Research Article

Assessment of Heavy Metals Accumulation in Leafy Vegetables in Terengganu and Kelantan, Malaysia

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Abstract | Heavy metal contamination of vegetables can seriously threaten the food chain as these plants easily absorb pollutants like copper, cadmium, lead, zinc, iron, and manganese from polluted soils. It is very important to determine the accumulation of heavy metals in vegetables in order to analyze the pollution in the environment. This study assesses heavy metal concentrations in leafy vegetables cultivated in Terengganu and Kelantan. The experiments were performed by random sampling of leafy vegetables, including water spinach (*Ipomoea aquatica*) and mustard greens (*Brassica juncea*), from Besut, Setiu, Pasir Puteh, and Bachok fresh markets. We dried the specimens and digested them using the acid digestion method. Heavy metal contents in specimens were then determined by using ICP-OES. The one-way ANOVA statistical test was used to measure the differences in the amounts of heavy metals accumulated between specimens. The analysis shows that the specimens examined have a high concentration of Mn, Cd, and Cu, which is above the permitted limit. However, other heavy metal elements detected were still within the permissible limit for consumption. Although a low level of heavy metal content is safe for consumption, the agricultural practices and atmospheric depositions of vegetables contribute significantly to the increase in heavy metal levels in vegetables, which may pose health risks to consumers of commodities produced locally.

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Introduction

Vegetables are a staple of diets because they are rich in fibre, minerals, vitamins, and antioxidants. Vegetables have many benefits to the consumer, including serving as experts at buffering the acid that is produced during digestion (Latif *et al*., 2018). Previous studies have also reported that green vegetables can defend against colon cancer, help prevent cancer formation, and reduce cancer incidence (Ağagündüz *et al*., 2022). However, plants have a well-known ability to pick up metals from polluted soils and via stains on plant components that are exposed to the air (Hisam *et al*., 2022). When plants are cultivated on polluted soils, the plant often absorbs more of these metals (Yazid *et al*., 2025). In fact, leafy vegetables have a high potential to accumulate heavy metals and cause consumer concern (Sharafi *et al*., 2024). Moreover, leafy vegetables rapidly absorb heavy metals in the edible sections when compared with grain or fruit crops (Asghar *et al*., 2024). The pollution begins on the soil's surface, is taken up by the apoplasts of plant roots, is dispersed, and accumulates in both the edible and inedible sections of the plants, posing a serious threat to the food chain (Ahmad *et al*., 2019; Alsafran *et al*., 2021). Given their importance in ensuring the quality of food, heavy metal contamination of vegetables cannot be disregarded.

Heavy metals and other pollutants are released in significant amounts into the environment, especially through agriculture and metal industries (Briffa *et al*., 2020). Previous studies have suggested that heavy metal levels were higher in vegetables planted close to industrial locations (Haque *et al*., 2021), mine sites (Zhou *et al*., 2016), roads (Gupta *et al*., 2021), and solid waste dump sites (Iya *et al*., 2025) than in those grown farther away. On the other hand, agricultural activities, including the use of organic and inorganic fertilizers, sewage sludge as fertilizer, pesticides, and polluted irrigation water, are some of the main factors that cause an increase in heavy metals in the soil (Sharafi *et al*., 2024).

Hazardous heavy metals can accumulate in humans and other animals from the food chain pyramid (Gupta *et al*., 2021; Prasad *et al*., 2021). They are particularly dangerous since they are non-biodegradable, have lengthy biological half-lives, and can accumulate in one or more different organs, causing many serious diseases (Briffa *et al*., 2020). For instance, although Mn is necessary for bone growth and the metabolism of amino acids, lipids, and carbohydrates in humans, a high amount can be harmful and lead to manganism and extrapyramidal syndrome, as found in Parkinson's disease (Li and Yang, 2018). In addition, excessive iron absorption can increase the risk of several types of cancer (Torti *et al*., 2021). Moreover, the buildup of heavy metals throughout time in the human kidney and liver due to extended exposure to hazardous levels of heavy metals in food may disrupt several biochemical processes and result in cardiovascular, neurological, kidney, and gastrointestinal problems (Lin *et al*., 2018; Balali-Mood *et al*., 2021).

