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Characterization of Street Dust Nearby the Holy Mosques in Ramadan and Hajj Seasons, Saudi Arabia

Abdel Hameed A. A [a], Ibrahim Y. H [a], Said Mounir [b], Habeeballah T [b], Elmorsy T. H [c]

[a] *Department of Air Pollution, National Research Centre, Dokki, Giza, Egypt*
[b] *Department of Environmental and Health Research, The Custodian of the Two Holly Mosques Institute for Hajj and Umrah Research, Umm Al Qura University, Saudi Arabia*
[c] *Department of Microbiology, National Organization for Drug Control and Research, Dokki, Giza, Egypt*

Abstract

Street dust is estimated as a main contributor of particualte matter (PM). Resuspension of street dust affects air quality and human health.The present study aims to evaluate concentrations of heavy metals (iron-Fe, lead-Pb, cadmium-Cd, and nickel-Ni), cations (Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}), anions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, $PO_4^{3-}$and SO_4^{2-}) and microoganisms (bacteria and fungi) associated dust particles ≤ 45µm.The dust samples were collected by sweeping an arera~1m^2 along both sides of the major streets surrounding Al-Haram mosque, in Makkah, and the Prophet's mosque in Al Madina Al Manwarrah, Saudi Arabia. The heavy metals and soluble ions were analysed using atomic absorption spectrometerand ion chromatograpgy, respectively. Nutrient agar and Malt extract agar media were used for counting bacteria and fungi associated dust, respectively. The dust size fraction of 1.7 µm constitued the highest percentage (10-25%) among various particles sizes ≤45 µm. Fe was found in the highest heavy metal concentration,and lead (Pb) achived high pollution index ≥3. The soluble ion profile (%) was: NO_3^-, SO_4^{2-}, Na^+,Ca^{2+}, Cl^-, NO_2^-, K^+, F^-, Mg^{2+}, NH^{4+}, Br^-, PO_4^{3-} and Li^+. The demolition/constrcution activities were main contributor of street dust. Bacterial and fungal concentrations ranged between 10^4-10^6 and 10^4-10^5 CFU/g, respectively, with the highest bio-pollution in the northern street dust at Al-Haram mosque. *Bacillus and Aspergillus* were the common bacterial and fungal genera, respectively. Microorganisms did not show any significant linear relationships with dust chemical composition. Characterization of street dust allows identifying its sources and consequently developing an appropriate abatement strategy.

Keywords: street dust; size fraction; heavy metal; microorganisms; pollution index

1. Introduction

Anthropogenic and natural sources are main sources of street/road dust (Ferreira-Baptista and DeMiguel, 2005; Hjortenkrans *et al*., 2006). Uncontrolled urbanization activities increase street dust loads with various particle size fractions and contaminants (Victoria *et al*., 2014). Paved and unpaved streets/roads, construction and demolition activities are the largest contributors of the street dust (EEA, 2004; Amato *et al*., 2009). Atmospheric aerosols and displaced soil are deposited in the streets (Yu *et al*., 2006). Traffic sector is considered a major contributor of heavy metal emission and dust particles ≤10 µm (Schauer *et al*.,2006; Pant and Harrison, 2013). Street dust is considered a sink/or carrier of chemical and microbial pollutants.Street dust not stays longer in the ground and resuspends into the air under the influence of human activities and wind action (Amato *et al*., 2009). Rain fall, water vapor, flushing and sweeping reduce the occurrence of street dust (Yu *et al*., 2006; Amato *et al*., 2010). Resuspension of street dust affects air quality and increases exposure to PM and its contents (Schauer *et al*.,2006). Exposure to street dust has been associated with adverse health effects (Lin *et al*., 2002; HEI *et al*., 2012).These effects are related to toxicity of dust-contents such as heavy metals (Lippmann and Chen, 2009), mineral compounds (Fanning *et al*., 2007;Schlesinger, 2006), and microorganisms (Lighthart, 1997; Alghamdi *et al*., 2014). Street dust has not been adequately characterized in the arid region despite its adverse effects on environment and human health. This study aims to characterize size fraction distribution of street dust particles ≤ 45 µm, and to determine the concentrations of some heavy metals (Fe, Pb, Cd, and Ni), cations (Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+}), anions (F^-, Cl^-, Br^-,NO_2^-, NO_3^-, PO_4^{3-} and SO_4^{2-}), and microoganisms (bacteria and fungi) associated dust particles ≤ 45µm, in the major streets near by the holy mosques, in Makkah and Al-Madina Al-Manwarrah cities, Saudi Arabia.

