The Influence of Meteorological Conditions on PM$_{10}$ Concentrations in Kathmandu Valley

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ABSTRACT: Air pollution is a problem in Kathmandu, Nepal. Particulate matter concentrations often exceed threshold values at which human health is severely affected. The problem is serious since it is in the valley topography wherein the meteorological parameters role is significant. This study addresses the linkages between meteorological processes and air pollution in the lower atmosphere of the Kathmandu Valley. The study establishes influence of meteorological conditions like temperature, rainfall, humidity, atmospheric pressure, wind direction and speed with elemental concentrations of PM$_{10}$ in Kathmandu Valley. Government of Nepal has established permanent air monitoring stations in the valley and a continuous PM$_{10}$ data is available on the public domain. The data relating to average daily temperature, rainfall, humidity, atmospheric pressure, wind speed and wind direction recorded in Tribhuvan International Airport was used for analysis. The mean association of PM$_{10}$ levels and meteorological parameters during the period of March 2003 and December 2005 is established. Pearson's coefficient of correlation was applied to study the association between PM$_{10}$ and meteorological variables. The atmospheric pressure, wind velocity and humidity was found to be significant factors compared to others influencing PM$_{10}$. Increase of rainfall and humidity has negative correlation with average PM$_{10}$ concentration in Kathmandu valley. The study also infers that the wind speed and atmospheric pressure inducing increment of average PM$_{10}$ concentration in Kathmandu Valley.

Key words: PM$_{10}$, Meteorological Parameters, Correlation Coefficient, Valley Environment

INTRODUCTION

Air pollution has emerged as a potential threat to the residents of Kathmandu Valley, Nepal, long predicted by a study which indicated the combination of the 'basin effect' along with limited air movement (Fleming, 1970) In Kathmandu Valley the air pollution is largely a fall-out of industrial emissions, house energy usage pattern, vehicular emission and the ambient microclimate. The valley is vulnerable to air pollution, particularly owing to particulate pollution attributable to bowl-like topography, exploding population inflow, rapid urbanization, valley centric industrialization and significant increase of vehicular transport in narrow streets. Particulate matter is a primary concern in Kathmandu Valley as reported by the exceeding levels to the prescribed value guideline value for ambient air quality WHO whereas other gaseous criteria pollutants like sulfur oxides, nitrogen oxides and carbon monoxide are below the WHO guideline values (URBAIR, 1997; Jha and Lekhah, 2003). The increase in particulate pollution is a potential human health risk. The bowl like topography restricts wind movement and retains the pollutants in the atmosphere particularly when thermal inversions occur, when cold air flowing down from the mountains is trapped under a layer of warmer air, which acts like a lid over a bowl. Furthermore, the mountain-valley setting produces mountain valley circulations that influence air pollution transport especially in winter. During the winter, air pollution is carried out of Kathmandu Valley during the day, while a mountain breeze causes pollution to return to the valley at night.

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Among many climatic factors, the most important is in the dispersion, transformation and removal of air pollutants from the ambient atmosphere. Study of the relationship of air pollution and individual meteorological variables may be misleading as it does not account for the interrelation between the variables, while air pollutant levels normally respond to all of meteorological variables representing an air mass (Lam and Cheng, 1998). Although the relationships between synoptic meteorology and air pollution have been investigated for pollutants such as ozone (Broomfield, *et al.,* 1996; Davis, *et al.,* 1998, Krupa, *et al.,* 2003), SO_2 (Kalkstein, *et al.,* 1986), NO_2 (Perez and Trier, 2001), and even visibility (Sequeria R. and Lai, 1998).In order to develop an environmental forecasting tool Slini, *et al.,* 2003 investigated correlation of air pollution and meteorological data using neural networks Limited information is available about the dependence of urban aerosol on the city's geographical, geological and meteorological conditions. This study examines the relationship between meteorological parameters and urban air pollutants, helping to understand relationships between the atmospheric circulation, local meteorology, and concentrations of troposphere air pollutants. This study also examines linkage between meteorological parameters and respirable particulate matter (PM_{10}) pollution dynamics in Kathmandu Valley and to delineate influence of meteorological parameters on PM_{10} episodes in Kathmandu Valley.

MATERIALS & METHODS

The study area is Kathmandu Valley, capital metropolis of the Himalayan Kingdom of Nepal. The valley has three districts, namely Kathmandu, Lalitpur and Bhaktapur. The valley is an oval shaped and has an area of 352 sq. Km., situated at an altitude of 1300 m to 1350 m. Kathmandu Valley is influenced by the Indian monsoon owing to the proximity to Bay of Bengal. There are four climatic seasons, post monsoon spanning from March to May months, monsoon from June to September, post monsoon from October to November and the winter from December to February. The general pattern is characterized by a windy hot and humid climate in March to May, followed by a well-defined monsoon. About

