Assessment of Ambient Particulate Matter Concentrations- PM10, PM2.5 and PM1 at Rinchending in Phuentsholing, Bhutan

Bharat Kumar Humagai, Kirtan Adhikari, Basant Pradhan & Tshering Yangzom

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Abstract

This paper presents the analysis and interpretation of daily, monthly and seasonal cycle of 1- minute average Particulate Matter (PM_{10}, $PM_{2.5}$ and PM_1) concentrations measured in Rinchending, located on the hilltop, 4 km away from Phuentsholing, the second largest city inBhutan between the period of March 2018 to March 2019. In diurnal cycle, the highest concentrations of PM were observed between 9AM – 10 AM in the morning and 5PM-7PMin the evening corresponding to the peak traffic hours. The concentrations of PM showed highest in the post-monsoon season, corresponding to October to February in Bhutan (PM_{10}=57.36 µg/m3, $PM_{2.5}$=33.73 µg/m3 and, PM_1=29.28) compared to monsoon season corresponding to June-September (PM_{10}=22.70 µg/m3, $PM_{2.5}$=15.51 µg/m3 and, PM_1=11.35) and pre-monsoon season corresponding to March-May (PM_{10}=54.9 µg/m3, $PM_{2.5}$=30.58 µg/m3 and, PM_1=24.36). The frequency distribution of PM_{10} showed that upto 25% of the time, the concentration was upto 20.8 µg/m3, 50% of the time, the concentration was upto 35.3 µg/m3 and 75% of the time, the concentration was upto 59 µg/m3.Similarly, the frequency distribution of $PM_{2.5}$ showed that upto 25% of the time, the concentration was upto 13.5 µg/m3, 50% of the time, the concentration was upto 22 µg/m3 and 75% of the time, the concentration was upto 38 µg/m3.The annual mean concentrations of PM_{10} (45.08 µg/m3) were violating the Annual WHO ambient air quality standard (20 µg/m3). The annual mean concentrations of $PM_{2.5}$ (26.83µg/m3) were also violating the Annual WHO ambient air quality standard (10 μg/m3). The wind analysis done through the wind rose diagram found a dominant south and south-west wind pattern.

Key words – Particulate matter; Wind rose diagram; Biomass burning; WHO, Diurnal cycle; Seasonal cycle, Monthly variations

Introduction

Atmospheric particulate matter, a very complex matrix, originating from natural and anthropogenic sources having different physical and chemical characteristics (Perrino et al., 2011) is increasing rapidly due to energy-intensive activities associated with urbanization and industrialization. Based on the aerodynamic diameter less than 10 μm, 2.5 μm and 1 μm, atmospheric particulate matter is classified as PM10, PM2.5 and PM1 respectively. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. Short- term as well as long-term exposures to PM10 and PM2.5 are associated with a broad range of human health impacts, including respiratory and cardiovascular effects as well as premature death. It is found that it causes around 3.7 million global premature deaths annually (WHO, 2014).The main sources of ambient PM concentrations in the urban centres are construction activities, vehicular emissions, industries and re-suspension of road dust. The traffic– generated emissions are accounting more than 50% of the total PM emissions in the urban areas (Wrobel, Rokita, & Maenhaut, 2000).In the recent times PM2.5 concentration has become a major health concern leading various researchers to investigate its temporal and spatial distribution using station data and remote sensing. (Murray, Chang, Holmes, & Liu, 2018; Narashid & Wan Mohd, 2010; Mei et al., 2009).

Currently Phuntsholing city is expanding rapidly due to ever rising population influx and demand for accommodation. There are numerous projects taking place in Phuentsholing. Some of the projects that contribute to particulate matter emissions are NHDCL housing complex, NAPA-II project, Thromde LAP projects, private construction companies and Amochu land-Reclamation project. Phuentsholing city also hosts numerous factories. Some of the prominent factories in Phuentsholing are Bhutan Polythene factory, Tashi Industries Carpet Factory, Pepsi factory and Bhutan Ply factory. Phuentsholing also gets lots of trans- boundary air pollutants being very close to India. Further, it was reported by Wangchuk & Lhendup, (2019) that during winter, PM concentrations escalates due to biomass combustion.

The assessment of PM_{10}, $PM_{2.5}$ and PM_1 for the duration of 1 year is first of its kind in Phuentsholing Bhutan. The objective of the study is to evaluate the hourly, daily, monthly and seasonal variation of particulate matter concentrations so that the appropriate information could be disseminated to relevant decision-making agencies. The meteorological impact on the variation of particulate matter over the one-year cycle is also discussed.

