Original Research

Concentration of Pb, Cu, Zn and Cd in the Roadside Soil of Doha: Effect of Traffic Volume and Season

Alaa H. Hawari[1]*, Moath Qasem[2], Wael Alhajyaseen[2]

[1]Department of Civil and Architectural Engineering, College of Engineering, Qatar University, Doha, Qatar
[2]Qatar Transportation and Traffic Safety Centre, College of Engineering, Qatar University, Doha, Qatar

Abstract

The concentration of copper (Cu), lead (Pb), zinc (Zn) and cadmium (Cd) in the roadside soil of Doha was evaluated. Three different roads were selected for the study namely, Mesrif street, Salwa road and Cornish street representing low, medium and high traffic volume, respectively. The roadside soil samples were collected during summer and winter seasons. The average concentration of Cu, Pb, Zn, and Cd was 10.76 ppm, 27.93 ppm, 190.07 ppm and 0.16 ppm, respectively. Pearson's correlation coefficient showed a high correlation between Cu and Zn in the summer and a high correlation between Zn and Cd in the winter. This high correlation indicates that the sources of the heavy metals were the same. Two-way analysis of variance (ANOVA) showed a significant relationship between traffic volume and season and Zn and Cd concentration.

Introduction

Qatar has a small geographical area of 11,571 km^2. Within this area, there are 8,500 km of highways and more than 1.6 million registered vehicles [1]. These vehicles are primary sources of different heavy metals such as: hafnium (Hf), molybdenum (Mo), niobium (Nb), nickel (Ni), antimony (Sb), tin (Sn), strontium (Sr) and zirconium (Zr). According to Miguel et al. (1997), fuel combustion in vehicles triggers the emission of lead (Pb), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni) and vanadium (V) into the atmosphere [2].

Moreover, tire wear produces cadmium (Cd), copper (Cu), molybdenum (Mo), tungsten (W), mercury (Hg), lead (Pb), cobalt (Co), chromium (Cr), manganese (Mn) and nickel (Ni) [3-6]. In addition, brake lining in vehicles is a major source of zinc (Zn), cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), lead (Pb) and antimony (Sb) [7, 8]. Bergbäck et al. (2001) estimated that 40% of copper (Cu), 80% of zinc (Zn), 90% of cadmium (Cd), and 85% of lead (Pb) in roadside soils are coming from vehicular emissions [4]. Heavy metals are non-biodegradable elements and have the potential to make the soil polluted by accumulating over time [9]. According to Viard et al. (2000), the contamination induced by vehicles on a highway can reach as far as 320 m, with maximum contamination between 5 m and 20 m [10].

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*e-mail: a.hawari@qu.edu.qa

In recent years, Qatar has experienced rapid urbanization endorsed by its 'National Vision 2030' [11]. This rapid urbanization and development in infrastructure and superstructure projects have led to an increased number of vehicles on the roads of Doha city the capital of Qatar. The population of Qatar in 2018 was 2.4 million (Khaled, 2019). The traffic department in the Ministry of Interior (MOI) reported that the number of active driving licenses in 2016 were 1,328,973. Therefore, it is important to monitor pollution produced from such high increase in the number of vehicles. The concentration of heavy metals in roadside soil is an indirect measure of pollution produced from vetches. Hence, the objective of this paper is to estimate the concentration of lead (Pb), copper (Cu), zinc (Zn) and cadmium (Cd) in Doha's roadside soil as an indicator of pollution produced from traffic. The heavy metals concentration was measured during summer and winter in three different roads in Doha representing low, medium and high traffic volumes. Statistical analysis was performed in order to find a correlation between heavy metals concentration, traffic volume and season.

Material and Methods

The methodology of the study is summarized in Fig. 1.