82 per cent of the rain falls during the period of monsoon associated with an annual rainfall of 1,400 mm. Other periods are characterized by spell of dry, cold winter. In winter the central valley-region experiences a minimum temperature often falling bellow 0 °C with a chilly 12 °C maximum, while in summer it rises up to 35 °C. Wind has a strong current in around the months of March to May. Major part of the winds blowing over the valley is southwesterly and northwesterly. Wind speed ranges between 0.5-7.5 m/s. Irrespective of the seasons, in the Kathmandu valley during afternoon (14:45 PM) and late afternoon (17:45 PM) period the wind speed observed was maximal on most of the occasions. The relative humidity reaches more than 80 % during monsoon season but decreases to about 50 % during dry season. Fog is common in the morning during the winter. Another winter characteristic is that of a high altitudinal variation with extreme diurnal radiation leads to a potentially strong cooling system in the night and a warming in the day. Inversion phenomenon is a common occurrence and conditions are conducive during summer as well as in winter seasons. The atmosphere then acts like a cover over the city and the concentration of pollutants may build up considerably due to poor atmospheric dilution (Pandey, 1987). Permanent air pollution monitoring sites is established by Government of Nepal at six sampling stations in the valley. The monitoring sites located at urban roadside station (representing urban traffic place at, Putalisadak and urban hospital place at Patan Hospital).
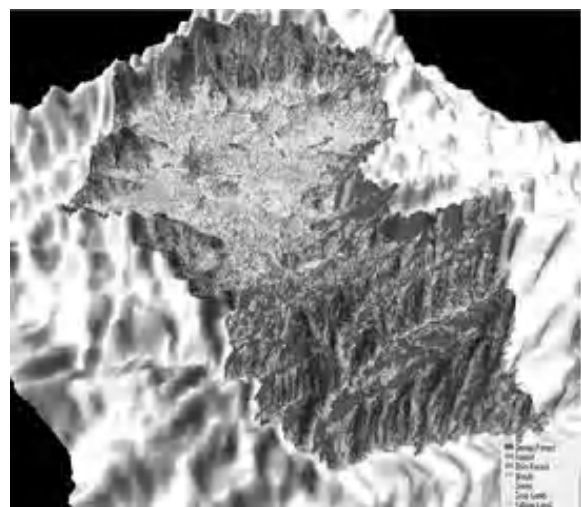

Fig. 1. Kathmandu Valley

The urban residential station is located at city core residential place, Thamel. The urban background station is represented by one station at Tribhuvan University, and the other at Bhaktapur. The valley background station is far away from urban areas located at Matsyagaon. The air monitoring is located in all directions and represents all predominant urban areas associated with high, medium and low human activities (Fig. 2). A similar establishment of air monitoring sites and PM_{10} monitoring conducted between years 1994 and 1999 from the network of air sampling stations in Taiwan is reported (Kuang, 2002).
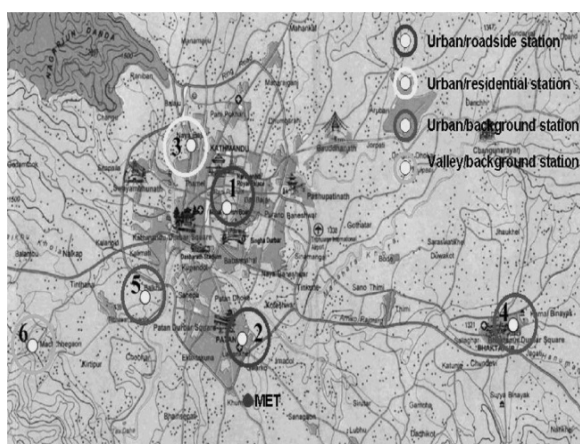

Fig. 2. Map showing the air monitoring sites in Kathmandu Valley (Gautam, *et al.*, 2004)

The Putalisadak air-monitoring station located almost in the central region of the city represents city core urban area. The approximate distance of other air monitoring stations from Putalisadak was Thamel at about 2 km (West), Patan Hospital at 5 km (South), Tribhuvan University (TU) at 6 km (Southwest), Matysagaon at about 7.5 km. (South-West) and Bhaktapur located at about 13 km (East). Putalisadak, Patan Hospital and Thamel are in the core city area. They have emerged as growing commercial centers of Kathmandu Valley. The area with large commercial buildings and heavy vehicular traffic characterize this place. TU, at Kirtipur is close to the urban center in Kathmandu but located in outskirts. Bhaktapur is a different city about 13 km from Kathmandu, however within the valley precincts. Bhaktapur area is having brick manufacturing plants in the 4 Sq. Km. areas around the air monitoring station. Matsyagaon falls under village development category and hence provides background information.

Since the air monitoring stations do not provide the data relating to climate and meteorological parameters required to establish the relation between the PM_{10} and meteorological parameter, the data recorded by government established official weather monitoring station at Tribhuvan International Airport (TIA) is considered for analysis. TIA is the only monitoring station in Kathmandu Valley that measures visibility together with meteorological variables including wind direction, wind speed, temperature, relative humidity, atmospheric pressure and precipitation.