2. Materials and Methods

2.1. Study area

Makkah, the holy city, contains Al-Haram mosque, is located at an altitude of 277 m, 21°29' N 39°45' E, and ~ 80 km in land from the Red Sea, with a population of ~ 2 million. However, Al-Madina Al-Munawwarah, the second holy city, contains the Prophet's mosque, is located at 340 km north of Makkah, and ~ 190 km from the Red Sea coast, 24°28N 39°36E, and it has a population of ~ 1.3 million. Makkah and Al-Madīnah Al Munawwarah cities are surrounded by mountains and hills, and the topography makes most of building/housing in the valley surrounding the holy mosques. The two cities are full of cultures, customs, and very busy along over the year due to their religious importance in the Muslim world. The regions around the holy mosques comprise the old cities, which are characterized by heavy traffic, many parking and hotels, no predominant plant cover, and heavy urban works "construction/demolition".

The dust samples were collected from the major streets around Al-Haram mosque, Makkah (Fig.1) and the Prophet's mosque, Al-Madīnah Al Munawwarah (Fig.2). During sampling temperature and relative humidity ranged between 32-44°C and 30 - 63%, respectively, higher temperature and relative humidity shifted towards Makkah city. The wind speed ranged between 0.5 to 2 m/s, with north to east was the prevailing wind direction.

2.2. Dust sampling

The dust samples were collected during two sampling campaigns, extended over Ramadan and Hajj seasons, in the dry period, in 2014. One sample was collected at each street direction surrounds the holy mosques per season (2 samples per direction), a total of 16 samples were collected.

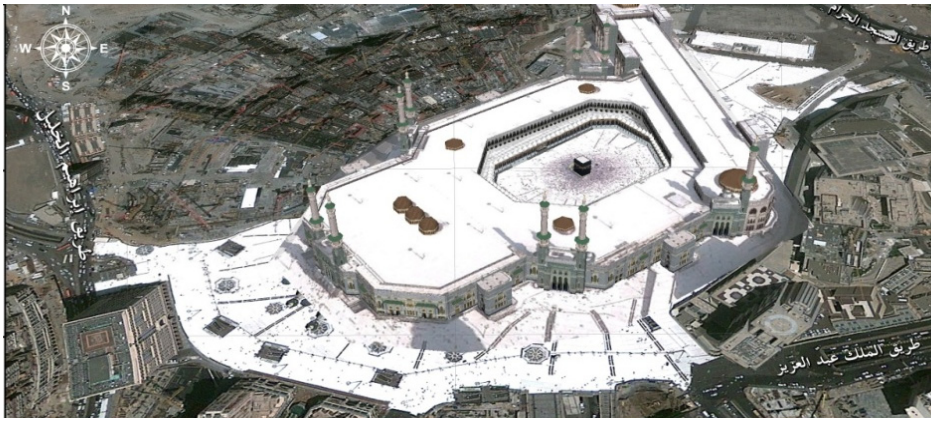

Figure 1. Map of the Al-Haram mosque in Makkah and the surrounding streets

Figure 2. Map of the Prophet's mosque in Al-Madīnah al-Munawwarah and the surrounding streets

The dust sample was collected from both sides of each street by sweeping sediments of an area of 1 m^2 using a brush, and this process was repeated at every 50 m along the street length. At each sampling location ~ 0.5-1 kg of dust was collected in a clean plastic bag. The dust samples were thoroughly mixed, dried at room temperature, and sieved using a sieve with a pore diameter ≤ 45 μm to remove particle size fractions ≥45 μm.

2.3. Dust size fraction distribution

The physical diameters of particles constituted street dust ≤45 μm were measured and counted. Dust ≤ 45 μm was spread onto a clean slide, and a minimum of 50-100 microscopic fields were screened by light microscopy (X=400), (Olympus CX31, Japan) using ocular "May Graticule" (Giever, 1976). May Graticule consists of a series of lines and circles of graduated size set on a glass disc. The aerodynamic diameter is calculated from the density (1g/m^3), shape (hypothetical sphere) and physical diameter (Hinds, 1999). The constituent percentage of each size fraction is determined in refereeing to the all sizes of the counted particles.

