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Factors affecting dirt pick up of traffic paints in areas with different characteristics: Tehran roads as a case study

Abstract

This study was performed to identify the weight distribution of affecting factors in contamination of traffic paint surfaces from environmental pollutants in different municipal districts. Traffic paint samples were collected from the major roads and less busy ones of different environmental condition in Tehran and was determined using the Energy-dispersive X-ray spectroscopy (EDS). Four pollutants namely fuel consumption, brake wear, tire wear and bitumen traces are the major environmental sources can affect dirt accumulation on surfaces of traffic paints. The analysis of variance shows that obtained concentration levels of elements under study namely tungsten (W), nickel (Ni), chromium (Cr), zinc (Zn), titanium (Ti), iron (Fe), lead (Pb), calcium (Ca) and copper (Cu) were highly significant in traffic paints collected from different areas. The quantities parameters such as "Pollution Load Index" and "Contamination Factor" were employed to identify possible levels of pollution from aforementioned pollution sources. Some elemental pairs such as Fe/Ti (0.72), Ni/Cr (0.64), Ca/W (0.81), Pb/Ni (0.70), Fe/Cu (0.71), and Zn/Ca (0.81) have strong correlation at 5% significant level. From the obtained results, it was concluded that the main source of dirt picked up by traffic paints might be originated from combustion of fuel which is known to contain trace levels of Cr, Ni and Pb. The roads, in which mostly cars of diesel fuel were travelling, had higher contamination levels on the traffic paints than others. Bitumen traces and the frequency of brake use were additional factors that affected the contamination levels. The degree of contamination of traffic paints in crossroads was mostly influenced by the road dust from brake wear.

Keywords: traffic paints, dirt pick up, tire wear, bitumen, brake wear, fuel combustion

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Abbreviations: EDS, energy-dispersive x-ray spectroscopy; W, tungsten; Ni, nickel; Cr, chromium; Zn, zinc; Ti, titanium; Fe, iron; Pb, lead; Ca, calcium; Cu, copper; BC, black carbon; OC, organic carbon

Introduction

In recent years, the dirt pick up problem and loss quality of brightness of traffic marking paints have widely attracted municipal authorities' attention. Reflective traffic paints and road marking are some of the most technologically advanced pieces of safety and traffic signs that should be there to have safe streets.[1–5] The most important problem regarding with today's traffic marking paints is their low resistance to dirt pickup. The dirt pick up can occur in two ways: migration of the stains from bottom substrate to paint surface and pollutant deposition on paint surfaces.[6] In the first case of the dirt type, low quality of asphalt make dirt migrate to the surface of the paint but the later happens when thousands of different solid and liquid particles suspended in the atmosphere is settled on the surface by dry or wet atmospheric deposition. The surficial dirt is made up of many components, including elemental or black carbon (BC) and organic carbon (OC) compounds, sulfate (SO_4^{-2}), nitrate (NO^{3-}), trace metals, crustal material (i.e. soil particles) and sea salt.[7] Dirt with amphiphilic characteristics adheres abnormally to painted surfaces (Figure 1). Pollutants emitted from different sources comes in a wide range of sizes and includes particulate matter with diameter less than or equal to 10µm (PM_{10}), fine particulate matter with diameter less than or equal to 2.5µm ($PM_{2.5}$), ultrafine particulate matter with diameter less than or equal to 0.1µm (PM0.1), and lastly nanoparticles pollutants with diameter less than or equal to 0.05µm (PM0.05).