In Kathmandu Valley particulate matter concentration is monitored by standard method on daily basis. A Low Volume Sampler LVS for PM_{10} and $PM_{2.5}$ without pneumatic movement of filters was used in order to select the most robust and simple instrumentation. The $PM_{10}/PM_{2.5}$ sampler was Model 85-02 of M/s. Instrumatic, Denmark. The $PM_{10}/PM_{2.5}$ air-monitors were custom designed specifically for use in the Kathmandu Air Quality Monitoring programme according to the EN12341 standard. The Instrument is automatic capable of taking 24 h continuous ambient air sample. The monitoring stations automatically collect 24 h samples through the eight filters mounted three meter above ground. The samples are collected once a week and analyzed in a local recognized laboratory (Gautam, *et al.*, 2004).

In this study we have considered the average of daily 24-hour average PM_{10} concentration recorded in six air monitoring sites in Kathmandu Valley representing PM_{10} concentration of entire valley. The data through the years 2003 to 2005 is taken up for analysis forming the study period. Meteorological data from TIA was used considering weather information of corresponding period. However on some occasions the data was not available owing to several logistic reasons. If data for any one of the stations is missing form any of the six air monitoring station, that day is removed from the analysis. A total of 690 observations were considered for the analysis. To get a better representation of PM_{10} concentration in the Kathmandu Valley and also to understand the influence of meteorological parameters on PM_{10}, only those days were considered in which the PM_{10} data were available for all six stations during study period.

After categorizing the data in different data subsets, an assessment of meteorological influence on PM$_{10}$ pollution concentration was completed using Excel spreadsheets and subsequently data analysis competed using SPSS statistical software tool. Descriptive statistical parameters like mean, standard deviation and simple box plots of the data were constructed in order to show differences between categories. Inferential statistical t-tests, ANOVAs and Tukey Honestly Significantly Different (HSD) procedure along with Levene test were applied to show the statistical significance of the differences. Scatter diagrams and simple correlations were performed to assess the relation between meteorological parameters and ambient concentration of particulate matter (PM$_{10}$) in Kathmandu Valley.

RESULTS & DISCUSSION

During the study period, in the year 2005, a highest PM$_{10}$ daily average of 633 µg/m^3 was observed. In Kathmandu Valley the highest mean concentration was recorded at the motor vehicular traffic-oriented commercial site of Putalisadak. The lowest concentrations were noted at Matsyagaon representing valley background. Except Matsyagaon air monitoring station, regardless of the year, the annual average concentration at TU, Bhaktapur, Thamel, Patan Hospital and Putalisadak were found to be higher compared to prescribed standard of 50 µg/m^3. The average concentrations in urban background site (TU) were 1.46 times higher than that observed in Matsyagaon where as the average concentrations in urban parts namely Thamel, Patan Hospital and Putalisadak were 2.80, 3.88, and 4.19 times higher than that observed in

Matsyagaon. Descriptive statistics for PM$_{10}$ concentration, during the study period are summarized in Table 1. Within the Kathmandu Valley area daily 24 h average PM$_{10}$ ranged from ₇ µg/m^3 (Matsyagaon in the year 2004 and 2005) to 633 µg/m^3 (Putalisadak in the year 2005). In Kathmandu valley annual average concentrations for the year 2003, 2004 and 2005 were 113.95 µg/m^3, 134.83 µg/m^3 and 116.45 µg/m^3 respectively. Irrespective of the year annual average concentrations at Kathmandu valley were found higher compared to annual limit value of 50 µg/m^3 proposed by US-EPA. Government of Nepal has set national ambient air quality standards; the maximum daily 24 h average PM$_{10}$ concentration in ambient air is 120 µg/m3. The Fig. 3 depicts trend of daily PM$_{10}$ variation over the Kathmandu Valley during the study period. The instances surpassing the prescribed limit of PM$_{10}$ were higher. The minimal levels of PM$_{10}$ were observed particularly during the monsoon seasons. Episodic very high levels were also observed during early summer. Out of 690 observations 48.7% exceedances was noted compared to the prescribed limit in Kathmandu Valley Area. Therefore viewing the data with respect to seasons provides a better understanding of dispersion characteristics of particulate concentration. In Kathmandu Valley area the PM$_{10}$ were observed high during winter followed by the pre-monsoon period characterized by a period of excess wind and warmer months. The levels were consistently lower in the monsoon period. The quality of air in the Kathmandu valley area observed was better between July to September months compared to other months.

Table 1. Descriptive statistics for daily average PM$_{10}$ concentration within Kathmandu Valley and in Kathmandu Valley Area values in (µg/m^3)

Statistics	Matsyagaon	TU	Bhaktapur	Thamel	atan Hospit	Putalisadak	Kathmandu Valley
N	690	690	690	690	690	690	690
Mean	47.64	69.76	103.87	133.54	184.99	199.58	123.23
Median	38.00	63.00	91.50	124.50	179.00	191.00	115.75
Std. Deviation	32.09	45.93	67.79	70.22	72.76	86.04	57.21
Range	236.00	310.00	326.00	452.00	542.00	606.00	377.17
Minimum	7.00	8.00	11.00	29.00	37.00	27.00	25.83
Maximum	243.00	318.00	337.00	481.00	579.00	633.00	403.00
Percentiles 10	18.00	20.00	31.00	54.00	101.00	98.00	58.69
Percentiles 90	91.90	128.90	203.90	228.00	276.00	314.90	196.00

The day to day pattern with respect to PM_{10} levels within a week during the study period indicates mean PM_{10} concentration attaining its minimum value on Saturday (119.74 $\mu g/m^3$) and a maximum value on Friday (128.41 $\mu g/m^3$) in the Kathmandu Valley.

