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Original Article

Air quality analysis over three years for different districts of Karnataka state, India

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Abstract

Analysis of ambient air quality parameters on a specific day over three years across 17 districts of Karnataka gives an insight into the air quality scenario of the entire Karnataka State. With this as an objective, air quality data from Central Pollution Control Board (CPCB online platform) has been used in the present study. Covering a large spatial distribution when acquiring air quality data becomes easy with the use of CPCB online data portal. The important observations made in the present study are as follows: The concentration of PM 2.5 is found to be high (142 $\mu g/m^3$) for the location Bengaluru during January 2023 and low (13 $\mu g/m^3$) for the location Chamarajanagar during January 2022. Highest value (152 .6 $\mu g/m^3$) of PM10 is found for the location Kolar in January 2023 and lowest (20 $\mu g/m^3$) for Madikeri in January 2023. The concentration of NO2 is found to be high (94 $\mu g/m^3$) for location Bengaluru in January 2023 and low (7 $\mu g/m^3$) for Madikeri in January 2023. Concentration of NH3 is found to be high (19 $\mu g/m^3$) for the location Koppal in January 2021 and low (1 $\mu g/m^3$) for Madikeri, Vijaypura & Yadgir in January 2021. Concentration of SO2 is found to be high (157.2 $\mu g/m^3$) for the location Kolar in January 2023 and low (1 $\mu g/m^3$) for Vijayapura in January 2021. Concentration of O3 is found to be high (97 $\mu g/m^3$) for the location Madikeri in January 2021 and low (5 $\mu g/m^3$) for Raichur in January 2021. Also, concentration of CO is found to be high (84 $\mu g/m^3$) for the location Hubballi in January 2023 and low (4 $\mu g/m^3$) for the location Kalaburagi in January 2023. The reason for increase in particulates & gaseous pollutants in the atmosphere across 17 districts of Karnataka might be an increase in anthropogenic activities. Deeper discussion in the light of population density changes and anthropogenic activities is presented in this paper.

Keywords: air quality, online data, CPCB, Districts of Karnataka

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1. Introduction

Monitoring air quality parameters on a regular basis for a given location becomes very important in order to predict the existing air quality features of that location. Also, simultaneous monitoring of air quality parameters across different locations gives very important and useful information regarding the quality of ambient air which can influence the human health.

Rising levels of air pollution are a global concern and they are caused by many factors such as increasing urbanization, industrial pollution, traffic emissions, agriculture and energy use (Kumar, Morawska, Birmili, Paasonen, Hu, Kulmala, Harrison, Norford, & Britter, 2014).

Both natural and human activities cause air pollution in rural areas (Dey, Tripathi, Singh, & Holben, 2004). Air pollution is a widespread problem that poses serious health risks. We are progressing towards modernization as technology advances. Using the most appropriate technologies makes our lives simpler and more convenient (Sonaviya & Tandel, 2019). In comparison to developed nations, health conditions are more prevalent in emerging countries. The main aim in terms of public health is to raise public consciousness so that people can take practical measures to protect themselves from the adverse effects of air pollution. A secondary aim is to increase awareness of the effects of existing levels of air emissions to inspire changes in human behaviour and public policy. With the increase in the number of vehicles and pollution from them, the air quality has changed drastically over time. Measuring the level of decline in the air quality standard is a time-consuming, complicated and expensive task. However, use of online/satellite data can overcome these complications to some extent. Timely monitoring predicts the level of air pollution at a specific location.

With the advances in life style, many health hazards can be anticipated. Newer innovations or advances are often linked to health risks. The three categories Environmental factors, Socio-economic factors, and Demographic factors, play significant roles in urbanization. Air pollution is a major environmental problem that mainly affects the health of urban communities. Increase in the amount of time we spend in ambient air raises the chance of an airborne illness related to cardiovascular, respiratory & lung disorders to name a few (Wolfgang & Van Kamp 2009). In India, air pollution was ranked as the second most important contributor to mortality and morbidity in 2017, after malnutrition and dietary risks (Institute for Health Metrics and Evaluation [IHME], 2019). The study made by Majia, Ghoshband, and Ahmed (2018) illustrates adverse health impacts such as respiratory & cardiovascular diseases from air pollution over Delhi in India. Factors such as topography, air movement, and climate, determine the amount of pollution in the atmosphere at a given time (Gautam, Gautam, Singh, James & Brema, 2021a; Gautam, Tripathi, Joshi, Mandariya, Singh, Mishra, & Ramola, 2021b; Gautam, Patra, Brema, Raj, Raimond, Abraham, & Chudugudu, 2021c).