Soil particles, soot, lead, asbestos, sea salt, & sulfuric acid droplets, solid particulate matter- generally referred to as 'dust' and Liquid suspensions- commonly called 'mist' all are considered as particulate matters. These particles or traces can be transported into applied traffic paints and leave either their permanent or nonresidue stain effects. At present, the particulate or trace pollution has become primary factors affecting Tehran's urban traffic paint quality.[3] Road dust and motor vehicle exhaust are two of the largest pollution sources associated with transport industry among large number of pollution sources; i.e. agricultural activities, dust storms, construction fugitive dust, Traffic resuspension, Combustion in energy and manufacturing industries (coal, coke, and heavy oil), windblown dust/construction and mining activities/industrial resuspension, etc.[8] It is found that road dust which directly emitted from anthropogenic (man-made) or natural sources (i.e. primary PM) is the main source of PM10 in urban atmosphere and motor vehicle exhaust mainly affects the concentration of PM2.5 and secondary particulate matters.[4] The fine particles, which are firstly deposited in the dockside and later suspended by the effects of port-related traffic or wind, can deposit on traffic paint skins and can readily penetrate microscopic pores and increase the tendency of paints to pick up dirt subsequently. In this paper, five major categories of sources are considered as traffic factors which interfere in emission of pollutant and the subsequent dirt pick up in traffic paints; i.e. tire wear, brake wear, road abrasion, fuel combustion and bitumen traces.[9] The contamination of traffic paints by the road dust is greatly affected by vehicle volume, speed and type, the road asphalt type, the neighboring environment and meteorological conditions, etc. This paper tries to analyze traffic paint dirt-pick up using element analysis to determine causes and the influences in different forms of urban conditions. After that it can be possible to develop quantitative parameters to serve as measure of weight distribution factors of dirt pick up control in traffic paint.

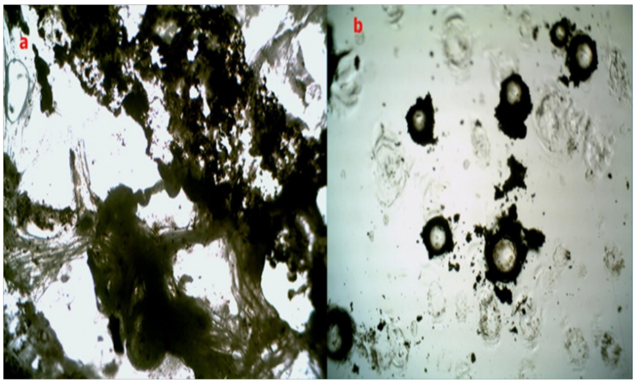

Figure 1 The light microscopic imaged of dirt picked up by the surface of traffic paints (taken from our laboratory) (A) 2K traffic paint (b) hot melt traffic paint.

Experimental

Sample collection

Total 34 samples of traffic marking paints (2-K or hot melt traffic paints) were collected from 28 urban locations in the metropolitan city of Tehran which had experienced various traffic volumes and environmental conditions (Figure 2).

The sampling sites for the traffic paints collection were categorized as follows:

EF1= High volume traffic roads in which mostly cars of gasoline fuel are traveled

EF2=High volume traffic roads in which mostly cars of gasoline fuel are traveled

EF3=roads suspended to dust traces

EF4=locations suspended to bitummen traces

EF5=locations with mostly brake wear

The information of the number of vehicles passing through the study areas and road name was given in Table 1. The piece of traffic paints samples was collected during a dry period in late autumn following a warm and dry summer season. The piece of traffic paints adhered to some asphalt substrate is picked up using chipping hammer and were transferred to the laboratory in plastic bags for further analysis. It is being noted that two samples were obtained at each point.

Road dust samples analysis

Determination of heavy metals was done per protocol "Metal ions that are readily exchangeable between the solid and solution phases together with those that are more strongly bound within the road dust solid phases" provided by Fadigas et al.[10] The road dust washed from paint surfaces and was air dried to constant weight and then sieved. Sample of 3 g was weighed into a mixture of 14.4ml HNO_3: HCl(1:3v/v) and 15.6 deionized water on a hot plate for 12 h. Then the digested samples were sonicated and then heated for 1 h in 70°C at a water bath. The digested samples were diluted to 20mL and transfer into the appropriate test tube. The Ca in the filtrate was determined using Atomic Absorption Spectrometer. The concentration of samples is verified by Energy-dispersive X-ray spectroscopy (EDS) which can provide rapid qualitative, with adequate standards, quantitative analysis of elemental composition with a sampling depth of 1-2 microns. The light microscope was used to detect the dirt structures laid on the surface of traffic paints. The weight ratio of trace elements such as C, N, O, Ti, Zn, Ca, W, Fe, Cr, Ni, Pb and Cu were determined. To verify the measured content of elements, some samples are subjected to XRF analysis.