Area of Study

Doha city is located on the Arabian Gulf at 25.29°N latitude and 51.53°E longitude. The weather in Doha is hot and humid during the summer with an average temperature of 40ºC and 49% mean relative humidity. In the winter the weather is pleasant with an average temperature of 22ºC and annual average rainfall of 76 mm. In this study, three different roads located in Doha were selected. The selected roads were: Meshrif street, Salwa road and Cornish street. The locations of the selected roads are shown in Figure 1. Meshrif street is located inside a residential area and has a posted speed limit of 60 km/hr. It is a four-lane road with a length of 1.6 km, and it has a 'low' average daily traffic and low heavy vehicle percentage. Salwa road is a highway that connects Doha with the industrial area and other western regions in Qatar. It has a posted speed limit of 100 km/hr. It is an eight-lane highway with controlled access roads. The road segment chosen for this study is 11 km in length and has 'medium' average daily traffic with high heavy vehicle percentage. Cornish street connects different residential areas with the commercial center of Doha and has a posted speed limit of 80 km/hr. It is located at the heart of Doha. It is 5 km in length and has 'high' average daily traffic along with a low percentage of heavy vehicles.

Average Daily Traffic Estimation

The average daily traffic for each of the selected roads was estimated using a pneumatic tube. The daily traffic was measured in two locations in Salwa road indicated by X and Y in Fig. 2. The daily traffic was measured at three locations in Cornish street indicated by X, Y and Z in Fig. 2. The daily traffic was measured at one location in Meshrif street indicated by X in Fig. 2. The daily traffic was measured for 7 days at each location.

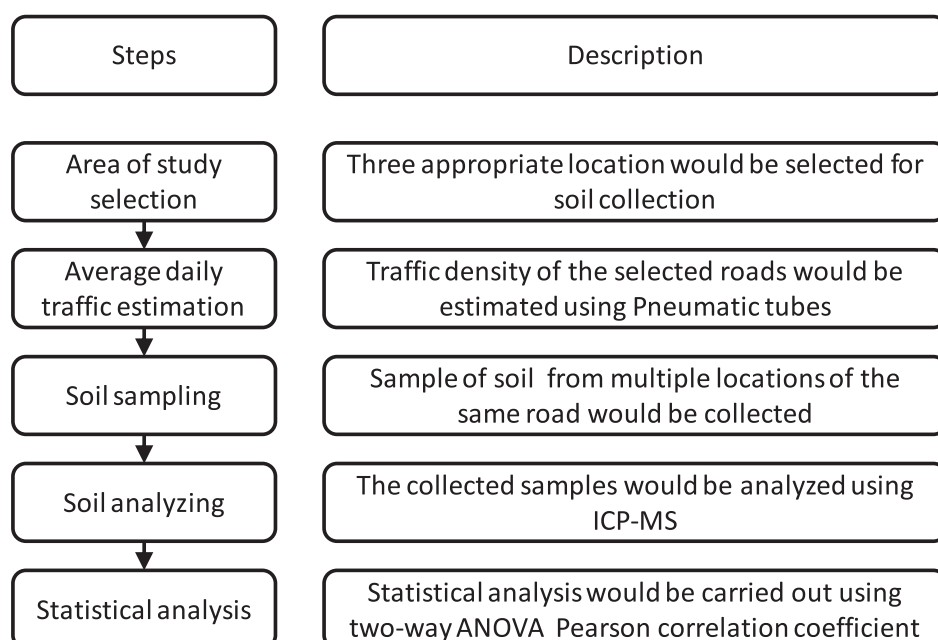| Steps	Description
Area of study selection	Three appropriate location would be selected for soil collection
Average daily traffic estimation	Traffic density of the selected roads would be estimated using Pneumatic tubes
Soil sampling	Sample of soil from multiple locations of the same road would be collected
Soil analyzing	The collected samples would be analyzed using ICP-MS
Statistical analysis	Statistical analysis would be carried out using two-way ANOVA Pearson correlation coefficient

