International Journal of Environment, Agriculture and Biotechnology
Vol-8, Issue-3; May-Jun, 2023
Peer-Reviewed International Journal
Journal Home Page Available: https://ijeab.com/
Journal DOI: 10.22161/ijeab

Relationship between traffic density, metal accumulation, pollution status, and human health problems in adjoining soils and vegetables within the South-South Region of Nigeria

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Received: 11 May 2023; Received in revised form: 04 Jun 2023; Accepted: 15 Jun 2023; Available online: 23 Jun 2023

Abstract— *Road transport is associated with the elevation of trace metals in the adjoining soils and vegetables and rate of metal accumulation on these media is directly related to the traffic density. This research investigated the association between traffic density, metal accumulation, pollution status, and human health problems in adjoining soils and vegetables within the southern Region of Nigeria. Top soils and vegetables (Vernonia amygdalina and Jatropha tanjorensis) were obtained from roadsides along roads with high traffic density namely: Abak, Aka, Ikot Ekpene, Nwanaiba, and Oron. Top soils and vegetables were also obtained from roadside along a road with low traffic density (Ekpri Nsukara) and used as the Controls. These samples and their Controls obtained within Uyo Metropolis using standard procedures were subjected to acceptable analytical treatments and determined the levels of Cd, Cu, Fe, Ni, Pb, and Zn using Spectroscopic methods. Results obtained revealed that, the mean concentrations of these metals in studied soils and vegetables were within their acceptable limits by FAO/WHO. However, higher mean concentrations of these metals were obtained in soils and vegetables from roads with high traffic density than in the Control. Higher mean levels of all the metals were recorded in J. tanjorensis than in V. amygdalina. The contamination factor of the metals in soil varied between moderate and very high contamination classes. The ecological risk factor of the metals ranged from low to the very high risk classes for the respective metals. Potential ecological risk factor revealed very high risks for the metals determined. Higher transfer factors were obtained for J. tanjorensis than V. amygdalina, though below one. Principal component analysis identified one key factor for the accumulation of these metals in the studied soils and vegetables. The metals were within their oral reference doses but, Cd and Pb were above their recommended daily intake limit. The consumption of V. amygdalina and J. tanjorensis exposed the consumers to risks associated with high Cd and Pb, respectively though; the consumers of J. tanjorensis were generally more susceptible to more non-cancer risks. The potential cancer risks associated with the trace metals via the consumption of the studied vegetables varied between the low and moderate cancer risk classes. However, the target cancer risk values obtained for the metals were higher than the threshold risk limit for ILCR < 1 $\times 10^{-4}$ by USEPA. The total cancer risk revealed that, Cd and Cu were the major carcinogens in the studied vegetables while, the consumers of V. amygdalina have a higher risk of developing cancer than J. Tanjorensis. The study has shown the relationship between road transport and traffic density on the* *accumulation of metals in soil and vegetables. Health risks associated with the exposure to metals via the consumption of the studied vegetables has also been exposed.*

Keywords— Road transport, Traffic density, Roadside soil, Roadside vegetable, Pollution risk, Human health risks, Southern Nigeria.

I. INTRODUCTION

The aspirations of human beings on earth have modified the natural settings of the environment thereby resulting the serious degradation and devastations (Ebong *et al*., 2014). Road transport as one of the human aspirations is major routes for metals accumulation in soil and plants. Globally, the negative impact of road transport is becoming a serious problem to human health. Vehicular emission is one of the main causes of the contamination of roadside soil and vegetation by toxic metals (Nabulo and Oryem-Origa, 2006; Chen *et al*., 2010; Ekundayo and Fatoba, 2020). These metals through biogeochemical cycling are transferred to the roadside vegetables and eventually impact negatively on the health of the consumers. However; the impact related to road transport in an area is directly proportional to the traffic density (Chen *et al*., 2010). Worldwide, human beings depend on vegetable as a good source of vitamins, essential metals, nutrients and antioxidants (Ali *et al*., 2020; Dada *et al*., 2021). As at 2005, literature has shown that there were almost 8.0 billion of cars on the roads globally and the number is expected to be higher now (Mavrin *et al*., 2020). Currently, within the European Union Nations road transport is the source of almost 73% of the carbon (IV) oxide emissions and the major route of environmental contamination/pollution (Mavrin *et al*., 2020). Considering the negative impact associated with exposure to roadside soils and vegetables, these media should be closely monitored to avert serious health hazards on the consumers (Jankowski *et al*., 2015).

Studies have shown that roadside dust and soils contain high level of trace metals (Adamiec *et al*., 2016; Ebong and Moses, 2016; Krailertrattanachai *et al*., 2019). Road transportation affects the metal loads of adjoining soils and vegetables through diverse ways such as combustion of fuel and lubricants, asphalt, tyres, abrasion of brake linings and pads (Radziemska and Fronczyk, 2015; Penkała *et al*., 2018; Fussell *et al*., 2022). Cd in roadside soils and plants originates mainly from the combustion of fuel and lubricants, asphalt, brake lining abrasion and tyres (Lindgren, 1996; Akbar *et al*., 2006; Pulles *et al*., 2012). The utilization of Zn for tyre and engine oil production as additive has resulted in the accumulation of the metal in roadside soil and plants caused by tyre attrition and oil leakage (Councell *et al*., 2004; Adamiec *et al*., 2016). Brake abrasion, combustion of fuel and lubricants, and corrosion of tyre are the major sources of Cu and Ni in relation to road traffic (Hjortenkrans *et al*., 2007; Lu *et al*., 2009). Fuel and lubricant oil combustion, tyre corrosion and brake lining are the sources of Pb to roadside soils and plants (De Miguel *et al*., 1997; Ikenaka *et al*., 2010; Apeagyei *et al*., 2011). The accumulation of Fe in the studied roadside soils and vegetables is closely related to abrasion of brake (Apeagyei *et al*., 2011; Adamiec *et al*., 2016; Skorbiłowicz *et al*., 2020; Skorbiłowicz *et al*., 2021).

