Atmospheric Pollution Research 3 (2012) 132-142

Atmospheric Pollution Research
www.atmospolres.com

Assessment of occupational and ambient air quality of traffic police personnel of the Kathmandu valley, Nepal; in view of atmospheric particulate matter concentrations (PM_{10})

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ABSTRACT

This paper presents the analysis and interpretation of occupational and ambient particulate matter concentrations measured as PM_{10} at a network of ten high density road traffic intersections in Kathmandu valley during the period of February 2008 to January 2009. The purpose was to understand the pollution trends associated with the high density road traffic intersections considering the levels of particulate matter concentrations (PM_{10}), representing the occupational and ambient air quality of the traffic police personnel of the Kathmandu valley, Nepal. The study indicates that the occupational PM_{10} play a significant dominant role in controlling ambient PM_{10} loads at the high density road traffic intersections. The occupational and ambient PM_{10} concentrations in high density traffic area and road intersection of Kathmandu Valley showed a marked monthly and seasonal variation. High density traffic areas and road intersection of the Kathmandu valley were seriously polluted by PM_{10}. Monthly and yearly average occupational and ambient PM_{10} concentration at the high density traffic areas and road intersection greatly exceeded the 24–h average limit value (120 μg m^{-3}) in Nepal.

Keywords:
Air Quality
PM_{10}
Seasonal variation
Cluster analysis
Fine Particles

Article History:
Received: 27 June 2011
Revised: 06 October 2011
Accepted: 28 October 2011

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doi: 10.5094/APR.2012.013

1. Introduction

Nepal, a relatively small country with 147 181 km^2 area inhabited by 22 million people, is known for exquisite environment. However, the real situation is quite different because urban areas are environmentally degrading due to rapid unplanned urbanization and industrialization. Increasing numbers of human population, industries and automobiles, decreasing agricultural productivity, the frequent occurrence of floods in the lowlands, landslides in the midlands and forest fires are the major environmental issues, and recent studies reveal that even the glorious mountain peaks of the high Himalayas have also undergone incipient pollution (Dokiya et al., 1992; Shrestha et al., 1997; Majumder et al., 2010a). Air pollution is considered to be one of the serious and prominent types of environmental pollution that is prevalent in most industrial towns and cosmopolitan cities of the world. It had been a general impression in the past that air pollution is exclusively a problem of the industrially developed nations; however, recent studies have shown that air pollution is a growing problem in developing countries as well, and hence, attention should be paid to this problem before it is too late (Shrestha et al., 1997). Recently, problems caused by atmospheric Particulate Matter (PM) in urban air have received greater attention. Various health effects attributable to PM have been documented (Brunekreef and Holgate, 2002). The most conclusive evidence has been provided by cohort and time series studies indicate that elevated concentrations of PM has linked with increased morbidity and mortality (Dockery and Pope, 1993; Pope et al. 1995). The majority of these studies have assessed the health effects of particles expressed as the risk per unit mass m^{-3} of $PM_{2.5}$ or PM_{10}. Airborne particle associated problems, such as health problems like asthma problems (Anderson et al., 2001) and haze problems like visibility impairment (Bhaskar et al., 2008) are typical environmental issues in urban cities. The chemical composition (Hillamo et al., 1993), health impact (Majumder et al., 2010b), and rate of deposition (Viana et al., 2002) of these particles vary significantly with their size.

Urban air quality management strategy in Asia (Kathmandu valley report) reported that PM_{10} concentration is 800 μg m^{-3} in Kathmandu (Shah and Nagpal, 1997). Shrestha (2002) reports the prevalence of respiratory illness in Kathmandu valley due to particulate matter. Giri et al., (2004) observed that the pre–monsoon and winter seasons are vulnerable due to increased level of particulates in the valley. Different studies found different concentrations of PM_{10} with in Kathmandu Valley, which was very high like 197–775 μg m^{-3} (RONAST, 1992), 59–127 μg m^{-3} (Karmacharya and Shrestha, 1993), 100–190 μg m^{-3} (ENPHO, 1999). PM_{10} was found to be 54–118 μg m^{-3} in a low traffic area in dry season and 33.2–114.1 μg m^{-3} in rainy season. Annual PM_{10} in high traffic area was found to be 261.4 ± 28.5 μg m^{-3} (Sapkota, 1996).

Traffic police personnel in the Kathmandu valley work within the close proximity to the vehicles. So they are exposed to high levels of air and noise pollution in a regular manner, which is largely contributed by vehicles. As the most common route for vehicular emissions to enter the human body is inhalation, the most common effect of air pollution is damage to the respiratory system. Exposure to air pollutants can overload or break down natural defense mechanisms in the body, causing or contributing to respiratory diseases such as lung cancer, asthma, chronic bronchitis and emphysema. Air pollution can also have adverse impacts on other important systems such as cardiovascular system and central nervous system.

The air pollution level in Kathmandu valley is very high. It is largely contributed by vehicular emissions. As traffic police personnel are exposed to the vehicular emissions in a regular manner, they can act as an indicator to assess the adverse health problems caused due to air pollution. In addition, doing the study on traffic police personnel can help to estimate the elevated forms of health problems among the road side shopkeepers or similar people who stay by the road for longer period of time than the traffic police personnel.

2. Objectives

The focal objective of this study was to assess the level as well as diurnal and monthly variations of air pollution in the Kathmandu valley, Nepal; in view of occupational and ambient particulate matter concentration (PM_{10}) affecting the traffic police personnel associated with a high density road traffic intersections. The study also aimed to explore dependency and variation of ambient PM_{10} with the concentration of occupational PM_{10} in different season, along with the variation of pollution trend during different seasons as well as at different times of the day.

3. Materials and Methods

3.1. Site description

The main study area for this research is Kathmandu valley. The reason behind choosing Kathmandu is that it has gone through rapid and haphazard urbanization and experienced a huge increase in the number of vehicles as well as industries in the recent years. Kathmandu's ambient air quality usually crosses international guidelines by 2–3 folds. This has potential adverse impacts on the environment and health of the people, especially to the traffic police personnel working there who are regularly exposed to the vehicular emissions during their duties on the streets. The different sites of Kathmandu where the vehicular flows are high compared to other sites were of special interest in this research.

3.2. Sampling design

The air quality monitoring was carried out for one year covering pre–monsoon, monsoon, post–monsoon and winter seasons during the period of February 2008 to January 2009 in ten major high density traffic areas (HDTA's) of Kathmandu valley. The samples were collected once in a month for each of the ten sites. On an average, the total sampling time was 10–12 hours in a day. These 12 hours in a day were divided into 4 hours shifts each covering pick hours of day 8 am to 8 pm. Those shifts were divided into 8:00 am to 12:00 pm in the morning (morning shift), 12:00 pm to 4:00 pm in the afternoon (afternoon shift) and 4:00 pm to 8:00 pm in the evening (evening shift). Morning and evening shifts representing the rush hour and afternoon shift representing the off hour. The sampling was conducted in rush hour and off hour in order to have a comparison between the concentration of PM_{10} to which the traffic police personnel were exposed to in rush and off hours. Air sampling was covered a total of 120 sampling days and thereby the total number of samples was 360.

