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Ecological Risks Attributed to the Heavy Metals Pollution of Dust Settled on the Surface of Coastal Roads along the Persian Gulf

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ABSTRACT

Introduction: Heavy metals (HMs) accumulated in the road dust may be transferred to the surrounding land and water bodies and pose ecological risks. Hence, such pollution should be considered, especially in coastal roads. This study focuses on the HMs pollution of dust settled on the surface of coastal roads along the Persian Gulf in Bandar Abbas city.

Materials and Methods: In this study, road dust samples were collected from 13 points in coastal roads and analyzed by ICP-OES for the measurement of As, Cd, Co, Cr, Cu, Mn, Ni, and Pb. Based on the HMs contents of dust, pollution, and ecological risk indices, including contamination factor (CF), modified pollution index (MPI), and modified ecological risk index (MRI) were calculated.

Results: Among the studied HMs, Cu (4.73) showed the highest CF value. The levels of MPI showed that the road dust was strongly polluted by HMs (4.02), but it was mainly contributed by a low toxic metal (Cu). Therefore, the mean value of MRI was 132.3, indicating the low ecological risk of such pollution. Note that the MRI value was > 150 in some sampling points, indicating moderate ecological risk.

Conclusion: This study showed that the road dust along the Persian Gulf coastline is polluted to different levels of the studied HMs and may pose various levels of ecological risks. The current level of HMs pollution in the study area was not significantly high. However, high pollution levels in the west roads should not be overlooked.

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Introduction

During last decades, extensive human activities have led to the vast development of communities and their industrialization. Accordingly, they have become centers of resource consumption. These issues have caused the emission of large volumes of pollutants into the environment [1]. Settled dust on the outdoor surfaces is a common potential sink for receiving the released pollutants emitted from human activities. One of the main concerns about dust is its transportability, since it is a particulate matter and can be resuspended [2, 3]. Therefore, dust particles that may be polluted with various toxic and persistent chemicals could be readily carried by wind from polluted sites to sensitive areas, and then affects the urban ecological system[4, 5]. Moreover, during rainfall events, the settled dust is transported and its pollution content is leached out

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by runoff. Therefore, the ecological risk of polluted dust that is settled on the urban surfaces is more pronounced in this condition[6].

Among various dusts settled on the urban surfaces, road dust is of utmost importance, since this media is in direct contact with the vehicles and may be polluted with various pollutants, especially heavy metals (HMs). Moreover, it may be readily resuspended by the vehicular movement [7, 8]. HMs is among the most important pollutants in the environment because they are ubiquitous, persistent, and non-biodegradable, and could be accumulated in living tissues in the biota[9, 10]. Road dust may be polluted with HMs originated from natural and anthropogenic sources, including soil parent material, road (exhaust or non-exhaust) and industrial emissions, construction activities, and etc. [11]. Road dust may be transported toward neighbor ecosystems by surface runoff [12]. Moreover, dust particles settled on the surfaces may be transported over long distances by wind [13]. Therefore, this phenomenon may move the road dust containing HMs into water bodies in the coastal roads. The translocated HMs may consequently cause various ecological risks and eventually enter the food chain [12]. In this regard and with respect to the significant role of road dust in sinking and carrying of HMs, especially in region with close proximity to the water bodies, characterizing such pollution and assessing attributed ecological risk is of importance. In water bodies, HMs bond to the fine-grained particles and bioaccumulated in the aquatic organisms, resulting in undesirable biological effects. Some HMs such as chromium (Cr), arsenic (As), lead (Pb), cadmium (Cd), nickel (Ni), copper (Cu) and cobalt (Co) have higher tendencies for bioaccumulation and may have adverse impacts on organisms[14]. Limited studies have considered the HMs pollution of road dust in coastlines. Recently, Yesilkanat et al., studied the ecological risks of toxic HMs in road dust along the Black Sea coast in Turkey and reported low to high ecological risks attributed to such pollution[5].

