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Metal concentration and environmental risk assessment of roadside soils in highly urbanized areas of Bukidnon, Philippines

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Abstract. *Labajo JRN, Cristobal JU, Pabiona MG, Tan RS, Gutierrez-Suson J, Ebare-Tiongco L. 2025. Metal concentration and environmental risk assessment of roadside soils in highly urbanized areas of Bukidnon, Philippines. Nusantara Bioscience 17: 68-83.* Five urbanized localities in Bukidnon were selected based on population density and vehicular activities. Soil samples were collected, and metal concentration was determined using AAS, sediment quality guidelines, and the contamination index. The study assessed the metal concentration and environmental risk assessment of soil along the road from five localities in the Province of Bukidnon: It was observed that the highest total concentration for Mn (229.46±21.26), Fe (199.87±51.78), Co (38.13±16.18), Zn (32.43±19.13), Cu (18.17±4.52), Cr (17.95±1.76), and Cd (0.901±0.063) mg kg^{-1} respectively, Mn, exhibited the highest (lgeo), of "moderately contaminated" level. Co was the highest CF value corresponding to "moderate contamination." The Pollution Load Index (PLI) value of all sampling sites was "perfection or low pollution index." Mn has the highest EFs of "moderately severe enrichment." The Potential Ecological Risk Index (PERI) revealed that metals are "low risk" and "low." For a multi-element factor, there is "no potential ecological risk" for all study sites. The Toxic Risk Index (TRI) shows "no toxic risk" observed by the metal(iod)s. While Cr has the highest mHQ, with "low severity of contamination." The study underscores the need for practical measures to mitigate metal contamination in agricultural areas, recommending that policymakers, local government officials, and stakeholders develop mitigation approaches to protect the environment and public health.

Keywords: Bukidnon, environmental risk assessment, geo-accumulation index, metal concentration, soil contamination

Abbreviations: Cfi: Contamination Factor, EF: Enrichment Factor, ERL: Effect Range Low, Igeo: Geoaccumulation, mHQ: Modified Hazard Quotient, MPI: Modified Pollution Index, PEL: Probable Effect Level, PERI: Potential Ecological Risk Index, PLI: Pollution Load Index, SEL: Severe Effect Level, SQGs: Sediment Quality Guidelines, TEL: Threshold Effect Level, TRI: Toxic Risk Index

INTRODUCTION

Bukidnon is a province situated in the Northern Mindanao region of the Philippines. It is regarded as one of the country's major agricultural regions and has a large land area. The region's rich soil supports the growth of crops such as rice, corn, sugarcane, bananas, and vegetables (Giles et al. 2019). Due to industrialization, bioaccumulation through food chains, metals potentially threaten ecological and agricultural systems and human health. With the increasing industrialization and growing amount of vehicle activities, recent studies show that the metal concentration in soil, water, air, or biological organisms exceeds the background levels of the respective element. Heavy metals may be released into the environment by human activities such as industrial processes, mining, and transportation, resulting in soil, water, and air contamination. Heavy metals hazardous effects on human health and the environment have motivated investigations into their occurrence, distribution, and accumulation in the atmosphere. Heavy metals in soil and vegetation can lead to bioaccumulation, where these metals are absorbed by plants and animals, ultimately leading to human exposure through the food chain (Jaishankar et al. 2014). Heavy metal exposure can result in serious health concerns such as cancer, neurological diseases, and organ damage (Mahurpawar 2015). The heavy metal pollution in Philippine urban centers, critical gaps remain in understanding contamination dynamics in unique agro-urban interfaces like Bukidnon. Urbanization and vehicular activities in Bukidnon contribute to elevated metal concentrations in roadside soils, posing ecological risks measurable through integrated pollution indices.

Sediment Quality Guidelines (SQGs) are instruments used in environmental regulation to evaluate sediment quality in bodies of water. Next, to protect aquatic organisms and public health, SQGs are created based on the concentration of toxic substances in sediment. Sediment toxicity tests, bioaccumulation studies, and ecological risk assessments are just a few sources from which the SQGs are derived. The SQGs are expressed as contaminant concentrations in sediment (Gao et al. 2016). The potential risk to aquatic organisms and public health is assessed by comparing these concentrations to those observed in the environment.

The Sediment Quality Triad is one of the SQGs frequently used and is more useful than global sediment quality (Lison et al. 2020). Three elements comprise the triad: chemical characterization of sediment contaminants, toxicity testing with benthic organisms, and assessment of the benthic community. Another commonly utilized set of SQGs is Canada's Sediment Quality Guidelines for the Protection of Aquatic Life (Canadian Council of Ministers of the Environment 2018). These recommendations provide threshold concentrations for various contaminants in sediment, such as metals, pesticides, and Polycyclic Aromatic Hydrocarbons (PAHs). SQG development is a continuous process as more knowledge about the toxicity of contaminants and their effects on aquatic life and human health becomes available.

The term "pollution assessment" in the context of heavy metals refers to the assessment of environmental contamination with heavy metals, which can result from various anthropogenic activities, including industrial processes, mining, and agriculture. The roadside soil contamination in Bukidnon, Philippines, was assessed employing six indices: Geo-accumulation (Igeo), Contamination Factor (CF), Pollution Load Index (PLI), Enrichment Factor (EF), Potential Ecological Risk Index (PERI), and Toxic Risk Index (TRI). By synthesizing these tools, the study bridges a critical gap in multi-index applications for agricultural-urban interfaces, offering a replicable model for similar regions in ASEAN. Heavy metal concentrations in soil, water, sediment, and biota are measured to assess the degree of pollution and identify potential risks to people's and ecosystems health. The technique has also been widely applied in numerous studies on the evaluation of heavy metal pollution, including the Index of Geoaccumulation (Igeo) (Muller 1969), Pollution Load Index (PLI) (Tomlinson et al. 1980), Enrichment Factor (EF) (Mokhtarzadeh et al. 2020), Potential Ecological Risk Index (PERI) (Hakanson 1980; Hu et al. 2019). A contamination factor, usually soil or sediment, is a measurement of the level of heavy metal contamination in that sample compared to a reference sample from an uncontaminated area. The contamination factor is frequently used in environmental research to evaluate the level of heavy metal pollution and the potential risks to the environment and human health. The work of Muller (1969), who created a method for assessing heavy metal pollution in sediment using several pollution indices, including the contamination factor, contains one of the earliest references to the contamination factor. Previous studies in the Philippines focused on single metals or regions, neglecting Bukidnon's unique agro-urban dynamics. This study addresses this by combining geochemical and ecological risk analyses. Heavy metal accumulation in Bukidnon's roadside soils threatens food safety and ecosystem health, yet comprehensive risk assessments are lacking.

This research assessed the metal concentration in the roadside soil of the five highly urbanized localities in Bukidnon, Philippines. Specifically, the study aimed to: (i) Determine the concentration of metals (e.g., cadmium, chromium, copper, cobalt, Iron, manganese, and Zinc) in soil samples collected from roadside areas Malaybalay, Valencia, Maramag, Don Carlos, and Quezon, Bukidnon; (ii) Evaluate the potential risks related with metal contamination in the roadside soil of the study area; and (iii) Compare the five localities metal concentrations in soil samples and identify any significant differences.

MATERIALS AND METHODS

Sampling sites, sample collection, and analysis

A 5-10 cm surface soil/topsoil was collected from each selected sampling site from five localities in the Province of Bukidnon along the Sayre Highway, shown in Table 1. Samples were collected 1 meter from roads to capture deposition from vehicular emissions, avoiding direct runoff. Composite samples (10-15 per site) ensured spatial representativeness. The collection was done during the dry season from April to May 2023. Twenty-four soil sediments were collected from five localities along the Sayre Highway from Cagayan to Davao Road (Figure 1). Soil samples from each location were homogenized and air-dried in circulating air at 30°C, sieved through a 0.2 mm mesh, placed in labeled ziplock bags, and analyzed in Soil and Plant Analysis Laboratory (SPAL), Central Mindanao University (CMU), Maramag, Bukidnon, Philippines. Metals were analyzed via Flame AAS (Agilent 240FS) after the soil was digested with H_2SO_4-H_2O_2 digestion method (Sanders 2012). Quality control included reference material. Cd, Cr, Cu, Co, Fe, Mn, and Zn were prioritized due to their prevalence in vehicular emissions (e.g., tire wear, lubricants). As and Pb were excluded due to equipment constraints but flagged for future work.

Sediment quality guidelines

Several experts have accepted Sediment Quality Guidelines (SQGs) for the toxicological evaluation of sediment-related metals, promoting soil condition monitoring and biota safety, and implementing ecological and environmental policies and guidelines. SQGs, such as Probable Effect Level (PEL), Severe Effect Level (SEL), Threshold Effect Level (TEL), Effect Range Low (ERL), Effect Range Medium (ERM), and Lowest Effect Level (LEL), were used to assess the potential biotic influence of metal(oid)s estimated in soil samples (Rahman et al. 2014).