Table 1 Summary of information on sampling locations in Tehran and vehicle numbers and travels, 2016

Vehicle no	Road name
EF1	Azadegan-Kazemi Highway, Fath Street
EF2	Besat Highway, Chamran Highway
EF3	Ashrafi and Rashid Crossroad
EF4	Kaj Street, Kashan Ave
EF5	Hashemi Street, Babaei Ave

EF1= High volume traffic roads in which mostly cars of gasoline fuel are traveled

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Criterion and characteristics

Figure 3 illustrates the major of pollutants weight ratio, namely, particulate matters, zinc (Zn), chromium (Cr), lead (Pb), copper (Cu), nickel (Ni), emitted from four sources of tire wear, fuel combustion, road abrasion and brake wear.[4] It is founded that concentration of metals in used brake pads are in the order iron (Fe)>titanium (Ti)>Cu. After the most abundant element measured in tires namely Zn, several other metals that followed were in the order calcium (Ca)>tungsten (W)>molybdenum (Mo).

Based on the evidences given here, we can consider the most important characteristics of tire wear to be the simple summation of weight percent of Zn, Ca, W (coded by ZCW). Similarly, we can use the sum of weight percent of three elements Cr, Ni and Pb (coded by CNP) as a tracer and measure for fuel consumption and finally the summation of Fe, Ti and Cu (coded by FTC) as useful criterion for pollutions originated by brake wear. As the ratio, C/H in a bitumen reference sample is in a range of 4.5-6.3, to characterize the bitumen tracing factor in a sample we may calculate and compare the value.[1–2]

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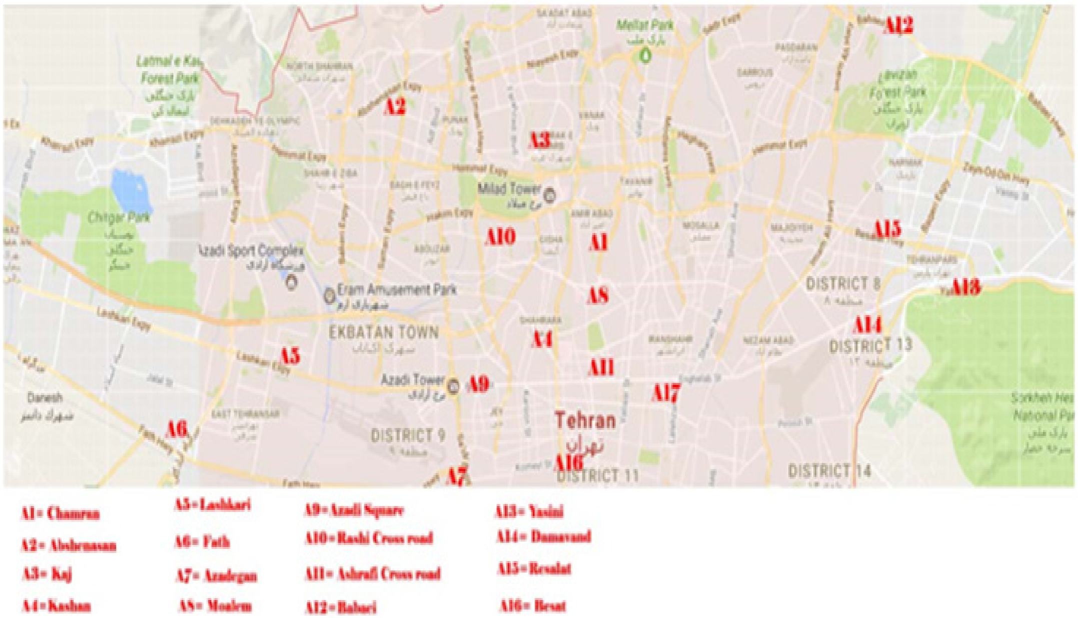

Figure 2 Map of sampling sites.

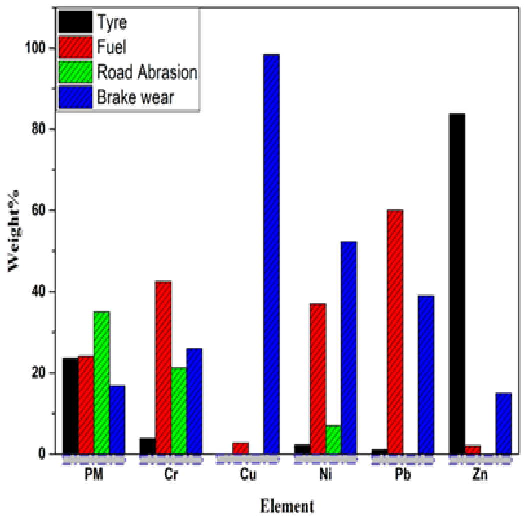

Figure 3 Characteristic elements in four main group of sources.