The quality and safety of vegetables are at risk from heavy metal contamination, which is brought on by soil and air. The risk posed by heavy metal contamination in vegetables can have a bad effect, especially on humans and animals. Since the consumption of heavy metal-contaminated vegetables can endanger human and animal health (Briffa *et al*., 2020), there is a need to determine the heavy metal levels in food consumed by local people. The information on the heavy metal content within vegetables can be used to create awareness as well as develop effective strategies to mitigate heavy metal contamination in agricultural practices, especially the cultivation and consumption of leafy vegetables.

Based on the random sampling of several fresh markets, this study aims to determine the heavy metal concentrations in leafy vegetables involving water spinach (*Ipomoea aquatica*) and mustard greens (*Brassica juncea*) cultivated in Terengganu (Besut and Setiu) and Kelantan (Pasir Puteh and Bachok). This research should help to identify the sources of vegetables in several fresh markets and prevent the potential health risks associated with consuming these vegetables.

Materials and Methods

Specimen selection and sampling locations

We collected the specimens from the fresh market of Terengganu (Besut and Setiu) and Kelantan (Pasir Puteh and Bachok), East Coast states of Peninsular Malaysia, between May and June 2023. There are between 20 to 30 fresh markets available in each district. The details of the fresh market's locations are shown in Table 1. Two leafy vegetables, including water spinach (*Ipomoea aquatica*) and mustard greens (*Brassica juncea*), were selected based on their availability and the vegetables that the locals consumed most. We collected three replicates of each species from three random sellers for each market. Each specimen collected was placed in a clean polythene bag before being brought to the laboratory.

Chemical and specimen preparations

The chemicals and reagents used were of analytical and trace metal grades. Trace metal grades, including 70 % HNO_3, 65 % $HClO_4$, and 70 % $HClO_4$, were supplied from Fisher Malaysia. Sodium borohydride ($NaBH_4$), sodium hydroxide (NaOH), l-ascorbic acid ($C_6H_8O_6$), and potassium iodide (KI) were obtained from Merck (Germany). Moreover, stock standard solutions for each heavy metal, including manganese (Mn), iron (Fe), cadmium (Cd), nickel (Ni), zinc (Zn), and copper (Cu), with a concentration of 1000 ppm, were supplied by Perkin Elmer USA. All glassware was soaked in 5 % (v/v) HNO_3 overnight, then rinsed with deionized water and dried using a lab dryer prior to use.

Table 1: *The sampling location of the fresh market.*

States	Districts	Locations	Coordinates
Terengganu	Besut	Kampung Raja	5.79858, 102.56426
Terengganu	Besut	Jabi	5.66794, 102.59572
Terengganu	Besut	Gong Bayor	5.74756, 102.57646
Terengganu	Setiu	Rhu Sepuluh	5.59240, 102.82407
Terengganu	Setiu	Permaisuri	5.52049, 102.74313
Terengganu	Setiu	Chalok	5.42576, 102.84873
Kelantan	Pasir Puteh	Kampung Guntong	5.84688, 102.36449
Kelantan	Pasir Puteh	Semerak	5.83543, 102.49757
Kelantan	Pasir Puteh	Tok Bali	5.89012, 102.48109
Kelantan	Bachok	Jelawat	6.01115, 102.37578
Kelantan	Bachok	Beris Kubor Besar	6.07333, 102.36081
Kelantan	Bachok	Gunong	5.98884, 102.34752

The specimen was prepared for the acid digestion step as described by Ali and Al-Qahtani (2012). We washed the vegetable specimens using running water to get rid of the dust, followed by three washings with distilled water to prevent contamination. The specimens were then dried using tissue paper. We chopped the specimens into small pieces using a clean knife and dried them in an oven at 80 °C for 24 hours to remove all moisture completely according to their parts (roots, stems, and leaves). After drying, we ground the samples into a fine powder using a mortar and pestle. The fine powder was kept in polyethylene bags until they were ready for the acid digestion protocol.

