# Health risk estimations and geospatial mapping of trace metals in soil samples around automobile mechanic workshops in Benin city, Nigeria

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ABSTRACT

This study was carried out to assess the distribution of trace metals in soil samples from selected automobile mechanic workshops (AMWs) in Benin City, spatially map the concentrations and estimate the health risk indices for the exposed populace. Topsoil samples were collected from twenty-one (21) AMWs in Benin City in 3 composites for three months at each station. Soil samples were analyzed for heavy metals (Pb, Cd, Fe, Cu, Ni, Cr, and Zn) using Atomic Absorption Spectrophotometer. The non-carcinogenic risks caused by exposure to the metals were insignificant, characterized by in mean values of hazard quotient (HQ) and hazard index (HI) below one (1) in adults and children. Carcinogenic risk (CR) occurred only in the children exposed to nickel through ingestion; attributable to ingestion. In adults and children, the risks associated with the uptake routes were in the order of ingestion > dermal contact > inhalation. The hazard index (HI) values of heavy metals for children and adults decreased in the order of Pb > Cr > Cd > Cu > Zn > Ni and were all lower than one (1), which indicated that the children and adults were not at non-carcinogenic risk. The contamination factors (CF) of all metals analyzed were lower than one (1), suggesting low contamination. The average CF decreased in the order of Pb (0.3715) > Zn (0.14) > Cu (0.087) > Cr (0.013) > Ni (0.01) > Fe (0.0007). Potential ecological risks of the trace metals in soils of these workshops revealed low pollution of the soils by the metals. Results indicated that the three routes of uptake in adults and children decreased in the order of ingestion > dermal > inhalation. The non-carcinogenic risks posed by metals to the children and adults were insignificant. Ingested nickel however posed potential carcinogenic risk to only the children. The toxicodynamics of heavy metals in the soil profile demonstrated in this study could be a vital information for future studies and decisions on the management of the health and environment of the study area.

## 1. Introduction

Recently in Benin City, Nigeria, there has been a rise in emigration rates to European countries. This has allegedly increased the rate of importations of used cars, commonly called "Tokunbo" car into the country, particularly in Benin City. Following the increase in demand for maintenance of these cars, there has been a commensurate sharp rise in the number of automobile mechanic workshops (AMWs) within the Benin metropolis. A survey of Benin City indicates that there are about 507 automobile departmentalized workshops scattered all over the city rendering car services which involve a change of the used engine oil and parts which are indiscriminately discarded in the environment may be a great source of soil contamination [14,38]. These workshops procure spare parts from two major automobile spare part markets within the city: Uwelu and Evbareke spare part markets [37].

Cadmium is released from tires' wear and tear and vehicular emissions, aided by lubricant oil. Cadmium is also used an automobile coating which offers good corrosion resistance. When exposed to cadmium, zinc (a vital trace element) is usually displaced by cadmium, thus may disrupt metabolic processes [42]. In developed countries, vehicular emissions are monitored by various regulations, and policies compared to developing countries which are the destination of automobiles that fail vehicular emission tests. Lead is released by the exhaust of such vehicles and from their worn metal alloys in the engine [2,84]. Lead might adversely affect mental health, causing cardiovascular and neurological diseases in humans, especially children. Exposure to lead
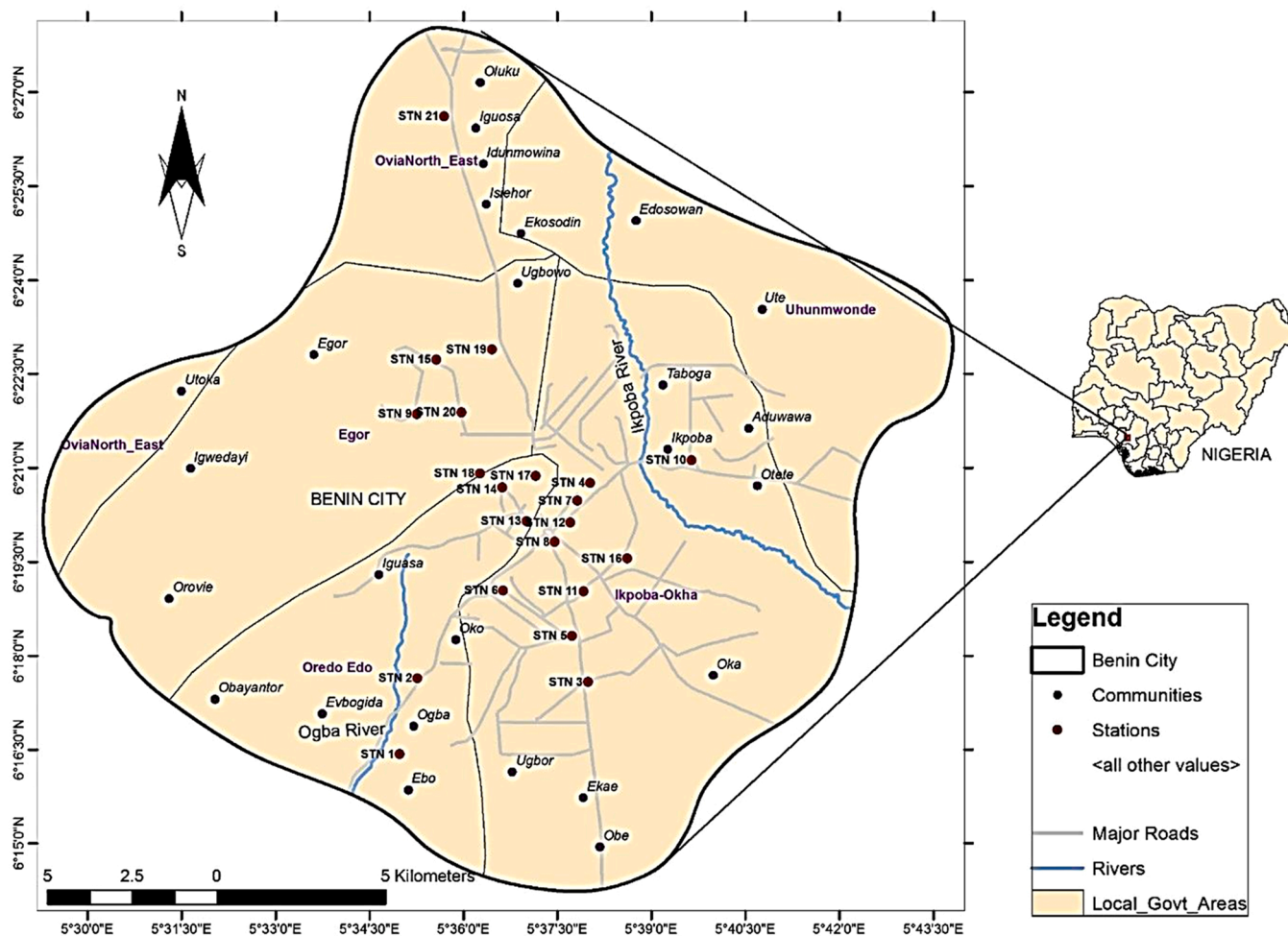
**Fig. 1.** Map showing sampled locations.

may cause kidney and brain damage and ultimately death. Impairment of cognitive performance by lead has also been reported [10]. Lead and cadmium are carcinogenic and can cause bone fractures and malformation, nephrological, neurological, hematological dysfunctions; hypertension, and immunosuppression [9].

Zinc is sourced mainly from the wear of galvanized parts such as fuel tanks. Brake wear is the primary source of copper and lead [84]. When an automobile engine is running, the engine oil, transmission oil, and hydraulic fluid pick up worn metal debris which contains Pb, Cd, Zn, Fe, Cu [25]. The incidence of engine wear and tear depends on the automobile's age, condition, and the transmission systems [1,87]. Sadly, used vehicles and spare part reuse are predominant in the metropolis of Benin City [3,16,56]. Contamination of soils with trace metals from AMWs has been widely reported in Nigeria [39,38,56,7,37]. For example, David and Sunday [23] reported a strong correlation between vehicular emissions and trace metal accumulation in the soil samples from roadsides within Ota metropolis, Ogun State, Nigeria. Elsewhere, Pam et al. [69] discovered the concentration levels of Pb, Cd, Ni, Cu, Mn, and Zn in soils around two major AMWs in Benue State were above background levels and permissible limits recommended for soils. Recently, Anegbe et al. [15] observed higher concentrations of trace metals in soil samples collected within the metropolis of Benin City were higher than the average concentration in other neighboring states. Ibrahim et al. [36] linked the contamination of soil samples from Borno State, Nigeria, to servicing practices of AMWs using pollution load indices.

Furthermore, health hazards associated with heavy metals in soil have also been reported over the years in Nigeria. Odukoya et al. [61]

reported notable health risk indices associated with exposure to concentrations of Mo, Ag, Cr, Ni, Cu, Pb, Zn, As, Sb, Bi, Cr, Tl, Se, Hg and Cd in soil samples within industrial estates of Southwestern Nigeria. Later on, Adedeji et al. [4] reported significant health risks due to exposure to Cd, Cr, Cu, Mn, Ni, Pb, and Zn the soil samples collected from Ijebu-Ode, Ogun State, Nigeria. Recently, Isibor et al. [43] reported notable health risk impacts of selected trace metals detected in the water and soil samples of a tropical rainforest river in Benin City, Nigeria. Soil is however an essential resource to agricultural and global food security. Because it plays a crucial role in maintaining the proper functioning and sustenance of the earth's ecosystems [12]), its contamination is thus a fundamental environmental problem in areas densely populated with AMWs [43].

