Variability of Surface Level Particulate Matter in Kathmandu and Pokhara and an Overview of Origin of Pollutants

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Abstract

The concentration of fine and coarse particulate matter at the surface level in Pokhara and Pulchowk (Kathmandu Valley) of Nepal was monitored from January to September 2020 using particulate matter sensors. Size-segregated particulate matter with diameters less than or equal to 1 micrometer (PM 1.0), PM 2.5, and PM 10 are analyzed hourly, daily, and seasonally. Pokhara is observed to be less polluted than Pulchowk, with an average of 58.96 µg /m3 during winter and 38.50 µg /m3 pre-monsoon. Pulchowk PM 2.5 averaged 99.64 µg /m3 during the winter season, December to February, and 55.94 µg /m3 during the pre-monsoon season, March to May. PM concentrations vary bimodally and decrease significantly in the daytime until 5 pm local time. There was a significant decrease in PM 2.5 after the last week of March in both cities, resulting from the COVID-19 lockdown, which indicates that most surface-level aerosol particles are anthropogenic such as traffic and cooking activities in the evenings and mornings might have significantly affected particulate matter concentrations. Based on seasonal variation, Pulchowk PM 2.5 leads to Pokhara by 1.63 times in winter, 1.46 times in pre-monsoon, 1.25 times in summer, and 1.32 times in post-monsoon, indicating Pokhara is less polluted than Pulchowk. In both cities, PM 2.5 contributes equally to PM 10, with fraction of 0.89 (0.86), 0.87 (0.85), 0.94 (0.92), and 0.76 (0.83), with the numbers in parenthesis representing Pulchowk and Pokhara, respectively.

Keywords:
Coarse Mode; Fine Mode; Particulate Matter (PM 2.5, PM 10); Spatio-Temporal Variation.

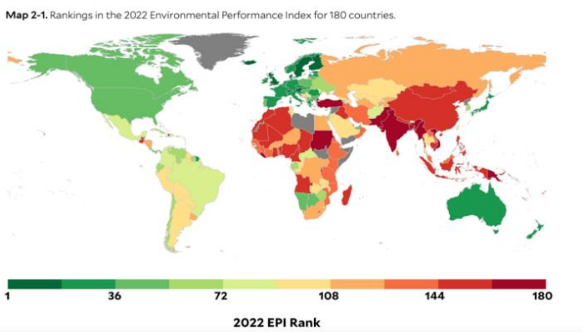
1. INTRODUCTION

Aerosol particles with an effective aerodynamic diameter of 2.5 m or less are called Particulate Matter (PM2.5) [1]. Particles like these have various health effects and play a significant role in climate change. PM is a chemically non-specific pollutant with different chemical compositions depending on its source [2]. The most important sources of such PM are biomass and fossil fuel combustion, along with diverse energy sources used in household activities [3].

Ground observations of aerosol particles are crucial as the level of uncertainty is very high due to various local and external factors [4]. Even though satellite observations can provide long-term and global coverage, they may not be as precise as surface measurements. As satellites view the entire atmospheric column, it is difficult to distinguish surface particles from those at a height [5]. It is necessary to update satellite data retrievals by considering regional bias corrections because satellite detection of surface-level and geographic data reduces its accuracy [6]. It is necessary to take multiple ground-based measurements at various locations to validate satellite and model-generated data. Further, establishing many ground-based measurement stations worldwide will be costly, and skilled human resources will be hard to come by. Low-cost sensors like Purple Air Monitor, which can be operated with general technical knowledge and transported to multiple locations quickly, can fill this gap.

In our study, we studied Kathmandu (the most polluted city in Nepal) and Pokhara (comparatively clean among Nepalese cities). Combined with rapid population growth, they are rapidly urbanizing. Pokhara has a population density of 4,626.3 / km^2, while Kathmandu has a population density of 19726 / km^2 (CBS, 2011). Apart from this, human activities such as the unplanned expansion of the city, the increase in vehicles, the haphazard construction of buildings, unmanaged industries, and biomass burning contribute to the pollution of the environment.

In the Environmental Performance Index (EPI) 2022, Nepal ranks 178th for air quality and 162nd in EPI (it was145th in 2020) among 180 countries (Figure1 a, b and c). It means the air quality is very poor and threatening, and mitigation is urgent. Statistics are essential for developing long- and short-term strategies. Only continuous and sufficient research will be able to accomplish this. The Kathmandu valley has had few studies analyzing PM 2.5 concentrations in the past. Aryal et al. (2009) reported that the valley has very high pollution levels, which peak in the morning and evening with higher values[7]. During winter mornings, pollutants remain within the inversion layer due to mixing layer activity under weak wind flow and basin topography of the valley [8]. Several other studies have also reported similar results [9]–[12]. However, a continuous and long-term study is always desirable to understand and know how air pollution is progressing. Kathmandu's source apportionment studies showed that 40% of it is from brick kilns, 37% from motor vehicles, and 22% from biomass/garbage burning) is Elemental Carbon, 47% from motor vehicles, 32% from biomass/garbage burning, and 13 percent from soil dust [13].



a

b.