Increase in population means more vehicles on the roads, which aggravates particulate matter emissions from burning fossil fuels. High level of particulate emissions also threatens human health. A correlation factor of 0.93 between PM10 and mortality has been observed for the state of Karnataka (Sharma, Taneja, & Bhatt, 2020). A quick overview of air quality features over different districts of Karnataka state becomes necessary to extract the present scenario of air quality, which acts as the basic study supporting further investigation. Taking the spatial heterogeneity of pollutant concentrations (which arise from varied anthropogenic activities) in India into account, which is in part due to mixed land-use, the data should be improved (e.g., better coverage, clear metadata, and QA/QC) to better support pragmatic regulatory assessment or epidemiology studies (Tiwari, 2002).

Karnataka ranks ninth in terms of population in India. The population density of the state is 319 per sq. km. The decadal growth rate of Karnataka's population is 15.7%. Karnataka's population was recorded as 61.13 million as per the 2011 Census of India. Out of this, 61.43% reside in rural areas (https://greentribunal.gov.in/). Increase in population means increase in anthropogenic activities which may lead to air pollution. Comparative study of air quality across the districts of Karnataka provides insight into the nature of anthropogenic activities, which helps in creating awareness among the general public. Such type of studies is very minimum with regard to Karnataka. The present work attempts to provide awareness among the public about the quality of ambient air in Karnataka state.

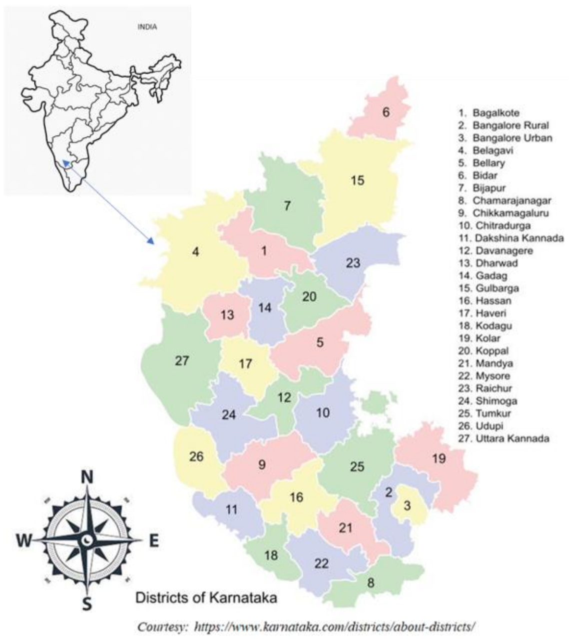

Figure 1. Districts in Karnataka State

2. Materials and Methods

2.1 Meteorological features of Karnataka

Due to climatic differences Karnataka is divided into three meteorological regions.

Coastal Karnataka: This region stretches over the districts of Udupi, Uttara Kannada and Dakshina Kannada. The entire coastal belt and the adjoining areas have tropical monsoon.

North Interior Karnataka: This region extends over the districts of Bagalkot, Belgaum, Bijapur, Bidar, Bellary, Dharwad, Haveri, Gadag, Gulbarga (Kalaburagi), Koppal and Raichur. This area is an arid zone. North Interior Karnataka receives the least amount of rainfall in the state.

South Interior Karnataka: This region spreads over the districts of Bangalore Rural, Bangalore Urban, Chitradurga, Chamrajnagar, Chikmagalur, Hassan, Kodagu, Kolar, Mysore, Shimoga and Tumkur. This zone experiences semi-arid type of climate (https://www.karnataka.com/profile/karnataka-climate/).

2.2 Seasons in Karnataka

Karnataka experiences the following four seasons in a year:

Summer: The summer season starts from March and extends till May. April and May are the hottest months in Karnataka.

Monsoon: The monsoon season begins in June and lasts until September.

Post-Monsoon: The post-monsoon season begins from October and continues until December.

Winter: The winter season extends from January to February. These are the coldest months in most parts of Karnataka and the temperature dips low.

2.3 Temperature in Karnataka

Karnataka experiences lowest temperature during the month of January and from this point onwards the temperature gradually increases. The temperature begins to soar rapidly during the month of March. The southern parts of the state generally experience the highest temperature during the month of April while in the coastal plains the temperature reaches its maximum during the month of May. Post monsoon, during the months of October and November the temperature decreases in the state and comes down further during the month of December.