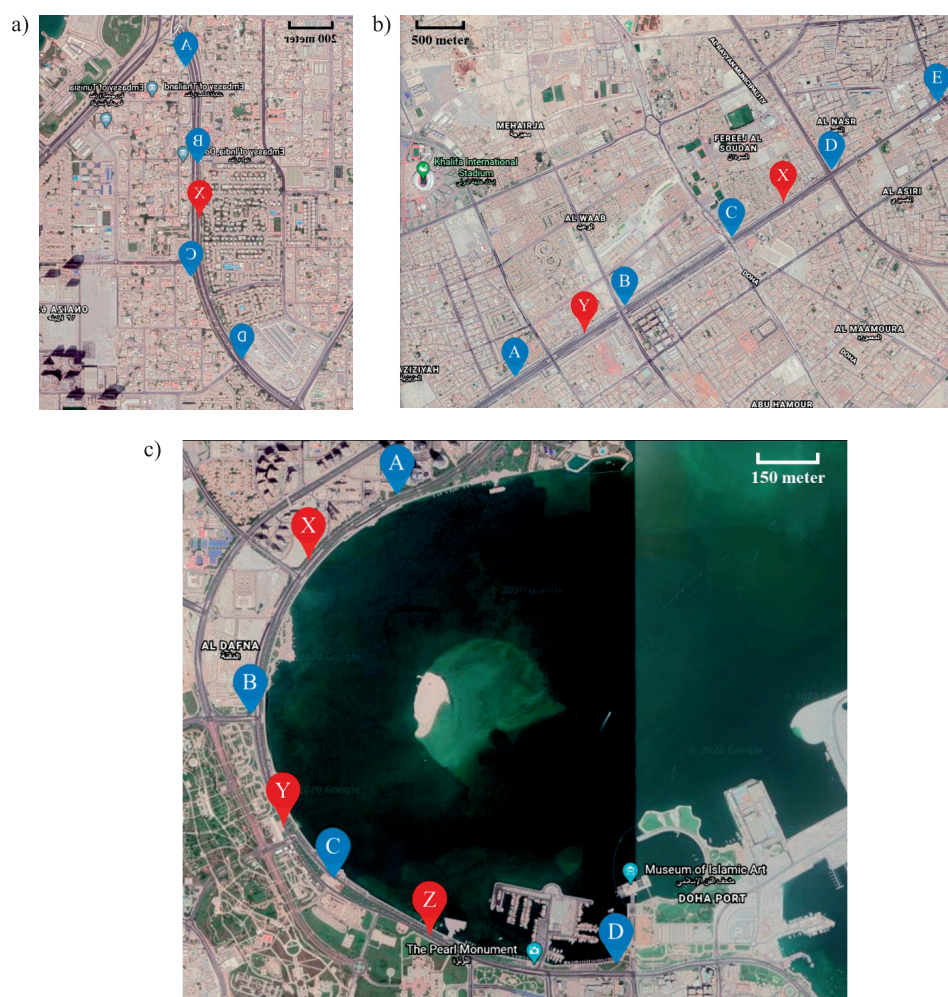Fig. 1. Steps followed to achieve the goal of this paper.

Fig. 2. Location of collected roadside soil samples (A, B, C, D and E) and location of measured traffic volume (X, Y and Z) from a) Meshrif street, b) Salwa road and c) Cornish street.

Soil Collection

Soil samples were collected from 13 different sites located along the 3 selected roads. As shown in Fig. 2 the roadside soil samples were collected from 4 sites along Meshrif street (i.e. Meshrif A, B, C and D), 5 sites along Salwa road (i.e. Salwa A, B, C, D and E) and 4 sites along Cornish street (i.e. Cornich A, B, C and D). A total of 78 samples were collected from the topsoil (0-10 cm), using a stainless-steel hand trowel and stored in polyethylene bags for testing. The soil samples were collected 3 m away from the road. From the 78 samples, 39 samples were collected during summer (August, 2018) and 39 samples were collected during winter (December, 2018).