The mechanics and residents within the catchment area are at risk of exposure to contaminated soil through dermal, ingestion, and inhalation. It has been reported that automobiles introduce several toxic metals into the Nigerian environment [50,60] through the wear and tear of tires and engine parts, grease and oil leaks, metal seepages from automobile catalysts, and panel beating [5]. These mechanic-associated anthropogenic activities increase the likelihood of exposure of the populace in the metropolis of Benin City, Nigeria [41,56,57], from which used engine oils and other motor oils containing trace metals are indiscriminately discharged by artisans in the business of automobile repairs and servicing [15]. Even essential metals, when in excess is injurious. Excess zinc in the human body can also disrupt the immune system [10]. Excess copper intake can elicit liver damage and initiate gastrointestinal complications [10]. Nickel is considered one of the leading human carcinogens. The study aimed to assess the spatial

distribution of trace metals in soil samples within the catchment areas of automobile mechanic workshops and estimate the associated health risk. The study seeks to employ Geo-accumulation indices (Igeo) and the potential ecological risk index (PER) methods to evaluate and assess the pollution severity.

## 2. Materials and method

### 2.1. 2.1 The study area

The sampling locations were 21 AMWs, located in selected parts of Benin City, Edo State, Nigeria (Fig. 1).

Map The map was designed using QGIS software version 3.10.1 'A Coruña' [70].

URL: https://qgis.org/en/site/forusers/download.html#.

The longitudes and latitudes of the stations' decimal degrees were 6.27368, 5.58302 (Station 1); 6.29393, 5.58775 (Station 2); 6.29288, 5.63317 (Station 3); 6.34599, 5.63379 (Station 4); 6.30521, 5.6289 (Station 5); 6.31736, 5.61061 (Station 6); 6.3412, 5.63032 (Station 7); 6.33023, 5.62429 (Station 8); 6.36433, 5.58767 (Station 9); 6.35201, 5.66074 (Station 10); 6.31709, 5.63196 (Station 11); 6.33538, 5.62848 (Station 12); 6.33575, 5.61679 (Station 13); 6.3447, 5.61034 (Station 14); 6.3788, 5.59276 (Station 15); 6.32582, 5.64361(Station 16); 6.34782, 5.61927 (Station 17); 6.34853, 5.60439 (Station 18); 6.38149, 5.6076 (Station 19); 6.36474, 5.59944 (Station 20); 6.44357, 5.59486 (Station 21).

### 2.2. Sample collection

Topsoil samples were collected at 10 cm depth from 21 AMWs in Benin City by digging 10 cm beneath the soil with the aid of sterilized trowel. This exercise was conducted monthly between May and July, 2019. At each station, three composites of soil samples were collected with the aid of a soil ager and then rigorously stirred with the aid of a rotator at to get a representative sample. The collected soil samples were preserved in labeled aluminum and transported to the laboratory. The sampling duration was spread over three months to capture the impacts of rain on the soil samples which might occur through surface runoff.

### 2.3. Sample preparation and analysis

The soil samples were air-dried for 48 h, sieved, and ground to smoothness using ceramic mortar and pestle. Soil samples were digested according to the modified method of Enuneku et al. [28]. Afterward, 1 g of the sample was digested in 10 mL freshly prepared aqua regia (3:1, $HNO_3$:HCl) in a hot sand bath for 45 min and allowed to cool afterward Twenty (20) mL of distilled water was added [28]. The sample was filtered using a Whatman filter paper (110 mm) into a 100 mL standard flask [28]. Thereafter the sample was made up to 100 mL mark with distilled water. Samples were then analyzed for the concentrations of lead, copper, zinc, iron, nickel, cadmium, and chromium using atomic absorption spectrophotometer (Buck Scientific, 210 VGP).

#### 2.3.1. Quality control and quality assurance

The precision of the AAS was validated by repeating the experimental procedure three times. Certified reference materials (CRM) and standard reference materials (SRM) provided by the Federal Environmental Protection Agency (2003) were adopted as a guide. The recovery rates ranged from 89% to 96%.

The relative standard deviation (SD) was < 6% suggested data reliability [43]. The curves were derived from the reference solutions prepared from analyte grade stock solutions containing 1000 g/kg of lead, copper, zinc, iron, nickel, cadmium, and chromium. The concentrations were stated in mg/kg [43].

The limits of detection (LOD) and the limits of quantification (LOQ) were estimated from the standard deviation of 10 readings from the analytical blanks and the slopes of the analytical curves (LOD = 3σ/ slope and LOQ = 10σ/ slope) [43]. The values were 0.05–0.07 μg/kg for Fe, 0.07–0.123 μg/kg for Pb, 0.06–0.121 μg/kg for Cd, 0.043–0.127 μg/kg for Cr, 0.023–0.132 μg/kg for Cu, and 0.013–0.117 μg/kg for Ni.

### 2.4. Health risk estimations

Human risk assessment was used to estimate the possible risk level inflicted by the metals on exposed individuals [47]. Identification of hazards, assessment of exposure, dose-response assessment, and risk characterization [59]. Health risk assessment was determined using the non-carcinogenic and carcinogenic risks for both adults and children. The health risks posed by metals were expressed as chronic daily intake (CDI) (mg/kg/day). The risks associated with uptake of metals through incidental ingestion ($CDI_{ing}$) and dermal contact ($CDI_{derm}$) were calculated thus;

$$CDI_{ing} = \frac{CS \times IRs \times CF \times FI \times EF \times ED}{BW \times AT}$$

$$CDI_{derm} = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{B \times AT}$$

$$CDI_{inh} = \frac{C \times IR(inh) \times EF \times ED}{PEF \times BW \times AT}$$

CS= metal concentration in the soil (mg/kg); IRs= ingestion rate (mg/day); CF= conversion factor (kg/mg); FI= fraction ingested from the contaminated source (unitless); ED= exposure duration (years); EF of the $CDI_{ing}$= exposure frequency (days/year); BW= average body weight (kg); AT= average time (days); ABS= dermal absorption factor (unitless); SA= exposed surface area of skin ($cm^2$/event); AF= skin adherence factor ($mg/cm^2$); EF of $CDI_{derm}$= exposure frequency (events/year); PEF= the particle emission factor.

#### 2.4.1. Non-carcinogenic risk assessment

The hazard quotient (HQ) was employed to assess the non-carcinogenic health risk of each metal on the individuals in the study area. It was expressed as the ratio of the average daily dose that each individual receives through the three routes of uptake to a reference value RfD [85]. The Hazard Index (HI) was expressed as the sum of the HQ values for the metals; expressed as the non-carcinogenic risk posed collectively by the heavy metals.

The equations were calculated thus:

$$HQ = \frac{CDI_{ing}}{RFD_{ing}} + \frac{CDI_{inh}}{RFD_{inh}} + \frac{CDI_{derm}}{RFD_{derm}}$$

$$HI = \sum_{i=1}^{n} HQi$$

#### 2.4.2. Carcinogenic risk

Carcinogenic risk (CR) was expressed as the product of the chronic daily intake (CDI) and the cancer slope factor (CSF) over a lifetime of an individual.

CR was calculated thus:

$$CR = CDI \times CSF(US EPA1989)$$

### 2.5. Data analysis

Results in this study were presented as mean ± standard deviation. Before conducting parametric tests, data characteristics were tested for homogeneity of variance and normality. Shapiro-Wilk's test was conducted, including a visual inspection of histograms, standard Q-Q plots, which showed that data were normally distributed as the null hypothesis was accepted at p = 0.001. One-way analysis of variance was carried out

**Table 1**

Trace metal concentration (mg/kg) in soil samples of AMWs.

