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SPATIAL AND TEMPORAL VARIATION OF AMBIENT $PM_{2.5}$: A CASE STUDY OF BANEPA VALLEY, NEPAL

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ABSTRACT
The study comprised of air quality monitoring during the day time at three municipalities of Banepa, Dhulikhel and Panauti in Kavre district of Nepal. In each of the municipalities three air monitoring stations were established representing industrial, commercial and residential areas. Particulate Matter ($PM_{2.5}$) has been estimated from air sampling programme which spanned 7 months and a total of 126 days reflecting all the three seasons. The study found that during winter season the concentration of $PM_{2.5}$ was more and among the areas commercial area noted highest level pollution. The seasonal trend in pollution levels show that winter > pre-monsoon > monsoon. The pollution concentration trend noted among the areas was commercial > industrial > residential on almost all the occasions except at pre-monsoon season between industrial and residential area in Banepa. This finding concludes that, commercial area of Banepa is more defined and is associated with higher particulate matter concentration compared to other areas.

Keywords: Nepal, Banepa, Particulate, Air Quality and Fine Particle Sampler.

INTRODUCTION
Adverse health effects, including increased risk of premature mortality, hospital admissions, and higher rates of adverse respiratory health indicators in children are highly associated with airborne particulate matter [1, 2].The United Nations estimated that over 600 million people in urban areas worldwide were exposed to dangerous levels of traffic-generated air pollutants [3]. Nepal, a relatively small country with 1,47,181sq km area inhabited by 22 million people, is known for exquisite environment. However, the real scenario is quite different because urban areas are environmentally degrading due to rapid unplanned urbanization and industrialization. Some recent studies reveal that even the glorious mountain peaks of the high Himalayas have also undergone incipient pollution [4, 5]. 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 evil before it is too late. Recently, problems caused by atmospheric Particulate Matter (PM) in urban air have received greater attention. Various health effects attributable to PM have been documented [6]. 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 [7, 8, 9, 10]. The majority of these studies have assessed the health effects of particles expressed as the risk per unit mass/m^3

of PM_{10} or $PM_{2.5}$. Airborne particle associated problems, such as health problems like asthma problems [11] and haze problems like visibility impairment [12] are typical environmental issues in urban cities. The chemical composition [13] health impact [5, 14] and rate of deposition [15] of these particles vary significantly with the size of particles. Also different aerosol emission sources tend to have different aerosol mass size ranges [16].

$PM_{2.5}$ is notorious because Characteristics of $PM_{2.5}$ that may be relevant to toxicity include metals, organic compounds adsorbed onto particles or forming particles themselves, biologic components, sulfate (SO_4^{2-}), nitrate (NO_3^-), acidity, and surface-adsorbed reactive gases such as ozone (O3) [17, 18] Compared with the large volume and varieties of studies carried out in the in Nepal focusing on Kathmandu Valley, very few air pollution study were conducted in semi urban areas of the country. Apart from this, the majority of the air pollution studies focused on traffic emissions, whereas industrial, domestic and other land use sources of air pollutants were not seriously undertaken in Nepal. Therefore, the prime objectives of this study, was to investigate spatial and temporal variation of $PM_{2.5}$ level.

