International Journal of Engineering Research & Management Technology
ISSN: 2348-4039
July-August-2021 Volume 8, Issue-4
Email:editor@ijermt.org www.ijermt.org

Investigating the long-term variability of air pollutants at five urban locations in Rajasthan

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Abstract

A long-term investigation of air pollutants, including meteorological parameters during 2010-2020 in five significant polluted cities in Rajasthan is carried out. During 2010-2020, MOPITT and OMI-derived daily datasets are analyzed for CO, NO_2, SO_2, and O_3 to evaluate monthly, seasonal and annual averages at Ajmer, Jodhpur, Jaipur and Kota in the current work. The multiannual percentage change reveals that mean pollutant concentrations (of 5 cities) have grown during the last decade due to rapid economic development and industrialization. MOPITT and OMI-derived daily datasets are analyzed for CO, NO_2, SO_2, and $O_3$and are used to estimate monthly, seasonal and annual averages at five urban sites in the present work for the study period. The multiannual percentage change reveals that mean pollutant concentrations (of 5 cities) have increased by 2.54%(CO),-1.3% (NO_2), -9.1% (SO_2) and 3.92% (O_3) from 2010. The monthly and annual variabilities indicated that Jaipur has the highest concentrations of 3 out of 4 air pollutants. Seasonal variability revealed the decline of air pollutants during lockdown and monsoon season. In the Pearson correlation test, data of meteorological variables were used to evaluate the relationship between pollutants CO, NO_2, SO_2, and O_3 for all five cities.

Keywords: *Air pollutants, Rajasthan, Long-term Study, Satellite Observations*

INTRODUCTION

In India, with the acceleration of industrialization and infrastructure expansion since modernization, air pollution has also increased, leading to significant health hazards and premature deaths. In recent years, major Indian cities have all been in the world's top 20 most polluted cities as recommended by WHO and CPCB (Central Pollution Control Board) (Lawrence and Fatima, 2014; Sharma and Mandal, 2017). CO, NO_2, SO_2, and $O_3$are gaseous pollutants, and their emissions are due to transportation, industry, coal-fired power plants, and incomplete combustion of fossil fuels. In any way, various forms of combustion or waste are released in the environment as fine particles (Gurjar et al., 2016; Sharma and Dikshit, 2016). NO_2 is a precursor element that produces ozone under sunlight and high-temperature conditions through CO, CH_4 and VOC reactions.

In contrast, surface ozone O_3 is a very harmful air pollutant that affects crop yields, human health and ecosystems as the third most obligatory greenhouse gas. The pollutants are of secondary origin and are produced by the gas and liquid phase oxidation of SO_2 and by the photochemical reaction of NO_x and VOC, so the two secondary pollutants share a common precursor. Many of these pollutants and other components also affect indoor air quality, such as solvents used in laundry, building materials, paints, carbon monoxide, pathogens, food processing, smoking, plastics, upholstery, and oil (Kotcher et al., 2019). Several studies have reported on the effects of these air pollutants on people who may be sensitive to indoor air pollutants over the long term. They are more susceptible to severe respiratory infections, particularly children, the elderly and people who are very tired, especially those with respiratory problems or cardiovascular disease, erythema, asthma, dyspnoeal and sneezing (Bergstra et al., 2018; Burnett et al., 2014). According to a recent study, the most prominent north-west Indian region, Rajasthan, is facing an increase in all types of pollution (Balakrishna et al., 2019). The 2020 Lancet report revealed that out of all deaths, more than a million deaths in Rajasthan are due to pollution. This number will increase as air quality deteriorates due to particulate matter and other environmental pollutants. RSPCB (Rajasthan State Pollution Control Board Department) is responsible for controlling and enforcing Air Pollution Rules and Policies in Rajasthan as amended. Pollution levels in Rajasthan have become a growing concern, driven by commercial advances driven by industrialization, infrastructure development and increasing air pollution to high-risk levels (Sharma et al., 2020). The environmental risks associated with exposure to these pollutants have been increased by human activities worldwide, and Rajasthan is no exception (Burnett et al., 2014). Various chemical solvents used in laundries, building materials, paints and varnishes, pathogens, food processing, fumigation plants, plastics manufacturing and petroleum affect indoor air quality (Rathore et al., 2022; Prabhakaran et al., 2022). This motivates us to conduct long-term studies and monitor pollution at selected sites in Rajasthan.