Acid digestion protocol

The acid digestion steps were done using the method published by Ali and Al-Qahtani (2012). We take a total of 1 g of powdered vegetable specimens and put them into the beaker containing 10 ml of the tri-acid mixture (70% HNO_3, 65% $HClO_4$, and 70% H_2SO_4) with a ratio of 5:1:1 (Uddin *et al.*, 2016). Then, the mixture was incubated in the oven at 80 °C for 30 minutes to digest the solution. The translucent solution was obtained after the powder was digested. We then cooled the digested samples and filtered them through the Whatman No. 42 filter paper. The filtrate was then diluted with deionized water to a final concentration of 50 mL in a volumetric flask and stored in the refrigerator at 4°C until instrumental analysis.

Heavy metals determination

Concentrations of Cu, Cd, Zn, Ni, Mn, and Fe were determined using optical emission spectrometry (ICP-OES, Perkin-Elmer Optima 7300 DV). ICP-OES is sensitive and capable of detecting metals and metalloids in samples at the ultra-trace level (Amin *et al.*, 2022). It is calibrated and maintained by technical staff using the protocol provided by the supplier. The specimen's heavy metal content was determined following the steps described by Hisam *et al.* (2022). One reagent blank was included for each batch of digestion. The filtered 50 ml of the plant sample was taken out of the refrigerator. We used a total of 15 mL when running ICP-OES for heavy metal analysis for each plant sample. The ICP-OES tube was labeled, and 15 mL of the sample was poured into the tube. The tube was placed in the ICP-OES machine, and the lab technician ran this process. The result can be obtained after 3 hours. We repeat the procedure three times to get more accurate results.

Equation 1 (US EPA, 2014) was used to calculate the actual concentration of heavy metals in plant samples based on the ICP-OES results:

$$Concentration\ (\mu g\ kg) = C \times VW \times S \ \ldots(1)$$

Where; C is the result value from ICP-OES (μg/L), V is the final volume after preparation (L), W is the wet sample mass (kg), and S is the % dry weight/100. While *% dry weight = g dry sample g sample × 100*

Statistical analysis

The data recorded from all sampling locations were pooled and analyzed using Microsoft Excel. A one-way ANOVA was used to analyze and assess the levels of the concentrations of heavy metals in the vegetables tested. The least significant difference (Fisher's protected LSD) was calculated following a significance *F*-test (at *P* =0.05).

Results and Discussion

Determination of heavy metal content in selected leafy vegetables

Assessing the presence of heavy metals in vegetables is critical for understanding food safety and environmental health. The analysis of the heavy metal content in vegetables from various fresh markets in Terengganu and Kelantan shows that the average concentrations of heavy metals in the specimens vary between locations. Within Besut fresh markets, Fe was the highest concentration of heavy metal found in mustard green, while Mn was the highest concentration of heavy metal found in water spinach. Moreover, Cd and Ni were found to have the lowest concentrations for both vegetables compared to other elements. The result is shown in Table 2. The analysis of the specimens in the Setiu fresh market shows a different trend. The highest concentration of heavy metal found in both vegetables was Fe, followed by Mn. In addition, Cd and Ni were found to be the lowest concentrations for both vegetables when compared to other elements. The result is shown in Table 3.

Table 2: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Besut market.*

Heavy metals	Mustard green	Water spinach
Mn	36.70 ± 3.76	47.30 ± 3.24
Fe	39.20 ± 4.24	37.80 ± 5.62
Cd	6.50 ± 1.63	6.50 ± 1.84
Ni	8.90 ± 1.89	9.20 ± 1.78
Zn	27.10 ± 6.11	11.90 ± 5.16
Cu	30.10 ± 5.27	31.70 ± 4.22

The analysis shows heavy metal concentrations of mustard green and water spinach using ICP-OES in Besut markets.

Table 3: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Setiu market.*

Heavy metals	Mustard green	Water spinach
Mn	41.36 ± 4.12	42.96 ± 4.36
Fe	46.93 ± 3.88	45.06 ± 3.28
Cd	6.50 ± 1.25	9.76 ± 1.08
Ni	8.83 ± 1.67	7.13 ± 1.33
Zn	38.53 ± 3.14	26.16 ± 4.88
Cu	30.80 ± 3.96	31.16 ± 3.32

The analysis shows heavy metal concentrations of mustard green and water spinach using ICP-OES in Setiu markets.