Materials and Methodology

Site Description

Figure 1 shows the sampling location of the study area. The observatory is located on the hill-top in the campus of the College of Science and Technology in Rinchending. Rinchending has the coordinates of 26°50'56.0"N and 89°27'23.32"E having an average elevation of 450m.

The monitoring site is perfectly located to receive the pollutants from Phuentsholing city as well as trans-boundary air pollutants from Jaigaon, India, which is just 4 km away.

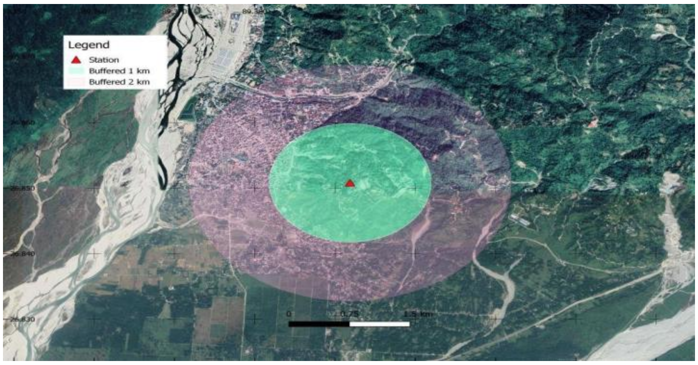


Figure 1.Study Site, Rinchending

Materials and Method: Results and Discussion

The mass concentrations of particulate matter were monitored using Grimm Aerosol Technik, a US-EPA and WHO approved Dust Monitor. The Grimm uses the optical technology (light scattering photometers) and gravimetrical principle and gives different PM values on real time basis. A constant flow rate ~2 L/min was maintained throughout the measurements. The instrument was set to record the data at 1-minute interval and store them in memory card placed inside the data logger.

Motor vehicles are considered as the major anthropogenic air pollution sources (USEPA, 2009). Based on the record maintained by the Road Safety and Transport Authority of Bhutan, 37,642 motor vehicles are registered in Phuentsholing as of February 2021(RSTA, 2021).This constitute to 33.3% of total motor vehicles in Bhutan. Table 1 and figure 1 show the motor vehicles registered in various regions of the country and its distribution.

Table 1: Total Number of Motor Vehicles as of February 28, 2021(RSTA, 2021)

SL. #	**Region**	**Total**
1	Thimphu	59887
2	Phuntsholing	37642
3	Gelephu	7485
4	Samdrupjongkhar	5470
5	Mongar	2408
	Grand Total	112892

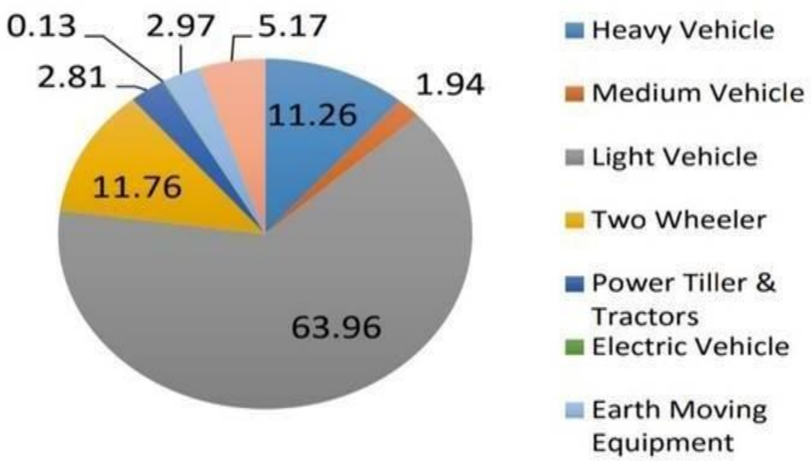


Fig.1 Types of vehicles in Bhutan (RSTA, 2016)

Variation of PM10, PM2.5 and PM 1 concentrations in the different time of the day

Figure 2 shows the hourly variation of PM10, PM2.5 & PM1 concentrations for the entire 1 year cycle. In the diurnal cycle, the 1 hour PM concentrations showed two peaks-one corresponding to morning peak between 9am-10am and another between 5pm-7pm. Both these timing intervals correspond to office peak traffic hours. The PM concentrations were observed significantly lower between 12-2pm. This is corresponding to the temporary halting of the construction activities and other vehicular movement owing to the lunch hour timing. The peak corresponding to evening hours all PM concentrations were significantly higher than the morning peak. This may be due to cumulative effect of PM concentrations. The night time PM concentrations were observed to be slightly higher than the day time concentrations. According to Bishop et al., (2015), at night, decreasing temperature create a temperature inversion which acts as a cap, inhibiting diffusion of particulate matter. Burning of biomass and wood at night for home heating is also the primary contributor of pollution concentrations at night.