The meteorological/seasonal features provide an approximate estimate of the air quality parameters. For example, wind speed, direction, temperature, humidity, rainfall, and solar radiation affect the dispersion of pollutants, as the warm air near the ground usually lifts pollution away. But in the winter, a layer of warm air above traps cold air and pollution near the ground. This is called a thermal inversion. With this basic idea, we can anticipate coastal Karnataka to have a relatively higher level of humidity. In northern parts of Karnataka, due to relatively high ambient temperature, the atmosphere gets filled with dust particles as and when wind blows. With these natural causes, the effects of anthropogenic activities on air quality need a thorough analysis.

2.4 Method of data collection and analysis

Air quality data from central pollution control board (CPCB) online platform have been used in the present study. Analysis of air quality data for the entire year covering all the districts of Karnataka state requires time and labour. Since the month of January acts as the bridge between previous year and the starting year, it is considered for data analysis. The guidelines for the measurement of Ambient Air Pollutants (NAAQS 2009) are based on the reference methods (Viz. Indian Standards, United States Environment Protection Agency and Inter Society Committee) based on field and laboratory experiences (https://cpcb.nic.in/).

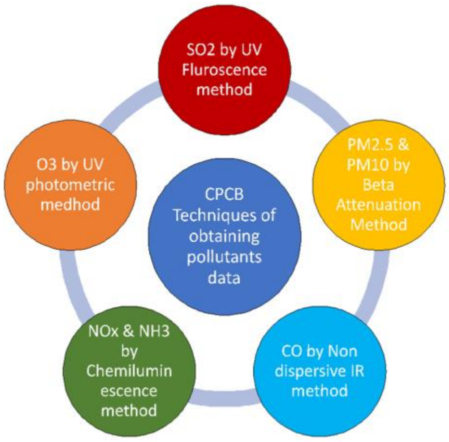

Figure 2. Overview of methods of data collection

2.5 Typical calculation

$$C\ (NO2\ \mu g/m^3) = [(As - Ab) \times CF \times Vs\ ] / [Va \times Vt \times 0.82]$$

where

C NO2 = Concentration of Nitrogen dioxide, $\mu g/m^3$
As = Absorbance of sample
Ab = Absorbance of reagent blank
CF = Calibration Factor (A measure of the ratio between a detector's reading and the actual concentration of the gas)
Va = Volume of air sampled, m^3
Vs = Volume of sample, ml
Vt = Volume of aliquot taken for analysis, ml
0.82 = Sampling efficiency (the degree to which NO2 is converted to nitrite during sampling, which depends on the air flow rate and humidity)

Air quality standards are the basic foundation that provides a legal framework for air pollution control. An air quality standard is a description of a level of air quality that is adopted by a regulatory authority as enforceable (https://cpcb.nic.in/). The basis of development of standards is to provide a rationale for protecting public health from adverse effects of air pollutants, to eliminate or reduce exposure to hazardous air pollutants, and to guide national/local authorities in pollution control decisions. With these objectives, CPCB notified (http://www.cpcb.nic.in) a new set of Indian National Air Quality Standards (INAQS) for 12 parameters [*carbon monoxide* (*CO*), *nitrogen dioxide* (*NO2*), *sulphur dioxide* (*SO2*), *particulate matter* (*PM*) *of less than 2.5 microns size* (*PM2.5*), *PM of less than 10 microns size* (*PM10*), *Ozone* (*O3*), *Lead* (*Pb*), *Ammonia* (*NH3*), *Benzo*(*a*)*Pyrene* (*BaP*), *Benzene* (*C6H6*), *Arsenic* (*As*), *and Nickel* (*Ni*)] . The first eight parameters have short-term (1/8/24 hrs) and annual standards (except for CO and O3) and the remaining four parameters have only annual standards (Table 1).

Table 1. Air quality parameter alarm limits as per NAAQ Standards in comparison with study area values

Pollutant	Time weighted average	Concentration in ambient air		Concentration of pollutants during study period
		Industrial, residential, rural and other areas	Ecologically sensitive area (notified by Central Government)	
Particulate Matter	Annual*	40	40	Max-Bengaluru-Jan 23
(size ≤ 2.5 µm) or $PM_{2.5}$ µg/m^3	24 hours**	60	60	142 µg/m^3
Particulate Matter	Annual*	60	60	Max-Kolar-Jan 23
(size ≤ 10 µm) or PM_{10} µg/m^3	24 hours**	100	100	152.6 µg/m^3
Nitrogen Dioxide (NO_2), µg/m^3	Annual*	40	30	Max-Bengaluru-Jan 23
	24 hours**	80	80	94 µg/m^3
Ammonia (NH_3), µg/m^3	Annual*	100	100	Max-Koppal-Jan 21
	24 hours**	400	400	19 µg/m^3
Sulphur Dioxide (SO_2), µg/m^3	Annual*	50	20	Max-Kolar-Jan 23
	24 hours**	80	80	157.2 µg/m^3
Ozone (O_3), µg/m^3	8 hours*	100	100	Max-Madikeri-Jan 21
	1 hour**	180	180	97 µg/m^3
Carbon Monoxide (CO), mg/m^3	8 hours*	02	02	Max-Hubballi-Jan 23
	1 hour**	04	04	84 µg/m^3