Soil Testing

The soil samples were air-dried and sieved through a 2 mm sieve where remains of stones and leaves were removed. 0.5 g of dried and sieved soil sample was weighted and digested with 9 ml of nitric acid (HNO_3) and 3 ml of hydrochloric acid (HCl). Then, microwave digestion was carried out at 180ºC for 2 hours. After microwaving, the samples were left to be cooled at room temperature. The samples were then diluted with 50 ml of deionized water in a volumetric flask and the acid digested extracts were filtered using a 0.45 μm pore size filters. Then the concentration of Pb, Cu, Zn and Cd was measured using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS).

Data Analysis

After determining the concentration of Zn, Pb, Cd and Cu in the collected samples, the mean ($\bar{x}$) and standard deviation (SD) were determined using the following formulas:

$$\bar{x} = \frac{\sum_1^N x_i}{N}$$

(1)

$$SD = \sqrt{\frac{\sum_1^N (x_i - \bar{x})^2}{N}}$$

(2)

In addition, Pearson's correlation factor and Two-way and One-way ANOVA analysis were carried out. The Person correlation factors were calculated using Microsoft Excel 2013. Pearson correlation is a relation between two variables that indicates the linearity of two variables [12]. The value of the factor is between -1 and 1. It is also known as product moment correlation coefficient (PMCC). Two variables are plotted on x-axis and y axis [12]. The slope of the relationship between the values indicates the Pearson correlation. Analysis of variance (ANOVA) can be performed when there are two or more groups of samples [13]. It is used to compare the means of two sample groups. ANOVA can be one way or two way ANOVA depending on the number of factors [13]. The analysis of variance (ANOVA) was carried out using SPSS statistics (IBM version 25). The two-way ANOVA was carried out with a 95% confidence level to investigate the relation between season and traffic volume on heavy metals concentrations. The normality test for sample residuals was carried out following the Shapiro-Wilk test of normality. Homogeneity of variances was tested using Levene's test of equality of variances. In cases where homogeneity and normality assumptions were violated transformation for the data was carried out.

Results and Discussion

Traffic Volume

Fig. 3 shows the number of vehicles in the three studied streets for each day of the week. As seen from Fig. 3, the highest traffic volume at Meshrif street, Cornish street and Salwa road were 3,460 vehicles, 103,962 vehicles and 162,826 vehicles, respectively. Whereas, the lowest traffic volume at Meshrif street, Cornish street and Salwa road were 2,446 vehicles, 57,501 vehicles and 75,865 vehicles, respectively. For all the selected streets, the highest traffic volume was observed on Thursday. Whereas, the lowest traffic volume was observed during Friday and Saturday. It should be noted that in Qatar, the weekends fall on Friday and Saturday. Thus, a smaller number of vehicles are expected during those two days. For Meshrif street, Cornish street and Salwa road, the average traffic volume was 3,095 vehicles, 83,999 vehicles and 122,874 vehicles, respectively.

Heavy Metal Concentration

Table 1 shows the concentration of Pb, Cu, Zn and Cd at the three different streets during summer and winter. Among the three streets, Meshrif street has the lowest traffic volume and the lowest concentration of Pb, Cu, Zn and Cd during summer (Table 1). The average concentration of Pb, Cu, Zn and Cd at Meshrif street during summer was found to be 7.85, 24.98, 102.27 and 0.07 ppm, respectively. The low concentration of these heavy metals at Meshrif street can be attributed to the low traffic volume (i.e. 3,460 vehicles/day). However, this trend was not seen in winter, where the average concentration of Pb, Cu, Zn and Cd increased to 19.16, 27.66, 267.10 and 0.29 ppm, respectively. The increase of heavy metals concentration in the roadside soil during winter can be attributed to the dissociation of heavy metals from rocks due to rainfall [14].