Figure 1: a. Global Environmental Performance Index (EPI) map for 2022. b. Nepal's Environmental Performance Index ranking. Source: https://global-reports.23degrees.eu/epi2022/root (Retrieved on 09/07/2022)

Earlier studies have shown that transboundary and local aerosol particles affect the Pokhara valley [4]. Some of them are local in origin, while others are transboundary. Pollutants from the IGP region significantly affect it as well as Kathmandu valley. According to reports, biomass burning, industrial pollution, desert dust, and urban activities are significant sources of pollution in the IGP region [14], [15]. Based on images from the MODIS satellite and NOAA's HYSPLIT MODEL back trajectory, Regmi et al. (2020) report that an aerosol haze layer extends from the IGP to the Pokhara valley (Figure 2. a and b).

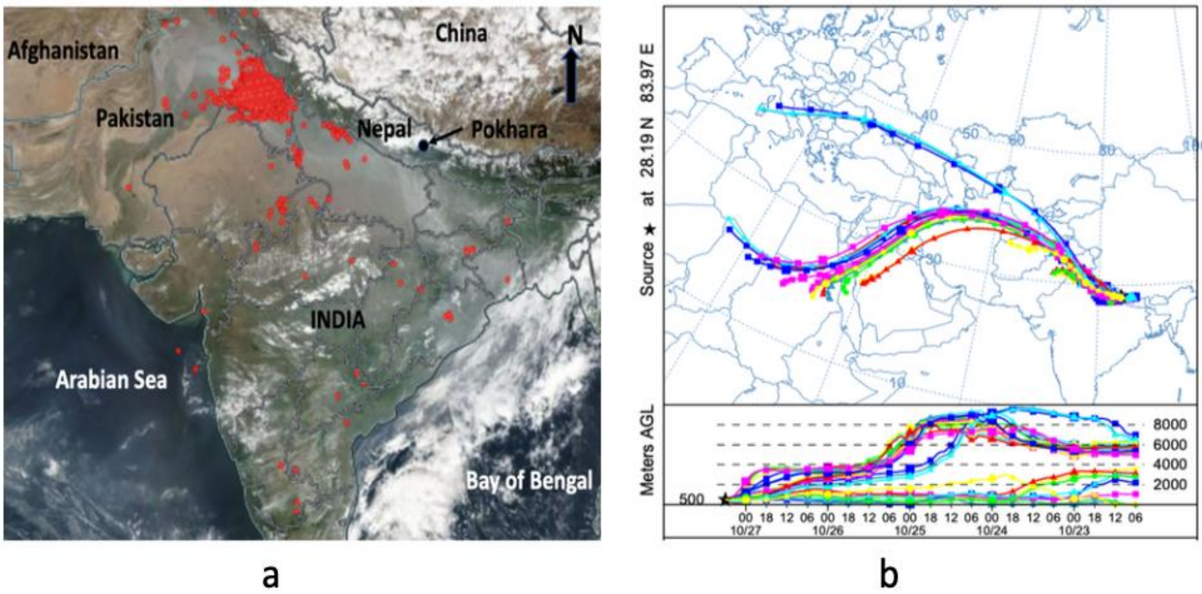


Figure 2: (a) The corrected reflectance true-color MODIS satellite image of 27 October 2017 shows intense air pollution plumes over the IGP. (b) NOAA HYSPLIT MODEL trajectories ended at 0600 UTC on 27 October 2017 (Regmi et al., 2020).

2. An overview of the materials and methods

2.1 The Purple air sensor's structure

A Purple-Air sensor was used to measure PM1.0, PM2.5, and PM10. This small and handy device can detect particles from 0.3 micrometers to 10.0 micrometers in six different sizes. This device has a six-sided shielding that provides high anti-interference performance and an option for air inlet/outlet direction. PMS5003 sensors are used to detect and count suspended particles in the air. ESP 8226 microcontrollers and BME 280 environmental sensors are used (Fig. 3). BME 280 sensors measure pressure, temperature, and humidity within the units. Consequently, the ESP 8266 microcontroller communicates with the PMS5003 sensors and the Purple Air server via Wi-Fi, allowing the PM concentration data to be viewed and downloaded live on the Purple Air map (https://www.purpleair.com/map) via the application programming interface (API).