Apart from that, the analysis of the specimens in the Pasir Puteh fresh market shows the same trend as the Setiu fresh market. The heavy metal with the highest concentration found was Fe, followed by Mn in both vegetables. However, water spinach has approximately 40% more Fe than mustard green within the Pasir Puteh fresh market. As in Terengganu, the concentration of Cd and Ni shows the lowest concentration detected for both vegetables compared to other elements. The result is shown in Table 4. Moreover, the analysis of the specimens in the Bachok fresh market has shown the same trend as in Besut fresh markets, where Fe had the highest concentration of heavy metal found in mustard green, while Mn had the highest concentration of heavy metal found in water spinach. In addition, the concentration of Cd and Ni remains the lowest concentration of heavy metal found within both vegetables. The result is shown in Table 5.

Table 4: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Pasir Puteh market.*

Heavy metals	Mustard green	Water spinach
Mn	35.60 ± 5.21	37.36 ± 4.78
Fe	40.53 ± 6.23	60.60 ± 2.56
Cd	6.70 ± 2.01	2.90 ± 3.88
Ni	7.30 ± 1.56	7.53 ± 1.42
Zn	20.00 ± 6.84	22.40 ± 4.98
Cu	31.80 ± 5.21	31.76 ± 4.76

The analysis shows heavy metal concentrations of mustard green and water spinach using ICP-OES in Pasir Puteh markets.

Table 5: *Heavy metal concentrations (mg/kg) of leafy vegetables in Bachok market.*

Heavy metals	Mustard green	Water spinach
Mn	40.70 ± 5.16	42.40 ± 4.71
Fe	41.73 ± 5.47	38.16 ± 5.13
Cd	6.50 ± 1.55	6.46 ± 1.87
Ni	8.73 ± 1.62	8.56 ± 1.12
Zn	20.16 ± 6.21	32.50 ± 3.46
Cu	30.50 ± 4.66	30.63 ± 3.98

The analysis shows heavy metal concentrations of mustard green and water spinach using ICP-OES in Bachok markets.

From the analysis, the average concentration of heavy metals identified in the Terengganu and Kelantan areas shows almost the same trends. The Fe shows the highest concentration within a mustard green in Terengganu, with an average of 39.20–46.93 mg/kg, followed by Mn, with an average of 36.70–41.36 mg/kg, and in Kelantan, with an average of 40.53–41.73 mg/kg, followed by Mn, with an average of

35.60–40.70 mg/kg. However, within water spinach, the highest heavy metal obtained was Mn (47.30–42.40 mg/kg) in the Besut and Bachok fresh markets and Fe (45.06–60.60 mg/kg) in the Setiu and Pasir Puteh fresh markets. Previous studies suggested that vegetables are usually contaminated with heavy metals from contaminated fields, irrigation water, industrial emissions, harvesting steps, storage, and industrial emissions (Antisari *et al*., 2015; Chen *et al*., 2024). Other studies also reported that the heavy metals that were dispersed into the water, soil, and air could be accumulated by the crops (Sultana *et al*., 2022).

Based on the analysis, the vegetable cultivation areas are contaminated with high amounts of Fe, Mn, Zn, and Cu. The limit for heavy metals according to the Malaysian Food Act 1983 and Regulation 1985 varies between different heavy metal elements, for instance, Fe (425.50 mg/kg), Mn (20.00 mg/kg), Zn (100.00 mg/kg), Cd (0.05 mg/kg), Ni (13.00 mg/kg) and Cu (30.00 mg/kg). The analysis shows that the specimens were high in Mn, Cd, and Cu, where the heavy metal concentration obtained in the vegetables is above the permitted limit. A previous study by Sulong *et al*. (2022) showed that the vegetables obtained from local markets, consisting of Mn, Zn, Mo, Cu, I, Ni, and Se, have exposure to the customers. The other studies in Sarawak, Sabah, and Pahang also found that local people detect heavy metals in vegetable consumption (Rajan *et al*., 2021; Sulaiman *et al*., 2020). Compared to previous studies, our specimens have a lower concentration of heavy metals than other places, including Mn (Sulong *et al*., 2022), Zn (Rajan *et al*., 2021), and Cd (Sulaiman *et al*., 2020).

