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CHANGES IN PARTICULATE MATTER CONCENTRATIONS AT DIFFERENT ALTITUDINAL LEVELS WITH ENVIRONMENTAL DYNAMICS

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ABSTRACT

Ambient air quality is defined not only by the source strength but a variety of meteorological parameters as well. In the current study, ambient concentrations of PM along with temperature and relative humidity levels were monitored at seven different locations of Pakistan. A DustTrak DRX (Model 8533, TSI Inc.) was employed for twenty four hours real time monitoring of particulate matter at the selected sites. A considerable variation was observed in the 24 hour trend of particulate matter (PM) at different locations owing to variation in meteorological conditions due to different altitudes and seasons, and natural and anthropogenic sources in the vicinity. The highest average concentrations of $PM_{2.5}$ (407µg/m³) were observed at highest elevation (Makra Peak, Shogran, 3089 m) while lowest averages (102 µg/m³) were obtained at the seaside (Hawks Bay, Karachi, 0 m).On the other hand PM_{Total} fraction exhibited highest levels at site B (506 µg/m³) and lowest at Site A (121 µg/m³).Correlation factors were determined for PM and meteorological parameters at each location. More research needs to be conducted to have a comprehensive knowledge about the physical parameters controlling particulate dispersal at different altitudes within the country.

Key words Particulate matter, Different altitudes, Pakistan, meteorological factors, carbon dioxide.

INTRODUCTION

Air pollution can be dispersed in the atmosphere at micro, meso, and/or macro scales. Dispersion of pollutants is primarily dependent upon the various meteorological parameters such as ambient air temperature, direction and wind velocity, precipitation, and solar radiation. Therefore the air quality of a region is defined not only by the pollutant sources located in that area but also by the local weather systems (Fu and Chen, 2009). Ambient air pollution is responsible for 3.7 million premature deaths annually with the children, immune-compromised and older people more at risk (WHO, 2014a).

Although there are a number of pollutants present in the air including volatile organic compounds, metal ions, gaseous compounds, particulate matter, bio-aerosols and many more, the present study focuses on the ambient levels of particulate matter at different altitudinal levels under varying meteorological conditions. Particulate matter (PM) is ubiquitous in the atmosphere and originates from both natural and anthropogenic sources (Alfaro-Moreno *et al*, 2010). Persistent daily exposure to PM results in increased mortality rates resulting from lung cancer and various respiratory and cardio-pulmonary diseases such as asthma, pneumonia, chronic obstructive pulmonary disease (COPD) and many others (Samet *et al*, 2000). Among the numerous fractions of PM, particles having an aerodynamic diameter below 10 microns are the most widely studied. Among these, $PM_{2.5}$ has significant public health implications. Their small size makes them penetrable deep into the lungs where they can interfere with gas exchange in the alveoli affecting the health more readily than the coarser fractions (Bates, 1996; Mikio, 2002; Pope and Dockery, 2006). It has been estimated that about 10% of the ambient aerosol levels are generated from human activities such as combustion of fossil fuels, industrial emissions, vehicular exhaust, construction and demolishing activities while the remaining 90% stems from natural processes including volcanic activity, dust storms, sea salt, forest fires etc. (Wallace and Hobbs, 1977; Hardin and Kahn, 1999). In the urban areas, human induced sources play a more pivotal role in defining the air quality of the area rather than the natural ones.

According to WHO (2014b), Pakistan is among the worst polluted countries with an annual average level of fine PM as high as 101 µg/m³ and that of PM_{10} to be 282 µg/m³. In Pakistan the air pollution in urban areas is much higher because of excessive vehicular and industrial emissions, solid waste burning and other domestic sources.

Knowledge about PM concentrations in Pakistan is sporadic and scattered. The available studies highlight deterioration of urban air quality due to an enormous increase in emission sources and minimal air quality management capabilities. The levels of various air pollutants, in particular, PM are in manifold in excess of guidelines proposed by WHO (Colbeck *et al*. 2010; Sanchez-Triana *et al*. 2014).