This adherence has encouraged us to look for different pathways and variables responsible for the last decade, 2010-2020. A significant drop in NO_2 from space has been marked by the European Space Agency (ESA, 2020). The Indian Pollution Control Agency (CPCB) reported that based on 34 station data, Delhi had observed a substantial reduction in $NO_2$and $O_3$and CO and a 40% refinement in the national air quality index to up to 50% the quality index during the lockdown (Mahato et al., 2020). This paper examined the fluctuations in pollutant concentration and meteorological data acquired from space-based instruments at Ajmer, Jodhpur, Jaipur, Udaipur and Kota in Rajasthan, India, for the period from January 2010 to December 2020. The analysis of the observations ends. The last decade explains the possible effects of pollution shifts over days with similar meteorological conditions. The work is split into four parts, including the introduction. The data sources, the importance of the study area, air pollutants and meteorological parameters, and the methodology used is explained in Section 2. The long-term results of the analysis are presented in Section 3, followed by a summary.

DATA AND METHODOLOGY

Study Area

In this report, five major cities in Rajasthan were selected for the long-term study of pollutant concentration variations over the period 2010-2020 (see Figure 1). Ajmer (26.4499 N, 74.6399 E) is located in the Aravalli Mountains. It is 486 m above sea level and was built in the 7th century by King Ajaipal Chohan as a place of pilgrimage. According to the census (2011), Ajmer is a semi-urban area with an average population density of 5750 inhabitants per square meter (Sharma et al., 2014). Jodhpur (26.2389 N, 73.0243 E) is the second largest city, with an average elevation of 231 m. The number of vehicles and the population in Jodhpur is proliferating, with an area of 40 km, 1,033,756 (2011 census). Jodhpur is a popular tourist destination on the Thar Desert outskirts. The climate is generally hot and dry during the dry season, which lasts most of the year. The Jaipur region lies on the eastern side of the Thar Desert and Aravalli ranges. Jaipur, the capital of Rajasthan, is a significant tourist destination, part of the Golden Triangle, and the "Pink City of India". With a tropical climate all year, Jaipur has been subject to rapid and unplanned urbanization in the past, which led to urban expansion, industrialization, and mining. A not-so-surprising rise in atmospheric particulate matter (PM), one of Jaipur's three main air pollutants, followed by NO_2, and SO_2. Udaipur (24.5854 N, 73.7125 E) lies in the foothills of Aravalli (see Figure 5.1). The city is a hotspot of major tourist attractions known worldwide. Therefore, modes of transport such as buses, cars, and two- and three-wheel vehicles contribute significantly to particulate and gaseous pollutants. Industrial plants and marble factories on the outskirts of Udaipur are also contributing to the deteriorating air quality, with annual vehicle growth of at least 10%. In recent years, PM2.5 and PM10 have increased due to combined fossil fuel combustion, industrial process and biomass combustion (Kapoor et al., 2009). The Kota city (25.2138° N, 75.8648° E) is located in south-eastern Rajasthan on the banks of the Chambal River. It has an elevation of around 271 m, with heavy industries. Kota is known for ancient artworks, palaces, and temples (Jhariya et al., 2016). A premier stone processing city, Kota also serves as a trading unit for agricultural seeds. Smaller industries such as oil milling, textiles, and metal manufacturing of art crafts are also present. Heavy Industries such as chemical, cement, engineering works and power plants (thermal, gas, nuclear) units are also present (Choudhary and Gupta, 2016). In recent years, PM2.5 and PM10 have increased due to the combined burning of fossil fuels, industrial processes and biomass burning (Kapoor et al., 2009). The salient features of the selected cities are mentioned in Table 1. Population trends from census2011 are Jaipur > Jodhpur >Kota > Ajmer > Udaipur. Industrial zones were created to promote industries in Kota, Jaipur, Udaipur, Bhilwara, Bhiwadi and Jhunjhunu in Rajasthan (Kundu et al., 2015). The primary industries in Rajasthan are cement, tourism, ceramics, chemicals, textiles, steel, handicrafts, marble and, more recently, IT and ITeS. Reports suggest that industrial, mining, and locomotive activities are the leading causes of air pollution in Rajasthan (Kuldeep et al., 2022). From a commercial point of view, Rajasthan is one of the largest producers of raw minerals, with over 75 minerals. A tourist attraction for historical palaces, wildlife sanctuaries, hot sand deserts, etc., Rajasthan attracts investors for various investment opportunities. The state also produces cement-grade limestone (Chaurasia et al., 2014). Approximately 26% of the country's proven limestone reserves are owned directly by the government. A significant portion of air pollution comes from factories, a source of workplace hazards and health consequences. The RSPCB is responsible for monitoring air quality in the states, and Kharol et al. (2013) presented a detailed review of the database.

