Scientific Research Publishing

Agricultural Sciences, 2023, 14, 843-854
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

A Preliminary Assessment of the Effect of Urban Waste Pollution in the Korle Lagoon Area of Accra, Ghana, on Nutrition and Growth of Maize (*Zea mays* L.) Plants

Eureka Emefa Ahadjie Adomako[1*], Dzifa Dellor[2]

[1]Department of Plant and Environmental Biology, University of Ghana, Legon, Accra, Ghana
[2]Department of Internal Medicine, University of Ghana Medical Centre, Legon, Accra, Ghana
Email: *eadomako@ug.edu.gh, dzifadellor@gmail.com

How to cite this paper: Adomako, E.E.A. and Dellor, D. (2023) A Preliminary Assessment of the Effect of Urban Waste Pollution in the Korle Lagoon Area of Accra, Ghana, on Nutrition and Growth of Maize (*Zea mays* L.) Plants. *Agricultural Sciences*, **14**, 843-854.
https://doi.org/10.4236/as.2023.146056

Received: May 27, 2023
Accepted: June 25, 2023
Published: June 28, 2023

Abstract

Disposal of domestic and industrial waste into the Odaw River and Korle Lagoon in Accra, Ghana, has led to pollution of the lagoon and surrounding soils. This study compared the elemental concentrations of heavy metals (lead and zinc) and essential plant macronutrients (nitrogen, phosphorus and potassium) in soils from the Korle Lagoon Area to those in baseline soils from the University of Ghana Agricultural Farm (UG Farm), also in Accra. A comparative pot experiment, using maize (*Zea mays* L.) as test plant, was conducted to assess the effect of each soil type on plant growth. Soil samples from the Korle Lagoon Area were significantly higher ($P < 0.001$) in lead (Pb), zinc (Zn), nitrogen (N) and potassium (K) concentrations than samples from the UG Farm. Mean plant height and mean leaf width of maize plants harvested 7 weeks after planting (WAP) were both significantly higher ($P < 0.003$) for samples from the Korle Lagoon Area soil compared to those from the UG Farm soil. Higher accumulation of Zn (448.3 ± 45.5) in maize shoot within 3 weeks of planting in the Korle Lagoon Area soil had phytotoxic effects on growth, resulting in shoot growth inhibition and reduced uptake of P and K in 11-week-old plants. The findings indicate that though nutrient enrichment due to sewage disposal into the lagoon may increase crop production, the nutritional quality of the crop produced could be compromised by heavy metal accumulation in the soil and subsequent uptake by the plant.

Keywords

Korle Lagoon, Waste Management, Soil Contamination, Plant Nutrition, Phytotoxicity

1. Introduction

The Korle Lagoon, a major water body in Ghana's capital city, Accra, covers a total surface area of about 0.6 km^2 and drains a total catchment area of about 400 km^2 [1]. Its main inlets are the Odaw River and its major tributary, River Onyasia. The Odaw River drains the communities of Achimota, Dome, Legon, Ring Road Industrial Area as well as the high-density, low-income areas of Nima, Maamobi and Accra Newtown; while River Onyasia drains the northern parts of Accra including Haatso, Papao and Agbogba [1] [2]. Due to poor management of domestic and industrial waste in the catchment area, the Odaw River and the Korle Lagoon (the major run-off receptacle into the Gulf of Guinea) have become home to all sorts of pollutants [3] [4].

Indiscriminate disposal of both solid and liquid waste, including sewage, has been cited as a major cause of nutrient element enrichment as well as heavy metal pollution in the Korle Lagoon [5] [6] [7]. Electronic waste (e-waste) recycling activities at Agbogbloshie in the upper reaches of the Korle Lagoon constitute another source of heavy metal pollution in the catchment area [8] [9]. A Pb concentration of 184 mg/kg in soil from the catchment area has been reported [10]. This is higher than the global average of <10 mg/kg for non-contaminated soils [11]. In a study of eight lagoons in the Central and Greater-Accra regions of Ghana, the highest mean concentrations of phosphate (~60 μmol/L) and ammonia (~1 mmol/L), a source of nitrogen, were recorded in water from the Korle lagoon [12]. Reference [6] also found high concentrations of ammonia (4.17 mg/l) and phosphate (4.51 mg/l) in water sampled from the Korle Lagoon. These values exceed their natural geogenic or background levels in ground and surface water [13] [14]. According to the World Health Organization (WHO), the presence of ammonia at higher than natural geogenic levels is an indication of faecal pollution [15]. These examples highlight the anthropogenic enrichment of macronutrients and heavy metals in water and soils in the Korle Lagoon Area. Since farming of food crops meant for human consumption occurs within the catchment area, there is the need to investigate the extent of uptake of these elements by the crops and elucidate the impacts on plant nutrition and growth.