Owing to the variable weather conditions, PM levels also tend to vary from location to location. Background concentrations are defined as those pollutants emerging from natural processes along with those transported through air from afar and share both natural and anthropogenic origin. The current monitored data provides the significance of spatial and temporal variability of PM across the zone in terms of background concentration. The potential sources were also identified during the monitoring which causes short term variability in background concentrations.

According to Colbeck *et al*. (2010) the annual concentration of PM_{10} in major cities in Pakistan ranges from 188 $\mu g/m^3$ to 250 $\mu g/m^3$. There is not much evidence regarding the trend in background concentrations in association with transport of particles on regional and continental scale. This study was intended to:

- Monitor ambient PM levels along with CO_2 temperature and relative humidity levels at different altitudes in Pakistan.
- Provide foremost estimates of average PM and background concentrations
- Identify the dominant sources including those exhibiting significant short-term variability affecting background concentrations at different altitudes of Pakistan
- Make recommendations with respect to future monitoring priorities in order to better define the magnitude and variability of background concentrations.

MATERIALS AND METHODS

Study area: Pakistan (30.00° N, 70.00° E) is located above the Tropic of Cancer in the temperate zone with the climate varying from tropical to temperate in different regions. The country covers a total land area of 796,095 km^2 with its coastline extending 1,046 km in length. The country is a blend of variable landscapes changing from deserts to plains, grasslands and high mountains. Three major geographical areas are recognized on the basis of topographical features of the country: the northern highlands, the Indus River plain and the Baluchistan Plateau. Four distinct zones are identified on the basis of climate i.e. highlands climate, lowlands climate (arid to semi-arid), coastal climate and arid climate (Blood, 1994). For the current research, seven locations at different elevations were selected across the country (Figure 1). A description and elevation of each site is given in Table 1.

Table 1: Description and elevation of the selected sites

Sr. No.	Site	Name of the Area	Elevation	Description
1	A	Hawks bay, Karachi	0 m	Coastal Climate, warm at day and cooler at night. High Humidity, Sea salt was identified as a major source of PM
2	B	TaunsaBarrage, Multan	136 m	Located in south-western Punjab, barrage was constructed over the Indus River, climate of the area falls in the lowland arid to semi-arid type. Temperature is extreme during summers, excessive rainfall during monsoon and cool winters.
3	C	Head Balloki, Lahore	174 m	Located on River Ravi near Lahore. BallokiHeadworks serves the purpose of irrigation and flood control.
4	D	Mirpur City	352 m	Mirpur is located in Kashmir region. Built along the bank of Mangla Dam, the city is 16km away from Mangla cantonment. The climate of the region is of sub-tropical and falls in lowland type. The summers are pleasant and the winters are foggy and much colder.
5	E	PirSuhawa	1232 m	Located on top of Margalla hills, 17 km away from Islamabad Capital Territory.
6	F	Khanspur	2204 m	The climate of Khanspur (Hill station) is tropical alpine with snow fall in winters. The summers are short but pleasant with cool nights.
7	G	MakraCatchments, Shogran	3089 m	Makra peak, Shogran (Hill Station) is a scenic tourist spot located in the northern areas of Pakistan. Highest elevation study point.

