Spatial Variations of Atmospheric Particulate Matters in Makkah, Saudi Arabia

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Abstract: ***Growing air pollution is a major concern in many major cities in the developed or developing countries all over the world. The current study intends to monitor and map different sizes ofParticulate Matters (PM) during December 2013 fromfour locations (Shebeka, Azizaih, Masfalah, Awaly district) in Makkah city, Saudi Arabia. In addition to Total Suspended Partciles (TSP), this paper analyses the levels of PM_1, $PM_{2.5}$, PM_7, and PM_{10}, which are particulate matters with aerodynamic diameter of 1, 2.5, 7 and 10 micron, respectively. The data were collected using a portable device PM Dustmeter AEROCET-531, in which the measuring locations was determined using the global positioning system (GPS). Spatial and temporal variability of PM have been investigated and the levels of PM were compared with the air quality standards. High levels of PM were observed in Shebeka district, and low levels of PM were observed in Awaly district. PM_{10}concentrations did not exceeded the air quality standards set by the Presidency of Meteorology and Environment (PME) of Saudi Arabia, however the WHO limits were exceeded on several occasions. The coarse and medium size PM were the most dominant fractions of PM, where it reached to (93.5, 89.6, 87.7, and 93.7 %) for Shebeka, Azizaih, Masfalah, Awaly districts, respectively. Re-suspended dust is a major contributor to ambient particulate matter, especially in the coarse particle fraction.The temporal variation in PM concentrations are probably caused by meteorological parameters, especially wind speed and direction. This work shows that the need for further characterization of the fine and coarse particles over a longer period of time in the whole city of Makkah. Further work is also required on source apportionment and for the quantification of potentially detrimental components. Also the health relevance of PM concentrations during these episodes should be investigated further.***

Keywords: Makkah, PM_1, $PM_{2.5}$, PM_7, PM_{10}, TSP.

1. Introduction

In recent years, urban air quality has emerged an important environmental issue due to its increasing levels and potential impacts on human health, therefore, routine air quality monitoring and modelling has become an integral part of many national and international organizations. Particulate matter (PM) is an important component of air pollution, having both long-term as well as short-term effects on human health, such as cardiovascular, lung and skin diseases, which sometimes leads to premature death [1]. PM consists of carbon and mineral particles of different sizes, ranging in diameter from 0.001 to 100 µm. Smaller particles are more important in terms of their adverse impacts on human health. Fine particles enter deeper into the respiratory system where they are retained for a long time and cause various health problems. Air pollution caused by the PM is one of the major air quality issues due to the arid nature and presence of vast sand deserts in Saudi Arabia.

Various health effects attributable to PM have been documented [2, 3]. The most conclusive evidence has been provided by cohort and time series studies that have linked elevated concentrations of PM to increased morbidity and mortality [4-7]. The majority of these studies have assessed the health effects of particles expressed as the risk per unit mass/m^3 of PM_{10} or $PM_{2.5}$.The majority of recent health studies suggest that fine particles ($PM_{2.5}$) arising mainly from man-made sources are more harmful than coarse particles [8-11] and, therefore, the measurement of PM in health effect studies has currently focused on fine particulate matter ($PM_{2.5}$), rather than on coarse particles ($PM_{2.5-10}$). Several efforts have also been specifically aimed at studying concentrations and potential health effects of the so-called ultrafine particles in the size range below 0.1 µm [13-15].

PM_{10} concentrations is affected by various atmospheric parameters, such as wind speed and direction, relative humidity, temperature, and rainfall. The entering of pollutants from the ground surface, their residence in the atmosphere, and the formation of secondary pollutants is controlled not only by the rate of emission of the pollutants into the air from the sources, but also by wind speed, turbulence level, air temperature, and precipitation [16, 17]. Makkah is one of the busiest cities in the world and every year millions of people visit the city due to its religious importance. Respirable and fine particulate matter concentrationsare of special concern due to its direct effect on human health. The reasons for the high particulate matter concentrations in Makkah are most probably due to high volume of road traffic, construction work, resuspension of particles, windblown dust and sand particles, and geographical conditions (arid region) with hot temperature and low rainfall [18]. It is important to assess the levels of PM and its size distributions in Makkah to determine whether human health related air quality limits are exceeded. High population density plus large number of visitors further emphasize the need for clean air in Makkah, especially in the central area (Haram Mosque). This paper assesses the levels of PM and analyses its spatial and temporal variability from four locations (Shebeka, Azizaih, Masfalah, Awaly district) in Makkah cityduring December 2013.