This study compared the concentrations of heavy metals and essential plant macronutrients in soil samples collected from the Korle Lagoon Area to samples of a baseline soil series collected from the University of Ghana Agricultural Farm at Legon, Accra. A pot experiment was set up to compare the growth of maize (*Zea mays* L.) plants in soils from the two sites. Studies have demonstrated the suitability of maize for such an experiment because of its ability to accumulate heavy metals such as lead (Pb) and zinc (Zn) in both the below- and above-ground parts of the plant [16] [17] [18]. The current study explored differences in maize shoot elemental concentrations vis-à-vis plant growth parameters in a bid to assess the effects of pollution in the Korle Lagoon Area on plant nutrition and growth.

2. Materials and Methods

Soils were collected from the Korle Lagoon Area and the University of Ghana Agricultural Farm (Legon) for chemical analysis and for the pot experiment.

2.1. Description of the Korle Lagoon Soil Collection Site

The Korle Lagoon soil was collected from a farm located on a mudflat in the Korle Lagoon, which was accessed using a canoe. The dominant plant species found growing along the lagoon were *Avicennia nitida* (black mangrove) and grass (mainly *Panicum*) species. There was evidence of solid waste pollution as the mangrove trees were covered in rags, sacks, tins and plastics. Food crops grown on the farm included maize and garden eggs. Personal communication with the farmer revealed that crop yields were high.

2.2. Description of the University of Ghana Agricultural Farm Soil Collection Site

The University of Ghana Agricultural Farm (UG Farm) is located on the north side of the university's main campus at Legon, which is also drained by the Odaw River. Unlike the Korle Lagoon area, Legon has not been reported in the literature for heavy metal pollution, hence its selection as the control site. Managers of the farm normally acquire heaps of different soils for comparative experimental studies. At the time of soil collection, there were three different soil types based on the parent material. These were identified as Adenta series, Touji series and Haatso series. The Adenta series was selected for this study because it was recommended by the farm managers as the most fertile of the three and the most used for agricultural experiments.

2.3. Soil Collection and Processing for Pot Experiment

At the Korle Lagoon site, a 5 m × 5 m rectangular plot was demarcated in an area identified as being representative of the sampling site. The topsoil within the demarcated plot was collected to a depth of 10 cm. Soil from the UG Farm at Legon was collected from the heap of Adenta soil series. **Figure 1** provides a map of a part of the Greater-Accra region of Ghana showing the soil collection sites.

At both sites, unwanted debris including fallen twigs, leaves and plastics were cleared from the soil surface before collection of the soil using a clean spade. The soils were placed in clean jute bags and transported to a potting shed at the Department of Plant and Environmental Biology, University of Ghana. Soil samples were air-dried for two weeks to remove excess moisture and subsequently sieved through a 2-mm sieve to remove foreign matter and homogenize the soil particles.

2.4. Experimental Design and Plant Growth Measurements

A total of twenty-four 5-litre plastic pails (pots) were used for the plant growth experiment with 12 pots per soil treatment. Each pot was filled with 1 kg of soil