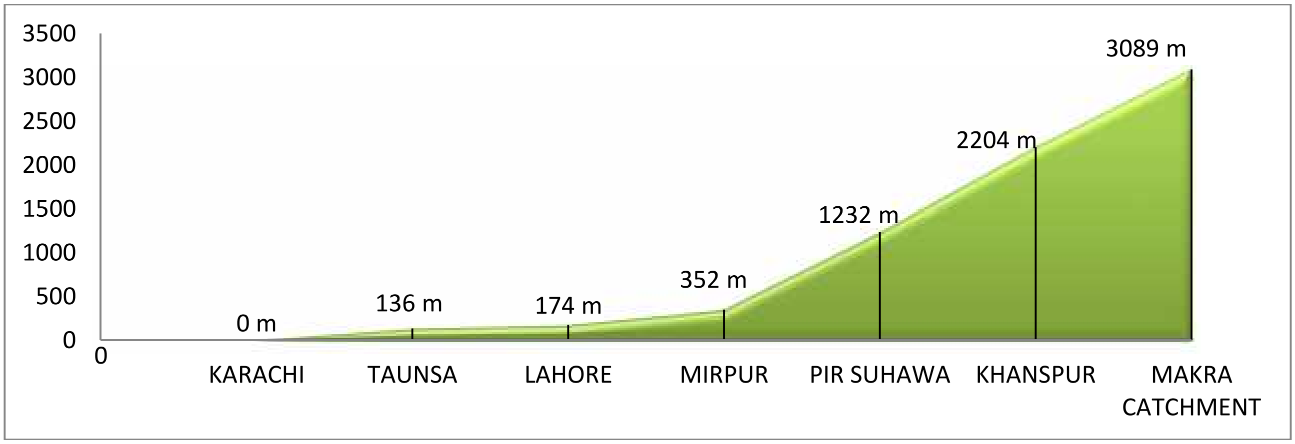

Figure 1: Monitoring sites along with their respective elevation from sea level

Experimental setup: Monitoring of particulate matter was carried out for twenty four hours at each site along with temperature, relative humidity, CO_2 and CO. The instrument used for PM was a DustTrak DRX (model 8533, TSI Inc.). It is a real time light scattering photometer with sensors for simultaneously detecting the mass concentrations of PM_1, $PM_{2.5}$, PM_4, PM_{10} and total PM fractions present in the air. Gas Probe IAQ (BW technologies) is a multi-gas analyzer and was employed for measurement of CO_2 and CO levels as well as ambient temperature and relative humidity (RH). All the selected sites were carefully chosen so there would be minimal influence on air quality by anthropogenic sources. The climatic conditions of the selected locations vary considerably from each other with Site A, falling in the coastal climate zone, Site B, C, and D experiencing lowland climate, and the remaining three sites in the highland climate zone (Figure 2). Monitoring was carried out from May, 2013 till September, 2014 with each site surveyed only once during this time duration.

Figure 2: Location of sampling sites for monitoring of ambient PM levels in Pakistan

RESULTS

Being located at different altitudes, the prevailing weather conditions of the selected localities were of significance. The sites were monitored during different times of the year and the temperature and relative humidity levels varied subsequently. The sites are labeled according to their elevation point rather than their sequence of monitoring. Table 2 shows ambient CO_2, temperature, relative humidity, and PM concentrations for each site.

Table 2: Concentrations of PM (µg/m^3), CO_2 (ppm), temperature (°C) and relative humidity (%) at each site.

	A	B	C	D	E	F	G
PM_{TOTAL}	121 ± 95.64	506±223.22	266±57.92	327±48.35	124±73.05	209±51.80	415±16.50
PM_{10}	114 ± 91.67	438±215.67	222±69.74	317±42.74	114±68.26	163±37.97	412±16.90
PM_4	106 ± 87.08	381±218.54	189±75.71	308±39.73	106±62.41	118±24.55	410±17.41
$PM_{2.5}$	102 ± 85.56	368±219.16	181±75.36	306±39.33	104±60.87	106±20.64	407±16.60
PM_1	98 ±82.20	352±210.92	171±71.47	290±38.57	100±56.62	96±17.88	405±15.87
CO_2	721±61.11	488±23.46	598±129.39	537±12.96	404±53.48	337±22.69	364±33.19
Temperature	27.4 ± 5.46	19.7±4.05	29.2±4.79	12.09±3.28	7.85±2.27	21.9±2.75	12.8±2.94
Humidity	64±29.35	74±19.66	79±18.89	74±15.17	49±4.67	41±11.32	76±9.70