Salwa road has higher traffic volume (i.e. 103,962 vehicles/day) than Meshrif street (3,460 vehicles/day) and lower traffic volume than Cornish street (162,826 vehicles/day). The concentration of Cu (29.10 ppm) and Cd (0.14 ppm) at the Salwa road during Summer was higher than Meshrif street but lower than Cornish street and the concentration of Zn (165.90 ppm) at Salwa road was almost the same as the concentration of Zn at Cornish street. The concentration of Zn at Salwa road was relatively high, this could be due to
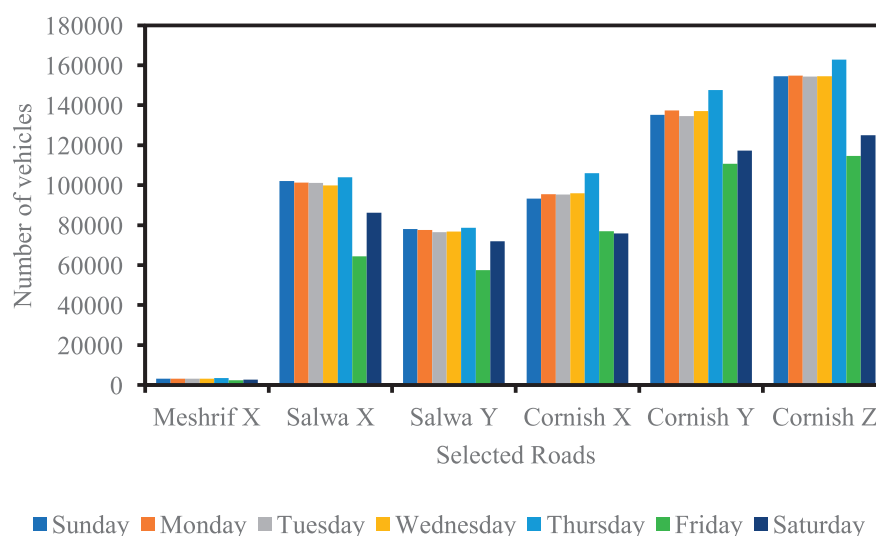

Fig. 3. Number of vehicles at different locations of the studied streets during each day of the week.

Table 1. Heavy metal concentration (ppm) at different streets in Doha.

Season	Sample Number	Pb	Cu	Zn	Cd
Summer	Meshrif A	10.02	21.97	90.68	0.13
	Meshrif B	8.72	18.96	103.10	0.02
	Meshrif C	8.13	40.05	118.52	0.04
	Meshrif D	4.52	18.92	96.78	0.09
	Mean	7.85	24.98	102.27	0.07
	SD	2.35	10.15	11.96	0.05
	Salwa A	6.77	33.53	172.37	0.32
	Salwa B	10.42	29.09	264.26	0.15
	Salwa C	16.63	31.87	145.09	0.05
	Salwa D	5.90	26.72	117.99	0.12
	Salwa E	7.07	24.29	129.80	0.08
	Mean	9.36	29.10	165.90	0.14
	SD	4.41	3.74	58.63	0.11
	Cornish A	9.41	29.31	73.03	0.22
	Cornish B	7.45	41.38	337.40	0.19
	Cornish C	10.47	33.24	164.60	0.16
	Cornish D	7.26	30.13	86.58	0.17
	Mean	8.65	33.52	165.40	0.19
	SD	1.56	5.51	121.56	0.03
Winter	Meshrif A	6.54	10.04	198.27	0.30
	Meshrif B	9.34	43.76	271.12	0.27
	Meshrif C	55.33	48.99	304.09	0.21
	Meshrif D	5.42	7.84	294.90	0.38
	Mean	19.16	27.66	267.10	0.29
	SD	24.17	21.74	47.94	0.07
	Salwa A	6.34	20.14	311.68	0.57
	Salwa B	12.55	57.92	342.07	0.17
	Salwa C	10.58	19.24	303.89	0.12
	Salwa D	13.15	20.63	317.54	0.33
	Salwa E	13.58	25.92	166.56	0.01
	Mean	11.24	28.77	288.35	0.24
	SD	2.97	16.50	69.56	0.22
	Cornish A	10.22	46.60	175.42	0.03
	Cornish B	6.91	13.97	128.55	0.04
	Cornish C	7.43	14.35	137.00	0.00
	Cornish D	9.68	19.44	164.72	0.00
	Mean	8.56	23.59	151.42	0.02
	SD	1.63	15.54	22.24	0.02
Total	*Mean*	10.76	27.93	190.07	0.16
	SD	9.51	3.49	72.09	0.10

the high percentage of diesel driven heavy vehicles at this road as Zn is emitted primarily from diesel leakage [15]. Table 1 shows that Salwa road had the highest concentration of Pb (9.36 ppm) during summer.