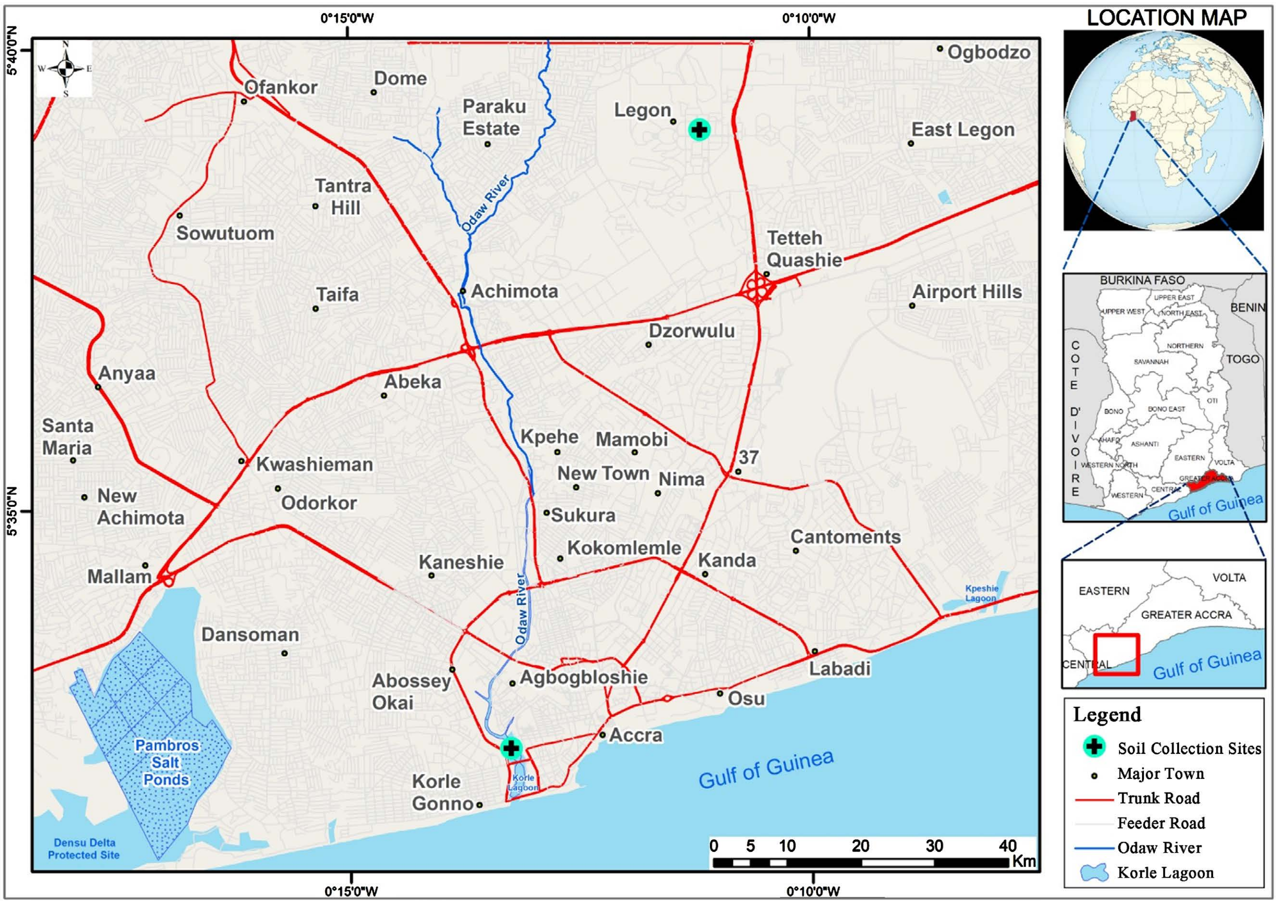

Figure 1. Map of a part of the Greater-Accra region of Ghana showing soil collection sites.

accurately weighed (±0.001 kg) using a weighing balance. The pots had four holes punched underneath each one (to prevent the soil from being waterlogged) and were placed in shallow plastic plates to hold excess water. This prevented nutrients from being lost from the set up. The potted soils were watered with equal amounts of water for two days before planting of the test plant. One seed of the Tuxpino variety of maize was planted in each pot and was watered daily with equal amount of water for the duration of the experiment. The experimental set-up was completely randomized.

For each soil treatment, 3 replicates of the maize plant were harvested 3, 7 and 11 weeks after planting (WAP) for laboratory analysis. The plants were gently uprooted, and the roots were washed with sufficient water to remove soil particles. After leaving to air dry for about an hour, the roots were separated from the shoots by cutting 5 mm above the base of the shoot. The fresh weights of roots and shoots were measured separately, after which they were placed in brown envelopes and oven-dried at 70˚C till constant weight. The dry weights were then recorded and the root-to-shoot ratio for each plant was calculated. Other growth parameters measured include plant height, plant girth, number of leaves, leaf length and leaf width. For uniformity, all plant girth measurements were taken 5 cm above the soil surface and plant height was measured from the base of the stem (1 cm above the soil surface) to the last leaf base closest to the stem apex.

