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Seasonal variations of gaseous and particulate pollutant in different location of urban Bangalore

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ABSTRACT

To understand how air pollution varies in emerging countries like India and its capital cities, monthly air-quality data with high temporal and geographical precision is necessary. For many Indian cities, yearly fluctuations in air pollution are still indeterminate. Spatial and temporal variations of seven air pollutants in fifteen monitoring station across the metropolitan city Bangalore during the year 2018 were analysed. The annual mean mass concentrations of $PM_{2.5}$ and PM_{10} were 63.1 ± 18.9 μg m^{-3} and 90.8 ± 18.4 μg m^{-3}, respectively, exceeding the Indian National Ambient Air Quality Standards established by the Central Pollution Control Board. The annual mean concentrations of SO_2 were 2.36 ± 0.1 μg m^{-3}, NO_2 31.34 ± 3.7 μg m^{-3}, CO 1.13 ± 0.2 μg m^{-3}, NH3 23.97 ± 3.7 μg m^{-3}, and lead values are 0.24 ± 0.5 μg $m^{-3}$are below the national limit. Saneguruvanahalli and Banasawadi Police Stations had lower concentrations of air pollutants, except for $PM_{2.5}$, than other stations in Bangalore, resulting in better air quality. Seasonally, the maximum $PM_{2.5}$ concentrations were found at ITPL Whitefield in the spring, followed by the autumn seasons. This analysis provides the basis for the pollutant to be considered in the formulation of future Bangalore air mitigation strategies.

Keywords: Nitrogen dioxide, $PM_{2.5}$, Particulate pollutant, Season wise, Sulphur dioxide

1. INTRODUCTION

Air pollution has become a major global health and welfare concern (WHO, 2016; Hansen *et al*., 2016), more fossil fuels are burned and automobiles are being used in developing country like India, resulting in higher levels of particulate matter ($PM_{2.5}$ and PM_{10}), carbon dioxide (CO_2), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), Carbon monoxide (CO) and ozone (O_3) in the atmosphere (Badami, 2005). In India, particularly in recent years, air pollution has sparked widespread public concern (Yusuf *et al*., 2020; Shetty*et al*., 2021). In major cities around the world, dramatic variations in PM and gaseous pollutants have been documented over the last several decades (Kumar *et al*., 2015; Lawrence and Lelieveld 2010; Tiwari *et al*., 2014; Yadav *et al*., 2017; Bhusal *et al*., 2021). To effectively assess the health hazards associated with air-pollutant exposure, high geographical and temporal resolution air pollution data is required. The spatial and temporal variability of

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air pollutants are important factors in determining the relationship between exposure and human health (Devaraj *et al.*, 2019).

India has a wide range of sources of air pollution, diesel fuel is used in the majority of commercial and private cars, which contributes to PM emissions (Burtscher, 2005). Carbon (41%) was found in a heavy-duty diesel engine, followed by unburned fuel (7%), unburned oil (25%) sulphate and water (14%), ash and other components (13%) according to Kittelson (1998) and Maricq (2007). Agarwal (2007) found that elemental carbon (31%) is the most common metal, followed by sulphates and moisture (14%), unburned fuel (7%), lubricating oil (40%) and other metal-containing compounds. Every year, more than 1 million people die prematurely in India due to poor outdoor air quality (Jerrett, 2015; Lelieveld *et al*., 2015; Reşitoglu *et al*. 2015).

Bangalore (today known as Bengaluru) is a metropolitan city in India's southern state of Karnataka, on the Deccan Plateau. In comparison to other northern Indian megacities, the city is less polluted. When compared to regulatory requirements, air pollution rates are rising (Chinnaswamy *et al.,* 2016; Thakur, 2017). Vehicle emissions are the most significant local source of air pollution in Bangalore. In Bangalore, Vreeland *et al.* (2016) documented extensive roadside waste burning. Transported aerosol from distant sources could also be present. The present study was done to assess the overall air quality in Bangalore urban from fifteen sites in order to estimate the limits of national and international annual standard levels and seasonal fluctuations in air pollutant concentrations.

