Journals Pub

International Journal of
Agro Chemistry

ISSN: 2456-7000
Volume 11, Issue 2, 2025
July–December
DOI (Journal): 10.37628/IJA

https://chemical.journalspub.info/index.php?journal=IJCPD

Research IJA

Implications of Asphalt Plant Discharge Water on Agro-Morphological Parameters and Photosynthetic Processes of Edible Vegetables

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Abstract

Untreated industrial waste discharges emitted into the environment have a negative impact on all components of the ecosystem, especially the soil properties. The aim of the study is to evaluate the effects of heavy metal concentrations present in asphalt plant discharges on the soil properties, photosynthetic activities and agro-morphology of the vegetable plants. Soil samples used for the experiment were collected from Federal University of Technology Owerri Botanical Garden. The physicochemical properties of the soils were determined and the heavy metal (Zn, Fe, Cu, Pb, Cr, Cd, Ni, Hg and As) concentrations in the soils were analyzed using Atomic Absorption Spectrophotometer. The seeds of Corchorus olitorius, Telfairia occidentalis and Solanun macrocarpon were grown in screen house with 3 kg of the soils in polythene bags. The control was watered with tap water (350 m/L) while treatment was watered with (100% of 350 m/L) asphalt plant discharge water three times a week for a duration of 20 weeks. Five sterilized seeds were grown in each polythene bag replicated five times. The polythene bags were laid out in a completely randomized experimental design. The results showed that asphalt plant discharge water had effects on the soil's physicochemical parameters, agro-morphology and photosynthesis based on the treatments from different study locations. The parameters of the treatments measured were significantly difference ($P < 0.05$) from the control. Generally, the asphalt plant discharged water altered the soil physicochemical properties, caused reduction in the agro-morphological parameters as well as photosynthesis. Therefore, there is a need to properly treat industrial discharges before emission into the environment.

Keywords: Asphalt plant discharges, emissions, agro-morphology, vegetables, soils

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Received Date: June 29, 2025
Received Date: July 04, 2025
Published Date: July 20, 2025

Citation: Akpovbovbo D. P., Duru C. M., Abara P. N., Ukaoma A. A., Nwachukwu M. O., Engeronu U. U., Obi U. D., Ude P. C. Implications of Asphalt Plant Discharge Water on Agro-Morphological Parameters and Photosynthetic Processes of Edible Vegetables. International Journal of Agro Chemistry. 2025; 11(2): 1–20p.

INTRODUCTION

Over time, industrial activities, such as asphalt plant productions have led to a greater quantity of heavy metals in the soil [1–2]. The elements that have specific gravity are 5 times greater than water can be referred to as heavy metals. Heavy metals are non-biodegradable with negative impact on plant growth and development [3]. Bitumen is one of the most important components of asphalt mixture. It is a by-product of crude oil distillation [4], with a high molecular weight hydrocarbon [5]. The heating of bitumen at a very high temperature (>170°C) during asphalt production process releases numerous heavy metals, such as manganese, nickel, mercury, chromium, lead, cadmium, copper, zinc, etc. in the air, soil, and nearby water bodies with the soil being the most

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important sink for all emitted pollutants [6]. This in turn accumulates in the soil with successive high dosages of heavy metal concentrations being absorbed and accumulated by plant tissues [7].

Plants are usually sessile in nature and the roots that are usually in contact with the soils accumulate heavy metals in the plant tissues that may directly or indirectly interferes with several biochemical, morphological, physiological functions, and productivity of the plants [8]. However, some of these heavy metals are important micronutrients and are required at low concentrations. Examples are manganese, zinc, chromium, copper, iron, and nickel. They are required in small quantity in different metabolic functions, activities of enzymes, protein transport, and hormonal functions at specific concentrations in plants and animals [9]. However, high concentrations above the permissible limit of the World Health Organization standards may lead to toxicity effects [10]. The second category of the heavy metals are the non-essential metals, which include lead, cadmium, mercury, and arsenic, with no identity of significant roles being played in living organisms, such as plants, animals, and humans, and may even be toxic to humans and plants in small doses [11].

In our contemporary world, soil pollution by heavy metals is increasing and it is a major challenge confronting sustainable agriculture, soil health, and food insecurity [12], because of its negative effects on crop growth and productivity. Its toxic effects interfere with seed germination and plant growth resulting in a general decline in growth [13]. Furthermore, exposure of seeds to lead and cadmium has resulted in delays in germination time as well as retardation of seedling growth [14]. Heavy metals can decrease plant height, root length, number of leaves, stem diameter, and biomass production [13–14]. Also, the exposure of hemp plants to heavy metals has been observed to cause a reduction in stomata conductance [15].

According to Hu et al. (2023) [16], stomata is one of the plant organs that is more susceptible to the effects of heavy metals and can interfere with chloroplast functions as well as light and dark reaction. Cadmium can interrupt with the integrity of the chloroplast membrane, the thylakoids and grana [16].

Production of crops is reduced by heavy metals through different physiological functions, such as reduced plant height, root length, number of lateral roots, leaves, and photosynthesis [17]. Therefore, the aim of this study is to investigate the implications of asphalt plant discharge water on agro-morphological parameters and photosynthetic processes of edible vegetables.

MATERIALS AND METHODS

Study Area

The study was carried out over twenty weeks from September 2023 to January 2024 in the screen house of the Department of Biology at the Federal University of Technology, Owerri (FUTO), located in Imo State, Nigeria (latitude 5°23'11.76"N, longitude 6°59'29.76"E). During the study period, the temperature within the screen house fluctuated between 36°C and 40°C.

Samples Collection

Collection of Asphalt plant discharge water

Asphalt plant discharge water was collected from the asphalt plants in T2 (Irete, Imo State), T3 (Umuahia Abia State), and T4 (Elele, Rivers State) using the downward displacement method. It consists of a hollow iron pipe. The top is connected to a funnel, which was suspended in the chimney of the asphalt plant to collect discharges during emission, while the bottom of the hollow pipe is suspended in 18 liters of water. The high speed through which the discharges are emitted passes through the hollow pipes and dissolved in the water which was collected and refrigerated for further use.

Collection of Soil Samples and Screen House Experiment

The soil samples used were collected from Federal University of Technology Botanical Garden at a depth of 0–15 and 15–30cm using soil auger and the soil sample were mixed to form homogenized

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sample. The selected vegetable crops that were used for the experiment, which represents the experimental units, were *Corchorus olitorius, Telfairia occidentalis* and *Solanun macrocarpon*.

The vegetable seeds were grown in screen houses with 3 kg of soil in a polythene bag of diameter (10 x 18 cm). The control was watered with tap water (350 m/L), while treatment was watered with (100% of 350 m/L) asphalt plant discharged water three times a week for a duration of 20 weeks. Before planting, the seeds were surfaced sterilized with 5 % sodium hydroponic (NaClO) for 15 minutes and then rinse with deionized water for three times. Five sterilized seeds were grown in each polythene bag replicated five times. The polythene bags were laid out in a completely randomized experimental design.

Soil Samples Analysis

The physicochemical characteristics of the soils were determined before and after cultivation using standard methods. Soil pH, organic carbon, nitrogen, and phosphorus were measured according to the method described by Qi et al. (2020) [18]. The cation exchange capacity (CEC) of the soil was assessed via KCl extraction and titration, following the method of Maclean R. (1965) [19]. Electrical conductivity was measured using a Corning model 230HT conductivity meter.

For heavy metals determination, 1 g of soil sample each from the control and treatments were digested in 10 ml of 1:1 HNO_3 and it was heated to 95°C to dry and thereafter, it was refluxed for 10 minutes without boiling. 5 ml of concentrated HNO_3 was continuously added until white fumes appeared. The solution was vaporized on the Mantle Set at 95°C with a wash glass over it. After cooling the solution, 2 ml of H_2O, and 3 ml of 30% H_2O_2 were added to it solution and the solution was placed on heating mantle to start the oxidation of peroxide. The acid-peroxide digestate was heated to about 5 ml at 95°C. 10 ml of concentrated HCL was added to the sample and placed on the heating source and refluxed for 15 minutes at 95°C. The digestate was filtered and the filtrate was collected for heavy metals analysis using Atomic Absorption Spectrophotometer (AAS, Perkin Elmer 2380) [20]. Heavy metals that were analyzed are manganese, copper, nickel, zinc, chromium, arsenic, mercury, cadmium and lead.

Digestion of Vegetables Samples and Heavy Metals Analysis

The samples of vegetable leaves collected from the study area were thoroughly washed with distilled water followed by a 1% hydrochloric acid solution to remove the surface contaminants and then dried**.** The dried samples were finely ground into powder and stored in clean, well-sealed containers. A representative portion of 1 g of sieved leaf samples were weighed into 100 cm^3 beaker and soaked with nitric acid overnight. The vegetable was heated and digested with mixture of nitric acid and perchloric acid solution (4:1) on an electric heating plate until white smoke appeared. The mixture was then cool. The resulting filtration was further diluted using 50 mL of deionized water [21]. Heavy metals (Mn, Cu, Ni, Zn, and Cr, As, Hg, Cd, and Pb) were analyzed using Atomic Absorption Spectrophotometer (AAS, Perkin Elmer 2380).