Data sources

Five urban locations of Rajasthan are selected to investigate the long-term variability and correlation among the meteorological parameters for 2010-2020. These sites are marked yellow on Rajasthan Map, as shown in Figure 1. MOPITT was developed by the University of Toronto and, with the support of the Canadian Space Agency (CSA), designed for the National Aeronautics and Space Administration (NASA) (Deeter et al 2010). The spatial resolution of MOPITT instruments is 22 km at nadir and can measure the concentrations of carbon monoxide in 5 km layers down a vertical column of the atmosphere (Deeter et al 2010). MOPITT CO total column measurement also has 10% accuracy. Daily gridded data from version 2 of the level 3 OMI product was used to analyse NO_2, SO_2, and O_3columns over the study region as it has low uncertainty and data bias (Deeter et al., 2017). Datasets mentioned overlay between each other. Meteorological Data such as Surface Temperature and Relative humidity are taken from Atmospheric Infrared Sounder, an advanced visible/near-infrared instrument designed to provide highly accurate atmospheric temperature profiles (Grajales and Baquero-Bernal, 2014; Acker and Leptoukh, 2007). The AIRS is the primary instrument of the AIRS/AMSUA/HSB trio, concentrated on measuring precise temperature and humidity profiles throughout the atmosphere. The meteorological datasets are taken from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA2) data (2000- 2020). It is a weather assimilation database, also the first long-term global reanalysis to assimilate spatial observations of aerosols and describe their interactions with other physical processes in the global climate system. MERRA-2 model updates the Goddard Earth Observing System model and analysis schema to assimilate observation types not available in its predecessor, MERRA and provides viable continuous climate analysis beyond its first version. MERRA-2 advances assimilation of aerosol observations, several improvements in stratospheric imaging, including ozone, and improved imaging of cryosphere processes. Other quality improvements in MERRA-2 compared to MERRA include reduced spurious trends associated with observational system changes and reduced biases and imbalances in aspects of the water cycle.

MERRA2 data covers the period from 1979 to date and is gridded on a 0.5° × 0.66° with 72 layers of height at a monthly mean. The primary goal of MERRA2 was to reanalyse autonomous land surface and atmospheric aerosol interactions. The GES DISC accumulates and maintains an online database for air quality. The present work uses daily average concentrations of four pollutants, including CO, NO_2, SO_2, and O_3, from MOPITT and OMI instruments from the public Giovanni platform (https://giovanni.gsfc.nasa.gov/giovanni/) and (https://disc.gsfc.nasa.gov/datasets). Meteorology data, i.e., Surface temperature, relative humidity (RH), Wind Speed, and PBLH (planetary boundary layer height), are taken from AIRS and MERRA2 model, respectively, from Giovanni. For the present analysis,based on the latitude and longitude of the sites, the data has been sliced from the more extensive daily observations. These daily datasets are cleaned based on the quality flags and uncertainty levels. Data with high uncertainty are scrapped. Then the daily datasets are used to calculate the monthly, seasonal, and annual averages. The comparative and correlated studies have been carried out from 2010-2020.

