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Spatial and temporal variation in the seasonal air quality index of Haryana, India

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सार — यह शोध हरियाणा के विभिन्न जिलों में वायु गुणवत्ता का मूल्यांकन प्रस्तुत करता है। गैसीय और कणिका प्रदूषकों के स्थानिक और कालिक विविधता (2019-2020) **का अनुमान लगाने के लिए भू-स्थानिक तकनीकों का उपयोग किया गया। केंद्रीय प्रदूषण नियंत्रण बोर्ड** (CPCB) **से छह नियत प्रदूषकों के आंकड़े एकत्र किए गए। इस संदर्भ में**, 2019 **और** 2020 **के लिए वायु प्रदूषक** (PM_{10}, $PM_{2.5}$, O_3, NOx, SO_2 **और** CO) **के आंकड़ों का मौसमी विश्लेषण किया गया।वायु गुणवत्ता सूचकांक** (AQI) **के स्थानिक-कालिक वितरण में स्पष्ट रूप से** 2019 **और** 2020 **में मौसम से संबंधित विभिन्न फसलों को दर्शाया गया। परिणाम दर्शातें हैं कि** 2019 **की सर्दियों और मॉनसूनोत्तर ऋतु में वायु गुणवत्ता बहुत खराब थी और** 2020 **में** COVID 19 **लॉकडाउन के कारण थोड़ा सुधार हुआ और दोनों वर्षों मेंमॉनसून और मॉनसून पूर्व ऋतु में वायु गुणवत्ता संतोषजनक देखी गई। यह भी देखा गया कि** 2019-20 **में खरीफ ऋतु (अप्रैल से सितंबर) की तुलना में रबी ऋतु (अक्टूबर से मार्च) में वायु की गुणवत्ता खराब थी। अध्ययन से पता चला कि ऑटोमोबाइल जैसे प्रमुख प्रदूषक स्रोतों को कम करने के साथ-साथ जलाने के बजाय पुआल के कचरे के सर्वोत्तम प्रबंधन से हवा की गुणवत्ता में सुधार किया जा सकता है।**

ABSTRACT. This paper presents the evaluation of the air quality in different districts of Haryana. Geo-spatial techniques were used to estimate the spatial and temporal variation (2019-2020) of gaseous and particulate pollutants. Data of six fixed pollutants were collected from Central Pollution Control Board (CPCB). In this context, data of the air pollutant (PM_{10}, $PM_{2.5}$, O_3, NOx, SO_2 and CO) were analyzed seasonally for 2019 and 2020. The spatio-temporal distribution of the air quality index (AQI) clearly depicted changes indifferent meteorological and crop seasons in 2019 and 2020. The result showed that the air quality was very poor in winter and the post-monsoon seasons in 2019 and slightly improved in 2020 due to COVID 19 lockdown and satisfactory air quality was observed in the monsoon and the pre-monsoon seasons for both years. It was also observed that the air quality was poor in the rabi seasons (October to March) as compared to the kharif seasons (April to September) in 2019 and 2020. The study suggested that the air quality can be improved by the best management of straw waste instead of burning, along with reducing major pollutant sources like automobiles.

Key words – Air Quality Index, The lockdown, COVID-19, meteorological seasons.

1. Introduction

The air quality index is one of the most serious topics, receiving attention from developing as well as developed countries. Most studies have also shown that the air quality was poor not in big cities but also in small cities with a population of 1.5 million (IAQP, 2010). Consequential population and economic growth surrounding industrial nuclei area serious concern for environmental deterioration in surrounding areas (Khandelwal *et al.*, 2018). Industries, automobiles etc. that are major source of air pollutants have now become a permanent land use feature that can't be omitted from the real world. Therefore, it is very hard to compare the air quality of a region on the temporal scale but 'with and without' these land uses, *i.e.*, industries and automobiles.