MATERIALS AND METHODS

Site Description

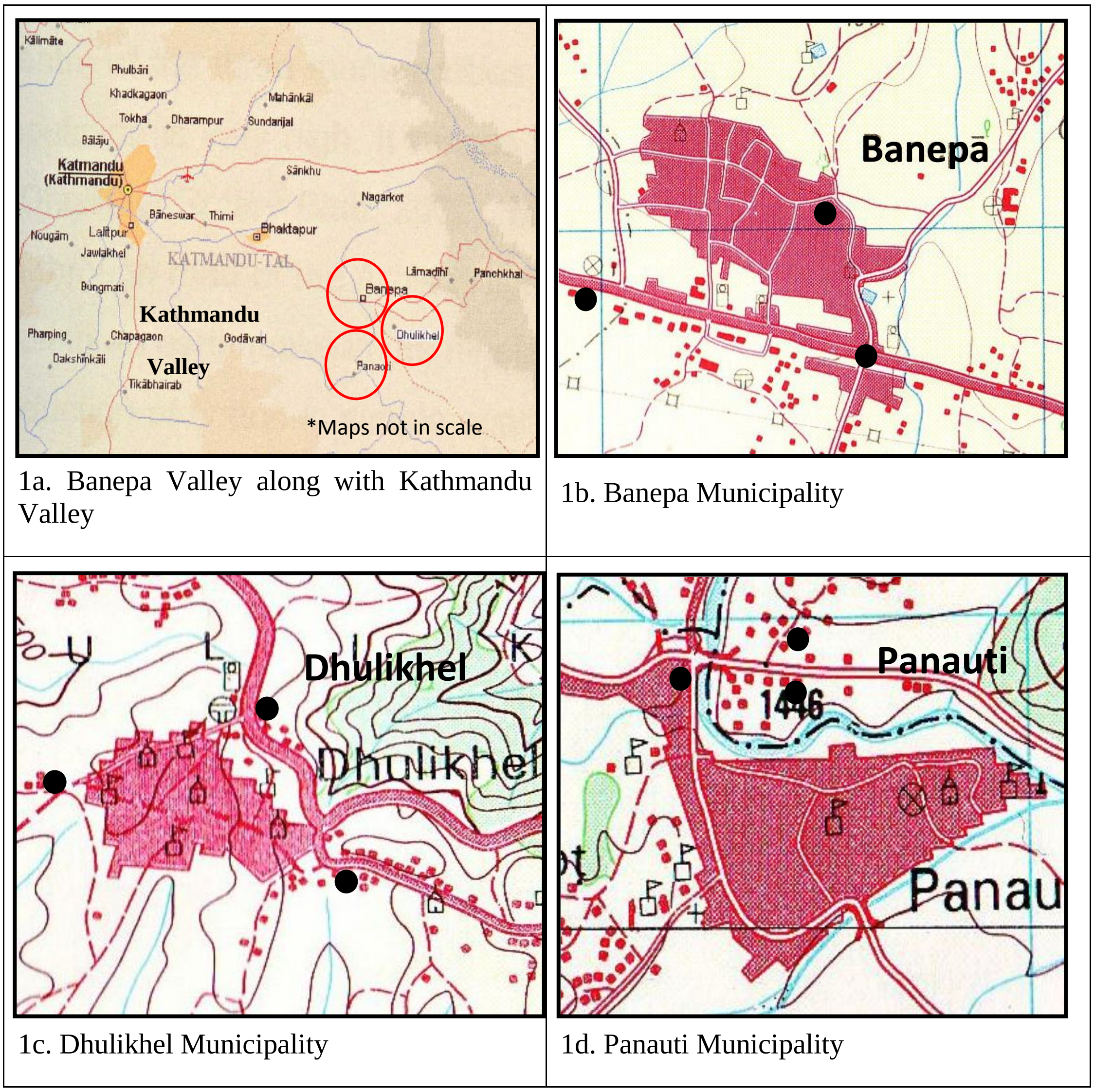
Banepa, Dhulikhel and Panauti are geographically located in the same valley region known as the Banepa valley (Figure 1) with distances of no more than 7 to 8 km in between them (Table 1). Banepa and Dhulikhel are both situated on the Arniko Highway. This highway is Nepal's only road to the Tibetan border. It is an important trade route for goods coming from China into Nepal. Panauti is attainable from the Arniko Highway in Banepa over a seven kilometers long side street. The study comprised of air monitoring during the day time at three municipalities of Banepa, Dhulikhel and Panauti. In each of the Municipalities three air monitoring stations were established representing Industrial, Commercial and Residential areas. So there were altogether 9 air sampling stations ware selected in Banepa Valley, as given below:

Table 1**:** General information about study area

Municipalities	**Distance from Banepa**	**Population**	**Number of monitoring sites**	**Area (sq. km)**
Banepa	0 km	15822	3	5.56
Dhulikhal	4 km	11521	3	8.22
Panauti	5.5 km	25563	3	19.71
Total	-	53006	9	33.49