Figure 2. Hourly variation of PM_{10}, $PM_{2.5}$ & PM_1 concentrations

Monthly variations of PM10, PM2.5 and PM 1 concentrations

PM concentrations were further analyzed to establish a monthly pattern as shown in the figure 3. As expected, higher concentrations were observed during January and February and lower concentrations during July to August. The highest PM concentrations were recorded in the month of March. This can be attributed to highly unstable atmosphere due to solar radiation and frequent changes in wind direction (Bathmanabhan & Saragur Madanayak, 2010)

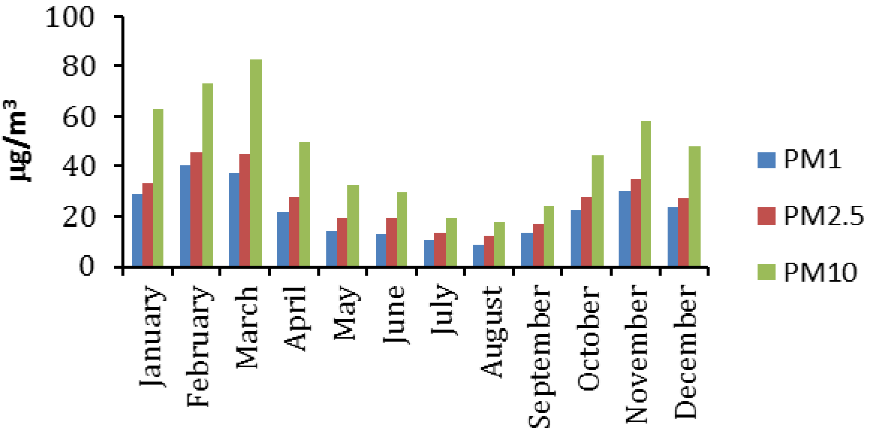


Figure 3. Monthly variation of PM10, PM2.5 and PM 1 concentration.

It was observed that the PM concentrations exceeded the annual WHO ambient air quality standard (PM10=20 µg/m3 and PM2.5=10 µg/m3) in all the months except for the month of August.

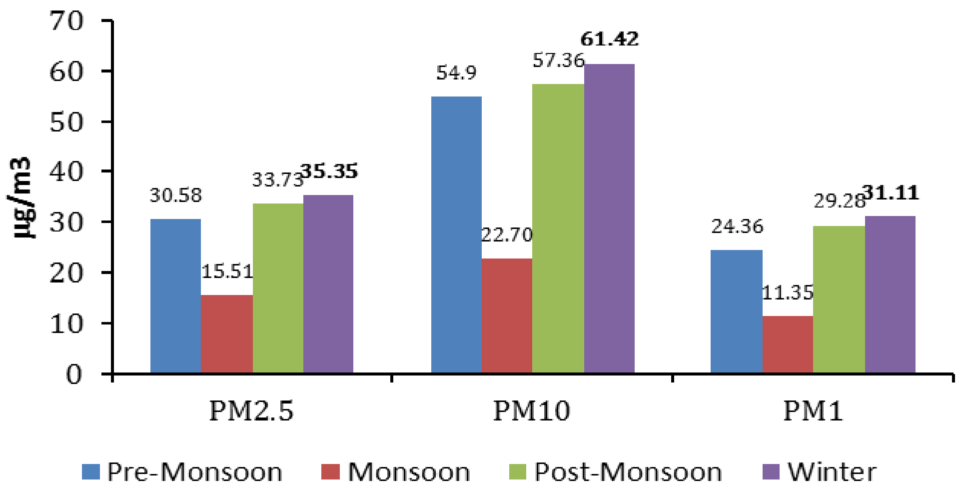
Seasonal variations of PM10, PM2.5 and PM 1 concentrations

According to National Centre for Hydrology and Meteorology of Bhutan, March - May is considered as pre-Monsoon season, while, June-September as Monsoon and October- February as post Monsoon season and December-February as the winter.

As shown in the figure 4, the PM concentrations were observed highest in winter (PM10=61.42 µg/m3, PM2.5=35.35 µg/m3, PM1=31.1 µg/m3) due to prevailing inversion conditions compared to Pre-Monsoon and Monsoon season.