2. MATERIALS AND METHODS

Study area

Bangalore (12.9716°N, 77.5946°E: 900 m above sea level) is India's sixth most populous metropolitan agglomeration, with a population of over 10.It is India's third-largest city and the fifth-largest urban agglomeration. The city, which is located on the banks of the Vrishabawathi River and has the highest elevation among India's main cities, is noted for its pleasant climate throughout the year. The city is recognised as the Silicon Valley of India and features one of the country's major information technology industries, with numerous well-known enterprises. It is also renowned as a garden city. Two important National Highways (NH44 and NH75) connect Jammu with Kanyakumari and Mangalore with Chennai, respectively. Bangalore's topography is mostly flat, while the western parts of the city are hills.

Data collection

The pollutant concentrations were first collected from the Karnataka Pollution Control Board's online air pollution monitoring database. For the year 2018, air pollutant concentrations at all fifteen locations (Table1 and Fig.1) were calculated using 8-hour daily data. For the purpose of analysing the seasonal variation of the pollutant, the following 12-month break-up was used: Winter months were December and January, spring months were February and March, summer months were May and June, monsoon months were July and August, and fall months were September and November. The statistical software SAS 9.3 was used to analyse monthly variations in air pollutants such as $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, NH3 and Pb.

Table 1: Description of the air pollutant sampling network in Bangalore, India

Sampling Site	Designation	Latitude	Longitude	Site description
Amco Batteries	AMC	12.96	77.58	Industrial
Central Silk Board, Hosur Road	CSB	12.91	77.62	Commercial, Traffic junction
Indhira Gandhi Children Health Care	ICH	12.93	77.59	Suburban, commercial
ITPL, Whitefield	ITP	12.98	77.7	Commercial, Residential
Kajisonnenahalli	KSH	13.03	77.76	Residential
Rail Wheel Factory,Yelahanka	RWF	13.1	77.58	Industrial
Swan Silk Pvt.Ltd., Peenya	SSP	13.02	77.52	Industrial, suburban
Urban Eco Park, Peenya	UEP	13.02	77.52	Industrial, suburban
Victoria Hospital, K.R. Market	VHM	12.97	77.57	Commercial
Yeshwanthapura Police station	YPS	13.01	77.55	Commercial
TERI Office, Domlur	TRI	12.96	77.63	Suburban
Banasawadi Police Station	BPS	13.01	77.64	Residential
UVCE, KR Circle	UVE	12.97	77.58	Commercial
City Railway Station, CAAQM	CRS	12.98	77.56	Commercial, Traffic junction
Saneguruvanahalli, CAAQM	SGH	12.99	77.54	Industrial, suburban