Air Sampling

A known volume of air was taken through a filter paper where the contaminant is captured. The sampling was done using *Envirotech APM 550* Fine Particulate Sampler. The result was expressed as microgram per cubic meter (µg/m^3). The volume of airflow (m^3) was calculated by multiplying the flow rate of air (liter/min) through the filter medium with the time (minutes) and by dividing with 1000 (to convert air volume into m^3). The concentration (µg/m^3) of pollutant was calculated by dividing the actual weight of contaminant (µg) by volume of airflow (m^3)



1a. Banepa Valley along with Kathmandu Valley

1b. Banepa Municipality

1c. Dhulikhel Municipality

1d. Panauti Municipality

Figure 1 Showing the study area (Black dots indicate monitoring sites)

During the present study air sampling cover a period of 7 months and a total of 63 days. The samples were collected once in a month for each of the nine sites. Every day two sample were collected in the morning and evening. So the total number of sample was 126. The total sampling time was 8 hours in a day. These 8 hours in a day were divided into 4 hours each covering pick hours of day 9am to 5pm.

RESULTS AND DISCUSSION

Spatial and Temporal Variation of $PM_{2.5}$

The seasonal mean values of commercial, industrial and residential areas of Banepa municipalities are presented in figure 2. From the figure it can be state that, during winter season $PM_{2.5}$levelwas higher and among the areas, commercial area in Banepa exhibited highest $PM_{2.5}$ level (Figure 2). In fact, at the commercial area the maximum level of 400.08 µg/m3 has been recorded on one occasion, which was not very much deviant to the mean level; indicating persistently higher levels of $PM_{2.5}$ in this particular area. The overall mean, standard deviation, minimum and maximum level of $PM_{2.5}$ in Banepa was respectively 202.22µg/m^3, 98.39µg/m^3, 76.28µg/m^3 and 400.08µg/m^3 (Figure 2).

The National Ambient Air Quality Standards (NAAQS) level for $PM_{2.5}$ had not been yet set for Nepal. The ambient $PM_{2.5}$standard set by WHO for 24 hour and annual average are respectively 25 µg/m^{3}and 10 µg/m^3. Once more, the ambient $PM_{2.5}$standard set by US EPA (1997) for 24 hour and annual average are 65µg/m^3 and 15 µg/m^3 respectively. From the Figure 2 it is clearly evident that, the level of $PM_{2.5}$ in all three season in all the three land use areas of Banepa had crossed the WHO and USEPA standard. The seasonal trend in $PM_{2.5}$ levels was Winter> Pre-monsoon > Monsoon, whereas the trend for areas was Commercial > Industrial > Residential on almost all the occasions. This finding suggests that commercial area of Banepa is more demarcated and is provoking with higher $PM_{2.5}$ than the industrial area. The seasonal trend in almost all cases shoed the pattern described above and reveals that, monsoon has a more washing effect on particulates from the atmosphere and hence the particulates restrictively get airborne. The seasonal mean values according to commercial, industrial and residential areas of Dhulikhel are presented in Figure 3. From the study it is found that, winter season showed the highest $PM_{2.5}$ level and Dhulikhel Industrial area noted highest mean $PM_{2.5}$ level. But at commercial area a maximal level of 246.44µg/m^3 has been recorded on one occasion, which was highest within the areas. The overall mean, standard deviation, minimum and maximum level of $PM_{2.5}$ in Dhulikhel was respectively 120.22µg/m^3, 57.43µg/m^3, 49.04µg/m^3 and 246.44µg/m^3 (Figure 3), which was quite higher than the $PM_{2.5}$ mean concentration of 61.4 µg/m^3, recorded in Belgrade [19].