Similarly, PM concentrations were observed to be lowest in

Monsoon (PM_{10}=22.70 µg/m3, $PM_{2.5}$=15.51 µg/m3, PM_1=11.35 µg/m3) which is attributed to the precipitation setting down the suspended particulate matter from the atmosphere. Post monsoon PM concentrations weremeasured to be significantly higher than the pre-monsoon. This was due to the early precipitation (March-May) recorded in that year.



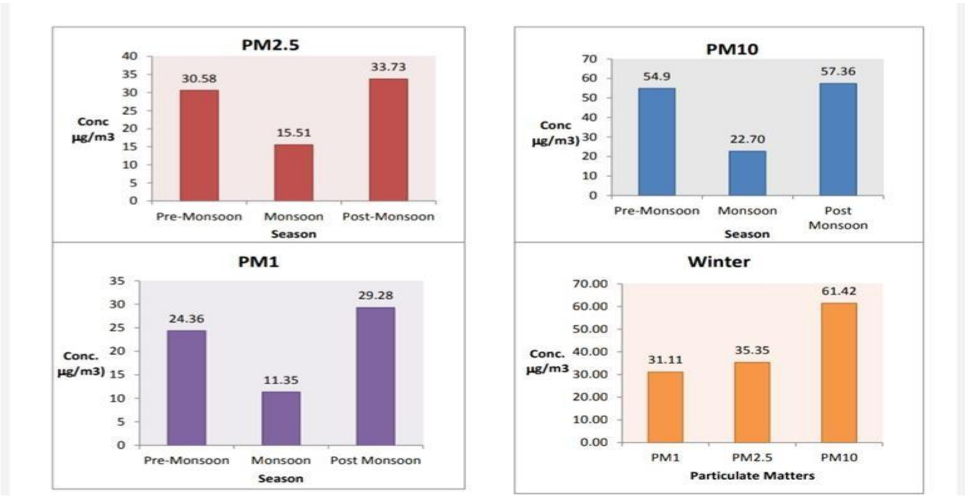


Figure 4. Seasonal variation of PM_{10}, $PM_{2.5}$ and PM_1 concentrations

The following table 2 and figure 5 show the average value and behaviors of PM concentrations during monsoon and winter season.

Table 2: Average concentration of particulate matter in monsoon and winter season.

Particulate Matter	Monsoon	Winter
PM_1	11.35μg/m^3	31.11μg/m^3
$PM_{2.5}$	15.25μg/m^3	35.35μg/m^3
PM_{10}	22.70μg/m^3	61.42μg/m^3

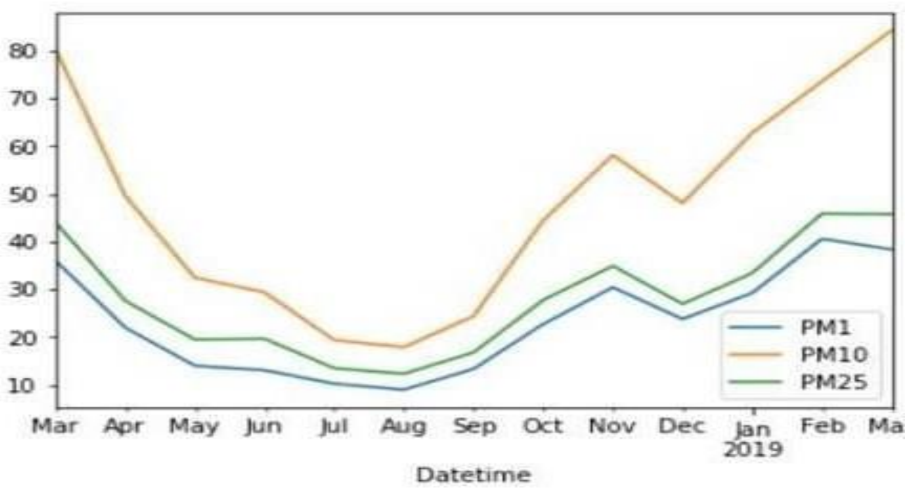


Figure 5 Behaviour of PM concentrations during various seasons

PM concentrations and correlation

The very strong co-correlation between PM_{10} vs $PM_{2.5}$ and PM_1 vs

PM10 were observed in all the seasons suggesting the same source of emission for all the particulate matter. Table 3 shows the correlation statistics of PM10, PM2.5 and PM1 concentrations.