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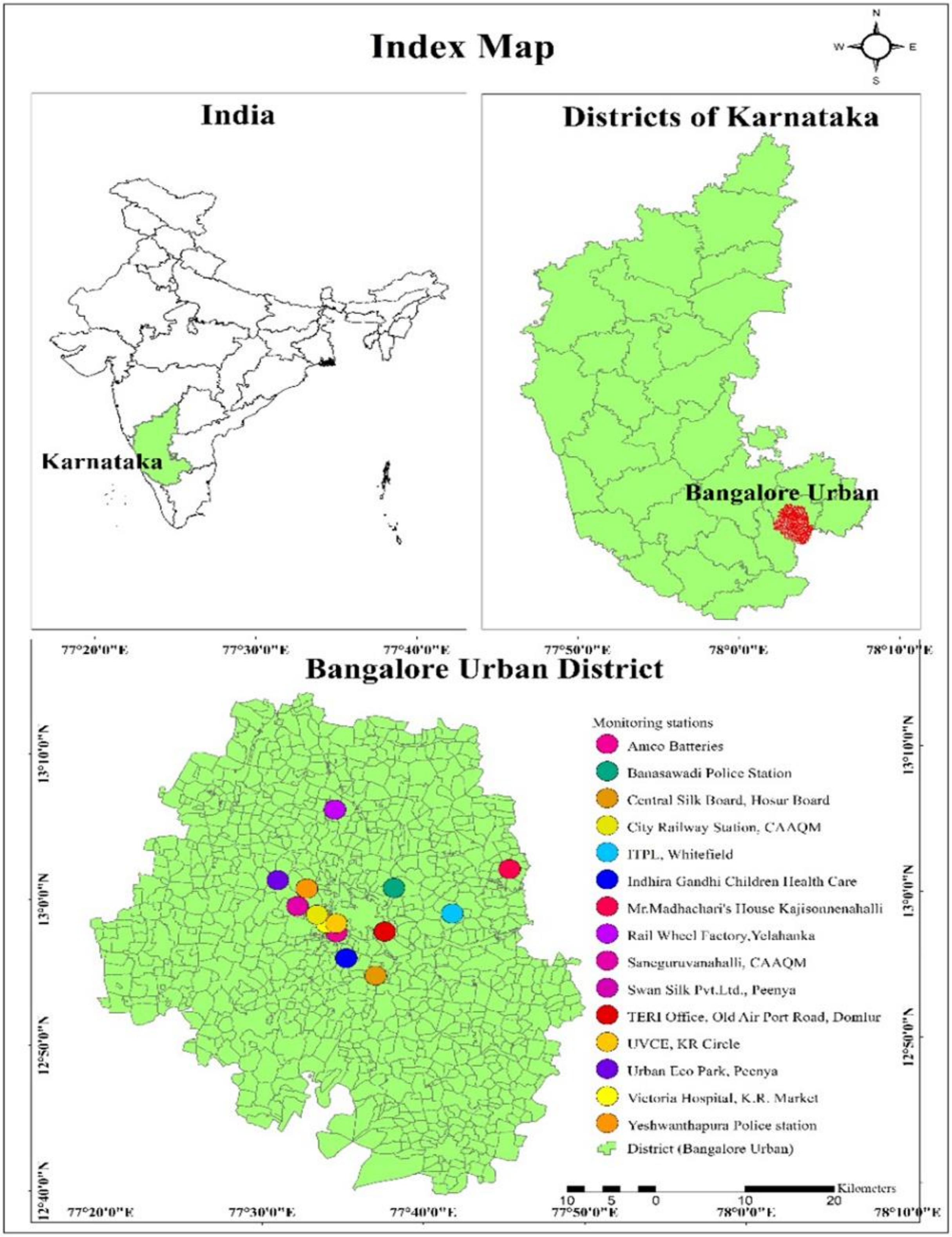

Fig. 1: Sampling sites for the monitoring of particulate matter and gaseous air pollutant in Bangalore.

3. RESULTS AND DISCUSSION

Annual air quality in Bangalore

The annual average (mean of daily data) mass concentrations of $PM_{2.5}$ (fine) and PM_{10} (inhalable) measured at different stations in Bangalore were 63.1±18.9 μg m^{-3} and 90.8 ± 18.4 μg m^{-3}, respectively. Due to the substantial fluctuation in monthly mass PM, the mean of monthly $PM_{2.5}$ and PM_{10} data was approximately 17 percent higher than the annual daily mean. Due to the generation of secondary aerosol from major building activity of metro lines as primary anthropogenic aerosol, topography, and transported from distance sources, the contributions of $PM_{2.5}$ and PM_{10} over Bangalore city were 69% and 28%, respectively (Devaraj *et al.*, 2019). The following were the average yearly concentrations of gaseous pollutants measured: SO_2concentrations are 2.36 ± 0.1 μg m^{-3}, NO_2 31.34 ± 3.7 μg m^{-3}, CO 1.13 ± 0.2 μg m^{-3}, NH3 23.97 ± 3.7 μg m^{-3}, and lead values are 0.24 ± 0.5 μg m^{-3} (Fig. 2).