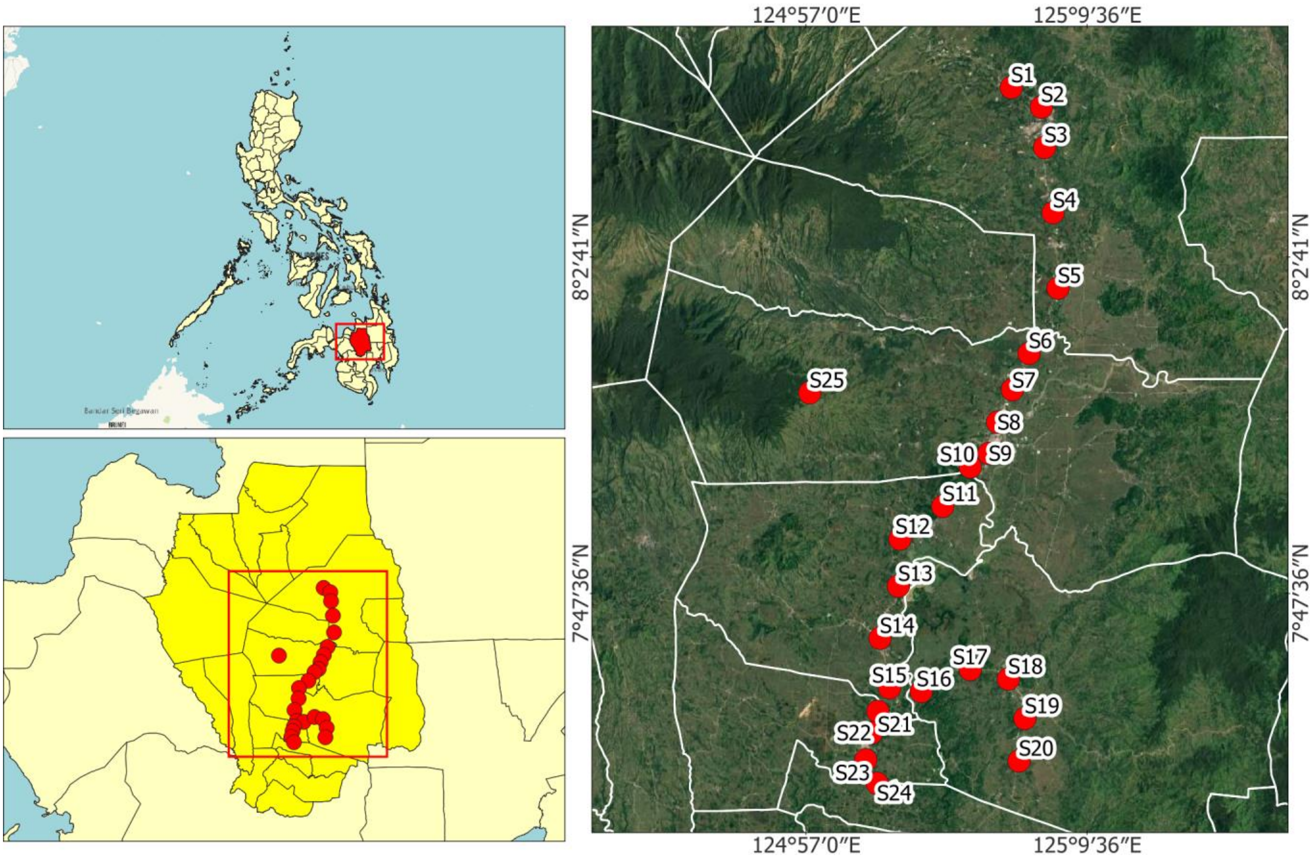

Figure 1. Location map of the study sites of the five localities in Bukidnon, Philippines

Table 1. Location of the five localities in Bukidnon along the Sayre Highway and sampling sites of the study

Location/localities	Barangay	Site	GPS Coordinates	
			Latitude	Longitude
Malaybalay City	Kalasungay-Sumpong, Sayre Highway	S1	8.171441°	125.103377°
	Malaybalay City Proper, Sayre Highway	S2	8.156778°	125.125834°
	Casisang-San Jose, Sayre Highway	S3	8.126646°	125.128267°
	Laguitas-Aglayan, Sayre Highway	S4	8.077913°	125.134625°
	Cabangahan-Bangcud, Sayre Highway	S5	8.021518°	125.138337°
Valencia City	Colonia-Dabong-dabong, Sayre Highway	S6	7.972782°	125.116646°
	Bagontaas, Sayre Highway	S7	7.945641°	125.104181°
	Hagkol, Valencia City, Sayre Highway	S8	7.921394°	125.093103°
	Poblacion, Valencia City, Sayre Highway	S9	7.898098°	125.086565°
	Lumbo, Sayre Highway	S10	7.887847°	125.072786°
Maramag	Musuan-Dologon, Sayre Highway	S11	7.858441°	125.052152°
	Tubigon-Bayabason, Sayre Highway	S12	7.834034°	125.020144°
	Panadtalan, Sayre Highway	S13	7.798834°	125.018918°
	Poblacion, Maramag, Sayre Highway	S14	7.759908°	125.005250°
	Camp 1, Sayre Highway (Quezon and Don Carlos)	S15	7.722809°	125.012364°
Quezon	Blue Water-Zubiri Village, Sayre Highway	S16	7.720066°	125.036069°
	San Jose, Sayre Highway	S17	7.736545°	125.072693°
	Poblacion, Quezon, Sayre Highway	S18	7.729403°	125.101166°
	Salawagan, Sayre Highway	S19	7.699946°	125.113549°
	Mibantang, Sayre Highway	S20	7.668192°	125.109175°
Don Carlos	Sinanguyan, Sayre Highway	S21	7.705232°	125.003633°
	Poblacion1, Don Carlos, Sayre Highway	S22	7.689238°	124.998808°
	Poblacion 2, Don Carlos, Sayre Highway	S23	7.669020°	124.994597°
	Pinamaloy, Sayre Highway	S24	7.651526°	125.003027°
Background soil	Mt. Kalatungan, Mt. Nebo Valencia City	S25	7.943360°	124.952730°

Metal pollution assessment

Six major indices were used in this study to assess pollution based on toxic metal concentrations in soil and samples: Geo-accumulation index (Igeo), Contamination factor (Cfi), Pollution Load Index (PLI), Enrichment Factors (EFs), Potential Ecological Risk Index (PERI), Modified Pollution Index (MPI), and degree of contamination (Cd). These indexes have the potential to be effective in comprehensively assessing the degree of soil pollution (Mazurek et al. 2017).

Geo-accumulation Index (lgeo)

Muller (1969) presented the geo-accumulation index (Igeo). This index quantifies the degree or level of metal pollution in the soil samples presented in Table 2. The following formula was used to determine the geo-accumulation index (Igeo) for sediment samples:

$$I_{geo} = \log_2\left[\frac{C_n}{1.5B_n}\right]$$

Where: "Cn" is the metal concentration measured in sediment samples in the study area. Bn is a natural compositional and mineralogical concentration of any specific metal in an undisturbed or parent source, and 1.5 is the background matrix correction due to lithological effects.

Contamination Load Index (CF)

The contamination factor for the same metal (c) was calculated by comparing the pre-industrial reference value with the same metal concentration in soil samples. The total of all contamination factors determines the degree of contamination, and the following is the formula used to calculate the Contamination Factor (Cfi):

$$C_f^i = \frac{C^i}{C_n^i}$$

Where: Cfi is the measured concentration of metals in soil samples, and Cni is the standard pre-industrial reference level Table 3. The contamination levels may be classified based on their intensities on a scale ranging from 0 to 6, "0" none, "1" none to medium, "2" moderate, "3" moderately to strong, "4" strongly polluted, "5" strong to very strong, "6" very strong.

Pollution Load Index (PLI)

The Pollution Load Index (PLI) was computed using the Contamination Factors (Cfi). The Cfi is the quotient calculated by dividing the concentration of each metal. By taking the n-root from the n-CFs that were obtained for each metal, the PLI of the site was determined. The Pollution Load Index (PLI) is often displayed as follows, according to Tomlinson et al. (1980):

$$\text{PLI} = \sqrt[n]{C_{f1} x C_{f2} x C_{f3} x \ldots\ldots\ldots x C_{fn}}$$

Where: "n" is the quantity of the studied metals, previously mentioned in a prior condition, and "Cf" is the contamination factor. The PLI supplies a simple yet reasonable intent to evaluate a site's quality where an estimation is made (Tomlinson et al. 1980). PLI less than one indicates perfection; PLI more than one indicates a decline in site quality; and PLI = 1 indicates that only baseline contamination levels are available.