Evaluation of Heavy Metals on Total Chlorophyll Concentrations

Leaf samples were extracted using 80% acetone following the method described by Liang et al. (2017) [22] and the chlorophyll content was determined every two weeks interval for a duration of 20 weeks using spectrophotometry. Approximately 1 g of fresh leaves were homogenized at room temperature with a laboratory blender and then centrifuged for 5 minutes in a 1.5 mL tube containing 1 mL of 80% acetone. The absorbance of the resulting supernatant was recorded at 646 nm and 663 nm (A_{646} and A_{663}) using a double-beam spectrophotometer. If absorbance values exceeded one, the samples were diluted with an equal volume of 80% acetone and remeasured. The chlorophyll concentration was determined using the following equations.

$$\text{Chlorophyll a } (\mu g/mL) = (-1.93 \times A_{646}) + (11.93 \times A_{663}) \quad (1)$$

$$\text{Chlorophyll b } (\mu g/mL) = (20.36 \times A_{646}) - (5.50 \times A_{663}) \quad (2)$$

$$\text{Total chlorophyll } (\mu g/mL) = (6.43 \times A_{663}) + (18.43 \times A_{646}) \quad (3)$$

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Phytotoxicity Assessment on Agromorphological Parameters of the Vegetable Plants

The number of leaves were counted manually on weekly basis for a period of 20 weeks [12]. Plant heights were measured with ruler graduated in centimeter (cm) starting from the surface of the soil to the terminal bud of the plant in a period of 20 weeks [22–23]. The measurement of root colar index was taken with the aid of vernier caliper [24]. Petiole length was measured with a straight meter rule graduated in centimeter (cm) from the base of each leaf lamina to the point in which petiole attaches to the main stem [24]. The internode which is mainly the length between two nodes was taken with straight meter rule in centimeter [24].

Statistical Analysis

Data analysis was carried out using analysis of variance (ANOVA) and the least significant difference (LSD) was used to determine the significant difference between means at $P < 0.05$.

RESULTS

Physicochemical Properties of Soil Samples

The result of the soil analysis before and after planting vegetables in the soil is shown in Table 1 below. The result indicated that the soils polluted by asphalt plant discharge water showed significant differences ($P < 0.05$) in their physical and chemical properties.

Sand: From the result of the study, there were significant differences ($P < 0.05$) in the mean concentration of sand before pollution and after pollution indicating the effects of asphalts plant discharge water on soils after pollution. The mean sand value recorded in T2 treatment was T2A (70.18 ± 0.01), T2B (69.23 ± 0.07), and T2C (68.88 ± 0.01 mg/kg). T3 treatment had a mean concentration of T3A (65.89 ± 0.00 mg/kg), T3B (74.27 ± 0.02 mg/kg), and T3C (66.87 ± 0.03 mg/kg). While T4 treatment recorded a mean concentration of T4A (67.38 ± 0.00 mg/kg), T4B (62.88 ± 0.01 mg/kg), and T4C (65.66 ± 0.02 mg/kg), respectively. The mean concentration of the control before planting the vegetables is (73.52 ± 0.01). T3B (74.27 ± 0.02) recorded a higher value of sand content as well as the control (73.52 ± 0.01), which indicate sandy soil. Generally, T4 treatment consistently had the lowest sand content across the soil samples with T4B showing the lowest value of (62.88 ± 0.01). This indicates that the soils polluted with asphalt plant discharge water from T4 treatment may have more clay content that may affect the drainage pattern, waterlogging, and poor aeration capacity when compared with the control soil.

Silt: The mean concentration of silt varies across the soils, and they are significantly different at ($P < 0.05$), except T2A and T2C that were not significantly different from the control. The mean value of silt recorded in T2A, T2B, and T2C treatments are 5.37 ± 0.25 mg/kg, 3.48 ± 0.02 mg/kg, and 5.42 ± 0.01 mg/kg, respectively. The mean values of T3A, T3B, and T3C are 6.27 ± 0.21 mg/kg, 4.22 ± 0.03 mg/kg, and 4.82 ± 0.29 mg/kg while T4A, T4B, T4C recorded the value of 6.37 ± 0.03 mg/kg, 5.89 ± 0.01 mg/kg, and 5.94 ± 0.03 mg/kg. The control obtained a value of 2.37 ± 0.01 mg/kg which is lowest. T4A recorded the highest mean value of 6.27 ± 0.21 mg/kg.

The clay content was significantly different ($P < 0.05$) in the polluted soil and the unpolluted soil (control). T3A shows a very high clay concentration of (74.27 ± 0.03 mg/kg), which reveals heavy clay soils that can significantly affect root growth due to waterlogging, poor drainage, and soil aeration. T3B and T3C had a mean concentration of 21.50 ± 0.01 mg/kg and 24.14 ± 0.03 mg/kg, respectively. T4B recorded the highest mean concentration of 31.22 ± 0.02 mg/kg that gradually decreases in concentration in T4A (26.27 ± 0.02) and T4C (25.01 ± 0.02 mg/kg). The clay content in T2A, T2B, and T2C is 24.42 ± 0.03 mg/kg, 27.32 ± 0.01 mg/kg, and 26.10 ± 0.10 mg/kg, respectively, while the control soil had a moderate clay content of 9.42 ± 0.2 mg/kg, indicating a loamy texture.

The pH measures the level of acidity and alkalinity in soil. The pH was significantly different ($P < 0.05$) across all treatments. However, (T2A and T2B), (T3A and T4A), and (T3B and T4B) were not significantly different ($P > 0.05$) from one another. Lower pH levels enhanced the solubility of toxic

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heavy metals and uptake thereby affecting plant growth and development [25]. From across all the treatments, the pH values range from (6.30 ± 0.05 to 7.10 ± 0.06 mg/kg). The mean concentrations of T2 treatment are T2A (6.51 ± 0.01 mg/kg), T2B (6.49 ± 0.02 mg/kg), and T2C (6.47 ± 0.04 mg/kg), indicating that the soil was slightly acidic. T3 treatment soils had a mean concentration value as follows T3A (6.30 ± 0.05 mg/kg), T3B (6.47 ± 0.01 mg/kg), and T3C (6.32 ± 0.01 mg/kg), which reveals that the soil was slightly acidic. T4 Treatment obtained a mean value of T4A (6.44 ± 0.02 mg/kg), T4B (6.52 ± 0.01 mg/kg), and T4C (6.37 ± 0.01 mg/kg), which shows slightly acidic condition. Meanwhile, the control recorded a mean concentration of 7.10 ± 0.06 mg/kg indicating a neutral soil.

The mean bulk density values for soil samples from the three treatments (T2, T3, and T4) vary from one another. The bulk density of all the locations was significantly different ($P < 0.05$) from the control. T2 treatment had a mean value of T2A (1.77 ± 0.02 mg/kg), T2B (1.04 ± 0.06 mg/kg), and T2C (1.17 ± 0.06 mg/kg). The mean value of T2B and T2C was low when compared with the control, which may result in soil compaction. T3 treatment had a mean concentration of T3A (1.34 ± 0.02 mg/kg), T3B (1.13 ± 0.02 mg/kg), and T3C (1.29 ± 0.02 mg/kg). The mean values from T3 were low in comparison with the control. In the same manner, T4 treatment recorded a low mean value of T4A (1.27 ± 0.06 mg/kg), T4B (1.28 ± 0.01 mg/kg), and T4C (1.18 ± 0.01 mg/kg). This condition may reduce the movement of water in the soil pore.

Table 1. Physicochemical properties of soil before and after planting vegetables.