Site A: Hawks bay, Karachi: Karachi is the industrial centre and largest city of Pakistan located by the Arabian Sea. Being a sea-port, the area experiences a coastal climate with warm days and cooler nights. The humidity levels are reported to be high with the temperature ranging from 13^{o}C at night during winters to an average of 34^{o}C during the summer days. Monitoring for air quality at this site was conducted during October, 2013. In our study, the mean temperature noted at the monitoring site (Hawks bay, N 24 50' 55" E 066 53' 39") was 27.4^{o}C while the relative humidity over the 24-hours period was 64% on the average. The humidity levels remained fairly constant and at above 90% during the night time while fluctuations were observed during the day. Sea salt was identified as the major contributor towards PM peaks during the monitoring (Figure 3).

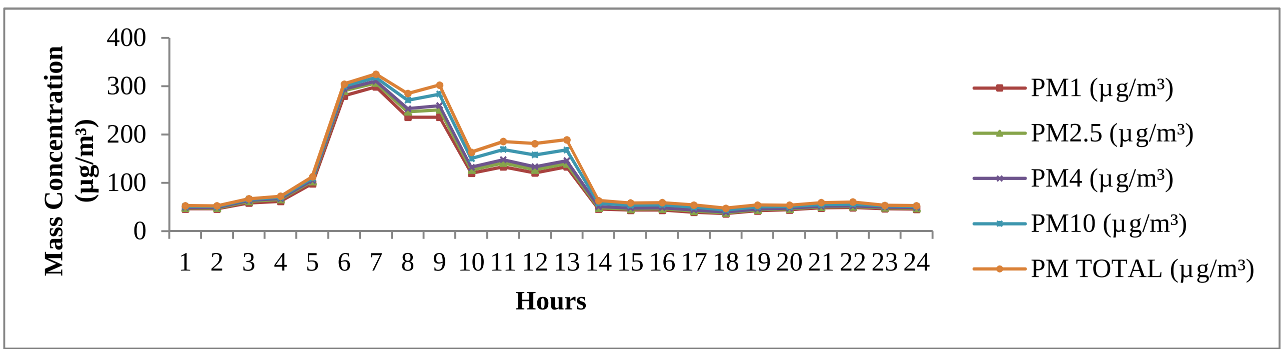

Figure3: Ambient levels of particulate matter at zero elevation (site A)

Site B: Taunsa barrage, Multan: Located at an elevation of 136 m above the sea level, Taunsa Barrage is located in south-western Punjab. The barrage was constructed over the Indus River, the largest river of Pakistan, in 1958. The area was declared a wildlife sanctuary in 1972 and later owing to its significance as a wetland for migratory waterfowls, and the presence of the critically endangered and endemic Blind Indus Dolphin, it was designated as a Ramsar site in 1996. The climate of the area falls in the lowland type (arid to semi-arid) characterized by extreme temperatures during summers, excessive rainfall during monsoon and cool winters. The landscape of the surrounding areas ranges from lush green areas to semi-arid patches as well. Being in vicinity of the river, the nights are cooler than the hot atmosphere of the day. The monitoring was done during November, 2013 and the 24 hours mean temperature was recorded to be 19.7^{o}C with a relative humidity level of 74% with a constant level around 90% observed during the night. PM Peaks were observed at night during barbecue activity nearby. No other significant source was observed (Figure 4).