2.4. Chemical analysis

2.4.1. Heavy metals

Two series, 0.2 gram, from each dustsample ≤45 μm were weighed and dissolved in 60 milliliter of sterilized distilled water and shaken well for 30-60 min. One third (1/3), 20 ml, of the original suspension was acid digested (HF, HNO_3, $HClO_4$), (Querol *et al*., 2001), and the heavy metals (Fe, Pb, Cd, and Ni) were analyzed using atomic absorption spectrometer (AAS 3300 Perkin Elmer, at the Central Laboratories, National Research Centre, Egypt).

2.4.2. Ions profile

Another third, 20 ml, of the original suspension was used to determine some soluble ions, cations: Li^+, Na^+, NH_4^+, K^+, Mg^{2+}, and Ca^{2+} and anions: F^-, Cl^-,Br^-, NO_2^-, NO_3^-, PO_4^{3-} and SO_4^{2-}concentrations using ion chromatography (Dionex-ICS-1100, USA). The concentrations of heavy metals, and soluble ions were expressed as microgram per gram of dust (μg/g).

2.5. Microorganisms associated dust

The last third, 20 ml, of the original suspension was used to determine the concentrations of bacteria and fungi associated dust. Aliquots, 0.5 ml, of the original sample and its serial dilutions up to 10^{-3} were spread-plated, in duplicate, onto the surface of nutrient agar supplemented with 50 ppm cycloheximide, and 3% malt extract agar supplemented with 50 ppm chloramphenicol (BD, Sparks, USA) for counting of bacteria and fungi, respectively.

Fungal plates were incubated at 28 °C for 5-7 days and bacterial plates at 37 °C for 48 hrs. The growing colonies were counted, the mean count was calculated, and the concentration was expressed as colony for mingunits per gram of dust (CFU/g).

Fungal isolates were purified and identified by direct observation on the basis of micro- and macro morphological features, reverse and surface coloration of colonies on different media (Raper and Fennell, 1973; Klich, 2002; Barnett and Hunter, 1999).Three to five bacterial isolates were identified using Gram stain, oxidation fermentation, oxidase and catalase tests described in the Bergey's Manual of Systematic Bacteriology (Sneath *et al*., 2000).

2.6. Pollution index (PI)

Pollution index is used to evaluate the extent of contamination of heavy metals, Fe, Pb, Cd, and Ni associated street dust (Rastmanesh *et al*., 2010).

$$PI = Cn / Bn$$

Where *PI* is the pollution index of the heavy metal, Cn is the concentration of heavy metal in street dust sample and Bn is the background concentration (Taylor and McLennan, 1985). The level of pollution was classified into 3 classes as the following:

PI≤1 = low level of pollution.
PI≤3 > 1 = moderate pollution level.
PI≥3 = high level of pollution.

2.7. Statistical analysis

The differences between chemical and microbial concentrations at the different sampling points were analyzed by using Mann Whitney-U-test. Regression analysis was performed to explain the change of the dependent variables (microorganisms) in relation to independent variables (heavy metals and soluble ions). Statistical analysis was performed using SPSS 18 (PASW Statistics 18). $P \leq 0.05$ was considered as significant. Log-transformation is used to normalize the concentration data (Snedecor and Cochran, 1980).