Most of the countries across the world have faced and some are even facing diseases spreading due to the corona virus (COVID-19). In India, on 24th March, when the virus infected more than 500 people, the govt. announced a complete lockdown in the country. The government norms were strict in Indian cities where people were not allowed to step out of their homes

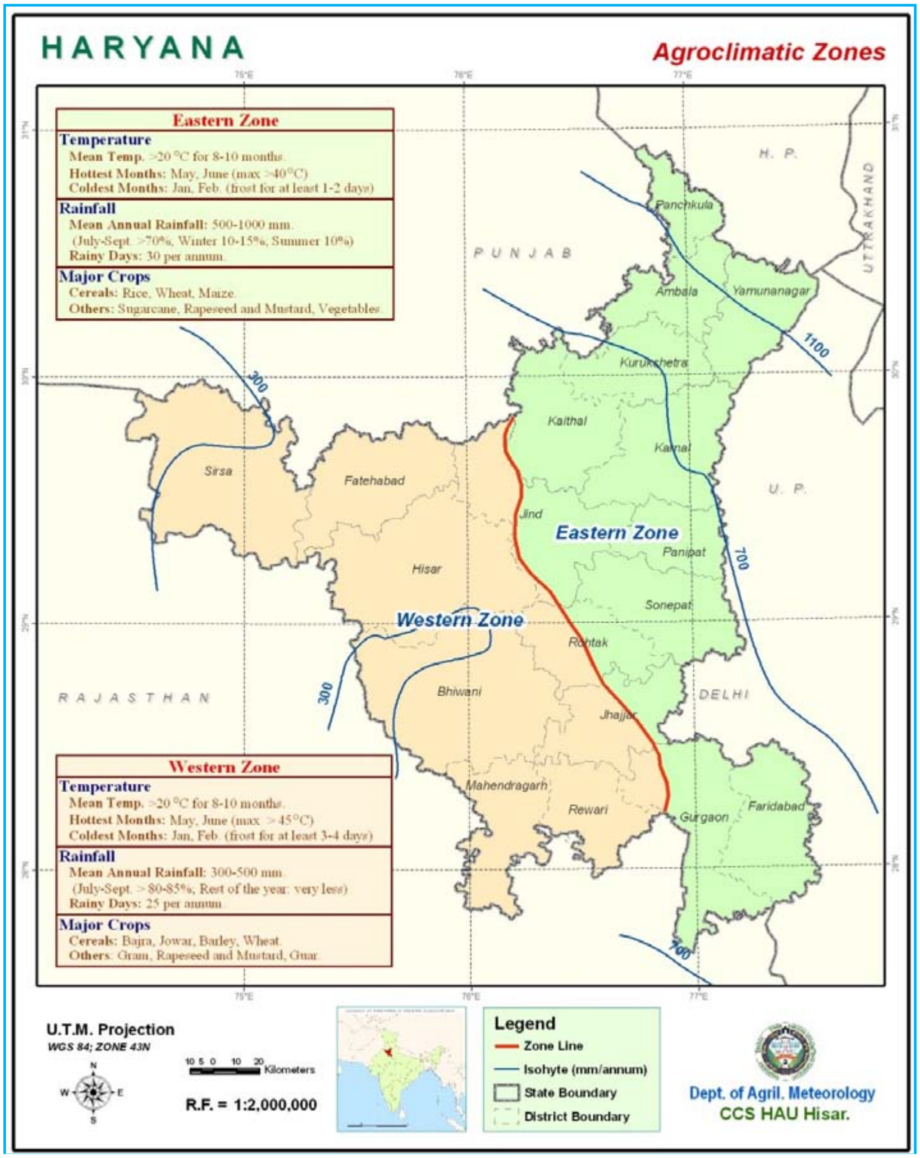

Fig. 1. Study area - Haryana State, India (Singh *et al*., 2010)