Reports have revealed that, apart from the greenhouse gases emanated from road transport, other harmful substances have also been released into the human environment (Condurat *et al*., 2017; Nwagbara and Iyama, 2019; Gnap *et al*., 2020; Mavrin *et al*., 2020). The negative impact of these toxic substances released will eventually manifest in human health (Briffa *et al*., 2020). Consequently, the inhabitants of an area with high traffic density should be aware of the harmful effects associated with the cultivation and subsequent consumption of edible plants by the roadside and possibly proffer some management measures.

Studies on the impact of road transport on metal loads in roadside soils and plants abound both within and outside Nigeria (Aslam *et al*., 2013; Tanee and Albert, 2013; Mohammed *et al*., 2019; Olajumoke and Ojo, 2020; Kuklová *et al*., 2022). Nevertheless, most studies conducted in the Study area concentrated specifically on the impact of road transport on the contaminants loads on air environment without assessing the metal loads on the adjoining soils and vegetables. Previous researches never assessed the health risks related to the consumption of vegetables from roadsides with high traffic density (Akpan *et al*., 2014; Mmom and Essiet, 2014; Ebong and Moses, 2016; Daniel *et al*., 2017).

One of the major problems of accurate management of traffic congestion is inadequate data collected. Hence, the installation and utilization of efficient technology including traffic lights that can provide accurate data on the traffic density and improve the traffic flow at all the necessary points in an area should be encouraged (Shepelev *et al*., 2020; Villagra *et al*., 2020).

This study has evaluated the impact of road transport on the metal loads in soil and vegetables from roadsides with high and low traffic density. It has also assessed the human health risks (non-carcinogenic and cancer related) associated with the utilization of vegetables from roadsides with high traffic density. The pollution status of trace metals associated with road transport in roads with high and low traffic density has also been appraised. Hence, the gap that existed in the area of road transport and the associated negative impact on adjoining soil, plants and the consumers in Uyo has been closed by this research. It is the belief of the authors that, the findings of this study will benefit the road users, Town Planners, consumers, road transport workers, civil Engineers, and environmental workers.

II. MATERIALS AND METHODS

Study Area

Uyo is the capital of Akwa Ibom State and is lying between latitudes 4°52′N and 5°07′N) and longitudes (7°47′E and 8°03′E). Uyo has a land mass of approximately 28.48km^2 and is located about 55km from the Atlantic Coast (Akpan *et al*., 2014). The State capital is bounded by many other local government areas namely: Ikono, Ibiono Ibom, Ibesikpo Asutan, Nsit Ibom, Etinan, Itu and Abak. The population of Uyo as at 2006 was 847,500 and the figure is expected to double this year 2023 (NPC, 2006). As a capital of a major oil producing State, the population and traffic density is expected to be high. Consequently, the volume of wastes generated and level of environmental contamination are also expected to be alarming. Uyo has dominant seasons, namely: dry (March to December) and wet (April to November). Based on the climatic conditions of the area, farming activities at both commercial and subsistent levels is highly favoured and various vegetables are cultivated and widely utilized in Uyo.

Sample Collection and Preservation

Top soil samples were collected at roadsides along roads with high traffic density according to Akpan *et al*. (2014) and Guaman *et al*. (2022) namely: Ikot Ekpene, Aka, Oron, Abak, and Nwanaiba using Soil Augar. Soil samples were also obtained from a road with low traffic density (Ekpri Nsukara) and used as the Control (Akpan *et al*., 2014; Guaman *et al*., 2022). The high and low traffic density classifications are Soil samples were collected at four different points at each location designated for this study and put together to form a composite sample for the location. Soil samples collected were dried under the sun for 3 days, homogenized and sieved. The sieved soil samples were preserved in dry polyethene containers for digestion and analysis.

At each of the locations where studied samples and Control were obtained, leaves of *Vernonia amygdalina* (Biter leaf) and *Jatropha tanjorensis* (Hospital too far) were also collected using stainless steel knife. The fresh leaves collected were washed first with tap water to remove dirt, then with distilled water and at last with deionized water. These leaves were later air dried, chopped into pieces and dried again in an oven at 60 ºC for 24 hours. Thereafter, the leaves were homogenized into powdered form with a porcelain mortar and pestle. The resulting material was preserved in polyethene containers for digestion and analysis.

Sample digestion and Analysis

One gram each of the samples was weighed into a 100ml beaker, and then 10ml of $HNO_3/HClO_4$ in the ratio of 2:1 was added on a hot plate with continuous stirring for complete digestion. The digested samples were later filtered into a 25ml volumetric flask and made to mark with deionised water. The total concentrations of metals in the soil and vegetables were analysed for in the filtrates obtained using UNICAM 969 atomic absorption spectrophotometer.

Pollution Indices Assessment

The pollution status of trace metals in the studied soils at the different locations investigated was established by the assessment of contamination factor, degree of contamination, ecological risk factor and potential ecological risk factor.

Contamination Factor (CF)

The contamination factor of trace metals in the studied roadside soils was assessed using Equation (1) below.

$$CF = \frac{Cm}{Bm} \text{ --- } (1)$$

Where Cm and Bm signify metal concentration in the studied soils and Control, respectively. According to Pekey *et al*. (2004) contamination factor is classified as low contamination (CF < 1), moderate contamination (1 ≤ CF ≤ 3), considerable contamination (3 ≤ CF ≤ 6), and very high contamination (CF > 6).

Degree of Contamination (C_{deg})

The degree of contamination of the different locations investigated was evaluated by the use of Equation (2).

$$C_{deg} = \Sigma CF \text{ -- } (2)$$

Where ΣCF represents the sum of contamination factor of the trace metals for a particular location. Contamination factor is classified as low degree of contamination when Cdeg < 8, moderate degree of contamination if 8 < Cdeg < 16, considerable degree of contamination when 16 < Cdeg < 32), and very high degree of contamination when Cdeg > 32 (Hakanson, 1980).