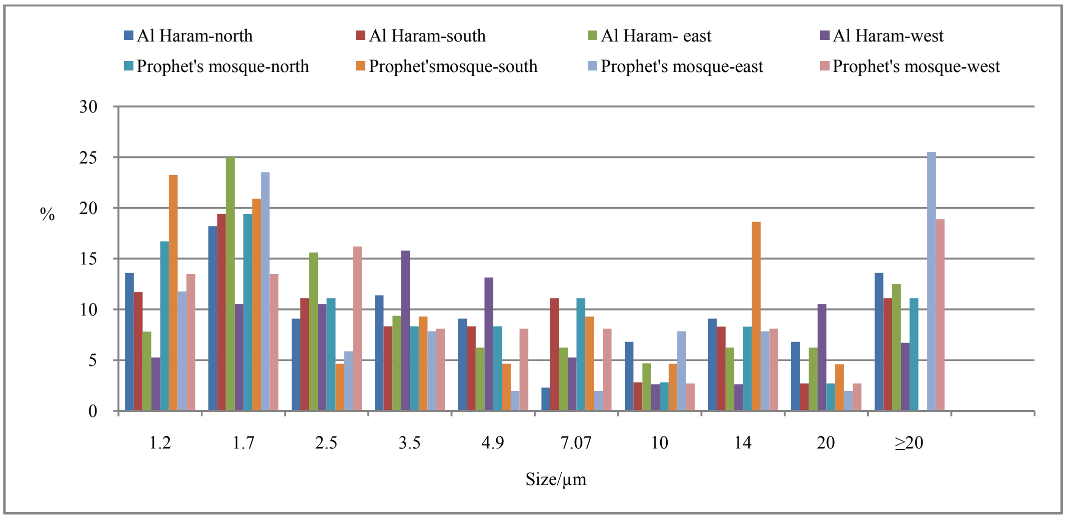

Figure 3. The percentages of different size fractions constituted street dust particles ≤45 µm

3. Results and Discussion

3.1. Size fraction distribution

The percentages of each size fraction constituted street dust particles ≤45 µm are shown in Fig.3. The size fraction distribution showed that fine particle (1.2 -10 µm) constituted the majority fraction of particles ≤45 µm. The size fraction of 1.7 µm constituted 10.5% - 25% of the total counted particle sizes, with the largest percentage in the eastern street at Al-Haram mosque, Makkah. The size fraction of 1.2 µm was found at the greatest percentage in the southern street at Al-Haram, Makkah (Fig.3). Street dust is generated from various sources (resuspension sources, vehicle emission, and human activities), thus particle sizes vary from fine to coarse fractions.The distribution of particle sizes not only provides information about sources of particles, but also plays an important role in determining settling site in respiratory system and regional lung dose (Vu *et al.*, 2015).

3.2. Heavy metal concentrations

Fig.4 shows the concentrations of heavy metals associated street dust. Fe (2680-4270 µg/g) was found in the largest concentration, in all samples. Fe is a natural content in soil and enriched in sites where traffic activity is high. Pb and Cd were detected in concentrations ranged between 40-200 µg/g and 1-9 µg/g, respectively. The highest Pb concentration was found in the southern street at Al-Haram mosque.

The variation of heavy metal concentrations is attributed to human activity, location, topography and geographical factors. Anthropogenic sources were contributors to Cd, Pb and Zn while both sources of human activities and natural origins were expected for Ni, Cr and Cu (Salmanzadeh *et al.*, 2015). Pb,Cd and Fe concentrations ranged between 40-179 µg/g; 1.61- 4 µg/g and 7796 - 14038 µg/g, respectively in Jeddah's street dust, Saudi Arabia (Khoder *et al.*, 2012). Pb and Cd averaged 208µg/g and 2.8 µg/g, respectively, in street dust in Riyadh (Ahmed and Al-Swaidan, 1993).