The concentrations were found to differ significantly (at 0.05 level) between year, months, seasons and were not found to differ significantly (at 0.05 level) between days of a week according to Analysis of Variance (ANOVA). The Homogeneity of Variance Levene test on PM_{10} values during study period suggests that there was consistency between the years and days of a week. However the variation levels differed significantly between the months and the seasons (at 0.05 levels). To establish the relationship between seasons and PM_{10} values, Chi-square test of independence was applied on the data set. The analysis revealed that in the Kathmandu Valley the quality of air depends on the seasons. Further the analysis revealed that the quality of air was independent on days of a week at 0.05 level of significance.

The pollutants get airborne from the ground surface, their residence in the ambient atmosphere and the formation of secondary pollutants is controlled not only by the rate of source-emission but also by wind speed, turbulence level, air temperature, and precipitation. The other integral phenomenon particularly in urban environment is re-suspension of particulates owing to vehicular movement. Particles, which have settled on ground surface, get dislodged and get air borne by such frequent turbulences. Once getting airborne the particulates get influenced by the prevailing climatic conditions, inferring that it has influence on weather and weather also having its own influence on pollutant concentration, distribution and translocation. Many studies indicated that TSP and PM_{10} concentration in ambient air is affected by wind speed, wind direction, solar radiation, relative humidity and rainfall. (Alpert, *et al.,* 1998; Monn, 2001). Among many weather parameters, temperature and wind direction were two main factors influence to pollutant load as a study of Netherlands has reported (Van der Wal, *et al.,* 1996, 2000). Another report from Hongkong relates to influence of monsoon and rain (Chang, *et al.,* 2000; Qin, *et al.,* 1997). The influence of wind speed and direction is reported from a study at Singapore (Orlic, *et al.,* 1999). In the South of Spain, a study related to the influence of wind direction on PM concentrations, inferring that the sources for PM Pollution were external and spread over the area (Gallero, *et al.,*, 2006).

Wind speed and direction provide real-time information on pollutant transport in a region and are used to assess the relationships between sources and pollutant levels.

Temperature affects fuel usage and ambient chemical reactions; radiation sets up photochemical reactions with other pollutants; precipitation and relative humidity largely removes pollutants from the atmosphere (Seinfeld and Spyros, 1998).
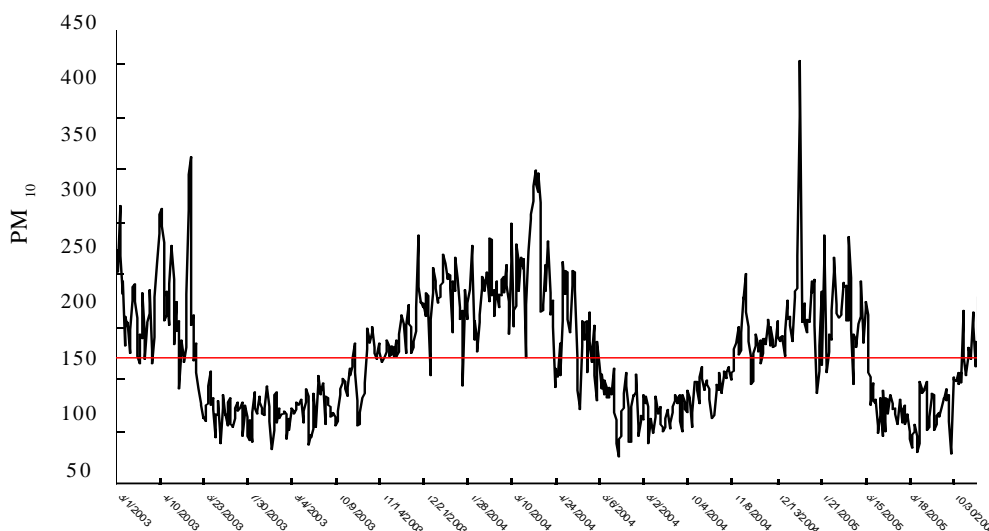

Fig. 3. PM_{10} Concentration in Kathmandu Valley Area

In a stipulated season and region, we can assume that the amount from anthropogenic emission sources are constant, therefore the observance of seasonal variation in PM_{10} concentrations should be partially attributable to changes in the meteorological conditions. The variation in mean PM_{10} concentrations noted at different sites in a Kathmandu Valley suggests influence of climate particularly the rain (Giri, *et al.,* 2006). In order to gain more understanding on their variability and interrelations, daily mean values of meteorological parameters and PM_{10} concentration were compiled and analyzed. The different meteorological and air pollutants time series were studied to determine seasonal variations and its influence. Besides this exercise, selected meteorological parameters were correlated with the PM_{10} concentration. The effect of maximum temperature, rainfall, atmospheric pressure, wind velocity and relative humidity on PM_{10} concentration was studied at the same location (Kathmandu Valley) during the study period. The Table 2 depicts average concentration values determined within selected ranges of temperature, precipitation, atmospheric pressure, wind speed and relative humidity in Kathmandu Valley. In Kathmandu Valley Area average concentration values determined maximum within ambient air temperature ranges 11-20; similar finding was observed in Abbassiya monitoring station, Cairo (Elminir, 2005).