2. Methodology

2.1 Study Area and Data Acquisition

Particulate matters (PM_1, $PM_{2.5}$, PM_7, PM_{10}, and TSP (Total Suspended Partciles)) data were collected from fourlocations (Shebeka, Azizaih, Masfalah, Awaly district)in Makkah city, Saudi Arabia (Fig. 1). Makkah is the most important cities in Saudi Arabia. It is distinctive in geographic characteristics from neighboring cities such as Taif and Jeddah city. Makkah city located in the west of the Kingdom of Saudi Arabia at latitude 19 " 25 '21 ° north, and longitude 46' '49' 39 ° to the east, on the lower slopes of the mountains Sarawat. It is rising from the sea by amount of 300 m and it is surrounded by mountains on all destinations, but there is easy ways westward reached by the city of Jeddah on the Red Sea, 75 km, a gate, sea and air from the south-east surrounded by the city of Taif above El-Hijazmountains 80 km to the north. Also, Makkah city is located approximately 400 km away from Madina city [18].

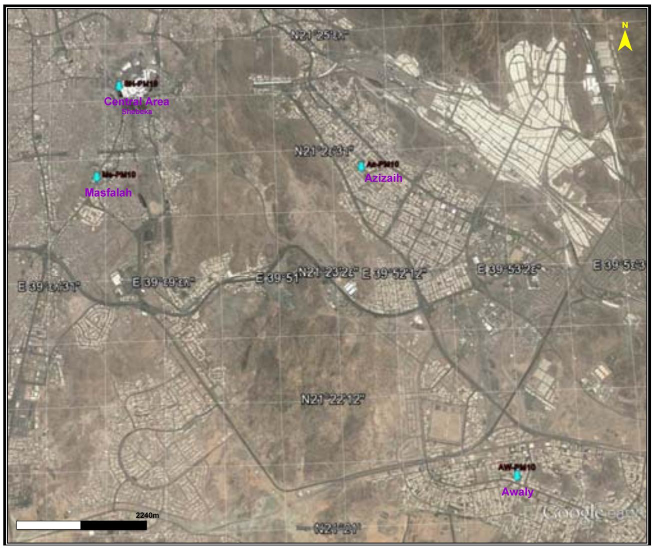
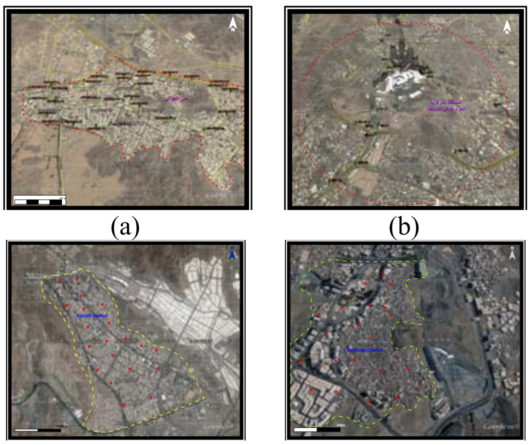


Figure 1: Four sampling locations with respect to Makkah city.

Samples were collectedduring December 2013, using handheld Dustmeter AEROCET-531 and the location of each point was determined using a hand-held GPS.The monitoring sites for each location are shown in Fig. 2 (a-d).



(a) (b)

(c) d)(

Figure 2: Sampling sites in location a) Awaly district; b) Central area (Shebeka district); c) Azizaih district; and d) Masfalah district.

Millions of people visit the Makkah city during Hajj and Ommraaseasondand as a result the Makkah city becomes very busy, particularly in terms of road traffic, which emit different types of chemicals including PM into the atmosphere. This paper intends to assess the levels of different size of PM during peak time and non-peak time.