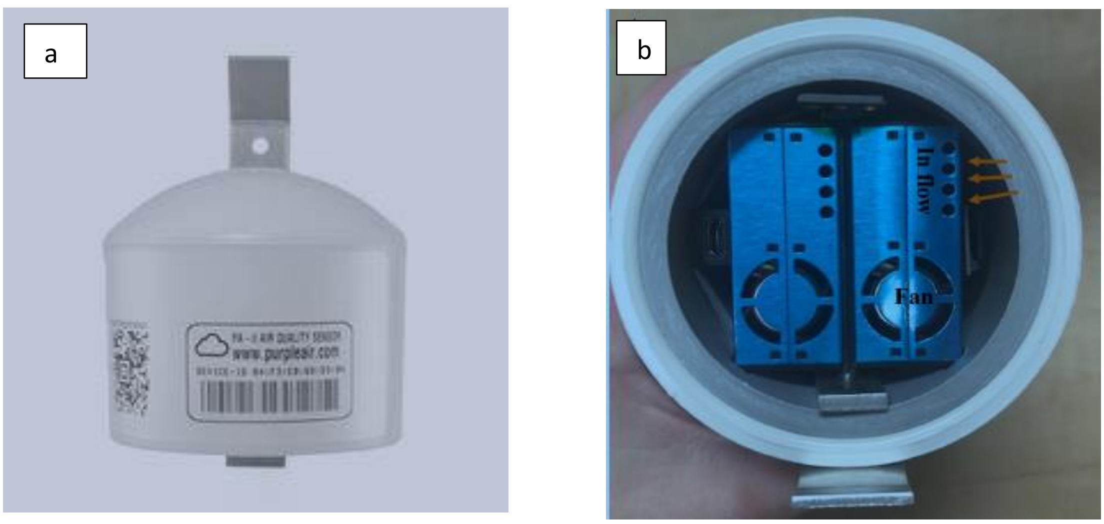


Figure 3: a. Photograph of Purple air. b. View of two blue sensors at the bottom of the PM-II unit.

2.2. Principles of operation

When the laser beam passes through an air passage, an air particle reflects some of the laser beams onto a detection plate using laser scattering. The detection plate measures the reflection as a pulse, and the pulse's length determines the particle's size. The number of pulses counts particles. Based on MIE theory, the equivalent particle diameter of the microprocessor and the number of particles with different diameters per unit volume are calculated (https://www.purpleair.com/map).

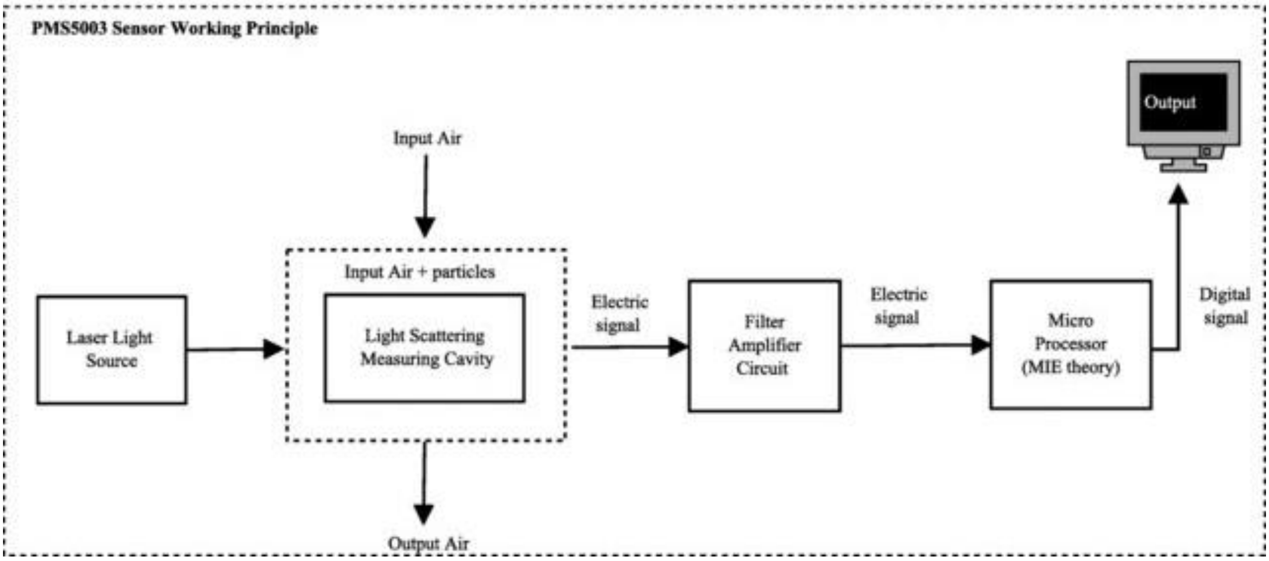


Figure 4: Purple Air II-AP/SD sensor and an overview of the PMS5003 working principle (Accessed on September 11, 2022 from http://www.aqmd.gov/docs/default-source/aq-spec/resources-page/plantower-pms5003-manual_v2-3.pdf)

2.3 Site Description:

Pokhara (28.23° N, 83.99° E) and Kathmandu (Pulchowk Engineering Campus 27.68° N, 85.31° E) are equipped with purple air monitors to measure the size of segregated PM in the air at the surface.

The Pokhara valley is the second-largest city in Nepal, located approximately 200 km west of Kathmandu at an altitude of 805 meters. The city is surrounded by hills, ranging in altitude from 1000 to 2000 meters. Approximately 35 km separates the north of IGP from the south side of Pokhara, while in the north, altitudes rise rapidly to over 7000 meters. During the summer, the mountains near Pokhara lift humid air masses, which leads to a lot of precipitation, which can significantly impact aerosol concentrations in the atmosphere [16].

Kathmandu valley, located 1325 meters above sea level, is the capital of Nepal. The city is located between the Indo-Gangetic Plain in the south, densely populated and a potential source of transboundary pollution, and the great Himalaya in the north [17]. It is surrounded by tall mountains with elevations ranging from 2000 m to 2800 m, creating a bowl-shaped structure that traps pollutants within the valley [18].

