Assessment of metal contamination in deposited dust of the industrial area and some streets - Aden city, Yemen

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Abstract

Air pollution from pollutant emissions has become a threat to the biological system and human health. The concentration levels and sources of heavy metals contamination were studied in deposited dust samples collected from various locations, including five different activity areas: industrial, highways, residential, mixed use and a remote area from contaminants in Aden, Yemen. Metal content of Cd, Pb, Cu, Zn, Co, Cr, Mn and Fe in dust was analyzed by Atomic Absorption Spectrophotometer (AAS). The results showed high concentration levels of Cd and Pb in industrial and residential areas. Deposited dust contamination was assessed by various methods: Enrichment factor (*EF*), Contamination factor (*CF*), Degree of contamination (*DC*) and potential ecological index (*RI*). The enrichment factor indicated extremely high enrichment of Cd, Pb and Zn. High EF of Cd, Pb and Zn showed that anthropogenic sources contribute a substantial amount of these metals to dust deposited. Contamination factor analysis showed that dust samples are significantly contaminated by Cd and Pb. Individual ecological risk (*Er*) indicated low to high contamination of Cd, but low contamination of Pb, Cr, Cu, Co and Zn. The degree of contamination (*DC*) and Potential ecological risk index (*RI*) indicated that most of the study areas demonstrated "Moderate to considerable category" risk index. The result suggest mixed origin of pollution sources; including Man-made sources, traffic sources, and lithogenic occurrences of the metals from construction sources and road construction currently in some of the sites studied.

Keywords: Metal Pollution, pH, Urban Dust, Roadside Soil Dust, Ecological Risk Index.

Introduction

Road dust originates from the interaction of solid, liquid and gaseous materials which are produced from different sources and deposited dust. The composition and quantity of chemical matrix of road dust are indicators of environmental pollution [9]. Road dust receives varying inputs of heavy metals from diversity of mobile or stationary sources such as vehicular emission, industrial plants, power generation plants, oil burning, waste incineration, construction and demolition activities as well as resuspension of surrounding contaminated soils [2&4]. Road surfaces receive varying amount of heavy metals by the process of atmospheric deposition, sedimentation, impaction and interception [34]. Particularly, in urban areas, the top soils and roadside dusts are indicators of heavy metal contamination from atmospheric deposition. Industries, traffic, mining activities, smelters and construction are some of the main anthropogenic sources of heavy metal pollution. However, naturally occurring heavy metals are rarely toxic and pose little or no threat to the soil ecosystem. Increased concentrations of heavy metals may lead to high risks to human health, plants and animals, among others [19].

Metals, such as Cd, Cu, Pb and Zn, are good indicators of contamination in soils because they appear in gasoline, car component, oil lubricants and industrial incinerators emissions [34]. It has been reported that the pollutants, such as As, Cd, Cr, Cu, Ni, Pb and Zn due to heavy traffic, are at high concentration levels at the sites close to roadside soils and dusts that affect the air environmental quality [15].

The aim of the present work was to assessment of metal contamination in deposited dust of the industrial area and some streets in Aden City, Yemen.

Material and Methods
The Study Area
Aden city is located at the southern part of Yemeni coast in Gulf of Aden, with the coordination 12° 28' - 12° 57' N and 44° 27' - 45° 07' E. It is located at the south west tip of Yemen and the Arab Peninsula. It is a semi island and consists of rocks. Aden's population is 865,000, according to the results of population projections for the year 2015. The population grows annually by (3.77%). Its population constitutes 3% of the total population of the Republic, with a land area of 35846 hectares (Fig.1 & Table 1).

Sampling and Pre-Treatment
Eleven samples of deposited dust samples collected from various locations including five different activity areas: industrial, highways, residential, mixed use and a remote area from contaminants in Aden city (Fig. 1 & Table 1), were collected in August 2014 using a clean brush and placed in clean plastic polyethylene bags and then transferred to the laboratory for preparation of some physical properties and estimation of heavy metals. All the collected dust samples were stored in sealed polyethylene bags, and labeled and then transported to the laboratory. All samples were dried in a laboratory oven at 105°C, and then sieved through a 2mm [37&49].

Analysis of Dust Properties (pH and EC)
The following properties were analyzed in the samples by methods Rhoades and Thomas [46&56]. Dust pH and EC was measured in 1:5 dust to water ratio.

Total Heavy Metals
The resulting deposited dust samples were used to analyze heavy metal concentration. A 0.5g of milled deposited dust sample, the dust sediment samples were digested with a mixture of HNO_3 and HCl (3:1 v/v) [26], and analyzed for the metals Fe, Zn, Cu, Pb, Mn, Cr, Cd and Co using Atomic Absorption Spectrophotometer.

Assessment of Metal Contamination
The assessment of soil or sediment enrichment can be carried out in many ways. The most common ones are the index of geoaccumulation and enrichment factors [46]. Contamination indices and ecological risk indices were analyzed to assess heavy metal contamination of deposited dust, using single and integrated indices. In this study, deposited dust contamination was assessed by various methods: Enrichment Factor (*EF*), Contamination Factor (*CF*), the degree of contamination (*Dc*), ecological risk factor (*Er*) and the potential ecological risk index (*RI).*

Assessment According to Sediment Quality Guidelines (SQG)
The level of heavy metal contamination is assessed by a comparison with the Sediment Quality Guidelines (SQG) proposed by *United States Environmental Protection Agency (USEPA) Standards* [42&43]. In this system, 3 classes are used to classify the sediment quality: non-

polluted, moderately polluted and heavily polluted, based on the SQG of US EPA. Another classification system is the Hong Kong Environmental Protection Department Classification system (EPD) [20]. In this system, 4 classes are used to classify the sediment quality. The first class showed to be classified as uncontaminated sediment (Class A), whereas, the second class represented (Class B) showed slightly contaminated sediment. The third and fourth class were considered as moderately and seriously contaminated (Class C & Class D), respectively.

Enrichment Factor (EF)

Enrichment factors of heavy metals were calculated for each street dust sample, based on the standardization of a measured element to a reference element. Iron the commonly used element, as reference [55,60,64]. The *EF* calculation is expressed bellow as:

$$EF = \frac{[C_x/C_{Fe}]_{Dust}}{[B_x/B_{Fe}]_{shale\ or\ crust}} \quad (1)$$

Where:

C_x = content of the examined element in the examined environment; C_{Fe} = content of the examined Fe or Al in the examined environment; B_x = Background value of metal (shale or crust); and B_{ref} = Background value of Fe or Al (shale or crust).