3.3. Sampling methods

During the study, *Envirotech APM 550* Fine Particulate Sampler with a flow rate of 1 $m^3\,h^{-1}$ (16.7 L min^{-1}) were used to monitor ambient air quality and SKC Personal Air Sampler (model PCXR4) were used to quantify the concentration of subjective exposure to PM_{10} in occupational environment in major High Density Traffic Areas (HDTA's) of Kathmandu Valley. With an operating range of 5 to 5 000 mL min^{-1}, this battery–operated air sampling pump is ideal for industrial hygiene and occupational health studies as well as environmental testing. Air flow was maintained constant at 2 L min^{-1} (simulating almost human respiratory rate) with the help of adjustment knob in the personal air monitoring sampler. Both, fine particulate sampler and SKC personal air samplers were calibrated with a primary flow meter before the sampling and were checked after the sampling. The sampler was charged for 10 to 12 hours every night prior to sampling.

In the field, the sample collection media (filter paper) was clipped in the breathing zone of traffic police and then pump was clipped to their belt. Before starting the sampling, batteries were checked and the flow rate was adjusted according to the requirement using the screw. Then the sampler was turned on. The starting and ending times were noted.

The concentration of PM_{10} was calculated using the gravimetric method. Upon the completion of sampling, the filter paper was removed carefully from the holder with the help of forceps, and kept in the filter paper storage bag and stored in the desiccators and then weighted. For a given volume of sample collected, the amount of the particulate matter (W in µg) can be calculated by taking the difference in the weight of the filter paper before and after sampling. The volume of airflow (V in m^3) was calculated by multiplying the flow rate of air (Q, 2 L min^{-1} in the present study) through the filter medium with the sampling time (T in minutes) and by dividing by 1 000 (to covert air volume into m^3). The concentration (µg m^{-3}) of PM_{10} was calculated by dividing the actual weight of PM_{10} (W in µg) by volume of air sample (m^3).

3.4. Laboratory preparation and data analysis

The conditioning of filter media was carried out using moisture absorbing chemical, anhydrous calcium chloride in a closed vessel (desiccators) in order to subject filter paper to standard conditions of temperature and humidity. The filter paper used was made up of glass fiber with the pore size of 7 µm and diameter of 37 mm. Before air sampling, the numbered filter papers were kept inside the desiccators for 24 hours and then taken out for pre–weighting. Then they were stored in the labeled air–tight plastic bags. After the sampling, the filter media was again kept inside desiccators for 24 hours and then the weight was taken as post weight. The filter paper discs were weighed in an environmentally controlled area. The balance (AB54, Mettler Toledo; Made in Switzerland) used was capable of weighing a minimum of 0.0001 mg.

Statistical analysis of the collected occupational and ambient PM_{10} data sets was performed in the present study using the SPSS 18 and normality test in the form of a Q–Q plot, regression analysis, correlation analysis and cluster analysis was performed using the Statistica 8 software.

4. Results and Discussion

4.1. Occupational and ambient PM $_{10}$ dynamics

Tables 1 and 2 summarizes minimums, maximums, averages with standard deviations of occupational and ambient PM_{10} concentrations in the ten high density traffic road intersection study areas, measured for one year, February 2008 to January

2009. During the study period, the highest annual average for both occupational and ambient PM_{10} concentration was observed in Koteshwor and the lowest annual average in Singhadurbar in comparison with the other study sites. The annual occupational and ambient PM_{10} average levels of all the studied sites measured during the present study, exceeded the standard 24–h average concentration of 120 µg m^{-3} set for Kathmandu valley, Nepal (Aryal et al., 2008). The Ministry of Population and Environment (MOPE), Nepal; published a descriptor categories to describe the effect on human health for different concentrations of PM_{10} in 2003. According to this categories, the air quality of an area can be considered as good (<60 µg m^{-3}), moderate (60–119 µg m^{-3}), unhealthy (120–349 µg m^{-3}), very unhealthy (350–425 µg m^{-3}) and hazardous (>425 µg m^{-3}) for human health in terms of $PM_{10.}$ As per MOPE categories, all the studied sites can be considered as hazardous, because in all the study locations the annual average concentrations of both occupational and ambient PM_{10} exceeded the benchmark of 425 µg m^{-3} (HMG/MOPE, 2003).

During the present study period, seasonal influence on PM_{10} dynamics was also observed. The minimal levels of occupational and ambient PM_{10} were observed particularly during the monsoon seasons. Episodic very high concentration was also observed during early pre–monsoon. In the study area, high concentrations of occupational and ambient PM_{10} were observed during winter followed by the pre–monsoon period. The occupational and ambient PM_{10} were consistently lower in the monsoon period. In most of the cases the highest value of occupational and ambient PM_{10} were recorded during December followed by November (Tables 1 and 2).

The highest occupational and ambient PM_{10} values in these high density traffic road intersection areas are mainly due to local traffic emissions in the area, along with other emissions. These findings are in agreement with Giri et al. (2008), who reported the influence of meteorological conditions on PM_{10} on different locations of the Kathmandu valley, Nepal. The occupational and ambient PM_{10} concentrations measured in these ten high density traffic areas, during the present study consistently showed much higher values than the other studies conducted in Nepal (Giri et al., 2006; Aryal et al., 2008; Giri et al., 2008) and somewhere else (Gerasopoulos et al., 2006; McNabola et al., 2011). The consistently higher concentrations of occupational and ambient PM_{10} in all the study areas might be because all these study sites are high density traffic intersections of the Kathmandu valley, Nepal. The other possible reasons for the discrepancy in PM_{10} concentrations from other studies might be due to the difference in sampling methods, and measurement periods. Regmi et al., (2003) reported that a significant number of patients suffer from respiratory symptoms related to high PM_{10} level exposure. As compared to Regmi et al. (2003), this research results showed much higher values of occupational PM_{10} in the valley. Thus the adverse health problems or symptoms associated with PM_{10} exposure would be more severe than the results reported earlier by Regmi et al. (2003).

Figure 1 shows dynamics of PM_{10} concentrations in the ten study locations for the sampling period, February 2008 to January 2009. Seasonal trends for PM_{10} levels showed the minimum levels during the monsoon (June–September) and the maximum ones during winter (December–February) in all sites. Thus these seasonal patterns seem to be highly dependent upon the meteorological parameters such as temperature, humidity, rainfall, and wind.

4.2. Monthly variation of occupational and ambient PM_{10} concentrations

Figure 2 visualizes the monthly discrepancy of average occupational and ambient PM_{10} levels at ten studied sites during morning, afternoon and evening during the year, February 2008 to

Table 1. *Seasonal minimum (Min), maximum (Max), average (Avg.) ± standard deviation (SD) values (µg m^{-3}) of occupational PM_{10} in the valley*

Sites	**Pre–monsoon (March– May)**			**Monsoon (June– Sept)**			**Post–monsoon (Oct– Nov)**			**Winter (Dec– Feb)**			**Year**		
	Min	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**
Koteshwor	961	1 410	1 215±154	622	1 111	917±151	876	1 358	1 094±165	1 120	1 992	1 614±295	622	1 992	1 195±331
Gaushala	485	796	654±107	354	720	526±108	426	774	601±124	638	1 013	829±134	354	1 013	646±162
Kalanki	809	1 321	1 117±190	599	1 024	862±145	710	1 290	1 036±207	1 064	1 705	1 374±238	599	1 705	1 083±270
Jawalakhel	528	862	726±115	384	670	554±96	598	888	742±136	694	1 210	963±169	384	1 210	731±199
Ratna Park	707	1 154	978±160	523	900	745±126	621	1 127	876±180	929	1 527	1 231±207	523	1 527	947±247
Singhadurbar	425	695	578±95	317	558	449±80	374	683	526±103	592	940	776±115	317	940	576±157
Maharajgunj	511	834	707±114	378	720	541±103	441	814	599±152	636	1 090	912±137	378	1 090	685±188
Satdobato	681	1 112	928±154	560	862	734±102	598	1 086	844±174	888	1 420	1 162±198	560	1 420	908±223
Bhotahiti	468	765	635±105	367	592	485±78	411	746	586±123	610	1 120	844±168	367	1 120	629±179
Thapathali	604	987	823±133	475	871	668±126	531	964	748±154	795	1 326	18±197	475	1 326	817±211
Total	**425**	**1 410**	**836±243**	**317**	**1 111**	**648±189**	**374**	**1 358**	**765±235**	**592**	**1 992**	**1 076±316**	**317**	**1 992**	**822±295**

Note: In a month the number of cases is 3 for each location.