| Stations | Lead Mean±SD(Min – Max) | Iron Mean±SD(Min – Max) | Zinc Mean±SD(Min – Max) | Copper Mean±SD(Min – Max) | Nickel Mean±SD(Min – Max) | Cadmium Mean±SD(Min – Max) | Chromium Mean±SD(Min – Max) |
|---|---|---|---|---|---|---|---|
| STN 1 | 2.07 ± 0.93(1.30 – 3.10) | 34.80 ± 2.96(31.40 – 36.80) | 7.90 ± 8.32(3.05 – 17.50) | 1.23 ± 0.84(0.41 – 2.08) | 0.33 ± 0.22 (0.19 – 0.59) | 0.00 ± 0.00(0.00 – 0.00) | 1.13 ± 0.27(0.81 – 1.29) |
| STN 2 | 7.43 ± 6.20 $^A$(1.20 – 13.60) | 35.97 ± 3.79(31.80 – 39.20) | 5.60 ± 5.31(2.01 – 11.70) | 0.89 ± 0.65(0.31 – 1.60) | 0.28 ± 0.21 (0.13 – 0.52) | 0.01 ± 0.02(0.00 – 0.03) | 1.03 ± 0.39(0.68 – 1.45) |
| STN 3 | 3.00 ± 2.09(1.60 – 5.40) | 33.77 ± 0.38(33.50 – 34.20) | 2.57 ± 0.91(1.83 – 3.59) | 0.62 ± 0.81(0.00 – 1.54) | 0.28 ± 0.34 (0.06 – 0.67) | 0.00 ± 0.01(0.00 – 0.01) | 0.23 ± 0.14(0.13 – 0.39) |
| STN 4 | 1.70 ± 0.26(1.40 – 1.90) | 30.30 ± 5.24(24.60 – 34.90) | 6.22 ± 8.42(0.00 – 15.80) | 1.04 ± 0.64(0.50 – 1.75) | 0.32 ± 0.05 (0.26 – 0.36) | 0.01 ± 0.01(0.00 – 0.02) | 1.11 ± 0.25(0.85 – 1.35) |
| STN 5 | 3.48 ± 2.43(1.50 – 6.20) | 34.07 ± 1.93(31.90 – 35.60) | 5.57 ± 5.69(1.74 – 12.10) | 0.49 ± 0.32(0.31 – 0.86) | 0.35 ± 0.15 (0.18 – 0.45) | 0.01 ± 0.02(0.00 – 0.03) | 0.61 ± 0.13(0.46 – 0.71) |
| STN 6 | 1.77 ± 1.36(0.70 – 3.30) | 33.10 ± 2.63(31.20 – 36.10) | 8.90 ± 12.26(0.73 – 23.00) | 0.64 ± 0.53(0.25 – 1.24) | 0.34 ± 0.16 (0.16 – 0.46) | 0.03 ± 0.02(0.01 – 0.05) | 0.66 ± 0.23(0.40 – 0.84) |
| STN 7 | 2.88 ± 1.29(1.40 – 3.70) | 35.40 ± 3.94(32.20 – 39.80) | 10.16 ± 11.64(3.23 – 23.60) | 1.29 ± 0.34(0.96 – 1.64) | 0.28 ± 0.25 (0.03 – 0.52) | 0.04 ± 0.02(0.02 – 0.05) | 0.88 ± 0.51(0.40 – 1.42) |
| STN 8 | 0.72 ± 0.68(0.00 – 1.35) | 33.67 ± 0.72(33.20 – 34.50) | 9.92 ± 13.40(2.13 – 25.40) | 0.55 ± 0.32(0.31 – 0.91) | 0.18 ± 0.24 (0.03 – 0.46) | 0.01 ± 0.02(0.00 – 0.03) | 1.09 ± 0.37(0.71 – 1.45) |
| STN 9 | 1.62 ± 0.84(0.65 – 2.20) | 34.50 ± 2.86(32.20 – 37.70) | 11.72 ± 15.40(2.31 – 29.50) | 3.54 ± 5.60 $^A$(0.17 – 10.00) | 0.06 ± 0.05 (0.01 – 0.09) | 0.01 ± 0.01(0.00 – 0.02) | 0.94 ± 0.69(0.40 – 1.72) |
| STN 10 | 2.80 ± 2.07(1.10 – 5.10) | 34.43 ± 2.04(32.20 – 36.20) | 6.24 ± 6.20(2.53 – 13.40) | 0.79 ± 0.15(0.62 – 0.88) | 0.68 ± 0.71 (0.12 – 1.48) | 0.00 ± 0.01(0.00 – 0.010) | 0.75 ± 0.43(0.45 – 1.25) |
| STN 11 | 1.10 ± 0.44(0.60 – 1.40) | 35.83 ± 3.69(31.60 – 38.40) | 2.72 ± 0.31 $^A$(2.36 – 2.91) | 0.55 ± 0.22(0.30 – 0.71) | 0.15 ± 0.13 (0.02 – 0.28) | 0.01 ± 0.02(0.00 – 0.03) | 0.37 ± 0.06(0.31 – 0.42) |
| STN 12 | 1.94 ± 0.58(1.52 – 2.60) | 35.00 ± 1.01(34.10 – 36.10) | 9.31 ± 12.21(2.00 – 23.40) | 1.19 ± 0.68(0.41 – 1.64) | 0.65 ± 0.75 (0.11 – 1.51) | 0.01 ± 0.02(0.00 – 0.04) | 0.79 ± 0.93(0.00 – 1.82) |
| STN 13 | 1.37 ± 0.06(1.30 – 1.40) | 33.76 ± 2.36(31.07 – 35.50) | 2.12 ± 0.78 $^A$(1.36 – 2.92) | 2.54 ± 2.00 $^A$(0.60 – 4.60) | 0.11 ± 0.10 (0.00 – 0.19) | 0.01 ± 0.00(0.01 – 0.01) | 0.11 ± 0.06(0.06 – 0.17) |
| STN 14 | 4.17 ± 3.26 $^B$(1.50 – 7.80) | 32.90 ± 5.21(27.10 – 37.20) | 13.28 ± 9.25(3.45 – 21.80) | 1.27 ± 1.1(0.33 – 2.56) | 0.33 ± 0.09 (0.26 – 0.43) | 0.01 ± 0.02(0.00 – 0.03) | 0.33 ± 0.40(0.00 – 0.78) |
| STN 15 | 1.21 ± 0.21(1.00 – 1.42) | 33.47 ± 1.07(32.30 – 34.40) | 4.55 ± 3.08 $^A$(2.62 – 8.10) | 3.93 ± 5.11 $^A$(0.65 – 9.81) | 0.20 ± 0.17 (0.06 – 0.39) | 0.00 ± 0.00(0.00 – 0.00) | 0.55 ± 0.23(0.39 – 0.81) |
| STN 16 | 1.90 ± 0.44(1.40 – 2.20) | 34.20 ± 2.81(31.30 – 36.90) | 1.47 ± 1.29 $^A$(0.00 – 2.39) | 2.98 ± 0.49 $^A$(2.45 – 3.41) | 0.29 ± 0.11 (0.17 – 0.39) | 0.01 ± 0.01(0.00 – 0.02) | 0.74 ± 0.17(0.57 – 0.90) |
| STN 17 | 2.20 ± 1.37(0.70 – 3.40) | 32.53 ± 1.58(30.80 – 33.90) | 2.42 ± 0.37 $^A$(2.09 – 2.82) | 0.61 ± 0.02(0.59 – 0.62) | 0.08 ± 0.01 (0.07 – 0.09) | 0.00 ± 0.01(0.00 – 0.01) | 0.64 ± 0.19(0.47 – 0.84) |
| STN 18 | 7.42 ± 9.28 $^A$(0.65 – 18.00) | 34.53 ± 1.33(33.00 – 35.40) | 5.87 ± 6.58(1.22 – 13.40) | 1.56 ± 1.19(0.19 – 2.40) | 0.09 ± 0.12 (0.00 – 0.23) | 0.01 ± 0.01(0.00 – 0.02) | 0.65 ± 0.29(0.34 – 0.91) |
| STN 19 | 0.93 ± 0.21(0.70 – 1.10) | 34.10 ± 2.10(32.00 – 36.20) | 2.04 ± 0.66 $^A$(1.42 – 2.73) | 0.32 ± 0.14(0.19 – 0.46) | 0.29 ± 0.11 (0.18 – 0.40) | 0.00 ± 0.01(0.00 – 0.010) | 0.69 ± 0.63(0.20 – 1.40) |
| STN 20 | 1.12 ± 0.28(0.85 – 1.40) | 34.17 ± 2.39(31.50 – 36.10) | 2.48 ± 0.33 $^A$(2.22 – 2.85) | 0.65 ± 0.12(0.51 – 0.73) | 0.24 ± 0.12 (0.11 – 0.34) | 0.01 ± 0.01(0.00 – 0.02) | 0.97 ± 0.53(0.38 – 1.41) |
| STN 21 | 1.58 ± 0.36(1.35 – 2.00) | 34.70 ± 1.76(32.70 – 36.00) | 2.19 ± 0.75 $^A$(1.65 – 3.05) | 0.71 ± 0.42(0.44 – 1.19) | 0.15 ± 0.16 (0.00 – 0.31) | 0.02 ± 0.03(0.00 – 0.05) | 0.76 ± 0.12(0.63 – 0.85) |
| **P value [30])** | **$p < 0.05$** 0.05 | **$p > 0.05$** < 1 | **$p < 0.05$** 1.5 | **$p < 0.05$** 0.3 | **$p > 0.05$** | **$p > 0.05$** 0.05 | **$p > 0.05$** 0.05 |

**Table 2**

Computed chronic reference doses for dermal, inhalation and ingestion of metals by adults and children.

| Metals | CM (mg/kg) | RfDderm (mg/kg/day) | RfDinh (mg/kg/day) | RfDing (mg/kg/day) | CDIderm (mg/kg/day) | CDIinh (mg/kg/day) | CDIing (mg/kg/day) | SFinh | SFing | SFderm |
|---|---|---|---|---|---|---|---|---|---|---|
| Pb | 2.50 | 0.000525 | 0.0035 | 0.0035 | $1.591 \times 10^{-7}$ | $1.203 \times 10^{-9}$ | $3.989 \times 10^{-6}$ | _ | 0.0085 | _ |
| Ni | 0.27 | 0.00540 | 0.0206 | 0.020 | $1.725 \times 10^{-8}$ | $1.304 \times 10^{-10}$ | $4.323 \times 10^{-7}$ | 0.81 | 0.84 | _ |
| Fe | 34.06 | _ | _ | _ | $2.172 \times 10^{-6}$ | $1.641 \times 10^{-8}$ | $5.443 \times 10^{-5}$ | _ | _ | _ |
| Cu | 1.30 | 0.012 | 0.0402 | 0.040 | $8.317 \times 10^{-8}$ | $6.286 \times 10^{-10}$ | $2.084 \times 10^{-6}$ | _ | _ | _ |
| Cd | 0.01 | 0.001 | 0.001 | 0.001 | $6.377 \times 10^{-10}$ | $4.820 \times 10^{-12}$ | $1.598 \times 10^{-8}$ | 6.30 | $5.01 \times 10^{-1}$ | $2.00 \times 10^{1}$ |
| Zn | 5.87 | 0.060 | 0.300 | 0.300 | $3.743 \times 10^{-7}$ | $2.829 \times 10^{-9}$ | $9.380 \times 10^{-6}$ | _ | _ | _ |
| Cr | 0.72 | 0.000006 | 0.0000286 | 0.003 | $4.56 \times 10^{-8}$ | $3.449 \times 10^{-10}$ | $1.144 \times 10^{-6}$ | 42 | _ | _ |

**Legends:** CM= concentration of metals in soil, RfDderm= reference dermal dose, RfDinh= reference inhalation dose, RfDing= reference ingestion dose, CDI-derm= dermal chronic daily intake, CDIinh= inhalation chronic daily intake, CDIing= ingestion chronic daily intake, SFinh= inhalation slope factor, SFderm= dermal slope factor [80,81,78]

to test for significant differences in heavy metal concentrations (spatial and temporal), and subsequently, post-hoc tests were done to locate the differences using SPSS (version 20).

*2.5.1. Spatial mapping of metal distribution*

Spatial mapping of heavy metal distribution in the soil of the catchment area of the AMWs was done using ArcGIS (version 10.4) software. The interpolation method adopted was inverse distance weighting (IDW) in the Geostatistical Analyst of ArcToolbox in the software [18]. IDW is a commonly used tools in the interpolation of pollution data [20].