Rain is shown to exhibit very good washing effect on PM_{10} concentration in Kathmandu Valley. Average PM_{10} concentration in Kathmandu Valley decreased as rainfall increased. As regards influence of humidity on particulates, the results in Kathmandu Valley found that the highest average concentration for PM_{10} occurred at humidity range 40-60%. This is largely attributable to the fact that humidity factor influences particles to gather mass and settle down on the ground rather getting air-borne. On account of this fact, the average PM_{10} concentration in Kathmandu Valley shows a decreasing trend with an increment in ambient relative humidity. As per the general expectation, PM_{10} concentrations should decrease when the there is an increased wind speed. However, this is not an obvious in Kathmandu Valley based on the findings. Average PM_{10} concentration in Kathmandu Valley increases with increase of atmospheric pressure as well as wind speed. Wind does not blow pollutant out from Kathmandu valley but it brings in the pollutant inside the valley, indicating no dilution-effect and transport by winds. This is possible due to the topography of the Kathmandu Valley. The finding is in agreement with a reported study from greater Seoul area, which brings out that the topographic features can serve as barriers that impede the transport of air pollutants to other areas (Ghim, *et al.,* 2001).

Table 2. Average concentration values determined within selected ranges of temperature, precipitation, atmospheric pressure, wind speed and relative humidity

T (°C)	N	Mean PM_{10}	P (mm)	N	Mean PM_{10}	AP (mmhg)	N	Mean PM_{10}	WS (m/s)	N	Mean PM_{10}	RH (%)	N	Mean PM_{10}
Less than 11	2	94.34	No rain	424	146.79	Less than 855.0	3	77.44	0	33	109.19	40.00-60.00	5	272.17
11.00-16.00	8	193.98	0.001-10.000	162	91.74	855.0-860.0	87	96.21	1-2	272	115.43	60.00-80.00	204	159.13
16.00-20.00	71	170.04	10.000-20.000	49	81.88	860.0-865.0	186	111.95	2-3	319	126.79	80 and above	481	106.45
20.00-24.00	152	145.05	20.000-30.000	25	80.89	865.0-870.0	287	135.13	3-4	57	142.57			
24.00-28.00	206	109.93	30.000-40.000	15	67.23	870.0-875.0	125	132.60	4 and above	9	161.87			
28.00-32.00	239	102.82	40.000-50.000	4	65.67	875.0 and above	2	123.09						
32 and above	12	162.29	50 and above	11	56.44									

In Katmandu Valley wind from the east and southeast accounts 5.5% and 6.8% respectively, where as wind from south and southwest accounts 17.7% and 31.2% of the total observations. Similarly wind from west and northwest accounts 22.5% and 10.5% of the total observations. The wind from north and northeast accounts 1.60% and 2.0% respectively of the total observations indicating the wind prevailing from the southwest and northwest. By analyzing the wind rose data, it was found that wind blows mainly from two directions west and south in Kathmandu Valley. The wind direction with respect to seasons is shown in the wind-rose pictures (Fig. 4).It can be observed from wind rose diagram that pre-monsoon and post-monsoon was predominated by wind southerly, southwesterly and westerly wind whereas monsoon period was predominated by southerly, south westerly, easterly and southeasterly. In winter air was dominated by southwesterly, westerly and northwesterly wind. The major prevailing wind directions are West-North of North West (NNW) direction in the winter season and South-West of South West (WSW) direction during other three seasons. This behavior closely reflects the geological structure of the region.

The average PM_{10} for each of the prevailing wind directions is shown in Fig. 5. Associated with ESE wind direction, which was observed only during monsoon season, the PM_{10} concentration were low (67.97 mg/m³) consequent to maximal precipitation during this period. Similarly associated with wind blowing from west direction, PM_{10} concentration were observed maximum (138.24 mg/m³).

The findings suggest that lower PM_{10} concentrations are associated with winds of the North–ENE sector occurring during the monsoon and post monsoon period. Higher levels of PM_{10} are associated when West–NNW winds prevail. Thus the topography of the area restricts dispersion of air owing to the presence of the mountainous arc surrounding the basin. In addition, winds of the southern sector, often favor the appearance of inversions, because of the transfer of warm air masses, from the southern part of the Nepal. High PM_{10} concentrations were more common in the Kathmandu Valley with wind blowing from WSW, West and WNW directions.