Table 2. *Seasonal minimum (Min), maximum (Max), average (Avg.) ± standard deviation (SD) values (µg m^{-3}) of ambient PM_{10} in the valley*

Sites	**Pre–monsoon (March– May)**			**Monsoon (June– Sept)**			**Post–monsoon (Oct– Nov)**			**Winter (Dec– Feb)**			**Year**		
	Min	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**	**Min**	**Max**	**Avg.± SD**
Koteshwor	673	1 173	958±170	485	851	677±115	591	1 092	838±178	892	1 449	1 148±172	485	1 449	891±237
Gaushala	382	649	531±95	280	485	387±65	336	622	484±99	485	825	652±113	280	825	505±135
Kalanki	639	1 083	869±155	474	808	661±107	413	1 030	709±239	772	1 376	1 088±211	413	1376	828±239
Jawalakhel	469	700	599±83	305	622	470±77	366	776	574±148	532	898	719±114	305	898	582±137
Ratna Park	558	946	770±138	380	849	606±121	637	916	780±122	677	1 202	929±170	380	1 202	757±182
Singhadurbar	350	570	476±82	201	579	362±93	302	550	427±84	423	730	572±111	201	730	454±122
Maharajgunj	403	770	581±124	229	510	410±82	306	655	471±134	515	912	690±128	229	912	533±157
Satdobato	638	912	792±107	339	680	550±104	472	873	673±143	687	1 150	895±154	339	1 150	717±184
Bhotahiti	369	624	506±86	297	468	376±51	324	873	581±217	468	848	632±131	297	873	507±155
Thapathali	477	809	655±112	344	604	481±81	419	775	597±127	596	1 028	798±140	344	1 028	623±164
Total	**350**	**1 173**	**674±193**	**201**	**851**	**498±144**	**302**	**1 092**	**613±193**	**423**	**1 449**	**812±234**	**201**	**1 449**	**640±224**

Note: In a season the number of cases is 9 for each location.

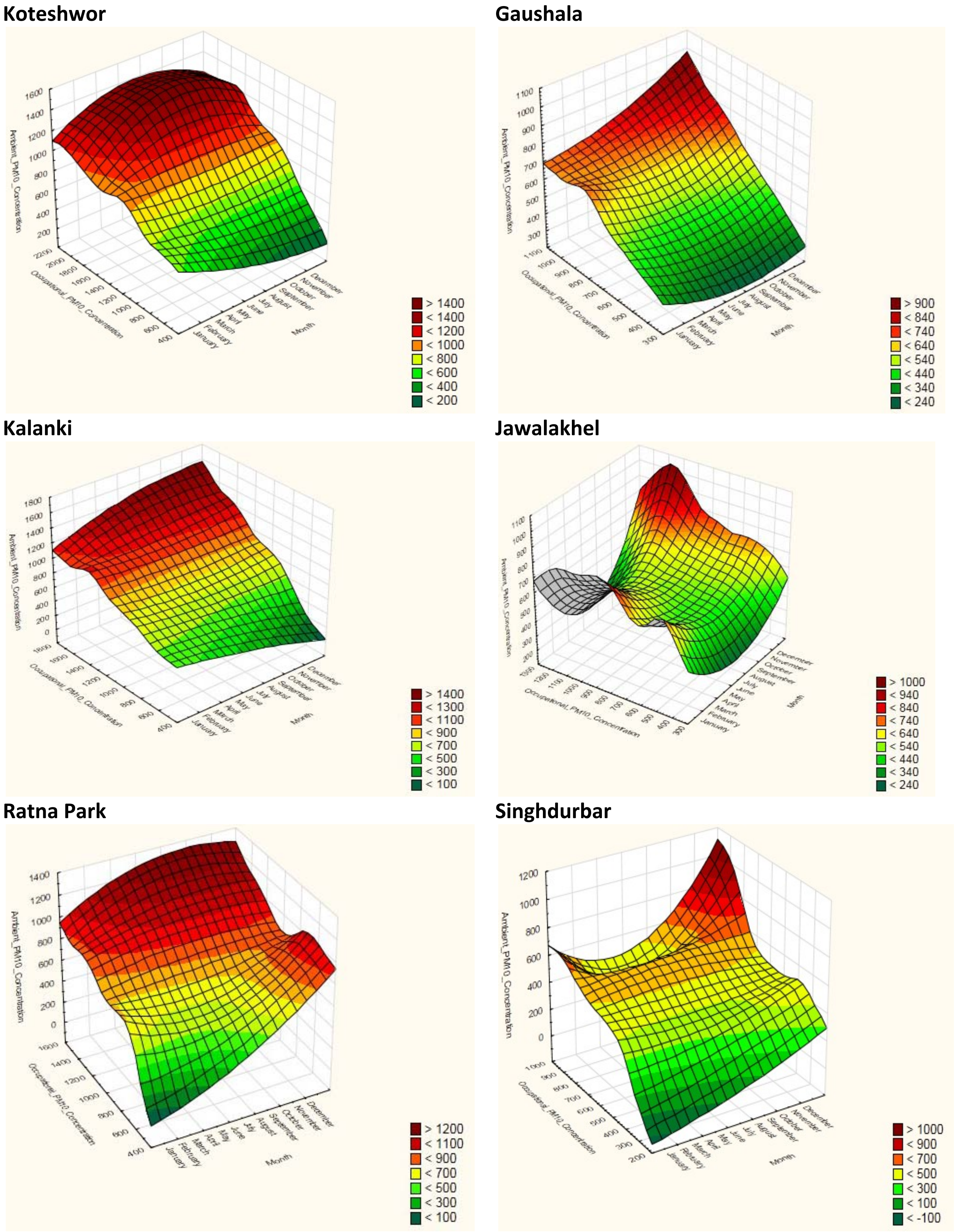
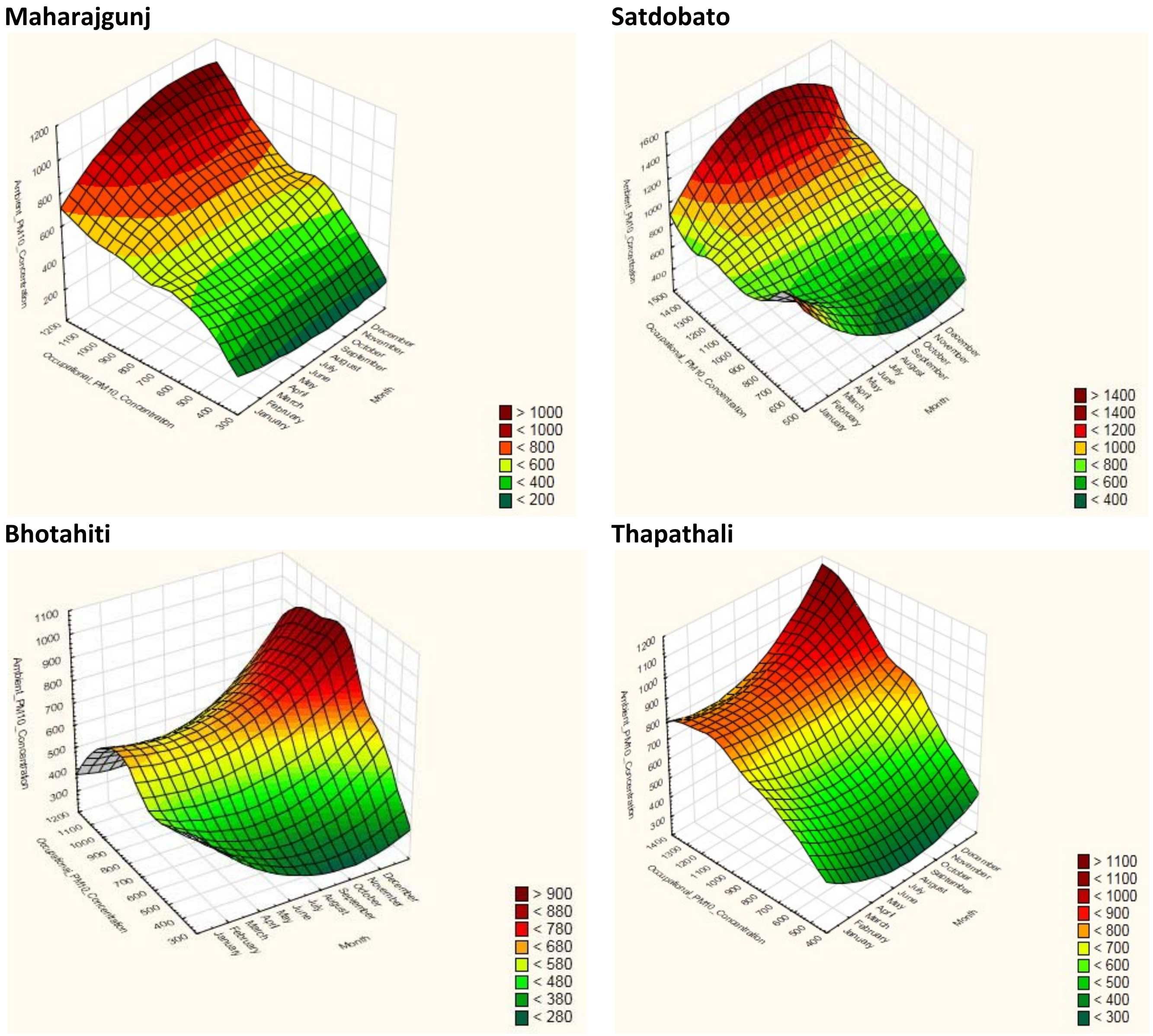