Five contamination categories are recognized on the basis of the enrichment factor [36]:

EF < 2   states deficiency to minimal enrichment
EF = 2-5   moderate enrichment
EF = 5-20   severe enrichment
EF = 20-40   very high enrichment
EF > 40   extremely high enrichment

The enrichment factor, due to its universal formula, is relatively simple and easy tool for assessing enrichment degree and comparing the contamination of different environment [45].

Contamination Factor (CF) and Degree of Contamination (DC)

The contamination factor (*CF*) and Degree of Contamination (*D*C) were suggested by Håkanson [24] and defined as follows:

$$CF = Cs / C_b \quad (2)$$
$$DC = \Sigma\ CF \quad (3)$$

Where C_s is the measured concentration of the examined metal in the road dust and C_b is the geochemical background concentration or reference value of the metal, or the background value of heavy metals in the uncontaminated soil [24&30]. Four classes of C_f have been suggested to evaluate the metal contamination levels [35], as follows:

 CF < 1   Low contamination factor
 $1 \leq CF < 3$ Moderate contamination factor
 $3 \leq CF < 6$ Considerable contamination factor
  $CF \geq 6$ Very high contamination factor

Four categories of *DC* were used to evaluate metal contamination levels as follows:

 DC <7   Low degree of contamination
 $7 \leq DC < 14$ Moderate degree of contamination
 $14 \leq DC < 28$ Considerable degree of contamination
 $DC \geq 28$ Very high degree of contamination, indicating serious anthropogenic pollution.

degree of contamination [17]. Dc is the sum of the contamination factors of all the elements examined, according to Håkanson [24].

Potential Ecological Risk (Er) and Potential Ecological Risk Index (RI)

The potential ecological risk index (*RI*) of the heavy metals is quantitatively evaluated by the potential ecological risk (*Er*) [24&65], which takes into account both contamination factor (*CF*) and the "Toxic-response" factor (*Tr*). The potential risk index can be acquired as follows:

$$Er = T_r \times CF \qquad (4)$$
$$RI = \Sigma\, Er \qquad (5)$$

Håkanson [24] suggested that the *Tr* values of Cd, Cr, Ni, Pb, Zn, Co and As are 30, 2, 3, 5, 1, 5, and 10, respectively. The potential ecological risk values obtained were compared with categories grade of *Er* and *RI* of metal pollution risk on the environment suggested by Håkanson and Shi *et al.,* [24 & 52].

Results and Discussion

pH Value and Electrical Conductivity (EC)

The pH is usually considered as an indicator or as a measurement of the chemical nature of dust. The pH value of the dust samples ranged from 6.3 -11.45 with an average of 8.24. The alkaline nature of the dust samples reflects the richness of carbonate [62] which caused the neutralization of dust acidity. This means that the changes of soil acidity can influence neutral compositions in the soils by removing the bivalent base (like Ca^{+2} and Mg^{+2}) from soil [33]. The lowest value of pH found is located in the vicinity of an a industrial area (especially the area surrounding the iron factory).

Electrical conductivity (*EC*) measurements obtained by water extraction of dust samples were shown in Figure (2). The dust samples have *EC* ranged from 2.3-8.06; 4.93 µS/cm. The amount of salt content in dust may account for such variation in the parameter among the study areas. The ions such, as Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, NO_3^- , PO_4^{3-}, CO_3^{-2} and HCO_3^-, constitute the ionic salinity [23]. The higher EC values in dust of the industrial area are likely due to a spill of material rich in salts or both have the common source of the metal and salts in dust samples.

Heavy Metals Concentration in Dust Samples

The results of heavy metal concentrations in eleven dust samples collected from the industrial zone and some streets of Aden city, Yemen, are shown in Figures (3 & 4). The variation in the concentration of heavy metals within different sites may be due to differences in their sources and the predominant physicochemical conditions and complex reactions such as adsorption, precipitation and redox conditions taking place in the dusts [28].

Lead (Pb): The highest lead values have been detected in deposited dust samples located in the vicinity of an industrial area (especially the area surrounding the iron factory) (107.93 µg/g) and Al-Boriqah (65.32 µg/g) (Figure 3a). The minimum lead concentration found in dust samples from site Cement Factory was 13.95 µg/g. The average of the measured values for this element is (43.29 µg/g). These values indicate that leaded fuel could be the potential source of lead contamination in the dust samples [53]. Lead found in fuel as tetraethyl lead and used as anti-knock agent in the combustion of gasoline. Pb pollution occurs on a local scale by industrial emissions and on a larger scale by emissions from vehicles that use leaded gasoline [10,31,59]. Lead comes mainly from automobile exhaust and vehicular emission, for example tire wear, bearing wear, break-lining wear [40]. Besides, the high content of Pb could be attributed to some other anthropogenic effects since the area is harbored with high-density road traffic including automobile repairing workshops in surroundings and high buildings resulting possibly in low wind speed at the point, the low wind speed might also be the cause of highest metal accumulation at this study.

Cadmium (Cd): The highest cadmium content was found in the industrial area (Iron Factory site) and Al-Mansoura (heavily traffic density, commercial area) (3.46 µg/g and 2.95 µg/g, respectively) (Figure 3b). These high concentrations of Cd at these sites may be attributed to industrial activities, traffic density and commercial activities, which are significant contributors to street dust. The main source of Cd in dust samples of gasoline stations was the fuel [61&63]. However, Cd may came mainly from motor vehicles [16], oil lubricants, car components [11&61] and wear and tear of tyres. It is found that Cd in old car tires is in the range 20-90 mg/kg as associated in process of vulcanization [11]. A large amount of cadmium (Cd) is released into the environment through human activities, weathering of rocks, forest fires and volcanoes cadmium is also produced as a by-product of the smelting zinc (Zn) from its ore. Another important source of Cd emission is the production of artificial phosphate fertilizers. Cadmium (Cd) is the by-product in the production of zinc and lead and the pyrometallurgy production of zinc is the most important anthropogenic source to the environment and combination with other metals [40] [35]. Several studies described Cd, Pb, Hg and As originate mainly derived from industrial processes, including mining, burning of fossil fuels, waste recycling, cement manufacturing, as well as paper and glass production [14].

