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

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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 (PM₁₀, PM₂.₅, O₃, NOₓ, SO₂ and CO) were analyzed seasonally for 2019 and 2020. The spatio-temporal distribution of the air quality index (AQI) clearly depicted changes in different meteorological and crop seasons in 2019 and 2020. The result showed that the air quality was very poor in winter and the post-monsoon season 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.
In the COVID-19 period, one of the positive things observed was improvement in the air quality (Sharama et al., 2020). In the Indo-Gangetic 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-Gangetic 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
air quality standards (Chen and 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 km², 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

<table>
<thead>
<tr>
<th>AQI Range</th>
<th>Category</th>
<th>Colour</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>Good</td>
<td>Green</td>
<td>Minimal impact</td>
</tr>
<tr>
<td>51-100</td>
<td>Satisfactory</td>
<td>Green</td>
<td>Minor breathing discomfort to sensitive people</td>
</tr>
<tr>
<td>101-200</td>
<td>Moderate</td>
<td>Yellow</td>
<td>Breathing discomfort to the people with lungs, asthma and heart diseases</td>
</tr>
<tr>
<td>201-300</td>
<td>Poor</td>
<td>Orange</td>
<td>Breathing discomfort to the most people on prolonged exposure</td>
</tr>
<tr>
<td>301-400</td>
<td>The very Poor</td>
<td>Red</td>
<td>Respiratory illness on prolonged exposure</td>
</tr>
</tbody>
</table>

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

**Fig. 3.** Spatial variations in AQI in different meteorological seasons 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, Charkhi Dadri, Rohtak, Rewari (Dhauhera), 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 (PM10), fine particulate matter (PM2.5), ozone (O3), nitrous oxide (NOx), sulfur dioxide (SO2) 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 PM10, PM2.5, O3, NOx, SO2 and CO etc.

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

$$I_P = \frac{(I_H - I_L)}{(B_H - B_L)} \times (C_P - B_P) + I_L$$

where $I_P$ is AQI for pollutant “P” ( Rounded to the nearest integer), $C_P$ is the actual ambient concentration of pollutant “P”, $B_H$ is the upper-end breakpoint concentration that is greater than or equal to $C_P$, $B_L$ is the lower end breakpoint concentration that is less than or equal to $C_P$, $I_L$ the sub-index or AQI value corresponding to $B_L$, $I_H$ the sub-index or AQI value corresponding to $B_H$ (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