(Ministry of Home Affairs, 2020). The manufacturing industries, mining and automobiles were paused. In the COVID-19 period, one of the positive things observed was improvement in the air quality (Sharama *et al.*, 2020). In Indo gangatic plain of the western region, the dominating cropping pattern of rice-wheat rotation is highly productive. The use of high technological harvest machinery leaves behind an abundance of scattered and root-bound residue that is difficult to remove and thus often burned post-harvest to prepare for the timely sowing of the next crop (Kumar *et al.*, 2015). However, the burning of post-monsoon rice residue can severely degrade air quality downwind of the agricultural fires over the Indo Gangatic Plain (Badarinath *et al*., 2006, Singh and Kaskaoutis 2014, Kaskaoutis *et al*., 2014, Liu *et al.*, 2018, Cusworth *et al*., 2018, Jethva *et al.*, 2018, Sarkar *et al*., 2018). In particular, smoke from rice residue burning in October and November may account for more than half the fine particulate matter ($PM_{2.5}$) concentrations in the Delhi National Capital Region (Cusworth *et al.*, 2018), which already experiences intense urban pollution from local and other regional sources (Amann *et al.*, 2017). Most common ambient air pollutants in our daily life are PM, Sulphur dioxide, nitrogen dioxide, ozone, carbon monoxide and carbon dioxide. Number of air pollutants are listed as criteria pollutants in the country's

AQI Range	Category	Colour	Impact
0-50	Good		Minimal impact
51-100	Satisfactory		Minor breathing discomfort to sensitive people
101-200	Moderate		Breathing discomfort to the people with lungs, asthma and heart diseases
201-300	Poor		Breathing discomfort to the most people on prolonged exposure
301-400	The very Poor		Respiratory illness on prolonged exposure

Fig. 2. AQI categories (Central Pollution Control Board)

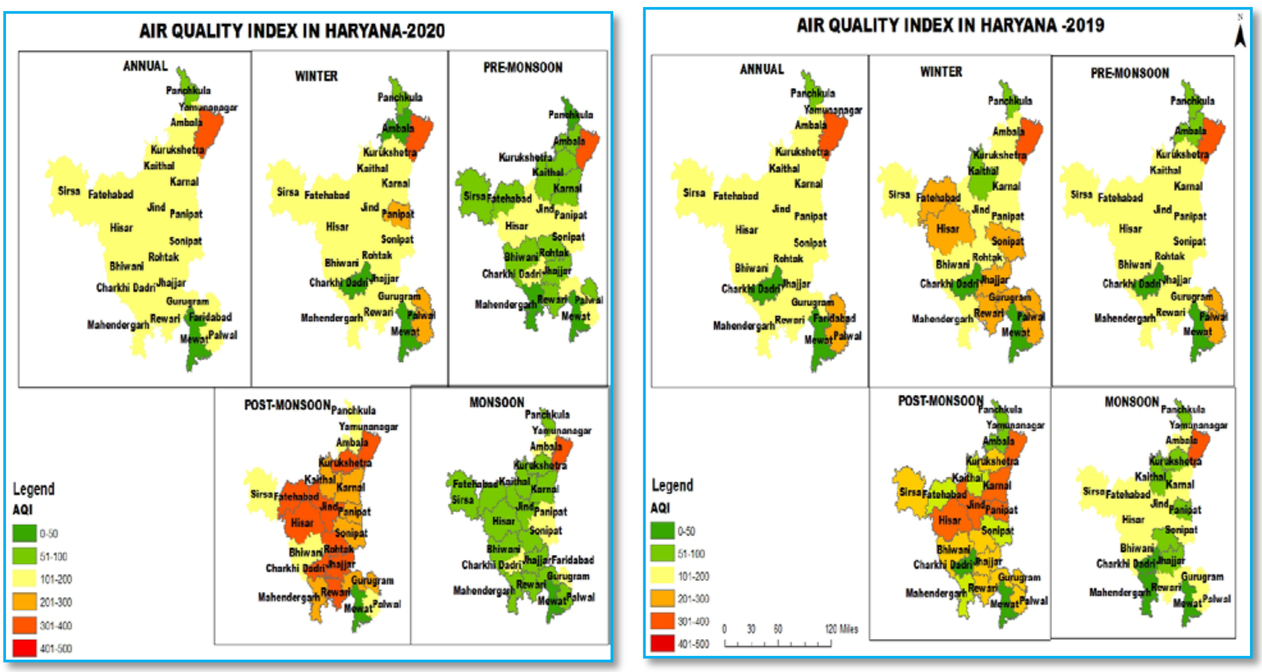

Fig. 3. Spatial variations in AQI in different meteorological seasons in Haryana in 2019 and 2020

air quality standards (Chenand Kan, 2008) but the objective of this study was to evaluate the temporal and spatial variations in the concentration of six pollutants for AQI in Haryana (India).