2.5. Soil Analysis

Sample preparation for determination of soil pH, electrical conductivity (EC) and particle size distribution followed standard protocols as described by Van Reeuwijk [19]. For determination of total N content of the soil samples, the Kjeldahl method of digestion was used [20]. For extraction of available P in the UG Farm soil, the Bray-1 method using a mixture of ammonium fluoride and hydrochloric acid in the ratio 0.03M:0.025M was used while the Olsen sodium bicarbonate method was used for the Korle Lagoon Area soil because of its high pH [21]. For digestion of the soils for determination of total potassium (K), lead (Pb) and zinc (Zn) concentrations, 1.0 g of each sample was weighed into a previously washed digestion tube and 10 ml of ternary mixture (20 ml $HClO_3$; 500 ml HNO_3; 50 ml H_2SO_4) was added under a fume hood. The contents were mixed and heated gently at medium heat on a block digester until dense white fumes of sulphuric acid (H_2SO_4) appeared; after which it was heated strongly for half a minute. It was then allowed to cool, and 40 - 50 ml of distilled water was added before bringing to the boil again for half a minute on the same block digester at medium heat. The solution was then cooled and filtered completely (using a 9-cm Whatman no. 42 filter paper) into a 100 ml Pyrex volumetric flask and made up to the mark with distilled water. Total soil K concentration was determined by flame photometry and all other soil elemental concentrations were determined using atomic absorption spectrophotometry [22].

2.6. Plant Analysis

For determination of Pb, Zn and K concentrations in the maize shoot, 0.1 g of each pulverized plant sample was weighed into a clean 50 ml Pyrex conical flask and 5 ml of concentrated H_2SO_4 was added and swirled to ensure that the entire sample was wetted. After allowing to stand for one hour, the flasks were put on a sand bath over medium heat in a fume chamber. Six drops of hydrogen peroxide (H_2O_2) were slowly added (2 - 3 drops at a time) to avoid vigorous reaction of the contents. This process was repeated until a colour change was observed, from black to brown. The burner heat was then turned up while still adding drops of H_2O_2. When the solution stayed colourless on cooling, H_2O_2 was added for the last time and left on the sand bath at high heat for 10 - 15 minutes. The digest was then transferred into a 100 ml volumetric flask and was made to the mark with distilled water [23]. The Kjeldahl digestion method [20] and the Bray-1 method [21] were used respectively for determination of total N and available P in the maize shoot samples. As with the soil analysis, total K concentration in the plant samples was measured by flame photometry. Atomic absorption spectrophotometry was used to measure all other elemental concentrations in the plant samples [22].

2.7. Data Analysis

Statistical analyses were conducted using Minitab version 21. The two-sample t-test was used to test the significance of observed differences in elemental concentrations and growth parameters.

3. Results

Both the Korle Lagoon Area soil and the UG Farm soil were sandy, but the latter had lower soil pH and EC values and contained a significantly higher amount of clay (Table 1). Significant differences were observed in soil Pb, Zn, N and K concentrations with samples from the Korle Lagoon Area recording higher values than samples collected from the UG Farm (Table 2).

Comparison of maize growth parameters in the two treatments showed significant differences in plant height and leaf width 3 WAP and 7 WAP, with plants in the Korle Lagoon Area soil recording higher values (Table 3). There was, however, no significant difference in plant height 11 WAP at which time root-to-shoot ratio for maize plants in the UG Farm soil was significantly lower than for those in the Korle Lagoon Area soil (Table 3), indicating better shoot growth in the UG Farm soil. Mean leaf width was, however, significantly higher in 11-week-old plants growing in the Korle Lagoon Area soil (Table 3).

Table 4 shows that maize shoot Pb concentrations were statistically comparable for 3-, 7-, and 11-week-old plants harvested from both experimental treatments although soil Pb concentration was significantly higher in the Korle Lagoon Area soil (Table 1). In the case of Zn, there was a significantly higher accumulation in 3-week-old plants harvested from the Korle Lagoon Area soil, after which shoot Zn concentrations in both treatments were statistically comparable (Table 4). The concentration of P recorded in maize shoots harvested 3 WAP was also significantly higher for the Korle Lagoon Area treatment than the UG Farm treatment (Table 4). Although the Korle Lagoon Area soil had a higher

Table 1. pH, electrical conductivity (EC) and texture of soils from collection sites.

Soil collection Site	pH	EC (μs)	Soil Particle Distribution (%)			Texture
			Sand	Silt	Clay	
Korle Lagoon Area	7.53 ± 0.14	967.0 ± 32.1	51.9 ± 3.2	34.7 ± 1.7	13.4 ± 0.8	Sandy loam
UG Farm	5.59 ± 0.08	222.0 ± 21.4	63.4 ± 4.1	8.4 ± 2.3	28.2 ± 5.2	Sandy clay loam
P-value	<0.001	<0.001	0.087	<0.001	0.003	-

Table 2. Elemental concentrations in soils from Korle Lagoon Area and UG Farm.