Bandar Abbas is an important city that lies along the north coastline of Persian Gulf and has experienced rapid urban and industrial growth in recent years[6, 15]. Throughout this city, main busy roads are lies in close adjacent to the Persian Gulf coastline. On the other hand, the dust settled on the surface of road in this city may receive HMs from local sources, such as traffic and industrial sources that mainly located on the west of this city. Moreover, this city is located in a humid tropical region with torrential rains. Hence, during the monsoon months, a huge amount of runoff may be flowed toward seawater[6, 16]. Therefore, an important ecological risk related to the contamination of surface dust in coastal roads of this city is the possible penetration of HMs into the Persian Gulf water. The pollution level of HMs in road dust throughout the Bandar Abbas city has been recently reported [6], but it is essential to focus on the roads near Persian Gulf, as an aquatic ecosystem, because the HMs polluted dust settled on these roads may be translocated to the sea water. Therefore, this study aims to evaluate the level of HMs pollution and ecological risk of HMs in the surface dust of roads adjacent to the Persian Gulf coastline and assess the ecological risks. Monitoring the levels of pollutants in such roads and assessing the attributed ecological risk is of utmost importance for encouraging the decision makers to control such pollution.

Materials and Methods

Sample collection, preparation and analysis

According to the authors' previous study[6], HMs concentration of road dust was determined in 2019 year as follows. Dust samples from the surface of coastal roads were collected from 13 points along the coastline of Bandar Abbas. At each site of sampling, road dust sub-samples were collected from 3 points. Each sub-sample with > 100 g weight was collected using a clean plastic brush from an area of 1 m^2 road surface. Therefore, each sample was composed from 3 sub-sample, that were homogenized, dried and sieved. Thereafter, samples were digested in Aqua regia solution, which was a mixture of hydrochloric acid and nitric acid. Then, the filtered digested sample was analyzed by inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 5300) for the determination of As, Cd, Co, Cr, Cu, Ni, Pb, Mn, and Sc concentrations. Along with the main samples, quality control samples were also analyzed in the same manner as main samples. Detection limits of Mn, Co, Cr, Cu, Ni, Pb, Sc, As, and Cd based on the dry weight were 5, 1, 1, 1, 1, 1, 0.5, 0.5, and 0.1 mg/kg of dust, respectively. Note that the sampling was done during a dry period to minimize the effect of HMs wash-off from road dust during torrential rain and resulted surface runoff. During a wet period, the HMs pollution of road dust is diluted and the results of the study will be underestimated.

Assessment of pollution level and ecological risk

Pollution level of each HMs was assessed by calculating contamination factor (CF) according to the following equation:

$$CF = \frac{C_i}{B_i} \quad (1)$$

Where C_i and B_i are the concentrations of each pollutant in the sample and background, respectively. The local background concentration values were obtained from previous study for local deep-soil in Bandar Abbas[6]. There are 4 classes for describing CF[17], including low (CF < 1), moderate (1 < CF < 3), considerable (3 < CF < 6), and very high (CF > 6) contamination.

The overall pollution level of coastal road dust was estimated by calculating modified pollution index (MPI) as follows[18]:

$$MPI = \sqrt{\frac{(EF_{avg})^2 + (EF_{Max})^2}{2}} \quad (2)$$

Where, EF_{avg} and EF_{max} are the average and maximum levels of enrichment factor (EF) for the HMs in each sample. EF was estimated as follows:

$$EF = (C_i/C_{ref})_{sample}/(B_i/B_{ref})_{background} \quad (3)$$

Where, C_i and B_i are the concentrations of pollutant i and reference element (Sc), respectively, in the sample. Also, B_i and B_{ref} are the background concentrations of pollutant i and reference element, respectively. There are 6 classes for describing of MPI including unpolluted (MPI < 1), and slightly (1 < MPI < 2); moderately (2 < MPI < 3); moderately to heavily (3 < MPI < 5); severely (5 < MPI < 10) and extremely (MPI > 10) polluted conditions18.