Chromium (Cr) and Cobalt (Co): The highest average content of Cr and Co (24.32 µg/g; 4.04 µg/g, respectively) was found in dust sample at Al-Boriqah city (Industrial area, traffic and residential area), while the lowest Cr and Co concentrations in dust (8.60 µg/g and 0.2 µg/g, respectively), was found in the Fuqum site, this may be related to the low traffic density and low work activities (Fig. 3c and Fig. 3d). The higher concentrations of Cr and Co are probably related to the urban construction and industrial activities. Co was primarily derived from construction sources [25]. Chromium is one of those heavy metals whose concentration steadily increases due to industrial growth, especially the development of chemical and tanning industries. Another source of Cr in roadsides dust is believed to be due to corrosion of vehicular parts [40]. The high value of Cr is located in the vicinity of a steel plant, a coal-fired power plant, a machinery plant, a cement plant and located near garages [25].

Zinc (Zn): The zinc concentration was found to be in the range of 115.00–205.17 µg/g (Figure 4a). The average of the measured values for this element is (139.74 µg/g). The highest mean zinc content was found in samples collected from site Al-Mansoura (heavily traffic density, commercial area); elevated Zn abundances in commercial areas probably originate from traffic sources. This could be attributed to the use of zinc in accumulators of motor vehicles or in carburetors, ovens and mechanical sites. Christensen and Gunn [12] mentioned that the main sources of Zn in the urban atmosphere are related industrial activities rather than auto-exhaust, while Al-Khashman [4] related the highest Zn concentrations to smelters, ovens and mechanical sites, and the lowest concentrations to furniture and wood industry [18]. However, the presence of this amount of Zn in the samples may be accounted by the fact that Zn compounds are used extensively as anti-oxidants and as detergent/depressants improving agents for motor oil. Vehicle brake linings and tire wear have been identified as possible sources of Zn [40]. Zinc alloy and galvanized board are widely used in motor vehicles. Zinc compounds have also been employed extensively as antioxidants and as detergent/dispersant improvers for lubricating oils [25].

Copper (Cu): The average of the measured values for copper is 53.95 µg/g, within the range between 3.0-174.28 µg/g (Figure 4b). The highest concentration of Cu was found in the vicinity of Iron factory, while the lowest value of copper was found in the samples from Fuqum site, which represents the western part of the Aden city. This site is considered a low residential area with a low population density and low traffic density. The source of copper in the deposited dust was

indicated by research as being due to corrosion of metallic parts of cars derived from engine wear, thrust bearing, brushing, and bearing metals [1&16]. However, in the other sites, copper present as a result of traffic emission [61], including gasoline and diesel fuel that contains variable quantities of Cu [63].

Manganese (Mn): Manganese values in dust samples were found to be within the range from 0.13 to 57.03 µg/g, with an average value of 29.92 µg/g, (Figure 4c). The highest value of manganese was found in the dust samples of Al-Shab and Al-Boriqah, while the lowest value of manganese was found in the Fuqum site. It reflects low traffic density. The major sources of manganese (Mn) are ferromanganese production, welding rods, incineration of manganese containing substance and organo-manganese fuel additives [18].

Iron (Fe): The highest lron content was found in the industrial area (the vicinity of Iron Factory) and Al-Mansoura city (this site is considered a high residential area with a high population density, high traffic density, commercial area) (1520.90 µg/g and 1435.08 µg/g, respectively), (Figure 4d). High values of iron was recorded at the workplace of car service indicating anthropogenic impact in the dust. This includes wear of brake linings and corrosion and wear of vehicle [57]. High concentration of Fe was found in car exhaust particulates and other car derivatives such as corrosion of body parts [27&38], while the lowest value was 550.53 µg/g found in the Fuqum site, which represents the western part of the Aden city. This site is considered a low residential area with a low population density and low traffic density.

When comparing the concentration of heavy metals between regions of the study, Figures (2-3) show that the mean concentrations of Co and Cr in Al-Boriqah street dust are appreciably higher than in other sites, whereas the mean concentrations of Pb, Fe, Cu and Cd in dust from the vicinity of industrial area (Iron Factory) are higher than those of other sites. The mean concentrations of Zn in Al-Mansoura street dust are appreciably higher than in other sites, whereas the mean concentrations of Zn, Fe, Cu, Mn, Co and Cr in Fuqum dust are lower than those of other sites. This shows that industrial activities and traffic volume is the major contribution to pollution. The metals follow the decreasing order of Fe>Zn>Cu>Pb>Mn>Cr>Cd>Co.

The results of the study indicate that the distribution of heavy metals with high concentration is located in the vicinity of industrial area (especially the area surrounding the iron factory) and may be due to the emissions of the plant containing these metals, construction sources and road construction, in addition to other sources from the industrial zone and the residential area near them.

The higher concentrations of Co, Cr, Mn and Pb in Al-Boraiqa city are probably related to the emissions from oil refineries and power station (industrial sources), the urban construction (traffic sources), emissions from vehicle and vehicle exhausts and construction sources, whereas the higher concentrations of Zn, Cd and Pb in Al-Mansoura city are probably related to the urban construction (heavily traffic density), emissions from vehicle and vehicle exhausts, emissions of the electric power station, gasoline, car component, oil lubricants and industrial incinerators emissions (industrial activities), construction sources, road construction and another sources. Metals, such as Cd, Cu, Pb and Zn, are good indicators of contamination in soils because they appear in gasoline, car component, oil lubricants and industrial incinerators emissions [34]. The degree of emissions of pollutants originating from road traffic are affected by vehicle age, fuel type and quality, wide variety of vehicle (e.g., passenger cars, trucks, etc.) and engine types (e.g., diesel or gasoline powered engine), type of tire, road conditions and traffic conditions (e.g., heavy or light traffic), etc. [41].

Comparison with Other Studies

    The heavy metal contents in the deposited dust of the industrial area and some streets in Aden city were compared with those found in different locations of the world (Table 2).
In comparison with other local studies (Aden Coast sediments), the levels of Cr, Co, Mn, Pb, and Fe in dust of Aden city was lower than other studies [47,3,48], except Pb which was higher than Saleh *et al*, [47], while the concentration of Cd and Cu was similar to other studies.