Investigation of heavy metal concentration in different local markets

The comparative analysis of the heavy metal accumulation between mustard green and white spinach shows that the heavy metal content trend was mixed between different markets. In the Besut local markets, mustard green has a higher accumulation of Fe and Zn, while water spinach has a higher content of Mn and Cu (Figure 1). Other heavy metal elements have almost similar concentrations. These four heavy metals (Mn, Fe, Cu, and Zn) were significantly higher ($p < 0.05$) compared with other metals in both vegetables. In Setiu local markets, mustard green has a higher accumulation of Fe, Zn, and Ni, while water spinach has a higher content of Mn and Cd (Figure 2). However, there was no significant ($p > 0.05$) difference in the level of Cu in both vegetables located in Setiu markets.

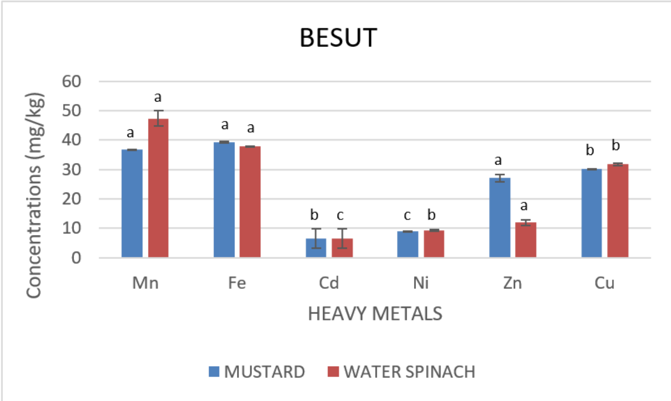

Figure 1: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Besut local markets. Means followed by the same lowercase letters within the same-colored column are significantly different according to the LSD test.*

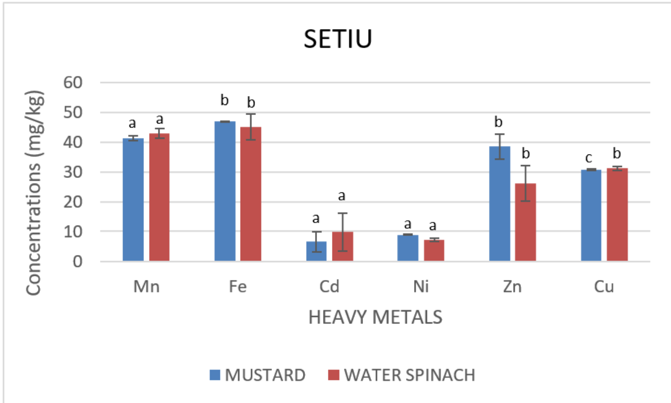

Figure 2: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Setiu local markets. Means followed by the same lowercase letters within the same-colored column are significantly different according to the LSD test.*

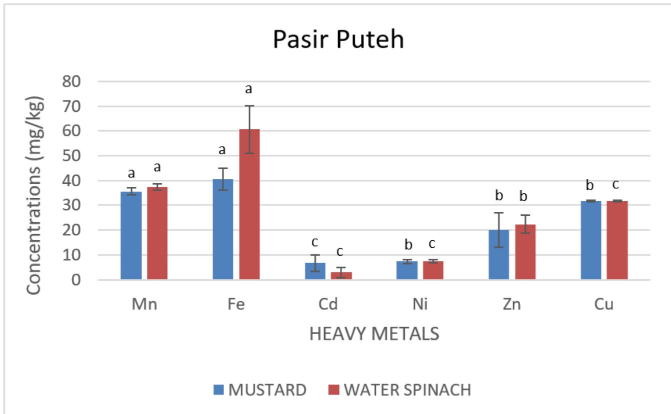

Figure 3: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Pasir Puteh local markets. Means followed by the same lowercase letters within the same-colored column are significantly different according to the LSD test.*

On the other hand, the analysis of heavy metal content in Kelantan local markets showed a similar trend to that of the Terengganu local market. In the Pasir Puteh local markets, mustard green has a higher accumulation of Cd, while water spinach has a higher content of Mn, Fe, and Zn (Figure 3). Other heavy metals have almost similar concentrations. Compared with Pasir Puteh local markets, Bachok local markets have a higher accumulation of Fe within the mustard green, while water spinach has a higher content of Mn and Zn (Figure 4). However, there was no significant ($p > 0.05$) variation in the level of Cu and Ni in both vegetables.