Table 2. Geo-accumulation index values

Index class	Lgeo value	Level of contamination classification
0	$I_{geo} < 0$	Uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderate contamination
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily (strongly) contaminated
4	$3 < I_{geo} < 4$	Heavily (strongly) contaminated
5	$4 < I_{geo} < 5$	Heavily (strongly) extremely contaminated
6	$I_{geo} \geq 5$	Extremely contaminated

Note: In most cases, obtaining the background value of any particular metal of interest from the pre-industrial period is practically impossible. Due to this reason, researchers have adopted different approaches for acquiring the (B_n) Background Value of any metal of interest to perform the I_{geo} calculation. The B_n is obtained using the standard permissible limit prescribed (WHO 1995, 2010, 2016). The geo-accumulation index was proposed by Muller in 1969 and is based on the seven grades or classes shown in Table 3

Table 3. Background levels of the metal

Metal	Background (mg kg^{-1})	Pre-industrial reference level	FAO/WHO maximum permissible values soil (mg kg^{-1})	Toxic response factor
Cadmium	1.1	1	0.800	30
Chromium	31	90	100	2
Cobalt	36	36	0.1-50	5
Copper	25	50	36	5
Iron	3.12	7000	7000-50000	--
Manganese	400	850	2000	1
Zinc	65	175	50	1

Enrichment Factor (EFs)

The level of contamination is measured using the enrichment factors and was determined using the formula based on Mokhtarzadeh et al. 2020:

$$EF = \frac{\left(\frac{C_i}{C_{ref}}\right)_{Sample}}{\left(\frac{C_i}{C_{ref}}\right)_{background}}$$

Where: "Ci" is the target element's concentration, and "C_{ref}" is the reference element's concentration. The reference element used was an undisturbed soil sample for each site because of its low concentration (Mokhtarzadeh et al. 2020). The classification of Enrichment Factors (EFs) using the following indicators: EF < 1 indicates no enrichment, EF < 3 is minor enrichment, EF = 3-5 is moderate enrichment, EF = 5-10 is moderately severe enrichment, EF = 10-25 is severe enrichment, EF = 25-50 is very severe enrichment, and EF > 50 extremely severe enrichment.

Potential Ecological Risk Index (PERI)

With the increasing amount of heavy metals in sediments that could harm ecological health, an ecological risk assessment has been used as a diagnostic tool for water pollution prevention for heavy metals (Hu et al. 2019). A technique for evaluating a potential ecological risk index was created by Hakanson in 1980. This method considers the potential Ecological risk factor (Eri) of a single element, and the following formulas can be used to calculate the PERI of a multi-element (Rahman et al. 2014):

$$E_r^i = T_r^i / C_f^i$$

$$RI = \sum_{i=1}^{n} E_r^i$$

Where: Cfi is the contamination factor for the element of "i"; "Tri" is the toxic response factor for the given element of "i," which accounts for the toxic and sensitivity requirements. Using the potential ecological risk assessment. Then, to assess the RI, the following terminology was used: RI < 150 is low risk, 150 ≤ RI < 300 is moderate, 300 ≤ RI < 600 considerable, and RI ≥ 600 is very high. Moreover, to describe the (ERF), the following terminology was used: Er < 40, low, 40 ≤ Er < 80, moderate, 80 ≤ Er < 160, considerable, 160 ≤ Er < 320, high, and Er ≥ 320, very high.

Toxic Risk Index (TRI)

Zhang et al. 2020 developed the toxic risk index, which was used to give a more thorough assessment of environmental biota danger. The following formula was utilized to determine TRI using two threshold values for SQGs (TEL and PEL standard):

$$TRI_i = \sqrt{\frac{(C_i/TEL_i)^2/(C_i/PEL_i)^2}{2}}$$

Where: The concentration of ith metal is Ci, and the probable effect level is "PEL," and threshold effect levels are "TEL" for the ith metals. To interpret the TRI using the following values: TRI ≤ 5 indicates no toxic risk, 5 < TRI ≤ 10, low toxic risk, 10 < TRI ≤ 15, moderate toxic risk, 15 < TRI ≤ 20, considerable toxic risk, and TRI > 20, very high toxic risk.

Modified Hazard Quotient (mHQ)

The modified hazard quotient is a novel approach to evaluating the level of risk that each metal poses to living organisms in an area (Barjoee et al. 2021). Its reliability, validity, and accuracy have been established by (Benson et al. 2018). This method detects contamination by comparing metal concentrations in sediment (mg kg^{-1}) to adverse ecological impact distributions at slightly different Threshold Effect Levels (TEL), Probable Effect Levels (PEL), and Severe Effect Levels (SEL), as previously described. The distributions are shown in Table 4. The mHQ index is determined using the following formula:

$$HQ = \sqrt[2]{\left[C_i\left(\frac{1}{TEL_i} + \frac{1}{PEL_i} + \frac{1}{CEL_i}\right)\right]}$$

Where: Ci is the analyzed sample's determined metal concentration. Eight categories of contamination were identified from the mHQ values: mHQ > 3.5 (extreme severity), 3.0 ≤ mHQ < 3.5 (very high severity), 2.5 ≤ mHQ < 3.0 (high severity), 2.0 ≤ mHQ < 2.5 (considerable severity), 1.5 ≤ mHQ < 2.0 (moderate severity), 1.0 ≤ mHQ < 1.5 (low severity), 0.5 ≤ mHQ < 1.0 (very low severity), and mHQ < 0.5 (nil to very low severity).

Data analysis

Microsoft Excel 2012 was used to perform statistical analysis on the mean and standard deviation. The associations between metal concentration were assessed using the Pearson correlation coefficient and stepwise multiple regression analysis using STAR IRRI Nebula Software.

Table 4. Recommended sediment quality guideline values for metal and associated levels of concern are to be used in assessing sediment quality

Metal	TEL, mg kg^{-1}	SEL, mg kg^{-1}	PEL, mg kg^{-1}
Cadmium	0.99	2	1.2
Chromium	43.4	110	26
Cobalt	--	--	--
Copper	31.6	110	16
Iron	--	--	--
Manganese	--	--	--
Zinc	121	820	163

Sources: MacDonald et al. (2000a, b); de Deckere et al. (2011)

RESULTS AND DISCUSSION

Total metal concentration

The total Cd concentration in soil samples taken from the study sites was 0.901 ± 0.063 mg kg$^{-1,}$ ranging from 0.772 to 1.034 mg kg^{-1} (Figure 2.A). The average Cd concentration in the sampling sites was found to be greater than the FAO's allowable limit value of 0.800 mg kg^{-1}, except for site 3, with the lowest Cd concentration of 0.772 mg kg^{-1}, and site 24, which shows the highest Cd concentration value of 1.034 mg kg^{-1}. Higher than the background value of 0.596 mg kg^{-1} from an undisturbed soil sample. A similar result was observed in roadside soils in the City of Cagayan de Oro, which had a Cd concentration ranging from 0.07 to 0.51 mg kg^{-1} (Olarte and Besagas 2019). Cd contamination is particularly concerning in urban areas, where vehicular emissions and other anthropogenic activities have been identified as significant contributors. Roadside soils are particularly vulnerable to cadmium contamination, which can contaminate crops and groundwater, pose significant health risks to humans and animals, and negatively impact soil quality and nutrient cycling, leading to ecological damage (Zhang et al. 2016). Cd exposure can have adverse effects on human health and the environment, including reduced growth and survival of plants, changes in soil microorganisms, and increased bioaccumulation of metals in the food chain (WHO 2010; Abbas et al. 2018).

The average total Cr concentration in soil sampling sites from five localities along the Sayre Highway was 17.95 ± 1.76 mg kg$^{-1,}$ ranging from 16.233 to 24.693 mg kg^{-1}, as shown in Figure 2.B. The mean Cr concentration of the studied soil samples was higher than or equal to the background soil value of 16.77 mg kg^{-1} and lower than the FAO/WHO maximum allowed value of 100 mg kg^{-1}. It also shows that the highest concentration of Cr among the 24 sampling locations was observed in site 2, which has a Cr concentration value of 24.693 mg kg^{-1}. In contrast, site 5, site 12, and site 23 showed the lowest Cr concentration value of 16.233 mg kg^{-1}. A similar result was observed in many places in the Philippines and other countries: Iloilo, Philippines (Sarinas et al. 2007), in Romblon Province (Senoro et al. 2022), lower than the soil quality standard of 64 mg kg^{-1} (Canadian Council of Ministers of the Environment 2022). Chromium contamination in roadside environments is a significant concern due to its potential environmental impact on human health. This contamination could result from chromium leaching from metal-plated car parts, brake linings, and other industrial sources (Bulska 2011; Balaji et al. 2023). Several studies have investigated the levels of chromium in roadside soils and plants, with many findings elevated concentrations of the toxic hexavalent form (Kaur et al. 2021; Prasad et al. 2021). Heavy metals contaminate areas through industrial effluents, sewage and sludge, and vehicular emissions. As a result, vegetables cultivated on such grounds are likely unfit for human consumption due to heavy metal contamination (Hembrom et al. 2020; Proshad et al. 2020).