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be compiled for 98% of the time, and they may exceed the limits but not on two consecutive days of monitoring.
Source: National Ambient Air Quality Standards, Central Pollution Control Board Notification in the Gazette of India, Extraordinary, New Delhi, 18th November, 2009

3. Results and Discussion

Analysis of January month's data over three years (2021-2023) has shown some important results which are depicted in Figures 3-5. The concentration of *PM 2.5 is found to be high* (142 µg/m^3) *for the location Bengaluru* during January 2023 and low (13 µg/m^3) for the location Chamarajanagar during January 2022. High value (152 .6 µg/m^3) of PM10 is found for the location Kolar in January 2023 and low (20 µg/m^3) for Madikeri in January 2023. *The concentration of NO2 is found to be high* (94 µg/m^3) *for location Bengaluru* in January 2023 and low (7 µg/m^3) for Madikeri in January 2023. NH3 concentration is found to be high (19 µg/m^3) for the location Koppal in January 2021 and low (1 µg/m^3) for Madikeri, Vijaypura and Yadgir in January 2021. SO2 concentration is found to be high (157.2 µg/m^3) for the location Kolar in January 2023 and low (1 µg/m^3) for Vijayapura in January 2021. CO concentration is found to be high (84 µg/m^3) for the location Hubballi in January 2023 and low (4 µg/m^3) for the location Kalaburagi in January 2023. Concentration of O3 is found to be high (97 µg/m^3) for the location Madikeri in January 2021 and low (5 µg/m^3) for Raichur in January 2021 (Figure 6).

PM2.5: During the year 2021, Bengaluru, Chikkaballapur, Gadag, Hubballi, Raichur, and Yadgir cities have shown values exceeding the NAAQ limit of 60 µg/m^3. During the year 2022, Chikkaballapur, Chikkamagalur, Kalaburagi, Raichur and Yadgir cities have shown higher values than the NAAQ limit. However, in the year 2023, Bengaluru, Chikkaballapur, Hubballi, Kalaburagi, Ramnagar and Yadgir cities have exceeded the NAAQ safe limit of 60 µg/m^3 (Table 1).

PM10 : During the years 2021 and 2022 Kalaburagi, while in the year 2023 Chikkaballapur and Kolar have recorded PM10 concentrations exceeding the NAAQ safe limit of 100 µg/m^3.

NO2: Bengaluru during 2023 has recorded the highest concentration of NO2.

NH3: All the locations have recorded values below NAAQ standard for NH3 concentration during three years of observation.

SO2: Kolar during 2023 has reported high value for SO2.

O3: All the locations under study have recorded below NAAQ standard values for O3.

CO: All the locations under study have recorded above NAAQ standard values for CO.

The reason for increase in particulates and gaseous pollutants in the atmosphere across 17 districts of Karnataka might be the increase in anthropogenic activities. The increase in Aerosol Optical Depth (AOD), which is a measure of solar extinction due to particulates of specific size, over major cities can be ascribed to the increase in urbanization (Ganesh K E, 2023). This point is evident from the increase in the percentage of population across the districts of Karnataka (Tables 2-5). Open burning of solid materials are significant sources of outdoor air pollution. This causes various health issues, primarily affecting the respiratory and cardiovascular systems (Gautam, Elizabeth, Gautam, Singh, & Abhilash, 2022).

The reason for high levels of NO2 in the atmosphere of Bengaluru might be fossil fuel burning by vehicles. Due to constant movement of vehicles on the roads of Bengaluru, even when rain washes the particulates, there will be new particulates released into the atmosphere immediately. However, exhausts from powerplants and industrial facilities result in high levels of SO2 in Kolar (Suthar G. *et al*., 2024).