Ecological Risk Factor (ERF)

The ecological risk factor of trace metals in the studied soils was determined by the means of Equation (3).

$ERF = TR\ x\ CF$-- (3)

In Equation (3) above, Tr is the toxic-response factor of trace metals and CF stands for the contamination factor of metals. The response factor for each of the metals based on the report by Hakanson (1980) for Cd, Cu, Fe, Ni, Pb, and Zn are 30.0, 5.0, 1.0, 5.0, 5.0, and 1.0, respectively (Gbadamosi *et al*., 2018; Huang *et al*., 2020). According to Ren *et al*. (2007) ERF are classified as follows: ERF < 40 = Low ecological risk, 40 < ERF≤ 80 is Moderate ecological risk, 80 < ERF ≤ 160 = Appreciable ecological risk, 160 < ERF ≤ 320 = High ecological risk, ERF > 320 = Severe ecological risk.

Potential Ecological Risk Index (RI)

In this study, potential ecological risk index of the trace metals determined in the studied roadside soils was evaluated using Equation (4).

$$\text{RI} = \Sigma(ERF) - - - - - - - - - - - - - - - - (4)$$

Where Σ(ERF) represents the summation of all the metals determined at each of the roads investigated. According to Ren *et al*. (2007) RI is divided into various classes namely: RI < 150 is low ecological risk, 150 < RI < 300 indicates moderate ecological risk, 300 < RI < 600 signifies high ecological risk, and RI > 600 shows significantly high ecological risk.

Transfer Factor (TF)

The transfer factor of trace metals from soil to vegetable was computed using Equation (5).

$$TF = \frac{Mp}{Ms} \text{--} (5)$$

Where Mp indicates the mean metal concentration in the vegetables, while Ms Stands for the metal concentration in the studied soils.

Assessment of Health Risk

The probable human health risk associated with trace metals due to the consumption of the studied vegetables was appraised by assessing the daily intake rate (DIM), non-carcinogenic risk index (THQ), hazard index (HI), and target cancer risk (TCR) of the trace metals determined (Chary *et al*., 2008; Adedokun *et al.*, 2016; Ogu and Akinnibosun, 2020; Asrade and Ketema, 2023).

Daily Intake Rate (DIM)

The daily Intake of trace metals via the consumption of the studied vegetables was calculated using Equation (6).

$$\text{DIM} = \frac{Cm\ x\ Cf\ x\ Dv}{Bwt} - - - - - - - - - - - - - - - - (6)$$

Where Cm signifies the concentration ($mgkg^{-1}$) of trace metal in the studied vegetables, Cf is the Conversion factor from fresh to dry weight which is 0.085, Dv indicates the daily intake of vegetable (65 g/kg) while, Bwt shows the average body weight in kg per individual (65 kg) (Ojiego *et al*., 2022).

Total Hazard Quotient (THQ)

The non-carcinogenic risk index otherwise known as hazard quotient of the metals was evaluated using Equation (7).

$$THQ = \frac{DIM}{RfDo} \text{--} (7)$$

In Equation (7) above, DIM is the daily intake rates of the trace metals through the consumption of studied vegetables and RfD indicates for the oral reference dose of the metals determined. The RfDo values of 0.001, 0.04, 0.700, 0.002, 0.0035, and 0.300 mg/kg/day were used for Cd, Cu, Fe, Ni, Pb, and Zn, respectively (USEPA, 2010).

Hazard index (HI)

Hazard index (HI) denotes the sum of all the hazard quotients (HQs) for all the metals determined was calculated with Equation (8).

$$HI = \Sigma HQ = HQCd + HQCu + HQFe + HQNi + HQPb + HQZn - - - - - - - - - - (8)$$

Where HI stands for hazard index and HQ is the hazard quotient of the metals determined in the vegetables. When the value of HI is less than one, the consumers of these vegetables are secured but if the HI value is equal to or higher than one, then the consumers are at risk of metal toxicity and related health problems (Cao *et al*., 2015)

Cancer risk assessment

Cancer risk shows the likelihood of the consumers of the studied vegetables developing cancer over a lifetime as a result of exposure to metals.

Incremental lifetime cancer risk (ILCR)

Incremental lifetime cancer risk (ILCR) by exposure to Cd, Cu, Ni, and Pb via the consumption of studied vegetables was estimated with Equation (9).

$$ILCR = CSF(oral)x\ DIM - - - - - - - - - - - - (9)$$

Where CSF(oral) signifies the oral cancer slope factor for the metals and DIM is the daily intake rates of the trace metals. In accordance with USEPA (2020) the values of CSF are 0.38, 1.5, 1.7, and 0.0085 mg/kg/day for Cd, Cu, Ni, and Pb, respectively. There were no CSF values for the calculation of CR for Fe, and Zn. The tolerable range of predicted lifetime risk for carcinogens is 10^{-4} to 10^{-6} (USEPA, 2011).

Target Cancer Risk (TCR)

The TCR of Cd, Cu, Ni, and Pb through the consumption of the studied vegetables was evaluated using Equation (10).

$$TCR = \Sigma ILCR = ILCRCd + ILCRCu + ILCRNi + ILCRPb - - - - - - - - - - (10)$$

Where $\Sigma ILCR$ indicates the summation of incremental lifetime cancer risk of all the trace metals determined in the studied vegetables.

Data Analysis

Results of this research were subjected to statistical analysis with IBM SPSS Statistics 20 (IBM USA). Multivariate analysis was done on six (6) trace metals by means of Varimax rotation method, and values from 0.707 and higher were regarded as being significant.