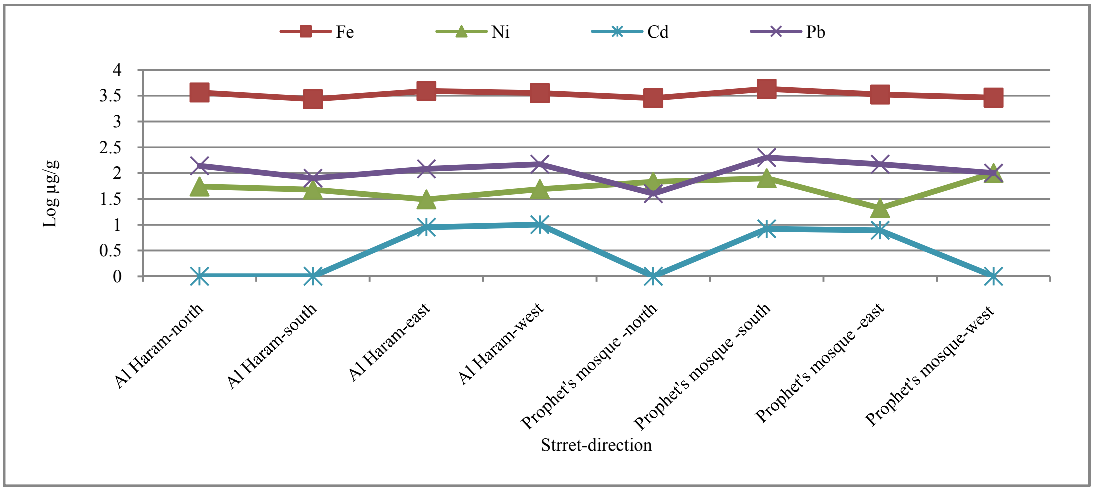

Figure 4. Log concentrations of heavy metals-associated street dust ≤45 µm

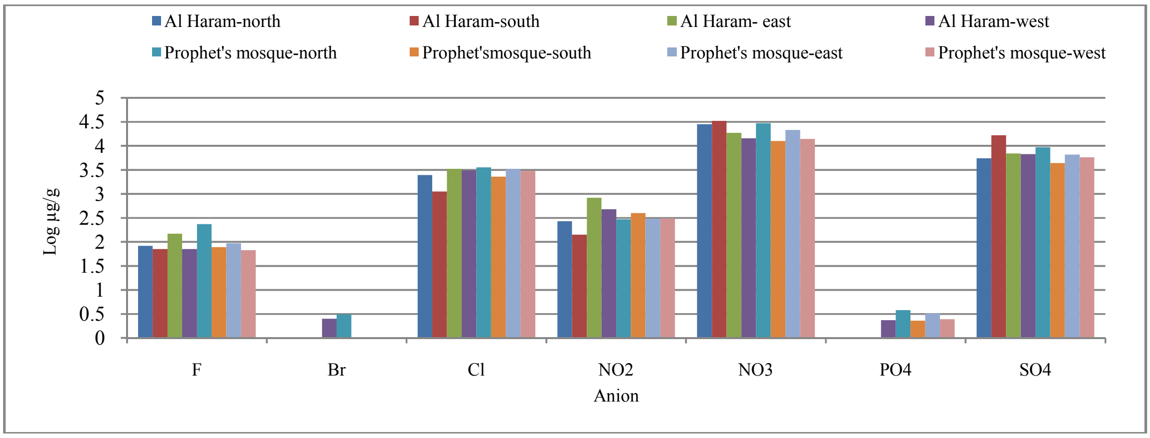

Figure 5. Log concentrations of anions-associated street dust

The highest Pb concentrations were found next to highways in Riyadh, Saudi Arabia (Al-Rajhi and Seaward, 1996) and Bahrain (Madany *et al.*, 1994). Pb and Ni averaged 408 µg/g and 49 µg/g, respectively in Beijing, China (Christoforidis and Stamatis, 2009), and Pb, Ni, Cd and Fe averaged 266 µg/g; 10 µg/g, 1.1 µg/g, and 11 572 µg/g, respectively in Angola (Ferreira-Baptista and DeMiguel, 2005).

3.3. Pollution index

Pollution index varied from low, moderate and high. Pb achieved high pollution index≥3 because it has longer half-life in soil. Paint fragments generated from demolition/construction activities near by the holy mosques was one contributor of Pb in street dust. Pb concentrations were found in soil in Hong Kong (Li *et al.*, 2004), and street dust in Saudi Arabia (Khoder *et al.*, 2010) despite it was phased out. Saudi Arabia phased out the leaded gasoline in 2001, allowable Pb concentration at 13 mg/l, which in high traffic location Pb may be still elevated (Khodier *et al.*, 2012).

Cd was also found in high pollution index≥3, only in the eastern and western streets at Al-Haram mosque, and the southern and eastern streets at the prophet's mosque, however Ni was found in a moderate pollution index PI≤3> 1 in the southern and western streets at the prophet's mosque.These streets may be most likely impacted by traffic emissions (vehicle exhaust particles, tire wear particles and brake lining wear). Resuspension of street dust represents a carrier of toxic heavy metals. Heavy metals chemically and physically interact with natural compounds in the environment and considered as a potential public health risk (Dube *et al.*, 2001; Shinggu *et al.*, 2007; Tchounwou *et al.*, 2012).

3.4. Soluble ions profile

The concentrations of anions and cations are presented in figures 5 and 6, respectively. The chemical composition highlighted the major constituents-associated street dust. The ions profile (%) was: NO_3^- (54.8%), SO_4^{2-}- (19.8%), Na^+ (7.96%), Ca^{2+} (7.90%), Cl^- (7.10%), NO_2^- (1%), K^+ (0.8%), F^-(0.26%), Mg^{2+} (0.16%), NH_4^+(0.07%), Br^-(0.05%), PO_4^{3-}(0.003%) and Li^+(0.0004%).