The average concentration of total Co in the soil samples from sampling sites along the Sayre Highway was 38.130 ± 16.183 mg kg$^{-1,}$ ranging from 8.852 to 70.191 mg kg^{-1} (Figure 2.C). The data shows that some of the sites have higher Co concertation samples from S1, S5, S7, S8, S10, S15, S17, S18, S22, and S24 having the highest recorded Co concentration values ranging from 37.580 to 70.191 mg kg^{-1} higher than the FAO/WHO maximum permissible limit of 36 mg kg^{-1} (WHO 1995), and higher than the background soil value of 32.15 mg kg^{-1}. Similar results were found in a study in Tacloban City, Philippines (Pacle-Decena et al. 2018). It shows that soil contamination of Co is anthropogenic, mainly due to activities like burning coal and oil or industrial waste and emissions. On the other hand, high doses may result in polycythemia, anemia, and congestive heart failure (Lison 2022). Cobalt plays a crucial role in the fixation of N2, which gives crops the macronutrient N (Hu et al. 2021). Co is part of the composition of proteins and enzymes in plant metabolism.

The soil samples had the second-highest concentration of total iron among all the elements assessed in the study. The concentration in the soil samples was 105.583 to 298.113 mg kg^{-1}, shown in (Figure 2.D), with an average value of 229.72 ± 21.46 mg kg^{-1}. The results in different sampling sites show a lower Fe concentration value than the FAO/WHO maximum permissible limit of 7,000 to 50,000 mg kg^{-1}. The study also shows an accumulation of Fe due to its higher concentration than the background soil concentration value of 58.191 mg kg^{-1}, indicating that the Fe source might be mainly anthropogenic. Most Bukidnon soil is predominantly Adtuyon soil series, which is clay loam derived from weathering basalts, andesites, and other igneous rock (Carating et al. 2014). In the Philippines, 6,367 mg kg^{-1} was observed in the Romblon Province (Senoro et al. 2022). Human activities such as industrial emissions, wastewater, and solid waste are the most significant anthropogenic sources of heavy metal soil pollution (Sodango et al. 2018). Iron can also negatively affect human health when it is present in high environmental concentrations. Exposure to iron-rich particulate matter from traffic was connected to a higher risk of lung cancer in urban populations (Fussell et al. 2022; Hammond et al. 2022).

This total Mn concentration in soil samples was 229.720 ± 21.458 mg kg^{-1}, with the highest element concentration among the other elements in the study (Figure 2.E). Soil samples have Mn concentrations ranging from 193.094 to 295.719 mg kg^{-1}. The sampling site 23 has the highest Mn concentration. However, the average Mn concentration value was higher than the background soil value of 35.490 mg kg^{-1} and lower than the FAO/WHO maximum allowable value of 2000 mg kg^{-1}. This indicates that Mn accumulation is present in these areas and that the primary sources of Mn in the study sites may be anthropogenic and natural. Senoro et al. 2022 also reported a 14.93 mg kg^{-1} Mn concentration in Romblon Province, Philippines, lower than the Mn concentrations of the present study. Mn is essential for proper neurological function, bone development, and wound healing. However, excessive intake or exposure to high Mn concentrations can negatively affect human health. Chronic exposure to elevated Mn levels can harm the central nervous system, liver, and kidneys, and neurotoxic effects, particularly a condition known as manganism (Miah et al. 2020).

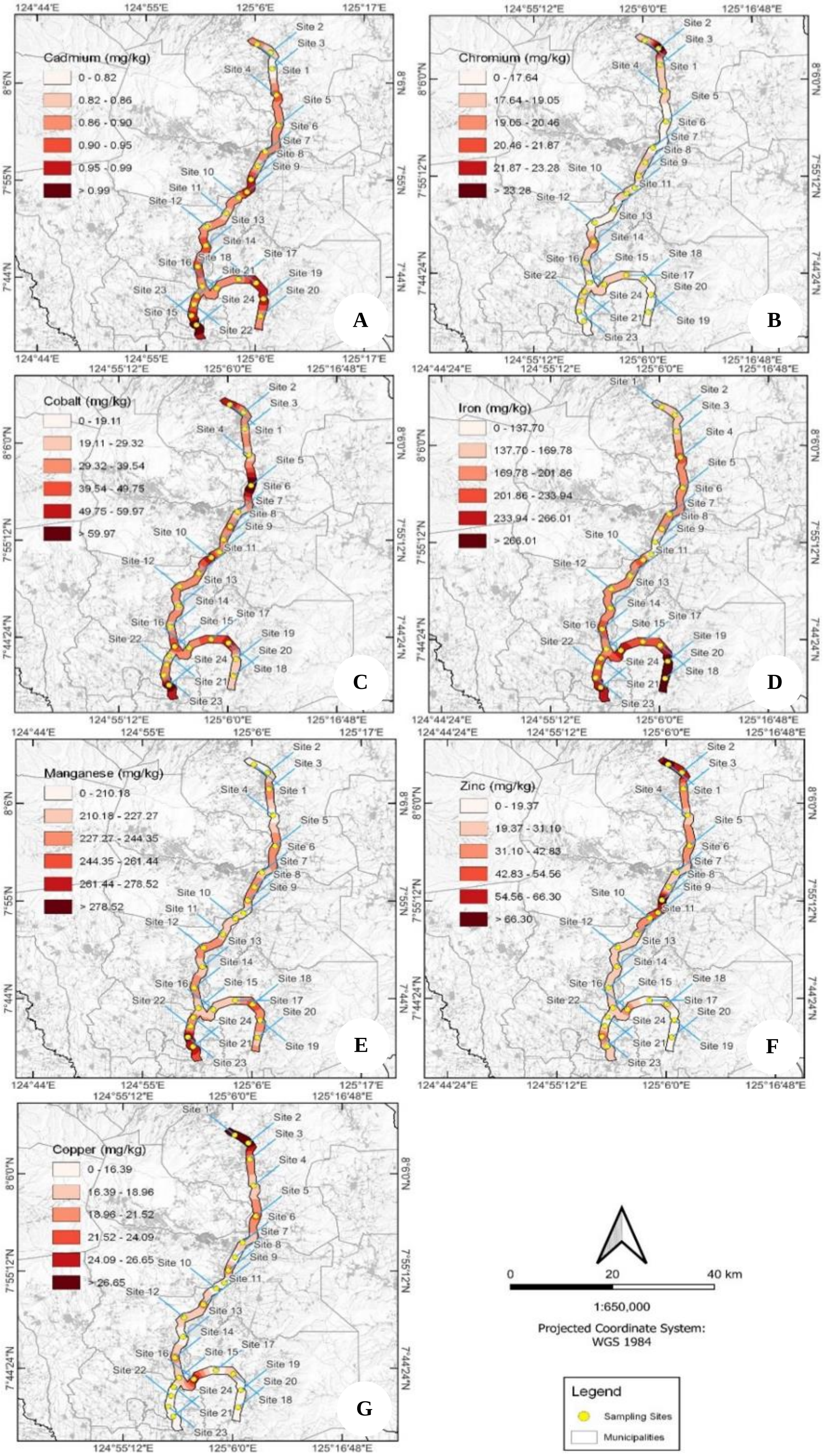

Figure 2. Spatial distribution of metal concentration for: A. Cadmium; B. Chromium; C. Cobalt; D. Copper; E. Iron; F. Manganese; and G. Zinc in roadside soil of five highly urbanized localities in the Province of Bukidnon, Philippines

The soil sampling sites had a mean total Zn concentration of 32.427 ± 19.133 mg kg^{-1}, ranging from 7.623 to 69.283 mg kg^{-1}. This study showed that the zinc concentration in soil samples from 24 sampling locations along the Sayre Highway is less than 50 mg kg^{-1} FAO/WHO maximum permissible value. However, some sampling sites that exceed the allowable limit, such as S1, S2, S9, and S23, are shown in (Figure 2.F). Zinc is also commonly used in industrial and consumer applications, such as galvanizing steel and manufacturing batteries. Excessive exposure to Zinc can adversely affect human health and the environment. Zinc contamination along roadsides can occur from various sources, including traffic-related emissions, road dust, and runoff from galvanized steel and other zinc-containing materials. Elevated zinc levels in roadside soils and plants can adversely affect soil quality and plant growth and pose the risk of human exposure (Alengebawy et al. 2021; Angon et al. 2024).