III. RESULTS AND DISCUSSION

Table 1: Concentrations (mgkg^{-1}) of trace metals in the studied roadside soils and Control

	Cd	Cu	Fe	Ni	Pb	Zn
Ikot Ekpene Road	1.03	8.35	512.69	2.21	8.64	12.20
Aka Road	1.12	8.21	488.16	1.95	8.27	11.64
Oron Road	1.18	8.09	541.47	3.61	9.10	13.31
Abak Road	1.14	9.17	493.35	3.42	8.32	12.46
Nwanaiba Road	0.78	5.42	465.68	1.84	6.72	10.60
Minimum	0.78	5.42	465.68	1.84	6.72	10.60
Maximum	1.18	9.17	541.47	3.61	9.10	13.31
Mean	1.05	7.85	500.27	2.61	8.21	12.04
SD	0.16	1.42	28.47	0.84	0.90	1.01
Control	0.24	3.17	261.32	0.40	1.68	4.25
Recommended Limit	3.00[a]	100.00[b]	5000.00[b]	50.00[a]	50.00[a]	300.00[b]

a = FAO/WHO (1999); b = (FAO/WHO (2001)

Trace metal levels in roadside soils from roads with high and low traffic density

The concentration of trace metals in surface soils from roadsides with high traffic density and Control (road with low traffic density) are shown in Table 1. The concentrations of cadmium (Cd) varied from 0.78 mgkg^{-1}at Nwanaiba Road to 1.18 mgkg^{-1} at Oron Road. This range is lower than 5.15 - 5.79 µgg^{-1} obtained in roadside soils in Jos by Abechi *et al*. (2010). Levels of lead (Pb) varied from 6.71mgkg^{-1} in Nwanaiba Road to 9.10 mgkg^{-1} at Oron Road. This range is lower than 3.02 - 30.08 mgkg^{-1} reported in Ogun State by Adedeji *et al*. (2013). Zinc (Zn) ranged between 10.60 and 13.31 mgkg^{-1} for Nwanaiba Road and Oron Road, respectively. The obtained range is below 26.46 - 215.02 mgkg^{-1} reported in roadside soils at Białystok-Budzisko Route, North-eastern Poland by Skorbiłowicz *et al*. (2021). Iron (Fe) that indicated the highest concentration amongst the metals determined varied between 465.68 mgkg^{-1} in Nwanaiba Road and 541.47 mgkg^{-1} at Oron Road. These values are much lower than 67,100.00 – 187,800.00 ppm obtained in roadside soils at Dhaka Aricha highway, Bangladesh by Ahmed *et al.* (2016). Concentrations of nickel (Ni) ranged from 1.84 mgkg^{-1}in Nwanaiba Road to 3.61 mgkg^{-1} at Oron Road. The obtained range is lower than 16.16-24.60 µgg^{-1} reported in roadside soils in Garki Area Council of Abuja, Nigeria by Kabiru *et al*. (2018). Concentrations of copper (Cu) ranged from 5.42 mgkg-1 in Nwanaiba Road to 9.17 mgkg-1 at Abak Road. This range is below 7.39 – 23.24 mgkg-1 obtained in roadside soils along Zaria-Giwa Road, Kaduna State, Nigeria by Upahi *et al*. (2021). Generally, the mean concentrations of all the metals in soil from roads with high traffic density were higher than the levels reported in soil from the road with low traffic density (Table 1). This is an indication of artificial inputs of these metals from road transportation into the studied roadside soils. Nonetheless, the mean concentrations of all the metals are within their recommended limits by FAO/WHO (1999) and (2001) (Table 1). However, since metals have the potential to bio accumulate and exhibit negative tendencies along the food chain, a regular assessment of their accumulation rates should be encouraged (Emurotu and Onianwa, 2017).

Table 2: Concentrations (mgkg^{-1}) of trace metals in the studied vegetables and Control

	Vernonia amygdalina						*Jatropha tanjorensis*					
	Cd	Cu	Fe	Ni	Pb	Zn	Cd	Cu	Fe	Ni	Pb	Zn
Ikot Ekpene Road	0.07	2.14	2.75	0.04	0.11	1.24	0.18	2.42	3.45	0.08	0.21	2.80
Aka Road	0.05	2.21	2.59	0.05	0.08	1.22	0.16	2.40	3.28	0.11	0.25	3.06
Oron Road	0.09	2.46	4.32	0.07	0.12	1.41	0.20	2.58	3.63	0.16	0.29	3.14
Abak Road	0.06	2.17	3.44	0.06	0.10	1.30	0.15	2.24	3.31	0.14	0.22	2.96
Nwanaiba Road	0.04	1.03	2.37	0.02	0.07	1.07	0.11	2.16	3.07	0.08	0.16	2.53
Minimum	0.04	1.03	2.37	0.02	0.07	1.07	0.11	2.16	3.07	0.08	0.16	2.53
Maximum	0.09	2.46	4.32	0.07	0.12	1.41	0.20	2.58	3.63	0.16	0.29	3.14
Mean	0.06	2.00	3.09	0.05	0.10	1.25	0.16	2.36	3.35	0.11	0.23	2.90
SD	0.02	0.56	0.79	0.02	0.02	0.12	0.03	0.16	0.21	0.04	0.05	0.24
Control	0.01	0.68	1.34	BDL	0.01	0.71	0.02	0.83	1.82	0.01	0.03	1.04
*Recommended Limit	0.2	73.3	425.5	67.9	0.3	99.4	0.2	73.3	425.5	67.9	0.3	99.4

*** FAO/WHO (2011).**

Trace metal levels in roadside vegetables from roads with high and low traffic density