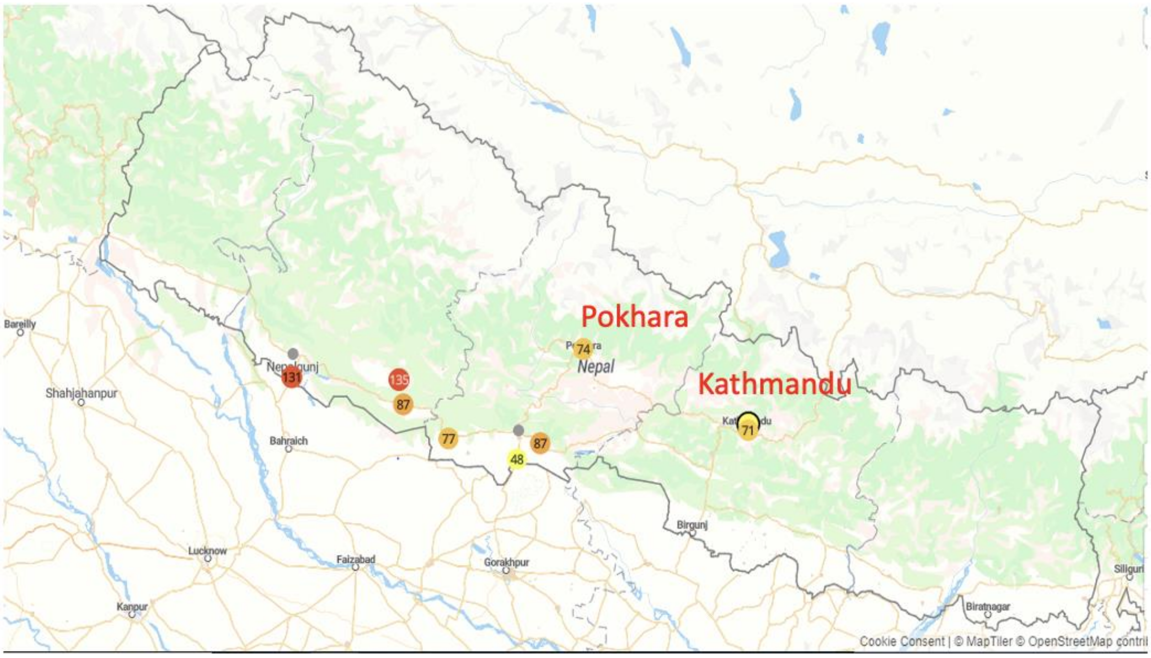


Figure 5: Map of Nepal showing the location of two sities, Kathmandu and Pokhara. Source: Purpleair.com/map
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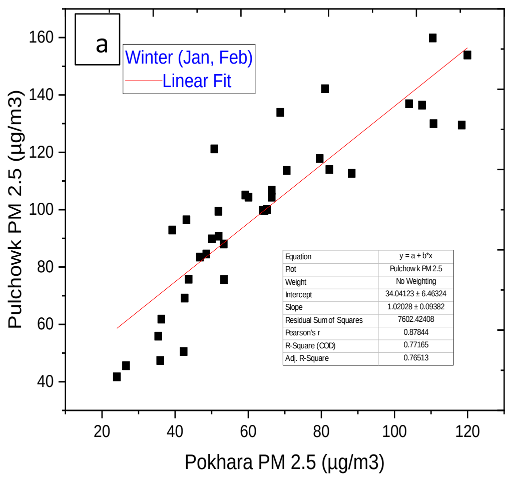
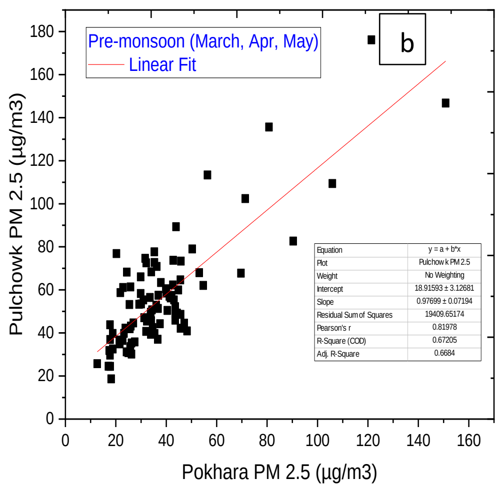
3.Results and Discussions:

3.1. Seasonal Variability of PM 2.5 and PM 10

Figure 6 (a to d) illustrate the seasonal scatterplot of simultaneously observed PM 2.5 data between Pulchowk and Pokhara. In Pulchowk and Pokhara, PM 2.5 correlates with 0.77 in winter, 0.67 in premonsoon, 0.62 in monsoon, and 0.66 in postmonsoon. The seasonal variation was analyzed using a year of data due to data availability. PM 2.5 levels in these two cities are correlated significantly, suggesting similar air pollution embedded over the atmosphere, such as roadside dust, traffic pollution, and transboundary air pollution.