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**TABLE 1**

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

<table>
<thead>
<tr>
<th>Season</th>
<th>Bhiwani</th>
<th>Balabhgarh (Faridabad)</th>
<th>Ambala</th>
<th>Kamal</th>
<th>Charkhi Dadri</th>
<th>Rohtak</th>
<th>Dharuhera (Rewari)</th>
<th>Sirsa</th>
<th>Mandikhera (Mewat)</th>
<th>Manesar (Gurugram)</th>
<th>Narnaul (Mahendragarh)</th>
<th>Palwal</th>
<th>Panchkula</th>
<th>Panipat</th>
<th>Bahadurgarh</th>
<th>Jind</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>151</td>
<td>151</td>
<td>199</td>
<td>165</td>
<td>119</td>
<td>NA</td>
<td>162</td>
<td>165</td>
<td>170</td>
<td>205</td>
<td>NA</td>
<td>205</td>
<td>121</td>
<td>75</td>
<td>136</td>
<td>152</td>
</tr>
<tr>
<td>2020</td>
<td>117</td>
<td>117</td>
<td>151</td>
<td>165</td>
<td>119</td>
<td>NA</td>
<td>162</td>
<td>165</td>
<td>170</td>
<td>205</td>
<td>NA</td>
<td>205</td>
<td>121</td>
<td>75</td>
<td>136</td>
<td>152</td>
</tr>
<tr>
<td>Winter</td>
<td>107</td>
<td>157</td>
<td>107</td>
<td>157</td>
<td>229</td>
<td>301</td>
<td>139</td>
<td>166</td>
<td>136</td>
<td>166</td>
<td>NA</td>
<td>144</td>
<td>176</td>
<td>154</td>
<td>102</td>
<td></td>
</tr>
<tr>
<td>Pre-monsoon</td>
<td>134</td>
<td>101</td>
<td>134</td>
<td>101</td>
<td>244</td>
<td>89</td>
<td>83</td>
<td>73</td>
<td>170</td>
<td>86</td>
<td>NA</td>
<td>173</td>
<td>162</td>
<td>80</td>
<td>133</td>
<td>101</td>
</tr>
<tr>
<td>Monsoon</td>
<td>92</td>
<td>80</td>
<td>92</td>
<td>80</td>
<td>132</td>
<td>116</td>
<td>149</td>
<td>178</td>
<td>109</td>
<td>63</td>
<td>NA</td>
<td>103</td>
<td>90</td>
<td>59</td>
<td>132</td>
<td>84</td>
</tr>
<tr>
<td>Post monsoon</td>
<td>296</td>
<td>170</td>
<td>296</td>
<td>170</td>
<td>302</td>
<td>282</td>
<td>93</td>
<td>110</td>
<td>304</td>
<td>227</td>
<td>NA</td>
<td>322</td>
<td>303</td>
<td>266</td>
<td>192</td>
<td></td>
</tr>
<tr>
<td>Rabi</td>
<td>191</td>
<td>140</td>
<td>191</td>
<td>140</td>
<td>265</td>
<td>248</td>
<td>111</td>
<td>NA</td>
<td>203</td>
<td>177</td>
<td>NA</td>
<td>221</td>
<td>266</td>
<td>197</td>
<td>129</td>
<td></td>
</tr>
<tr>
<td>Kharif</td>
<td>112</td>
<td>91</td>
<td>112</td>
<td>91</td>
<td>166</td>
<td>107</td>
<td>127</td>
<td>148</td>
<td>124</td>
<td>70</td>
<td>NA</td>
<td>119</td>
<td>66</td>
<td>137</td>
<td>96</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Season</th>
<th>Fatehabad</th>
<th>Kurukshetra</th>
<th>Sonipat</th>
<th>Hisar</th>
<th>Yamunanagar</th>
<th>Kaithal</th>
</tr>
</thead>
<tbody>
<tr>
<td>2019</td>
<td>152</td>
<td>139</td>
<td>127</td>
<td>124</td>
<td>136</td>
<td>145</td>
</tr>
<tr>
<td>2020</td>
<td>152</td>
<td>139</td>
<td>127</td>
<td>124</td>
<td>136</td>
<td>145</td>
</tr>
<tr>
<td>Winter</td>
<td>198</td>
<td>106</td>
<td>164</td>
<td>152</td>
<td>274</td>
<td>151</td>
</tr>
<tr>
<td>Pre-monsoon</td>
<td>173</td>
<td>103</td>
<td>126</td>
<td>95</td>
<td>143</td>
<td>125</td>
</tr>
<tr>
<td>Monsoon</td>
<td>131</td>
<td>82</td>
<td>93</td>
<td>73</td>
<td>120</td>
<td>113</td>
</tr>
<tr>
<td>Post monsoon</td>
<td>163</td>
<td>334</td>
<td>301</td>
<td>308</td>
<td>145</td>
<td>208</td>
</tr>
<tr>
<td>Rabi</td>
<td>150</td>
<td>249</td>
<td>214</td>
<td>223</td>
<td>146</td>
<td>172</td>
</tr>
<tr>
<td>Kharif</td>
<td>153</td>
<td>96</td>
<td>109</td>
<td>83</td>
<td>134</td>
<td>119</td>
</tr>
</tbody>
</table>

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The data was analyzed in MS Excel for daily and seasonal calculations on the basis of hourly data.
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. In the monsoon period, 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 of air 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.

Acknowledgment

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Disclaimer: The contents and views expressed in this study are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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