Regarding the amount of wind the valley receives, it is found that during the study period at night periods wind-flow was from the north, northeast and east were less common while during the day time wind flow was maximal. Due to this a sloshing effect is not a common occurrence in Kathmandu Valley. Sloshing occurs due to mountain valley breezes generated by thermodynamic circulation owing to differential heating and cooling of higher terrain surrounding the valley during day and night respectively. Pollutants carried away by winds flowing from the south, southwest and west during the day appear to be brought back again by winds flowing from the north, northeast and east during the night. Table 3 summarizes mean and standard deviation of seasonal PM_{10} and some selected meteorological parameters in Kathmandu Valley. The pre-monsoon season is associated with high wind speed, relatively less humidity whereas monsoon season is associated with high temperature, precipitation and humidity. This helps to clean the lower atmosphere of pollutants in monsoon seasons. An interesting observation is an underlying connection between high wind speed and low humidity during pre-monsoon and high PM_{10} concentrations. Other associations of relevance were high precipitation and low atmospheric pressure during monsoon and low PM_{10} concentration; low temperature and high PM_{10} concentrations during winter possibly reflect a dry-freezing effect. Thus, it appears that each season has its own unique meteorological parameters that influence concentrations of PM_{10} in the ambient air of Kathmandu Valley. The most severe pollution problem occurred in winter where daily temperatures ranged from -1 ⁰C to 15 ⁰C. The winds are weak and have a predominant West-NNW direction. Rain is almost absent, so there is no possibility of removal of pollutants by wet precipitation. Weather strongly influences PM_{10} concentrations in Kathmandu Valley. Road dust emissions are the largest source of PM_{10} exceedances of the NAAQS are almost always associated with prolonged periods of dry, cool weather. Lower than normal precipitations in April are associated with high PM_{10}. During the pre-monsoon period the highest PM_{10} concentrations were observed when temperatures fall at night and warm-up during the day.
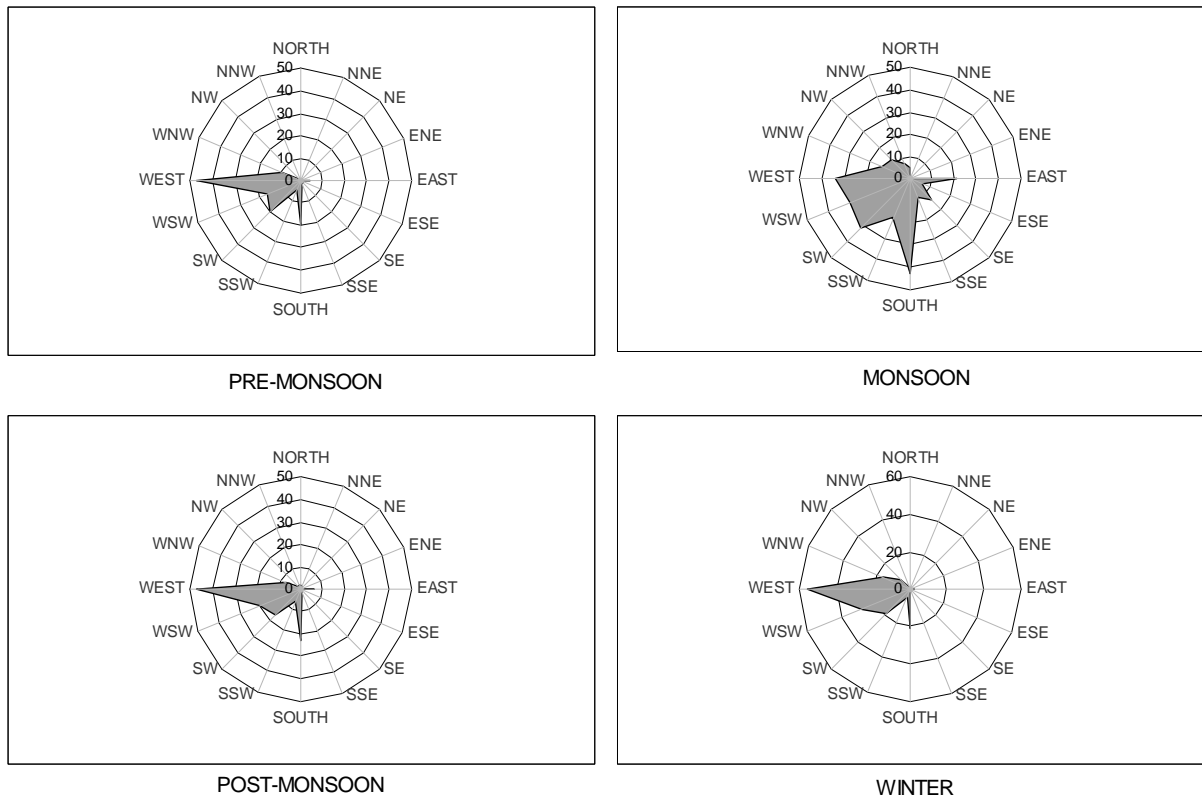
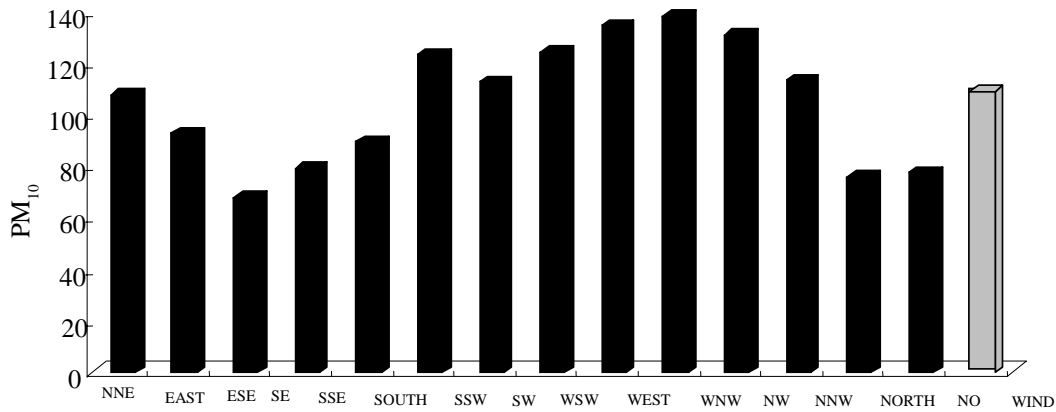**Fig. 4. Prevailing wind directions in different seasons in Kathmandu Valley**