Figure 1. *Occupational and ambient PM_{10} concentrations in February, 2008 to January, 2009 measured at the ten study sites.*


Maharajgunj

Satdobato

Bhotahiti

Thapathali

Figure 1. *Occupational and ambient PM$_{10}$ concentrations in February, 2008 to January, 2009 measured at the ten study sites (Continued).*

January 2009 as an explicatory example. The occupational and ambient PM$_{10}$ average levels showed a marked daily (morning, afternoon and evening) and monthly variation. The dailyand monthly variation of occupational and ambient PM$_{10}$ levels showed similar patterns in most of the study sites. Much higher occupational and ambient PM$_{10}$ values were measured in all locations in winter (December–February) as well as during morning and evening of the studied period. The occupational and ambient PM$_{10}$ concentration reached a minimum in monsoon periods (July–September) in all the studied sites and continued to amplify again in the post–monsoon periods (October– November). The high and low occupational and ambient PM$_{10}$ values during winter and monsoon indicate a strong seasonal variation in the Kathmandu valley, Nepal; which is also supported by the findings of Aryal et al. (2008) and Giri et al. (2008). During winter, energy use increases with decreasing air temperature, leading to more air pollutant emissions, such as PM$_{10}$, NO$_x$ and SO$_x$, and could form secondary particulate matter (Liu et al., 2004; Barman, et al., 2010). This is accompanied with the low air temperatures and calm winds during the winter resulting in reduction in ambient ventilation that might be the cause for increased occupational and ambient PM$_{10}$ levels in the valley (Aryal et al., 2008). The increased average air tempera–ture during summer periods generates upward movement of the air in the valley, resulting in an increase of the ambient ventilation in the valley. Air temperature also increases in summer, because of lower energy uses and thus resulting lower air emissions, later which accompanied with lots of rainfall during monsoon. As a result large amounts of PM$_{10}$ are removed by rainfall during monsoon and are diluted by the increased ambient ventilation during pre–monsoon. This is also supported by Giri et al. (2008) who reported that the pre–monsoon season is associated with high wind speeds, relatively less humidity whereas monsoon season is associated with high temperature, precipitation and humidity, resulting in cleaning of the lower atmosphere of pollutants during monsoon.

4.3. Relationship of occupational and ambient PM$_{10}$

Normality test was performed in the form of a Q–Q plot, where observed values were plotted against a known distribution. If the distribution is normal, the plot would have observations distributed closely around a straight line. In Figure 3, the expected normal distribution is the straight line and little dots are the observed values from our data. Figure 3 shows that the distribution deviates for a few cases from normality at the low and upper end for occupational and ambient PM$_{10}$. The authors conclude that the distribution is pretty much normal, except for some outliers.