PM10 and PM1 show the best correlation coefficient of 1 during pre-monsoon while PM10 and PM2.5 shows best correlation coefficient during pre-monsoon at 0.99.

Table 3: Correlation statistics of PM10, PM2.5 and PM1 concentrations

Description	Seasonal	Best fit equation	R^2
PM_{10} vs. $PM_{2.5}$	Pre-Monsoon	y=0.5137x+2.3794	0.99
	Monsoon	y=0.6339x+1.1157	0.98
	Post-Monsoon	y=0.6147x-1.5277	0.89
PM_1 vs.PM_{10}	Pre-Monsoon	y=0.4683x-1.3488	1
	Monsoon	y=0.3638x+3.0896	0.79
	Post Monsoon	y=0.5825x-4.135	0.92

Annual Statistics of PM Concentrations

As mentioned in the table 4, the annual mean PM1 concentration was recorded at 22.16µg/m3while the annual mean PM2.5 and PM10 concentrations were recorded at 26.83 µg/m3 and 45.08 µg/m3 respectively. Standard deviation of PM1, PM2.5 and PM10 were found to be 16.5, 18.53 and 37.5 respectively.

Table 4: Annual Statistics of PM Concentrations

Description	PM1	PM2.5	PM10
Mean	22.16	26.83	45.08
Std	16.5	18.53	37.5
Min	0	0	5.08
25%	10.4	13.5	20.8
50%	17.8	22	35.3
75%	29.5	35.8	59
Max	307.2	442	995.79

Annual mean ratio of PM2.5 to PM10 was recorded as 0.59.That means in Phuentsholing, the course particles dominates the air. All the PM concentrations violated the Annual WHO ambient air quality standard of 20 μg/m3 and 10 μg/m3 for PM10 and PM2.5 respectively.

Impact of meteorological parameters on PM concentrations

The particulate matter concentration varies considerably with time, location and depending on meteorological conditions and source emissions rate (Beer, 2001; Elminir, 2005).Under inversion conditions; the PM concentrations may rise to several times higher than the normal level (Elminir, 2005). Table 5 shows the details of the meteorological variables and their ranges during pre-monsoon, monsoon and post monsoon including winter.

It was observed that the concentrations of PM decreased significantly during the pre- monsoon and monsoon season due to rainfall phenomena.

Table 5: Season wise values of meteorological parameters

Season	Description	Temperature (°C)	Pressure (hPa)	Wind speed (m/s)	Wind direction	Humidity (%)	Rainfall daily (mm)
Pre-Monsoon (March-May)	Average	24.35	960.54	1.24	195.4	64.29	18.65
	Max	35.4	967.79	11.8	359.89	81.1	270
	Min	16.9	952.59	calm	0	35.1	0
	std	3.44	2.55	0.91	129.7	13.46	44.2
	25%	21.7	958.7	0.6	69.7	30	
	50%	23.6	960.59	1	229.7	35	
	75%	26.9	962.4	1.6	321.5	50	
Monsoon (June-Sept)	Average	26.69	955.39	0.86	145.7	92.79	35.3
	Max	41.1	967.5	12.3	359.89	100	230
	Min	20.9	944.79	calm	0	56.2	0
	Std	3.07	3.54	0.71	129.9	6.6	46.89
	0.25	24.5	953.2	0.4	24.7	40	
	0.5	26	954.9	0.7	116	70	
	0.75	28.1	957.4	1.2	270	100	
Post Monsoon (Oct-Feb)	Average	20.59	966.43	1.02	197.64	45.31	0.93
	Max	34.9	973.2	8.8	359.89	61.5	28.4
	Min	11.4	958.8	calm	0	24.5	0
	Std	4.62	2.59	0.73	135.7	10.1	3.4
	0.25	17	964.56	0.5	53.8	28	
	0.5	20	968.29	0.9	245.5	30	
	0.75	23.8	973.2	1.4	329.3	37	

Impact of wind direction on PM concentrations (wind-rose diagram)

The figure 6 shows the wind-rose diagrams for the various seasons. During winter, wind direction is from SSW, whereas in monsoon, wind blows from SSE. Wind direction fluctuates during post monsoon season. The border town of Jaigaon (India) lies in the SW of the study site and Pasakha industrial estate lies in SE, therefore the wind pattern indicates a significant role in carrying trans-boundary air pollutants