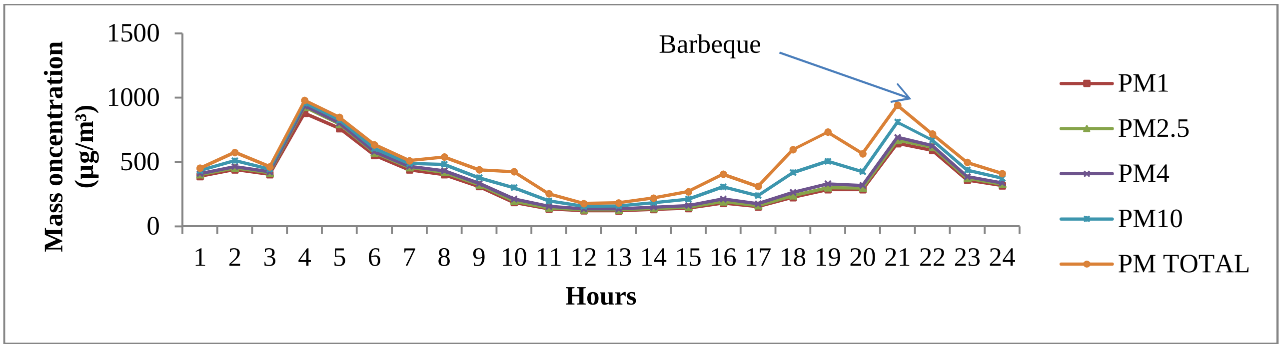

Figure 4: Ambient levels of particulate matter at an elevation of 136 m above sea level

Site C: Head Balloki, Lahore 174 m: BallokiHeadworks (N 31 13' 44" E 073 51' 29") is located on River Ravi near Lahore serving the purpose of irrigation and flood control. The ambient air temperature at the location was 29.2°C while the relative humidity was 79%. Being located near the river, the relative humidity increased during the night time and remained above 90% with lower values during the day. Variations in PM were observed throughout the day but in the absence of any particular source, it can be said that natural levels of PM persisted rather than anthropogenic ones. (Figure 5)

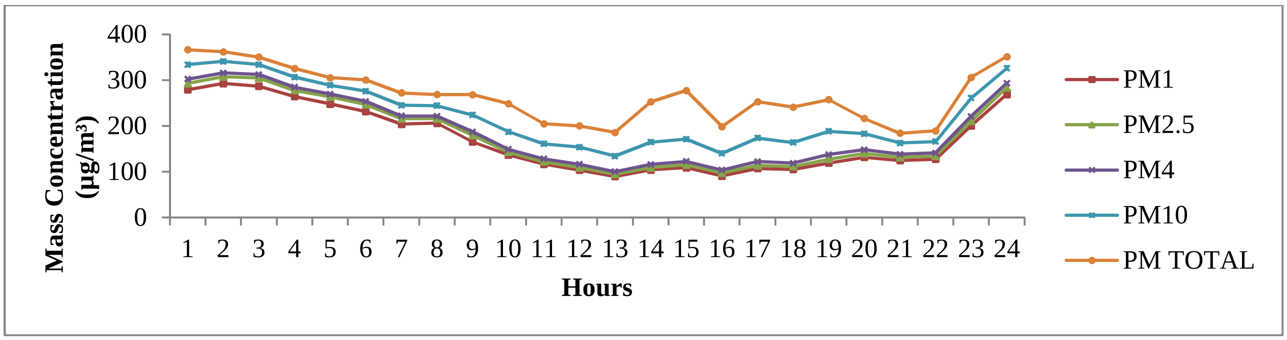

Figure 5: Ambient levels of particulate matter at an elevation of 174 m above sea level

Site D: Mirpur city: Mirpur is an important economic hub of the Pakistan administered Jammu and Kashmir region. Built along the bank of Mangla Dam, the city is 16km away from Mangla cantonment. The climate of the region is of sub-tropical type and falls in lowland type. However being present at a higher altitude than Site B and C and having a sub-mountainous topography, the weather is colder than these two sites. The summers are pleasant rather than too hot and the winters are foggy and much colder. The monitoring site selected (N 33 06' 50" E 073 47' 44") was at an elevation of 352 m above the sea level on a hilly area in New Mirpur settlement which was under the process of development at the time. Humidity had an average of 74 % while the mean temperature was 12°C. The PM levels were observed to increase only when there was cooking activity in the nearby houses. (Figure 6).Biomass fuel was being used as cooking fuel as the area had no access to natural gas at the monitoring time.