The high concentration of Pb at Salwa road could be due to the fact that this road has the highest posted speed limit of 100 km/hr and the highest percentage of heavy vehicles. Higher posted speed limit and higher percentage of heavy vehicle lead to higher rate of tire wear which is the prime source of Pb emission from vehicles [16-19]. From Table 1 , it can also be seen that, during winter the concentration of Pb, Zn and Cd at Salwa road increased to 11.24, 288.35 and 0.24 mg/g, respectively, whereas, the concentration of Cu remained almost the same at 28.77 mg/g. The increase of Pb, Zn and Cd concentration in roadside soil during winter could be attributed to the dissociation of heavy metals from the nearby soil due to rainfall [14]. Apart from soil dissociation, increased rate of tire wear during winter also increases Pb emission from vehicles [20].

The highest traffic volume in Doha was observed at Cornish street. Consequently, the concentration of Cu (33.52 ppm) and Cd (0.19 ppm) were highest at Cornish street during summer, as seen in Table 1. The concentration of Zn (165.40 ppm) at Cornish street was almost similar to the concertation of Zn at Salwa road. The concentration of Pb at the Cornish street was higher than the concentration of Pb at Meshrif street but lower than concentration of Pb at Salwa road. Lower concentration of Pb at Cornish street could be due to the fact that this street has lower posted speed limit and lower heavy vehicles percentage. As seen from Table 1, at Cornish street during winter, the concentration of Pb, Cu, Zn and Cd reduces to 8.56, 23.59, 151.42 and 0.02 ppm, respectively. The reduction in Pb, Cu, Zn and Cd concentration can be attributed to the location of Cornish street which is located in front of the sea. The presence of the sea causes high atmospheric dispersion and wind during winter which may result in high air dispersion of the soil at the Cornish street [21].

Table 1 shows the standard deviation of the studied metals at the three different locations during summer and winter. It can be seen from Table 1 that during summer the standard deviations of Pb, Cu and Cd are low. However, the standard deviation of Zn was always higher. This can indicate additional sources of zinc originating from plated gutters, road signs, gates and other metal surfaces in the roadside soil [22].

Table 2. Correlation Coefficients Between Heavy Metal Elements during summer.

	Pb	Cu	Zn	Cd
Pb	1			
Cu	0.178	1		
Zn	0.083	0.562*	1	
Cd	-0.222	0.334	0.276	1

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Correlation Coefficients Between Heavy Metal Elements in Winter.

	Pb	Cu	Zn	Cd
Pb	1			
Cu	-0.112	1		
Zn	-0.341	0.346	1	
Cd	-0.340	-0.126	0.692**	1

**. Correlation is significant at the 0.01 level (2-tailed).

In addition, Table 1 shows that the standard deviation of the heavy metals concentrations during winter is also high. This implies that, during winter additional sources of heavy metals might be present such as the dissociation of metals from rocks. The correlation between traffic volume and metals concentration during summer and winter was further statistically analyzed.

Statistical Analysis

Table 2 and Table 3 list the Pearson correlation coefficient for metal concentrations obtained during summer and winter, respectively. During summer, a significant correlation was found between Zn and Cu ($r = 0.562$). The high correlation between these two metals reflects that they are emitted from similar pollution sources [23]. However, this correlation was not found in winter ($r = 0.346$). This indicates that external factors have affected the concentration of Zn and Cu

Table 4. Season and Traffic Interaction Investigation through ANOVA.