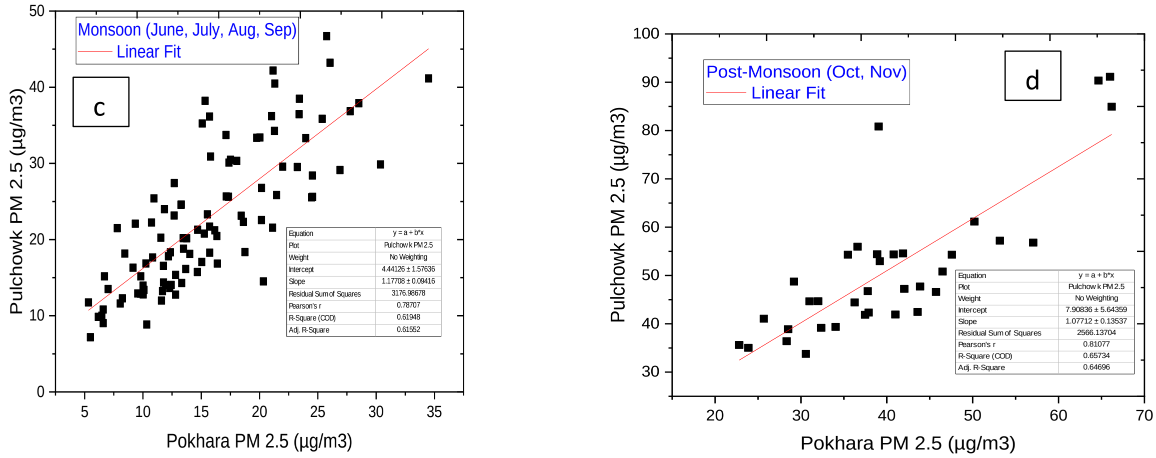


Figure 6. This figure shows the seasonal scatterplot for PM 2.5 in Pulchowk and Pokhara in 2020 a. winter b. pre-monsoon c. monsoon and d. post monsoon season.

Table 1 shows a seasonal variation of average PM2.5 and PM10 concentrations, along with standard deviations. Based on this data, Pokhara is relatively cleaner than Pulchowk. In Pokhara, fine and coarse mode particle concentrations are lower in all seasons than in Pulchowk. Pulchowk's PM2.5 average is 1.63 times higher in winter, 1.46 times higher in premonsoon, 1.25 times higher in summer, and 1.32 times higher post-monsoon than Pokhara's. Similarly, Pulchowk leads Pokhara in PM 10 ratio by 1.71 in winter, 1.50 in premonsoon, 1.28 in monsoon, and 1.21 in post-monsoon compared to Pokhara. We notice that Pulchowk has significantly higher PM concentrations in winter and premonsoon. The remaining two seasons are also significantly polluted in Pulchowk. While Pokhara shows a low PM 2.5 concentration except during winter (40µg/m3 NAAQS, 2012), Pulchowk shows a high level all year but during monsoon. In Pokhara, PM 2.5 concentrations are lowest during monsoon (17.35 ± 3.51 µg/m3) and highest during winter (61.11 ± 15.67 µg/m3). Pulchowk also recorded the lowest value during monsoon (21.73± 5.53) µg/m3 and maximum value during winter (99.72± 12.65) µg/m3 significant seasonal variation in the concentration of PM 2.5. As shown in Table 1, PM 10 concentrations in both sites are lowest in monsoon and highest in winter. As shown in table 1, PM2.5 / PM10 measures fine particles in an area's atmosphere compared to coarse particles, which contribute similarly to total particulate matter in both cities.

Table 1: Seasonal average concentrations of PM 2.5 and PM 10 in Pokhara and Pulchowk along with the ratio of PM 2.5 to PM 10.

	$PM_{2.5}$ µg/m^3		PM_{10} µg/m^3		$PM_{2.5}$ / PM_{10}	
	Pokhara	Pulchowk	Pokhara	Pulchowk	Pokhara	Pulchowk
Winter	61.11±15.67	99.72± 12.65	68.05±13.03	116.39±12.87	0.89	0.86
Pre-Monsoon	38.03±20.59	55.72 ±19.95	43.57±10.91	65.49±23.86	0.87	0.85
Monsoon	17.35 ± 3.51	21.73± 5.53	18.38 ±7.77	23.56±7.67	0.94	0.92
Post-Monsoon	39.85± 9.66	52.78± 29.80	52.36± 6.60	63.54±31.72	0.76	0.83

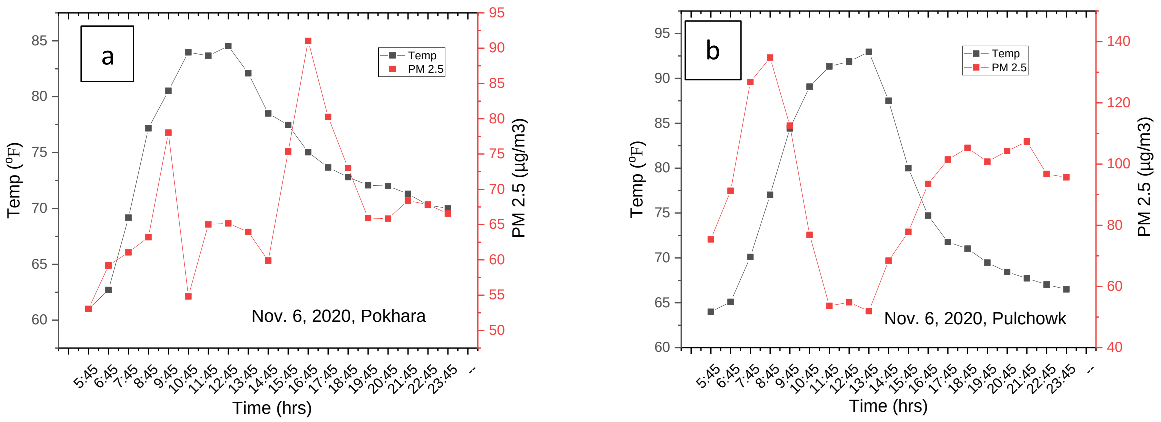
3.2 An Overview of Meteorological Parameters and Variation of PM 2.5