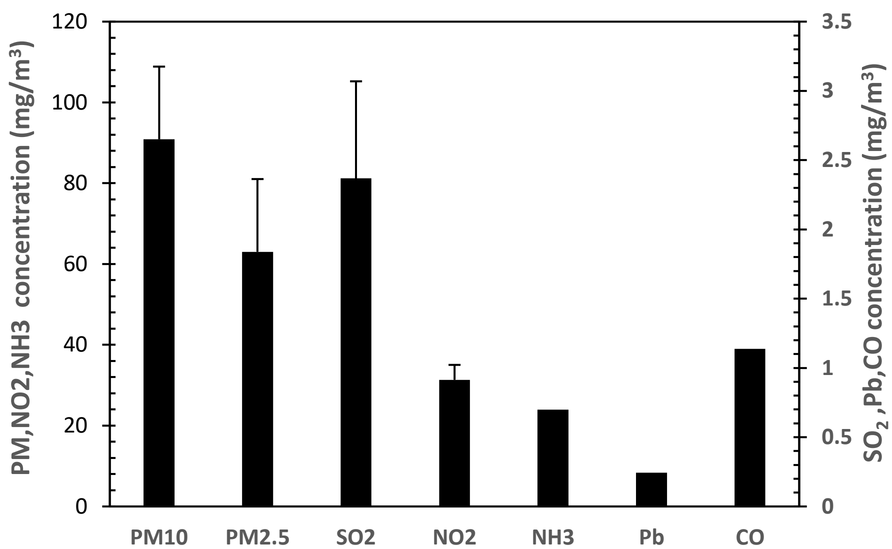

Fig. 2: Average annual air pollutant concentration measured at fifteen stations of Bangalore.

Station wise annual and monthly variation of air pollutant

The contributions of particular air pollutants at different stations over Bangalore were also investigated. For PM_{10}, at CSB contributed the most (113.3 ± 11.3 μg m^{-3}), followed by CRS (111.04 ± 29.5 μg m^{-3}) and YPS (106.1 ± 21.8 μg m^{-3}) monitoring sites; however, for $PM_{2.5}$, the CRS (96.2 ± 0.3μg m^{-3}) monitoring site contributed the most and the BPS (26± 0.1 μg m^{-3}) monitoring site contributed the least (Table 2). Different emissions sources in and near sampling sites were responsible for the considerable variation in PM mass between sites. During the study period, significant monthly changes in PM2.5 and PM10 were found across Bangalore city, as shown in Figs. 3. In comparison to the other sites, $PM_{2.5}$ concentrations were substantially greater at CRS due to vehicular junction and civil work activities. It has been discovered that in-vehicle induced PM concentrations are higher than ambient PM concentrations, which are higher than the Central Pollution Control Board of India's stipulated National Ambient Air Quality Standards (Jain, 2017) (Table 3).

The traffic junction site CRS had the greatest amounts of SO_2, NO_2, CO, and Pb, while the suburban sites SGH and BPS had the lowest mean concentration of gaseous pollutant. Except for $PM_{2.5}$ and PM_{10}, all pollutant concentrations observed at individual stations were lower than the yearly Indian National Ambient Air Quality Standards.