Parameters	Control soil	Vegetables Grown in Soil Polluted with Asphalt Plant Discharge Water								
		T2A	**T2B**	**T2C**	**T3A**	**T3B**	**T3C**	**T4A**	**T4B**	**T4C**
Loc.	Futo	Irete (Imo)	Irete (Imo)	Irete (Imo)	Umuahia (Abia)	Umuahia (Abia)	Umuahia (Abia)	Elele (Rivers)	Elele (Rivers)	Elele (Rivers)
Sand	73.52 ± 0.01^{b}	70.18 ± 0.01^{c}	69.23 ± 0.07^{d}	68.88 ± 0.01^{e}	65.89 ± 0.00^{h}	74.27 ± 0.02^{a}	66.87 ± 0.03^{g}	67.38 ± 0.00^{f}	62.88 ± 0.01^{j}	65.66 ± 0.02^{i}
Silt	2.37 ± 0.01i	5.37 ± 0.25^{e}	3.48 ± 0.02^{h}	5.42 ± 0.01^{e}	6.27 ± 0.21^{a}	4.22 ± 0.03^{g}	4.82 ± 0.29^{f}	6.37 ± 0.03^{b}	5.89 ± 0.01^{d}	5.94 ± 0.03^{c}
Clay	19.42 ± 0.2j	24.42 ± 0.03^{e}	27.32 ± 0.01^{c}	26.10 ± 0.10^{d}	74.27 ± 0.03^{a}	21.50 ± 0.01^{h}	24.14 ± 0.03^{f}	26.27 ± 0.02^{g}	31.22 ± 0.02^{b}	25.01 ± 0.02^{d}
pH	7.10 ± 0.06^{a}	6.51 ± 0.01^{b}	6.49 ± 0.02^{b}	6.47 ± 0.04^{b}	6.30 ± 0.05^{bc}	6.47 ± 0.01^{b}	6.32 ± 0.01^{cd}	6.44 ± 0.02^{bc}	6.52 ± 0.01^{b}	6.37 ± 0.01^{cd}
BD	1.49 ± 0.1^{b}	1.77 ± 0.02^{a}	1.04 ± 0.06^{h}	1.17 ± 0.06^{f}	1.34 ± 0.02^{c}	1.13 ± 0.02^{g}	1.29 ± 0.02^{d}	1.27 ± 0.06^{e}	1.28 ± 0.01^{d}	1.18 ± 0.01^{f}
OC	0.72 ± 0.01f	0.55 ± 0.02c	0.49 ± 0.01b	0.50 ± 0.01b	0.45 ± 0.01a	0.56 ± 0.02c	0.52 ± 0.01b	0.60 ± 0.01d	0.67 ± 0.01e	0.62 ± 0.03d
N	1.71 ± 0.18^{a}	1.70 ± 0.15^{c}	0.50 ± 0.01^{ab}	0.50 ± 0.01^{ab}	1.50 ± 0.12^{c}	1.50 ± 0.12^{c}	1.68 ± 0.1^{c}	0.60 ± 0.01^{ab}	0.67 ± 0.01^{b}	2.54 ± 0.02^{d}
P	14.32 ± 0.02^{j}	3.70 ± 0.01^{i}	3.48 ± 0.01^{e}	3.60 ± 0.01^{h}	2.92 ± 0.01^{d}	2.51 ± 0.01^{a}	2.89 ± 0.02^{c}	3.51 ± 0.01^{f}	2.73 ± 0.01^{b}	3.52 ± 0.01^{g}
K	0.11 ± 0.06^{d}	0.05 ± 0.02^{c}	0.04 ± 0.01^{c}	0.05 ± 0.01^{c}	0.04 ± 0.01^{c}	0.03 ± 0.01^{b}	0.05 ± 0.02^{c}	0.03 ± 0.01^{ab}	0.02 ± 0.01^{a}	0.02 ± 0.01^{ab}
EC	0.73 ± 0.01^{a}	89.22 ± 0.01^{d}	46.29 ± 0.05^{i}	90.11 ± 0.01^{e}	104.78 ± 0.01^{h}	94.40 ± 0.04^{f}	87.78 ± 0.01^{c}	95.32 ± 0.01^{g}	90.28 ± 0.01^{e}	87.33 ± 0.02^{b}
CEC	1.56 ± 0.01^{d}	0.28 ± 0.01^{a}	0.30 ± 0.05^{ab}	0.40 ± 0.05^{c}	0.35 ± 0.02^{abc}	0.31 ± 0.01^{ab}	0.32 ± 0.06^{abc}	0.35 ± 0.01b^{c}	0.29 ± 0.02ab	0.34 ± 0.02^{ab}

Note: Mean ± SE along the row having different superscript of alphabets differ significantly at ($P < 0.05$) level.

Legend: Loc= Location (Irete -Imo State) T2A= Soil (*Corchorus olitorius*)*;* T2B = Soil (*Solanum macrocarpon*)*;* T2C = Soil (*Teifaria occidentalis*).

Loc = Location (Umuahia Abia State) T3A = Soil (*Corchorus olitorius*); T3B = Soil (*Solanum macrocarpon)*; T3C = Soil (*Teifaria occidentalis)*

Loc = Location (Elele Rivers State) T4A = Soil (*Corchorus olitorius);* T4B = Soil (*Solanum macrocarpon)*; T4C = Soil (*Teifaria occidentalis).*

BD = Bulk density; OC = Organic carbon; N = Nitrogen; P = Phosphorus; K = Potassium; EC = Electrical conductivity; CEC = Cation exchange capacity.

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There were significant differences ($P < 0.05$) in the mean concentrations of organic carbon between the control and the treatments. The mean concentration of organic carbon in T2A, T2B, and T3C are 0.55 ± 0.02 mg/kg, 0.49 ± 0.01 mg/kg, and 0.50 ± 0.01 mg/kg, respectively. In addition, T3A, T3B, and T3C recorded a mean value of 0.45 ± 0.01 mg/kg, 0.56 ± 0.02 mg/kg, and 0.52 ± 0.01 mg/kg, while T4A, T4B, and T4C obtained a value of 0.60 ± 0.01 mg/kg, 0.67 ± 0.01 mg/kg, and 0.62 ± 0.03 mg/kg, respectively, while the control had a mean value of 0.72 ± 0.01 mg/kg. Nitrogen is one of the most essential nutrients required by plants for normal growth and productivity. About 80 % of the atmosphere consists of nitrogen gas and 98% of nitrogen in soils is in organic form which cannot be used directly by plants, rather they take in other forms of nitrogen like nitrate and ammonia. The control was not significantly different ($P > 0.05$) from T2B, T2C, and T3A but showed a significant difference ($P < 0.05$) with other treatments. The mean concentration of nitrogen is T2A (1.70 ± 0.15 mg/kg), T2B (0.50 ± 0.01 mg/kg), and T2C (0.50 ± 0.01 mg/kg). Among the studied soil, T3 treatment recorded the overall higher nitrogen concentration with T3A (1.50 ± 0.12 mg/kg), T3B (1.50 ± 0.12 mg/kg), and T3C (1.68 ± 0.1 mg/kg), when compared with T2 and T4 treatments. Furthermore, the mean value of T4A is (0.60 ± 0.01 mg/kg), T4B (0.67 ± 0.01 mg/kg), and T4C (2.54 ± 0.02 mg/kg), while the control showed a mean concentration of (1.71 ± 0.18 mg/kg). The elevated nitrogen levels encountered in T4C (2.54 ± 0.02 mg/kg) can promote rapid leaf growth at the expense of fruit or flower production. On the other hand, T2 studied soil had lower nitrogen levels which indicate that the asphalt plant discharge affected the soils.

There were significant differences ($p < 0.05$) in the mean concentration of phosphorus between the treatments and control. However, the control was not significantly difference from T24, T2C, and T3BC at 5% probability level. The mean concentration of the control soil was (14.32 ± 0.02 mg/kg) suggesting a fertile soil that can support root and flower development. The mean concentration obtained in T2 treatments were T2A (3.70 ± 0.01 mg/kg), T2B (3.48 ± 0.01) and T2C (3.60 ± 0.01 mg/kg). There is a decrease in the mean concentrations recorded in T2 treatments when compared with the control. Similarly, low concentration values were detected in T3 treatments. The mean concentration recorded in T3 treatments were T3A (2.92 ± 0.01 mg/kg), T3B (2.51 ± 0.01 mg/kg) and T3C (2.89 ± 0.02 mg/kg), while T4 treatment obtained a mean value of T4A (3.51 ± 0.01 mg/kg), T4B (2.73 ± 0.01 mg/kg) and T4C (3.52 ± 0.01 mg/kg).

From the result analysis, there were significant differences at ($P < 0.05$) in the mean value of potassium between the control and treatments. T4 treatments recorded the lowest mean concentration of potassium with T4A (0.03 ± 0.01 mg/kg), T4B (0.02 ± 0.01 mg/kg), and T4C (0.02 ± 0.01 mg/kg) followed by T3 treatments with a mean potassium value of T3A (0.04 ± 0.01 mg/kg), T3B (0.03 ± 0.01 mg/kg), and T3C (0.05 ± 0.02 mg/kg), while T2 treatments recorded the highest potassium content of T2A (0.05 ± 0.02 mg/kg), T2B (0.04 ± 0.01 mg/kg), and T2C (0.05 ± 0.01 mg/kg) while the control mean concentration was (0.11 ± 0.06 mg/kg).

The electrical conductivity (EC) ranged from 0.73 ± 0.01 to 104.78 ± 0.01 with the control emerging with the lowest mean concentration while T3A (104.78 ± 0.01) was the highest. The observed mean showed that there was significant difference ($p < 0.05$) between the control and the treatments (T2, T3, and T4). In General, T3 treatments had the highest mean values of T3A (104.78 ± 0.01), T3B (94.40 ± 0.04), and T3C (87.78 ± 0.01), next is T4 treatments with a mean value of T4A (95.32 ± 0.01), T4B (90.28 ± 0.01), and T4C (87.33 ± 0.02). The least was T2 with a mean concentration value of T2A (89.22 ± 0.01), T2B (46.29 ± 0.05), and (90.11 ± 0.01). The mean value of cation exchange capacity (CEC) ranges from (1.56 ± 0.01 to 0.28 ± 0.01 mg/kg), with the control having the highest mean concentration, while T2A recorded the lowest mean value. There were significant differences ($p < 0.05$) between the control and the treatments. The control soil has the highest CEC (1.56 mg/kg), indicating good nutrient retention capabilities. Meanwhile T2, T3, and T4 treatments showed much lower CEC values in the range of 0.28 ± 0.01 to 0.40 ± 0.05 mg/kg which may result in poor nutrient retention in the polluted soils. This could limit plant nutrient uptake, leading to nutrient deficiencies. The increased electrical conductivity and reduced cation exchange capacity in the polluted soils suggest that the pollutants have impacted soil health by increasing salinity and reducing nutrient retention.