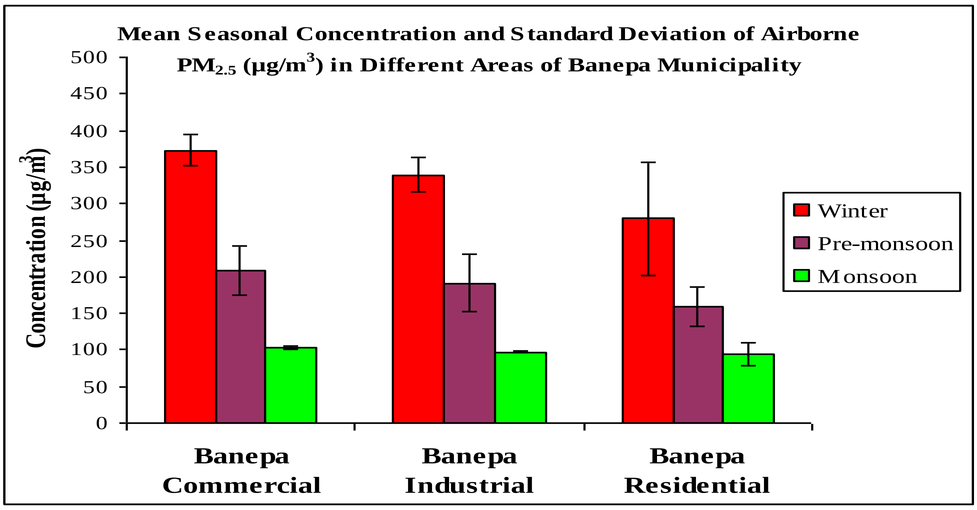


Figure 2 Mean Seasonal Concentration and Standard Deviation of Airborne $PM_{2.5}$ in Different Areas of Banepa Municipality.

The seasonal trend in $PM_{2.5}$ levels was Winter> Pre-monsoon > Monsoon. The trend noted among the areas was Industrial > Residential >Commercial on almost all the occasions except Pre-monsoon season, where the scenario is Commercial>Industrial > Residential.

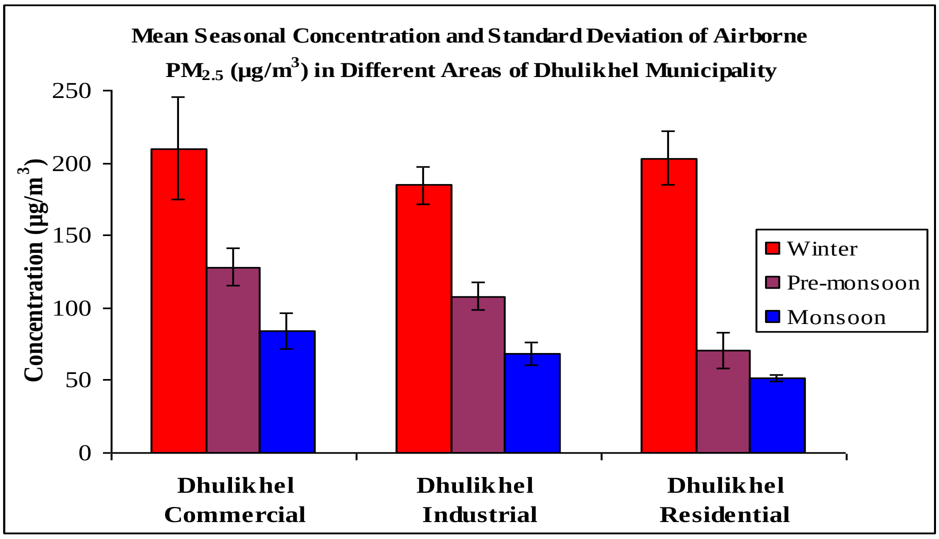


Figure 3 Mean Seasonal Concentration and Standard Deviation of Airborne $PM_{2.5}$ in Different Areas of Dhulikhel Municipality.

These findings conclude that, commercial area of Dhulikhel is more distinct and is threatening with higher $PM_{2.5}$ concentration compared to industrial area. The level of $PM_{2.5}$ was minimum during monsoon because of washing effect on particulates from the atmosphere. The seasonal mean values of commercial, industrial and residential areas of Panauti are presented in Figure 4. During winter season the $PM_{2.5}$ concentration was high and Commercial area in Panauti exhibited highest mean $PM_{2.5}$ concentration among all the areas, in contrary to the extreme level of 347.60µg/m^3 recorded on one occasion in Panauti Industrial area, which was also highest within the areas as well as in all seasons. The overall mean, standard deviation, minimum and maximum level of $PM_{2.5}$ in Panauti was respectively 135.56µg/m^3, 82.88µg/m^3, 52.55µg/m^3 and 347.60µg/m^3. The seasonal trend in $PM_{2.5}$ levels was Winter>Pre-monsoon > Monsoon. Among the areas the trend was Commercial > Industrial > Residential on almost all the occasions.