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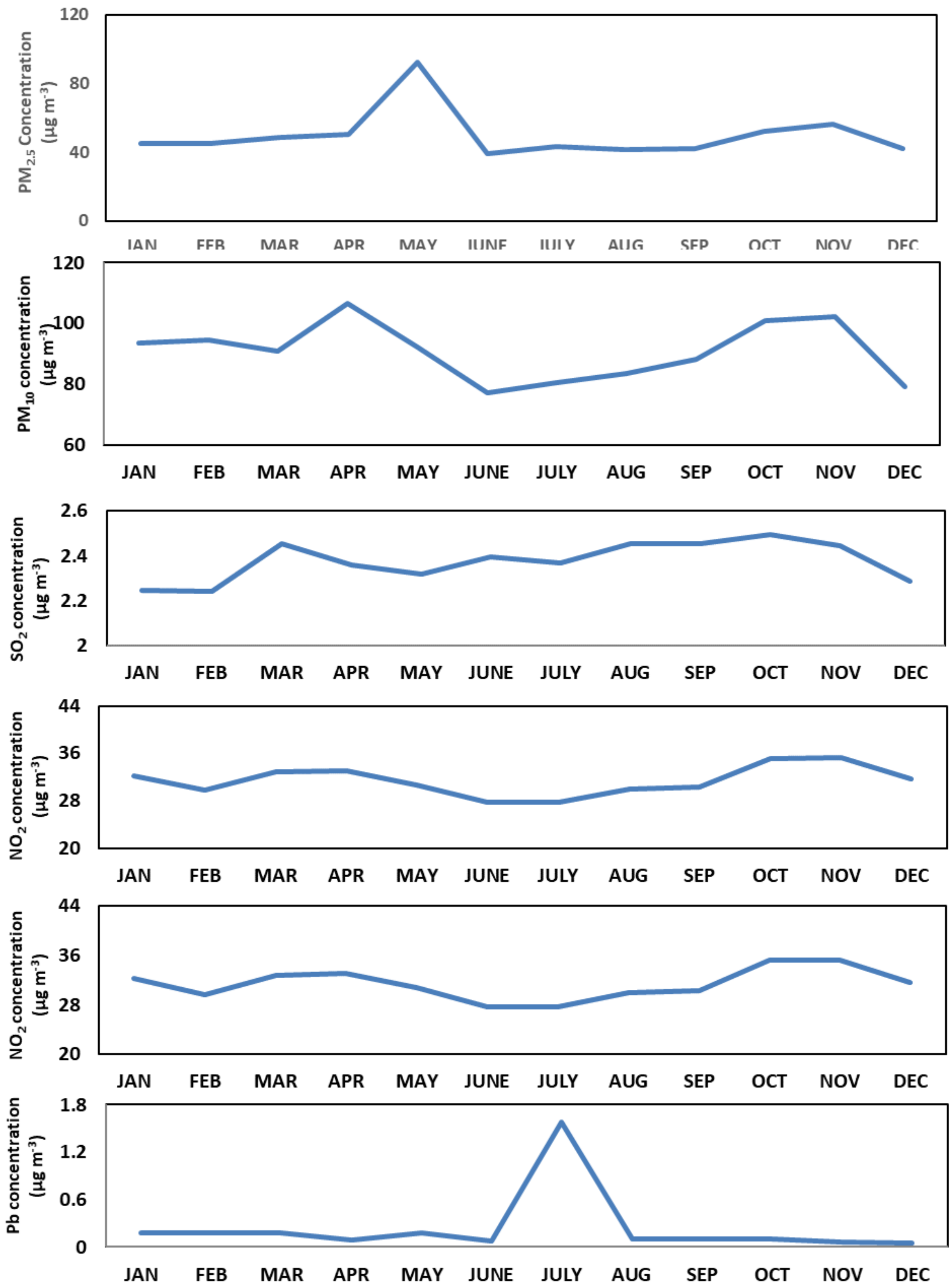

Fig. 3: Monthly variability of measured air pollutant in Bangalore during the study period

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Table 2: Annual average of air pollutant concentration at different locations of Bangalore.