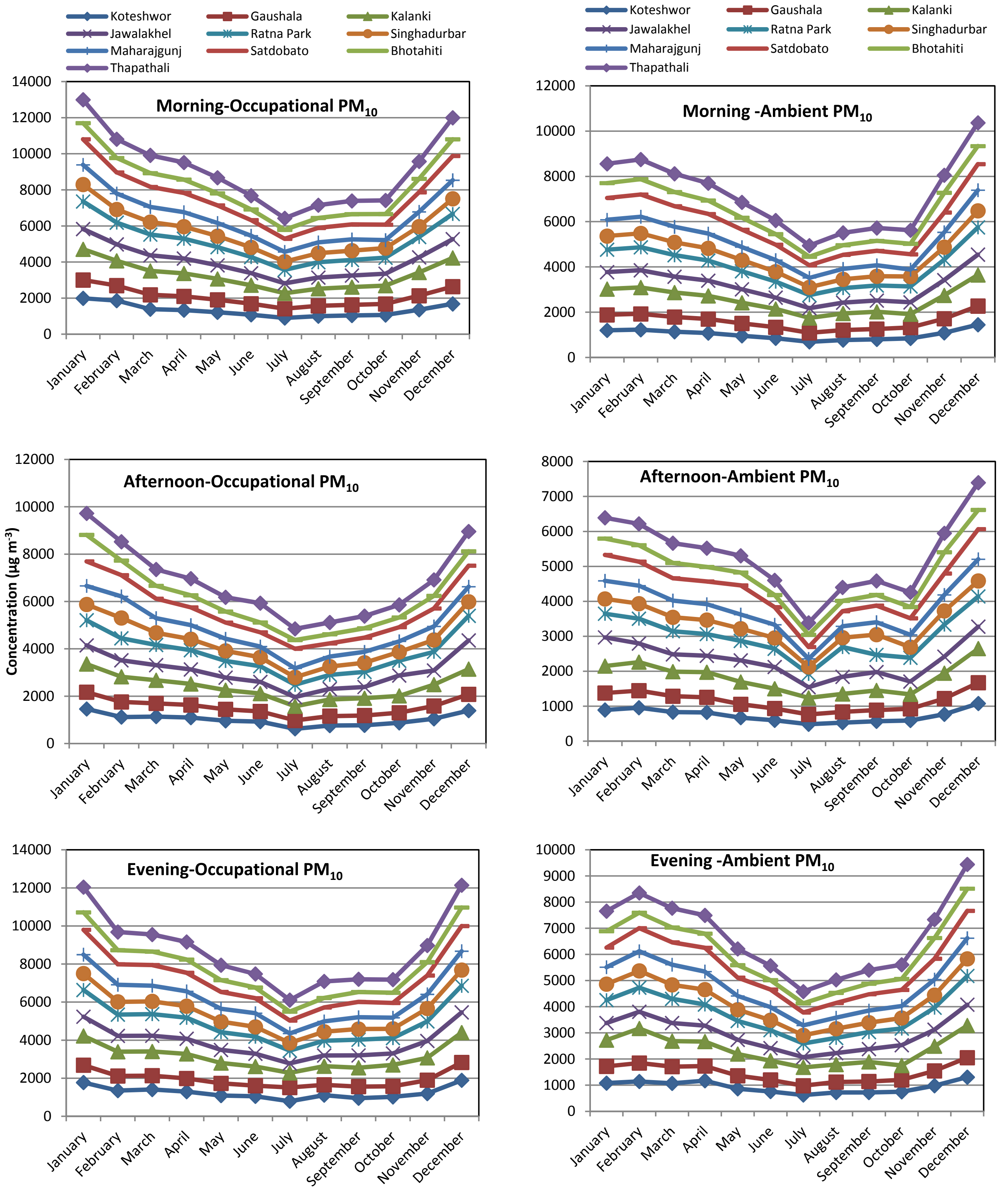


***Figure 2.** Monthly variation of occupational and ambient PM$_{10}$ concentrations at the ten study sites.*

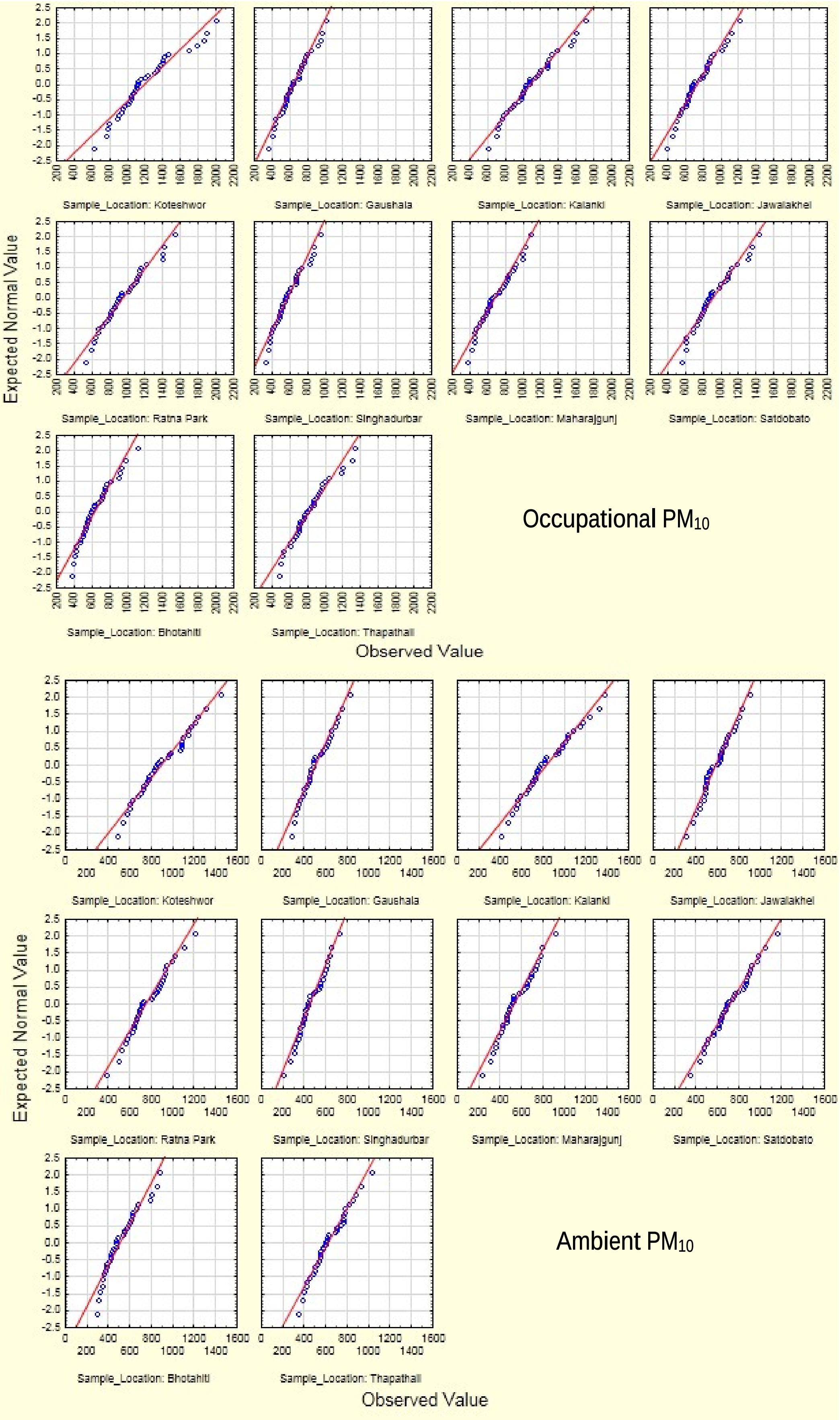


Figure 3. *Observed and expected occupational and ambient PM_{10} concentrations at the ten study sites.*

The occupational and ambient PM_{10} ratio was an indicator for evaluating the difference between occupational and ambient atmosphere during different seasons, and their dependency could imply a source of relationship between occupational and ambient environments. Figure 4 showed that, occupational and ambient PM_{10} are significantly ($P = 0.00$) related at the studied sites during all seasons. The relationship between the two variable is considered is a good one if $R^2>0.5$ and it is stronger when the value is close to 1. R^2 values for pre–monsoon, monsoon, post–monsoon and monsoon are 0.93, 0.76, 0.69 and 0.71, respectively. The relationship is stronger during pre–monsoon and monsoon than the post monsoon and winter seasons. Interestingly, during all seasons ambient PM_{10} concentrations increased at all sites significantly ($P = 0.00$) with the increasing concentration of occupational PM_{10}. The slopes of the trend–lines for the occupational PM_{10} were positive with the strong value of R^2 during pre–monsoon and monsoon. This might be due to the, high wind speed and low humidity during pre–monsoon and high precipitation and low atmospheric pressure during monsoon.