Assessment of trace elements contamination

Contamination factor: To assess the extent of contamination of each group of elements picked up the surface of traffic coatings, contamination factor and degree of contamination has been used.[3] The W_f^i is the single element index which is determined by the following equation:

$$W_f^i = \frac{W_{0-1}^i}{W_n^i} \quad (1)$$

Where W_f^i the contamination factor of the group of elements of interest is, W_n^i is the concentration of the element sample, W_n^i is the background concentration. W_f^i is defined per four categories: < 1 low contamination factor, 1-3 moderate contamination factors, 3-6 considerable contamination factors and > 6 very high contamination factor.

Pollution load index: The road dust was assessed for the extent of metal pollution by employing the method based on the pollution load index (PLI) developed by[3] is as follows:

$$PLI = \sqrt[n]{CF1 \times CF2 \times CF3} \quad (2)$$

Where n is the number of main groups of elements studied and CF is the contamination factor calculated as described in an earlier equation. The PLI provides simple but comparative means for assessing a sample quality, where a value of PLI<1 denote perfection; PLI=1 present that only baseline levels of pollutants are present and PLI>1 would indicate deterioration of sample quality.[3]

Statistical analysis

To measure how strong a relationship is between the characteristics of traffic paint dirt, the concentrations of elements content on traffic paint surfaces were subjected to Pearson's significant correlation analysis using SPSS version 19. The analysis of variance (ANOVA) was used for collected data to assess whether analyzed elements varied significantly between various locations under study, possibilities less than 0.05 ($p<0.05$) will be considered statistically significant.

Results and discussion

Elemental concentration of the traffic paints

Per the study conducted, 4 main groups of characteristics mentioned above were identified in the 32 traffic paints samples collected along 18 different conditional traffic zone roads in Tehran. The weight percent for each group of element was computed and results presented in Table 2. The results revealed that, the weight percent (wt%) of CNP (Cr,Ni,Pb) on traffic paints in azadegan-kazemi highway was the highest thus 53.4%wt where cars with gasoline fuel is more traveled. The CNP value is ranged from 17 to 60%wt in all the samples collected. It can be observed that ZCW have the greatest contamination level of 43.35%wt for Ashrafi crossroad where trace of brake line of cars was clearly observed. The value of ZCW is ranged from 8 to 44%wt. The maximum FTC concentrations (wt%) along traffic paints sampling site belongs to Fath highway with 27.45%wt. The maximum values of bitumen trace (48.9wt%) is obtained in sampling Kaj street where the asphalt visual quality was very low.

Table 2 Elemental level in the samples collected from the different zones of Tehran

Road name	CNP	ZCW	FTC	Bitumen	Others
Chamran	50.15	9.35	10.1	18.3	12.1
Abshenasan	32.9	15.8	17.3	25.6	12.7
Kaj	17.25	14.1	14.2	48.9	16
Kashan	14.7	19	17.8	32.1	16.41
Lashkari	53.4	8.3	10.56	28	8
Lashkari Yellow	25.6	31.5	17.41	21.1	4.15
Fath	20.5	11.65	27.45	30	10.4
Azadegan	53.45	10.8	15.85	17	2.9
Molem	21.1	20	28.5	20.4	10.6
Azadi Square	48.4	10.7	19.38	15.9	5.36
Rashid Crossroad	46.7	17.5	13.3	22.3	0.2
Ashrafi Crossroad	32.9	43.35	3.6	10	10.7
Babaei	26.6	21.14	12.3	20	20.6
Yasini	47.8	18.9	8.1	23.1	2.1
Damavand	36.6	20.35	19	14	10.05
Resalat	20	9.5	11.5	25.6	11.1
Besat	46.7	9.4	16.7	23.6	3.6
Hashemi	29.5	11.8	14.1	20.7	23.9

Statistical analysis of heavy metals

The analysis of variance shows that weight ratio of elements which are using in calculation of PLI and contamination factor were highly significant in traffic paint samples collected from various roads and we can rely on (Table 3).