Stations	Air pollutant concentration in µg m^{-3}						
	PM 10	**PM2.5**	**SO_2**	**NO_2**	**NH3**	**Pb**	**CO**
AMC	103.2 ± 11.6	50.7 ± 15.8	2 ± 1.0	32.1 ± 2.4	26.1 ± 2.8	0.19 ± 0.07	
CSB	113.8 ± 11.2	73.1 ± 11.2	2 ± 1.0	31.75 ± 2.3	26.5 ± 3.8	0.11 ± 0.03	
ICH	70.8 ± 16.1	44.3 ± 16.1	2 ± 1.0	31.4 ± 2.7	24.5 ± 2.5	0.04 ± 0.03	
ITP	110.2 ± 22.3	59.4 ± 16.5	2 ± 1.0	32.6 ± 1.9	25.3 ± 2.6	0.10 ± 0.04	
KSH	82.8 ± 12.8	98.0 ± 11.4	2 ± 1.0	31.1 ± 1.8	24.5 ± 2.9	0.16 ± 0.17	
RWF	105.1 ± 25.7	123 ± 15.3	2 ± 1.0	31.7 ± 2.4	24.7 ± 2.4	0.07 ± 0.03	
SSP	90.0 ± 13.5	52.8 ± 18.3	2 ± 1.0	31.8 ± 2.4	24.8 ± 2.8	1.91 ± 0.10	
UEP	101.2 ± 12.6	55.6 ± 36.1	2 ± 1.0	32.5 ± 1.7	26.2 ± 3.4	0.15 ± 0.10	
VHM	71.2 ± 14.4	66.0 ± 12.6	2 ± 1.0	31.7 ± 2.0	24.6 ± 2.6	0.05 ± 0.05	
YPS	106.1 ± 21.8	51.6 ± 13.6	2 ± 1.0	32.0 ± 2.2	24.5 ± 2.5	0.09 ± 0.04	
TRI	89.1 ± 21.5	44.2 ± 11.2	2 ± 1.0	31.8 ± 2.0	25.4 ± 3.2	0.08 ± 0.08	
BPS	67.4 ± 22.5	26.0 ± 3.8	2 ± 1.0	28.2 ± 2.2	24.2 ± 5.3	0.07 ± 0.09	
UVE	83.4 ± 23.2	41.4 ± 11.4	2 ± 1.0	28.0 ± 2.7	24.6 ± 6.5	0.07 ± 0.07	
CRS	111.1 ± 29.5	96.2 ± 12.6	6 ± 1.0	38.8 ± 16	18.1 ± 8.7	0.19 ± 0.07	1.5 ± 0.2
SGH	57.2 ± 17.1		3 ± 0.4	24.2 ± 9.8	15.0 ± 3.18	0.11 ± 0.03	0.7 ± 0.1

Table 3. National ambient air quality standards (NAAQS) and World Health Organization guideline for air pollutant levels.

Pollutants	Concentration of ambient air (µg/m^3)					
	Industrial, Residential, Rural and Other Area					
	NAAQS				WHO	
	Annual	24 hrs	8 hrs	1 hrs	Annual	24 hrs
SO_2	50	80				40
NO_2	40	80			10	25
PM_{10}	60	100			15	45
$PM_{2.5}$	40	60			5	15
NH3	100	400				
Pb	0.50	1.0				
CO (mg/m^3)			2	4		

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Table 4: Seasonal Variability of PM measured at the 15 sites in Bangalore (μg m^{-3})

Seasons	**Winter**		**Spring**		**Summer**		**Monsoon**		**Autum**	
Pollutant (μg/m³)	*PM 2.5*	*PM10*	*PM 2.5*	*PM10*	*PM 2.5*	*PM10*	*PM 2.5*	*PM10*	*PM 2.5*	*PM10*
AMC	39.5	94.5	48.5	107.5	43	92	48	104.33	56	123
CSB	50	110		121.5	30	116.3		106	60	118
ICH	34	59	36	59.5	43.5	179		80.33		96.5
ITP	37	84	68.5	106.5	38	103.3		105.6	59	127.5
KSH		82		81	41	85		78.66		88.5
RWF		79.5		131.5	51	113		85.33		121.5
SSP	50	98	44.5	91.5	63	92	38	74		101.5
UEP	46	98	46	106	25	121	40	87	41	105
VHM		69		58	45.3	65.3		71		96
YPS	53	120	52.5	117	36	103.33	38.33	83	58	118.5
TRI	46	104	42.5	99		75	36.5	80	49	98.5
BPS		69	26	68	47	70.5		75.66		84
UVE	36	69.5	35	59.5		99	42	86.33		101.5
CRS		110		148		109.7		102.36		59.33
SGH		58.5		76.15		57.25		45.16		54.85