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Heavy Metal Concentrations of the Soil Samples Before and After Planting

The result of heavy metals concentrations recorded in the soils samples before and after planting is presented in Table 2.

Table 2. Heavy metal contents soil before and after planting vegetables on soils.

Parameters	Control Soil	Vegetables Grown in Soil Pollute with Asphalt Plant Discharge Water								
		T2A	T2B	T2C	T3A	T3B	T3C	T4A	T4B	T4C
Zinc	47.53 ± 0.12j	9.78 ± 0.01f	6.78 ± 0.01b	10.12 ± 0.03g	4.28 ± 0.01a	7.19 ± 0.03c	8.46 ± 0.02d	10.43 ± 0.05h	11.08 ± 0.05i	9.32 ± 0.01e
Iron	2.60 ± 0.05f	1.28 ± 0.02a	2.09 ± 0.01cd	2.11 ± 0.03d	1.94 ± 0.05c	2.45 ± 0.06e	1.98 ± 0.04cd	1.78 ± 0.05b	2.05 ± 0.05cd	1.30 ± 0.02a
Copper	0.00 ± 0.00a	0.065 ± 0.02e	0.029 ± 0.01c	0.067 ± 0.03e	0.017 ± 0.01b	0.047 ± 0.02d	0.043 ± 0.03d	0.022 ± 0.01bc	0.200 ± 0.02f	0.024 ± 0.01c
Lead	0.00 ± 0.00a	0.034 ± 0.02bc	0.012 ± 0.01abc	0.014 ± 0.02abc	0.008 ± 0.01ab	0.013 ± 0.03abc	0.010 ± 0.01ab	0.019 ± 0.01abc	0.004 ± 0.01ab	0.040 ± 0.02c
Chromium	0.00 ± 00a	0.012 ± 0.01ab	0.041 ± 0.03b	0.037 ± 0.03ab	0.003 ± 0.01ab	0.009 ± 0.02ab	0.006 ± 0.01ab	0.005 ± 0.01ab	0.020 ± 0.02ab	0.006 ± 0.01ab
Cadmium	0.00 ± 00a	0.013 ± 0.03d	0.046 ± 0.04e	0.016 ± 0.02d	0.014 ± 0.01d	0.043 ± 0.04e	0.051 ± 0.05f	0.004 ± 0.01b	0.057 ± 0.05g	0.009 ± 0.01c
Nickel	0.00 ± 0.00a	0.000 ± 0.00a	0.000 ± 0.00a	0.000 ± 0.00c	0.007 ± 0.02a	0.000 ± 0.00d	0.011 ± 0.03cd	0.006 ± 0.02a	0.000 ± 0.00bc	0.008 ± 0.03bc
Mercury	0.0=0 ± 0.00a	0.000 ± 0.00a	0.007 ± 0.01b	0.007 ± 0.01b	0.008 ± 0.02b	0.006 ± 0.01b	0.008 ± 0.04b	0.007 ± 0.02b	0.008 ± 0.03b	0.009 ± 0.03b
Arsenic	0.00 ± 0.00a	0.000 ± 0.00a	0.000 ± 0.00a	0.000 ± 0.00b	0.000 ± 0.00a	0.000 ± 0.00a	0.000 ± 0.00a	0.001 ± 0.00a	0.000 ± 0.00a	0.002 ± 0.00a

Note: Mean ± SE along the row having different superscript of alphabets differ significantly at (P <0.05) level.
Legend: Loc = Location (Irete-Imo State) T2A = Soil (*Corchorus olitorius*); T2B = Soil (*Solanum macrocarpon*); T2C = Soil (*Telfairia occidentalis*).
Loc = Location (Umuahia Abia State) T3A = Soil (*Corchorus olitorius*); T3B = Soil (*Solanum macrocarpon*); T3C = Soil (*Telfairia occidentalis*).
Loc = Location (Elele Rivers State) T4A = Soil (*Corchorus olitorius*); T4B = Soil (*Solanum macrocarpon*); T4C = Soil (*Telfairia occidentalis*).

Zinc (Zn): Based on the heavy metals analyzed, zinc showed the highest concentrations in all the soil samples analyzed, and the control soil was significantly different ($P < 0.05$) from the treatments. The mean concentration of zinc from the control was the highest with a total of 47.5 mg/kg, while the lowest mean concentration was found in T3A treatment which obtained a value of 4.78 mg/kg. The overall total obtained from all the heavy metals analyzed showed that zinc was the most abundant element with a total value of 77.44 mg/kg.

Iron (Fe): The concentration of iron in the analyzed soils from (T2A, T2B, T3C), (T3A, T3B, T3C), and (T4A, T4B, T4C) were found to be in the range of 1.28–2.6 mg/kg. There were significant differences (<0.05) in the mean concentration between the control and the polluted soils. The control showed the highest mean value of 2.60 mg/kg, while T2A showed the lowest mean concentration of 1.28 mg/kg. The increased mean concentrations of iron in the control soils samples may be due to high concentration of organic matter in the soil samples. Iron is the second most prevalent element obtained from all soil samples.

Copper (Cu): The concentrations of copper in the soil samples were in the range of 0.017–0.2 mg/kg. The mean copper concentration in the control was significantly different ($P < 0.05$) from all the treatments. The highest mean concentration was obtained from T4B and the lowest from T3A. Meanwhile, copper was not detected in the control and it is the 3rd most abundant element encountered in the soil samples.

Lead (Pb): The concentration of lead in the control was significantly different ($P < 0.05$) from the treatments. However, some of the treatments were not significantly different ($P > 0.05$) in the mean

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concentrations. The concentration of lead in the soil samples range between 0.004 and 0.01 mg/kg. The least concentration of lead was found in soil sample of T4B, while the highest concentration in T3C. Lead is the 5th most abundant element detected in the soil samples. Lead was not detected in control.

Chromium (Cr): The concentration of chromium in the control was significantly difference ($P < 0.05$) from the treatments. Meanwhile, there was no significant difference between the treatments. The mean concentration ranged from 0.003–0.041 mg/kg. T3A was found to have the lowest value (0.003 mg/kg), while T2B recorded the highest mean value (0.041 mg/kg). Meanwhile, Chromium was not detected in the control.

Cadmium (Cd): The concentration of cadmium range between 0.004 and 0.057 mg/kg with the lowest mean concentration found in T4A while the highest mean concentration obtained from T4B. Meanwhile, the soil analysis showed that the mean concentration of cadmium in the control was significantly different ($P < 0.05$) from the treatments.

Nickel (Ni): Nickel was one of the least abundant elements found in the sample analyzed. It was the 8th most common element in terms of abundance. There were no significant differences ($P > 0.05$) between the control and T2A, T2B, T3A, and T4A, but significantly different ($P < 0.05$) from other treatments. It ranged from 0.006–0.011 mg/kg with T4A appearing as the lowest and T3C was found to have the highest mean concentration.

Mercury (Hg): Mercury was not detected in the control as well as the T2A. The control was significantly different ($P < 0.05$) from the treatment soils. Nevertheless, there was no significant differents ($P > 0.05$) between the control and T2A soil. It ranged from 0.006–0.009 mg/kg. T3B had the lowest mean value, while T4C obtained the highest mean concentration. The mean concentration of arsenic in the control was not significantly difference ($P < 0.05$) from the treatments and the range is between 0.001 and 0.002 mg/kg. T4A had the lowest mean concentration while T4C recorded the highest mean concentration. In all the elements detected in the soil samples, nickel was the least with a total concentration of 0.003 mg/kg making nickel ranked 9th most abundant element in the soil samples.

Effect of Heavy Metals on Chlorophyll Contents

The chlorophyll content of leaves in the control and the treatments are presented in (Figure1 to 4) from three selected vegetables (*Telfairia occidentalis*, *Solanum macrocarpon*, and *Corchorus olitorius*) over 20 weeks period (WAP -Weeks after Planting). For the control (Figure 1), the concentration of chlorophyll contents in leaves increased as the week increases until 16 weeks before a general decline was observed (Figure 1). The analysis of individual performances showed that *Telfairia occidentalis* showed the highest rise in chlorophyll content, peaking at around 16 WAP (29.8 mg/g) before a slight decline. This was followed by *Solanum macrocarpon*, which also rises steadily and peaks at approximately 18 WAP (19.7 mg/g) before a slight drop. *Corchorus olitorius* increases more gradually and reaches its peak (around 10 mg/g) at 16–18 WAP before a slight decline. The general trends are that Chlorophyll content increases over time for all three plant species but at varying rates.

In T2 treatment (Figure 2), the chlorophyll contents in the three plants species maintained a steady increase for the first 6 weeks of planting and thereafter a general decline was observed beginning from 8th week. *Telfairia occidentalis* exhibited the highest chlorophyll contents of 5.4 mg/g around 6 weeks of planting before declining significantly. Furthermore, *Solamun macrocarpon* reaches its peak (3.5 mg/g) at 6 weeks of planting and decreased gradually afterward. The chlorophyll concentration of *Corchorus olitorius* increases gradually but showed the lowest peak (1.8 mg/g) at 6th weeks of planting suggesting adverse effects from prolonged treatment with asphalt plant discharge water.