	Pb (mg/kg)	Zn (mg/kg)	N (%)	P (%)	K (%)
Korle Lagoon Area	66.5 ± 0.3	154.3 ± 0.6	0.20 ± 0.002	0.02 ± 0.000	0.09 ± 0.001
UG Farm	23.4 ± 3.1	40.8 ± 10.4	0.14 ± 0.003	0.02 ± 0.005	0.04 ± 0.005
P-value	<0.001	<0.001	<0.001	0.857	<0.001

Table 3. Maize growth parameters recorded 3, 7 and 11 weeks after planting (WAP).

		Plant Height (cm)	Plant Girth (cm)	Number of Leaves	Leaf length (cm)	Leaf width (cm)	Root-to-Shoot Ratio
3 WAP	Korle Lagoon Area	19.5 ± 1.8	0.8 ± 0.1	6.7 ± 0.6	24.3 ± 1.5	2.2 ± 0.2	0.57 ± 0.14
	UG Farm	14.0 ± 0.9	0.7 ± 0.1	6.3 ± 0.6	23.4 ± 2.7	1.6 ± 0.1	0.52 ± 0.20
	P-value	0.009	0.101	0.519	0.626	0.009	0.723
7 WAP	Korle Lagoon Area	34.0 ± 3.0	1.0 ± 0.1	10.0 ± 1.0	40.7 ± 2.1	3.4 ± 0.3	0.78 ± 0.09
	UG Farm	21.0 ± 1.5	1.0 ± 0.1	8.7 ± 0.6	37.2 ± 2.1	2.1 ± 0.2	0.66 ± 0.06
	P-value	0.003	1.000	0.116	0.107	0.003	0.135
11 WAP	Korle Lagoon Area	39.0 ± 1.4	1.4 ± 0.1	11.7 ± 1.5	57.4 ± 2.3	4.1 ± 0.2	1.06 ± 0.06
	UG Farm	32.3 ± 5.4	1.3 ± 0.2	10.7 ± 1.5	49.7 ± 6.2	3.0 ± 0.5	0.74 ± 0.05
	P-value	0.106	0.435	0.468	0.111	0.020	0.002

Table 4. Elemental concentrations in maize shoots harvested 3, 7 and 11 WAP.

		Pb (mg/kg)	Zn (mg/kg)	N (%)	P (%)	K (%)
3 WAP	Korle Lagoon Area	177.1 ± 28.8	448.3 ± 45.5	1.38 ± 0.11	0.26 ± 0.02	2.40 ± 0.09
	UG Farm	150.1 ± 18.2	258.7 ± 32.5	2.04 ± 0.33	0.11 ± 0.02	2.06 ± 0.26
	P-value	0.241	0.004	0.031	0.001	0.102
7 WAP	Korle Lagoon Area	226.9 ± 71.4	260.1 ± 26.1	1.85 ± 0.28	0.19 ± 0.02	1.64 ± 0.14
	UG Farm	183.9 ± 5.5	223.0 ± 13.2	2.00 ± 0.28	0.16 ± 0.03	1.91 ± 0.19
	P-value	0.357	0.093	0.557	0.253	0.121
11 WAP	Korle Lagoon Area	221.3 ± 39.6	252.4 ± 17.7	1.25 ± 0.25	0.05 ± 0.02	1.34 ± 0.13
	UG Farm	190.7 ± 15.4	247.8 ± 39.6	1.15 ± 0.15	0.18 ± 0.03	1.95 ± 0.26
	P-value	0.280	0.864	0.619	0.003	0.021

N content (**Table 1**), maize shoots harvested from the soil 3 WAP had a significantly lower mean concentration of N compared to the UG Farm treatment (**Table 4**). No significant differences were observed in maize shoot elemental concentrations 7 WAP. However, shoot samples harvested from the Korle Lagoon Area soil 11 WAP had significantly lower concentrations of P and K (**Table 4**).

4. Discussion

The acceptable concentration range of Pb in world background soils is 10 – 30 mg/kg with an average of <10 mg/kg [11]. Thus, the mean Pb concentrations recorded in soils from the Korle Lagoon Area (66.5 ± 0.3 mg/kg) and the UG Farm (23.4 ± 3.1 mg/kg) were both above the global average. The mean for UG Farm was, however, within the acceptable range. Mean soil Zn concentrations for both sites were also within the acceptable range of 10 - 300 mg/kg, but the mean value for the Korle Lagoon Area (154.3 ± 0.6 mg/kg) exceeded the global average of 50 mg/kg [24]. It is not surprising that Pb and Zn concentrations were significantly higher in the Korle Lagoon Area soils since studies have found the two elements, along with cadmium (Cd) and copper (Cu), to be among the dominant contaminants in water and sediments sampled from the area [5] [9].