    The concentration of Cr, Mn, and Co in the dust samples in the present study was lower than other levels reported in Table (3), expect Cr which was similar to Bahrain and Lulea (Sweden). The average levels of Zn and Cu found in the present study was similar to Ottawa and Islamabad, they were while lower than Hong Kong, Navi Mumbai, Amman, Shanghai, Massachusetts, Greece, and higher that the reported value for Sweden, Turkey, Nigeria and China. Lead concentration ranged from 10.04 to 107.93 μg/g, with a mean of 43.29 μg/g, was much lower compared with previous studies in several cities except for Ottawa, Sweden, Nigeria and China, whereas the concentration of Cd in the present study is similar to Amman (Jordan), Bahrain and Jeddah (Saudi Arabia), it was while lower than Islamabad, Kayseri (Turkey), and much higher than Greece, Sweden, Nigeria and Navi Mumbai, while the levels of Fe found in the present study was lower than Massachusetts, Jeddah and higher that the reported value for Navi Mumbai, and Nigeria.

Comparison with Maximum Allowed Levels for Different Countries and WHO

    Results show that the average content of Zn, Cr and Mn is lower than the maximum allowed levels of the World Health Organization (WHO) and different countries suggesting (Zn and Mn) that the study area were not contaminated with those metals (Table 3). While the average content of lead, copper, and cadmium elements are higher than the maximum allowable levels according to WHO and USA, UK, Poland for Cd; all countries except Canada for Cu; UK, Poland and Austria for Pb. The maximum concentration of Cd, Pb and Cu was more than the maximum allowed levels permissible limit found in the dust samples around the industrial zone. The site was highly polluted hence the possibility of posing some health problem associated with the excess lead, cadmium and copper in soils, for instance, dust from those contaminated sites could affect those people who live closer to the sites [8&50].

    The source of Cr and Mn is a mixture of natural sources and industrial emissions of iron and steel plant and coal-fired power plant. Cu Pb and Zn mainly were originated from traffic emissions. Co was primarily derived from construction sources [12]. Zn and Cu may be derived from mechanical abrasion of vehicles as they are used in the production of brass alloy itself and come from brake linings, oil leak sumps and cylinder head gaskets [18].

Assessment of Heavy Metals Contamination Status in Deposited Dust of the Industrial Area and some Streets in Aden City
Assessment According to Sediment Quality Guidelines (SQG)

    The level of heavy metal contamination is assessed by a comparison with the Sediment Quality Guidelines (SQG) proposed by the United States Environmental Protection Agency (USEPA) [42&41]. These criteria for the measured heavy metals are presented in Figures 3 and 4. The result of the present study shows that the dust samples from the industrial area and some streets in Aden are not polluted for Fe, Mn and Cr. The concentration of Pb is indicating heavily polluted at the sites of Iron Factory and Al-Boriqah; moderately polluted in the Al-Mansoura site; not polluted at anther sites. The Zn metal is indicating moderate polluted in the all the sites, except Al-Mansoura site where it is heavily polluted. The concentration of Cu was heavily polluted of Iron Factory and Al-Mansoura; moderately polluted in Al-Boriqah and the Cement Factory; not polluted in Al-Shab and Fuqum.

The level of cadmium contamination is assessed by a comparison with classification system from Hong Kong Environmental Protection Department (EPD) [20], the average values of the cadmium were seriously contaminated (Class D) in the all sites, except Al-Boriqah and Fuqum were uncontaminated (Class A), (Figure 3).

Assessment According to Enrichment Factor (EF)
    Enrichment factors, among other things, were used to assess the relative contributions of natural and anthropogenic heavy metal inputs to dust, soils and sediments. The Enrichment Factor (*EF*) of heavy metals under the current study was computed (Table 4) for each metals for deposited dust samples relative to the background value of the element in continental crust average value of the element. The enrichment factor of Pb, Zn, Cu, Mn, Co, Cr and Cd is in the range of 21.94 –166.77, 41.40–103.35, 6.62 – 117.97, 0.01 – 2.24, 0.55–7.48, 4.38–9.51 and 36.37–322.02 with an average of 80.58, 61.59, 40.46, 1.23, 2.19, 6.19 and 218.26, respectively. The mean *EFs* increased in the order Cd>Pb>Zn>Cu>Cr>Co>Mn. The mean *EF* calculation results indicated that Mn (*EF*=1.23), Co (*EF*=2.19) and Cr (*EF*=6.19) were in the category of mineral, moderate and server enrichment, respectively. However, Cd, Pb, Zn, and Cu were in the category of extremely high enrichment, whereas *EF*>2 indicated that the element is of anthropogenic origin [54].

    In this study, there are two major contributors of pollution in deposition dust: these are anthropogenic and lithogenic. The lithogenic effects come from the origin of material, while anthropogenic effects come from the industrial waste and urban construction (heavily traffic density), emissions from vehicle and vehicle exhausts.

Assessment According to Contamination Factor (CF) and Degree of Contamination (DC)
    The heavy metal contamination of the deposited dust was evaluated based on the contamination factor and the degree of contamination suggested by Håkanson [24]. The calculated values of *CF* are shown in Table 5. The results show CF range from 0.0002 to 10.03.

    The concentrations of Cd is indicating high contamination (Industrial zone and Al-Mansoura City), considerable at Al-Shab City, and moderate contamination of Fuqum and Al-Boriqah, while Pb values indicated considerable contamination (Iron Factory and Al-Boriqah City), moderate (Fuqum and Al-Mansoura City), and low contamination in the cement factory and Al-Shab City. The concentrations of Cu indicated considerable contamination (Iron Factory), moderate (Al-Boriqah and Al-Mansoura City), and low contamination in the Fuqum, cement factory and Al-Shab City. Zn values were moderate contamination in all locations, while the values of the contamination factor (*CF*) for Co, Cr and Mn were found to be low contamination in all sites.

    Table 5 illustrates the mean *CF* increase in the order **Cd>>Pb>Zn>Cu**>Cr>Co>Mn.
Results of degree of contamination (*DC*) in sampling sites showed low (at Fuqum), moderate at (Al-Boriqah, Al-Shab, Cement Factory), and considerable at (Al-Mansoura and Iron Factory) levels of contamination for the heavy metals (Figure 5).

Ecological Risk Assessment (Er) and Potential Ecological Risk Index (Risk Index:RI)
    The results of evaluation on ecological risk coefficient (*Er*) and the potential ecological risk index (*RI*) are summarized in Table (6) and Figure (6).