3. Measuring Method

The AEROCET 531 (Fig. 3) is a combined mass profiler and particle counter in a small, handheld, battery operated, and completely portable unit.When used as a particle counter the AEROCET 531 provides visual real time countinformation in two channels on the LCD display. After one minute, the AEROCET 531displays the two most popular cumulative particle sizes: >0.5µm and >5.0 µm.When used as a Mass Profiler the AEROCET 531 provides a fast indication ofparticulate mass concentration per cubic meter of sampled air for the most commonlytested particle size fractions; PM_1, $PM_{2.5}$, PM_7, PM_{10} and TSP.The AEROCET 531 measurements can compare favorably with expensivereference methods. The AEROCET 531 uses the stored particle count data from eightdifferent particle size ranges and a proprietary algorithm to derive the massconcentration for the aerosol sample.The AEROCET 531 comes with an iso-kinetic probe that attaches to its inlet nozzle withthe short piece of Tygon tubing provided (Fig. 3).

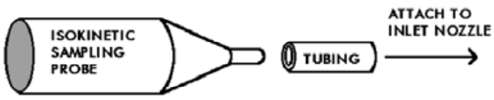


Figure 3: Mechanism of PM measuring device.

The iso-kinetic probe helps reduce count errors related to the sample flow velocity andthe aerodynamics of small particles. When taking a sample of typical indoor or outdoor aerosols the opening of the isokineticprobe should always face upward. The AEROCET 531 can be held in your handor placed on a flat surface with its display facing towards you. When sampling in an area that has a constant airflow, such as a clean room, duct, ventor the downstream side of a filter, always align the opening of the iso-kinetic probe tothe air movement.The length of the Tygon tubing going from the inlet of the AEROCET 531 to the isokineticprobe can be increased if necessary. However, longer lengths can burden thepump and slow the sample flow rate or cause premature pump failures. Also, countlosses, especially for larger particles, will increase. Met One Instruments recommendsto keep the tubing length as short as possible. The tubing length should never exceedfour feet.

Data acquisition and handling were carried out according to the study protocols. Raw data weremanually operated andsubsequently typed into computer files which were checked for possible errors and outliers. Datafrom computer controlled measurement device were recorded into raw data files that werechecked and combined to the final datasets, which were used in the statistical analyses. Fig. 4 shows PM monitoring instruments.

Figure 4: Monitoring PM instrument and its calibrator.

2.3 Mapping of PM

Contour line is an imaginary line joining points of equal value with a fixed contour lines having a specific contourinterval that can be represented by the vertical distance betweencontours. To construct the areal distribution of the measured PM data, a software package "Surfer" is utilized which can be described as a full-function 2/3D visualization, contouring and surface modeling package that runs under Microsoft Windows. Surfer is used extensively for terrain modeling, bathymetric modeling, landscape visualization, surface analysis, contour mapping, watershed and 3D surface mapping, gridding, volumetrics, and much more.

Surfer 12.4.784 (2014) is a software package written for Windows XP, Vista, and 7. Surfer transforms XYZ datato create 2Dcontour maps, 3D surface maps, 3D wireframe maps, shaded relief maps, rainbow color"image" maps, post maps, classed post maps, vector maps, and base maps.

After forming the data in XYZ format, and by using the default griddingmethod, which is ‘kriging’ with a linear variogram. This method was selected as the default because itdoes a good job of gridding a wide variety or data sets. However, this method doesn't always produce the desired results with every dataset, so it sometimes pays to consider the other gridding methods.

The krigingmethod uses trends in the map to extrapolate into areas of no data,sometimes resulting in minimum and maximum Z values in the grid that are beyondthe values in the data file. This could be acceptable in a structure map ortopography map, but not in an isopach map where the extrapolation producesnegative thickness values. After creating a grid file, the contour map is displayed and produced with the default settings.

The collected data sets are created on XYZ form on all areas of the Prophet's Mosque to show and demonstrate all the measured parameters of PM in a way of 2D contour maps in order to display the data in a smooth and easy manner to enable familiarity and to be clearly understood without confusion.After creating the contour maps for all measured parmeters for all days, the interpretation and explaination process become easier.

4. Results and Discussions

3.1 Mapping PM Concentrations

In this section the spatial variations of the different sizes of PM are analysed, Which was collected from four locations (Shebeka, Azizaih, Masfalah, Awaly districts) in Makkah city, Saudi Arabia. The contour maps of PM_1,$PM_{2.5}$,PM_7,PM_{10},and TSPfor various loctionsare presented in Fig. 5 (a-e), Fig. 6 (a-e), Fig. 7 (a- e), and Fig. 8 (a- e), respectively.