The collected soil samples have a mean total Cu concentration of 18.173±4.516 mg kg$^{-1,}$ ranging from 13.073 to 29.220 mg kg^{-1}. The highest Cu concentration was at sampling site 1, while the lowest Cu concentration was found to be at S20, as shown in Figure 2.G. Subsequently, the study findings were lower than the Cu concentration in soil/sediments of FAO/WHO maximum permissible value/limit of 50 mg kg^{-1} (Table 3). It also revealed that soil samples from different sampling sites were higher than the background soil sample of 12.765 mg kg^{-1} Cu, which showed an accumulation of Cu in the soil. All soil samples were lower than the WHO permissible limit, indicating a low impact of Cu on ecology and suggesting enough supply of Cu for plant uptake. A study by Senoro et al. 2022, shows 233.10 mg kg^{-1} of Cu in the Romblon Province, higher than the Cu permissible limit. Copper can enter the environment through natural processes and human activities, such as mining, smelting, and waste disposal (Nyiramigisha, 2021). Elevated levels of copper in soils and water bodies can adversely affect human health and the environment (Xu et al. 2024; Chowdhary et al. 2020). Copper contamination along roadsides can occur from various sources, including traffic-related emissions, road dust, and runoff from copper-containing materials, such as brake pads and wires. Ingestion of high levels of copper has been linked to the development of Wilson's disease. This genetic disorder leads to copper accumulation in the body (Barber et al. 2021; Lucena-Valera et al. 2023). Elevated levels of copper in roadside soils and plants can adversely affect soil quality and plant growth and pose a risk of exposure to humans and wildlife. The pressing issue of heavy metal accumulation in roadside soils can have serious adverse effects on the environment and human health. These results show the critical need for pollution management strategies, sustainable road infrastructure development, and continuous monitoring to reduce heavy metal contamination in urban and rural settings.

Soil total metal concentration in five localities

Table 5 shows the metal concentration in the roadside soil at the five studied localities along the Sayre Highway. The mean and standard deviation values show the average analysis of the results, which shows the decreasing order of metal accumulation in soil samples mg kg^{-1} that was Mn (229.46±21.26) > Fe (199.87±51.78) > Co (38.13±16.18) > Zn (32.43±19.13) > Cu (18.17±4.52) > Cr (17.95±1.76) > Cd (0.901±0.063), respectively. The result showed that the metal concentrations at the sites in the study are below the maximum allowable values or limits for soil and sediments set by the WHO (World Health Organization). According to metal analysis, the soil samples had the highest Mn concentration and the least accumulated cadmium. These metals have accumulated, and as a result, their levels are significantly higher than those of the background soil sample. Additionally, it demonstrates that the average metal concentrations shown were below the standard allowable limit, indicating that the metal concentrations in the roadside soil along the Sayre High in Don Carlos, Malaybalay City, Valencia City, Maramag, and Quezon, Bukidnon, Philippines, are low.

Heavy metal and toxic element accumulation in topsoil horizons in urban areas is a significant environmental issue since it may long-term affect human health, well-being, and soils (Nikolov et al. 2020). The data revealed that Don Carlos Bukidnon, Philippines, has the highest Cd with a mean concentration value of 0.951 ± 0.064 mg kg^{-1}. Higher Cr concentration was found in Malaybalay and Valencia with Cr values of 18.95 ± 3.03 mg kg^{-1} and 18.03 ± 0.951 mg kg$^{-1,}$ respectively. Malaybalay City has the highest average Cu, Co, and Zn concentrations of 23.22 ± 5.28 mg kg^{-1}, 43.32 ± 20.63 mg kg$^{-1,}$ and 46.41 ± 18.59 mg kg^{-1}, respectively. The locality of Quezon, Bukidnon, has the highest concentration in the study, with an average Fe concentration value of 262.568 ± 34.92 mg kg^{-1}. Mn concentration in the soil samples collected from Don Carlos, Bukidnon, with the Mn of 253.57 ± 33.76 mg kg$^{-1,}$ has the highest observed concentration.

Table 5. Metal concentration of soil samples from five different localities along the Sayre Highway in Bukidnon, Philippines (mg kg^{-1})

Area/sites	Total Cd	Total Cr	Total Cu	Total Co	Total Fe	Total Mn	Total Zn
Malaybalay	0.852±0.055	18.95±3.30	23.22±5.28	43.32±20.63	173.12±28.21	218.02±22.17	46.41±18.59
Valencia	0.907±0.070	18.03±0.951	16.85±2.71	38.05±14.16	161.27±55.83	222.54±12.81	43.61±24.89
Maramag	0.891±0.047	17.54±1.53	17.81±2.06	35.10±11.97	179.04±19.13	227.91±10.45	26.27±5.20
Quezon	0.913±0.058	17.41±0.730	17.44±5.65	36.18±14.30	262.57±34.92	231.34±14.71	17.90±11.91
Don Carlos	0.951±0.064	17.758±1.25	14.89±0.571	37.97±25.35	229.25±33.55	253.57±33.76	26.82±17.42
Permissible limit	0.800	100	0.1-50	36	7000-50000	2000	50
Background soil	0.596	16.77	12.77	32.15	58.19	35.49	5.75

The trends of metal concentration of roadside soil in Sayre Highway of five localities in the Province of Bukidnon, Philippines, are shown in Table 6. Mn and Fe are the most common elements found in the roadside soils along the Sayre Highway, where heavy metals are present and accumulate. The elevated amounts of metals relative to background soil values suggest continuous buildup, which may result in long-term environmental deterioration and possible health hazards, even while metal concentrations are still below regulatory limits. Hence, to reduce the dangers of heavy metal pollution, it is crucial to have tighter emission restrictions and ongoing monitoring of metal accumulation.

Pollution assessment

Geo-accumulation Index (lgeo)

The geo-accumulation index (lgeo) has been used widely to assess the degree of pollution. Comparing the differences between pre-industrial and current concentrations makes it possible to evaluate environmental contamination (Li et al. 2014). The average of lgeo values from different sampling sites was found to be Mn (2.104 ± 0.130 mg kg^{-1}), Zn (1.668 ± 0.871 mg kg^{-1}), Fe (1.146 ± 0.395 mg kg^{-1}), Cd (0.008 ± 0.100 mg kg^{-1}), Cu (0.114 ± 0.326 mg kg^{-1}), Co (-0.476 ± 0.668 mg kg^{-1}), Cr (-0.493 ± 0.129 mg kg^{-1}). The detailed data for each metal sampling site can be found in Figure 3. This study revealed that the lgeo for Mn in S1, S2, S4, and S9 were 1.85, 1.98, 1.93, and 1.91, respectively, belonging to index class 2 and indicating "moderately contaminated" Table 2. The rest of the sampling site revealed that the lgeo for Mn, ranging from 2.02 to 2.47, belongs to the index class 3, indicating that the soil samples from this site are "moderately heavily (strongly) contaminated." In S1 and S8 samples, the lgeo for Zn was 3.00 and 3.17, which belong to index class 4, which indicates that there is "heavily (strongly) contaminated," S2, S5, S9, S10, S16, and S23 has lgeo value ranging from 2.11 to 2.88, which belongs to index class 3 which indicates that soil samples are "moderate heavily (strongly) contaminated," S19, S20, S21, and S17 belongs to index class of 1 and 0 respectively which indicates soil samples is "no contamination or uncontaminated to moderately contaminated" samples. While S3, S4, S6, S7, S11, S12, S13, S14, S15, S20, and S24 have a lgeo value ranging from 1.02 to 2.00 belongs to index class 2, which indicates that there is "moderate contamination" among all samples.

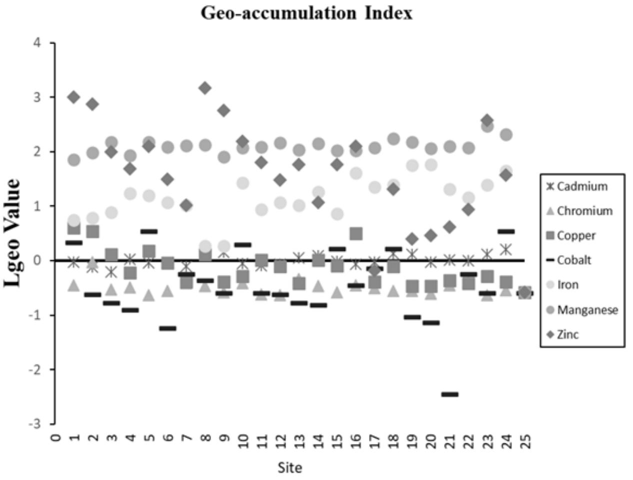

Figure 3. Metal geo-accumulation index (Igeo) of soil in five localities along the Sayre Highway

Table 6. The trend of metal concentrations in the roadside soil in Sayre Highway Bukidnon, Philippines