    The ecological risk Assessment (*Er*) of heavy metals were all lower than 40, which belong to low ecological risk, while Cd fell within low risk (Al-Boriqah City); medium risk (Fuqum); considerable risk (Al-Shab City) and high risk category (Cement Factory, Al-Mansoura and Iron Factory).

    The average *Er* increased in the order **Cd>Pb>**Zn>Cu>Cr>Co>Mn. The levels of the examined metals in deposited dusts of Aden city are not evenly distributed throughout the studied areas.

The total ecological risk index (*RI*) of seven heavy metals were low (Fuqum, Al-Boriqah and Al-Shab City), moderate (Al-Mansoura and cement Factory) and high ecological risk categories in the vicinity of a industrial area (Iron Factory).

The ecological risk assessment results showed that dust posed a low to high potential ecological risk. Pb and Cd presented higher ecological risks than any other metal, particularly in both main intense traffic density and industrial dusts.

Conclusion

In this study, there are two major contributors of pollution in deposited dust: anthropogenic and lithogenic. The lithogenic effects come from the origin of the material, while anthropogenic effects come from industrial wastes and urban construction (heavily traffic density), emissions from vehicle and vehicle exhausts.

Both Single indices include *Enrichment Factor (EF)*, Contamination Factor (*CF*), Ecological risk Assessment (*Er*) and the integrate indices include Degree of contamination (*Dc*) and potential ecological Risk Index (*RI*) that were studied in order to determine the possible contamination of heavy metals by industrial waste and urban construction (heavily traffic density), emissions from vehicle and vehicle exhausts. The street dust should be continually monitored over time. The aim of monitoring would help in putting adequate measures in vehicle emission control, as well as the establishment an air quality control system in the industrial area, heavily traffic areas, main and secondary streets.
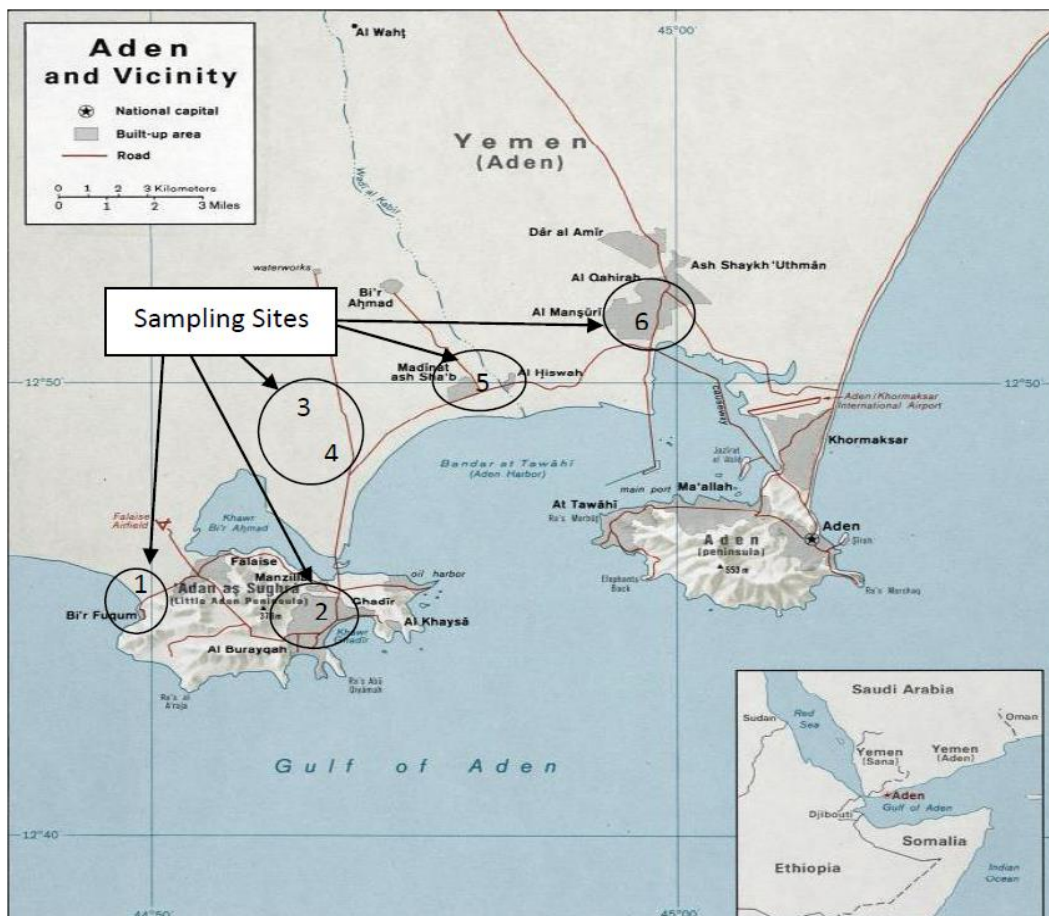