In addition to the pollution level, ecological risk was also assessed by modified ecological risk index (MRI) according the following equation:

$$MRI = \sum_{i=1}^{p} Tr^i \times EF^i \quad (4)$$

Where, p refers to the number of HMs, and T_{ri} and EF_i are the "toxic-response factor" and enrichment factor of HMs i, respectively. The T_r^i values for As, Cd, Co, Cr, Cu, Mn, Ni, and Pb are 10, 30, 5, 5, 5, 1, 5, and 2, respectively [19]. The classification of MRI includes low (MRI < 150), moderate (150 < MRI < 300), considerable (300 < MRI < 600), and very high (MRI > 600) risk[18]. All the statistic measures, and pollution level and ecological risk indices were calculated in Excel 2019 software.

Ethical issue

The ethical issue of this research was IR.HUMS.REC.1397.087

Results

A summary statistics of HMs pollution of the surface dust of roads along the Persian Gulf coastline is presented in Table 1. Concentrations of As, Cd, Co, Cr, Cu, Mn, Ni, and Pb were ranged from 5.5-18.1, 0.34-1.60, 7.0-13.0, 54.0-97.0, 56.0-322.0, 389.0-614.0, 52.0-95.0, and 10.0-215.0 mg/kg, respectively.

Table 1: HMs levels in settled dust of coastal roads in Bandar Abbas*

HMs	Mean (mg/kg)	STD (mg/kg)	Median (mg/kg)	Coefficient of variation, (CV) (%)
As	9.1	3.5	8.2	38.8
Cd	0.53	0.34	0.42	63.8
Co	10.0	1.5	10.0	15.3
Cr	72.0	11.6	73.0	16.1
Cu	158.5	85.5	138.0	54.0
Mn	470.5	56.4	11.0	12.0
Ni	66.0	10.7	65.0	16.3
Pb	72.5	67.4	56.0	92.9

* Note that the HMs levels for all roads of Bandar Abbas city and its suburb were presented in the authors' previous study[6]

The distribution of CF values for the HMs in the road dust is shown in Figure 1. According to the figure, the mean (min-max) values of CF for As, Cd, Co, Cr, Cu, Mn, Ni, and Pb were 1.25 (0.75-2.48), 1.37 (0.87-4.10), 0.79 (0.55-1.02), 1.01 (0.76-1.37), 4.73 (1.67-9.61), 0.89 (0.73-1.16), 0.77 (0.61-1.11), and 0.85 (0.12-2.51), respectively. Therefore, the highest and lowest contamination levels were assigned to Cu and Ni, respectively. The minimum, maximum, median, and mean values of MPI are presented in Figure 2. Accordingly, the mean value was 4.02 and the MPI values in various sampling points ranged from 1.68 to 9.94. The highest MPI value was observed in the coastal road located in the west side of the city, i.e., Shahid Bahonar port.

By considering the toxicity of HMs, the MRI was calculated and its mean and median values were 132.3 and 99.6, respectively (Figure 2). The highest amounts of MRI were in two places located in the west side of Bandar Abbas, in the area of Shahid Bahonar port (245.4 and 353.2). In Figure 3, different levels of HMs effect on the MRI are presented and reveal that the highest contribution to the overall MRI was attributed to Cd and Cu with contribution percentages of 41.3 and 23.6, respectively.