Figure (5-a), Showed that distribution contouring of two-dimensional for very fine PM diameter less than 1 µm (PM_1) in the central area (Shebeka district). Where PM_1 measured during December 2013 was ranged between 0-14 µg/m^3. It was increased in the northern and the central parts, but decreased in the western part of the central area (Shebeka district).

Figure (5-b), Showed that distribution contouring of two-dimensional for PM diameter less than 2.5 µm ($PM_{2.5}$) in the central area (Shebeka district). Where $PM_{2.5}$ measured during December2013 was ranged between 15-150 µg/m^3. It was increased in the northeastern, and west central partswhile decreased in the northern and eastern parts of the central area (Shebeka district).

Figure (5-c), Showed that distribution contouring of two-dimensional for PM diameter less than 7 µm (PM_7) in the central area (Shebeka district). Where PM_7 measured during December 2013 was ranged between 50-1000 µg/m^3. It was increased in the western part, and decreased in the northern part of the central area (Shebeka district).

Figure (5-d), Showed that distribution contouring of two-dimensional for PM diameter less than 10 µm (PM_{10}) in the central area (Shebeka district). Where PM_{10} measured during December 2013 was ranged between 150-1300 µg/m^3. It was increased in the central and western parts, and decreased in the northern, southwestern parts of the central area (Shebeka district).

Figure (5-e), Showed that distribution contouring of two-dimensional for PM diameter greater than 10 µm (TSP) in the central area (Shebeka district). Where TSP measured during December 2013 was ranged between 200-1900 µg/m^3. It was increased in the western part, central part, and decreased in the northern part of the central area (Shebeka district).

Contour maps show that generally,major PM concerntrations are higher in the the western and central parts and show lower concentration in the northern part. It should be noted that high concentrations of PM in various sizes may be attributed to the intensity of the current construction operations and urban development in the central area.

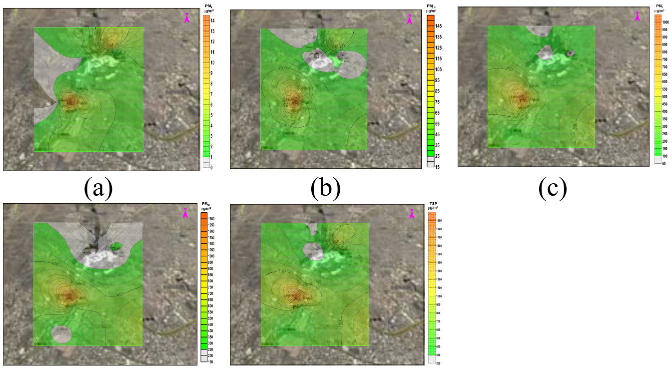


Figure 5: Contour maps of Central area (Shebeka district) for: (a) PM_1; (b) $PM_{2.5}$; (c) PM_7; (d) PM_{10}; and (e) TSP.

Figure (6-a), Showed that distribution contouring of two-dimensional for very fine PM diameter less than 1 µm (PM_1) in Azizaih district. Where PM_1 measured during December 2013 was ranged between 2-6 µg/m^3. It was increased in the west-northern, the eastern, and the southern parts, but decreased in the east-northern part of Azizaih district.Figure (6-b), Showed that distribution contouring of two-dimensional for fine PM diameter less than 2.5 µm ($PM_{2.5}$) in the Azizaih district, which ranged between 31-54 µg/m^3. Figure (6-c), Showed that distribution contouring of two-dimensional for very fine PM diameter less than 7 µm (PM_7) in the Azizaih district, that ranged between 93-162 µg/m^3. Figure (6-d), Showed also the contouring of two-dimensional for PM_{10} diameter less than 10 µm (PM_{10}) in the Azizaih district, where PM_{10}concentratiosnranged between 155-270 µg/m^3. Finally, figure (6-e), Showed the distribution contouring of two-dimensional for total suspended particulates (TSP) in the Azizaih district, where measured TSP concentratiosnranged between 295-513 µg/m^3. It is clearly for all the previously mentioned contour maps, the PM concentrations for all measured different sizes increased in the west to south passing with the central parts, but decreased in the eastern and northeastern parts of Azizaih district that corresponding completely to the general track of main street on Azizaih.