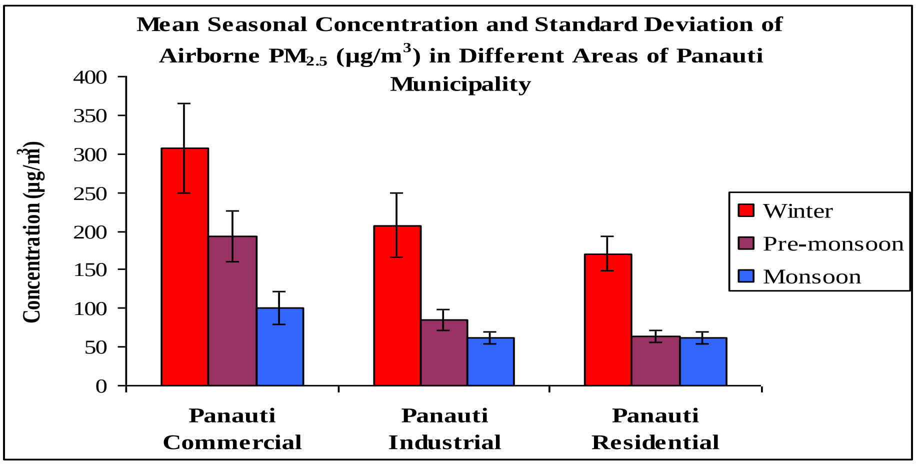


Figure 4 Mean Seasonal Concentration and Standard Deviation of Airborne $PM_{2.5}$ in Different Areas of Panauti Municipality.

This finding suggests that commercial area of Panauti is more demarcated than all other areas and is suffering with higher $PM_{2.5}$ concentration compared to industrial and residential areas. Due to the washing effect of particulates from the atmosphere during monsoon, the level of $PM_{2.5}$ was lowest in almost all occasion.

Seasonal Variation of $PM_{2.5}$

From the table 2, it is deceptive that, Banepa Commercial area has the highest seasonal mean $PM_{2.5}$ concentration with mean concentration of 227.81µg/m^3 among all the 9 places of 3 municipalities. It documented highest level of concentration in all three seasons of winter, pre-monsoon and monsoon. Panauti Residential area has lowest concentration with a mean concentration of 98.96µg/m^3. These results are also in agreement with [20] who identified strong seasonal and geographic variations in $PM_{2.5}$.

Table 2: Mean Seasonal Concentration of Airborne $PM_{2.5}$ (µg/m^3) in all the Study Areas

Sites	Winter	Pre-monsoon	Monsoon	Seasonal Mean	Rank
Banepa Commercial	372.76	208.37	102.29	227.81	1
Banepa Industrial	339.10	191.11	96.64	208.95	2
Banepa Residential	279.18	159.83	94.39	177.80	4
Dhulikhel Commercial	210.13	128.18	83.81	140.71	5
Dhulikhel Industrial	184.61	108.16	68.50	120.42	6
Dhulikhel Residential	203.21	70.79	51.39	108.46	8
Panauti Commercial	306.91	192.81	100.28	200.00	3
Panauti Industrial	207.20	85.91	62.04	118.38	7
Panauti Residential	170.91	64.08	61.88	98.96	9
Over all mean	252.67	134.36	80.14	155.72	-

The chronology of the highest to lowest pollutant area in all three municipalities are as Banepa Commercial>Dhulikhel Commercial >Banepa Industrial>Panauti Commercial>Banepa Residential>Panauti Industrial>Dhulikhel Residential >Dhulikhel Industrial >Panauti Residential.