Seasonal Variability of air Pollutant in Bangalore

Seasonal PM ($PM_{2.5}$ and PM_{10}) concentrations showed a lot of fluctuation, with maximums in the fall (53.8 and 99.6 μg m^{-3}) and spring (44.3 and 95.3 μg m^{-3}) and a lot of variation in the peak month among the locations (Table 4). $PM_{2.5}$ and PM_{10} concentrations followed a similar pattern, with winter having 2 and 1.6 times greater concentrations than the other seasons. For $PM_{2.5}$, the highest values were found in the autumn season, followed by spring, winter, summer, and monsoon seasons; however, for PM_{10}, the highest values were found in the autumn season, followed by summer (Abdel, 2021).

Seasonally, the highest $PM_{2.5}$ concentrations were observed at ITP during the spring (68.5 μg m^{-3}), followed by the autumn (59.0 μg m^{-3}), winter (37.0 μg m^{-3}), and summer (38 μg m^{-3}) seasons. The impact of meteorological conditions as well as seasonal emissions of particulate matter from manmade (incomplete combustion of fossil fuels) and natural sources (combustion process, soil dust, unpaved road dust, transported fumigate dust particles, etc.) in and around the city caused a large variability in PM mass concentrations (Satsangi and Yadav, 2014).

The lowest PM concentrations are found during the monsoon season due to higher precipitation rates and washout of ambient PM. The significant higher mass concentrations of the inhalable particle (PM_{10}) during the summer are associated with extreme sporadic peaks of soil dust particles, road dust suspension, mineral dust, etc., (Kubilay *et al.,* 2000). Particulate matter and gaseous pollutants are important indicators of air pollution caused by a wide range of natural and human activities. It is clear from this study that local and regional emissions, as well as meteorological, have altered the concentrations of $PM_{2.5}$, PM_{10}, and their precursor gases over time. The current study examined at the temporal and spatial variability of air pollutant concentrations at fifteen stations (from January to December 2018). At the majority of the site, the yearly average mass concentrations of $PM_{2.5}$ and PM_{10} were 63.1 18.9 g m-3 and 90.8 18.4 g m-3, respectively, exceeding the WHO standards limit values and the Indian NAAQS for PM_{10}. Many of aerosols components appear to have their own pattern of seasonal variation. However, the measure of PM mass concentration is suitable for representing urban aerosol pollutions.

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Author's contribution:

Shyni: Data collection, preparation of manuscript; **Prabhakaran N**: Preparation of manuscript, statistical analysis; **G V Venkataraman**: Statistical analysis, data interpretation, and correction of manuscript.