Fig. 5. Average PM$_{10}$ for each of the prevailing wind directions in Kathmandu Valley

Elevated PM$_{10}$ concentrations occur during the period when temperatures fall, particularly during the morning times when traffic commutation is heavy.

It could also be seen in the results that precipitation and wind velocity probably is of greater importance and has a stronger connection to PM$_{10}$ concentrations in Kathmandu valley. It has been also seen that moisture probably is of greater importance and has a stronger connection to PM$_{10}$ concentrations in pre-monsoon and winter period than monsoon period, and that the temperature probably is also of greater importance and have stronger connection to PM$_{10}$ concentrations in winter season. Higher relative humidity and more rain corresponded with a lower concentration of PM$_{10}$ in the atmosphere of Kathmandu Valley.

The Chi-square test of independence at 0.05 level of significance, reveled that the quality of air in the Kathmandu Valley depended on the ambient air temperature, precipitation, atmospheric pressure, wind speed, relative humidity and predominantly prevailing wind direction.The

correlation of PM_{10} and meteorological parameters were divided in total study period variations (Table 4) and seasonally variation part (Table 5). Positive and negative correlations were found between several of the meteorological parameters and PM_{10} values in Kathmandu valley. The association between PM_{10} in Kathmandu Valley and temperature was found to be negative and significant during the study period. This indicates that increased temperature does not favor the re-suspension of fine particulate matter. Similar relation was found between ambient temperature and PM_{10} in Abbassiya monitoring station, Cairo (Elminir, 2005). Regarding to relation with precipitation, the correlation coefficient between air pollutant concentrations and precipitation was negative and not high. Precipitation levels also influence ambient PM_{10} levels. The observed variations in PM_{10} concentrations during the study period were inversely related to precipitation amounts. A previous study of urban atmospheric pollution suggests precipitation reduces re-entrainment from roads and leads to wash-out of PM from the atmosphere during rainy period. The

correlation coefficient between air pollutant concentrations and relative humidity is negative and strength of relation was higher compared with other meteorological parameters. Precipitation and relative humidity exhibited a washing effect, as shown by its negative correlation with fine particle fractions. This finding is in agreement with the study in urban Islamabad, Pakistan (Shaheen, *et al.*, 2005). PM_{10} concentration in the valley has positive relationship with atmospheric pressure and wind speed. In general, diffusion and transport of pollutants are determined by atmospheric conditions such as wind speed, vertical temperature gradient, and solar radiation (Seinfeld and Spyros, 1998). As atmospheric pressure and wind speed increases PM_{10} concentration in Kathmandu valley increases. Especially interesting is temperature, atmospheric pressure and wind velocity, which seems to have different connection to PM_{10} dependent on season. During the period of pre-monsoon and monsoon the relation between PM_{10} concentration in Kathmandu Valley with maximum temperature and wind velocity was positive.

Table 3. Mean and standard deviation of PM_{10} concentration and some selected meteorological parameter in different seasons in Kathmandu Valley

Season	Parameter	Mean $\pm$ Std. Deviation
Pre-monsoon (N=124)	PM_{10}	178.3225 $\pm$ 48.7184
	Maximum Temperature	27.2952 $\pm$ 2.8658
	Precipitation	3.0056 $\pm$ 7.5633
	Humidity	76.0504 $\pm$ 8.455
	Atmospheric Pressure	865.03 $\pm$ 4.3764
	Wind Speed	2.57 $\pm$ 0.7288
Monsoon (N=258)	PM_{10} In Kathmandu Valley	78.1188 $\pm$ 35.0208
	Maximum Temperature	28.6884 $\pm$ 1.9875
	Precipitation	9.9891 $\pm$ 15.7717
	Humidity	85.6347 $\pm$ 4.2443
	Atmospheric Pressure	862.6608 $\pm$ 3.3534
	Wind Speed	1.98 $\pm$ 0.7575
Post-monsoon (N=143)	PM_{10}	105.5256 $\pm$ 29.672
	Maximum Temperature	24.807 $\pm$ 2.5055
	Precipitation	1.5042 $\pm$ 6.8016
	Humidity	81.986 $\pm$ 4.1253
	Atmospheric Pressure	869.5844 $\pm$ 2.4468
	Wind Speed	1.84 $\pm$ 0.7283
Winter (N=165)	PM_{10}	167.703 $\pm$ 39.0635
	Maximum Temperature	20.0073 $\pm$ 2.9118
	Precipitation	0.5582 $\pm$ 2.4395
	Humidity	81.3791 $\pm$ 6.0985
	Atmospheric Pressure	868.0787 $\pm$ 3.2362
	Wind Speed	1.99 $\pm$ 0.7518