The regression lines between the ambient and occupational PM_{10} concentrations at the two sites are also presented in Figure 4 and a high dependence ($R^2>0.5$) of ambient PM_{10} on occupational PM_{10} is revealed in all seasons. The significant ($P = 0.00$) ($R^2 = 0.93$) dependency, in combination with the slope of 0.77, shows that the ambient PM_{10} variability during pre–monsoon season is controlled by the occupational PM_{10}, while the intercept of 32.81 demonstrates the influence of the other parameters like wind speed, humidity, turbulance, etc. In monsoon, a slope of 0.66 and an intercept of 67.64 demonstrate the common fluctuation of the ambient PM_{10} levels due to high precipitation and low atmospheric pressure affecting the ambient atmosphere of the studied site. Similar significant ($P = 0.00$) moderate ($R^2>0.5$) dependency of ambient PM_{10} on occupational PM_{10} is deduced with data from the post monsoon and winter seasons. The above results obviously specify (i) the dominant role of occupational PM_{10} in controlling ambient PM_{10} loads at all the studied sites, and (ii) each season has its own unique meteorological parameters that influence concen–trations of PM_{10} in the occupational and ambient air in high density traffic road intersections of Kathmandu Valley.

Figure 5 shows the interrelationships among occupational PM_{10} and ambient PM_{10} concentrations at the study sites, in terms of seasons, months, and shifts. The occupational PM_{10} showed a significant ($P<0.05$) positive relationship with seasons; however, there were significant ($P<0.05$) negative relationship with the months and significant ($P<0.05$) strong ($r = 0.91$) positive relation–ship with ambient PM_{10}. The ambient PM_{10} also showed a signifi–cant ($P<0.05$) positive relationship with seasons.

Cluster analysis was performed to see whether the studied sites form natural clusters that can be labeled in a meaningful manner. Figure 6 shows the dendrogram plot obtained from cluster analysis with z–score normalization. For cluster analysis, euclidean distance and complete linkage has been considered. Euclidean distance is the probably the most commonly chosen type of distance, in which case, simply the geometric distance in the multidimensional space computed as: distance $(x,y) = \{S_i\,(x_i - y_i)^2\}^{½}$. On the other hand, in the complete linkage method, the distances between clusters are determined by the greatest distance between any two objects in the different clusters (i.e., by the furthest neighbors). z–score normalization changes the rate of attributes,

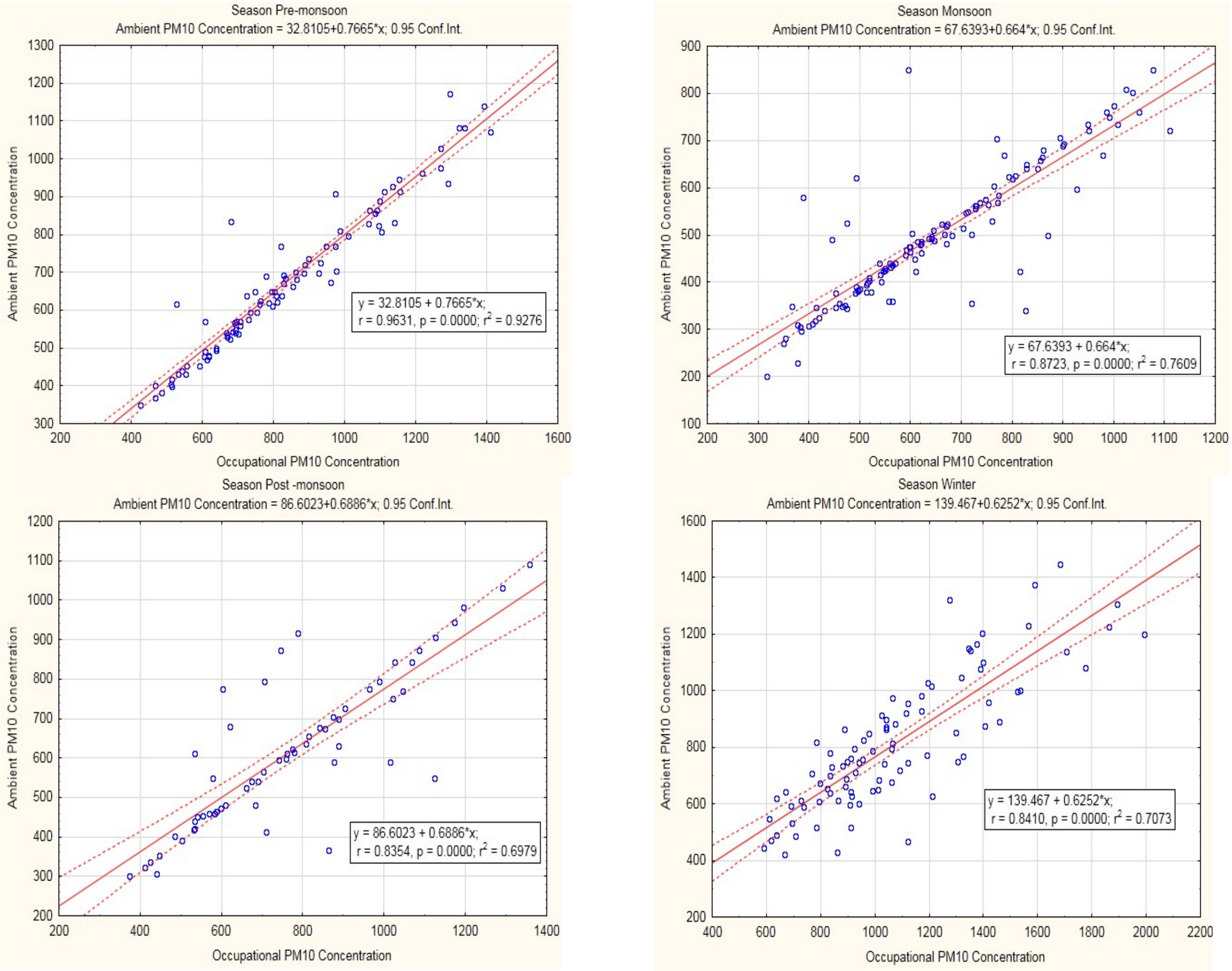


Figure 4. *Occupational and ambient PM_{10} ratios at the ten study sites during different season.*