**Table 3**

The hazard quotient for dermal, inhalation,l ingestion, and hazard index for adults.

| Metals | HQing | | HQderm | | HQinh | | HI | CR | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | | CRing | CRinh |
| Pb | $1.14 \times 10^{-3}$ | $8.27 \times 10^{-4}$ | $303 \times 10^{-4}$ | $2.20 \times 10^{-4}$ | $3.44 \times 10^{-7}$ | $2.49 \times 10^{-7}$ | $1.44 \times 10^{-3}$ | $3.39 \times 10^{-8}$ | _ |
| Ni | $2.16 \times 10^{-5}$ | $1.25 \times 10^{-5}$ | $3.20 \times 10^{-6}$ | $1.85 \times 10^{-6}$ | $6.32 \times 10^{-7}$ | $3.67 \times 10^{-9}$ | $3.81 \times 10^{-6}$ | $3.63 \times 10^{-7}$ | $1.06 \times 10^{-10}$ |
| Cu | $5.21 \times 10^{-5}$ | $4.07 \times 10^{-5}$ | $6.93 \times 10^{-6}$ | $5.41 \times 10^{-6}$ | $1.56 \times 10^{-8}$ | $1.22 \times 10^{-8}$ | $5.91 \times 10^{-5}$ | _ | _ |
| Cd | $1.60 \times 10^{-5}$ | $1.56 \times 10^{-5}$ | $6.38 \times 10^{-5}$ | $6.22 \times 10^{-5}$ | $4.82 \times 10^{-9}$ | $4.70 \times 10^{-9}$ | $7.97 \times 10^{-5}$ | $7.99 \times 10^{-9}$ | $1.45 \times 10^{-12}$ |
| Zn | $3.13 \times 10^{-5}$ | $1.86 \times 10^{-5}$ | $6.24 \times 10^{-6}$ | $3.72 \times 10^{-6}$ | $9.43 \times 10^{-9}$ | $5.62 \times 10^{-9}$ | $3.75 \times 10^{-5}$ | _ | _ |
| Cr | $3.81 \times 10^{-4}$ | $1.49 \times 10^{-4}$ | $7.61 \times 10^{-4}$ | $2.97 \times 10^{-4}$ | $1.21 \times 10^{-5}$ | $4.71 \times 10^{-6}$ | $9.29 \times 10^{-4}$ | _ | $1.45 \times 10^{-8}$ |
| ΣHQ/CR/HI | $1.64 \times 10^{-3}$ | $1.06 \times 10^{-3}$ | $1.14 \times 10^{-3}$ | $5.90 \times 10^{-4}$ | $1.32 \times 10^{-5}$ | $4.99 \times 10^{-6}$ | $2.54 \times 10^{-3}$ | $4.05 \times 10^{-7}$ | $1.46 \times 10^{-8}$ |

**Legends:** HQ= hazard quotient, HI= hazard index, CR= cancer risk, HQing= hazard quotient of ingestion, HQderm= hazard quotient of dermal, HQinh= hazard quotient of inhalation. CRing= carcinogenic risk of ingestion, CRinh= carcinogenic risk of inhalation

**Table 4**

The mean Hazard quotient for dermal, inhalation, ingestion, and hazard Index for children.

| Metal | HQing | | HQdermal | | HQinh | | HI | CR | |
|---|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | | CRing | CRinh |
| Pb | $9.121 \times 10^{-3}$ | $6.622 \times 10^{-3}$ | $1.70 \times 10^{-3}$ | $1.24 \times 10^{-3}$ | $2.75 \times 10^{-6}$ | $2.00 \times 10^{-6}$ | $1.08 \times 10^{-2}$ | $2.71 \times 10^{-7}$ | _ |
| Ni | $1.73 \times 10^{-4}$ | $1.00 \times 10^{-4}$ | $1.79 \times 10^{-5}$ | $1.04 \times 10^{-5}$ | $5.06 \times 10^{-8}$ | $2.93 \times 10^{-8}$ | $1.91 \times 10^{-4}$ | **$2.9\,0 \times 10^{-6}$** | $8.45 \times 10^{-10}$ |
| Cu | $4.17 \times 10^{-4}$ | $3.25 \times 10^{-4}$ | $3.89 \times 10^{-5}$ | $3.05 \times 10^{-5}$ | $1.25 \times 10^{-7}$ | $9.76 \times 10^{-8}$ | $4.56 \times 10^{-4}$ | _ | _ |
| Cd | $1.28 \times 10^{-4}$ | $1.25 \times 10^{-4}$ | $3.58 \times 10^{-4}$ | $3.49 \times 10^{-4}$ | $3.86 \times 10^{-8}$ | $3.76 \times 10^{-8}$ | $4.86 \times 10^{-4}$ | $6.39 \times 10^{-8}$ | $2.43 \times 10^{-10}$ |
| Zn | $2.50 \times 10^{-4}$ | $1.49 \times 10^{-4}$ | $3.50 \times 10^{-4}$ | $2.09 \times 10^{-4}$ | $7.54 \times 10^{-8}$ | $4.50 \times 10^{-8}$ | $2.85 \times 10^{-4}$ | _ | _ |
| Cr | $3.05 \times 10^{-3}$ | $1.19 \times 10^{-3}$ | $4.27 \times 10^{-3}$ | $1.67 \times 10^{-3}$ | $9.65 \times 10^{-5}$ | $3.77 \times 10^{-5}$ | $7.42 \times 10^{-3}$ | _ | $1.45 \times 10^{-8}$ |
| ΣHQ/CR/HI | $1.31 \times 10^{-2}$ | $8.51 \times 10^{-3}$ | $6.42 \times 10^{-3}$ | $3.32 \times 10^{-3}$ | $9.95 \times 10^{-5}$ | $3.99 \times 10^{-5}$ | $1.96 \times 10^{-2}$ | **$3.23 \times 10^{-6}$** | $1.56 \times 10^{-8}$ |

**Table 5**

Pollution load index of the metals in the soil samples.

| Stations | Pb | Fe | Zn | Cu | Ni | Cd | Cr | PLI |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.1035 | 0.0007 | 0.0832 | 0.0273 | 0.0049 | 0.0000 | 0.0126 | 0.0147 |
| 2 | 0.3715 | 0.0008 | 0.0589 | 0.0198 | 0.0041 | 0.0333 | 0.0114 | 0.0157 |
| 3 | 0.1500 | 0.0007 | 0.0271 | 0.0138 | 0.0041 | 0.0000 | 0.0026 | 0.0086 |
| 4 | 0.0850 | 0.0006 | 0.0655 | 0.0231 | 0.0047 | 0.0333 | 0.0123 | 0.0129 |
| 5 | 0.1740 | 0.0007 | 0.0586 | 0.0109 | 0.0051 | 0.0333 | 0.0068 | 0.0118 |
| 6 | 0.0885 | 0.0007 | 0.0937 | 0.0142 | 0.0050 | 0.1000 | 0.0073 | 0.0119 |
| 7 | 0.1440 | 0.0008 | 0.1069 | 0.0287 | 0.0041 | 0.1333 | 0.0098 | 0.0153 |
| 8 | 0.0360 | 0.0007 | 0.1044 | 0.0122 | 0.0026 | 0.0333 | 0.0121 | 0.0100 |
| 9 | 0.0810 | 0.0007 | 0.1234 | 0.0787 | 0.0009 | 0.0333 | 0.0104 | 0.0131 |
| 10 | 0.1400 | 0.0007 | 0.0657 | 0.0176 | 0.0100 | 0.0000 | 0.0083 | 0.0145 |
| 11 | 0.0550 | 0.0008 | 0.0286 | 0.0122 | 0.0022 | 0.0333 | 0.0041 | 0.0071 |
| 12 | 0.0970 | 0.0007 | 0.0980 | 0.0264 | 0.0096 | 0.0333 | 0.0088 | 0.0157 |
| 13 | 0.0685 | 0.0007 | 0.0223 | 0.0564 | 0.0016 | 0.0333 | 0.0012 | 0.0070 |
| 14 | 0.2085 | 0.0007 | 0.1398 | 0.0282 | 0.0049 | 0.0333 | 0.0037 | 0.0146 |
| 15 | 0.0605 | 0.0007 | 0.0479 | 0.0873 | 0.0029 | 0.0000 | 0.0061 | 0.0120 |
| 16 | 0.0950 | 0.0007 | 0.0155 | 0.0662 | 0.0043 | 0.0333 | 0.0082 | 0.0115 |
| 17 | 0.1100 | 0.0007 | 0.0255 | 0.0136 | 0.0012 | 0.0000 | 0.0071 | 0.0077 |
| 18 | 0.3710 | 0.0007 | 0.0618 | 0.0347 | 0.0013 | 0.0333 | 0.0072 | 0.0132 |
| 19 | 0.0465 | 0.0007 | 0.0215 | 0.0071 | 0.0043 | 0.0000 | 0.0077 | 0.0074 |
| 20 | 0.0560 | 0.0007 | 0.0261 | 0.0144 | 0.0035 | 0.0333 | 0.0108 | 0.0091 |
| 21 | 0.0790 | 0.0007 | 0.0231 | 0.0158 | 0.0022 | 0.0667 | 0.0084 | 0.0085 |

*2.5.2. Pollution load, geo-accumulation and potential ecological risk indices*

The pollution load index (PLI) was calculated thus;.

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times \ldots\ldots CF_n)^{1/n}$$

Contamination factor (CF) = $[C_{metal}]/ [C_{background}]$

The contamination was graded on a scale range of 1–6 (0 = not polluted, 1 = none to moderately polluted, 2 = moderately polluted, 3 = moderately to strongly polluted, 4 = strongly polluted, 5 = strongly to very strongly polluted, 6 = very strongly polluted [53].

The geo-accumulation index was computed to analyze the concentrations of the metals in the soil in comparison to the natural background level [49]. This gives a clear picture as to the progress of the soil contamination in time and space.

Geo-accumulation index (Igeo) was calculated thus;.

$$Igeo = Log_2 (B6/ B8 \times B9)$$

$$Igeo = log_2 Cs$$

*2.6. 1.5 X Gb*

Cs= concentration of metal in soil, the B8 = conversion factor (1.5), and Gb is the geochemical background value of the metal.

The potential ecological risk index (PER) of the trace metals in soil samples was estimated to determine the possibility of the metals causing ecological hazards that might impair the ecological services such as ground water purification and support for plants.