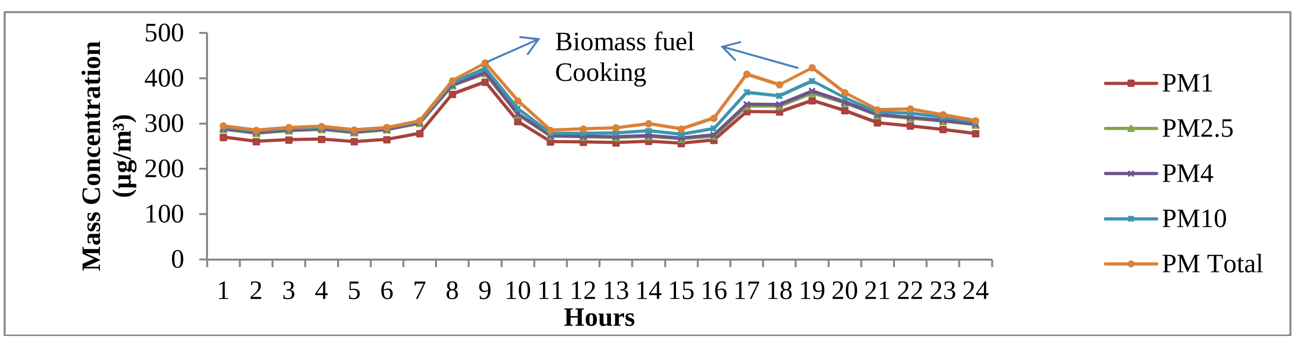

Figure 6: Ambient levels of particulate matter at an elevation of 352 m above sea level

Site E: PirSuhawa 1232 m: PirSuhawa is a tourist resort located on top of Margalla hills, 17 km away from Islamabad Capital Territory. The average humidity recorded in the area was 49% while the mean temperature was low i.e. 7.8°C. During the study period, the only significant activity which contributed towards PM rise was the arrival of a diesel-fueled tourist buses around mid-day (Figure 7). Apart from this disturbance, no other major activity was noted to affect the air quality of the area.

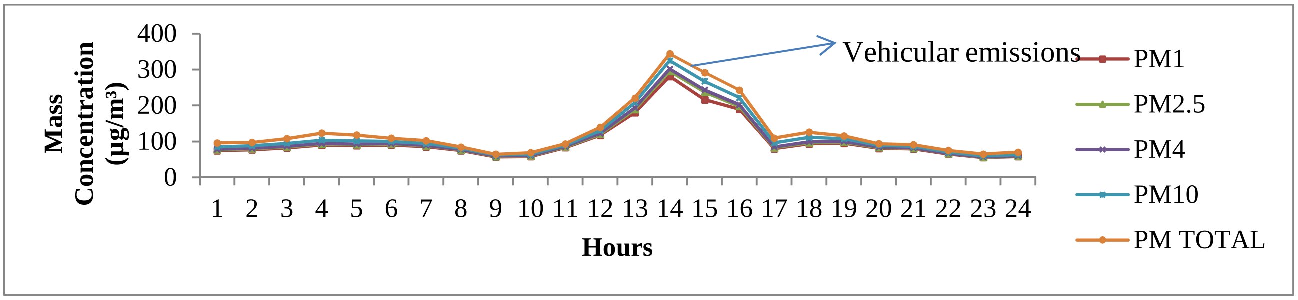

Figure 7: Ambient levels of particulate matter at an elevation of 1232 m above sea level

Site F: Khanspur: Khanspur is a popular hill station located at an altitude of about 2250 m. The climate of the area is tropical alpine type with snow fall in winters. The summers are relatively short but pleasant with cool nights. Many institutes including the University of the Punjab have established their field stations in Khanspur to support field research. The monitoring site was selected to be Sir Syed Campus, Punjab University (N 34 01' 14" E 073 25' 09"). The monitoring was carried out during the summer season in the month of May. Although the humidity levels increased up to 74 % during the night the mean level remained at 41%. The temperature gave an average reading of 21.9°C. The levels of PM_{10} and PM_{Total} were higher than the other fractions owing to a dust storm during the monitoring (Figure 8).