Correlation matrix of the elements

The aim of this section is to present correlation matrix of the elements to verify classifying the analyzed elements into three main groups which have been discussed above thus FTC, ZCW and CNP. Some elemental pairs such as Ni/Cr(0.88), Pb/Cr(0.75), Fe/Ti(0.78), Fe/Cu(0.81), Zn/Ca(0.61) and Zn/W(0.56), have strong correlation with each other at 1% significant levels (Table 4). The correlation analysis shows that pairs of the elements correlated strongly indicating common source of pollution.

Apeagyei et al.[1] analyzed three used brake pads using XRF detecting 22 metal. They observed high concentration of Iron (Fe), Titanium (Ti) as well as copper in samples of brake pad. The source of pairs of Pb/Ni, Cr/Ni and pairs of Zn/W and Zn/Ca in the road dust in the is believed to come from combustion of fuel and wear-and-tear of tires, respectively.

Table 3 Summary of statistical analysis of variance of various element weight ratio (wt%)

Element	Mean	Standard deviation	Fischer probability
W	1.67	0.034	0.023*
Ni	5.7	0.023	0.01**
Cr	3.5	0.034	0.01**
Ti	5.1	0.05	0.03*
Fe	6.7	0.045	0.02*
Pb	1.6	0.023	0.04*
Zn	0.05	0.038	0.00**
Ca	8.7	0.076	0.04*
Cu	3.1	0.054	0.00**

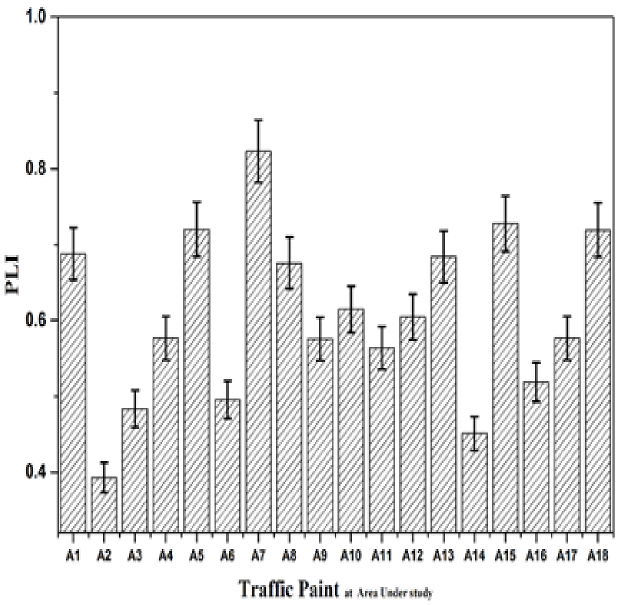

Figure 4 Estimated PLI in areas under study.

Contamination factor assessment in traffic paints

The contamination factor for each groups of element was computed and results shown in Table 2. The results show that the four main groups most have values greater than 1 in various areas signifying a range of moderate to high contamination of traffic paints from sources of fuel consumption, brake wear, tire wear and bitumen. Based on results presented in Table 5, the overall contamination factor by the eighteen areas is of the order fuel combustion (=1.34)>bitumen (=0.83)> tire wear (=0.6)≈brake wear. The contamination factor for the various factors except for fuel combustion was less than 1 indicating low contamination factor.

Pollution load index (PLI)

The pollution load index was calculated based on equation 2, to effectively compare whether traffic paint in various areas and generally in Tehran suffer from a dirt picked up originated from four aforementioned sources. The PLI provides an estimate of assessing the degree of overall contamination at a traffic paint where a value of PLI<1 denote perfection; PLI=1 that suggest a baseline concentration and PLI>1 would show deterioration of sample quality.[10,11] Based on results presented in Figure 4, fath highway has the highest PLI and abshenasan has the lowest PLI. As observed, the PLI for the various areas were less than1 thus PLI<1 indicating perfection (that is no overall pollution from four main groups of pollutants which have been discussed here).