The table 2 presents the seasonal meteorological parameters for Pokhara and Pulchowk to illustrate the overall atmospheric dynamics. Both cities experience similar temperature variations, but Pokhara's relative humidity and air pressure are significantly higher than Kathmandu's. As a result of Pokhara's higher relative humidity, the monsoon has had a more significant impact on overall aerosol concentration during summer than in Kathmandu, Pulchowk. According to a previous study, wind, temperature, humidity, rain, and solar radiation all influence air pollution levels [19]. Pokhara's higher rainfall may contribute to its lower PM 2.5 level, significantly lower than Pulchowk's. PM levels were examined at two stations on the same day based on temperature and relative humidity. The two days were selected based on the complete availability of data for all day hours at the two sites. Pokhara's PM 2.5 variation does not show any significant trend with temperature, as shown in figure 7 (a and b). However, it shows some inverse variation with temperature during the day, especially at noon and in the afternoon, which can be due to a reduction in traffic activities or the diffusion of air pollution. In Pulchowk, however, PM concentrations show a change in PM variation opposite to temperature after around 8 am.

Figures 7 (c and d) show the significant relationship between PM 2.5 concentrations and relative humidity (RH). In both sites, PM increased with an increase in RH on two specific days (Jan 28 and Nov 6, 2020); however, we cannot draw any specific conclusions about the results. It is likely that this variation results from anthropogenic pollution produced in the morning and evening at the same time as traffic, biomass burning, and lower temperatures that increase relative humidity. Few studies have found that PM concentrations increased relative humidity [20]. On the other hand, an industrial area with low precipitation had a negative correlation [21]. As far as PM production and dispersion are concerned, RH does not appear to have an effect [22].

Table 1: Seasonal climate parameters for Pokhara and Pulchowk from January 2020 through November 2020 in Pokhara and Pulchowk.

Season	Temperature (° C)		Relative Humidity (%)	
	Pokhara	Pulchowk	Pokhara	Pulchowk
Winter (Jan, Feb)	16.80	17.98	59.22	50.73
Pre-Monsoon (Mar, Apr, May)	24.22	24.01	55.80	48.76
Monsoon (June, July, Aug, Sep)	28.91	29.04	66.99	59.11
Post-Monsoon (Oct, Nov)	24.47	25.91	58.56	45.93



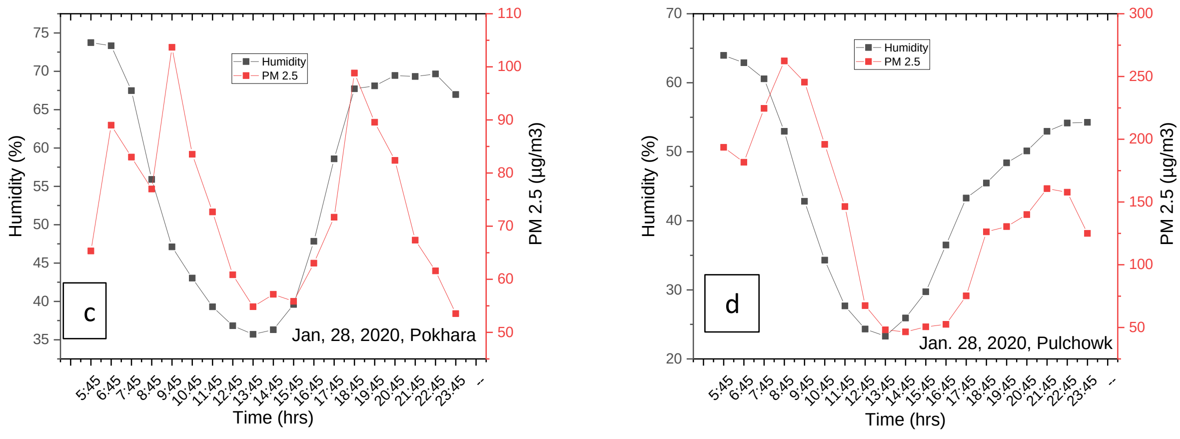
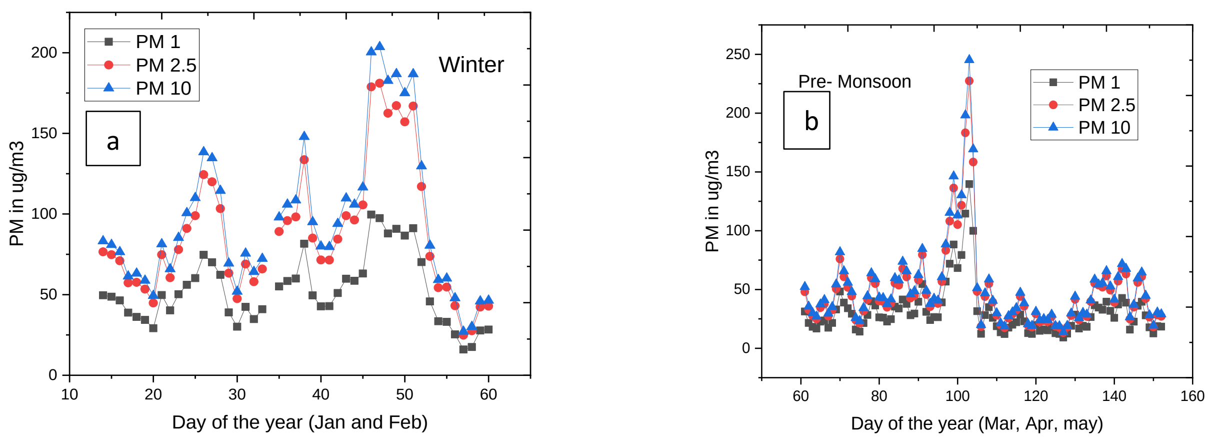