Description of air pollutants and meteorological parameters

Data characterizing meteorological trends are also estimated. P-values between Pearson correlation coefficients and CO, NO_2, SO_2, and O_3during the study period (2010-2020) are also estimated. Air pollutants are their correlations with each other along meteorological parameters also estimated. The correlation is either 'Negative' or 'Positive', while the strength of the correlation is presented as 'Weak', 'Moderate' or 'Strong'. These air pollutants and their correlations with other parameters are also investigated.

RESULTS AND DISCUSSION

Monthly Variability

Figure 2 shows the monthly variation in the average concentration of CO, NO_2, SO_2, and O_3 at Ajmer, Jodhpur, Jaipur, Udaipur and Kota during 2010-2020 as a box plot. The central line in each month shows the average concentration. The mean CO, NO_2, andSO_2 concentrations at all the sites decrease during monsoon, except O_3. Similarly, the winter months show a sharp enhancement in pollutants except for O_3. In January, Jaipur witnessed the highest CO columns, at least 10% higher than the other cities. Similar trends are observed for Feb and March. From April to June, the CO column starts declining and approaches the minimum at all locations, indicating the relationship between temperature and humidity. In July, mean CO columns minimum are observed at all sites. The mean SO_2 also shows similar characteristics to mean CO, except it reaches a minimum in the July-August months. From September month, CO, NO_2, and SO_2, rising trends are seen. The Ozone has the opposite trend compared to the rest of the pollutants. The minima and maxima in Ozone are seen during Nov-Dec and Apr-May months at all sites. From this figure, the CO and NO_2 monthly means show Jaipur as the highest pollutants than the rest of the sites. For SO_2 monthly mean, Jaipur and Kota have the highest pollutants than the rest of the sites. The ozone concentrations were highest in Jaipur, Jodhpur and Ajmer than in Udaipur and Kota. High pre-monsoon levels are associated with air mass movement in northern India and northeast Pakistan and areas dotted with numerous coal power plants and power plants. Winter O_3 values are lower because the measurement point is separated from the plane by boundary layer dynamics similar to the free conditions of the troposphere

Seasonal Variability

The Indian Meteorological Agency (IMD) has defined four climatic seasons. Winter (December-February: DJF), pre-monsoon or summer (March-May: MAM), monsoon (June-August: JJA) and post-monsoon (September-December: SON), of which MAM is considered the hottest season among all.

(a) CO

Figure shows the seasonal comparison between the sites. The top panel displays annual average CO column values at Ajmer, Jaipur, Jodhpur, Udaipur, and Kota. The Jaipur has the most increased values during all four seasons. The overall tendencies in all the sites are similar because they are urban sites. Ajmer has the least CO column values for all seasons. The effect of lockdown constraints is depicted from the Summer and Monsoon months, as the CO concentrations decline at all sites. However, in the post-monsoon seasons, the CO columns increase due to relaxation in the lockdown restrictions. The disparity between Jaipur and the rest of the sites reveals the poor air quality and raises apprehensions over the increasing health issues. A comparison of Jaipur and nearby areas like Ajmer, Udaipur, and Kota shows that air quality in Jaipur is inferior in urban areas compared to semi-urban sites, particularly for people dwelling near the industrial areas. The area is subject to extreme weather conditions, and Jaipur has high levels of air pollution and subpar air quality year-round and contrasting seasonal differences.