Concentrations of trace metals in the vegetables (*Vernonia amygdalina* and *Jatropha tanjorensis)* from roadsides with high and traffic density are shown in Table 2. Generally, concentrations (mgkg^{-1}) of the trace metals determined varied as follows: 0.04 – 0.20, 1.03 – 2.58, 2.37 – 4.32 and 0.02 – 0.16 for Cd, Cu, Fe, and Ni, respectively. While the concentrations of Pb and Zn in both vegetables ranged from 0.07 to 0.29 and 1.07 to 3.14, respectively. Results in Table 2 indicate higher mean concentrations for the metals in vegetables from roads with high traffic density than the control site (Road with low traffic density). This shows anthropogenic addition of these metals to the soil from road transportation as previously opined by Naser *et al*. (2012). The study also revealed relative higher concentrations of the metals in *J. tanjorensis* than in *V. amygdalina.* The observed variations could be attributed to the difference in plant species, tolerance levels, growth rate etc as reported by Duman *et al*. (2009). Consequently, *J. tanjorensis* has higher potentials to accumulate these metals from a contaminated soil than *V. amygdalina.* It can also be deduced that, the cultivation of vegetables by the roadside should be discouraged to avoid bioaccumulation of toxic metals and associated health problems on the consumers. The utilization of *J. tanjorensis* from roadside as a medicine should also be discouraged since it is consumed raw without exposure to high temperature that may have reduced the metals load and their toxicities (Inobeme *et al*., 2020; Adjei-Mensah *et al*., 2021; Phrukphicharn *et al*., 2021). The level of Cd reported in this study is higher than that reported by Sulaiman and Hamzah (2018) whereas; concentrations of Cu are lower than that reported by Ogundele *et al*. (2015). Concentrations of Fe and Ni obtained in the studied vegetables are lower than values reported by Inoti *et al*. (2012) and Naser *et al*. (2012), respectively. Nevertheless, the concentrations of Fe reported for both vegetables were relatively higher than the concentrations of other metals. This is similar to the results obtained by Skorbiłowicz *et al*. (2021) in vegetables from roadsides with high traffic density. The mean values of Pb and Zn obtained in the studied vegetables are also higher than those reported by Olasupo *et al*. (2020) and Kuklová *et al*. (2022), correspondingly. However, the concentrations of all the metals determined in both vegetables are within the permissible limits for leafy vegetables by FAO/WHO (2011) (Table 2). Hence, these vegetables may be suitable for human consumption.

Pollution Indices of Trace metals in Roadside Soils

Contamination Factor

Table 3: Contamination factor and Ecological risk factor of trace metals in the studied roadside soils

	Cd	Cu	Fe	Ni	Pb	Zn	Cd	Cu	Fe	Ni	Pb	Zn
	Contamination Factor (CF)						Ecological Risk Factor (ERF)					
Ikot Ekpene Road	4.29	2.63	1.96	5.52	5.14	2.87	128.70	13.15	0.00	27.60	25.7	2.87
Aka Road	4.67	2.59	1.87	4.88	4.92	2.74	140.10	12.95	0.00	24.4	24.6	2.74
Oron Road	4.92	2.55	2.07	9.03	5.42	3.13	147.60	12.75	0.00	45.15	27.1	3.13
Abak Road	4.75	2.89	1.89	8.55	4.95	2.93	142.50	14.45	0.00	42.75	24.75	2.93
Nwanaiba Road	3.25	1.71	1.78	4.60	4.00	2.49	97.50	8.55	0.00	23.00	20.00	2.49

Results for the contamination factors (CF) of trace metals determined in roadside soils are shown in Table 3. CF values of the trace metals varied as follows: 3.25 – 4.92, 1.71 – 2.89, 1.78 – 2.07, and 4.60 – 9.03 for Cd, Cu, Fe, and Ni, respectively. The CF values for Pb and Zn ranged from 4.00 to 5.42 and 2.49 to 3.13, respectively. Based on the classifications by Pekey *et al.* (2004), Cd and Pb belong to the considerable contamination class. Cu and Fe are in the moderate contamination class while, the CF of Ni vary between considerable and very high contamination classes. Zn varies between moderate and considerable contamination class. The highest CF value was recorded for Ni at Oron Road. This can be attributed to the high traffic density in the area as reported by Zhang *et al.* (2012) and Kuklová *et al*. (2022). The sequence for CFs of trace metals determined in roadside soils follows the order: Ni>Pb>Cd>Zn>Cu>Fe. This reveals the high relative availability of toxic metals in the roadside soils than the essential ones. The results also indicate the various degree of trace metals enrichment in roadside soils by road transportation.

Ecological Risk Factor

The ecological risk factors (ERF) of trace metals determined in roadside soils are shown in Table 3. The ERF values for the metals varied as follows: 97.50 – 147.60, 8.55 – 14.45, 23.00 – 45.15, and 20.00 – 27.10 for Cd, Cu, Ni, and Pb respectively. The ERF for Zn ranged from 2.49 to 3.13 whereas; Fe has no ERF value because it is not considered as a toxic metal hence without a toxic response factor. Based on the classifications of Ren *et al*. (2007), Zn belongs to the low risk class while Cu varied between moderate and considerable risk classes. Ni and Pb belong to the high risk class while Cd is in the very high risk class. Consequently, living cells including humans exposed soils from these roads directly or indirectly are susceptible to high concentrations of Cd, Ni, and Pb alongside their attendants' health problems. This also indicates that, road transportation has the potential of elevating metal loads in adjoining soil environment (Wang and Zhang, 2018; Skorbiłowicz *et al*., 2021).