While 'bad' ozone is not emitted directly into the air, it is created by chemical reactions between oxides of nitrogen and volatile organic compounds in the presence of heat and sunlight.

$$NOx + VOC + Sunlight \rightarrow O3$$

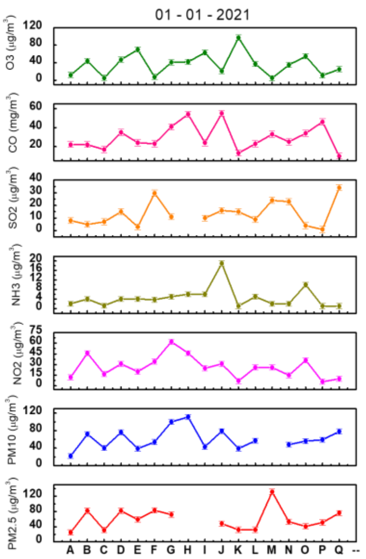

Figure 3. Concentrations of various pollutants across the districts of Karnataka State on 1st January 2021 [x axis : A-Q refers to districts code]

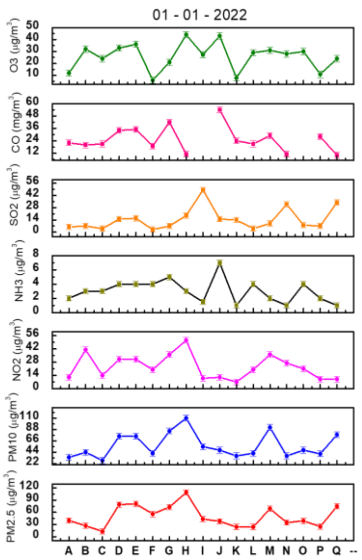

Figure 4. Concentrations of various pollutants across the districts of Karnataka State on 1st January 2022 [x axis : A-Q refers to districts code]

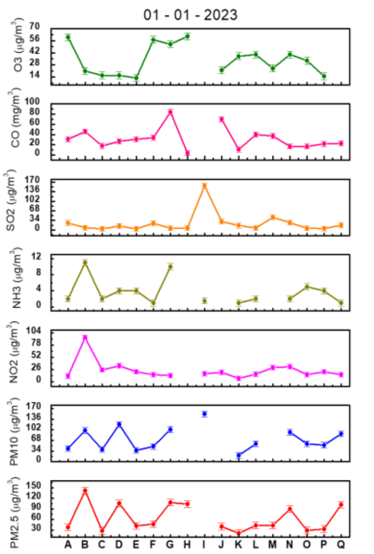

Figure 5. Concentrations of various pollutants across the districts of Karnataka State on 1st January 2023 [x axis : A-Q refers to districts code]

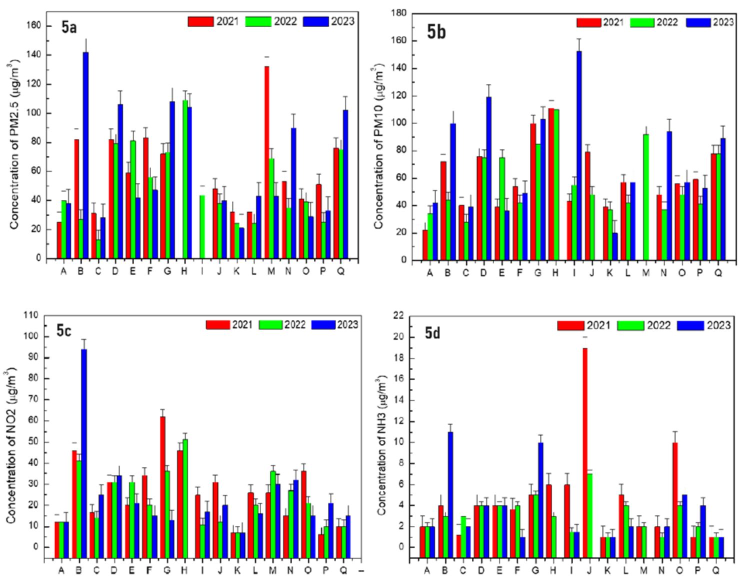

Figure 6. Variation of concentrations of PM 2.5, PM10, NO2, and NH3 across the districts of Karnataka during the study period [x axis : A-Q refers to districts code]

The residential energy use is a significant emissions source, primarily due to household cooking with solid fuels in the non-urban areas. Other sources of air pollution in nonurban areas include stubble burning, brick kilns, coal-fired factories, agricultural processing, power generation, cement factories, and cottage industries (Ravishankara, Liji, David, Jeffrey, Pierce, & Chandra, 2020).