(b) NO_2

Figure shows the seasonal comparison between the sites from the analysis of OMI NO_2. The top panel shows annual average NO_2 column values at Ajmer, Jaipur, Jodhpur, Udaipur, and Kota. The Jaipur has the highest values during all four seasons, closely followed by Kota. The overall trends in all the sites are similar because they are urban sites (Jaipur > Kota > Ajmer> Udaipur> Jodhpur). Jodhpur has the least NO_2 column values for all seasons. The effect of lockdown restrictions is depicted from the Summer months, as the NO_2 concentrations decline at all sites in March-April-May. However, in the post-monsoon seasons, the NO_2 columns increase due to relaxation in the lockdown restrictions. The difference between Jaipur and the rest of the sites is little, indicating periodic changes due to anthropogenic activities. A comparison of Jaipur and nearby areas like Ajmer, Udaipur, and Kota shows that air quality in Jaipur is inferior in urban areas compared to semi-urban sites, especially for people staying near the industrial areas. The region is subject to extreme weather conditions, and other sites are also experiencing high levels of air pollution.

(c) SO_2

Figure shows the seasonal comparison between the sites from the analysis of OMI SO_2. The top panel shows annual average SO_2 column values at Ajmer, Jaipur, Jodhpur, Udaipur, and Kota. The SO_2 data has gaps in observations at a few sites. DJF records Jaipur while Ajmer leads the highest values in the remaining seasons. The overall trend in all the sites is entirely random, owing to the data gap. The effect of lockdown restrictions is depicted from the pre-monsoon; during monsoon and post-monsoon, SO_2 declines at all sites in 2020. However, before the lockdown, SO_2 columns increased at Jaipur, Ajmer, and Udaipur. The multiannual and interannual percentage change shows significant differences between the sites, indicating periodic changes. All the sites show worsening air quality in the last decade than in rural areas, impacting people’s lives. Low SO_2 to NO_2 ratios indicate fossil fuel combustion from mobile sources as significant contributors to the ambient air over these regions (Malick and Lal, 2014).

(d) O_3

Figure shows the seasonal comparison between the sites for the O_3 column during 2010-2020. The panels show annual average O3 column values (DU) at Ajmer, Jaipur, Jodhpur, Udaipur, and Kota in DFJ, MAM, JJA, and SON. The Jodhpur and Jaipur have the highest O_3 column values during all four seasons. The overall trends in all the sites are identical because they are urban sites. Udaipur has the least column values for all seasons. The effect of lockdown regulations is depicted from the Monsoon months, as the concentrations decline at all sites. However, in the post-monsoon seasons, the column values show upward trends due to relaxation in the lockdown restrictions. The difference between Jaipur and the rest of the sites is less than 5% suggesting all the sites have poor air quality and raising concerns over the increasing health issues. The region is subject to severe weather conditions, and Jaipur has elevated levels of air pollution and poor air quality year-round and contrasting seasonal differences. The results showed a significant uniformity in O_3 column enhancement while absent for other pollutants.