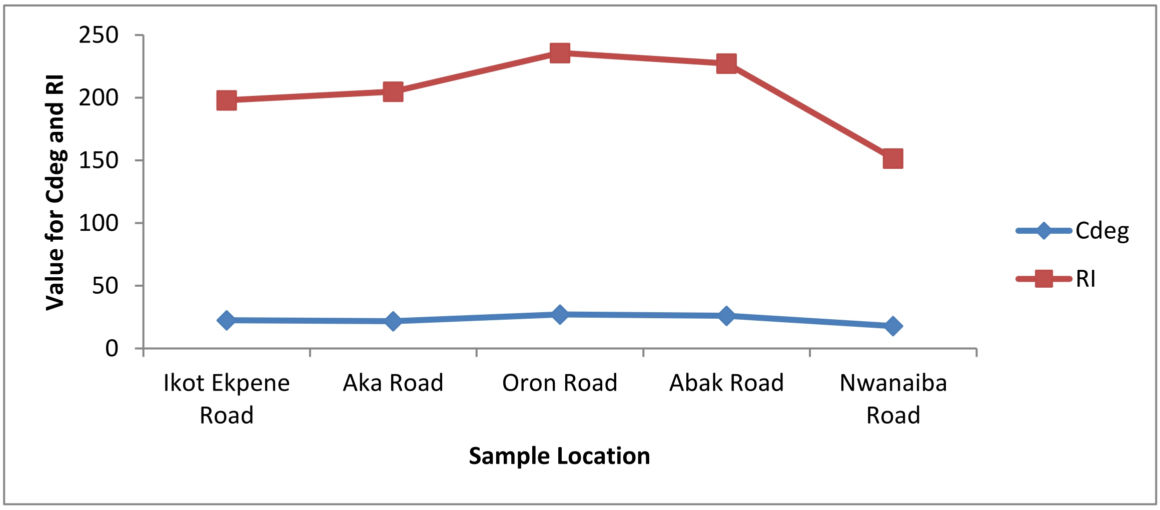

Fig.1: Degree of contamination (Cdeg) and Potential ecological risk index (RI) in the studied soils.

Degree of Contamination

Results for the degree of contamination (Cdeg) of the different roadside soils are illustrated in Figure 1. The results revealed that, Cdeg ranged for 17.83 at Nwanaiba Road to 27.12 at Oron Road. This reveals that the degree of contamination of the various roadside soils is exclusively in the considerable degree of contamination (Hakanson, 1980). The observed variations of Cdeg value from one road to the other may be due to the disparity in traffic density along each road. The Cdeg for the different roads investigated followed the trend Oron > Abak >Ikot Ekpene>Aka > Nwanaiba. This corroborates the findings by contamination factor in Table 3 concerning the high traffic density of Oron Road. The key contributors to the reported Cdeg for the studied roads are Cd, Ni, and Pb.

Potential Ecological Risk

Results for the potential ecological risk index (RI) for the studied roadside soils varied between 151.54 at Nwanaiba to 235.73 at Oron Road (Figure 1). This indicates that the potential effects of trace metals determined in the roadside soils are solely in the very high risk class (Ren *et al*., 2007). This is dangerous to those exposed to soils along these roads either directly or indirectly since high RI values is directly related to human health according to Mugosa *et al*. (2016). The RI values of trace metals in the different roads following the sequence: Oron>Abak>Aka>Ikot Ekpene> Nwanaiba. The high traffic density and the associated health problems along the food chain along Oron Road are also confirmed.

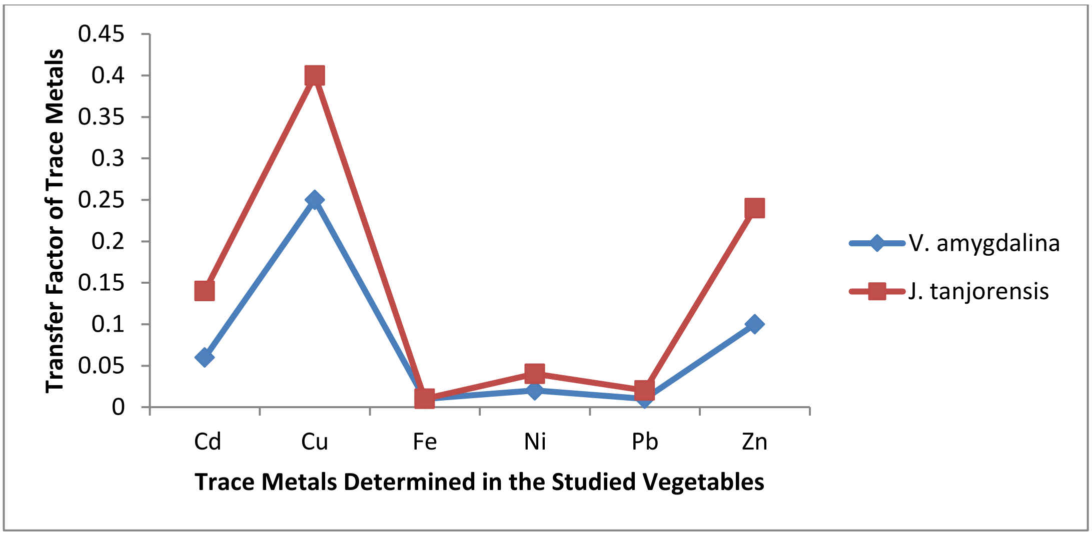

Fig.2: Transfer factor of trace metals from soil to vegetables

Transfer factor of Trace Metals from the Studied Soils to Vegetables

The transfer factor (TF) of a metal in vegetable indicates the level of such metal that is readily available along the food chain. Consequently, it is this level of the metal that can impact on the consumers of these vegetables (Chojnacka *et al*., 2005; Etuk *et al*., 2022). The mean transfer factors of the metals obtained in *V. amygdalina* are as follows: 0.06, 0.25, 0.01, 0.02, 0.01, and 0.10 for Cd, Cu, Fe, Ni, Pb, and Zn, respectively. However, relatively higher mean TF values were reported in *J. tanjorensis* for all the metals except Fe (Figure 2). The mean TF values of the metals in *J. tanjorensis* are 0.14, 0.40, 0.01, 0.04, 0.02, and 0.24 for Cd, Cu, Fe, Ni, Pb, and Zn, respectively. Accordingly, the consumers of these vegetables are more exposed to the trace metals determined via *J. Tanjorensis* than *V. amygdalina.* However, the transfer factors of all the metals were below one (1) which is consistent with the reports by Ebong (2015) and Baburo *et al*. (2022). Consequently, these vegetables could be applied as excluders and for phytostabilization but may not function effectively for phytoremediation (Suman *et al*., 2018; Nedjimi, 2021). The low TF values reported also signifies the low human exposure to these metals via the consumption of these metals (Jolly *et al*., 2013; Kulkarni *et al*., 2014).