Element	Main Factors	P-Value	Distribution Pattern	Significance
Pb	Season & Traffic Volume	0.585	Log Normal	Not Significant
	Season Only	0.087		Not Significant
	Traffic Volume Only	0.521		Not Significant
Cu	Season & Traffic Volume	0.694	Inverse	Not Significant
	Season Only	0.081		Not Significant
	Traffic Volume Only	0.308		Not Significant
Zn	Season & Traffic Volume	0.032	Normal	Significant
	Season Only	0.002		Significant
	Traffic Volume Only	0.105		Not Significant
Cd	Season & Traffic Volume	0.013	Log Normal	Significant
	Season Only	0.952		Not Significant
	Traffic Volume Only	0.599		Not Significant

Table 5. Comparison of Average Metal Concentrations (ppm).

Year	Location	Reference	Metal Concentrations			
			Pb	Cu	Zn	Cd
2001	Hong Kong	[24]	93.40	24.80	168.00	2.20
2005	Seoul, South Korea	[25]	214.00	445.60	2665.00	4.30
2009	Kavala, Greece	[26]	359.40	42.70	137.80	0.20
2010	Beijing, China	[27]	35.40	29.70	92.10	0.22
2013	Dubai, UAE	[28]	309.33	11.05	50.52	0.51
2015	Qinghai–Tibet, China	[29]	49.15	23.33	201.77	0.49
2016	Hamedan, Iran	[30]	113.05	ND	ND	1.65
2016	Melbourne, Australia	[31]	80.00	8.00	49.55	0.35
2019	Doha, Qatar	This Study	9.60	27.90	190.10	0.20

ND: Not Determined

in winter. During winter a significant correlation was found between Zn and Cd (r = 0.692).

Table 4 shows the Two-way and One-way ANOVA analysis. ANOVA analysis show the significance of traffic volume and season on the concentration of the heavy metals. From the reported p-values in Table 5, a significant effect of season and traffic volume on the concentration of Zn and Cd can be seen as the p-value was 0.032 and 0.013, respectively. Furthermore, one-way ANOVA analysis showed a significant relation between season and Zn concentration with a p-value of 0.002.

Comparison of Heavy Metals Concentrations in Roadside Soil in Doha with other Cities

Table 5 shows the heavy metals concentration in roadside soil in several metropolitan areas in the world. As seen in Table 4, the highest concentration of Pb, Cu, Zn and Cd are found in Kavala, Seoul, Seoul and Seoul, respectively. Whereas the lowest concentration of Pb, Cu, Zn and Cd are found in Doha, Melbourne, Melbourne and Kavala, respectively. From Table 4, it can be also noticed that, the average concentration of Pb, and Cd in the roadside soil of Doha is lower than their average concentration in other cities. However, the average concentration of Cu and Zn is higher than Hong Kong, Beijing, Dubai and Melbourne. This might be attributed to higher traffic density in the selected roads in Qatar (>100,000 vehicles/day) compared to other cities like Melbourne where roads with more than 15,000 vehicles per day were considered to be high density roads.

Conclusions

In this study, the concentration of four main heavy metals; namely, lead (Pb), copper (Cu), zinc (Zn) and cadmium (Cd); in the roadside soil of Doha has been investigated during summer and winter. The Cornish street had the highest traffic volume at 162,826 vehicles/day followed by Salwa road (103,962 vehicles/day) and Meshrif street (3,460 vehicles/day). The concentration of Pb, Cu, Zn and Cd in the roadside soil of Doha were found to be 19.42 ppm, 27.93 ppm, 190.07 ppm and 0.16 ppm, respectively. During winter, dissociation of rocks increased the concentration of heavy metals at Meshrif street and Salwa road. However, the concentration of heavy metals at Cornish street decreased due to atmospheric dispersion. Pearson's correlation co-efficient showed that the source of Cu and Zn during summer and the source of Zn and Cd during winter to be similar. Two-way ANOVA analysis showed a significant relationship between traffic volume and season on Zn and Cd concentration.

Conflict of Interest

The authors declare no conflict of interest.

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