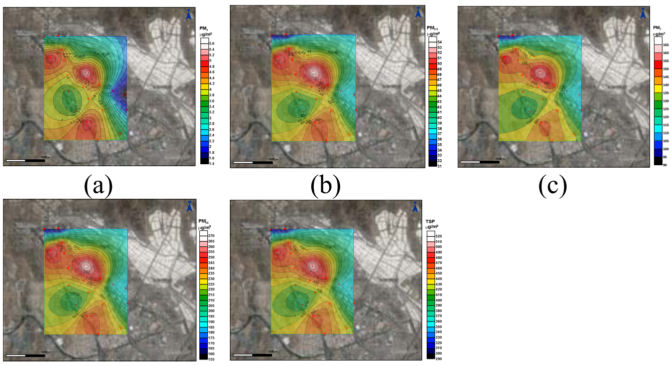


Figure 6: Contour maps of Azizaih district for: (a) PM_1; (b) $PM_{2.5}$; (c) PM_7; (d) PM_{10}; and (e) TSP.

Figure (7-a), Showed that distribution contouring of two-dimensional for very fine PM diameter less than 1 µm (PM_1) in Masfalah district. Where PM_1 measured during December 2013 was ranged between 3-5 µg/m^3.Figure (7-b), Showed that distribution contouring of two-dimensional for fine PM diameter less than 2.5 µm ($PM_{2.5}$) in the Masfalah district, Where $PM_{2.5}$concentrations ranged between 28-46 µg/m^3. Figure (7-c), Showed that distribution contouring of two-dimensional for PM diameter less than 7 µm (PM_7) in the Masfalah district, inwhich PM_7cocnentrationsranged between 71-115 µg/m^3. Figure (7-d), Showed that distribution contouring of two-dimensional for PM diameter less than 10 µm (PM_{10}) in the Masfalah district that ranged between 141-229 µg/m^3. Figure (7-e), Showed that distribution contouring of two-dimensional for total suspended particulates (TSP) in the Masfalah district, which ranged between 226-366 µg/m^3.

It is clearly that all the previously mentioned contour maps, the PM concentrations for all measured different sizes had the same trend which increased in the east-northern, and the eastern parts, but decreased in the northwestern part of Masfalah district that corresponding completely to the most crowded residential areas of Masfalah district.

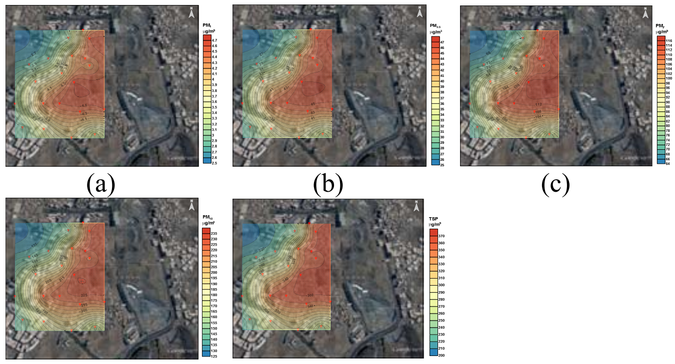


Figure 7: Contour maps of Masfalah district for: (a) PM_1; (b) $PM_{2.5}$; (c) PM_7; (d) PM_{10}; and (e) TSP.

Figure (8-a), Showed that distribution contouring of two-dimensional for very fine PM of diameter less than 1 µm (PM_1) in Awaly district. Where PM_1 measured during December 2013 was ranged between 0-3 µg/m^3. It was increased in the northern, the eastern, and the western parts, but decreased in the southern part of Awaly district, where figure (8-b), Showed that, $PM_{2.5}$ was ranged between 4-20 µg/m^3 which increased in the northern, the southern, and the western parts, but decreased in the eastern part of Awaly district during the same measuring period.

Figure (8-c), Showed that 2D contouring for PM_7 in Awaly district, in which ranged between 25-135 µg/m^3, where increased in the northern, and the western parts, but decreased in the eastern part of Awaly district during the same measuring period.Figure (8-d), Showed the distribution PM_{10} in Awaly district,where ranged between 30-200 µg/m^3 and increased in the southern, and the western parts, but decreased in the eastern and the northern parts during the same measuring period.