PER was calculated thus;

**Table 6**
Geoaccumulation index (Igeo) of heavy metals in soils of AMWs.

| Stations | Pb | Fe | Zn | Cu | Ni | Cd | Cr |
|---|---|---|---|---|---|---|---|
| 1 | -3.8573 | -10.9904 | -4.1730 | -5.7782 | -8.2719 | | -6.9005 |
| 2 | -2.0135 | -10.9427 | -4.6694 | -6.2449 | -8.5089 | -5.4919 | -7.0342 |
| 3 | -3.3219 | -11.0338 | -5.7931 | -6.7665 | -8.5089 | | -9.1971 |
| 4 | -4.1414 | -11.1902 | -4.5179 | -6.0202 | -8.3163 | -5.4919 | -6.9263 |
| 5 | -3.1078 | -11.0210 | -4.6771 | -7.1060 | -8.1870 | -5.4919 | -7.7899 |
| 6 | -4.0831 | -11.0627 | -4.0010 | -6.7207 | -8.2288 | -3.9069 | -7.6763 |
| 7 | -3.3808 | -10.9658 | -3.8100 | -5.7094 | -8.5089 | -3.4919 | -7.2612 |
| 8 | -5.3808 | -11.0381 | -3.8445 | -6.9393 | -9.1464 | -5.4919 | -6.9525 |
| 9 | -4.2109 | -11.0029 | -3.6039 | -4.2531 | -10.7313 | -5.4919 | -7.1661 |
| 10 | -3.4215 | -11.0059 | -4.5133 | -6.4169 | -7.2288 | | -7.4919 |
| 11 | -4.7694 | -10.9484 | -5.7112 | -6.9393 | -9.4094 | -5.4919 | -8.5112 |
| 12 | -3.9508 | -10.9822 | -3.9360 | -5.8259 | -7.2939 | -5.4919 | -7.4169 |
| 13 | -4.4527 | -11.0342 | -6.0708 | -4.7320 | -9.8569 | -5.4919 | -10.2612 |
| 14 | -2.8468 | -11.0714 | -3.4236 | -5.7320 | -8.2719 | -5.4919 | -8.6763 |
| 15 | -4.6319 | -11.0467 | -4.9690 | -4.1023 | -8.9944 | | -7.9393 |
| 16 | -3.9809 | -11.0155 | -6.5990 | -4.5015 | -8.4583 | -5.4919 | -7.5112 |
| 17 | -3.7694 | -11.0878 | -5.8798 | -6.7899 | -10.3163 | | -7.7207 |
| 18 | -2.0155 | -11.0017 | -4.6015 | -5.4353 | -10.1464 | -5.4919 | -7.6983 |
| 19 | -5.0116 | -11.0198 | -6.1263 | -7.7207 | -8.4583 | | -7.6122 |
| 20 | -4.7434 | -11.0168 | -5.8445 | -6.6983 | -8.7313 | -5.4919 | -7.1208 |
| 21 | -4.2470 | -10.9946 | -6.0239 | -6.5709 | -9.4094 | -4.4919 | -7.4727 |
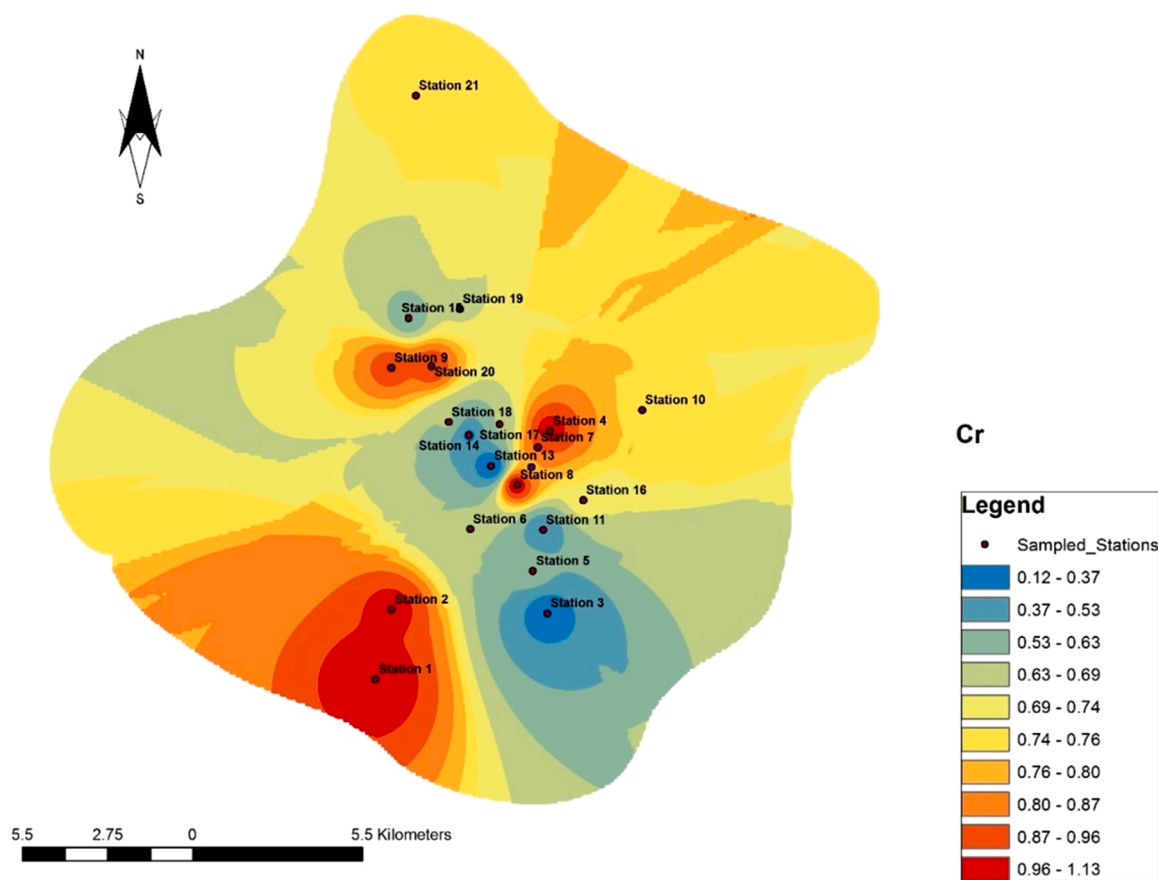


**Fig. 2.** Spread of Cr across the study area.

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

$$E_r^i = T_r^i X \ C_f^i$$

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

$C_f^i$ = pollution coefficient of each metal.

$C^i$ = measured concentration of each soil sample.

$C_n^i$ = background concentration of metal in soil.

$T_r^i$ = toxicity factors of Pb (5), Cd (5), Fe (1), Cu (5), Ni (10), Cr (2), and Zn (1) were adopted from Xu et al. [86].

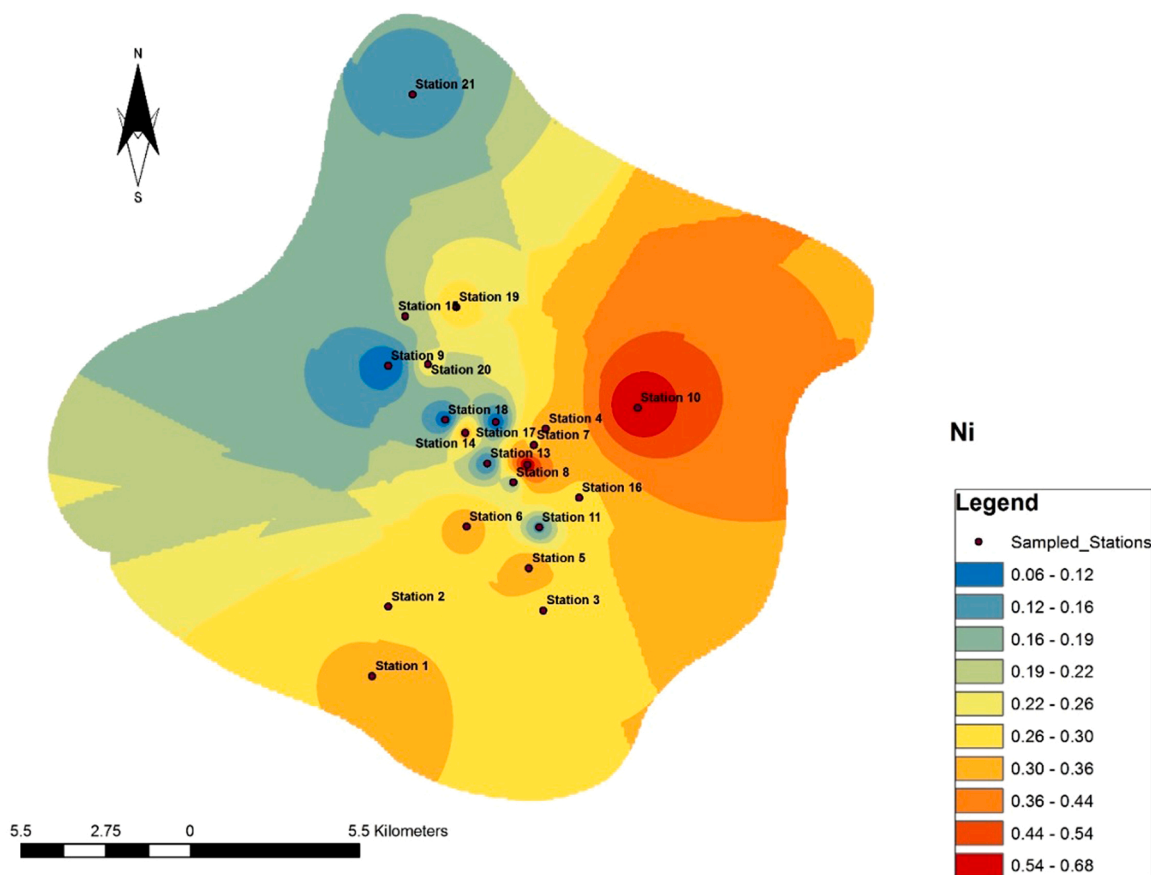$E_r^i$ = potential ecological risk factor of each metal.