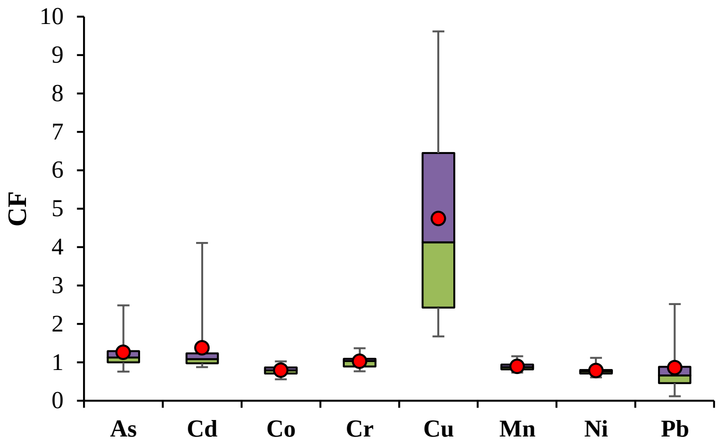

Figure 1: CF of HMs in the road dust samples

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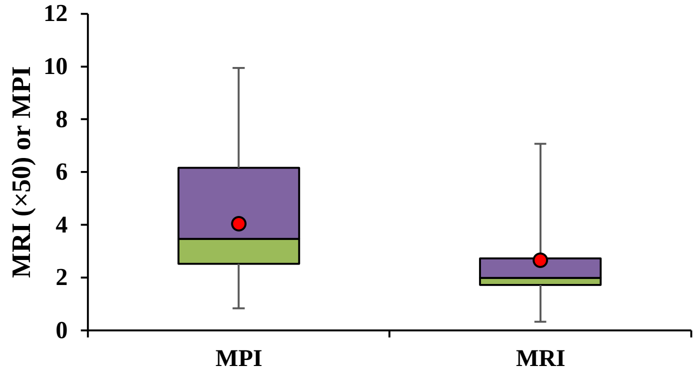

Figure 2: Levels of MPI and MRI attributed to the HMs pollution road dust

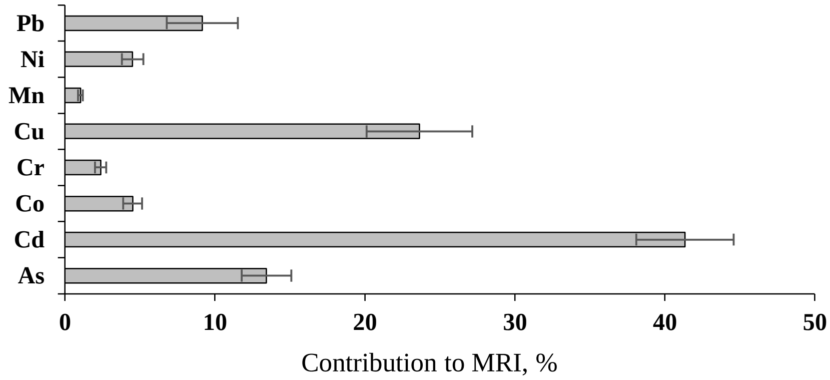

Figure 3: Contributions of various HMs to the overall MRI

Discussion

In this study the HMs pollution of settled dust on the surface of coastal roads of Bandar Abbas city was assessed and the attributed ecological risks were investigated. As shown in Table 1, the levels of the HMs were in the order of Mn > Cu > Pb > Cr > Ni > Co > As > Cd. In Table 2, the HMs concentration levels in the study area are compared to those of some cities in Iran and other countries. Among the studied cities, the lowest HMs levels were reported for Muscat (Oman)[20]. The levels of Cd, Cu, and Pb in the study area were comparable to that of coastal roads of Black Sea[5].

Table 2: Comparison of HMs concentrations in the study area with other locations around the world

Location	As	Cd	Co	Cr	Cu	Mn	Ni	Pb	Reference
Tehran, Iran	-	0.43	-	38.2	286.1	-	45.1	81.3	21
Bushehr, Iran	6.4	0.35	-	45.8	118.0	-	35.0	94.9	22
Muscat, Oman	1.4-5.4	-	16.4-20.4	1.5-2.7	49.7-68.2	-	-	17.6-19.4	20
Guilin, China	36.9	0.80	-	101.0	142.0	1033.0	27.9	91.6	23
Beijing, China	4.1	0.51	-	99.5	97.4	536.3	40.8	62.3	24
Black Sea coast highway, Turkey	-	0.10	-	41.0	81.0	-	26.0	36.0	5
Persian Gulf coast roads, Iran	9.1	0.53	10.0	72.0	158.5	470.5	66.0	72.5	This study