Along with motor vehicles' exhaust, emissions from industrial facilities and electric utilities, gasoline vapors and chemical solvents act as some of the major sources of oxides of nitrogen (NOx). A mechanism known as gas-particle conversion also contributes to the total load of the particulate matter (Lazaridis, 2011; Seinfeld and Pandis, 2006; Tripathi, *et al.*, 2024). Also, incomplete burning of fossil fuels such as coal, oil and gasoline to produce energy for electricity or transportation releases CO at a high level into the atmosphere (www.epa.gov). It seems that urbanization and population growth (Table 2) has contributed significantly to the increase in concentrations of gases and particles in the atmosphere across several districts of Karnataka (Figures 6).

Table 2. Population counts across the districts of Karnataka State

Code	District	Latitude	Longitude	Population	Increase%
A	Bagalkot	16.12 N	75.45 E	1889752	14.40%
B	Bengaluru	12.58 N	77.38 E	9621551	47.18%
C	Chamarajnagar	11.56 N	77.00 E	1020791	5.73%
D	Chikkaballapur	13.26 N	77.46 E	1255104	9.23%
E	Chikkamagalur	13.18 N	75.49 E	1137961	-0.26%
F	Gadag	15.25 N	75.42 E	1064570	9.54%
G	Hubballi	15.36 N	75.12 E	1847023	15.13%
H	Kalaburagi	17.32 N	76.83 E	2566326	18.01%
I	Kolar	13.09 N	78.11 E	1536401	10.77%
J	Koppal	15.20 N	76.13 E	1389920	16.21%
K	Madikeri	12.42 N	75.73 E	554519	1.09%
L	Mysuru	12.18 N	76.42 E	3001127	13.63%
M	Raichur	16.21 N	77.35 E	1928812	15.51%
N	Ramanagara	12.54 N	78.02 E	1082636	5.05%
O	Shivamogga	13.56 N	75.38 E	1752753	6.71%
P	Vijaypura	16.83 N	75.71 E	2177331	20.50%
Q	Yadgir	16.76 N	77.14 E	1174271	22.81%

Courtesy: https://www.census2011.co.in/census/state/districtlist/karnataka.html

Table 3. Air quality parameters across the districts of Karnataka State on 1st January 2021

1st January 2021		μg/m³						mg/m³	Rainfall (mm)
Districts	Code	PM2.5	PM10	NO2	NH3	SO2	O3	CO	
Bagalkot	A	25	22	12	2	8	12	22	6.3
Bengaluru	B	82	72	46	4	5	44	22	15.7
Chamarajnagar	C	31.2	40.28	16.73	1.2	7.06	5.3	16.86	10.6
Chikkaballapur	D	82	76	31	4	15	47	35	8.1
Chikkamagalur	E	59	39	20	4	3	70	24	58.1
Gadag	F	83	54	34.33	3.66	29.66	7.33	23	23.8
Hubballi	G	72	100	62	5	11	41	41	17.6
Kalaburagi	H	**	111	46	6	**	42	54	0.6
Kolar	I	**	43	24.86	6	10	63	24	12.2
Koppal	J	48	79	31	19	16	21	55	7.5
Madikeri	K	32	39	7	1	15	97	13	60.2
Mysuru	L	32	57	26	5	9	37	23	14.2
Raichur	M	132	**	26	2	24	5	33	0.8
Ramanagara	N	53	48	15	2	23	35	25	28
Shivamogga	O	41	56	36	10	4	55	34	46.7
Vijaypura	P	51	59	6	1	1	11	46	0.4
Yadgir	Q	76	78	10	1	34	25	10	0

Table 4. Air quality parameters across the districts of Karnataka State on 1st January 2022

1st January 2022		μg/m³						mg/m³	Rainfall (mm)
Districts	Code	PM2.5	PM10	NO2	NH3	SO2	O3	CO	
Bagalkot	A	40	34	12	2	6	12	22	2.1
Bengaluru	B	27	44	41	3	7	32	20	1.4
Chamarajnagar	C	13	28	14	3	4	24	21	2.9
Chikkaballapur	D	79	75	31	4	15	33	34	1.8
Chikkamagalur	E	81	75	31	4	16	36	35	1.9
Gadag	F	56	42	20	4	3	6	19	1.2
Hubballi	G	73	85	36	5	7	21	42	2.1
Kalaburagi	H	109	110	51	3	19	44	11	4.9
Kolar	I	43.54	54.92	10.87	1.5	48.18	27.37	**	2
Koppal	J	38	48	12	7	15	43	54	2.1
Madikeri	K	24	37	7	1	14	8	24	3.2
Mysuru	L	24	42	20	4	4	29	21	2.7

Table 4. Continued.