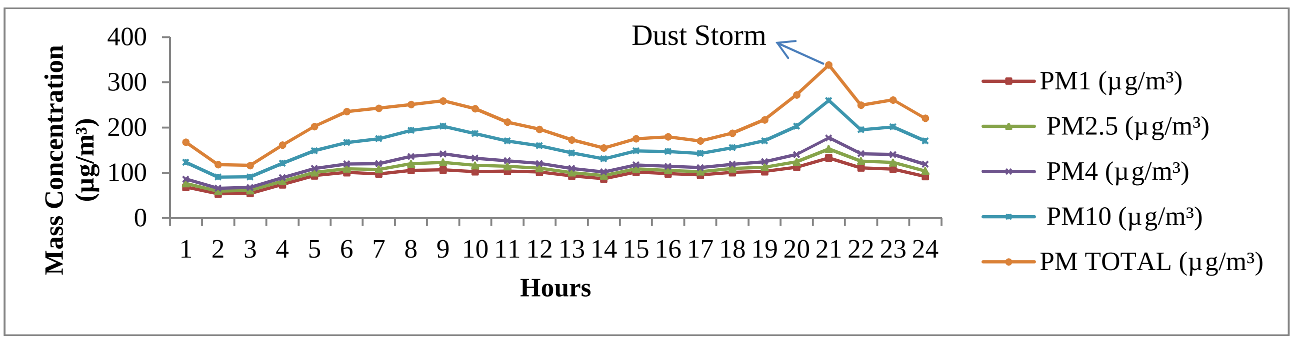

Figure 8: Ambient levels of particulate matter at an elevation of 2204 m above sea level

Site G: Makra peak, Shogran: Makra Peak, Shogran (N 34° 37’ 42’’ E 73° 29’ 22’’) is a scenic tourist spot located at an elevation of 3089 m in the northern areas of Pakistan. The water from snow covered peak collects in the catchments of Payee meadows. During the monitoring there were short spells of showers from time to time resulting in increased humidity (mean RH 76%) while the temperature was also low (12.8°C).The mean PM levels were recorded to be the highest at this site as compared to other locations (Figure 9).

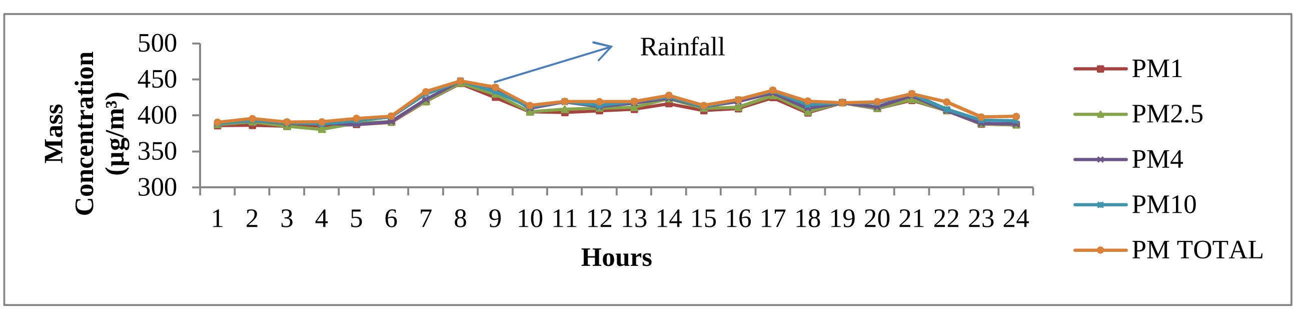

Figure 9: Ambient levels of particulate matter at an elevation of 3089 m above sea level

CO_2 levels at the monitoring sites: Carbon monoxide was observed only at site A along the sea coast (3.88 ppm). Mean concentrations of CO_2 were also highest at sea level as compared to other sites (Table 2).

