wang X, Sato T, Xing B, Tao S. Health risks of heavy metals to the general public in Tianjin, China via consumption of vegetables and fish. Science of the Total Environment 2005; 350: 28–37.

Weng H, Zhang F, Zhu Y, Qin Y, Ji Z. Treatment of leachate from domestic landfills with three-stage physiochemical and biochemical technology. Environmental Earth Science. 2011; 64: 1675-1681.

Wiszniowski J, Surmacz-Gorska J, Robert D, Weber J. The effect of landfill leachate composition on organics and nitrogen removal in an activated sludge system with bentonite additive. Journals of Environmental Management 2007; 85: 59-68

Zhou H, Yang W, Zhou X, Liu L, Gu JF, Wang WL, Zou JL, Tian T, Peng PQ, Liao BH. Accumulation of Heavy Metals in Vegetable Species Planted in Contaminated Soils and the Health Risk Assessment. International Journal of Environmental Research and Public Health. 2016; 13: 289-291.