**Fig. 3.** Spread of Ni across the study area.

## 3. Results

### 3.1. Concentrations of trace metals in soil samples

The concentrations of Pb, Fe, Zn, and Cu in the soil samples at all the stations exceeded the established regulatory limits set by FEPA (Table 1). Conversely, the concentrations of chromium were below the established limit of FEPA [30]. The lead concentration at Stations 2 and 18 were significantly higher than the concentration at Station 14, which was in turn higher than other stations (p < 0.05).

Iron concentrations in soil samples at Stations 11, 13, 15, 16, 17, 19, 20, and 21 were significantly lower than the concentrations at other stations. The concentrations of copper at Stations 9, 13, 15, and 16 were significantly higher than the concentrations detected in soil samples at other stations (p < 0.05). No significant difference occurred in nickel and chromium concentrations in the soil samples across all stations (p > 0.05).

Numbers with the same superscript are significantly different (p < 0.05). Sample size (N) = 21.

### 3.2. Human health risk assessment

The components for computations of health risks posed to adults and children (Table 2) were adopted were adopted from USEPA [80], USEPA [81] and [78]. Hazard quotients (HQ) or hazard index (HI) > /= 1, and cancer risk (CR) from $10^{-6} - 10^{-4}$ were considered significant [80]. The non-carcinogenic risks of Pb, Ni, Cu, Cd, Zn, and Cr in soil samples at AMWs in Benin City through the three exposure routes showed that the risks posed to adult and children were insignificant; with all HQ mean values < 1 (Tables 3 and 4). Results indicated that the three routes of uptake in adults and children were in the decreasing order of ingestion

> dermal > inhalation (Tables 3 and 4).

The contribution of HQing to HI was the highest, 67% for children and 55% for adults, suggesting that ingestion was the main exposure pathway associated with significant health risks tendencies. The HI values of heavy metals for adult and children was in the order of Pb > Cr > Cd > Cu > Zn > Ni (Tables 3 and 4). The HI values for all the metals were < 1, indicating no non-carcinogenic risk for adults (Table 3). Only ingested nickel posed CR to the children, while other elements posed no significant risk (Table 4).

**Legends:** HQ= hazard quotient, HI= hazard index, CR= cancer risk, HQing= hazard quotient of ingestion, HQderm= hazard quotient of dermal, HQinh= hazard quotient of inhalation. CRing= carcinogenic risk of ingestion, CRinh= carcinogenic risk of inhalation. Emboldened figure is significant.

### 3.3. Pollution load index (PLI) for trace metals

The result of the contamination factors ($C_f^i$) and pollution load index (PLI) for Pb, Fe, Zn, Cu, Ni,Cd and Cr at the stations were all < 1, which is an indication of low contamination. Analysis of the results showed that the average $C_f^i$ was in the order of Pb (0.3715) > Zn (0.14) > Cu (0.087) > Cr (0.013) > Ni (0.01) > Fe (0.0007). The pollution load index (PLI) values show that the highest value (0.0157) was both in stations 2 and 12, while the lowest (0.0070) was in station 13 (Table 5).

### 3.4. Geoaccumulation index (Igeo) of trace metals in soils of the AMWs

The geoaccumulation indices ($I_{geo}$) values for the seven metals were: − 5.38 to − 2.01 for Pb, − 11.19 to − 10.94 for Fe, − 6.60 to − 3.42 for Zn, − 7.72 to − 4.10 for Cu, − 10.73–7.23 for Ni, 5.49–3.49 for Cd and 10.26–6.90 for Cr. The average values of $I_{geo}$ were negative in all stations
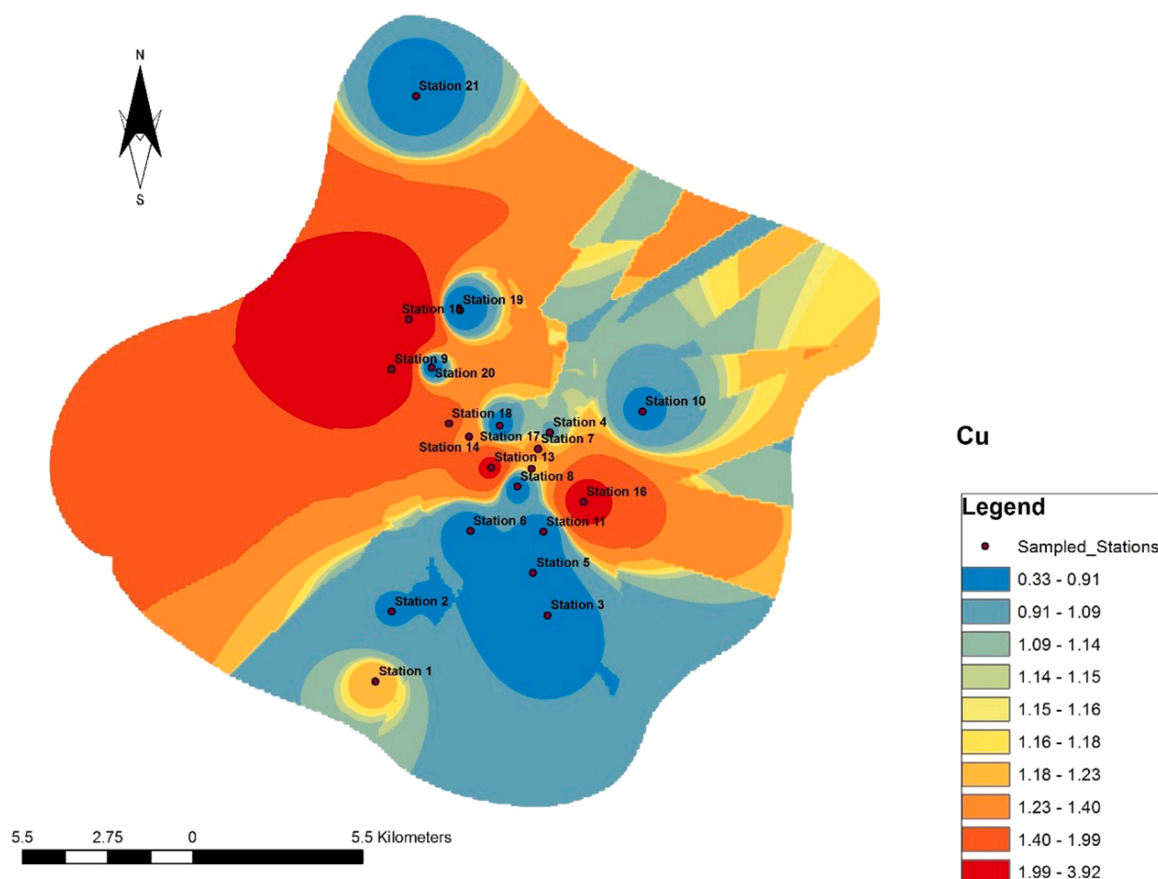
**Fig. 4.** Spread of Cu across the study area.

and decreased in the following order: Pb (−3.87) > Zn (−4.89) > Cd (−5.18) > Cu (−6.05) > Cr (−7.73) > Ni (8.80). > Fe (−11.02) with all the metals showing no sign of contamination. The calculations for $I_{geo}$ Indicate that the metals in the soil samples presented no ecological risk (Table 6).

### 3.5. Potential ecological risk index (PER) of trace metals in soils of AMWs

The range of the potential ecological risk assessment (PER) of the metals were Pb= 0.18–1.86, Zn= 0.01–0.12, Cu= 0.03–0.44, Ni= 0.00–0.03, Cr= 0.00–0.03 and Cd= 0.00–4.00. The PER of the metals was in the order of Cd > Pb > Cu > Zn > Ni > Cr.

### 3.6. Spatial distribution of trace metals in sampled locations

Mapping the distribution of trace metals across the 21 sampling stations around the AMWs in Benin City was conducted using inverse distance weighing in ArcGIS 10.4.

The hotspots where Cr concentration was dominant were Stations 1, 2, 4, 7, 8, 9, and 20, which were the significant sources of spread; from where it tapered to the minimum at Stations 3 and 11; between which a slight intermediate rise occurred at Station 5 (Fig. 2), while an abrupt rise occurred at Station 13; from range 0.12 mg/kg - 0.37 mg/kg, through 0.69 mg/kg - 0.74 mg/kg to the peak (0.96 mg/kg - 1.13 mg/kg) at Stations 7 and 8. Other peaks occurred at Stations 1, 2, 4, 9, and 20 instead of linked in constant ascending gradients.

The spread of nickel contamination was fareasonablyow compared to that of chromium. Tnickel peakkel was only reached at Stations 8 and 10, while the minimum concentrations occurred at Stations 9, 13, 17, 18, and 21 (Fig. 3). A smooth transition from lowest to highest

concentrations occurred between Stations 21 and 10, respectively. Station 10 was the primary source of distribution of Ni to other stations.

A notable and dramatic spread occurred in copper across the sampled stations, dominated by highest and lowest concentrations, with minimal intermediate concentrations (Fig. 4). The lowest concentrations occurred at Stations 2, 3, 5, 6, 8, 10, 11, 18, 19, 20, and 21. Intermediate stations were scanty, and the low concentrations were abruptly interjected by the highest concentrations, which occurred only at Stations 9, 13, 15, and 16. A spread occurred from Stations 9 and 16 to Station 21.

The peak concentrations of zinc occurred at Stations 6, 8, 9, 14, which were dominated by the lowest concentrations, which occurred at Stations 3, 11, 13, 16, 17, 19, 20, and 21 (Fig. 5). The intermediate boundaries between the clusters of the highest and lowest Stations were locations of gradient transitions.

The study area was dominated by peak concentrations of Fe, which occurred at Stations 1, 2, 7, 9, 10, and 11, while the lowest concentrations occurred only at Station 4 (Fig. 6). The border zones between the highest and lowest points were dominated by interspersed mixtures of abrupt and gradient fluctuations. A free and uninterrupted spread occurred from Station 11 to Station 6; and, and Station 21 to Station 16.