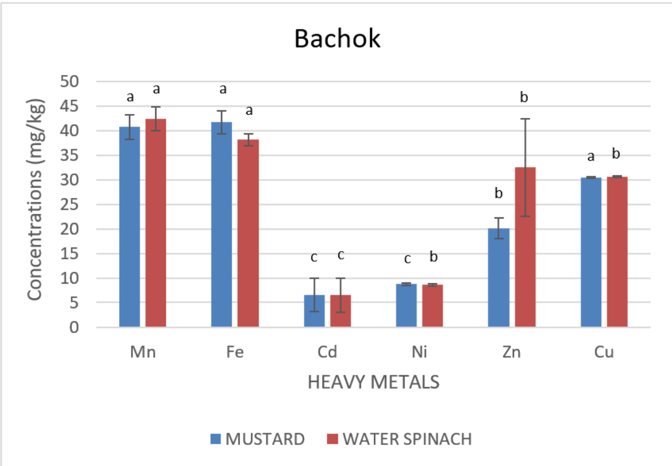

Figure 4: *Heavy metal concentrations (mg/kg) of leafy vegetables in the Pasir Puteh local markets. Means followed by the same lowercase letters within the same-colored column are not significantly different according to the LSD test.*

Table 6: *Sources of vegetables that contain contaminated vegetables.*

Market	Source of vegetables
Besut	Kota Bharu
Setiu	Permaisuri and some villagers grow their own vegetables
Pasir Puteh	Machang
Bachok	Kota Bharu and Tunjong

The survey of vegetable sources from four districts in Terengganu and Kelantan.

Apart from that, an investigation into the sources of vegetables has found that most of the vegetables come from similar sources. The vegetables that were detected to have high Mn and Fe content were supplied from the Kota Bharu, Tunjong, and Permaisuri areas (Table 6). Vegetables sold in Setiu mostly originate from Permaisuri, and the villagers there also grow their vegetables. Moreover, they did not import their vegetables from Kelantan, unlike the other three local markets.

Effective sampling is very important, where vegetables are randomly collected from various markets (Ogbeide and Henry, 2024). These methods allow the identification of the extent of contamination and the specific heavy metals present in vegetables at random places. The assessment of data by comparing the detected levels of heavy metals against established safety standards can determine potential risks to human health as well as understand how phytoremediation can be employed to mitigate these risks (Abdelaal *et al*., 2021).

The differences in heavy metal content between locations can be attributed to several factors. Previous studies have found that agricultural activities, including the use of fertilizers and pesticides, have also become one of the main factors that have elevated the heavy metal content in soil and water (Alengebawy *et al*., 2021). The cultivation of leafy vegetables, including pak choi, choy sum, and amaranth in Pahang, shows a high content of arsenic and Pb (Sulaiman *et al*., 2020). On the other hand, the *S. oleracea* collected from the conventional farms in Kuala Selangor has high concentrations of Pb and Cd (See *et al*., 2025). Besides, the *S. oleracea* specimen collected from Pasar Siti Khadijah, Kota Bharu, has a high content of Fe, Cu, Zn, and Pb (Synn and Samad, 2022).

Fe was found to be one of the highest metals recorded in mustard green and water spinach in Terengganu and Kelantan. The main sources of Fe toxicity are usually soil waterlogging, which increases Fe availability exponentially (Leblebici *et al*., 2020). Apart from that, the accumulation of Fe in plants may be the consequence of irrigation with contaminated water, the addition of fertilizers and metal-based pesticides, industrial emissions, transportation, harvesting process, activities during storage, and sale (Nikolić *et al*., 2014). High contents of this heavy metal in soil are supposed to increase the risk of uptake by plants, considering the positive correlation between the metal content in soils and vegetables (Sandeep *et al*., 2019).