The analysis of T3 treatment (Figure 3) showed, that *Telfairia occidentalis* maintained the highest chlorophyll content of (5.1 mg/g) at 6 weeks after planting, which was accompanied by a sharp decrease in chlorophyll content. The chlorophyll content of *Solanum macrocarpon* rises to the peaks (3.5 mg/g)

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International Journal of Agro Chemistry
Volume 11, Issue 2
ISSN: 2456-7000

slightly earlier, around 4 weeks after planting, and then decreases steadily, while *Corchorus olitorius* increases but shows the lowest chlorophyll peak (1.9 mg/g) between 4 and 6 weeks after planting and declines sharply thereafter. This trend suggests that the asphalt plant discharge water negatively impacts chlorophyll production. The overall analysis of T4 treatment (Figure 4) showed that chlorophyll content increases for all three plant species up to 6 weeks after planting and then gradually decline over time. Based on individual analysis, *Telfairia occidentalis* showed the maximum peak (3.2 mg/g) at 6 weeks of planting and thereafter a gradual decline. *Solanum macrocarpon* attained a peak of (2.1 mg/g) in 6 weeks of planting while *Corchorus olitorius* increased initially and reached the lowest peak at (1 mg/g) in 6 weeks of planting and also decreased as the weeks progressed which indicated long-term damage to the leaves due to asphalt plant discharge water.

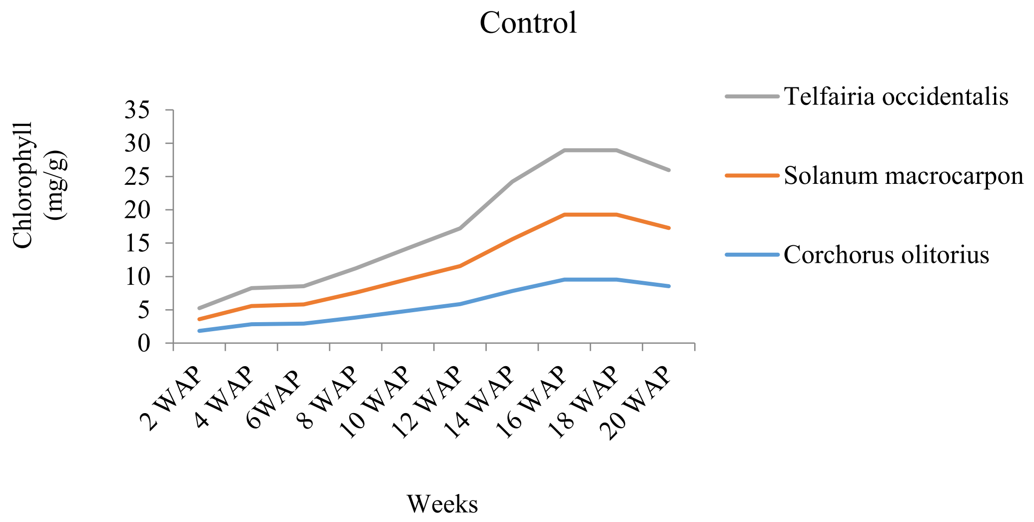

Figure 1. Chlorophyll contents of edible vegetables grow on control soil.

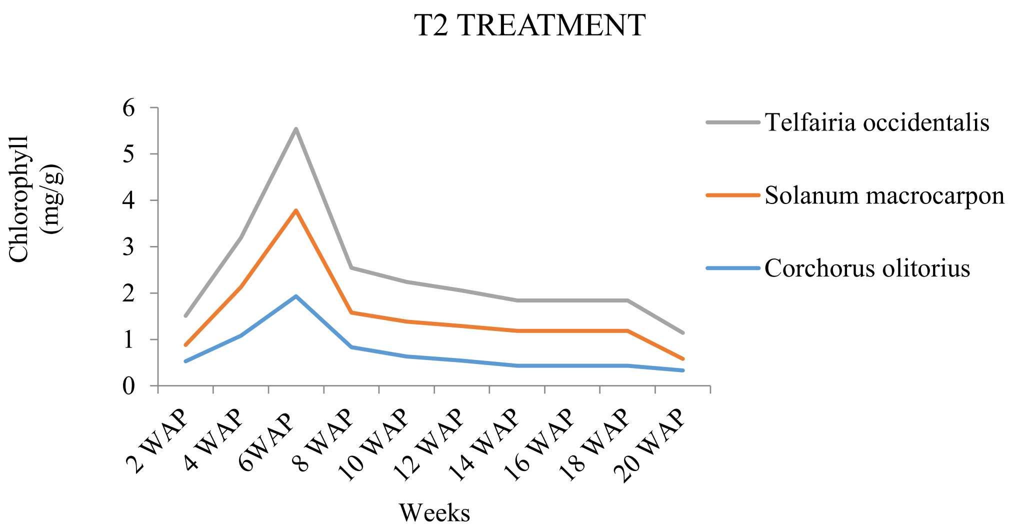

Figure 2. Chlorophyll contents of edible vegetables grown on soils polluted with asphalt plant discharge water from T2 treatment (Irete, Imo State).

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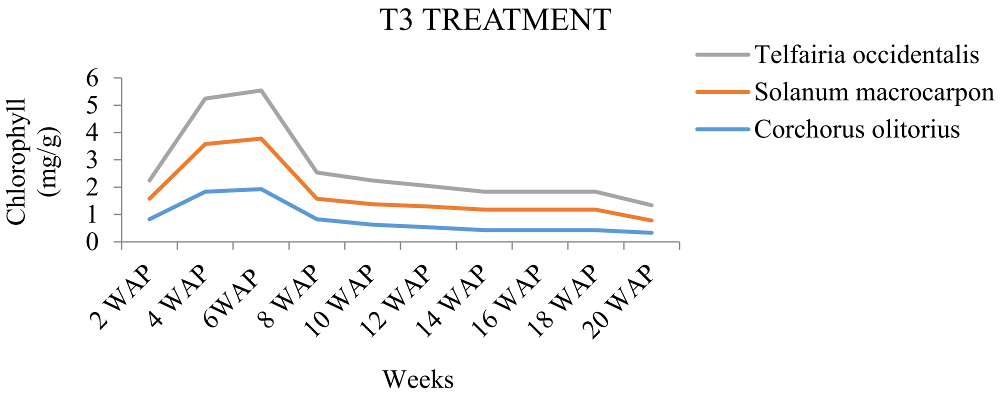

Figure 3. Chlorophyll contents of edible vegetables grown on soils polluted with asphalt plant discharge water from Umuahia, Abia State.

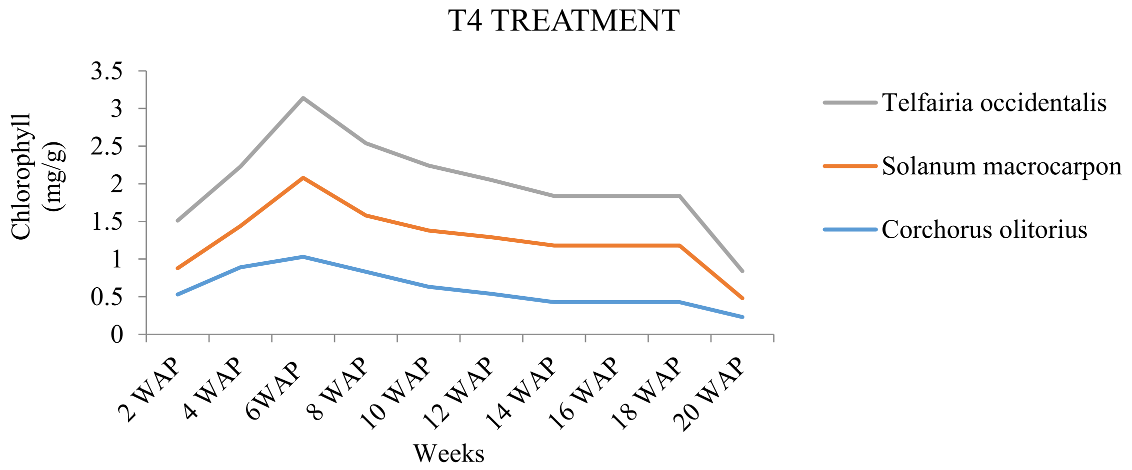

Figure 4. Chlorophyll contents of edible vegetables grown on soils polluted with asphalt plant discharge water from Elele, River State.

Toxicity Assessment on Phytomorphology

The results of the phytotoxic effects of asphalt plant discharge water on plant growth parameters, namely: number of leaves, stem height, root colar index, petiole, and internode length are presented in the (Figures 5 to 9).

There is a reduction in the mean number of leaves in all the treatments, when compared with the control (Figure 5). There were significant differences ($P < 0.05$) between the control and the treatments. Nevertheless, *Solanum macrocarpon* in all the treatments were not significantly difference ($P > 0.05$) from the control. The control recorded the highest mean number of leaves of 168.2 ± 21.84, while the lowest mean value of 27.3 ± 2.44 was obtained in T3 treatments. The stem heights in all the plants grown in the control are significantly difference ($p < 0.05$) from the treatments (Figure 6). Meanwhile, there is no significant difference ($P > 0.05$) between *Corchorus olitorius* and *Solanum macrocarpon* in all the treatments. The control was found to have the highest stem height of (262.70 ± 23.48), while the lowest mean stem height of (24.33 ± 3.68) was recorded inT4 treatment. For the root colar index, the result (Figure 7) showed that there were significant differences ($P < 0.05$) between the control and the treatments. Meanwhile, the treatments were not significantly difference ($P > 0.05$). The control recorded the highest mean value of (0.89 ± 0.06 cm), while the T4 treatment obtained the lowest mean value of (0.23 ± 0.06 cm).