2. Material and methods

2.1. *Study area*

The present study was conducted in Haryana state, located between 27°39' to 30°35' N latitude and between 74°28' and 77°36' E longitude. Haryana is a landlocked state in northern India. The study area includes 22 districts of the state, with a total area of 44,212 km^2, *i.e.*, 1.3% of the total area of the country. As per agroclimatic classification (Singh *et al.*, 2010), the state is divided into two zones as shown in Fig. 1. The eastern zone includes the districts of Panchkula, Ambala, Yamunanagar, Kurukshetra, Karnal, Kaithal, Panipat, Sonipat, Faridabad and parts of districts of Jind, Rohtak, Jhajjar and Gurgaon. It covers about 49 per cent of areas of the state which comprises Gurgaon tract, Rohtak tract, Central plain and

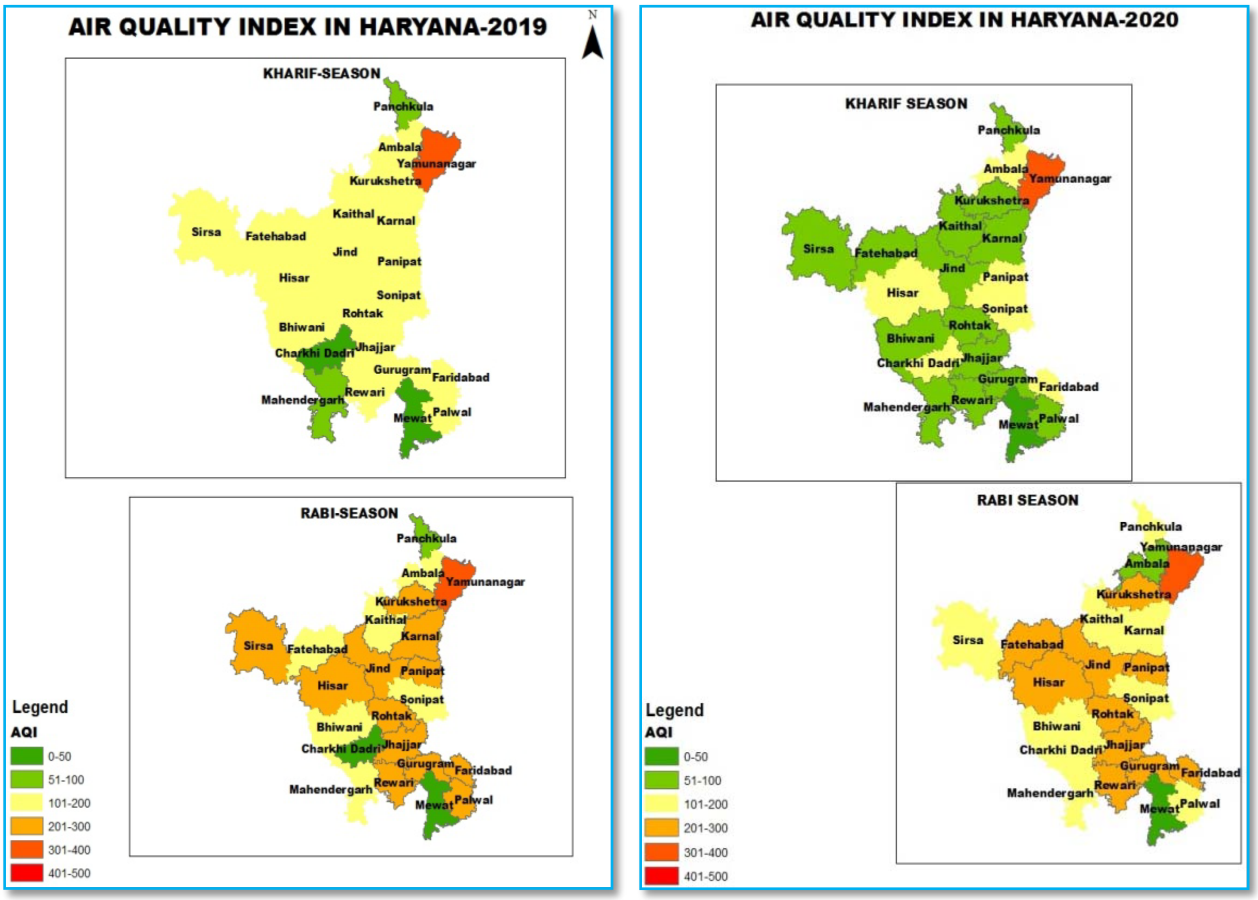

Fig. 4. Representation of seasonal air quality conditions in Haryana in 2019 and 2020