Moreover, manganese is also found in higher concentrations in Terengganu and Kelantan local markets. Mn can be found normally in water, air, and rocks (Haque *et al*., 2021). Vegetables derived from raw wastewater areas were found to contain high quantities of heavy metals, especially in the developing world (Aftab *et al*., 2023; Maryam *et al*., 2025). When other available heavy metals like calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), and silicon (Si) are insufficiently present, Mn toxicity can be increased (Sandeep *et al*., 2019). Numerous studies have demonstrated that several crops, including potato, onion, garlic, carrot, and radish, followed by green vegetables such as spinach, lettuce, cabbage, and cauliflower, have a high accumulation of Mn (Sandeep *et al*., 2019; Sulaiman *et al*., 2020; Ilyas *et al*., 2023; Amjad *et al*., 2024).

Apart from that, the analysis has shown that the vegetables grown in Terengganu and Kelantan have a lower level of Mn, Fe, and Ni compared to Sarawak, Sabah, Pahang, and Selangor, but it is highly contaminated with Cu (Sulong *et al*., 2022; Rajan *et al*., 2021; Sulaiman *et al*., 2020; See *et al*., 2025). Various factors, including the chemical composition of the soil and the presence of pollutants in the surrounding environment, influence this phenomenon. The Beach Ridges Interspersed with Swales (BRIS) soil of the eastern Peninsular may contribute to the high Cu content. BRIS soil has characteristics that include low nutrient content, sandy soil, and low water retention capacity (Ishaq *et al*., 2014). Farmers need to use more fertilizers, such as copper-related fertilizers, fungicides, and pesticides, to increase the yield. These factors can increase the copper content in the vegetables found in the local markets.

Understanding these dynamics is crucial for researchers aiming to mitigate health risks associated with heavy metal consumption through vegetables, emphasizing the need for regulatory measures to monitor and improve vegetable quality in contaminated areas.

Conclusions and Recommendations

The present study successfully met its experimental objectives by determining the levels of heavy metals in selected vegetables and identifying the sources of contamination in fresh market produce. The analysis revealed significant variations in heavy metal concentrations across the vegetables tested. These differences may be attributed to the geological characteristics of the study area and the varying abilities of plant species and their specific parts to accumulate metals. While most heavy metal concentrations were below the maximum permissible limits, elevated levels of manganese, cadmium, and copper were observed. Overall, the majority of the sampled vegetables appear to be safe for human consumption. Nonetheless, regular monitoring by appropriate regulatory bodies is recommended to reduce potential health risks associated with heavy metal contamination. As this study focused solely on leafy vegetables, there is a need for further research into tuber and non-leafy vegetables to evaluate their associated health risks. Future studies should broaden the range of vegetable types analyzed and aim to assess health risks across a wider population.

Additionally, conducting a detailed analysis of metal bioavailability would contribute to a more accurate evaluation of health risks. Further investigation is essential to thoroughly assess the health impacts of daily consumption of leafy vegetables, particularly among vulnerable population groups. The findings of this study may serve as a valuable resource for stakeholders in developing strategies to prevent long-term health effects from heavy metal exposure.

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Novelty Statement

Although a small amount of heavy metal is essential for plant growth, high amounts could become toxic to vegetables and consumers. In the current study, the specimens were collected randomly from three different fresh markets in two districts of Terengganu and Kelantan, respectively. The specimens were screened for the heavy metal content and their sources of planting areas.

Author's Contribution

Azman Azid, Saiful Iskandar Khalit and Mohd Fahmi Abu Bakar: Designed the study and analyzed the data.
Nurul Hazirah Shahrul Nizam: Performed the field work and collected the data.
Nik Marzuki Sidik and Mohd Fahmi Abu Bakar: Drafted and reviewed the manuscript.

Generative AI and AI-assisted technology statement
The authors have declared there is no generative AI and AI-assisted technology used in this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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