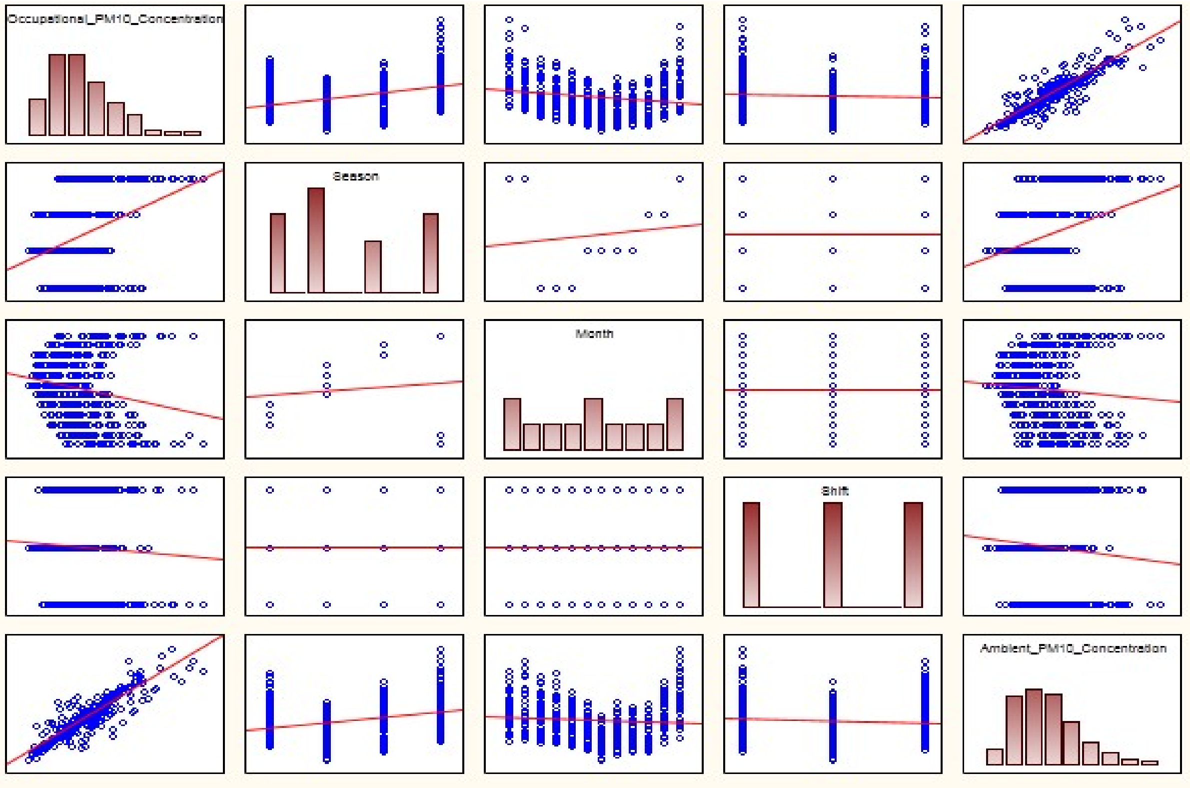


Figure 5. *Correlations of occupational PM_{10}, season, month, shift and ambient PM_{10} concentration at the study sites.*

and thus they have same mean and variance *[Z = (S–μ)/σ]*, where *Z* refers to the *z*–score, *μ* is the estimate of the sample's mean, *σ* is the estimate of the sample's standard deviation, and *S* is an individual score within the distribution having a mean *μ* and variance *σ*. When the relationship among the studied sites is considered in terms of occupational PM_{10}, apparently, first there is three clusters consisting of only Koteshwor and Kalanki as first cluster; Gaushala, Bhotahiti, Maharajgunj, Singhadurbar, and Jawalakhel as the second cluster; and Ratna Park, Satdobato and Thapathali as the third cluster. The second and third clusters, join at the approximate linkage distance out to 60, finally, the first cluster joined with the other clusters at the linkage distance of approximately 100. In terms of ambient PM_{10}, there is also three clusters consisting of only Koteshwor and Kalanki as first cluster as it is for occupational PM_{10}; Ratna Park, Satdobato and Thapathali as the second cluster; Gaushala, Bhotahiti, Maharajgunj, Singhadurbar, and Jawalakhel as the third cluster, suggesting elevated resemblance between these studied sites. The first and second clusters, join at the approximate linkage distance out to 60, finally, the third cluster joined with the first and second clusters at the linkage distance of approximately 100.

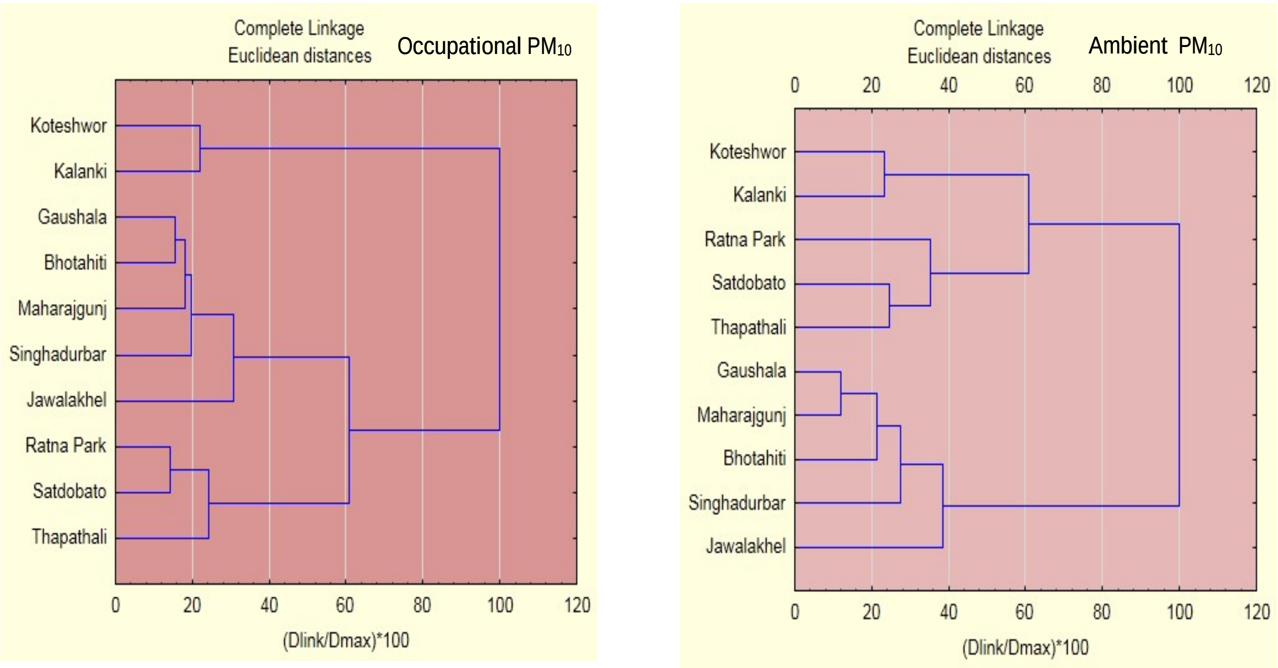


Figure 6. *Relationships of occupational, ambient PM_{10} concentrations among the study sites.*

5. Conclusion

The time, monthly and seasonal patterns of average occupational and ambient PM_{10} concentrations measured in some high density traffic areas and road intersections of Kathmandu valley during the period of one year were analyzed and discussed. The authors reached to the following conclusions:

- The occupational PM_{10} play a significant dominant role in controlling ambient PM_{10} loads at the high density traffic areas and road intersections of Kathmandu valley.
- The occupational and ambient PM_{10} concentrations in high density traffic areas and road intersections of Kathmandu Valley are highly predisposed by monthly and seasonal change and each season has its own unique meteorological parameters that manipulate the variation in concentrations.
- The occupational and ambient PM_{10} concentrations in high density traffic areas and road intersections of Kathmandu Valley showed also a marked variation with time (morning, afternoon and evening) during the day. In most of the cases the highest value of occupational and ambient PM_{10} were recorded during December followed by November.
- High precipitation, humidity and low atmospheric pressure during monsoon help to clean the lower atmosphere resulting in lower concentrations of occupational and ambient PM_{10} during monsoon seasons, while low temperatures and low wind speeds in winter caused greater accumulation of PM_{10} in the occupational and ambient air.
- High density traffic areas and road intersection of the Kathmandu valley were seriously polluted by PM_{10}. Monthly and yearly average occupational and ambient PM_{10} concentrations at the high density traffic areas and road intersections greatly exceeded the 24–h average limit value ($120\,\mu g\,m^{-3}$) in Nepal. As per MOPE categories, all the studied sites can be considered as “hazardous” in comparison with the benchmark of $425\,\mu g\,m^{-3}$. More research is needed to assess the health impacts of air pollution on traffic police in Kathmandu valley, Nepal.