The higher concentrations of N, P and K in the Korle Lagoon Area soil relative to the UG farm soil are attributable to the discharge of sewage into the lagoon [6]. Nitrogen plays a vital role in plant growth because it forms a part of the chlorophyll molecule, which is required for photosynthesis. It is an integral part of amino acids, the building blocks of nucleic acids and proteins including enzymes, which serve as regulators of all plant metabolic reactions [25] [26]. Phosphorus is also important in photosynthesis and several enzymatic reactions because of its major role in the transfer of energy [26]. It is necessary for proper cell division and for the development of meristem tissue. It is also required for sugar and starch formation and carbohydrate transport [27]. Potassium is an enzyme activator and, hence, promotes plant metabolism. It has been shown to improve the size of grains and seeds. It plays a role in photosynthesis by promoting the translocation of photosynthates (sugars) for storage in fruits and roots or for plant growth [26]. The significant increase in plant height and leaf width exhibited by 3- and 7-week-old maize plants growing in the Korle Lagoon Area soil (**Table 3**) could, therefore, be attributed to the higher N, P and K concentrations as compared to the UG Farm soil (**Table 1**).

Though a heavy metal, Zn is an essential micronutrient for plant growth and development that is required at a much smaller concentration than N, P and K. Excessive accumulation of Zn in plants has phytotoxic effects that include chlorosis, reduced yields and stunted growth [28] [29]. Pb, which is non-essential for plant growth, has similar phytotoxic effects as Zn when present above acceptable limits. The effects of Pb toxicity on maize plants include reduction in root and plant growth, chlorosis and blackening of roots [16]. A study on heavy metal accumulation in maize at a long-term wastewater irrigation site in China found that Zn accumulated mainly in the fruit while Pb, along with chromium (Cr) and nickel (Ni), accumulated mainly in the roots [18]. This is a probable explanation for the statistically comparable maize shoot Pb concentrations recorded in this study for both experimental treatments (**Table 4**).

According to Marschner [30], the critical toxicity levels of Zn recorded in the leaves of crop plants range between 400 and 500 mg/kg dry weight. The results of this study suggest that the higher shoot Zn concentration in 3-week-old plants grown in the Korle Lagoon Area soil (448.3 ± 45.5 mg/kg) had a limiting effect on shoot growth, which became evident 11 WAP with the significant increase in root-to-shoot ratio (**Table 3**). This phytotoxic effect of Zn on shoot growth has been attributed to reduced P and K uptake [31], which would explain the significant decrease in P and K concentrations in 11-week-old plants harvested from the Korle Lagoon Area soil (**Table 4**). A negative correlation between maize shoot K concentrations and the concentrations of heavy metals, including Zn, supplied to experimental plants has been reported in another study [32].

Studies on the effects of metal toxicity on root characteristics have shown that, generally, Zn toxicity represses root elongation but increases root branching [29] [32] [33]. This would explain the higher root-to-shoot ratio recorded for plants growing in the Korle Lagoon Area soil. The average concentrations of N, P and K in plant shoot dry matter that are sufficient for adequate growth are 1.5, 0.2, and 1%, respectively [30]. It can be argued, therefore, that the mean concentration of P (0.05 ± 0.02 mg/kg) recorded in 11-week-old maize shoots harvested from the Korle Lagoon Area soil was below average. Reference [34] also found a significant increase in the root-to-shoot ratio of maize plants grown under low-P treatment.

Since P and K are important for photosynthesis and carbohydrate transport in plants, their deficiency in the maize shoot would affect grain yield [27]. Besides, excessive transfer of the Zn accumulated in the shoot to the grains would compromise their nutritional quality. The current study focused on the vegetative growth of the maize plants and, hence, no grains were analysed. Comparison of the elemental concentrations in mature maize grain with corresponding shoot and soil concentrations would further elucidate the effects of metal toxicity on plant nutrition and, hence, on the nutritional quality of the food crops produced in the Korle Lagoon Area. This should be considered in future studies.

5. Conclusion

This study has confirmed earlier findings that disposal of sewage and other urban waste into the Korle Lagoon has caused heavy metal contamination as well as plant macronutrient enrichment of the surrounding soils. The plant growth stimulating effects of macronutrient enrichment could increase crop production as indicated by the farmer from whose plot soil was collected for the current study. This positive effect is, however, counteracted by the phytotoxic effects of heavy metals like Zn. Crops grown in the Korle Lagoon Area could, therefore, end up with high concentrations of heavy metals and low concentrations of the essential elements required for plant growth as well as for healthy human and animal diets. Further studies are required to inform decisions regarding their suitability for use as food and fodder.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Monney, I., Boakye, R., Buamah, R., Anyemedu, F.O.K., Odai, S.N. and Awuah, E. (2013) Urbanization and Pollution of Surface Water Resources in the Two Largest Cities in Ghana. *International Journal of Environmental Monitoring and Analysis*, **1**, 279-287. https://doi.org/10.11648/j.ijema.20130106.12

[2] Okertchiri, J.A. (2012) Dying Korle Lagoon. Daily Guide Newspaper.