Hill tract. The Western zone includes the districts of Sirsa, Hisar, Bhiwani, Fatehabad, Mahendragarh, Rewari and some parts of Jind, Rohtak, Jhajjar and Gurgaon. A rapid development in industry, transportation and the economy had been observed in the state in last two decades. And therefore, the air pollution that comes from development had become a serious matter. The air quality of the state varies seasonally also from good to severe in different months of a year. The present analysis for temporal and spatial characteristics of air pollutant are, therefore, important for assessing and monitoring the air quality in Haryana.

2.2. *Data sources*

The 'monitoring station data' used in this study was obtained from CPCB (Central Pollution Control Board) for the districts, *viz*., Bhiwani, Faridabad (Ballabgarh), Ambala, Karnal, Charki Dadri, Rohtak, Rewari (Dharuhera), Fatehabad, Kurukshetra, Sonipat, Gurugram, Hisar, Yamunanagar, Kaithal, Jind, Sirsa, Faridabad, Mewat (Mandikhera), Gurugram (Manesar), Mahendragarh (Narnaul), Palwal and Panchkula. Six air pollutants, namely, coarse particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$), ozone (O_3), nitrous oxide (NO_X), sulfur dioxide (SO_2) and carbon monoxide (CO) were considered for analysis in the present work. Data was retrieved on hourly basis and averaged for every 24 hr. Data missing was also there for some of the locations, *viz*., Charkhi Daderi (2019), Mewat (2019 & 2020) and Kaithal.

AQI is a dimensionless index that quantitatively describes the air quality. According to the Central Control Pollution Board, the Air Quality Standards implemented by the Ministry of Environment Forest and Climate Change, AQI can be calculated by an AQI-calculator given by CPCB by using various factors such as PM_{10}, $PM_{2.5}$, O_3, NOx, SO_2 and CO etc.

AQI greater than 50 represents the excess of major pollutant concentration in the atmosphere. The higher the

TABLE 1

Air quality index during meteorological and crop seasons during 2019 and 2020

Season	Bhiwani		Balabhgarh (Faridabad)		Ambala		Karnal		Charkhi Dadri		Rohtak		Dharuhera (Rewari)		Sirsa	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Annual	151	117	151	117	199	165	119	NA	162	105	NA	NA	170	149	163	114
Winter	107	157	107	157	229	301	139	NA	136	166	NA	NA	144	176	154	102
Pre-monsoon	134	101	134	101	244	89	83	73	170	86	NA	173	162	80	133	101
Monsoon	92	80	92	80	132	116	149	178	109	63	NA	103	90	59	132	84
Post monsoon	296	170	296	170	302	282	93	110	304	227	NA	322	303	321	266	192
Rabi	191	140	191	140	265	248	111	NA	203	177	NA	NA	221	266	197	129
Kharif	112	91	112	91	166	107	127	148	124	70	NA	118	119	66	137	96

Season	Mandikhera (Mewat)		Manesar (Gurugram)		Narnaul (Mahendragarh)		Palwal		Panchkula		Panipat		Bahadurgarh		Jind	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Annual	113	101	192	130	NA	NA	205	121	75	72	157	171	152	144	170	169
Winter	163	128	266	152	157	136	222	248	79	74	146	290	301	114	148	187
Pre-monsoon	129	96	176	102	125	NA	235	115	66	43	147	143	134	95	145	103
Monsoon	79	53	129	89	NA	77	108	78	62	56	102	121	87	76	107	79
Post monsoon	164	189	283	309	200	207	309	159	96	157	322	262	243	323	321	337
Rabi	150	141	250	226	168	NA	265	146	85	94	252	215	242	251	261	301
Kharif	105	68	141	94	NA	NA	146	94	64	50	124	131	109	84	124	93