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Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. Abdel Salam M. Seasonal variation in indoor concentrations of air pollutants in residential buildings. J Air Waste Manag Assoc. 2021:71:761-777.
2. Agarwal, A.K. Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines. Prog energy combust sci. 2007: 33: 233-271.
3. Badami, M.G. Transport and urban air pollution in India. Environ. Manag. 2005: 36: 195-204.
4. Bhusal B, Oli M, Adhikari B, Neupane P. Monthly and seasonal variation on particulate matter (PM2.5) and meteorological parameters over Beijing. Discovery, 2021, 57(306), 479-494
5. Burtscher, H. Physical characterization of particulate emissions from diesel engines: a review. J Aerosol Sci. 2005: 36: 896-932.
6. Chinnaswamy, A. K et al. Air pollution in Bangalore, India: an eight-year trend analysis. Int J. Environ Tech Manag., 19(3-4), 177-197 (2016).
7. Devaraj, S et al. Spatial and temporal variation of atmospheric particulate matter in Bangalore: a technology-intensive region in India. Arch Environ Contam Toxicol., 77(2), 214-222 (2019).
8. Hansen, A. B., Ravnsaer, L., Loft, S., Andersen, K. K., Bräuner, E. V., Baastrup, R., and Andersen, Z. J: Long-term exposure to fine particulate matter and incidence of diabetes in the Danish Nurse Cohort. Environ Int, 91, 243-250 (2016).
9. Jain, S: Exposure to in-vehicle respirable particulate matter in passenger vehicles under different ventilation conditions and seasons. Sustain Environ res., 27(2), 87-94(2017).
10. Jerrett, M. The death toll from air-pollution sources. Nat. 2015: 525: 330-331.
11. Kittelson, D.B. Engines and nanoparticles: a review. J Aerosol Sci. 1998: 29: 575–588.
12. Kubilay, N., Nickovic, S., Moulin, C., and Dulac, F: An illustration of the transport and deposition of mineral dust onto the eastern Mediterranean. Atmos Environ., 34(8), 1293-1303 (2000).
13. Kumar, P et al. New directions: Air pollution challenges for developing megacities like Delhi. Atmos Environ., 122, 657-661 (2015).
14. Lawrence, M. G.,and Lelieveld, J. Atmospheric pollutant outflow from southern Asia: a review. Atmos Chem Phys. 2010: 10: 11017-11096.
15. Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., and Pozzer, A.The contribution of outdoor air pollution sources to premature mortality on a global scale. Natur. 2015: 525: 367-37.
16. Maricq, M. M. Chemical characterization of particulate emissions from diesel engines: A review. J Aerosol Sci. 2007: 38: 1079-1118.
17. Reşitoglu, İ. A., Altinisik, K., and Keskin, A. The pollutant emissions from diesel-engine vehicles and exhaust after treatment systems. Clean Tech Environ Policy.2015: 17: 15-27.
18. Satsangi, P. G., and Yadav, S. Characterization of PM 2.5 by X-ray diffraction and scanning electron microscopy–energy dispersive spectrometer: its relation with different pollution sources. Intern J Environ Sci Tech. 2014: 11: 217-232.
19. Shetty, B. S. P., D'Souza, G., and Padukudru Anand, M: Effect of Indoor Air Pollution on Chronic Obstructive Pulmonary Disease (COPD) Deaths in Southern Asia—A Systematic Review and Meta-Analysis. Toxics. 2021: 9: 85.
20. Thakur, A: Study of ambient air quality trends and analysis of contributing factors in Bengaluru, India. Orient. J Chem. 2017: 33: 1051-1056.
21. Tiwari, S., Bisht, D. S., Srivastava, A. K., Pipal, A. S., Taneja, A., Srivastava, M. K., and Attri, S. D: Variability in atmospheric particulates and meteorological effects on their mass concentrations over Delhi, India. Atmos res. 2014: 145: 45-56.

22. Vreeland et al. Chemical characterization and toxicity of particulate matter emissions from roadside trash combustion in urban India. Atmos Environ., 47, 22-30(2016).
23. World Health Organization. Ambient air pollution: a global assessment of exposure and burden of disease. Geneva: WHO, (2016).
24. Yadav, R., Sahu, L. K., Beig, G., Tripathi, N., and Jaaffrey, S. N. A: Ambient particulate matter and carbon monoxide at an urban site of India: influence of anthropogenic emissions and dust storms. Environ Pollut. 2017: 225: 291-303.
25. Yusuf, S., et al. Modifiable risk factors, cardiovascular disease, and mortality in 155 722 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study. The Lancet. 395(10226), 795-808 (2020).

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