[3] Boadi, K.O. and Kuitunen, M. (2002) Urban Waste Pollution in the Korle Lagoon,

Accra, Ghana. *The Environmentalist*, **22**, 301-309.
https://doi.org/10.1023/A:1020706728569

[4] Ntajal, J., Höllermann, B., Falkenberg, T., Kistemann, T. and Evers, M. (2022) Water and Health Nexus—Land Use Dynamics, Flooding and Water-Borne Diseases in the Odaw River Basin, Ghana. *Water*, **14**, Article 461.
https://doi.org/10.3390/w14030461

[5] Acheampong, S.M., Ocloo, A., Wutor, C.V. and Adamafio, N.A. (2014) Physico-Chemical Characteristics of Water Samples from Selected Water Bodies in and around Accra, Ghana. *Pollution Research*, **33**, 835-841.

[6] Aglanu, M.L. and Appiah, D.O. (2014) The Korle Lagoon in Distress: The Stress of Urban Solid Waste on Water Bodies in Accra, Ghana. *International Journal of Innovation and Applied Studies*, **7**, 717-728.

[7] Clottey, C.A., Nukpezah, D., Koranteng, S.S. and Darko, D.A. (2021) Assessment of Physicochemical Parameters and Heavy Metals Contamination in Korle and Kpeshie Lagoons, Ghana. *Indo Pacific Journal of Ocean Life*, **6**, 36-50.
https://doi.org/10.13057/oceanlife/o060105

[8] Adomako, E.E.A., Raab, A., Norton, G.J. and Meharg, A.A. (2022) Potential Toxic Element (PTE) Soil Concentrations at an Urban Unregulated Ghanaian E-Waste Recycling Centre: Environmental Contamination, Human Exposure and Policy Implications. *Exposure and Health*. https://doi.org/10.1007/s12403-022-00516-x

[9] Huang, J., Nkrumah, P.N., Anim, D.O. and Mensah, E. (2014) E-Waste Disposal Effects on the Aquatic Environment: Accra, Ghana. In: Whitacre, D., Ed., *Reviews of Environmental Contamination and Toxicology*, Springer, Cham, 19-34.
https://doi.org/10.1007/978-3-319-03777-6_2

[10] Fosu-Mensah, B.Y., Addae, E., Yirenya-Tawiah, D. and Nyame, F. (2017) Heavy Metals Concentration and Distribution in Soils and Vegetation at Korle Lagoon Area in Accra, Ghana. *Cogent Environmental Science*, **3**, Article 1405887.
https://doi.org/10.1080/23311843.2017.1405887

[11] Davies, B.E. (1995) Lead. In: Alloway, B.J., Ed., *Heavy Metals in Soils* (2*nd Edition*), Blackie, London, 177-198.

[12] Nixon, S.W., Buckley, B.A., Granger, S.L., Entsua-Mensah, M., Ansa-Asare, O., White, J.M., McKinney, R.A. and Mensah, E. (2007) Anthropogenic Enrichment and Nutrients in Some Tropical Lagoons of Ghana, West Africa. *Ecological Applications*, **17**, S144-S164. https://doi.org/10.1890/05-0684.1

[13] DCCEEW: Department of Climate Change, Energy, the Environment and Water (2022) Total Phosphorus. Factsheet of the Australian Government Department of Climate Change, Energy, the Environment and Water.
https://www.dcceew.gov.au/environment/protection/npi/substances/fact-sheets/total-phosphorus

[14] World Health Organization (2011) Guidelines for Drinking-Water Quality. Geneva.

[15] World Health Organization (2003) Ammonia in Drinking-Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality. Geneva.