Multivariate Analysis of Trace Metals in the Studied Soils

Table 4: Result of principal component analysis indicating relative loading for trace metals of the studied roadside soils and vegetables

	Soil	***V. amygdalina***	***J. tanjorensis***
Variable	Factor	Factor	Factor
Cd	0.936	0.938	0.940
Cu	0.845	0.890	0.924
Fe	0.880	0.917	0.932
Ni	0.812	0.933	0.764
Pb	0.963	0.920	0.974
Zn	0.984	0.996	0.920
% Total Variance	82.0	87.0	83.1
Eigen value	4.9	5.2	5.0

Results for the Principal component analysis of trace metals in the studied soils are shown in Table 4.The principal component analysis revealed one major factor responsible for the metal loads in the studied roadside soil, *V. amygdalina and J. Tanjorensis*. In soil, the factor has Eigen value of 4.9 and a total variance of 82.0% with significant positive loadings on all the metals determined in the soil. *V. amygdalina* has Eigen value of 5.2 and 87.0% total variance with strong positive loadings on all the metals. Eigen value and total variance of 5.0 and 83.1%, respectively were recorded for *J. Tanjorensis* with strong positive loadings on all the parameters (Table 4). This indicates exclusively the negative effects of road transportation on the accumulation of metals on roadside soil and plants as reported by Altaf *et al*. (2021) and Skorbiłowicz *et al*. (2021).

Health Risks Indices

Table 5: Results of non-carcinogenic hazard of trace metals determined in V. amygdalina and J. Tanjorensis from roadsides with high traffic density in Uyo metropolis

	Vernonia amygdalina						***Jatropha tanjorensis***					
	Cd	Cu	Fe	Ni	Pb	Zn	Cd	Cu	Fe	Ni	Pb	Zn
DIM	8.5E-4	1.70E-4	2.63E-4	4.24E-6	8.50E-6	1.06E-4	1.36E-5	2.01E-4	2.85E-4	9.35E-6	1.96E-5	2.47E-4
HQ	8.5E-3	4.25E-3	3.76E-4	2.12E-4	2.43E-3	3.53E-4	1.36E-2	5.03E-3	4.07E-4	4.68E-4	2.67E-2	8.23E-4
HI	1.61E-2						4.70E-2					

Daily intake rate (DIM) of trace metals through the consumption of V. amygdalina and J. Tanjorensis

The health implications of trace metals on human through the consumption of the studied vegetables could be established by the assessment of DIM (Etuk *et al*., 2022). Results for the daily intake rate of trace metals through the consumption of the studied vegetables are shown in Table (5). Results obtained revealed that, the mean DIM values for all the metals were lower than their recommended oral reference doses (RfDs) by USEPA (2010). The mean values for Cd and Pb were higher than their recommended daily intake (DI) limit of trace metals for the consumers studied vegetables between the ages of 19 and 70 years by (FDA 2001) and Garcia-Rico (2007). However, the mean DIM values of Cd and Pb were within their upper tolerable daily intake level (UL) by (FDA 2001) and Garcia-Rico (2007). This is consistent with the report by Adedokun *et al.* (2016) who obtained higher DI values for Cd and Pb. The low mean DI values for other trace metals reported is similar to the report by Ara *et al*. (2021). The mean DIM values for the trace metals followed the sequence Cd > Fe > Cu > Zn > Pb > Ni for *V. amygdalina* and Fe > Zn > Cu > Pb > Cd > Ni for *J. tanjorensis.*

Non-carcinogenic risks

Results for the non-cancer health risks THQ and HI of trace metals via the consumption of studied vegetables are shown Table 5. The mean THQ values of the metals through the consumption of both *V. amygdalina* and *J. Tanjorensis* was less than one. Hence, the consumption of the studied vegetables may not pose serious health problems to the consumers (Kigigha *et al.*, 2018). The low mean THQ values reported for the metals in this study is consistent with the findings by Adedokun (2016). The THQ of the exposure to metals via the consumption of *V. amygdalina* and *J. Tanjorensis* varied as follows: Cd>Cu>Pb>Fe>Zn>Ni and Pb>Cd>Cu>Zn>Ni>Fe, respectively. This reveals that, the consumers were more exposed to health risks associated with Cd toxicity and its attendants' health implications as reported by Jaishankar *et al.* (2014) via *V. amygdalina.* Whereas, the consumption of *J. Tanjorensis* may expose the consumers to Pb toxicity and the related health problems as reported by Kumar *et al.* (2020). Generally, relatively higher mean THQ values were reported for the trace metals via the utilization of *J. Tanjorensis* than *V. amygdalina.* Consequently, the consumption of *J. Tanjorensis* from roadsides with high traffic density may expose the consumers to high non-cancer health risks.

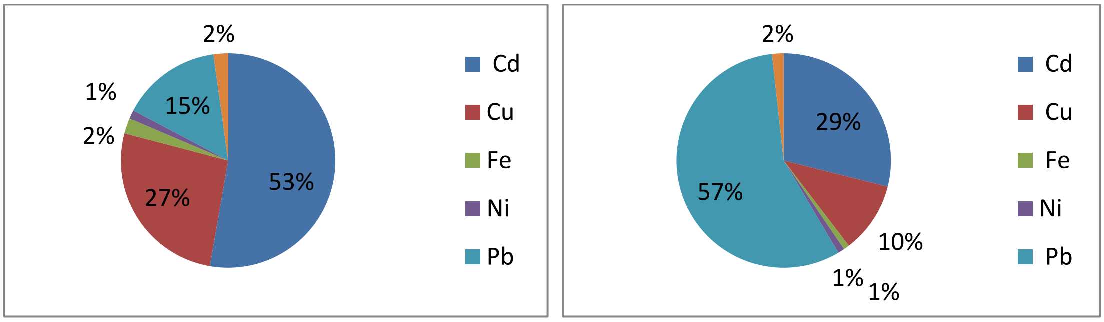

Fig. 3: Mean hazard quotient for trace metals via the consumption of V. amygdalina (A) and J. Tanjorensis (B)