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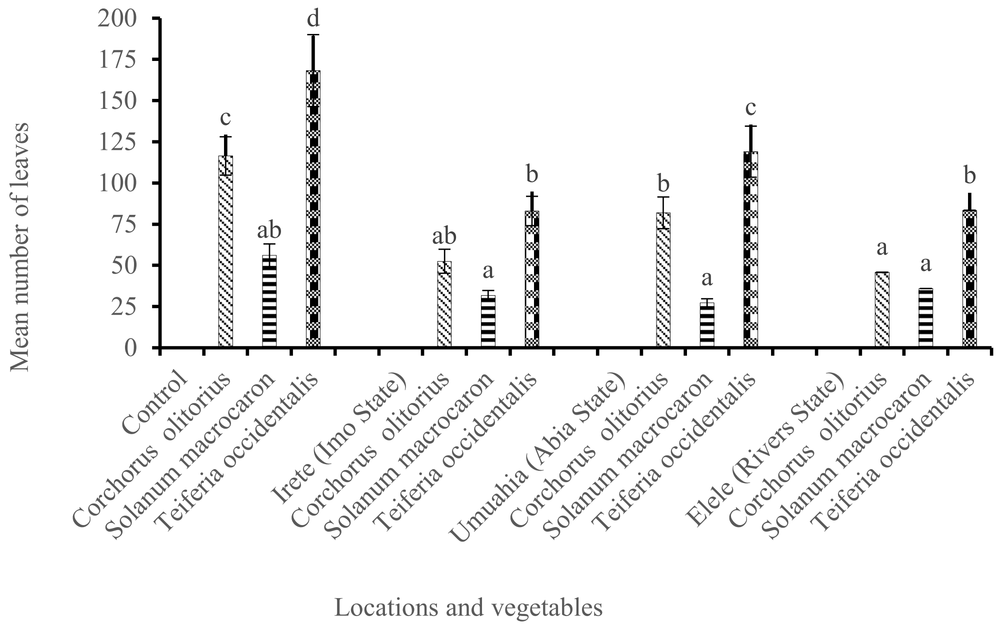

Figure 5. Effect on leaves of edible vegetables grown on soils polluted with asphalt plant discharge water. Means ± SE with different letters above the bar signify statistically significant differences at (P < 0.05).

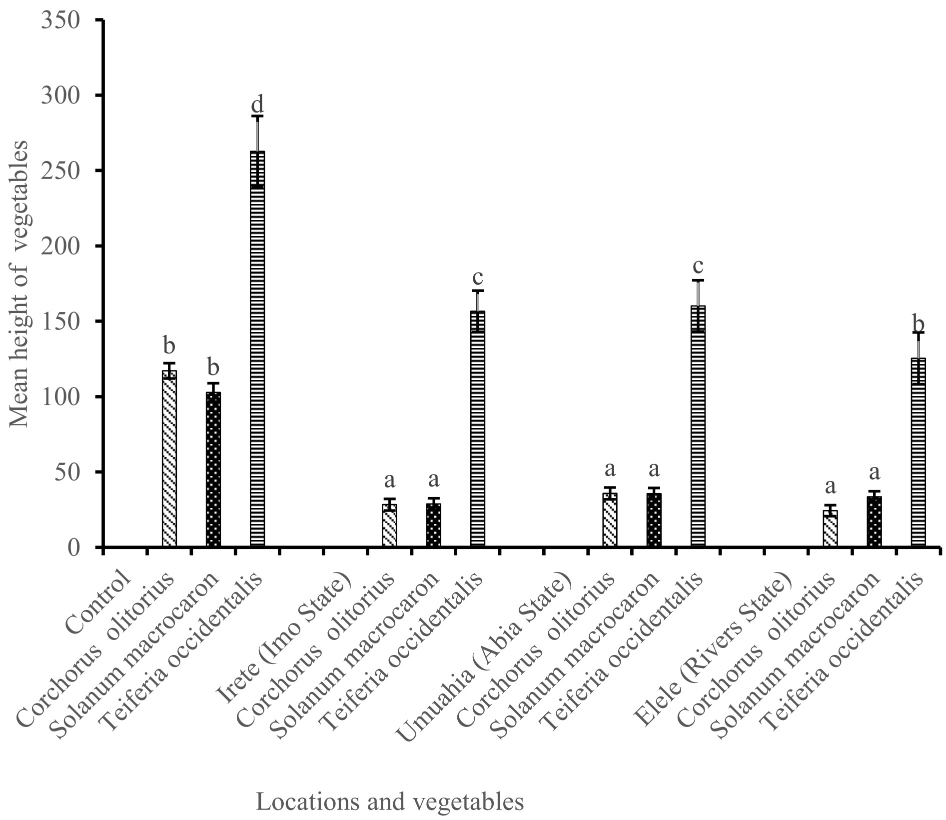

Figure 6. Effect of asphalt plant discharge water on stem height of edible vegetable. Means ± SE with different letters above the bar signify statistical significant differences at (P < 0.05).

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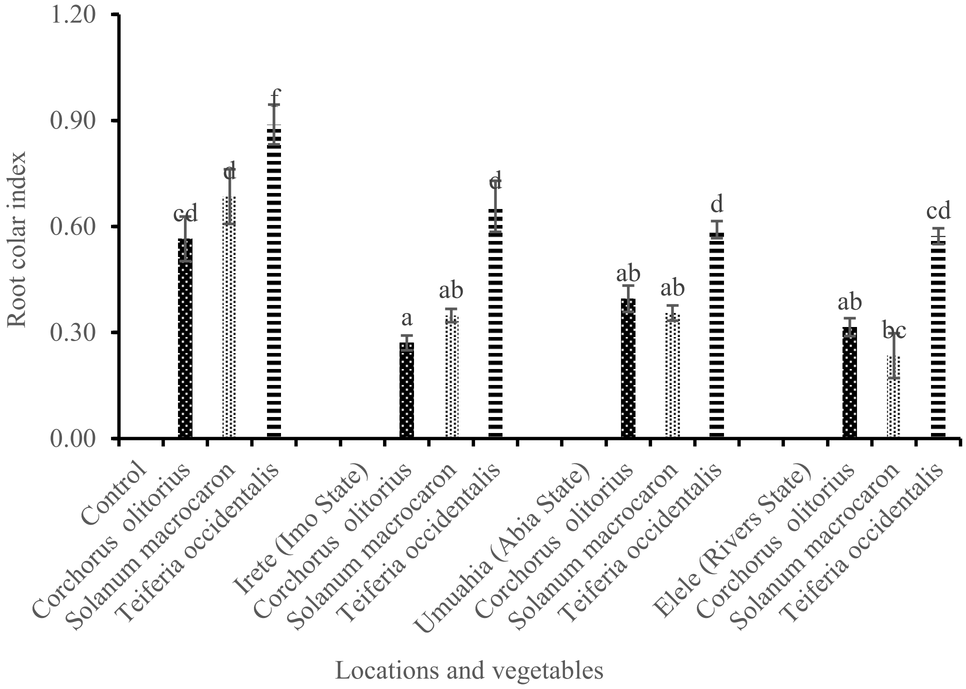

Figure 7. Effect on root color index of edible vegetables grown on soils polluted with asphalt plant discharge water. Means ± SE with different letters above the bar signify statistically significant differences at (P < 0.05).

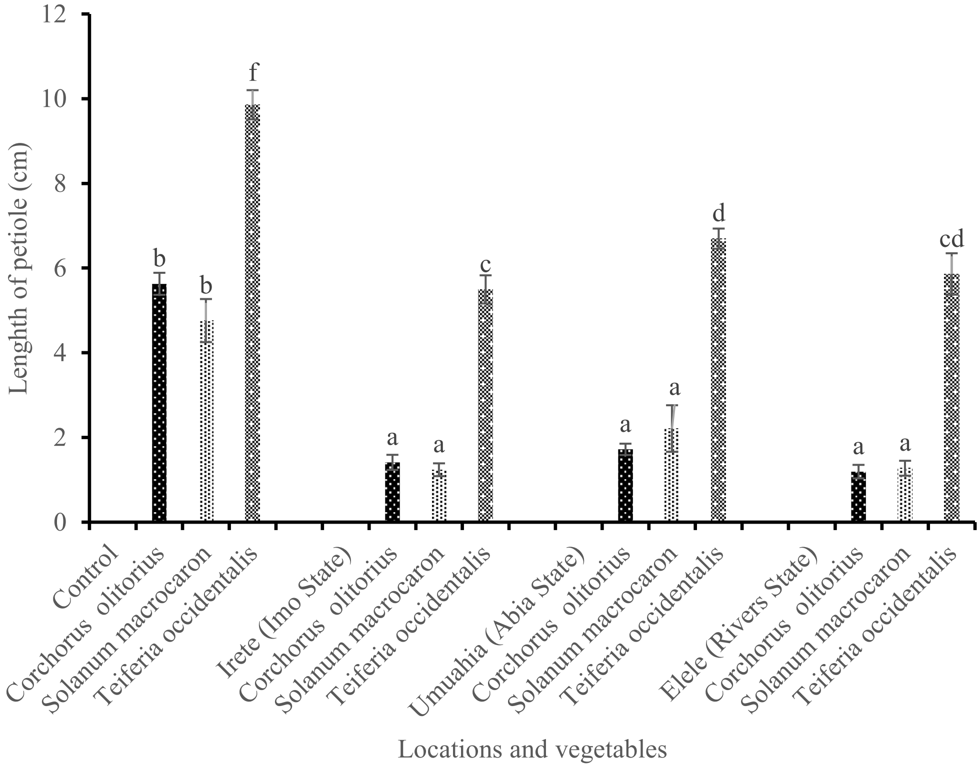

Figure 8. Effect of asphalt plant discharge water on petiole length of edible vegetable. Means ± SE with different letters above the bar signify statistically significant differences at (P < 0.05).