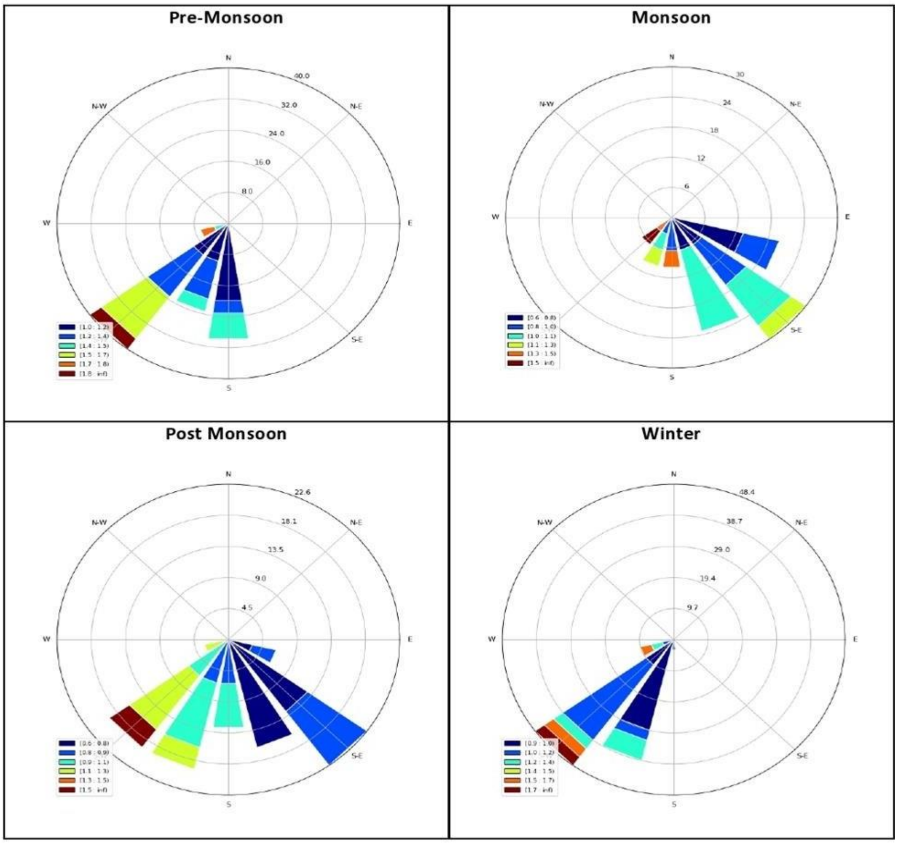


Figure 6: Wind-rose diagram

Conclusion

In this study, the assessment of PM concentration were carried out for the one year cycle and the concentrations of PM10,PM2.5 and PM1 had exceeded the WHO annual ambient air quality standard of 20µg/m3 and 10 µg/m3 respectively for the entire observation period. The diurnal cycle of 1-h PM concentrations showed two peaks-one corresponding to morning rush hour at 9am-10am and another at 5pm-7pm in the evening. This is attributed to peak traffic hours of the day. The PM concentrations decreased significantly during pre-monsoon and monsoon season due to the process of wet deposition, whereby particulate matter is removed from the atmosphere by inclusion or solution in precipitation.

The PM10, PM2.5 and PM1 were also found to be strongly co-related to each other despite of variations in the seasonal meteorological parameters. This strongly suggested that the source of emission is same for all the particulate matters. The assessment of wind speed and wind direction strongly supported the idea of trans-boundary air pollution as the seasonal winds were mostly observed to be blowing from the South, SW or SE direction.

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About the Authors

Mr. Bharat Kumar Humagai had joined the College of Science and Technology in the year 2007 and had been serving the College since then. Mr. Humagai is currently working in the Department of Science & Humanities of the College. Mr. Humagai had completed his masters in Chemistry with Environmental Chemistry components from Osmania University, India. Currently Mr. Humagai teaches Engineering Chemistry and Environmental Science to all the undergraduate engineering Students. He also serves as the centre manager of the Happiness &Wellbeing Centre of the College. After completing various courses in Environmental Toxicology and Air Quality Monitoring from Bhutan and abroad, Mr. Humagai has developed the keen research interest in the field of air quality monitoring. Currently, he is also looking after the air quality monitoring station based at CST. He also provides expert services to the stakeholders in the area of water and airquality.

Mr. Kirtan Adhikari and Mr.Basant Pradhan are the faculty members in the College of Science and Technology in Civil Engineering Department and Department of Science and Humanities respectively while Ms Tshering Yangzom represents the National Environment Commission Secretariat of Bhutan.