Among the studied HMs, the concentration levels of As, Cd, Cu, and Pb in the coastal road dust were at least two times higher than those of marine sediments in Persian Gulf [25]. Therefore, a part of HMs in the surface dust of roads adjacent to Persian Gulf shores was probably originated from anthropogenic sources. In this regard, pollution level indices attributed to each HM and all HMs were assessed by CF and MPI, respectively. Among the studied HMs, based on CF values, road dust was heavily polluted with Cu, and moderately polluted with As, Cd, and Cr. Moreover, the CV values of these HMs (except Cr) and Pb were significantly high, indicating the high concentrations in some sampling points, which might be caused by distinct anthropogenic sources [26, 27]. Copper mainly originates from industrial sources, construction activities and traffic emissions[24, 28]. Moreover, Pb and Cd are widely used in brake pads and Zn is used in tire wear, and As is mainly attributed to the fertilizers and fuel combustion [6]. The highest pollution was observed in the roads in the west of Bandar Abbas around Shahid Bahonar port. This region is characterized by high road traffic. The CF values of ≤1 for Cr, Co, Mn, and Ni along with their low variations reveals that there were no significant anthropogenic sources for them in the study area. Even, the concentrations of these HMs were not high in the west roads.

The integrated pollution level of road dust was evaluated by MPI. The mean value of this index was 4.02 and in half of the samples it was above 3, indicating the moderately to heavily pollution of road dust along the Persian Gulf coastline with HMs. The MPI as high as 9, for single sampling sites, reveals the sever pollution of dust settled on the coastal road with HMs. This condition indicates that the settled dust in the coastal roads in Bandar Abbas was polluted with anthropogenic-originated HMs. The anthropogenic HMs pollution of coastal roads has also been reported for the coastlines of Black Sea and Sea of Oman [5, 20].

The pollution indices of CF and MPI reflect the level of HMs pollution of environmental matrices, without reflecting the level of attributed ecological risks. For assessing such risk, MRI was also calculated. As shown in Figure 3, although the MPI showed moderately to heavily pollution, the mean MRI value indicated low-risk level. Similarly, the ecological risk associated to the HMs pollution of road dust in the Muscat, a city on the shores of Sea of Oman, was also low, while the mean risk in the Black Sea coast highway, Turkey, was moderate. A study on the road dust in Bushehr revealed that among 24 road dust sites (samples), the ecological risks in 2, 4, 8, and 10 sites were very high, considerable, moderate, and low, respectively[22].

Although, the most contributor of MPI was Cu with the highest CF level among the studied HMs, the toxicity of this metal is low, resulting in low value of MRI. Due to the different toxicity of the studied HMs, their contribution to the MRI was different from their CF ranking. According to Figure 3, MRI was mostly affected by Cd (41.5%) followed by Cu (24.1%). Among the sampled sites, the HMs in the road dusts around Shahid Bahonar port (west of Bandar Abbas) may pose moderate to considerable risk. In this port, in addition to light-duty vehicles traffic, there is high traffic of heavy-duty diesel vehicles. In the study area, especially around Shahid Bahonar port, the ecological risk related to the road dust polluted with HMs should not be overlooked, especially around Shahid Bahonar port, the ecological risk of road dust containing HMs should not be overlooked, especially during rainfall events. In this condition, HMs in dust may be translocated and leached out by the runoff[29]. As noted previously, torrential rainfalls may be occurred during the monsoon months in the study area, which may result in huge surface runoffs flowing toward seawater[16, 30]. Therefore, the possible leakage of HMs contained road dust into seawater through wind erosion and runoff could be considered as a crucial ecological challenge of roads along the Persian Gulf coastline.

Conclusion

The results of this study showed that the dust settled on the surface of coastal roads in Bandar Abbas is polluted with various levels of HMs. The CF values for Cu, As, Cd, Cr, and Pb showed probable anthropogenic contamination of Cu, As, Cd, Cr, and Pb. The MPI level showed moderate HMs pollution of road dust. However, the pollution was mainly contributed by Cu and due to the low toxicity of this metal; the ecological risk was not significant. However, the pollution level and ecological risk levels were significantly high in some points, especially in the west of the city and the pollution in this region may be penetrated to the Persian Gulf water.

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Conflict of interests

The authors of this article declare that there is no conflict of interest.

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