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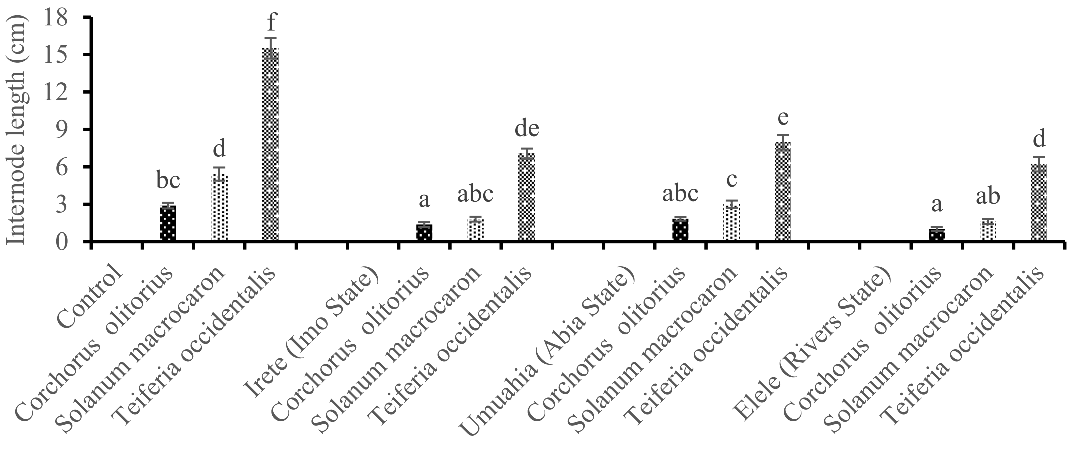

Figure 9. Effect on internode length of edible vegetables grown on soils polluted with asphalt plant discharge water. Means ± SE with different letters above the bar signify statistical significant differences at ($P < 0.05$).

The reduction in petiole lengths exposed to asphalt plant discharge water were presented in (Figure 8). The results showed that the control was significantly difference ($P < 0.05$) from all the treatments (T2, T3, and T4). However, between the treatments, there was no significant difference ($P > 0.05$) in *Corchorus olitorius* and *Solanum macrocarpon.* Considering the overall petiole length, the control recorded the highest petiole length of (9.86 ± 0.35 cm). On the other hand, T4 treatment was found to have the lowest petiole length of (1.19 ± 0.16 cm). The internodes showed that there was significant difference ($P < 0.05$) between the control and the treatments (Figure 9). Meanwhile, there were no significant differences ($P > 0.05$) in *Corchorus olitorius* and *Solanum macrocarpon* across all treatments. The control had the highest mean value of (15.15 ± 0.83 cm) and the lowest mean value was obtained from the T4 treatment. The above results confirmed that plants grow better in unpolluted soils than polluted soils.

DISCUSSION

Physicochemical Properties of Soil After Harvesting Vegetables from the Soil

The study of the physicochemical properties of soils is very essential because the physical as well as the chemical properties of the soil have effects on crop yield [26–36] as presented (Table 1). Also, the physicochemical property of any given soil controls the availability of metals and other nutrient minerals in the soil to plants.

Sand plays an important role in soil management. It influences root penetration, water drainage pattern, aeration and the ability of the soil to retain water. There were significant differences ($P < 0.05$) in the mean concentration of sand before pollution and after pollution. This finding agrees with the report of Mbaegbu et al. (2024) [26], who studied the impact of waste dump on soil quality in Nekede and Orogwe, Owerri State, Nigeria. He found out that the sand content in the polluted soil was (>80 %). Silt provides better nutrients and water retaining capacity, but excess silt can cause soil hardness and waterlogged. Excessive silt can lead to poor drainage, causing root rot, and making it difficult for plants to access oxygen. Asphalt plant discharge water contains fine particles that may have increased the silt contents in the polluted soils of the treatments than the control soils. The results are consistent with Mbaegbu et al. (2024) [26], who observed that waste dump affected the soil quality in Nekede and Orogwe, Imo State and there were significant differences in silt concentration in the treatments compared to the control. However, the result of this study is at variance with the findings of Zhang et al. (2024) [28], who observed that as the concentration of heavy metals in contaminated soil increases, there is a linear decrease in the silt content.

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Clay content can enhance nutrient retention quality but can also cause decrease soil aeration, drainage and compaction. All the treatments including the control were significantly different at 5% probability level. The asphalt plant discharge water, which was used to irrigate the soils showed an increase in mean concentrations of clay contents in all treatments, which may have impacted the soil structures negatively by increasing the clay content. The findings of the result corroborate with the report of Zhang et al. (2024) [27]. He observed that increased in heavy metals concentration in soils accelerated the clay contents. The results of the pH showed that there was a significant difference ($P < 0.05$) between the control and treatments. The acidic nature of all the locations is due to the acidic nature of the asphalt plant discharge water used in polluting the soil. These slightly acidic conditions may reduce nutrient availability, particularly phosphorus, which becomes less available in acidic soils. pH is one of the most important soil properties that ensure the bioavailability of ions and nutrients to plants. Increased level of pH and Alkalinity cause harm to plants. This change caused variation in the biochemical reactions of the soil *Pandey and Kamboji, 2022 [28]. Okorie et al.,2024 [29] who carry out a study on,* who carry out a study on the physicochemical properties and health assessment of heavy metals from soil in Ifite-Akwa, Anambra State, Nigeria, also observed pH range from 5.0 to 7.5, which is consistent with the findings of this study. There was also an agreement between the results of this study with Onoyima & Okibe (2021) [30], but at variance with the work of Redko et al. (2024) [31], who observed a higher pH value in dumpsites than the control.

The bulk density is the air pores normally filled with water that enables the plants root to easily penetrate the soil [28]. The physicochemical status of the soil can also affect bulk density. Parameters that influence bulk density functionality include minerals matter, organic matter, texture, and porosity of the soil. Such knowledge is essential for soil management and planning of a modern farm technique [28]. The low bulk density value obtained in all the treatments in comparison with the control (1.49 ± 0.1 mg/kg) suggests that the asphalt plant discharge water may have led to increase soil compaction that may be associated with the asphalt plant discharge water. Crops planted in compacted soil may show poor root growth. The result of this study was at variance with Crnobrna et al. (2022) [32], who observed a higher value of bulk densities in the waste dump sites than the control sites. Organic carbon is a measure of organic materials in the soil. Organic matter is a source of humus which supplies nutrients to plants and is an essential component in maintaining the fertility of soil [30]. When most of the organic materials are degraded, carbon dioxide (CO_2) is released which replaces some of the oxygen molecules in the soil pores. The portion of organic matter that remains after the decomposition is known as humus. Increased organic matter can boost crop production and enhanced cation capacity exchange which in turn promote nutrient retention in plants. All the mean values of all the treatments were lower than the control. This is due to the treatment with asphalt plant discharge water [33]. These findings disagree with the observation of Redko et al. (2024) and Udeh et al. (2021) [31, 34], who observed high organic matter in dumpsite soil and cassava farmland near industrial area than the control which may be due to constant deposition of organic materials in the soils.

Nitrogen concentration in soil enhances soil fertility. The amount of mineral nitrogen that can be absorbed in the soil is about 2 % of the total nitrogen present in the soil. However, soil biota can also add mineral nitrogen to the soil by decomposition of organic matter. Phosphorus is an important micronutrient required for plants to grow, root development as well as flowering. Phosphorus is required in large quantity by plant. However, there were low levels of phosphorus generally recorded in all the treatments suggesting that the asphalt plant discharged water have led to phosphorus deficiency in the soil. Also, potassium is one of the most important elements for plant development. It plays a very important role in photosynthetic process. Soils lacking potassium alter the growth of the plant and decrease productivity. The presence of pollutants likely alters the soil's texture, reduces nutrient availability, such as potassium, and could affect the growth of vegetables. This result was at variance with the work of Gbarabe & Emmanuel (2021) [23], who reported higher level of potassium. Electrical conductivity refers to the ability/capacity of the soil sample to conduct electricity. Electrical conductivity is another important property of the soil that is used to check the health or quality of the soil. It is the measure of the salts or ions in soil. Excess salt hinders soil-water balance, nutrient uptake

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in plants, and soil microorganism activities thereby reducing crop yield [35–36]. As salt or ions in the solution or soil samples increases, electrical conductivity increases also. Electrical conductivity values in the polluted soils (T2, T3, and T4) are significantly higher, which is an indication that the asphalt plant polluted water could have increased the salinity level. The result of the study is at variance with Brown & Ogboeli [37], who observed a low level of conductivity compared to the high conductivity observed in this study. The difference may be due to the level of contaminants present in the discharge of water. Cation Exchange Capacity is the ability of the soil to hold cations (positively charged ions), due to their surfaces that are negatively charged. This is a soil surface character that permits heavy metals adsorption on soil surfaces. High level of cation exchange will lead to increase in solubility and mobility thereby accelerating metal ions for plant uptake. CEC is essential for nutrient retention. The control had better retention capacity than the three treatments.