Season	Fatehabad		Kurukshetra		Sonipat		Hisar		Yamunanagar		Kaithal	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Annual	152	139	127	124	136	145	205	169	379	379	NA	116
Winter	198	106	164	152	274	151	254	185	374	376	NA	111
Pre-monsoon	173	103	126	95	143	125	154	111	380	380	126	95
Monsoon	131	82	93	73	120	113	117	97	379	379	100	79
Post monsoon	163	334	301	308	145	208	319	331	380	380	173	262
Rabi	150	249	214	223	146	172	289	289	378	379	NA	154
Kharif	153	96	109	83	134	119	130	106	379	379	113	88

value, the poorer will be the air quality. There are six AQI categories described by CPCB and their ranges are 0-50, 51-100, 101-200, 201-300, 301-400 and 401-500 as shown in Fig. 2. The corresponding pollution levels are good, satisfactory, moderate, poor, very poor, and severe respectively.

The mathematical equation for calculating sub-indices of AQI is as follows:

$$I_p = \frac{(IHI - ILO)}{(BPHI - BPLO)} \times (CP - BPLO) + ILO$$

where I_P is AQI for pollutant "P" (Rounded to the nearest integer), CP is the actual ambient concentration of pollutant "P", BPHI is the upper-end breakpoint concentration that is greater than or equal to CP, BPLO is the lower end breakpoint concentration that is less than or equal to CP, ILO the sub-index or AQI value corresponding to BPLO, IHI the sub-index or AQI value corresponding to BPHI (National air quality index, 2015).

2.3. *Data processing*

The data was analyzed in MS Excel for daily and seasonal calculations on the basis of hourly data. Data was analyzed for each of pollutant and GIS package was used to map the temporal and spatial variations of the air pollution. The spatial analysis and mapping was performed using Arc GIS software (Environmental Systems Research Institute (ESRI), USA available in the Geoinformatics lab of Dept. of Agricultural Meteorology, CCS HAU Hisar.

3. Results and discussion

3.1. *Characteristics of AQI during meteorological seasons*

The derived AQI on all the stations is presented in Table 1 for different time periods, *i.e*., annual, meteorological seasons as well as crop seasons prevailing in Haryana state, *i.e.*, rabi (or winter, October to March) and kharif (or summer, April to September). Fig. 3 shows the annual and seasonal (meteorological and crop seasons) variations in AQI in Haryana in 2019. The figure indicates that the AQI of Yamunanagar was in the very poor category in all meteorological as well as agronomic seasons. Ahuja, N. and Sharma, P., (2017) found that airpollution problems were due to thermal power plant, sugar and paper mill in Yamunanagar, Haryana. In the winter seasons, Panchkula and Kaithal were shown satisfactory air quality. The districts Charkhi Dadri, Mewat are shown as black because of the unavailability of data.

On an annual time period, the AQI in Haryana during 2019 showed a mixed pattern ranging from 379 highest in Yamunanagar to 75 lowest in Panchkula district. Thereby, the AQI was between very poor to satisfactory categories (Fig. 3) and the poor AQI was seen in the northern parts and southeastern parts mainly. The rest of the districts fall in the moderate (100-200) AQI level. In 2020, the only district that appeared with a higher AQI was Yamunanagar. The rest of the whole state showed an improved air quality index and fell in the range of 100-200 (moderate). The completed lockdown of COVID-19 had a great impact on air quality, especially in urban industrial regions like Faridabad and Palwal area.

In the winter season (January - February), the nine districts (Yamunanagar, Fatehabad, Hisar, Sonipat, Jhajjar, Gurugram, Rewari, Faridabad, and Palwal) were under the poor category in 2019 while in 2020 situation improved and only four districts (Yamunanagar, Panipat, Faridabad and Palwal) remained in this poor AQI category.