Annual Variability

The present work compares the annual mean of air pollutants at all the sites in figure 7. Jaipur city shows the highest CO column values in 2010-2020 among all sites. Ajmer city shows the least CO column values in 2010-2020 among all sites. Jaipur city shows the highest NO_2 column values in 2010-2020 among all sites. Jodhpur city shows the least NO_2 column values in 2010-2020 among all sites. An annual cycle is seen from the monthly variations, with a mean fluctuation between 2-5%. The cycle of enhancement and reduction is due to seasonal and human activity. The most notable increase was observed in 2004, 2012 and 2015 (Fadnavis et al., 2011; Palve et al., 2018). Although CO columns have declined most of the years, over the last two years (2020-2021), the average CO columns decreased by at least 10% across all urban sites. The lockdown period is ousted from the present study because the larger variability resulted from the return of normalcy and abrupt increase in automotive sources and biomass combustion and oxidation of hydrocarbons. However, other causes, including fires, burning agricultural waste, and burning biofuels, are under investigation. Jaipur is also famous for its mineral mining operations, such as limestone, mica, and others in the surrounding area (Agrawal et al. 2019). Various industrial units, such as manufacturing, textiles, dye, food, chemicals, etc., cause industrial pollution (Singh and Chandel 2006). In October, air pollution was also spawned due to the festival, where crackers exploded at all Rajasthan resorts, including Jaipur, contributing to the pollution. Most air pollution in urban sites comes from cars, factories, and homes (Jawaid et al., 2017). Northern India has (~ 10% - 130%) the highest concentration of all pollutants than southern India, with only SO_2 having the same layers (Sharma & Mauzearall, 2020). Earlier, Saw et al. (2021) reported that NO_2 emissions from nine plants in the Delhi area ranged by 8–30.6 kt/year from following NO_2 emissions from tropical power plants in Northern India using data from TROPOMI. Behera et al. (2021) showed significant reductions in NO_2, SO_2, HCHO and the Absorbing Aerosol Index (AAI) during March-May 2020 compared to the same period in 2019, while NO_2, SO_2, HCHO and CO levels increased significantly by -2021 compared to March. -May 2020. Changes in Global tropospheric Nitrogen dioxide (NO_2) has different or opposite effects on the photochemical formation of ozone in different regions under different climates and emissions conditions (Cai et al., 2022). The interannual and multiannual percentage changes were calculated to identify the significance of trends in the last decade. It is revealed from the analysis that pollutants originating from anthropogenic sources fall for a short-term period and affects the seasonal variability; however, transports will be seen long term studies

Correlation study at selected sites

The strong correlation between pollutants and meteorological parameters confirms studies of various consequences of the environment on air quality. If ground observations are also known, can this study determine whether transport can induce air pollution in the study area? This section is divided into two parts. We first correlate the parameters of atmosphere and CO, and then we correlateNO_2, SO_2, and O_3. Second, we briefly present annual and seasonal comparisons of CO and NO_2, SO_2, and O_3 across all regions.

Planetary boundary layer height properties play a significant role in the diffusion of pollutants near the earth's surface. During the winter season, low PBL height may be partially accountable for several pollutants such as Anthropogenic: burning of fossil fuel, wood burning, natural sources (e.g., pollen), the transformation of precursors (NOx, SOx, VOCs) and Biogenic: dust storms, forest fires, dirt roads in the air of the urban area associated with fog and can increase human cardiovascular risk (Al-Delaimy et al., 2020).Likewise, the correlation between NO_2, SO_2 and CO implies that the augmented control of regional transport activity compared to local contributions in the urban site is the key responsible factor for the reduction (Sharma et al., 2020) The correlation between O_3 and SO_2 is not apparent (Mahato et al., 2020).

There is a reasonable correlation between temperature and PBL. Atmospheric conditions, spatial structure and urban settlement issues are the main elements controlling air pollutants' dispersion, accumulation and chemical transformation in all urban sites (Dandotiya et al. ., 2020). Correlation analysis showed a good association between O_3 and PBL elevation, suggesting that the increase in surface ozone may be due to it mixing in the deeper boundary layer with ozone-rich air at altitude. For all observation sites, NO_2 and CO concentrations were very well coupled, indicating that CO and NO_2 were generated from similar sources (vehicle activity) (Kerimray et al., 2020).

SUMMARY

The present study analyses the regional air pollutants during 2010-2020 and the correlation of pollutants in five cities of Rajasthan. The area, population and industries part of anthropogenic sources are enlisted. During 2010-2020, MOPITT and OMI-derived daily datasets are analysed for CO, NO_2, SO_2, and $O_3$to estimate monthly, seasonal and annual averages at Ajmer, Jodhpur, Jaipur, Udaipur, and Kota in the current work. The multiannual percentage change reveals that mean pollutant concentrations (of 5 cities) have increased by 2.54%(CO),-1.3% (NO_2), -9.1% (SO_2) and 3.92% (O_3) from 2010. The monthly and annual variabilities indicated that Jaipur has the highest concentrations of 3 out of 4 air pollutants. Seasonal variability showed the reduction of air pollutants during the lockdown and consecutive monsoon season. Important variables affecting the spread of air pollutants are temperature, PBL, Relative humidity and wind direction. Various meteorological conditions such as high temperature, low relative humidity and high solar radiation are advantageous for ozone production at the surface. In the Pearson correlation test, data of meteorological variables were employed to assess the relationship between pollutants CO, NO_2, SO_2, and O_3. The results are significant for North Indian regions where air pollution is currently high, highlighting the importance of improving air quality in the long term. The analysis reported here only spotlights air quality trends of five major cities. However, in order to restrain pollution, an effective policy with possible financial resolutions must be enforced.