Areas/sites	Metals in roadside soil
Malaybalay	Mn > Fe > Zn > Co > Cu > Cr > Cd
Valencia	Mn > Fe > Zn > Co > Cr > Cu > Cd
Maramag	Mn > Fe > Co > Zn > Cu > Cr > Cd
Quezon	Fe > Mn > Co > Zn > Cu > Cr > Cd
Don Carlos	Mn > Fe > Co > Zn > Cr > Cu > Cd

Table 7. Comparison of metal concentrations (mg kg^{-1}) in roadside soils with International Guidelines and Regional Studies

Metal	This study (Bukidnon, Philippines)	WHO/FAO permissible limit	EPA RSL (residential soil)	Previous studies in the Philippines	Other regional studies (Asia)
Cd	0.901 ± 0.063	0.800	0.78	0.07-0.51 (Cagayan de Oro)*	0.2-2.2 (Chiang Mai & Lamphun, Thailand)**
Cr	17.95 ± 1.76	100	210	14.93 (Romblon)†	7.84-18.94 (Central Java, Indonesia)‡
Cu	18.17 ± 4.52	50	3100	233.10 (Romblon)†	153.7 (Southern Vietnam)§
Co	38.13 ± 16.18	50	23	10.5 (Tacloban)¶	8.3 (Hanoi, Vietnam)ǁ
Fe	199.87 ± 51.78	7000-50,000	N/A	6367 (Romblon)†	14,410-30,590 (Dhaka, Bangladesh)**
Mn	229.46 ± 21.26	2000	1800	14.93 (Romblon)†	573.32 (China)††
Zn	32.43 ± 19.13	50	23,000	25-70 (Cagayan de Oro)*	70.8-164.2 (Singapore)‡‡

Note: WHO/FAO: World Health Organization/Food and Agriculture Organization. EPA RSL: U.S. Environmental Protection Agency Regional Screening Level (US EPA 2024). * Olarte and Besagas (2019); ** Somsunun et al. (2023); Senoro et al. (2022); Dewi et al. (2021); § Dat et al. (2021); ¶ Pacle-Decena et al. (2018); ǁ Nguyen et al. (2021); ** Khan and Shah (2023); †† Kun et al. (2023); ‡‡ Goh et al. (2022)

The Fe lgeo in the sampling site shows that "contamination" exists. S1, S2, S3, S8, S9, S11, and S15 values ranging from 0.27 to 0.89 belong to index class 1, which indicates that there is "uncontaminated to moderate contamination." While the rest of the sampling sites belong to index class 2 with the lgeo values ranging from 1.01 to 1.77, which indicates that soil samples from these sites are "moderately contaminated." lgeo for Cd in sampling sites S4, S8, S9, S13, S14, S18, S19, S21, S22, S23, and S24 belong to index class 1, which indicates that the soil samples from these following sites are "uncontaminated to moderate contamination." In contrast, the remaining samples from different areas are "uncontaminated." The Cd lgeo values from soil sampling sites S4, S8, S9, S13, S14, S18, S19, S21, S22, S23, and S24 are falling to index class 1, or "uncontaminated to moderately contaminated." In contrast, other sample sites have belonged to "uncontaminated." lgeo values for Cu show that sampling sites from S1, S2, S3, S5, S8, S11, S14, and S16 indicating that there are "uncontaminated to moderately contaminated" in these sampling sites are class 1; other samples were found to be "uncontaminated," the lgeo of Cr were less than zero indicating that the soil samples were not polluted, detailed data of the lgeo values are presented in (Figure 3). While Cd, Cu, Co, and Cr mostly stay within the uncontaminated to moderately contaminated range, Mn and Zn exhibit the highest contamination levels across the sampling sites, according to the geo-accumulation index (Igeo) analysis. These results show possible environmental hazards that could impact soil quality, plant growth, and the general health of the ecosystem, especially in sites with greater contamination levels.

Contamination Factor (CF)

(Cf) was used to quantify the level of contamination concerning measured background values from geologically similar and uncontaminated places or the average crustal composition of a particular metal (Ladigbolu and Balogun 2011), while PLI was used to evaluate the degree to which the soil sediment associated with heavy metals might impact the microflora and macrofauna of the soil (Yadav and Yadav 2018), these two essential indices were proposed to measure the metal pollution in the sediment sample (Hakanson 1980). The Cf of all of the samples from sampling sites of the five localities along the Sayre Highway had the following order: Co > Cd > Cu > Mn > Cr > Zn > Fe with the Cf mean ± SD values of 1.059±0.450, 0.901±0.063, 0.363± 0.090, 0.270±0.025, 0.199±0.019, 0.185±0.109, 0.029±0.007 respectively, falling into class 1 "none to moderate contamination"; detailed information on Cf values for each sampling site is presented in Table 8. Based on the Contamination Factor (Cf) analysis, the highest contamination levels are found in Co and Cd, and all sampled sites along the Sayre Highway fall into the "none to moderate contamination." Although the current level of heavy metal deposition is not yet dangerous, continuous monitoring is necessary to avoid ecological hazards since extended exposure may impact microbial populations, soil health, and general environmental quality. The constant human activities, including industrial discharge, agricultural practices, and vehicle emissions, may eventually lead to an increase in the buildup of heavy metals.

Table 8. Soil quality guidelines for metal concentration for Contamination Factor (CF), Pollution Load Index (PLI)

Area/sites	**Contamination factor**							**Pollution load index**	
	Cd	**Cr**	**Cu**	**Co**	**Fe**	**Mn**	**Zn**	**PLI_{value}**	**PL_{Iindex}**
S 1	0.881	0.204	0.584	1.691	0.021	0.227	0.396	0.319	Perfection
S 2	0.823	0.274	0.558	0.871	0.021	0.247	0.362	0.297	Perfection
S 3	0.772	0.195	0.415	0.785	0.023	0.284	0.197	0.251	Perfection
S 4	0.913	0.199	0.330	0.720	0.029	0.240	0.159	0.241	Perfection
S 5	0.870	0.180	0.436	1.950	0.029	0.284	0.212	0.303	Perfection
S 6	0.871	0.191	0.372	0.569	0.026	0.266	0.140	0.230	Perfection
S 7	0.836	0.210	0.292	1.130	0.025	0.272	0.100	0.235	Perfection
S 8	0.967	0.203	0.415	1.044	0.015	0.272	0.446	0.286	Perfection
S 9	0.996	0.188	0.292	0.893	0.015	0.236	0.335	0.248	Perfection
S 10	0.864	0.210	0.314	1.648	0.034	0.263	0.225	0.294	Perfection
S 11	0.842	0.183	0.388	0.893	0.024	0.267	0.173	0.249	Perfection
S 12	0.853	0.180	0.356	0.871	0.026	0.282	0.138	0.242	Perfection
S 13	0.927	0.221	0.287	0.785	0.025	0.257	0.168	0.243	Perfection
S 14	0.950	0.203	0.388	0.764	0.030	0.280	0.103	0.243	Perfection
S 15	0.882	0.188	0.361	1.562	0.023	0.255	0.168	0.265	Perfection
S 16	0.854	0.205	0.542	0.979	0.038	0.255	0.212	0.294	Perfection
S 17	0.880	0.197	0.292	1.216	0.032	0.263	0.044	0.217	Perfection
S 18	0.977	0.191	0.356	1.562	0.033	0.297	0.123	0.277	Perfection
S 19	0.973	0.190	0.277	0.656	0.042	0.283	0.065	0.221	Perfection
S 20	0.881	0.184	0.277	0.613	0.043	0.262	0.068	0.215	Perfection
S 21	0.906	0.205	0.298	0.246	0.031	0.270	0.076	0.189	Perfection
S 22	0.895	0.211	0.287	1.130	0.028	0.263	0.095	0.238	Perfection
S 23	0.970	0.180	0.314	0.893	0.033	0.348	0.296	0.289	Perfection
S 24	1.034	0.192	0.292	1.950	0.039	0.313	0.147	0.297	Perfection
Mean±SD	0.901±0.063	0.199±0.019	0.363±0.090	1.059±0.450	0.029±0.007	0.270±0.025	0.185±0.109	0.258±0.034	Perfection

Pollution Load Index (PLI)

The pollution in the particular study areas was determined using the pollution load index (PLI) (Tomlinson et al. 1980). This index is a convenient tool for comparing the pollution levels of various sites. The list provides a crucial and pertinent approach when rating a place or an area class. A score of one indicates that only benchmark levels of contaminants are present, whereas zero indicates perfection. On the other hand, some attributes would indicate dynamic site and quality degradation. This study found that the average PLI value for 24 sampling sites was 0.258 ± 0.034, ranging from 0.189 to 0.319, as shown in Table 8. All soil samples pollution load index values were PLI < 1, indicating "perfection or low pollution" status. However, Rahman et al. (2021) and Unsal et al. (2024) suggested that continual observation should be required to measure the pollutant load index more precisely, owing to the contamination of heavy metals in indoor dust samples. In the Pollution Load Index (PLI) analysis, every location sampled has a PLI of less than 1, which denotes a "perfection or low pollution" classification. This implies that no severe heavy metal contamination has occurred in the research locations. However, measurable pollutant levels emphasize the necessity of ongoing monitoring because anthropogenic activities and long-term environmental conditions may lead to progressive accumulation.