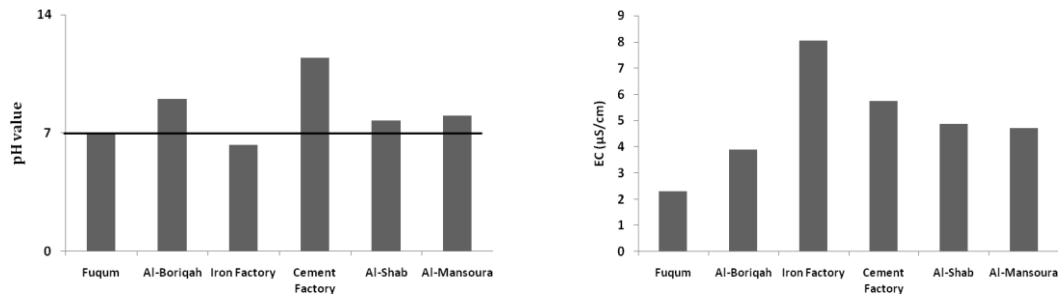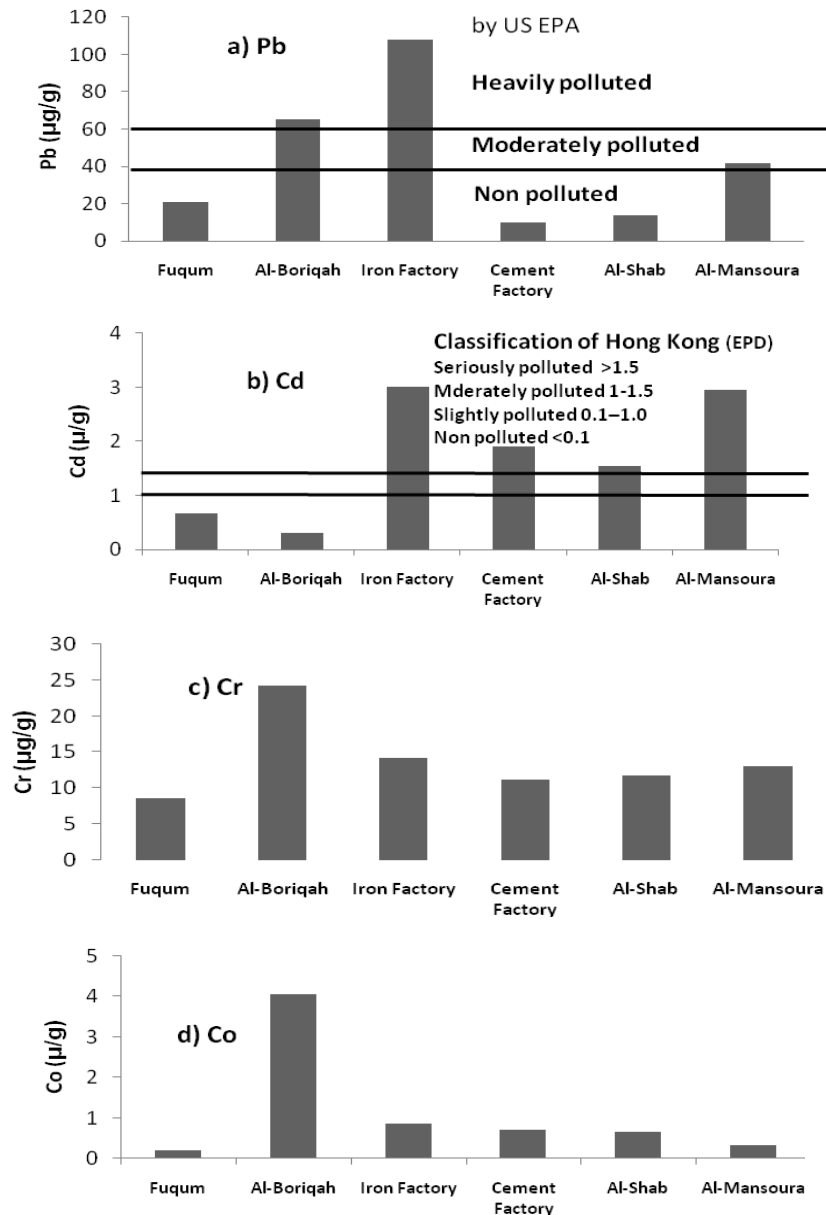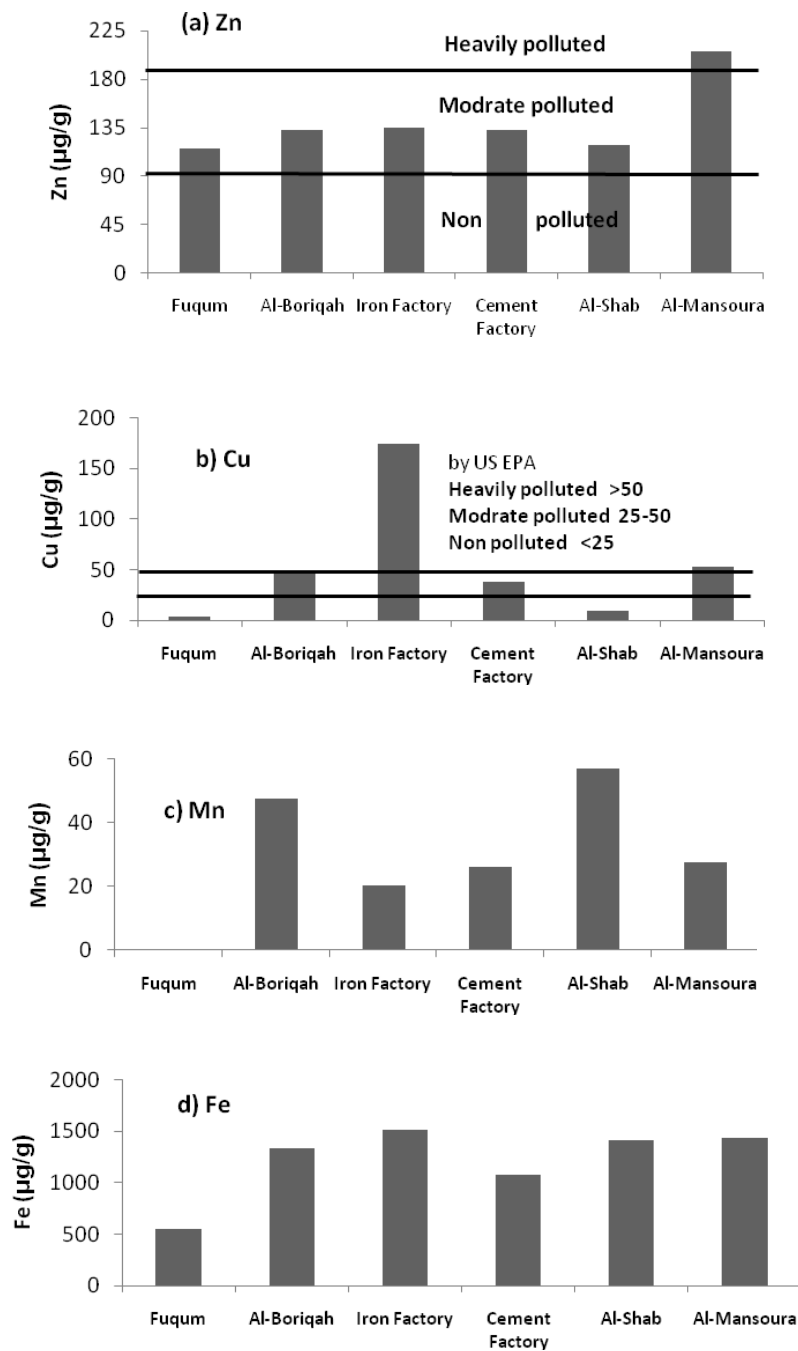Figure 1: Sampling locations of the study area