DISCUSSION

Ambient levels of PM are influenced by a variety factors which include not only the point and/or non-point sources but also the physical parameters associated with weather. Moreover the location of place, its topography and altitude also play a pivotal role in defining the air quality of the area under consideration. For example the formation of thermal inversion layers traps the pollutants near to the ground surface deteriorating the air quality of the locality. The effect of meteorological factors upon local air quality has been investigated by many researchers and found a significant correlation between PM and wind speed, wind direction, temperature, relative humidity, precipitation, mixing height and cloud cover (Al Jallad *et al*, 2013; Shi *et al*, 2012; Owoade*et al*, 2012).Apart from these studies, high levels of PM at higher temperatures and low wind speed have been reported by Jung *et al*. (2002) and Hien *et al*, (2002) while relative humidity also played a role during the winter season (Chiang *et al*, 2005).

In the present study, the PM levels at each site were defined by the specific area sources while the elevation of the sites was not observed to be a strong factor in defining the air quality. Since different locations were monitored during different times of the year, seasonal impact was also of importance. As discussed earlier, sources of PM vary from place to place and in different seasons. A brief overview of perceived sources rendering a significant impact upon PM levels during the course of this study is given.

Among the seven sites monitored four of them were located near water bodies (Site A-D). During statistical analysis, it was noticed that a negative correlation existed between PM and temperature at these sites while relative humidity had a positive relation with PM levels. In contrast, temperature levels at the remaining three sites had a positive relation with PM and at site E and G, relative humidity had a negative correlation. At site F however, relative humidity exhibited direct correlation with PM but it should be remembered that Site F was monitored during the month of May (summer season). Increase in temperature and humidity accelerates the deposition velocity of particles (Han *et al*, 2011) and there was some heavy rain towards the end on monitoring at site F.

Transport of aerosols is affected by turbulence caused by thermal-dynamic property of the air. Although there is still not sufficient data on behavior of fine particulate matter at different elevations, Silcox*et al*., (2012) documented an increase in PM levels at lower elevations (around 150 m) with the levels decreasing as the elevation increased. Similarly Gajananda*et al*, (2005) observed lower PM levels at higher elevations. Moreover the concentrations were lower during the colder months and increased significantly during the summers due to more rapid dispersal facilitated by thermal buoyancy. Our results contradict the above studies and more research needs to be conducted in this context.

Conclusion

- At site A sea salt was observed to be a major contributor towards PM levels.
- At site B, barbecue activity in the night time contributed considerably towards particulate matter.
- At site C no specific source was identified and the variations in PM levels were due to natural sources rather than induced by humans.
- At site D combustion from cooking activity using biomass fuels and motor vehicles on the nearby road contributed towards peaks in PM concentrations
- At site E also, vehicular activity was the most important source.
- At site F a dust storm caused rise in PM_{10} and PM total levels
- At site G, there was again no apparent source of PM to be observed. Moreover there were short spells of rain at site G during the monitoring. Rainfall tends to washout the airborne particles as observed by Massey *et al*., (2013).

However in our results, PM levels were the highest at site G despite the rain. Diesel exhaust and vehicular emissions are a major source of particulate matter in urban areas and in our results too, vehicular emissions had a definite impact on PM levels (Lighty*et al*, 2000; Fu, 2001; Goyal, 2006). Moreover the concentrations were lower during the colder months and increased significantly during the summers due to more rapid dispersal facilitated by thermal buoyancy.

Limitations of the study: The various sites were monitored during different times of the year so seasonal variations could have an effect upon PM levels. Moreover, each location was monitored only once. Data for wind speed and wind direction was unavailable which could have given a better understanding of the behavior expressed by PM levels at all sites.

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