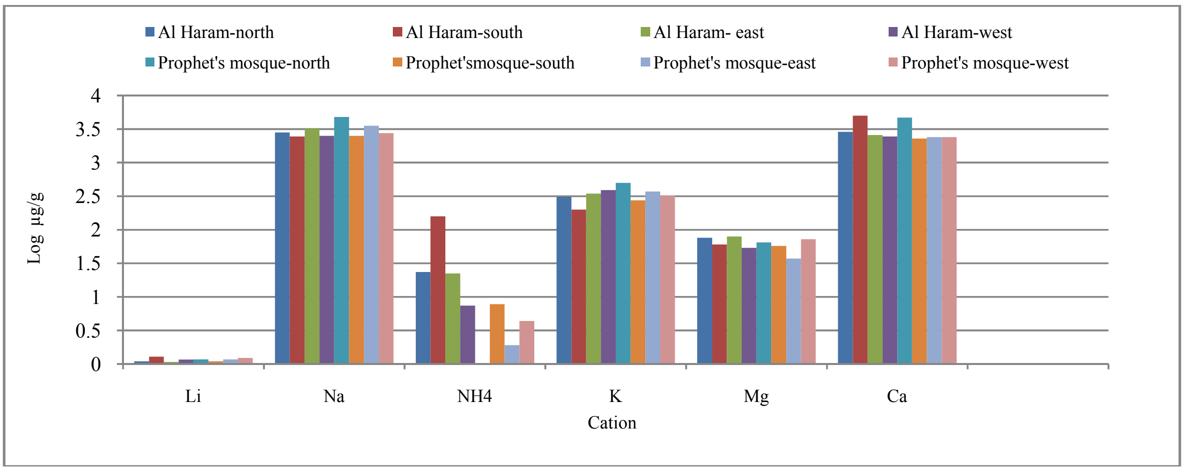

Figure 6. Log concentrations of anions-associated street dust

Non-significant differences *($P \geq 0.05$)* were found between the anion and cation constituents around the Al-Haram mosque and the Prophet's mosque. However, a significant difference *($P \leq 0.05$)* was found between PO_4^{3-} concentrations in dust, the higher concentration shifted towards Al-Madīnah al-Munawwarah.

NO_3^-(50.4%) and SO_4^{2-} (18.17%) were the highest contributions of street dust samples.This is attributed to fugitive mineral dust generated from demolition/ construction activities around the holy mosques. NO_3^- and SO_4^{2-} are related to combustion and coal activity (Demirak, 2007) and secondary atmospheric aerosols (Galindo *et al*., 2011). NH_4^+ was found in relatively low mass concentration due to volatilization of NH_4^+ compounds under the effect of higher temperature, and permanently removes biowastes accumulated near by the holy mosques.

Ca^{2+} is a crustal component and related with demolition-construction activities. The demolition/ construction and traffic emissionare main contributors of street dust nearby the holy mosques. K^+ is used as a tracer of biomass burning and meat cooking (Pachon *et al*., 2013). Moreover K^+, Ca^{2+}, Na^+ and Mg^{2+} are found in building materials, cement and gypsum (Xu *et al*., 2009).

3.5. Microorganisms-associated dust

The range and mean concentrations of bacteria and fungi associated street dust are shown in Table 1. Bacterial concentrations ranged between $7x10^4$- $1.9x10^6$ CFU/g, with the highest mean concentrations in the northern street at Al Haram mosque, and the lowest in the northern street at the Prophet's mosque. This is due to intensive construction and demolition activities in the northern side of Al-Haram, Makkah.

Significant differences were found between concentrations of bacteria in the northern street at Al-Haram mosque with those were found in the northern street at the Prophet's mosque *($p < 0.01$)* and the southern street at Al-Haram mosque *($p < 0.05$)*.

Fungi ranged between 0.0 - $6X10^5$CFU/g with the highest concentration at the eastern side of the Prophet mosque, and the lowest at the southern street of the holy mosque. Significant difference was found *($p < 0.05$)* between fungal concentration associated dust in the eastern street of Al-Haram mosque and its counterpart associated dust in the eastern street at the Prophet mosque.