Conversely, high lowest concentrations of Pb dominated the study area, occurring at Stations 8, 11, 15, and 19. The highest concentrations of Pb occurred at Stations 2 and 18, spreading at a constantly decreasing gradient towards Stations 6, 8, 9, 11, 13, 16, 19, 20, and 21 (Fig. 7).

The distribution for cadmium was not interpolated due to very low concentrations.

## 4. Discussion

Assessments of heavy metals contamination from soils in AMWs offer some insight into the levels of contamination of the soils in automobile
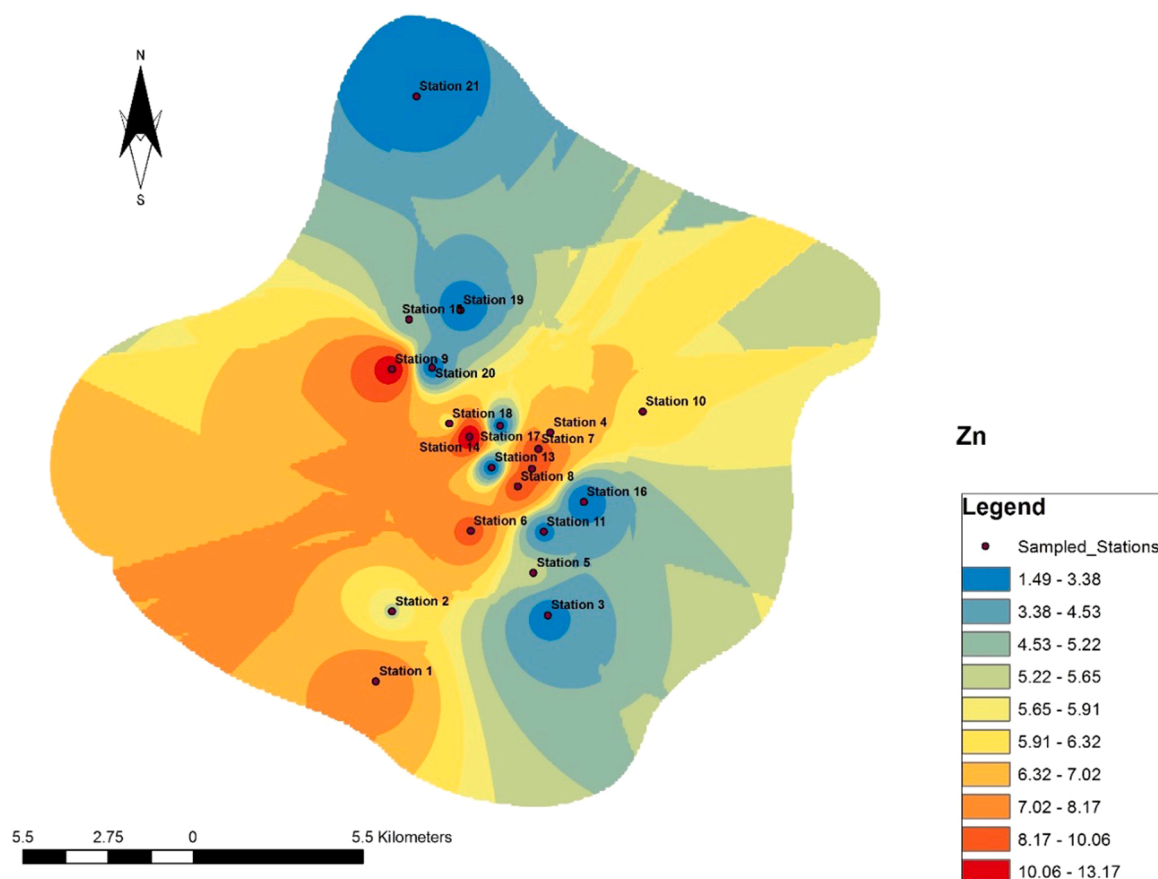
**Fig. 5.** Spread of Zn across the study area.

shops [6]. The heavy metal levels in soils of AMWs in Benin City were assessed in this study, and their human health risks and potential ecological risk were determined.

### 4.1. Heavy metal concentration in soil samples

The lead concentrations in all the soil samples greater than 1.0 mg/kg indicates that the AMWs may be the source of pollution [28]. The lead concentration in this study ranged between 0.70 and 7.43 mg/kg across the stations. This consistent result indicates that the pollution of the soils samples with lead is attributable to the automobile activities or spill of automobile fluids at AMWs [40,45,46,54,65]. This is of concern as AMWs are almost evenly distributed around residential areas inhabited by middle-class citizens. The implication of this is that children in such areas are often left to play on the streets with peer groups. Some of the children's activities that may elicit lead-associated health risks include playing with sands and scavenging discarded auto parts. Although the mean concentration of Pb in the current study may be lower than 15.1 mg.kg$^{-1}$ reported by [7], 28.1 mg/kg reported by Anegbe et al. [15] as well as 14.13 mg/ kg reported by Babatunde et al. [17], 76.92 mg/ kg reported by Okunola et al. [64], 47.8 mg/ kg reported by Sitkol et al. [76], and the set limit of Department of Petroleum Resources [24]- 85 mg/ kg, the current study area being a residential environment is however of a great concern. Details of the current study and previous reports of works done in Nigeria consistently show that most of the Nigerian soil samples analyzed were contaminated with lead. Hence, stringent measures may be required to place restrictions and sanctions on the use of lead-containing products. Elevated lead concentrations may be linked to lead deposition in soils within the AMWs and, hence, the topsoil's retention [15]. Studies have shown that the application of tetraethyl lead as an anti-knocking agent in gasoline

releases lead from fossil fuel combustion through emissions from automobiles [11,66,68,74].

Although chromium is an essential element, it may become toxic at high levels. Elevated levels of chromium can pose health risks to humans because chromium can be accumulated in the skin, lungs, muscles, and liver, where it can be linked to various health conditions [71]. Chromium concentrations in the current study ranged between 0.11 and 1.13 mg/kg. The mean chromium levels observed in the soil samples analyzed were lower than the standard regulatory limits of CCME (1999) whose assessment criteria is 20.00 mg/ kg and the DPR target value of 100 mg/ kg. The concentrations of chromium in the soil samples of the AMWs were also lower than those reported by Idugboe et al. [37] and Zakir et al. [88] but higher than values reported by Adebayo et al. [6].

Cadmium has no biological purpose in the human body [48] but it is rather of notable ecological significance [6]. Cadmium was below detectable limits (0.00 mg/kg) in station 1 and 15 throughout the months of sampling. According to Ebong et al. [27], the presence of cadmium could be due to the disposal of polyvinyl chloride plastics, nickel-cadmium batteries, motor oil and disposal sludge in the AMWs. The mean cadmium concentration in the soils of the current study was lower than values reported by Anegbe et al. [15] in some auto AMWs in Benin City. The discrepancy in the concentrations of cadmium may be due to the age difference of the AMWs. The current study area being a new residential environment, and the AMWs also being less than a decade of operation, may explain the relatively concentrations of most heavy metals detected in the soil samples.

Plants take up nickel from nickel-rich soils such as soils of lands designated for tea, beans, and vegetables cultivation. The risks of cancers of the lung, nose, larynx, prostate, respiratory failures, congenital disabilities, and heart diseases are associated with nickel exposure [15, 26]. The nickel concentrations in the current study area ranged between
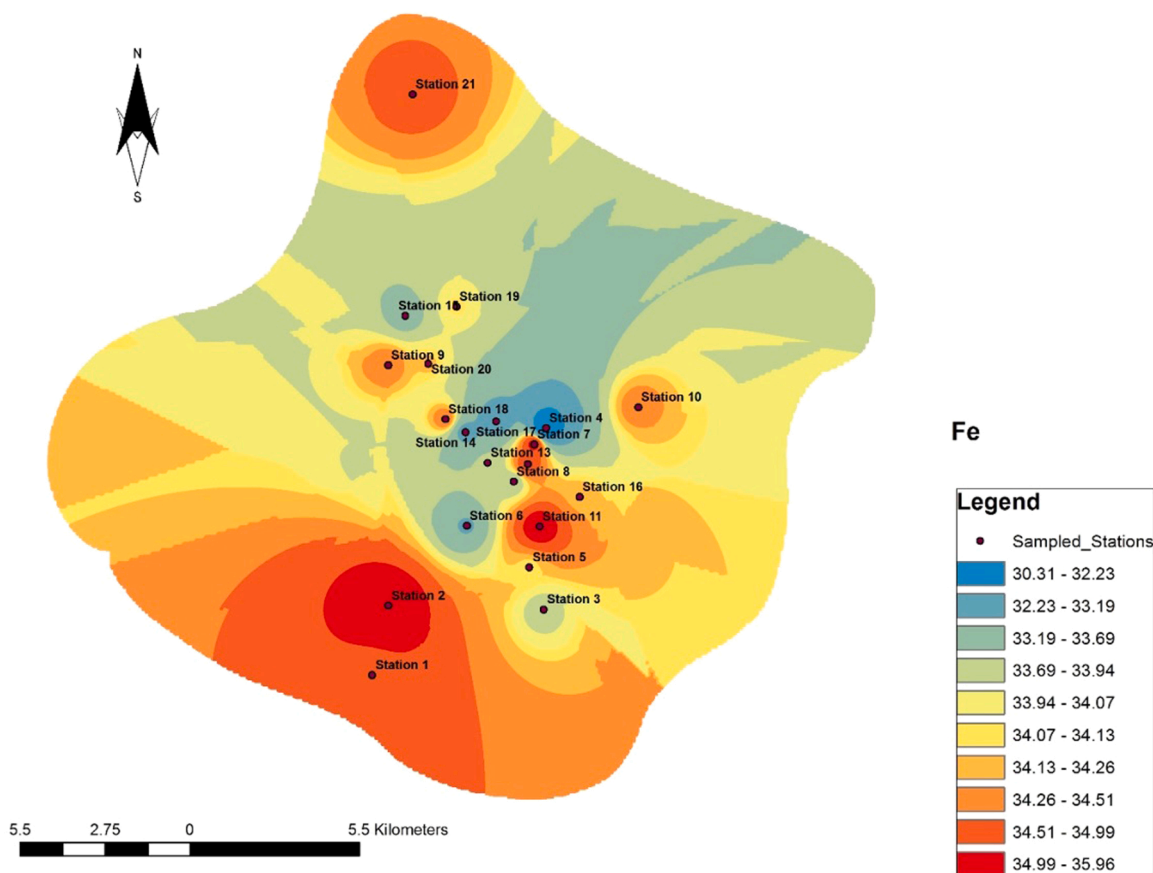
**Fig. 6.** Spread of Fe across the study area.