Table 4 Correlation matrix of the analyzed elements in the traffic paints

	W	Ni	Cr	Ti	Fe	Pb	Zn	Ca	Cu
W	1	-0.42	-0.89	0.067	0. 54	-0.06	0.78	0.56	-0. 68
Ni		1	0.88	0.57-	0.02	0.35	0.01	-0.45	-0.48
Cr			1	0.2	0.7	0.75	-0.11	-0. 86	-0.55
Ti				1	0.78	-0.23	-0.47	0.07	0.63
Fe					1	0.25	0.24-	-0. 45	0.81
Pb						1	-0.2	-0.043	-0.85
Zn							1	0.61	-0.23
Ca								1	-0.02
Cu									1

Table 5 Contamination factor in the samples collected from the different zones of Tehran

Road Name	CNP	ZCW	FTC	Bitumen	Others
Chamran	2.15645	0.40205	0.4343	0.7869	0.5203
Abshenasan	0.658	0.316	0.346	0.512	0.254
Kaj	0.43125	0.3525	0.355	1.2225	0.4
Kashan	0.441	0.57	0.534	0.963	0.4923
Lashkari	2.403	0.3735	0.4752	1.26	0.36
Lashkari Yellow	0.768	0.945	0.5223	0.633	0.1245
Fath	0.9225	0.52425	1.23525	1.35	0.468
Azadegan	2.6725	0.54	0.7925	0.85	0.145
Molem	0.633	0.6	0.855	0.612	0.318
Azadi Square	1.936	0.428	0.7752	0.636	0.2144
Rashid Crossroad	2.0081	0.7525	0.5719	0.9589	0
Ashrafi Crossroad	1.4147	1.86405	0.1548	0.43	0.4601
Babaei	0.931	0.7399	0.4305	0.7	0.721
Yasini	1.673	0.6615	0.2835	0.8085	0.0735
Damavand	1.464	0.814	0.76	0.56	0.402
Resalat	0.72	0.342	0.414	0.9216	0.3996
Besat	1.868	0.376	0.668	0.944	0.144
Hashemi	1.121	0.4484	0.5358	0.7866	0.9082

What is the reason of bitumen traces?

The poor compounding formulation of asphalt and not paying enough attention to suitable aggregate characteristics as well as inappropriate environmental and processing conditions in the mix plant are the most important causes that make the asphalt not resist against stresses exerted by car rolling wheels. The breaking of the adhesive bond between the aggregate surface and the wetting bitumen in an asphaltic pavement or mixture is named stripping depending on many variables, including the type and use of a mix, bitumen characteristics, aggregate characteristics (such as surface texture, porosity and pore structure), environment, traffic, construction practice, and the use of anti-strip additives. Lack of attention to the optimal parameters gets one use improper bitumen and aggregates in the mix plant significantly affecting the asphalt-aggregate bond strength, and, in turn, altering the physical state of the final asphalt. This usually causes low temperature debonding at the aggregate/asphalt interface and therefore cracking of the asphalt pavement.

Under this circumstance, sealing and filling asphalt cracks with polymer modified bitumen sealants and hot applied mastics is a common road maintenance activity to prevent the intrusion of water and incompressible material into the cracks and increase its durability. Our field study and visual inspections show that there are lots of places (Figure 5) where asphalt repair mastic is applied on traffic paints and makes the surface layer of traffic paint dirty. Maybe, here is the major contributions to traffic paints dirt pick up that can deteriorate the appearance of a traffic paints, albeit further studies should be conducted to confirm the result.

Figure 5 Cracking and sealing at asphalt surface.

Conclusion

The study was conducted to determine the weight distribution of affecting factors in contamination of traffic paint surfaces from environmental pollutants from selected major roads in municipal districts of Tehran.

Despite the overall of contamination factor of four main groups of pollutants thus FTC, ZCW and CNP were found to be lower than the alert values in most the traffic paints samples collected, the fuel combustion and bitumen have the major contribution to dirt-picked up by traffic paints. The overall degree of contamination (PLI) calculated for the four main groups of elements also confirm the previous result. The results show that the traffic paints in crossroads and roads with heavy vehicles (gasoline fuel) are more subjected to dirt picked up. Accordingly, the very poor appearance of traffic paint which is overall observed in tehra's roads can be contributed to another factor thus low quality of asphalt. The analysis of variance shows that analyzed elements weight ratio levels were highly significant in traffic paints collected from various roads. The statistical analysis of elements verifies well that some of the elements correlated strongly indicating common source of pollution. Some elemental pairs such as Ni/Cr(0.88), Pb/Cr(0.75), Fe/Ti(0.78), Fe/Cu(0.81), Zn/Ca(0.61) and Zn/W (0.56), have strong correlation with each other at 1% significant levels.

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None.

Conflict of interest

The author declares no conflict of interest.

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