Monthly Variation of$PM_{2.5}$

During the study period of seven months among all the nine sites, Banepa Commercial site displayed the highest concentration of $PM_{2.5}$ with a mean level of 225.03µg/m^3. Among the seven months, in all the months it recorded highest $PM_{2.5}$ concentration except in July. On the other hand Panauti Residential areas recorded lowest concentration of $PM_{2.5}$, with a mean level of 93.98µg/m^3. During the study period of seven months, in all the months it exhibit, lowest $PM_{2.5}$ concentration except in the month of June and July.

Table 3: Mean Concentration of Airborne $PM_{2.5}$ (µg/m^3)in all the Study Areas According to Months

Sites	January	February	March	April	May	June	July	Average	Rank
Banepa Commercial	375.20	370.32	246.52	205.22	173.37	103.50	101.08	225.03	1
Banepa Industrial	334.11	344.10	231.75	196.80	144.77	96.39	96.90	206.40	2
Banepa Residential	344.01	214.35	177.40	168.15	133.96	106.95	81.83	175.23	4
Dhulikhel Commercial	239.66	180.61	142.61	126.40	115.53	93.64	73.98	138.92	5
Dhulikhel Industrial	190.98	178.24	117.57	108.44	98.47	73.93	63.07	118.67	6
Dhulikhel Residential	217.93	188.49	84.91	69.61	57.86	51.22	51.56	103.08	8
Panauti Commercial	339.79	274.02	224.20	198.06	156.17	111.95	88.60	198.97	3
Panauti Industrial	200.18	214.23	99.46	86.22	72.06	64.05	60.04	113.75	7
Panauti Residential	178.34	163.49	73.35	61.84	57.06	59.72	64.04	93.98	9
Total Average	268.91	236.43	155.31	135.64	112.14	84.59	75.67	152.67	-

Influence of Meteorological Parameters on $PM_{2.5}$

Seasonal variation

To check the influence of meteorological parameter on $PM_{2.5}$ level, some meteorological parameter such as Temperature in (^{O}F) Fahrenheit; Humidity in Percentage (%); Dew point in (^{O}F) Fahrenheit; Wind speed in MPH; Barometric Pressure in inches; Rainfall in inches and solar radiation in W/m^{2}we have been selected. Table 4 represents the influence of meteorological parameter on $PM_{2.5}$ level.

From the table 4, it is observed that when the ambient temperature increases the $PM_{2.5}$ level decreases. The maximum $PM_{2.5}$ concentration 260.64 µg/m^3 was observed in average temperature of 52.93 ^{O}F and as the average temperature increases to 74.91^{O}F the $PM_{2.5}$ decreases to 79.10µg/m^3. The mean $PM_{2.5}$ was found to be lower with decrease of relative humidity. The $PM_{2.5}$ concentration of 260.64µg/m^3 was recorded in relative humidity of 76.30% and as this increase to 80.88% the $PM_{2.5}$ decreases to 79.10µg/m^3. The dew point exhibited a reverse relation with $PM_{2.5}$,becauseas it is increased the $PM_{2.5}$ concentration is decreased. The $PM_{2.5}$ concentration of 260.64µg/m^3 was recorded, when the dew point was 45.23 ^{O}F and as the dew point increased in 67.78 ^{O}F, the $PM_{2.5}$ concentration decreased to 79.10µg/m^3(Table 4).

Table 4: Seasonal $PM_{2.5}$ concentration in relation with metrological parameter

Season		$PM_{2.5}$	Temp	Humidity	Dew point	Wind Speed	Barometric Pressure	Rainfall	Solar Radiation
Winter	N	32	32	32	32	32	32	32	32
	Mean	260.64	52.93	76.30	45.23	0.99	30.33	0.02	282.70
	Std. Deviation	79.26	4.46	10.73	3.19	0.42	0.09	0.09	160.45
Pre-monsoon	N	24	24	24	24	24	24	24	24
	Mean	112.94	74.07	65.54	60.43	1.51	29.94	0.01	480.21
	Std. Deviation	47.92	5.89	17.36	4.35	0.67	0.11	0.01	168.33
Monsoon	N	17	17	17	17	17	17	17	17
	Mean	79.10	74.91	80.88	67.78	0.82	29.76	0.06	333.56
	Std. Deviation	21.15	4.93	16.98	4.16	0.59	0.08	0.14	146.68
Total	N	73	73	73	73	73	73	73	73
	Mean	169.81	65.00	73.83	55.48	1.12	30.07	0.02	359.48
	Std. Deviation	101.12	11.85	15.73	10.24	0.62	0.26	0.09	180.43