Table 4 . Pearson's coefficient of correlation between PM$_{10}$ and selected meteorological parameters for the total observations during the study period

		Max. Temp	Precipitation	Humidity	Atmospheric Pressure	Wind Speed.
PM$_{10}$	Pearson Correlation	-0.358[**]	-0.358[**]	-0.539[**]	0.237[**]	0.162[**]
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
	N	690	690	690	690	690

** Correlation is significant at the 0.01 level (2 -tailed)

Table 5. Pearson's coefficient of correlation between PM$_{10}$ and selected meteorological parameter in different seasons

			Max. Temp	Precipitation	Humidity	Atmospheric Pressure	Wind Speed
Pre-monsoon	PM$_{10}$	Correlation	0.296	-0.446	-0.605	0.077	0.252
		Sig. (2-tailed)	0.001	0	0	0.397	0.005
		N	124	124	124	124	124
Monsoon	PM$_{10}$	Correlation	0.287	-0.238	-0.52	-0.045	0.080
		Sig. (2-tailed)	0	0	0	0.476	0.202
		N	258	258	258	258	258
Post-monsoon	PM$_{10}$	Correlation	-0.563	-0.294	-0.001	0.161	-0.158
		Sig. (2-tailed)	0	0	0.993	0.055	0.06
		N	143	143	143	143	143
Winter	PM$_{10}$	Correlation	-0.036	-0.252	-0.046	0.021	-0.124
		Sig. (2-tailed)	0.642	0.001	0.556	0.785	0.111
		N	165	165	165	165	165

The relation was negative for the period of post-monsoon and winter. In pre-monsoon and monsoon as maximum temperature and wind velocity increases the PM$_{10}$ concentration increases in the Kathmandu Valley.

Irrespective of the season rainfall and humidity has negative relation with the PM$_{10}$ concentration in Kathmandu Valley. With increase of rainfall and humidity the PM$_{10}$ concentration decreases. Regarding to the relation between atmospheric pressure and PM$_{10}$ concentration in Valley in different seasons except for monsoon period atmospheric pressure has positive relation with PM$_{10}$ concentration in Valley. A correlation analysis indicates significant positive correlation between PM$_{10}$ concentration and wind speed during pre-monsoon and monsoon. Such behavior is because of presence of non-crustal elements being air bone by higher wind speed accounting for high ambient atmospheric particulate pollution. The relationship between the pollutant concentrations and selected meteorological parameters showed that they varied according to the season. Similar result is reported from studies from Korean cities (Jo and Park, 2005).

CONCLUSION

In Kathmandu valley a lower concentration of PM$_{10}$ along with temperature, precipitation, and increasing relative humidity was noted. Statistically significant positive association was observed between PM$_{10}$ with wind speed and atmospheric pressure. There is negative and statistically significant correlation between PM$_{10}$ with precipitation and relative humidity exhibited a washing effect evidenced by its negative correlation with fine particle fractions.

Precipitation and relative humidity exhibited a washing effect, as shown by its negative correlation with fine particle fractions, temperature, precipitation and relative humidity. The study, clearly points out that wind and relative humidity are the most important meteorological parameters influencing the behavior of air pollutants. However, analysis of the precipitation, wind and relative humidity alone will not adequately explain the variability in the concentrations of air pollutants. The lower correlation coefficient for PM_{10} and selected meteorological parameter illustrates the competition of two mechanisms firstly the atmospheric dispersion (particles are removed from contaminated surface air by dry deposition and by wet deposition in precipitation), secondly the aerosolization from surfaces (emissions of aerosol particles by vehicles traveling on the city's narrow roads, industry and resuspended soil dust). This linear correlation provides evidence in support of the fact that most of the PM_{10} present in the Kathmandu valley has an anthropogenic origin. Based on this it can be inferred that fine particulate mass dominance is due to automobile source emissions in the area. The results showed that rainfall, humidity and speed are the most important factors influencing the PM_{10} concentrations in Kathmandu valley. Wind from the west and southwest remains dominant throughout the study period, wind blows mostly in the afternoon time and during the night when the wind is either stagnant or very weak. The effect of wind direction was not found to affect the change in PM_{10} concentration in Kathmandu Valley. Particulate pollution was associated with dry conditions, low humidity, high wind speed and atmospheric pressure.

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