Enrichment Factor (EF)

The enrichment factor (EF) of the metal indicator in Table 9 is used to identify the presence and extent of anthropogenic pollution deposition on the topsoil. The possible contamination index is determined by the normalization of one metal's presence in topsoil concerning the presence of another element. An exceptionally stable component of the soil, devoid of vertical movement and degradation events, is referred to as a reference element. Reference elements are selected based on their association with finer particles and their resistance to anthropogenic alterations, ensuring that their concentrations reflect natural processes rather than human activities (Barbieri 2016). Al, Fe, Mn, and Rb are commonly used as reference elements in geochemical investigations, as they aid in identifying geochemical anomalies and normalizing heavy metal concentrations in sediment studies (Sun et al. 2018; Dominech et al. 2022).

Iron (Fe) was chosen as the reference element for determining the enrichment factor in a study by Vineethkumar et al. (2020), pointing out that many researchers studying marine and estuarine ecosystems have used this method. The results of EF of metals in the study are shown in Table 9. The EF ranges from (1.295 to 1.735) with an average of (1.511 ± 0.105) for Cd, (0.968 to 1.472) with an average EF value of (1.070 ± 0.105) for Cr, (1.083 to 2.288) an average of (1.423 ± 0.354) for Cu, (0.275 to 2.183) with an average of (1.186 ± 0.503) for Co, (1.814 to 4.716) for Fe with an average of (3.435 ± 0.890), (5.441 to 8.332) for Mn with an average of (6.473 ± 0.605), and (1.325 to 13.576) with an average EF value of (5.639 ± 3.327) for Zinc respectively.

Table 9. Soil quality guidelines for enrichment factor (*EF)* of the soil samples from five different localities along the Sayre Highway

Area/sites	**Enrichment factor**						
	Cd	**Cr**	**Cu**	**Co**	**Fe**	**Mn**	**Zn**
S 1	1.478	1.095	2.288	1.893	2.527	5.441	12.049
S 2	1.381	1.472	2.184	0.976	2.578	5.923	11.009
S 3	1.295	1.045	1.623	0.879	2.782	6.801	6.005
S 4	1.532	1.070	1.291	0.807	3.545	5.751	4.835
S 5	1.460	0.968	1.706	2.183	3.443	6.801	6.459
S 6	1.461	1.026	1.457	0.638	3.138	6.370	4.250
S 7	1.403	1.128	1.145	1.266	3.036	6.508	3.049
S 8	1.622	1.089	1.623	1.169	1.814	6.525	13.576
S 9	1.671	1.007	1.145	1.000	1.814	5.647	10.197
S 10	1.450	1.128	1.228	1.845	4.054	6.301	6.850
S 11	1.413	0.981	1.519	1.000	2.883	6.387	5.257
S 12	1.431	0.968	1.395	0.976	3.138	6.749	4.186
S 13	1.555	1.185	1.125	0.879	3.036	6.164	5.127
S 14	1.594	1.089	1.519	0.855	3.596	6.697	3.146
S 15	1.480	1.007	1.415	1.749	2.731	6.112	5.127
S 16	1.433	1.102	2.122	1.096	4.563	6.112	6.459
S 17	1.477	1.057	1.145	1.362	3.850	6.301	1.325
S 18	1.639	1.026	1.395	1.749	3.952	7.110	3.730
S 19	1.633	1.019	1.083	0.734	5.072	6.783	1.976
S 20	1.478	0.987	1.083	0.686	5.123	6.284	2.073
S 21	1.520	1.102	1.166	0.275	3.749	6.456	2.301
S 22	1.502	1.134	1.125	1.266	3.341	6.301	2.885
S 23	1.628	0.968	1.228	1.000	3.952	8.332	8.995
S 24	1.735	1.032	1.145	2.183	4.716	7.489	4.478
Cn	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Mean±SD	1.511±0.105	1.070±0.105	1.423±0.503	1.186±0.503	3.435±0.890	6.473±0.605	5.639±3.327

This study revealed that 100% of Cd EF values are EF<3, "minor enrichment," Cr shows 12.5% of the samples are EF<1, which indicates "no enrichment," and 87.5% of the soil samples had Cr values in the EF<3 range which means "minor enrichment." 100% of Cu EF values were EF<3, or "minor enrichment" was observed. On the other hand, Co EF values were identified as 50% EF<1 and 50% EF<3 of the sampling sites falling into "no enrichments" and "minor enrichment," respectively. The Fe EF values showed that there are 8.33, 29.17, and 62.5% are classified as EF<3 "minor enrichment," EF=3-5 "moderate enrichment," and EF=5-10 "moderately severe enrichment," respectively. Mn EF values are classified as "severe enrichment," with 100% of the sampling site being EF=5-10. While Zn EF values indicate that there is a "minor enrichment," "moderate enrichment," "moderately severe enrichment," and "severe enrichment" were observed with 20.88% EF<3, 29.17% EF=3-5, 29.17% EF=5-10, and 16.67% EF=10-25 respectively with a soil sample from S1 has the highest EF value for Zn at 12.05 (Mokhtarzadeh et al. 2020). The result shows that some sampling sites have higher EF values than 1. The presence of these elements in the sampling sites has increased relative to the average natural abundance because of human activity and pollution (Bern et al. 2019). The results suggest that the elevated levels of these metals in the soil result from human activities such as industrial emissions, agricultural inputs, and vehicle pollution. The necessity for focused pollution management measures is highlighted by the high EF values for Mn and Zn in several locations, which show significant deviations from natural background levels.

Potential ecological risk

The results of the assessment of the Ecological Risk Factor (ERF) and Ecological Risk Index (ERI) are shown in Table 10. This study shows that the potential ecological risk factor is in the following decreasing order: Cd > Zn > Mn > Cu > Cr > Co, ranging from (29.014 to 38.860), (2.525 to 22.727), (2.874 to 4.405), (8.562 to 18.051), (7.299 to 11.111) and (2.564 to 20.325) respectively with mean ± SD values of (33.460 ± 2.307) for Cd, (7.598 ± 4.896) for Zn, (3.729 ± 0.328) for Mn, (14.445 ± 2.960) for Cu, (10.110 ± 0.833) for Cr, and (5.824 ± 3.549) for Co. The ERF for all elements in soil sampling sites was observed to be lower than RI<150. The results indicate "low" that soil samples collected in Malaybalay, Valencia, Maramag, Quezon, and Don Carlos, Bukidnon pose a minimal potential ecological risk. The result of ERF shows that 100% of the soil sampling sites in five localities along the Sayre Highway had an average value of (2.053 ± 0.039) ranging from 1.99 to 2.12, with S17 showing the highest ERF value and S1 as the lowest ERF value, this also shows ERF is lower than 40, which indicates that the potential ecological risk index for soil sampling sites is low. In the Ecological Risk Index (ERI) and potential Ecological Risk Factor (ERF) analyses, all soil sampling locations demonstrate low ecological risk, with Cd having the highest risk potential of all the metals examined. All elements ERF values are below the 40 thresholds, indicating little environmental concern. These results suggest that although there is some metal contamination, the environment is not currently seriously threatened. However, as growing anthropogenic activities may increase ecological risk, continuous monitoring is necessary to identify any changes.