Table 2 shows the percentages of identified fungi and bacteria isolates associated street dusts. Identification of microorganisms helps identifying health problems and reduces risks resulting from microbial exposures. *Aspergillus fumigatus* and *Bacillus*, respectively were the common fungal and bacterial types associated street dust. *Bacillus* bacteria are linked to dust and with stand harsh conditions; however *Aspergillus fumigatus* is a thermo-tolerant fungus and has ability to grow in various substrata in all regions under different weather conditions (Alghamdi *et al*., 2014).The gram positive cocci are linked to human beings and their execrations.

In the present study, *Pseudomonas*-Gram negative bacteria (Gamma Proteobacteria) was only detected in the southern street at Al-Haram mosque. The detection of *Pseudomonas* is an indicator of the presence of stagnant water (ablution points) and sprinklers. *Pseudomonas* is always found in a biofilm attached to various surfaces, need initial food, and resistant to salts and dyes. Gram negative bacteria were found in low counts as a result of their sensitivity to climate, chemical pollutants, and nature of its cell wall composition (Cox and Wathes, 1995).

The low microbial diversity is attributed to severe weather conditions, arid environment, and geographical characteristics. Fungi were found in low counts in hot weather conditions (Fröhlich-Nowoisky *et al*., 2012). The chemical constituents may have negative impact on survivability of microorganisms, as a result of their interactions with cell wall components (Handley and Webster, 1995; Abdel Hameed *et al*., 2012).

Table 1. The range and mean concentrations of bacteria and fungi associated street dust

Street/ Direction	Bacteria -CFU/gx10^5		Fungi- CFU/g x10^4	
	Al-Haram mosque	Prophet mosque	Al-Haram mosque	Prophet mosque
North	14.5±2.7	0.73±0.09	9.1±6.7	10.8±4.5
South	1.33±0.5	5.04±1.15	6.6±7.4	17.5±20.5
East	11.5±2.7	5.32±3.2	7.5±2.5	30±8.1
West	10.8±3.9	10.23±4.5	10±6.4	18.3±8.1

Table 2. The percentages of the identified bacteria and fungi associated street dust

	Al-Haram mosque		Prophet's mosque	
	No*	%	No	%
Bacteria				
Bacillus	51	54.8	48	51
Diplococci	13	13.97	19	20.2
Sarcina	17	18.3	15	16
Staphylococci	9	9.7	12	12.8
Pseudomonas	3	3.2	-	-
Total counts	93	100	94	100
Fungi				
Aspergillus funmingatus	37	48.7	86	68.8
Asp. niger	7	9.2	9	7.2
Asp. flavus	4	5.2	5	4
Emericella nidulans	15	19.7	12	9.6
Eurotium	5	6.6	3	2.4
Rhizopus	-	-	3	2.4
Sterial hyphae	8	10.5	7	5.6
Total count	76	99.9	125	100

No*: number of microbial isolates

In the present study, fungal and bacterial counts did not show any significant linear relationships with any of the studied heavy metals and soluble ions. However, significant non-linear relationships were found between fungal counts and PO_4^{3-} *(P= 0.017)*, Ni *(P= 0.038)* and Mg^{2+} *(P= 0.027)*, and between bacterial counts and Ca^{2+} *(P= 0.007)*, NH_4^+ *(P= 0.041)* and Pb *(P= 0.017)*. The non-linear regression model proofs that chemical elements, individually/or aggregately, affect survivability of microorganisms associated dust at certain concentration point.

4. Conclusions

Street dust is a carrier of contaminants. The particle size fraction of 1.2-1.7 μm constituted the highest percentages among dust particles ≤45 μm.High percentages of NO_3^- and SO_4^{2-} indicated fugitive dust from construction/demolition activities. Lead was found in high pollution index ≥3 despite it was phased out from fuel sources. Construction/demolition activities were the main sources of street dust, with low contribution of vehicles related pollutants. The southern, eastern and western streets at the prophet's mosque and the eastern and western streets at the Al-Haram mosque were more impacted by vehicle emissions.Chemical composition of dust may increase/ or decrease microbial counts. The street dust is a contributor of heavy metalsand microbes. The contribution of street dust to particulate matter-air pollution should be studied in the future.

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Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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Correspondence to
Dr. Abdel Hameed A.A
Department of Air Pollution,
National Research Centre,
Dokki, Giza,
Egypt
E-mail: abed196498@yahoo.com