1st January 2021		μg/m³						mg/m³	Rainfall (mm)
Districts	Code	PM2.5	PM10	NO2	NH3	SO2	O3	CO	
Raichur	M	69	92	36	2	10	31	29	2.3
Ramanagara	N	35	37	27	1	32	28	11	1.8
Shivamogga	O	39	48	21	4	8	30	**	0.9
Vijaypura	P	25	41	10	2	7	11	28	3.1
Yadgir	Q	75	78	10	1	34	24	10	4.6

Table 5. Air quality parameters across the districts of Karnataka State on 1st January 2023

1st January 2023		μg/m³						mg/m³	Rainfall (mm)
Districts	Code	PM2.5	PM10	NO2	NH3	SO2	O3	CO	
Bagalkot	A	38	42	12	2	25	60	31	5.1
Bengaluru	B	142	100	94	11	8	21	46	13.7
Chamarajnagar	C	28	39	25	2	4	16	18	27.3
Chikkaballapur	D	106	119	34	4	14	16	27	0.8
Chikkamagalur	E	42	36	21	4	4	13	31	9.8
Gadag	F	47	49	15	1	24	57	34	13.7
Hubballi	G	108	103	13	10	6	52	84	21.5
Kalaburagi	H	104	**	**	**	7	61	4	7.2
Kolar	I	**	152.6	17	1.5	157.2	**	**	12.9
Koppal	J	40	**	20	**	30	22	70	9.5
Madikeri	K	21	20	7	1	16	38	11	18
Mysuru	L	43	57	16	2	7	40	40	32.9
Raichur	M	43	**	30	**	45.11	24	37.33	13.6
Ramanagara	N	90	94	32	2	26	40	17	4.4
Shivamogga	O	29	57	15	5	6	33	17	2.8
Vijaypura	P	33	53	21	4	5	15	22	0
Yadgir	Q	102	89	15	1	17	60	23	17.9

Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) from National Aeronautics and Space Administration, has provided visualizations of PM2.5 variations across India. With regard to Karnataka state, observations on the days of study reveal the same information as discussed in the results section (Figure 8). With regard to Bengaluru, which is the capital city of Karnataka state, both 1st January 2021, & 1st January 2023 have recorded slightly higher concentration of PM2.5 exceeding the NAAQ safe limit of 60 μg/m³ (https://gmao.gsfc.nasa.gov/reanalysis/ MERRA-2/data_access/).

This study gives the generalised air quality scenario on specific days of three years. Best conclusions can be drawn by combining the air quality data related to individual districts of the Karnataka state.

3.1 Some limitations of CPCB data

As the instruments for deriving air quality parameters are stationed at specific fixed locations, the CPCB data have their own spatial limitations. Also, cross verification of the data can be performed for few urban locations only, due to the non-availability of resources across every place of the Karnataka State.

3.2 Rainfall data analysis

The rainfall pattern across the districts of Karnataka for the month of January remains the same for all the three years of observation. It has been observed that rainfall is highest for the location Madikeri followed by locations Chikkamagalur and Shivamogga. Lowest rainfall has been observed for the locations Kalaburagi, Raichur and Vijayapura. January 2023 records the highest rainfall among the three years, and January 2021 has received relatively low rainfall with January 2022 being in the middle. Usually when the rainfall is higher, it washes away the accumulated particulates in the atmosphere. Even with this scenario, Bengaluru has recorded larger value for particulate concentration. This might be due to the constant addition of particulates/gases by anthropogenic activities. which is the result of about 47.18% increase in the population as depicted in Table 1.

4. Conclusions

One of the important observations made in the present study is that an increase in the particulate and gaseous pollutants in the atmosphere is due to the increase in the