In the pre-monsoon period (March - May) there was substantial changes in air quality over Haryana due to the lockdown period in 2020. In 2019, the air quality prevailed as usual in this season and three districts (Yamunanagar, Faridabad, and Palwal) were having poor AQI limits. Only two districts (Ambala and Panchkula) were in safer AQI limits. But in 2020, due to the introduction of lockdown because of COVID-19 and the pausing of all industrial and automobile activities, a marked change in AQI was observed. Nearly the whole of the state, except for Yamunanagar was under safer limits (Good to satisfactory) of AQI, *i.e*., less than 100. Although central parts of the state comprising of Hisar, Jind, Panipat, Sonipat, Gurugram and Palwal showed moderate levels, but their AQI values had decreased to a considerable extent from 2019 as 28%, 29%, 0.02%, 13%, 42%, and 51% reductions observed respectively. The districts falling in Delhi National Capital Region (NCR) like Gurugram, Faridabad, and Palwal also had better air quality in this season in 2020 and Faridabad surprisingly observed with satisfactory level of AQI that could be rarely possible in normal time periods.

During the monsoon period (June - September) the same pattern was seen in the state. In the 2019 monsoon period, eleven districts were in the moderate AQI category while in the 2020 monsoon period, it remained only five. Most of the districts showed better air quality and AQI was lower than 100 or in satisfactory or good categories. The Yamunanagar district remained in very poor category in both of the years as shown in Fig. 3. Air pollution was severe due to paper mills (Yadav *et al*., 2010), sugarmill and thermal power plants (Sharma and Chaudhry, 2013).

The post-monsoon period (October - December) strangely exhibited a reverse pattern of air quality in the state. During 2019, 14 districts were under the poor (9) to very poor (5) category and the spread of pollution was extended more in 2020 due to which there were 21districts were under poorer AQI. A total of 9 districts were very poor, 7 districts were under poor, and 5 were under moderate AQI level. Mor *et al*., (2022) showed that crop residue burning significantly influences the post-monsoon season and the biomass burning in winter on Haryana’s air quality.

3.2. *Characteristics of AQI in crop season during 2019 and 2020*

Being Haryana an agrarian state, the air quality analysis is also important to be assessed crop season-wise (Fig. 4). Two crop seasons prevail in the state, *i.e.*, Rabi (October to March) and Kharif (April - September). During Kharif 2019, the whole of the state except for three districts, *i.e*., Yamunanagar, Panchkula and Mahendragarh was having moderate air quality with AQI ranging from 101-200. But in 2020 the AQI level improved considerably and most of the districts appeared at satisfactory and good levels (less than 100). Only 6 districts had moderate AQI levels as shown in Fig. 4. The improvement in AQI was more in central parts of the state.

The rabi seasons coincide with winters and pollution due to stubble burning in stable atmospheric conditions is a well-known issue in the NCR zone. In the 2019 rabi season, 12 districts were in very poor AQI levels with 6 in the poor category. The concentration of these poor and very poor AQI districts was in the central parts of the state. In 2020, the number of districts in very poor AQI category were slightly decreased to 10 while poor category districts increased to 9. Although there was the impact of pollution, it was on the lower side as compared to the same time period of 2019.

4. Conclusion

The study was conducted to represent and compare the air quality index in a normal year with the lock-down year due to COVID 19. The result showed that the air quality was improved during the lockdown period to a greater extent. In meteorological seasons, the air quality was more severe in the post-monsoon and winter seasons and in agronomic seasons, the rabi seasons showed poor air quality in 2019 and improved AQI in 2020. The study provided an estimate on the contribution of the industrial and automobile sector on AQI as in 2020 these activities were seized due to lockdown while agriculture operations were continued. Therefore, the decrease in air pollution in 2020 can be attributed to fewer industrial activities and vehicular emissions. The study is relevant in terms of the understanding of the Spatio-temporal characteristics of the air quality index in Haryana in recent years. The study provides critical insights into future pollution control and its spatial dynamics. In addition to the merits, the study has limitations also. The district's air pollution level is represented by the average of points monitored concentrations within the area, which may lead to extrapolation errors. Furthermore, air quality is affected by various factors, such as weather and human activities, and there is a lack of quantitative analysis of these aspects ofair quality. There is a need for future work to combine remote-sensed data and ground-monitored data to control extrapolation errors and to explore relationships between other driving factors and air pollutants for more urban sites.

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