Acknowledgements

This paper is the outcome of the PhD research work of the 1st author under the supervision of third and fourth authors. The authors are grateful to NUFU Network Project, Norway and International Centre for Integrated Mountain Development (ICIMOD), Nepal for financially support the study. The authors are grateful to all the subject traffic policemen and the authorities of Kathmandu Metropolitan Traffic Police specially Mr. Bikash Shrestha, The Deputy Superintendent of Police for permitting and co–operating during the entire study period. Thanks to the Department of Environmental Science and Engineering of Kathmandu University for providing the equipments and lab facilities.

References

Anderson, H.R., Bremner, S.A., Atkinson, R.W., Harrison, R.M., Walters, S., 2001. Particulate matter and daily mortality and hospital admissions in the west midlands conurbation of the United Kingdom: associations with fine and coarse particles, black smoke and sulphate. *Occupational and Environmental Medicine* 58, 504-510.

Aryal, R.K., Lee, B.K., Karki, R., Gurung, A., Kandasamy, J., Pathak, B.K., Sharma, S., Giri, N., 2008. Seasonal PM_{10} dynamics in Kathmandu valley. *Atmospheric Environment* 42, 8623-8633.

Barman, S.C., Kumar, N., Singh, R., Kisku, G.C., Khan, A.H., Kidwai, M.M., Murthy, R.C., Negi, M.P.S., Pandey, P., Verma, A.K., Jain, G., Bhargava, S.K., 2010. Assessment of urban air pollution and it's probable health impact. *Journal of Environmental Biology* 31, 913-920.

Bhaskar, B.V., Rajasekhar, R.J., Muthusubramanian, P., Kesarkar, A., 2008. Measurement and modeling of respirable particulate (PM_{10}) and lead pollution over Madurai, India. *Air Quality, Atmosphere and Health* 1, 45-55.

Brunekreef, B., Holgate, S.T., 2002. Air pollution and health. *Lancet* 360, 1233-1242.

Dockery, D.W., Pope, C.A., 1994. Acute respiratory effects of particulate air pollution. *Annual Review of Public Health* 15, 107-132.

Dokiya, Y., Maruta, E., Yoshikawa, T., Ishimori, H., Tsurumi, M., 1992. Chemical species in the deposition at some peaks of the Himalaya. *Environmental Science* 5, 109–114.

ENPHO, 1999. Reduction of Pollution and Waste in the Himal Cement Company Limited. Environment and Public Health Organization (ENPHO), Kathmandu, Nepal, 52 pp.

Gerasopoulos, E., Kouvarakis, G., Babasakalis, P., Vrekoussis, M., Putaud, J.P., Mihalopoulos, N., 2006. Origin and variability of particulate matter (PM_{10}) mass concentrations over the eastern Mediterranean. *Atmospheric Environment* 40, 4679-4690.

Giri, D., Krishna, M.V., Adhikary, P.R., 2008. The influence of meteorological conditions on PM_{10} concentrations in Kathmandu valley. *International Journal of Environmental Research* 2, 49-60.

Giri, D., Murthy, V. K., Adhikary, P.R., Khanal, S. N., 2006. Ambient air quality of Kathmandu valley as reflected by atmospheric particulate matter concentrations (PM_{10}). *International Journal of Environmental Science and Technology* 3, 403-410.

Giri, D., Murthy, V.K., Adhikary, P.R., Chhetri, R.B., Khanal, S.N., Sharma, C.K., 2004. Descriptive Statistical Analysis of PM_{10} Values in Selected Air Monitoring Sites in Kathmandu Valley. RONAST, Nepal.

Hillamo, R.E., Kerminen, V.M., Maenhaut, W., Jaffrezo, J.L., Balachandran, S., Davidson, C.I., 1993. Size distributions of atmospheric trace elements at Dye 3, Greenland - I - distribution characteristics and dry deposition velocities. *Atmospheric Environment. Part A. General Topics* 27, 2787-2802.

HMG/MOPE, 2003. Draft Report on Air Emission Inventory. Kathmandu, Nepal.

Karmacharya, A.P., Shrestha, R.K., 1993. Air Quality Assessment in Kathmandu Valley Report. Environment and Public Health Organization, Kathmandu. 28 pp.

Liu, Y., Chen, R., Shen, X., Mao, X., 2004. Wintertime indoor air levels of PM_{10}, $PM_{2.5}$ and PM_1 at public places and their contributions to TSP. *Environment International* 30, 189-197.

Majumder, A.K., Carter, W.S., Bajracharya, R.M., Khanal, S.N., Acharya, S., Kandel, P., Koju, R., Tuladhar, N.R, Akhter., J., 2010a. Study of the pathogenic microorganism's prevalence in respiratory tract of the traffic police personnel due to heavy air pollution in Kathmandu valley, Nepal. *Journal of Environmental Science and Natural Resources* 3, 211-214.

Majumder, A.K., Acharya, S., Kandel, P., Bajracharya, R.M., Khanal, S.N., Carter, W.S., Koju R., Pant, P., 2010b. Air pollution impact assessment for traffic police personnel of Kathmandu valley: a hematological finding in the blood samples. *Bangladesh Journal of Environmental Science* 18, 125-128.

McNabola, A., McCreddin, A., Gill, L.W., Broderick, B.M., 2011. Analysis of the relationship between urban background air pollution concentrations and the personal exposure of office workers in Dublin, Ireland, using baseline separation techniques. *Atmospheric Pollution Research* 2, 80-88.

Pope, C.A., Thun, M.J., Namboodira, M., Dockery, D.W., Evans, J.S., Speizer, F.E., Health, C.W.Jr., 1995. Particulate air pollution as a predictor of mortality in a prospective study of U.S. adults. *American Journal of Respiratory Critical Care Medicine* 151, 669- 674.

Regmi, R.P., Kitada, T., Kurata, G., 2003. Numerical simulation of late wintertime local flows in Kathmandu valley, Nepal: implication for air pollution transport. *Journal of Applied Meteorology* 42, 389-403.

RONAST, 1992. A Study on Traffic Volume in Busy Streets of Kathmandu Valley. Royal Nepal Academy of Science and Technology (RONAST) to MEIP/URBAIR, 13 pp.

Sapkota, B.K., 1996. Study of Visibility and Particulate Pollution over Kathmandu Valley, Project report, Institute of Engineering, Pulchowk Campus. Nepal.

Shrestha, P., 2002. *Study on Prevalence of Respiratory Illness in Kathmandu Valley Due To Suspended Particulate Matter*. BS degree thesis, St. Xavier's College, Kathmandu, Nepal, 78 pp.

Shrestha, P., 2002. *Study on Prevalence of Respiratory Illness in Kathmandu Valley due to Suspended Particulate Matter*. Dissertation submitted in partial fulfillment of the requirements of the degree of Bachelor of Science (Environmental Science), St. Xavier's College, Kathmandu, 78 pp.

Shah, J.J., Nagpal, T., 1997. Urban Air Quality Management Strategy in Asia: Kathmandu Valley Report. The World Bank Technical Paper No. 378/1997, Washington D.C., USA, 155 pp.

Viana, M., Querol, X., Alastuey, A., Cuevas, E., Rodriguez, S., 2002. Influence of African dust on the levels of atmospheric particulates in the Canary Islands air quality network. *Atmospheric Environment* 36, 5861-5875.