Figure 2: pH value and Electrical Conductivity (EC) in the study area

Figures (3a-3d): The concentration levels of Cd, Pb, Cr and Co in deposited dust of the industrial area and some streets in Aden City

Figures (4a-4d): The concentration levels of Zn, Cu, Mn and Fe in deposited dust of the industrial area and some streets in Aden City
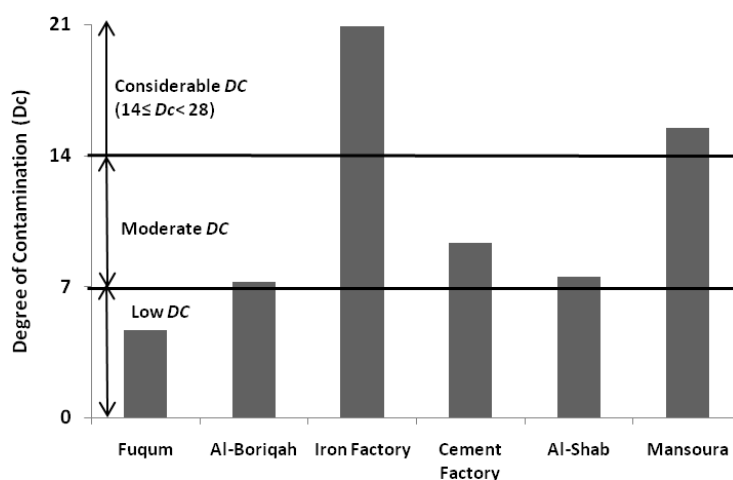
Figure 5. Degree of Contamination (*DC*) of heavy metals in deposited dust of the industrial area and some streets in Aden City
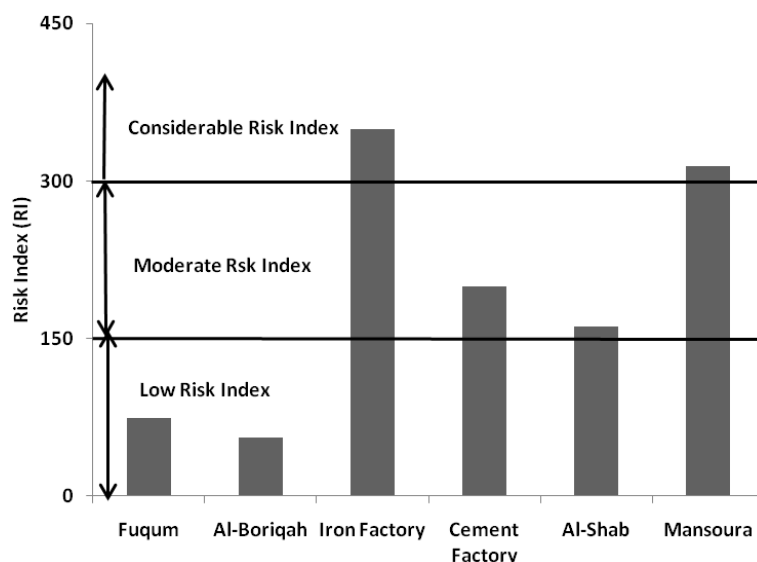
Figure 6. Evaluation on Potential Risk Index (*IR*) of heavy metals pollution in deposited dust of the industrial area and some streets in Aden City

Table 1. Description of study area

Name of site	Site description
Fuqum Village	Low traffic, Fishermen's area, rural area
Al-Boriqah City	Medium Traffic, Aden Refinery, Oil Harbor, small power station, commercial, residential area, recreational center
Industrial area	Iron Factory, Cement Factory, Plastic Factory, Food Factory and road construction sites
Al-Shab and Al-Hasswa	Educational institutions, semi-urban commercial areas, recreational, commercial, Repair of roads, Construction of towns, Electro thermal station, Agricultural area
Al-Mansoura City	Heavy traffic, commercial, residential area, high population, urban road dust, and road construction sites, oil lubricants, industrial and incinerator emissions

Table 2. Comparison of heavy metal concentration in dust from some popular cities of the world with data from the deposited dust of the industrial area and some streets in Aden –Yemen

City	Pb	Zn	Fe	Cu	Mn	Co	Cr	Cd	Ref.
Aden City (Yemen) (Min, Max., Average)	10.04-107.93 / 43.29	115-205.17 / 139.74	550.5-1521 / 1,221.2	3.5-174.3 / 53.95	0.13-57.03 / 29.92	0.20-4.04 / 1.13	8.60-24.32 / 13.89	0.31-3.01 / 1.73	Present study
Aden Coasts (Yemen)	28.15	54.7	2772.7	15.8	214.85	16.2	24.87	1.6	[47]
Aden Coasts	ND-1350	62.3-381	285-1205	11-120.6	548-2250	18.4-42.4	135-389	0.93-3.3	[3]
Aden Coasts	77.28	128.6	2577.8	19.89	350.5	23.97	82.19	-	[48]
Nigeria	0.001-0.033	1.58-3.68	19.54 -23.98	0.35-2.16	-	-	-	0.001-0.003	[41]
Jeddah (KSA)	53-105.76	214-340.8	7678.8	-	389.7-514	-	40.1-72.93	1.32-2.24	[31]
Ghana	22.89	133.52	-	60.53	564.42	-	744.02	-	[61]
Hong Kong	120.0	3840.0	-	110.0	594.0	-	-	-	[63]
China	64.9	89.5	-	29.4	572.1	60.2	189.6	-	[12]
Amman (Jordan)	270.5	350.7	-	139.4	-	32.4	29.2	1.87	[6]
Islamabad (Turkey)	104.0	116.0	-	52.0	-	-		5	[22]
Massachusetts (USA)	73	240	28,091	105	456	-	95	-	[21]
Kavala (Greece)	301.00	272.2	-	124.00	-	-	196.00	0.20	[13]
Bahrain	742.00	67.00		-	-	-	9.60	1.50	[39]
Lulea (Sweden)	34.00	60.00	-	24.00	-	-	13.00	0.10	[29]
Kayseri (Turkey)	74.80	112.00	-	36.90	-	-	29.00	2.53	[58]
Nicosia (Cyprus)	8.8-42.6	61.0-326.7	-	35.9-137.8	-	1.4-14.9	239.4-457.3	-	[32]
Ottawa (Canada)	39.1	112.5	-	65.8	431.5	-	-	-	[44]
Navi Mumbai (India)	152.91	938.80	119.53	136.54	-	-	-	0.0201	[7]
Shanghai	294.9	733.8	-	196.8	-	-	159.3	-	[53]