0.06 mg/kg - 0.68 mg/kg in the stations. The highest concentration of nickel obtained in this study is lower than values reported by Oguntimehin and Ipinmoroti [63] and Nwachukwu et al., [58]. The highest mean concentration of nickel obtained in this study is however higher than that reported by Pam et al. [69] and Adebayo et al. [6].

The mean iron concentration ranged between 30.30 mg/kg-35.97 mg/kg in the soils across the stations, thus making iron the metal with the highest concentration in the soils. The high concentration of iron in soils has been alluded to by several authors [13,22,63,8]. The mean values of iron in this study are lower than those reported by Osakwe [67], Oguntimehin and Ipinmoroti [63], Nwachukwu et al. [57], Idugboe et al. [37] and Anegbe et al. [15]. High concentrations of iron are attributable to rust of old vehicles bodies, welding and vehicular panel beating activities at the site. Acute exposure of Fe may elicit cardiac depression and life-threatening metabolic acidosis [6].

The mean zinc concentration ranged between 1.47 mg/kg - 13.28 mg/kg across the stations. The range of values in this study was higher than the values reported by Nwachukwu et al. [58], Ubwa et al. [77] and Anegbe et al. [15]. Oguntimehin and Ipinmoroti, [63], Zakir et al. [88] and Osakwe [67] all reported higher values than in the current study. Elevated zinc concentration in the soils is attributable to the prolonged period the site has been existing on the roadside. Moreover, contaminated roadside soil is attributable to the wear and tear of vehicle parts [88]. The heat conductivity of zinc is applied in brake linings of vehicles, engine oil and vehicle tyres [11,51,52]. In the event of spills of automobile oil, coolants, and other fluids, zinc contamination of soil occurs [55,67].

### 4.2. Human health risk assessment

The results presented in this study indicate that the order of HQ in

the three exposure pathways to metals in adults and children was ingestion > dermal contact > inhalation. Nickel is the metal that requires strict monitoring to avoid the synergy AMW source with other anthropogenic sources [9,11,21]. Since most of the automobile chemicals used are in the liquid form, the inhalation might not be as impactful as the dermal route of exposure. This conforms to the results showing inhalation route ranked the last in the order of impacts. As observed in the results presented, the children are expected to be more susceptible than adults as playing with sand is predominant among children in the sub-urban areas of the country. The situation might be worse if their playground is located near any of these mechanic workshops. This may explain why the non-carcinogenic risk was higher in the children that in the adults. The findings of the current study conform to the observations of Wei and Yang [82], and Xiao et al. [85]. The highest route of exposure was ingestion because risk in children is attributable to the frequency of hand-to-mouth habit [82]. Notably, although the concentration of nickel in the soil was below the regulatory limit, the CR posedto the children was however significant. This shows that only studying background concentrations of contaminants in the environment is not sufficient, health risk analyses are effective in giving early warning signals. Nickel is a ubiquitous element in the environment. The metal has no determinate physiological function in animals and human beings [32]. Exposure to nickel can cause allergy, cardiovascular and kidney dysfunctions, lung fibrosis. Most importantly, the children in the current study area could be afflicted with cancer of the respiratory system [32]. Due to the molecular mechanisms of nickel-induced toxicity, mitochondrial dysfunctions and oxidative stress have a primary and crucial role. Nickel induces cancer through epigenetic alterations which perturb the genome [31,33,34]. This metal can cause an allergy that manifests as contact dermatitis, headaches, gastrointestinal and respiratory manifestations [54,65,73,75,86,87]. The molecular mechanisms of Ni
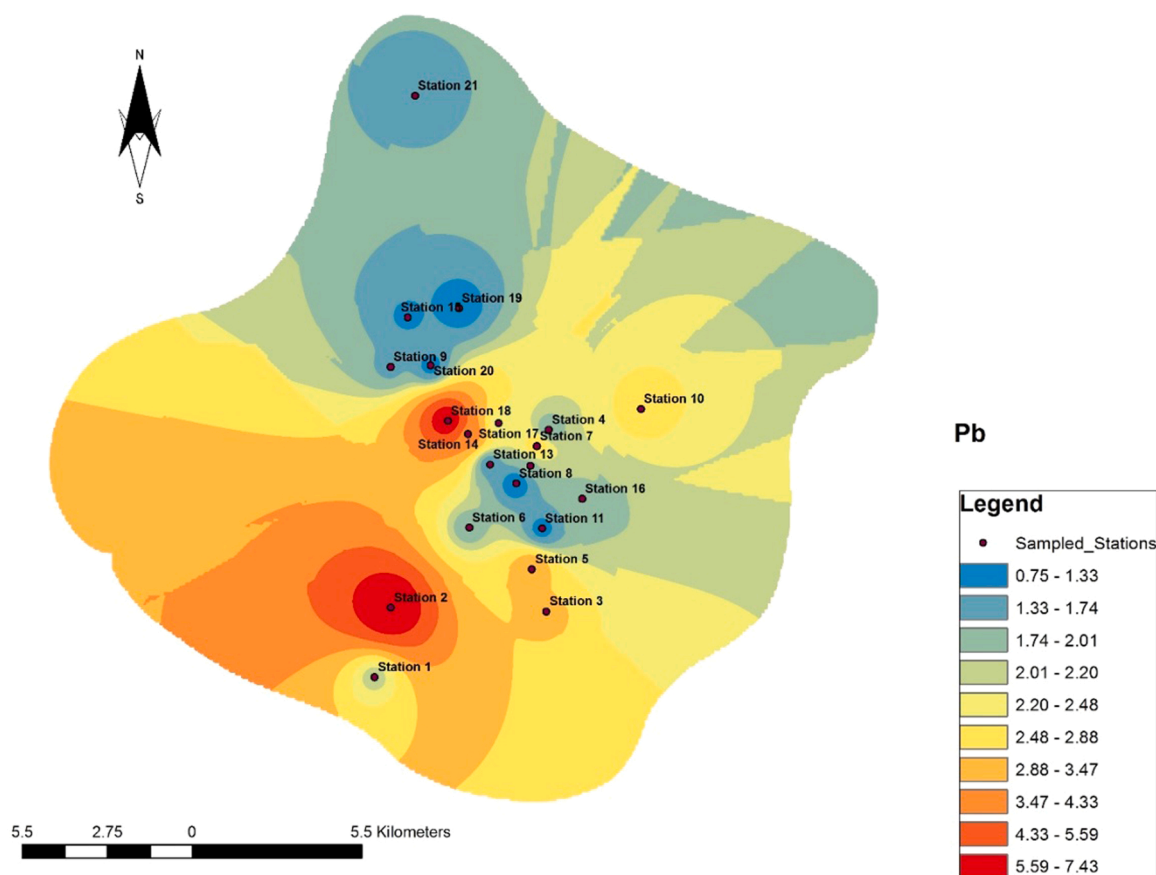
**Fig. 7.** Spread of Pb across the study area.

induced neurotoxicity are initiated through mitochondrial damage which precedes mitochondrial membrane potential damage, followed by reduced mitochondrial ATP concentration and ultimately mitochondrial DNA damage. The damage exerted on mitochondrial functions interferes with the mitochondrial transport chain, amplifies ROS and enhances oxidative stress. The current study indicates that the inadvertent hand-to-mouth habit in children may put them at higher health risk than adults as characterized by the high risks recorded in the ingestion pathway.

The sensitivity of biological communities to heavy metals was presented as potential ecological risk (PER) as proposed by Islam et al. [44]. As proposed by Hakanson [35], the elemental abundance and release capacity was represented as potential ecological risk index (PER) in this study. PRI was thus employed as a tool to assess the degree of heavy metal pollution in the soil samples based on the toxicity of heavy metals and the corresponding response of the environment [19,83]. The mean PER of the analyzed metals was in the order of Cd > Pb > Cu > Zn > Ni > Cr. The results of the current study indicate that Cd may have posed the highest ecological risk. Similarly, Enuneku et al. [28] reported high potential ecological risk posed by Cd among other heavy metals investigated. In the current study, the ecological risk of other heavy metals in the sampled soils were relatively low across all the study stations.The concentrations of metals in the soil may rise to notable levels in the future due to the indices obtained from the geoaccumulation and bioaccumulation analyses [19,29,33,62].

### 4.3. Recommendations and conclusion

Potential ecological risks of the trace metals in soils of these workshops revealed low pollution of the soil. Although the concentrations of metals in the soil were within safe limits, the children are however at

risk of nickel-initiated cancer through hand-to-mouth habits. Parents are thus advised to prevent their children from contact with the soil and enforce regular hand washing as recommended by World Health Organization. Although naturally, surface runoff and percolations in the ground may reduce the concentrations of metals in the soil overtime but these will cause pollution problems in the receiving destinations which are surface water bodies and underground water respectively. The soil in the study area can however be remediated by cost-effective and sustainable techniques such as phytoaccumulation or phytoextraction in which the plants uptake the metals into their tissues through absorption and accumulation [72,73,75,79,89]. The toxicodynamics of heavy metals in the soil profile demonstrated in this study could be a vital information for future studies and decisions on the management of the health and environment of the study area. Further studies for proper validation of data obtained for ingestion routes using consumable environmental media have however been suggested.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.toxrep.2022.03.021.

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