Heavy Metal Contents of the Soils After Harvesting Vegetables

The results of heavy metals concentrations in soils after planting of vegetables are shown in (Table 2). The result indicates a wide variation in mean concentration of heavy metals in soils from T2 treatments (T2A, T2B, T2C), T3 treatments (T3A, T3B, T3C), and T4 treatments (T4A, T4B and T4C). There was significant difference ($p < 0.05$) between the control and the soils polluted with asphalt plant discharge water from T2, T3, and T4 treatments. The higher concentrations of heavy metals in the polluted soils than the control could be associated with the presence of pollutants in the discharge water [38].

The result of zinc analysis showed that the concentrations of zinc recorded in all the soil samples were below the World Health Organization permissible limit of 50 mg/kg [39]. This means that zinc was not a source of pollutants to the soil. These findings corroborate with the work of Sagagi et al. (2022) [40]. However, it was at variance with Bartels & Boardi (2023) [41], who observed higher level of zinc pollution in the soils than the control in Ghana. Iron is one of the most prevalent elements detected in the soil sample because iron is very mobile, but its concentration was below WHO standard guidelines. This finding corroborated with the work of Orosun et al. (2023) and Nwosu et al. (2021) [42–43]

The result of mean concentration of copper was presented in Table 2. The mean concentration of copper recorded in the soil samples was below the World Health Organization maximum permissible limit of 36 mg/kg [39]. Copper is an essential element required for healthy plant growth. Meanwhile, copper was not detected in the control. This agrees with the report of Sagagi et al. 2022 and Yahaya et al. (2023) [39, 44], where copper was higher in the treatment than the control. Similarly, Alagoa et al. (2023) [45] in his study of the presence of heavy metals in soils with cassava processing activities in Toru-Ebeni, Bayelsa State, Nigeria recorded a higher level of copper in the polluted site than control. The concentration of lead in the soil sample ranges between 0.004 and 0.01 mg/kg. Lead was not detected in control. In all, the level of lead in the soil samples was below (WHO/FAO) guidelines of 50 mg/kg [46]. This may be due to high accumulation of lead in the part of the vegetables. Lead is very toxic when accumulated in plant tissues. This finding is like observation of Bartels & Boardi (2023), Samuel et al. (2022), and Bawwab et al. (2022) [41, 47–48]. However, the work of Ogbuene et al. (2023) [49] is at variance with the current study who observed a higher level of lead that exceeded the WHO permissible limit.

Chromium was the 6th most frequent element in the soil samples. However, in all soil samples the level of chromium was below the (FAO/WHO) permissible limit of 3 mg/kg [46]. Chromium was not detected in the control. The findings were consistent with the work of Nduka et al. (2023) [50], who observed that industrial emissions are sources of chromium contamination. The concentration of cadmium in the soil samples ranked the 4th most abundant elements in all the samples analyzed. This result was corroborated with the findings of Yahaya et al. (2023) and Okosa et al. (2023) [44, 51]. However, the study by Adewale et al. (2023) [52] was at variance with the current result. This could be because of differences in lead concentration in the soils [16]. Nickel concentration in the soil sample was in the range of 0.006–0.011 mg/kg. Nickel's concentration in the soil samples was below the WHO

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recommended value of 35 mg/kg [39]. The findings of this result were varied with the observation of Sagagi et al. (2022) [40], who found higher levels of nickel accumulation in the soil polluted with wastewater than the control. This may be due to low concentration of nickel in the discharged water.

Mercury values in soil were below (WHO/FAO) recommended value of 1 mg/kg [46]. Though the concentration detected in the soil samples is low, it should be a concern because Mercury has toxicity effects even *at* low concentration [3]. The mean concentration of arsenic in the control was not significantly difference ($P < 0.05$) from the treatments and the range is between 0.001 and 0.002 mg/kg.

Arsenic concentration in the soil samples was not above the WHO/FAO limit of 20 mg/kg [46]. The findings are like the work of Dike Ijere & Okechukwu (2022) [53]. However, it was at variance with the work of Hussaini et al. (2021) [54], who observed a higher level of arsenic. This may be because of low mobility of arsenic in the soil.

Effect of Heavy Metals on Chlorophyll Concentrations

The concentrations of chlorophyll were reduced after treatment with the asphalt plant discharge water (Figures 1–5). According to Martins et al. (2023) [55], Chlorophylls are essential for photosynthesis and growth of plants. Chlorophylls are commonly found in green vegetables and their abundance in plants plays a vital role in photosynthesis by capturing light energy and transforming it into chemical energy that enhanced the growth of the plants. However, the concentration of chlorophyll in the selected vegetables studied was reduced in the order of *T. occidentalis* > *S. macrocarpon* > *C. olitorius*. The current result is like the findings of Hu et al. (2023), Azizi et al. (2020), El Rasafi et al. (2022), and Riaz et al. (2021) [16, 56–58]. This may be ascribed to the fact that the site of photosynthesis in plants is considered as most affected by pollutants, which may alter chloroplast functions and pigment functions [59]. The presence of heavy metals in the soil may lower cell division, peroxidase activity, protein concentration, and chlorophyll a and b pigment in plants. It may have negative impact *on* gas exchange, transpiration rate, stomata conductance, and carbon dioxide concentration [60].

Phytotoxicity Assessment of Phytomorphological Parameters of the Vegetable Plants

Industrial wastewater is considered an environmental pollutant. The constituent of industrial wastewater vis-a-vis asphalt plant discharge water is sources of heavy metals [61]. The overall mean number of leaves recorded showed that the control obtained the highest number of leaves (Figure 5). The observed reduction in the mean number of leaves treated with asphalt plant discharge water corroborated with the findings of Jabbarov et al. (2024) [62], who observed that crude oil products contamination of the soil resulted in stressful conditions for the plants nutrient uptake leading to retarded growth as well as reduced number of leaves. Accumulation of heavy metals in soils have negative effects on enzymes, cell division, seed germination, as well as alteration in plant nutrients, and water balance leading to reduction in number of leaves [12]. Soils contaminated with pollutants lead to destruction of the soil structure, reduced permeability of water and alteration in the nutritional absorption of the plants, which impact plants negatively in their plant growth. The stem height in all the plants grown in the control is significantly different ($p < 0.05$) from the treatments (T2, T3, and T4). As observed in the study, stem heights in the treatments were greatly affected when compared to the control (Figure 6). The recorded increase in stem height of the control plants can be attributed to the healthy, unpolluted and structure of the soil that permits normal metabolic activity of the plants. This finding is consistent with the documentation of Ukaoma et al. (2023) [63], who studied tolerance threshold of growth and development of *Telfairia occidentalis* in diesel polluted soil. The findings showed that soil polluted with diesel at 100 ml, 200 ml, 300 ml, and 400 ml significantly reduced plant height. This also agrees with the earlier report of Salam et al. (2022) [64], who observed reduced stem height in soils contaminated with diesel.

The root colar index in the (T2, T3, and T4) treatments were specifically affected as express in the mean reduction values (Figure 7). Crude oil contamination of the soil has been reported by researchers to inhibit plant growth as well as general reduction in growth parameters [65]. Gbarabe

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& Emmanuel (2021) [23] Observed the effects of simulated crude oil pollution on soil and performance of Italicized *Zea mays*, documented that the performance of Italicized *Zea mays* in terms of stem height, girth, and number of leaves decreased with increased in crude oil applications. Also, Odiyi et al. (2020) [66] observed a similar result. This may be a result of unfavorable soil conditions, where growth enhancing microbes are affected, reduction in biochemical activity of the plant and disruption of nutrient and water uptake by plants.

The reduction in petiole lengths and internode exposed to asphalt plant discharge water as presented in (Figure 8 and 9) showed, that the control was significantly different ($P < 0.05$) from all the treatments (T2, T3, and T4). The above results confirmed that plants grow better in unpolluted soils than polluted soils. Soil contaminated with heavy metals reduced plant growth parameters, such as plant height, root colar index, number of leaves, petiole length, and internode [67].

CONCLUSIONS

This study revealed that growing vegetables in farmland near industrial areas can lead to poor productivity in vegetable yields thereby minimizing the farmer profits as well labor but little harvest. Soil watered with asphalt plant discharges had negative effects on the physical and chemical properties of the soil which resulted in adverse effects on soil fertility and created unfavorable, stressful conditions for the vegetable plant morphologies. Hence, there is a need for environmental agencies to monitor industrial discharges to reduce pollution and protect agricultural farmlands for sustainability and food security.

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