Table 3. Average value obtained in present study in comparisons with maximum allowed levels for different countries and WHO in µg/g

Metal	Austria	Canada	Poland	Japan	UK	Germany	USA	WHO	**Present Study**
Cd	5.00	8.00	3.00	-	3.00	-	0.70	3	**3.01**
Cu	100	100	100	125	50	100	500	50	**174,3**
Pb	100	200	100	400	100	500	200	100	**107.93**
Zn	300	400	300	250	300	300	300	300	205.17
Mn	-	-	-	-	-	-	-	1000	57.03
Cr	-	-	-	-	-	-	-	100	24.32

Table 4. Enrichment Factors *(EF)* in deposited dust of Aden city, Yemen

Sample sites	**Pb**	**Zn**	Cu	Mn	Co	Cr	**Cd**
Fuqum village	**88.02**	**103.35**	6.66	0.01	0.90	8.16	**190.66**
Al-Boriqah City	**114.96**	**49.25**	35.67	1.98	**7.48**	**9.51**	**36.37**
Iron Factory	**166.77**	**43.80**	117.97	0.75	1.42	4.90	**310.06**
Cement Factory	**21.94**	**61.01**	37.11	1.36	1.63	5.46	**278.22**

Al-Shab City	**23.25**	**41.40**	6.52	2.24	1.14	4.38	**172.21**
Al-Mansoura City	**68.56**	**70.73**	38.80	1.06	0.55	4.74	**322.02**
Average	**80.58**	**61.59**	40.49	1.23	2.19	6.19	**218.26**

Table 5: Contamination Factor (*CF)* and Degree of Contamination (*DC*) of heavy metal for study area

Sample sites	Contamination Factor (*CF*)							*DC = Σ CF*
	Pb	**Zn**	**Cu**	Mn	Co	Cr	**Cd**	
Fuqum village	1.03	1.21	0.08	0.0002	0.01	0.10	**2.23**	4.66
Al-Boriqah City	**3.27**	1.40	1.01	0.06	0.21	0.27	**1.03**	7.25
Iron Factory	**5.40**	1.42	3.82	0.02	0.05	0.16	**10.03**	20.9
Cement Factory	0.50	1.40	0.85	0.03	0.04	0.13	**6.37**	9.32
Al-Shab	0.70	1.24	0.20	0.07	0.03	0.13	**5.17**	7.54
Al-Mansoura	2.09	2.16	1.18	0.03	0.02	0.14	**9.83**	15.45
Average	**2.17**	**1.47**	**1.19**	0.04	0.06	0.16	**5.78**	10.85

Table 6: The potential ecological risk index of some heavy metals in the sampling sites

Sample sites	**Er-Cd**	Er-Cr	Er-Co	Er-Mn	Er-Cu	Er-Zn	**Er-Pb**	**IR**
Fuqum village	66.9	0.20	0.05	0.0002	0.40	1.21	5.15	73.91
Al-Boriqah City	30.9	0.54	1.05	0.06	5.05	1.40	16.35	55.35
Iron Factory	**300.9**	0.32	0.25	0.02	19.10	1.42	27.0	**349.01**
Cement Factory	**191.1**	0.26	0.20	0.03	4.25	1.40	2.50	**199.74**
Al-Shab	**155.1**	0.26	0.15	0.07	1.00	1.24	3.50	**161.32**
Al-Mansoura	**294.9**	0.28	0.10	0.03	5.90	2.16	10.45	**313.82**
Average	**173.30**	0.31	0.30	0.04	5.95	1.47	10.83	**192.19**

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تقييم التلوث المعدني للغبار المترسب في المنطقة الصناعية وبعض الشوارع في مدينة عدن، اليمن

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الملخص

تهدف الدراسة إلى تقييم التلوث ببعض العناصر الثقيلة في الغبار المترسب على المنطقة الصناعية وبعض شوارع مدينة عدن لما لهذه العناصر من مخاطر على النظام الحيوي وصحة الإنسان، وذلك من خلال دراسة المصادر المحتملة لتلك العناصر. حيث تم جمع عينات الغبار من خمس مناطق مختلفة تشمل: الصناعية، الطرق السريعة، السكنية، سكنية-صناعية، والبعيدة من مصادر التلوث في مدينة عدن، اليمن. تم تحليل وقياس المحتوى المعدني للعناصر الكادميوم -الرصاص -النحاس -الزنك -الكوبالت -الكروم -المنجنيز والحديد في الغبار باستخدام جهاز طيف الامتصاص الذري. أوضحت الدراسة أن أعلى تركيز للكادميوم والرصاص وجد في أتربة المناطق الصناعية والسكنية. تم تقييم مستوى التلوث في الغبار المترسب بعدة طرق: معامل الإثراء (EF)، عامل التلوث، درجة التلوث، عامل المخاطر الايكولوجية، ومؤشر المخاطر الايكولوجية المحتملة. أظهرت نتائج التقييم أن أعلى قيم لمعامل الإثراء (EF) كانت لعناصر الكادميوم، الرصاص والزنك ويعود مصدرها صناعي، بينما بينت نتائج تقييم التلوث (CF) إن عينات الغبار ملوثة بالكادميوم والرصاص. ومن خلال نتائج حساب عامل المخاطر الايكولوجية (Er) يتضح بأن قيم الكادميوم تتوزع من مستوى منخفض إلى عالي الخطورة، بينما تمثل العناصر الرصاص، الكروم، النحاس، الكوبالت، والزنك مستوى خطورة أقل. وقد أظهرت نتائج التقييم باستخدام معيار تقييم درجة التلوث (DC) ومؤشر الخطورة الايكولوجية المحتملة (RI) بان معظم مناطق الدراسة تصنف من مناطق معتدلة التلوث إلى مناطق مرتفعة التلوث. ويرجع مصدر التلوث كما تشير الدراسة إلى عاملين وهي مصادر صناعية تشمل المخلفات الصناعية وحركة المرور، ومصادر طبيعية ناتجة من أعمال البناء وشق الطرق التي تحدث في تلك المناطق.

الكلمات المفتاحية: التلوث المعدني، درجة الحموضة، الغبار الحضري، الغبار المترسب بجانب الطرق، دليل الخطورة الايكولوجية.