The result showed that, as the wind speed increases the $PM_{2.5}$ decreases. The level of $PM_{2.5}$ was 260.64g/m^3, when the wind speed of was 0.99 MPH and as this increased to 1.51MPH the $PM_{2.5}$ decreased to 112.94µg/m^3. It specifies that, wind speed help in decreasing the level of $PM_{2.5}$ and it is due to the ability of wind speed to blow away the particulate matter. There was a positive relation with barometric pressure and $PM_{2.5}$ concentration. It shows that, in the winter when the barometric pressure was higher (30.33) the $PM_{2.5}$ concentration was also higher (260.64µg/m^3) and in the monsoon with the decreases of barometric pressure (29.76) there was a decreasing trend of 79.10µg/m^3 $PM_{2.5}$ concentration (Table 4).

Rainfall showed an inverse relation with $PM_{2.5}$. From the table 4, it is seen that $PM_{2.5}$ concentration decreases with the increases of rainfall. It is observed that in winter when the mean rainfall was 0.02 inches, the mean $PM_{2.5}$ was 260.64µg/m^3 whereas in monsoon the $PM_{2.5}$ comes down in 79.10µg/m^3 with the increases of 0.06 inches of rainfall. This may be due the washing effect of the rainfall in monsoon season. The solar radiation also showed an inverse relation with the level of $PM_{2.5}$, because as it was increased the $PM_{2.5}$

concentration decreased. The maximum $PM_{2.5}$ 260.64µg/m^3 was observed in radiation of 282.70 W/m^2. When the solar radiation increases to 333.56W/m^2, the $PM_{2.5}$ decreases to 79.10µg/m^3. This may be due to the increase in temperature as the solar radiation increases.

Diurnal Variation

Table 5 represents the Diurnal $PM_{2.5}$ concentration in relation with metrological parameters. From the table it is observed that in the evening the $PM_{2.5}$ concentration is higher than in the morning. In the evening when the maximum temperature increases, the $PM_{2.5}$ concentration also increases. The mean $PM_{2.5}$ was found to be higher with the increase of relative humidity. The $PM_{2.5}$ concentration of 166.82 µg/m^3 was found in relative humidity of 67.55% in the morning and 172.72 µg/m^3 when the relative humidity increases to 79.38%.

Table 5: Diurnal $PM_{2.5}$ concentration in relation with metrological parameters

Time		$PM_{2.5}$	Temp	Humidity	Dew point	Wind Speed	Barometric Pressure	Rainfall	Solar Radiation
Morning	N	36	36	36	36	36	36	36	36
	Mean	166.82	66.76	67.55	54.58	1.12	30.03	0.02	294.33
	Std. Deviation	99.98	12.33	16.22	10.48	0.60	0.25	0.09	156.24
Evening	N	37	37	37	37	37	37	37	37
	Mean	172.72	63.28	79.93	56.35	1.12	30.11	0.03	422.87
	Std. Deviation	103.51	11.27	12.70	10.07	0.64	0.26	0.09	181.67
Total	N	73	73	73	73	73	73	73	73
	Mean	169.81	65.00	73.83	55.48	1.12	30.07	0.02	359.48
	Std. Deviation	101.12	11.85	15.73	10.24	0.62	0.26	0.09	180.43

CONCLUSION

The study provided base line data on air quality in terms of $PM_{2.5}$concentration that provided in representative semi urban areas of Nepal. The contemporary Acts and Regulation dealing to abate air pollution is not only very superficial but also comprehensive coordination among concerned ministries. Environmental legislation and regulations for pollution control are weak along with their implementation. Both Nepal Standard Act and Environment Protection Regulation are seeking to control air pollution by means of command and control approaches. But further working modalities are yet to publish. So this study will certainly initiate more comprehensive air pollution studies in the semi urban areas of Nepal other than Kathmandu.

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