Author contributions

Dhanraj Meena : Conceptualization; Investigation; Methodology;
Abhishek Saxena: Writing original draft; Writing - review & editing
Masoom Jethwa: Data Analysis; Software;
Vikram Bhati: Formal Analysis

Acknowledgements

MOPITT and OMI processed datasets used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. The authors thank Beaudoing, H. and M. Rodell (NASA/GSFC/HSL) for online access to the MERRA model for scientific research.

Conflict of interests

The authors declare that there is no competing interest.

Figure 1. Study area: Ajmer, Jodhpur, Jaipur, Udaipur and Kota highlighted in yellow.

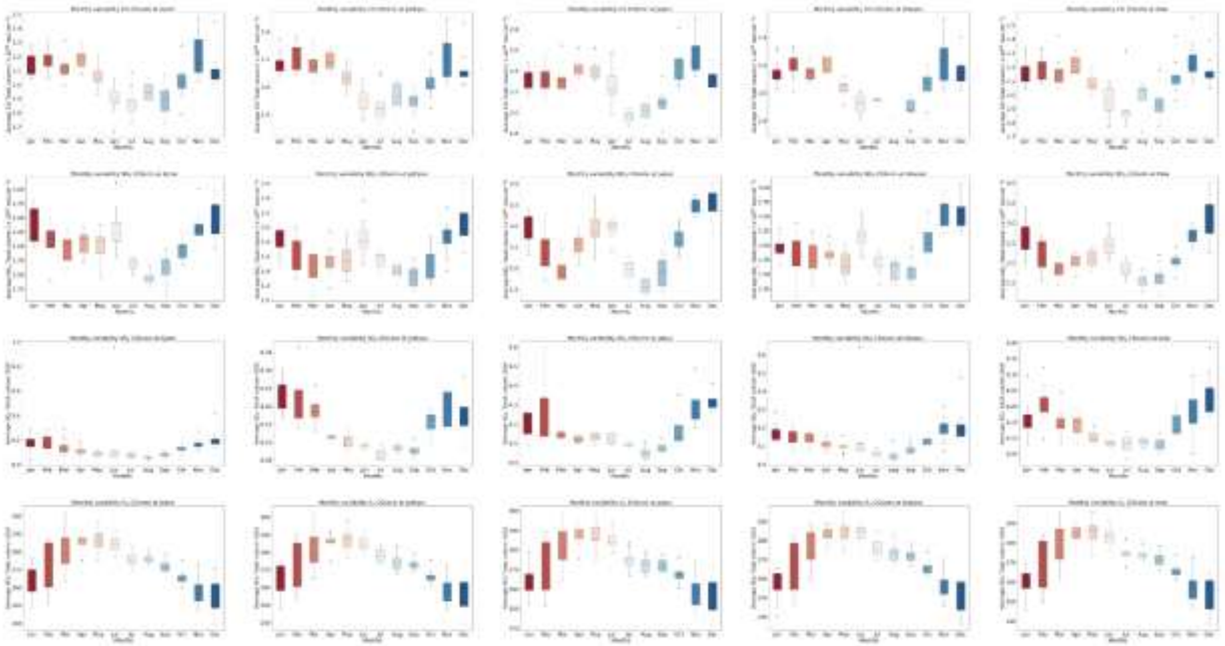

Figure 2. Monthly variability of pollutants at Ajmer, Jodhpur, Jaipur, Udaipur and Kota.

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