[16] Abedi, T., Gavanji, S. and Mojiri, A. (2022) Lead and Zinc Uptake and Toxicity in Maize and Their Management. *Plants*, **11**, Article 1922.
https://doi.org/10.3390/plants11151922

[17] Brennan, M.A. and Shelley, M.L. (1999) A Model of the Uptake, Translocation, and Accumulation of Lead (Pb) by Maize for the Purpose of Phytoextraction. *Ecological*

Engineering, **12**, 271-297. https://doi.org/10.1016/S0925-8574(98)00073-1

[18] Lu, Y.T., Yao, H., Shan, D., Jiang, Y.C., Zhang, S.C. and Yang, J. (2015) Heavy Metal Residues in Soil and Accumulation in Maize at Long-Term Wastewater Irrigation Area in Tongliao, China. *Journal of Chemistry*, **2015**, Article ID: 628280. https://doi.org/10.1155/2015/628280

[19] Van Reeuwijk, L.P. (2002) Procedures for Soil Analysis. 6th Edition, International Soil Reference and Information Center, Wageningen.

[20] Bremner, J.M. (1960) Determination of Nitrogen in Soil by the Kjeldahl Method. *Journal of Agricultural Sciences*, **55**, 11-33. https://doi.org/10.1017/S0021859600021572

[21] Olsen, S.R. and Sommers, L.E. (1982) Phosphorus. In: Page, A.L., Ed., *Methods of Soil Analysis*, *Part* 2: *Chemical and Microbiological Properties* (2*nd Edition*), American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, 403-430. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

[22] The Perkin-Elmer Corporation (1996) Analytical Methods for Atomic Absorption Spectroscopy. http://www1.lasalle.edu/~prushan/Intrumental%20Analysis_files/AA-Perkin%20Elmer%20guide%20to%20all!.pdf

[23] Novozamsky, I., Houba, V.J.G., van Eck, R. and van Vark, W. (1983) A Novel Digestion Technique for Multi-Element Plant Analysis. *Communications in Soil Science and Plant Analysis*, **14**, 239-248. https://doi.org/10.1080/00103628309367359

[24] Kiekens, L. (1995) Zinc. In: Alloway, B.J., Ed., *Heavy Metals in Soils* (2*nd Edition*), Blackie, London, 284-305.

[25] Russell, E.W. (1973) Soil Conditions and Plant Growth. 10th Edition, Longman, London and New York.

[26] Uchida, R. (2000) Essential Nutrients for Plant Growth: Nutrient Functions and Deficiency Symptoms. In: Silva, J.A. and Uchida, R., Eds., *Plant Nutrition Management in Hawaii's Soils*, *Approaches for Tropical and Subtropical Agriculture*, College of Tropical Agriculture and Human Resources, University of Hawaii, Manoa, 31-55.

[27] Wang, C. and Ning, P. (2019) Post-Silking Phosphorus Recycling and Carbon Partitioning in Maize under Low to High Phosphorus Inputs and Their Effects on Grain Yield. *Frontiers in Plant Science*, **10**, Article 784. https://doi.org/10.3389/fpls.2019.00784

[28] Broadley, M.R., White, P.J., Hammond, J.P., Zelko, I. and Lux, A. (2007) Zinc in Plants. *New Phytologist*, **173**, 677-702. https://doi.org/10.1111/j.1469-8137.2007.01996.x

[29] Rout, G.R. and Das, P. (2003) Effect of Metal Toxicity on Plant Growth and Metabolism: I. Zinc. *Agronomie*, **23**, 3-11. https://doi.org/10.1051/agro:2002073

[30] Marschner, H. (1986) Mineral Nutrition of Higher Plants. Academic Press Limited, London.

[31] Shetty, K.G., Hetrick, B.A.D. and Schwab, A.P. (1995) Effects of Mycorrhizae and Fertilizer Amendments on Zinc Tolerance of Plants. *Environmental Pollution*, **88**, 307-314. https://doi.org/10.1016/0269-7491(95)93444-5

[32] Romdhane, L., Panozzo, A., Radhouane, L., Dal Cortivo, C., Barion, G. and Vamerali, T. (2021) Root Characteristics and Metal Uptake of Maize (*Zea mays* L.) under Extreme Soil Contamination. *Agronomy*, **11**, Article 178. https://doi.org/10.3390/agronomy11010178

[33] Balafrej, H., Bogusz, D., Triqui, Z.A., Guedira, A., Bendaou, N., Smouni, A. and Fahr, M. (2020) Zinc Hyperaccumulation in Plants: A Review. *Plants*, **9**, Article 562. https://doi.org/10.3390/plants9050562

[34] Xia, Z., Zhang, S., Wang, Q., Zhang, G., Fu, Y. and Lu, H. (2021) Effects of Root Zone Warming on Maize Seedling Growth and Photosynthetic Characteristics Under Different Phosphorus Levels. *Frontiers in Plant Science*, **12**, Article 746152. https://doi.org/10.3389/fpls.2021.746152