Results for the mean hazard index (HI) of the metals via the utilization of the studied vegetables are indicated Table 5. Mean HI values of 1.61E-2 and 4.70E-2 were reported for the metals via the utilization of *V. amygdalina* and *J. Tanjorensis*, respectively. This confirms the high exposure of the consumers to the non-carcinogenic health risks via the consumption of *J. Tanjorensis.* Although, the mean HI values of the metals via both vegetables were less than one, the level of exposure should be minimized as metals have the tendency to bio-accumulate over time (Ojiego *et al.*, 2022). In *V. amygdalina*, Cd, Cu and Pb contributed 53, 27, and 15%, respectively to the HI (Figure 3A). Figure 3B also illustrates that in *J. Tanjorensis*, Pb, Cd, and Cu contributed 57, 29, and 10 %, respectively to the HI. Consequently, Cd, Cu and Pb in *V. amygdalina* contributed a total of 95% of the HI while Fe, Ni and Zn contributed only 5%. However, in J. *Tanjorensis* Pb, Cd, and Cu contributed a total of 96% of the HI while Fe, Ni and Zn contributed 4% only. Thus, for both vegetables, Cd, Cu and Pb were the major contributors to the HI and this is very risky for the consumers as Cd and Pb are highly toxic even at very low concentrations (Haider *et al.*, 2021; Collin *et al.*, 2022).

Carcinogenic Risks Indices

Table 6: ILCR and the cumulative cancer risk value (ΣILCR) of trace metals via the consumption of studied vegetables

	Vernonia amygdalina						***Jatropha tanjorensis***					
	Cd	Cu	Fe	Ni	Pb	Zn	Cd	Cu	Fe	Ni	Pb	Zn
ILCR	3.23E-4	2.25E-4	-	7.21E-6	7.23E-8	-	5.17E-6	3.02E-4	-	1.59E-5	1.67E-7	-
TCR	5.55E-4						3.23E-4					

USEPA recommended safe limit (ILCR < 1 × 10^{-6}); threshold risk limit (ILCR < 1 × 10^{-4}). Source: USEPA (2015).

Incremental Lifetime Cancer Risks (ILCR)

Results for the carcinogenic risks associated with the consumption of studied vegetables are shown in Table 6. According to USEPA (2018) cancer risk values of ≤ 10^{-6} belong to the low cancer risk class, values ranging between 10^{-5} and 10^{-3} are in the moderate cancer risk, while values varying from 10^{-3} to 10^{-1} are in the high cancer risk. Consequently, the potential cancer risks related to Cd and Cu via the consumption of *V. amygdalina* are moderate, whereas Ni and Pb are low over a life time duration of exposure. The cancer risk associated with Cd and Pb through the consumption of *J. Tanjorensis* is in the low category whereas; risks related with the exposure to Cu and Ni via *J. Tanjorensis* are moderate (USEPA, 2018). According to USEPA (2015) Cd, Cu, Ni, and Pb are categorized as cancer causing agents. Hence, exposure to these metals through the consumption of the studied vegetables even at low concentrations may cause cancer and cancer-related ailments (WHO, 2010). Results for the target cancer risk in Table 6 indicate mean values of 5.55E-4 and 3.23E-4 for the consumers of *J. Tanjorensis* and *V. amygdalina*, respectively. These values are within the USEPA recommended safe limit of ILCR < 1×10^{-6} but higher than the threshold risk limit of ILCR < 1×10^{-4} (USEPA, 2015).

Target Cancer Risk (TCR)

Results of the target cancer risk in Table 6 indicates a mean values of 5.55 E-4 and 3.23E-4 for those exposed to the metals via the consumption of *V. amygdalina and J. Tanjorensis*, respectively. It was also observed that, Cd, Cu, and Ni contributed 58, 41, and 1%, respectively to the total TCR value via the consumption of *V. amygdalina* but, 2, 93, and 5% via the consumption of *J. Tanjorensis.* However, Fe, Pb and Zn did not contribute substantial value to the total TCR value via the consumption of both vegetables. Consequently, the consumers of the studied vegetables are susceptible to cancer due to high Cd and Cu. Thus, Cd and Cu are the main carcinogens in the locations investigated and this should be properly managed to forestall exposure of the population to cancer risks. The study revealed that, the consumers of *V. amygdalina* have a higher risk of developing cancer than *J. Tanjorensis.* It was also observed that, Cd, Cu, and Ni contributed 58, 41, and 1%, respectively to the total TCR value while Fe, Pb and Zn did not contribute any value via the consumption of *V. amygdalina.* In *J. Tanjorensis*, Cd, Cu, and Ni contributed 2, 93, and 5% to the total TCR while Fe, Pb and Zn did not have substantial impact on the total TCR reported.

IV. CONCLUSIONS

The study has shown that, road transport has the potential of contaminating and subsequently polluting the environment especially the adjoining soils and plants. The mean concentrations of all the trace metals in the studied soils and vegetables were within their acceptable limits. However, higher concentrations of the metals were obtained in soils and vegetables from roads with high traffic density than in the control site. The highest mean concentrations of the metals were recorded in samples from Oron Road while the lowest was at Ekpri Nsukara Road. Consequently, the mean concentrations of metals were closely related to the traffic density on each of the roads investigated. The study also identified road transport as the major factor responsible for the accumulation of trace metals in the adjoining soils and vegetables. *Jatropha tanjorensis* exhibited higher potentials for the accumulation of metals than *Vernonia amygdalina.* Nevertheless, the potential was not high enough for its utilization for phytoremediation. The roads with high traffic density were highly contaminated with the trace metals. The consumption of these vegetables exposed the consumers to health risks associated with Cd and Pb. This research discovered Cd and Cu as the major cancer-causing agents associated with the consumption of these vegetables and the consumers of *Vernonia amygdalina* being more vulnerable to cancer risks. This work has established that road transport has the ability to elevate metal loads in adjoining soils and plants. It has shown that, metal accumulation in the adjoining soils and plants has a close relationship with traffic density along the road. Hence, the cultivation crop plants and their consumption should be discouraged to avoid the accumulation and associated health problems on the consumers.

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