Table 10. Potential Ecological Risk Index (PERI) of soil samples from the five localities along the Sayre Highway

Area/sites	**Ecological risk index**						**Ecological risk factor**	
	Cd	**Cr**	**Cu**	**Co**	**Mn**	**Zn**	**ER_{value}**	**ER_{index}**
S 1	34.052	9.804	8.562	2.957	4.405	2.525	1.991	Low
S 2	36.452	7.299	8.961	5.741	4.049	2.762	2.007	Low
S 3	38.860	10.256	12.048	6.369	3.521	5.076	2.059	Low
S 4	32.859	10.050	15.152	6.944	4.167	6.289	2.056	Low
S 5	34.483	11.111	11.468	2.564	3.521	4.717	2.020	Low
S 6	34.443	10.471	13.441	8.787	3.759	7.143	2.067	Low
S 7	35.885	9.524	17.123	4.425	3.676	10.000	2.079	Low
S 8	31.024	9.852	12.048	4.789	3.676	2.242	1.998	Low
S 9	30.120	10.638	17.123	5.599	4.237	2.985	2.033	Low
S 10	34.722	9.524	15.924	3.034	3.802	4.444	2.037	Low
S 11	35.629	10.929	12.887	5.599	3.745	5.780	2.052	Low
S 12	35.170	11.111	14.045	5.741	3.546	7.246	2.062	Low
S 13	32.362	9.050	17.422	6.369	3.891	5.952	2.054	Low
S 14	31.579	9.852	12.887	6.545	3.571	9.709	2.050	Low
S 15	34.014	10.638	13.850	3.201	3.922	5.952	2.038	Low
S 16	35.129	9.756	9.225	5.107	3.922	4.717	2.020	Low
S 17	34.091	10.152	17.123	4.112	3.802	22.727	2.125	Low
S 18	30.706	10.471	14.045	3.201	3.367	8.130	2.030	Low
S 19	30.832	10.526	18.051	7.622	3.534	15.385	2.101	Low
S 20	34.052	10.870	18.051	8.157	3.817	14.706	2.116	Low
S 21	33.113	9.756	16.779	20.325	3.704	13.158	2.143	Low
S 22	33.520	9.479	17.422	4.425	3.802	10.526	2.072	Low
S 23	30.928	11.111	15.924	5.599	2.874	3.378	2.029	Low
S 24	29.014	10.417	17.123	2.564	3.195	6.803	2.026	Low
Means±SD	33.460±2.307	10.110±0.833	14.445±2.960	5.824±3.549	3.729±0.328	7.598±4.896	2.053±0.039	Low

Toxic Risk Index (TRI)

The (TRI) alternative computation offers a more detailed evaluation of the possible toxicity of the specific metal(oid) in the ecosystem illustrated in Table 11. The TRI value of Cd, Cr, Cu, and Zn was calculated using the Threshold Effect Levels (TEL), Probable Effect Levels (PEL), and Severe Effect Levels (SEL) values shown in Table 4. Based on the result of this study, the average TRI value in decreasing order: Zn > Cd > Cr > Cu was 0.953, 0.857, 0.424, and 0.038. The study's average value suggests that metal(iod)s provide no risk, and the TRI value was less than 5 (TRI < 5; no toxic risk) (Zhang et al. 2016). This suggests that soil health and ecological stability may not be at risk by the presence of these metals in the study locations along the Sayre Highway.

Modified Hazard Quotient (mHQ)

Figure 4 shows a pollution index that measures the degree of contamination. Benson et al. (2018) established the Modified Hazard Quotient (mHQ), which indicates each metal concentration used to evaluate the degree of pollution in soil samples and sediments, as well as the threshold edge for harmful environmental dispersions such as TEL, PEL, and SEL. The evaluation of mHQ is essential since it assesses the risk of a specific metal(oid) to the aquatic environment and biota (Emenike et al. 2020). The Cr levels in the soil samples revealed that 100% of the sampling sites are 1.0≤ mHQ < 1.5 "low severity of contamination" with an average Cr mHQ value of (1.50 ± 0.021), same with Cr and Cu shows 100% of the sampling sites are classified as 0.5 ≤ mHQ < 1.0 "very low severity of contamination," with an average mHQ value of (0.678 ± 0.029) and (0.800 ± 0.084) with values ranging from (0.649 to 0.785) and (0.714 to 0.9980 respectively. Zn has an average mHQ value of (1.277 ± 0.169) with sampling sites S8 and S9 shown to be 0.5 ≤ mHQ < 1.0 "very low severity of contamination" with mHQ values of (0.938). At the same time, 91.67% of the sample belongs to 1.0 ≤ mHQ < 1.5 "low severity of contamination," with a value ranging from (1.106 to 1.572) for Zn. Therefore, it has been suggested that the study sites were at "very low severity of contamination" to "low severity of contamination" and indicated no concern for ecological and environmental risk (Benson et al. 2018).

Relationship of metal concentration between metals in the soil

Correlation between metals in soil: Analyzing the correlation between metal concentrations can explain the migration and transportation rules of different forms of metals and be used for soil remediation and mitigations. Table 12 shows the r-values for the correlation between soil Cd concentration and Cr, Cu, Co, Fe, Mn, and Zn, which were -0.255, -0.405, 0.133, 0.195, 0.340, and 0.052, respectively. The data shows that Cr and Cu concentrations have a negative, non-significant correlation with Cd concentrations. Co, Fe, Mn, and Zn positively correlate with Cd concentration, indicating that Co, Fe, Mn, and Zn in the soil increase with the increase of soil Cd concentration. There was a negative correlation between soil Co, Fe, and Mn with r-values of -0.108, -0.227, and -0.315, respectively, with the Cr concentration. This implies that when Cr concentration in the soil decreases, the amount of Co, Fe, and Mn increases.

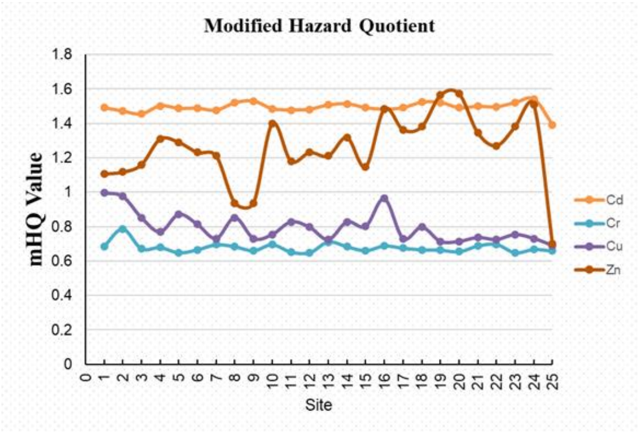

Figure 4. Modified Hazard Quotient (mHQ) values of soil samples from the five localities of the study along the Sayre

Table 11. Toxic risk index of metals along the study site of Sayre Highway

Metal(oid)s	**TRI_{values}**	**TRI_{factor}**
Cadmium	0.857	TRI ≤ 5' is considered as no toxic risk
Chromium	0.425	TRI ≤ 5' is considered as no toxic risk
Copper	0.358	TRI ≤ 5' is considered as no toxic risk
Zinc	0.952	TRI ≤ 5' is considered as no toxic risk

Table 12. Pearson's multi-linear correlation analysis of metal concentration

	Zn_p	**Cd_s**	**Cr_s**	**Cu_s**	**Co_s**	**Fe_s**	**Mn_s**	**Zn_s**
Cd_s	-0.183	1						
Cr_s	0.111	-0.255	1					
Cu_s	0.404	-0.405	0.382	1				
Co_s	0.030	0.133	0-.108	0.198	1			
Fe_s	-0.351	0.195	-0.227	-0.326	-0.002	1		
Mn	-0.601**	0.340	-0.375	-0.315	0.106	0.402	1	
Zn_s	0.386	0.052	0.281	0.604**	0.219	-0.623**	-0.180	1

Note: *: Correlation is significant at the 0.05 level; **: Correlation is significant at the 0.01 level

Cu and Zn positively correlated with Cr concentration with r-values of 0.382 and 0.281, respectively. The Cu concentration has a positive, highly significant correlation with Zn with an r-value of 0.604** and a positive correlation in Co with an r-value of 0.198. In contrast, Fe and Mn had a negative, non-significant correlation with r-values of -0.108 and -0.227, respectively. The Co concentration shows a positive correlation with Mn and Zn and a negative non-significant correlation with Fe with r-values of 0.106, 0.219, and -0.002, respectively. Lastly, the correlation between Mn and Zn had a negative, non-significant correlation with each other, with an r-value of -0.180.

In conclusion, the result of this study on metal concentrations in roadside soil shows the possible risks it would cause to human health and the environment. The concentrations in the soil complied with the FAO/WHO maximum permissible limits, suggesting a potential transfer of these heavy metals from the soil to the plants. The metal concentrations in roadside soil samples offer valuable understanding of metals distribution and accumulation patterns in the studied localities. These results can serve as a basis for developing targeted mitigation strategies to reduce human exposure to dust and the consumption of plants along highways. The indices used in this study, such as the (lgeo), (CF), (ERI), (PLI), (EF), and (TRI), helped assess the contamination levels, ecological risks, and possible toxicity associated with heavy metals in the soil. All of these indices show a low risk of ecological damage. However, it also highlights the importance of continuous monitoring to ensure the long-term sustainability and health of the ecosystem. Sampling was limited to the dry season, potentially underestimating wet-season leaching. Preventive measures must be taken to reduce metal contamination in agricultural areas and ensure the safety of food production systems. Implementing green barriers along highways and enforcing emission standards could reduce metal deposition.

Future research should focus on identifying the source, doing long-term monitoring, and developing sustainable agricultural practices that lessen the amount of heavy metals that plants absorb. Adopt phytoremediation using native plant species to immobilize metals. While this study focuses on 7 metals, future studies should include Pb, As, and Hg. More studies on the possible health effects of long-term exposure to heavy metals are needed to protect the community's well-being and advance safe and sustainable farming practices.

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