Figure 7: variation of PM 2.5 with relative humidity on two randomly selected days in Pokhara and Pulchowk. a. Variation of PM.25 and Temperature at Pokhara, b. Variation of PM.25 and Temperature at Pulchowk, c. Variation of PM.25 and Relative Humidity at Pokhara d. Variation of PM.25 and Relative Humidity at Pulchowk.

3.3 Daily Variation of PM 1, PM 2.5 and PM 10 in different Seasons

In figure 8 (a to d), the daily mean concentrations of PM 1, PM 2.5, and PM 10 in Pokhara are shown for different seasons, and in figure 9 (a to d), the daily mean concentrations of PM 1, PM 2.5, and PM 10 in Pulchowk are depicted for various seasons. According to the data, Pulchowk's PM 10 and PM 2.5 concentrations are higher than Pokhara's throughout the year. While observing the overall data each season, Pulchowk and Pokhara had maximum daily averages of 115.33 µg/m3 and 159.86 µg/m3 of PM 2.5, respectively, in winter. The pre-monsoon air quality in Pokhara was 155.24 µg/m3, and in Pulchowk, it was 176.14 µg/m3. As a result of the lockdown, followed by COVID-19, the average concentration decreased in both cities. Nevertheless, it shows that the concentration is highest during the winter season, gradually decreases until the monsoon, then increases again during the post-monsoon.

Comparing the PM concentrations in Pokhara, mixed types of particles of all sizes contribute to the particulate matter during all seasons. Both PM 10 and PM 2.5 (coarse and fine modes) contribute nearly equally, with coarse mode dominating slightly. The ultrafine particles (PM 1) contribute significantly less, which may be due to the low effectiveness of the low-cost sensors, as previous studies have indicated that they are unreliable enough to track ultrafine particles [23].



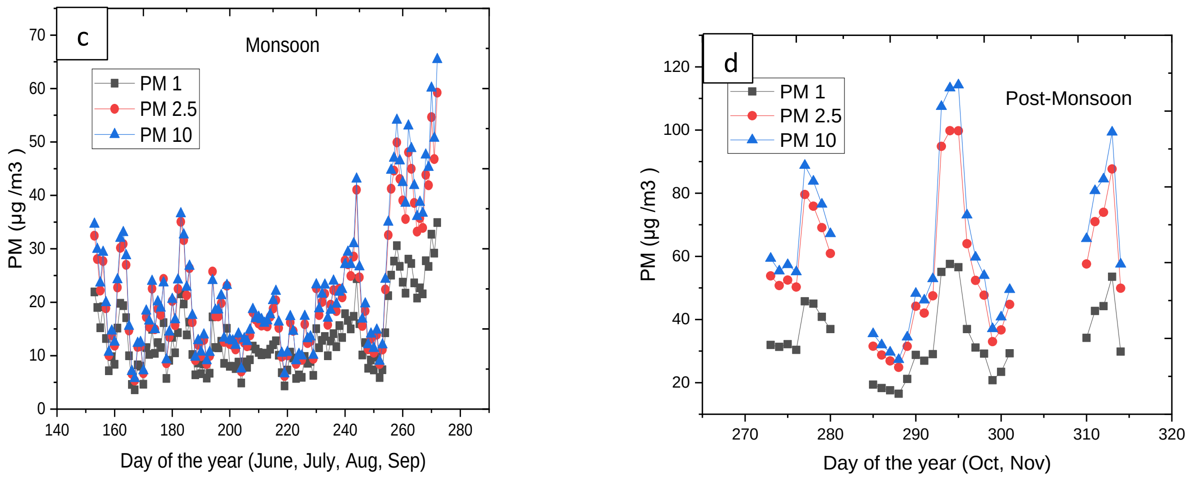


Figure 8. Comparison of Concentration of PM 1 µg/m^3, PM 2.5 µg/m^3 and PM 10 µg/m^3 in Pokhara observation site during (a) winter, (b)pre-monsoon, (c) monsoon and (d) post monsoon season 2020.