Finally, Figure (8-e), Showed the2D contouring TSP in Awaly district during December 2013, where ranged between 80-420 µg/m^3, and was increased in the west-southern part, but decreased in the northern part of Awaly district.

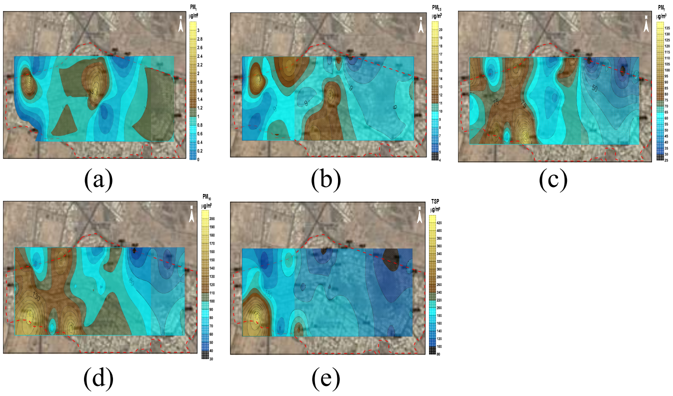


Figure 8: Contour maps of Awaly district for: (a) PM_1; (b) $PM_{2.5}$; (c) PM_7; (d) PM_{10}; and (e) TSP.

3.2 Particle Size Distribution

The acquired PM data were classified according to the particle size to determine the major fractions of PM. The PM_7 data are subtracted from PM_{10} data to determine the coarse fraction of PM (PM_{10}-PM_7); the $PM_{2.5}$ data are subtracted from PM_7 data to determine the medium fraction of PM (PM_7-$PM_{2.5}$); and the PM_1 data are subtractedfrom $PM_{2.5}$ data to determine the fine fraction of PM ($PM_{2.5}$-PM_1).PM_1 represent the finest fraction of PM. Mathematically it can be represented as:

$$TSP= \{(PM_{10}-PM_7) /TSP + (PM_7-PM_{2.5}) /TSP + (PM_{2.5}-PM_1) /TSP + PM_1/TSP\}$$

The pie diagram (Fig. 9 a-d) of the different fractions of PM for various locations showed that [TSP-PM_{10}] fractions were(40.3, 47.4, 37.5, and 38.6 %) for Shebeka, Azizaih, Masfalah, Awaly districts, respectively.[PM_{10}-PM_7] fractions were (21.0, 21.1, 31.3, and 20.9 %) for Shebeka, Azizaih, Masfalah, Awaly districts, respectively.[PM_7-$PM_{2.5}$] fractions were (32.2, 21.1, 18.9, and 34.2 %) for Shebeka, Azizaih, Masfalah, Awaly districts, respectively. The results of this study concluded that the coarse and medium size PM were the most dominant fractions of PM, whereit reached to (93.5, 89.6, 87.7, and 93.7 %)for Shebeka, Azizaih, Masfalah, Awaly districts, respectively from the total percent of TSP.These highly percentage of meduin and coarse size PM means thatre-suspendedand windblown dust-and-sand particles are the doimanant source in districts of Makkah city. Beside to traffic emissions and human activities during Omraah and Hajj seasons.

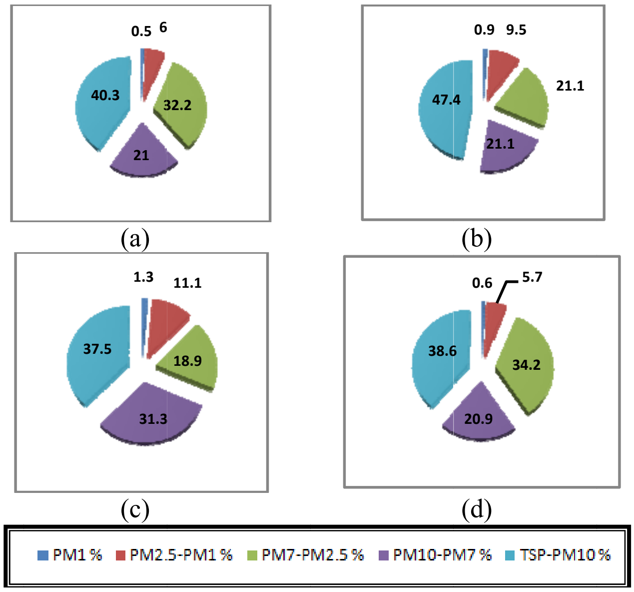


Figure 9: Volumetric Distribution of PM (<1 µm <2.5 µm <7 µm <10 µm<TSP µm) for differentLocations (a) Central area (Shebeka district); (b) Azizaih district; (c) Masfalah district; (d) Awaly district.