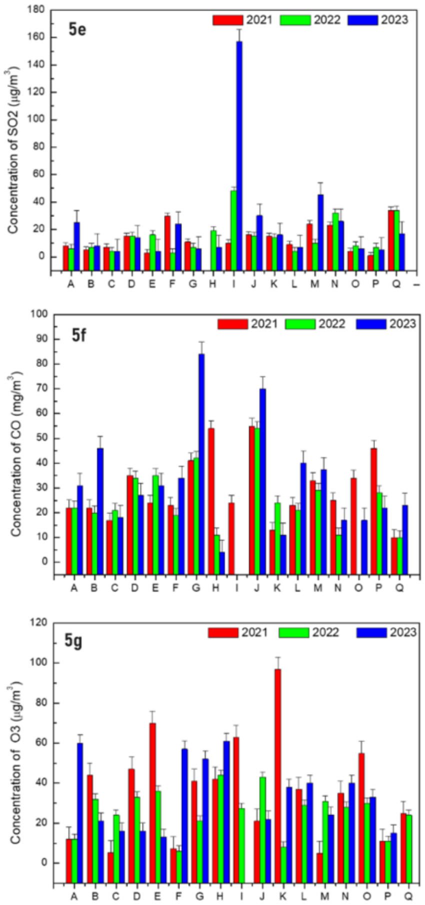

Figure 7. Variation of concentrations of SO2, CO, and O3 across the districts of Karnataka during the study period [x axis : A-Q refers to districts code]

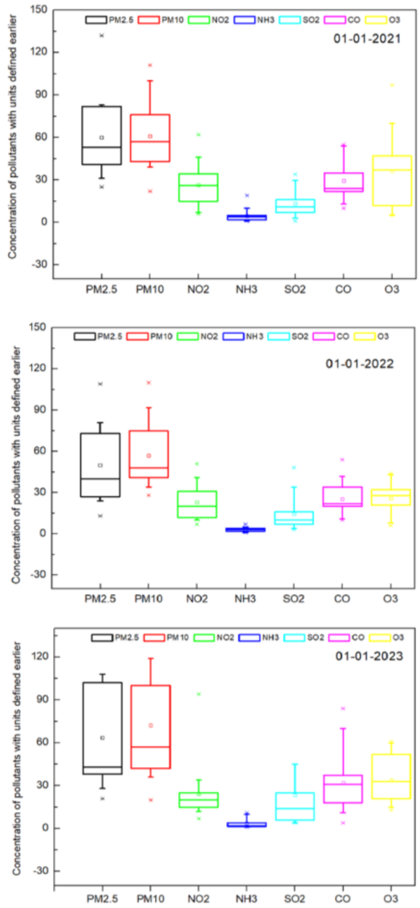

Figure 8. Box plots of various pollutants in Karnataka during the study period

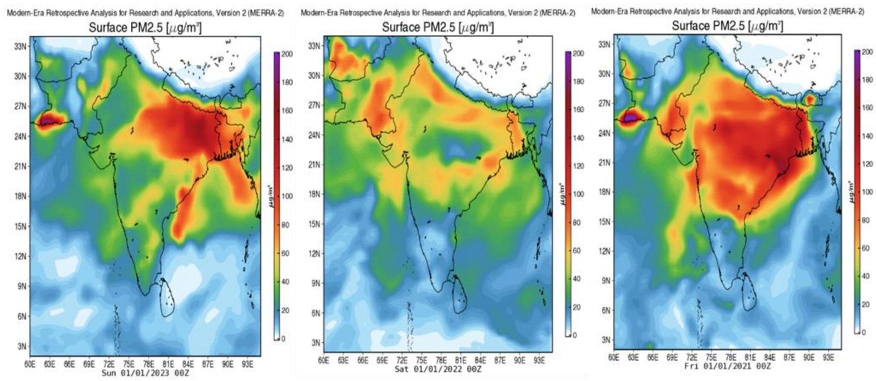

Figure 9. MERRA-2 visualization of PM2.5 concentrations on the days of study

anthropogenic activities. Increase in anthropogenic activities is purely due to increase in the population density across the locations under study. Anthropogenic activities such as fossil fuel burning, exhausts from powerplants and industrial facilities, are some of the reasons for different types of particulates/gases that get added into the atmosphere. For all the 17 districts under study, the particulate pollutants such as PM2.5 & PM10 have shown large fluctuations throughout the study period, sometimes crossing the NAAQ limit. Gaseous pollutants such as O3 & CO are under control over the majority of districts in Karnataka. However, Bengaluru, which is the capital city of Karnataka state, has recorded the highest NO2 concentration and Kolar has recorded the highest SO2 concentration during January 2023. Increase in gaseous pollutants in the atmosphere can be attributed to increase in population density for the locations under study. This in turn reflects the various anthropogenic activities such as vehicular emissions, biomass burning, and industrial emissions. Availability of online air quality data from CPCB online portal has made this study possible and the visualization provided by Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) from National Aeronautics and Space Administration has strengthened our predictions. Annual and Seasonal data analysis for all the districts of Karnataka requires time and labour. However, the present study provides insights into the existing air quality features across the 17 districts of Karnataka state.

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