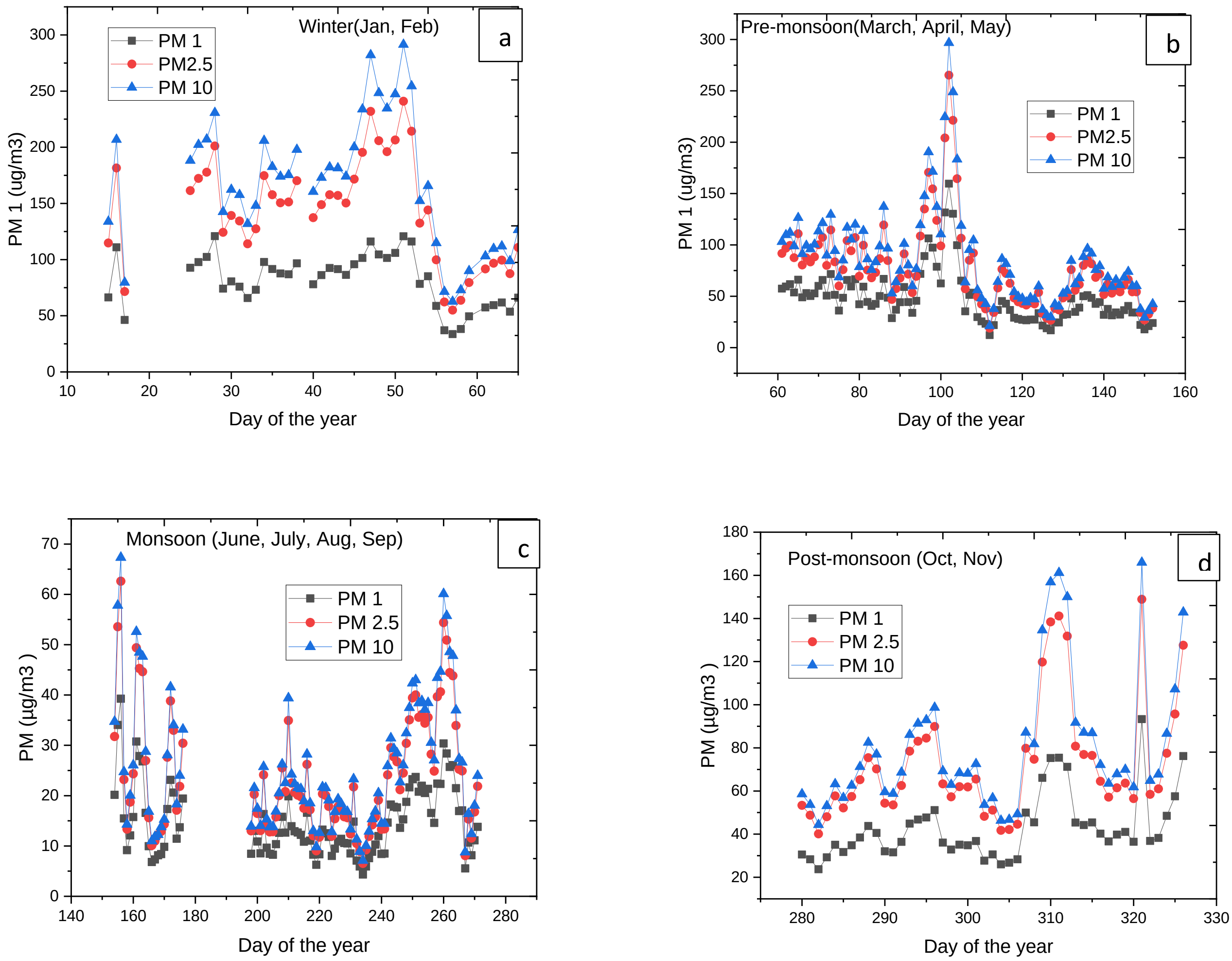


Figure 9. Comparison of Concentration of PM 1 µg/m^3, PM 2.5 µg/m^3 and PM 10 µg/m^3 in Pokhara observation site during (a) winter, (b)pre-monsoon, (c) monsoon and (d) post monsoon season 2020.

Conclusions:

This study used Purple-Air sensors to measure and analyze PM1.0, PM2.5, and PM10 aerosol particles. The Purple-Air sensor data were also examined in ambient conditions to confirm air pollution trends observed in Kathmandu and Pokhara, Nepal's two major cities and climatically vulnerable regions between the Indo-Gangetic Plain (IGP) and the high mountains. The cities are also rapidly urbanizing, with many anthropogenic pollution sources locally. With such a low-cost sensor, we could also monitor the fluctuation in air pollution caused by traffic variations, such as the COVID-19 lockdown, and we noticed the decrease in pollution with the traffic reduction during this lockdown. Particulate matter concentration varied bimodally with peaks in the mornings and evenings, coinciding with significant traffic in both cities, Kathmandu and Pokhara. In addition, this study indicates that coarse mode particles, which are mainly associated with roadside dust, have a significant impact. Studying the detailed temporal data of these two large cities will be very beneficial for studying the impact of transboundary air pollution since they are highly affected by the transport of pollutants over long distances. At two cities, a seasonal scatterplot of PM2.5 with a significant correlation of 0.77, 0.67, 0.62, and 0.65 was obtained by two purple air monitors during winter, pre-monsoon, and monsoon, respectively. This indicates that the two monitors are valid and that there are similar pollution sources in two big cities in Nepal.

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