The term re-suspension is commonly used to include both suspension of newly generatedparticles and re-entrainment of previously deposited particles into the atmosphere. Re-suspension is a complex process that can be initiated by mechanical disturbancessuch as wind, traffic-induced turbulence and tyre stress, and construction activities. The windblowndust is often called 'natural dust' because of its origin from mostly non-urban areas thatare subject to suspension by the wind [19]. In non-arid urban environments, PM can be made available for resuspension in a variety of ways, includingapplication of traction sands or de-icing salts, track-out from construction sites and otherunpaved areas, vehicle exhaust, tyre and brake wear, oil leaks and spills from vehicles,wearing and maintenance of streets, and atmospheric deposition of anthropogenic PMemissions[20].

Re-suspended dust is a major contributor to ambient particulate matter, especially in the coarseparticle fraction. The current study, mentioned that PM_{10} varies from 21.0 % to 31.3 % which were lower than that found in Europe (the annual mineral dust load in PM_{10} varies from 13% to 37% resulting from heavily traffic rural background) [21, 22]. Also, was significantly lower compared to proportions found in some aridareas, for example in Arizona and Nevada, U.S.A., where fugitive dust sources (paved andunpaved roads and construction activities) account for more than 80% of PM_{10}[19, 23]. In the study area, being part of an arid region dominated by large deserts, the proportion of resuspended and windblown particles coulbe even greater.

The temporal variation in PM concentrations are probably caused by meteorological parameters, especially wind speed and direction. Meteorological conditions were important factorsthat influenced the PM level andchemical composition. Strong winds may cause regionaltransport of dust, and local road dust resuspension,resulting in a high PM levels.Circuitous air movements, high RH% and low windspeeds facilitated secondary particle formation, notonly for inorganic salts, such as sulfate and nitrate, butalso secondary organic carbon.

PM levels reported in Saudi Arabia, as well as in many other countries aroudthe world, such as China, India, Taiwan, Switzerland, Italy, Greece, Brazil, and Tanzaniaare shown in table 1.

Table 1: PM_{10} average concentrations on different cities allover the world ($\mu g/m^3$) [24-28]

Country	*City*	*PM_{10}*
KSA	Makkah, 2010 Makkah, 2011	145.4 296.1
China	Nanjing Shanghai Beijing	682 230.5 506.9
India	Mongolia Tibet Ahmedabad	53 55.54 171
Taiwan	Taiwan	172.0
Switzerland	Bern	40.2
Italy	Monte Simon	16
Greece	Athens	44.1
Brazil	Rio de Janeiro Sao Pauloa,	34.4 38
Tanzania	Dar es Salaam	69

5. Conclusions

The PM (PM_1, $PM_{2.5}$, PM_7, PM_{10}, TSP) data used in this paper were collected during December 2013 from four locations (Shebeka, Azizaih, Masfalah, and Away districts) in Makkah city, Saudi Arabia. Spatial and temporal variability of PM have been investigated and the levels of PM were compared with the air quality standards. High levels of PM were observed in Shebeka district, and low levels of PM were observed in Awalydistrict. The temporal variation in PM concentrations are probably caused by meteorological parameters, especially wind speed and direction. Furthermore, the coarse and medium size PM were the most dominant fractions of PM, where it reached to (93.5, 89.6, 87.7, and 93.7 %) for Shebeka, Azizaih, Masfalah, Awaly districts, respectively from the total percent of TSP. Re-suspended dust is a major contributor to ambient particulate matter, especially in the coarse particle fraction. This work shows that the need for further characterization of the fine and coarse particles over a longer period of time in the whole city of Makkah. Further work is also required on source apportionment and for the quantification of potentially detrimental components. Also the health relevance of PM concentrations during these episodes should be investigated further.

6. Acknowledgement

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