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Original Research

Assessment of Air Pollution Index (API) using FAHP and correlations between PM_{10} and Sentinel 5P (TROPOMI) AOD of Jharkhand, India

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Abstract: In the World Air Quality Report 2022, India ranked 8th in terms of average $PM_{2.5}$ concentration globally with a value of 53.3 μg/m^3 and a number of the 7 most polluted cities are located in India out of 50 top cities. The presence of poor air quality in mining cities has a positive relationship with mining activities and this scenario persists in different cities of Jharkhand state. In this study, we draw the API (Air Pollution Index) with the help of the fuzzy analytical hierarchy process (FAHP) across the state of Jharkhand, by considering parameters such as CO, O_3, NO_2, SO_2, and PM_{10} and the relationship between Sentinel 5P aerosol optical depth (AOD) and CPCB published ground data of PM_{10} (i.e., monthly and seasonal) was also explored. The outcome depicts that a high concentration of API is dominant along the north-eastern part of the state due to the intensive mining activity along this part of the state, and the trend of concentration of PM_{10} in the air is continuously increasing from 2012-2018 as per the GOJ (Government of Jharkhand) report. This study will give insight into the pollution scenario in the mining-dominated state of Jharkhand and along with that, it will also spread awareness of the impact of mining activities on the atmosphere.

Key Words	PM_{10}; Aerosol optical depth; fuzzy analytical hierarchy process; air pollution index; Jharkhand
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1. INTRODUCTION

In recent decades, the global environment has undergone rapid changes in the form of climate, flora, fauna, urban morphology, and various anthropological changes (Hase et al. 2021). A number of factors have influenced and hastened these global changes, including global warming (Change 2018), deforestation (Ritchie and Roser 2021), unplanned urban growth (Patra et al. 2022), rapid population increase (Ray and Ray 2011), and, most notably, the deterioration of air quality in developing countries (Foster and Kumar 2011). Surprisingly, despite being heavily polluted in the past, most developed countries have already reduced their air pollution levels and are now implementing norms and regulations for developing countries to reduce the emission of air pollutants (Tao and Hou 2023). According to the World Health Organization (WHO), the consolidated impact of household air pollution and ambient air pollution causes approximately 6.7 million premature deaths globally each year (WHO 2022). WHO considered the concentration of $PM_{2.5}$ as the most significant determinant of air pollution (WPR 2023).

According to the World Air Quality Report 2022, India ranked 8th in terms of average $PM_{2.5}$ concentration globally with a value of 53.3 µg/m3, and Bhiwandi (92.7 µg/m3) was the top-ranked $PM_{2.5}$ concentrated city in India (IQAir 2022). Delhi is ranked as the 4th most polluted city globally out of 50 cities, and a number of the 7 most polluted cities are present in India, according to a 2018 Greenpeace South Asia report (Greenpeace 2018). India ranked 2nd in terms of coal production after China in 2022, and in India, Jharkhand accounts for almost 86500 million metric tons of coal reserves, making it 2nd after Odisha (88000 million metric tons) (MoC 2022). Jharkhand state shares a decent percentage of other mineral production in India, such as iron ore (10%), bauxite (8%), kyanite (31%), and copper ore (1%) (MoM Annual Report 2023).

Environmental issues are very common in the mining sector, and the presence of poor air quality has a positive relationship with mining activities because it requires drilling, blasting, mine hot spots, mineral recovery, acid effluents, underground mines, and poor ventilation (Chaulya 2004, Huertas et al. 2012, Asif and Chen 2016, Asif et al. 2018). Health issues due to short-term and long-term exposure to mining activities induced air pollution are many where it can cause simple breath difficulties to permanently damage the respiratory system which can lead to death also (Patra et al. 2016, Nayak et al. 2018, Tian et al. 019, anisalidis et al. 2020, Hendryx et al. 2020). Moreover, mining activities induced air pollution also affects the environment through acid rain, haze, ground level ozone concentration and global climate change (Ghose and Majee 2000, Fugiel et al. 2017, Manisalidis et al. 2020). Other than these factors, the close proximity of railways and roads to mining areas induces air pollution (Dubey et al. 2012). Air quality issues related to mining sectors are primarily focused on particulate matter, including $PM_{2.5}$, PM_{10}, and dust deposition (Schwegler 2006, Dong et al. 2009, Moreno et al. 2019). Bui et al. (2019)applied artificial intelligence techniques such as “support vector regression (SVR) and particle swarm optimization (PSO)” to estimate and control PM_{10} concentrations influenced by mining activities in order to mitigate health risks caused by poor air quality . Bada et al. (2013) have used descriptive statistics, correlation, and Duncan multiple range (DMR) tests to demonstrate significant $PM_{2.5}$ (0.130 ± 0.010 mg/m3) and PM_{10} (0.231 ± 0.018 mg/m3) concentrations on the drilling and crushing site in the vicinity of the quarry, and these suspended particles are inversely correlated with the distance from the quarry site. Aside from these, Prusty attempted to monitor ambient air quality in terms of NO_2, SO_2, RPM, SPM, and CO in the Kachchh region of Gujarat, India. (Prusty 2012). In recent years, the application of geospatial technology in the field of air quality monitoring has taken a spike, and nowadays a majority of researchers are applying this technology and associated techniques to measure the concentration of different indices (i.e., particulate matter, SO_2, NO_2, O_3, and CO) of air quality in mining areas of India as well (Patra et al. 2021). Amar et al. (2021) proposed using a Python data science tool (i.e., pandas, tkinter, and matplotlib) to generate an exception report on the state of air quality over coal mines in Maharashtra, India. Another study conducted by Choudhary and Kumar (2021) used time series analysis methods such as moving average (MA), standard error (SE), and root mean square error (RMSE) to measure the concentration of AOD at coalfield sites in India. Apart from these, various studies have used different statistical, data science, geospatial, machine learning, and AI techniques such as principal component analysis (PCA) (Pandey et al. 2014), poisson regression (Nayak and Chowdhury 2018), linear regression (Hendryx et al. 2019), analytical hierarchy process (AHP) (Chen et al. 2007), fuzzy logic (Katushabe et al. 2021), ANN & Random Forest (Kang et al. 2018), dynamic neural network (Zhu et al. 2018), SOM algorithm, and deep learning (Bougoudis et al. 2016) to analyze air quality in the atmosphere on different scales.

The usage of satellite data (i.e., MODIS) and ground data (i.e., AERONET) to measure the AOD always differs (Endale et al. 2024); thus, Soni et al. (2016) conducted a comparative study on these two datasets to overcome the error in the Indo-Gangetic Plains. A long-term (over 20 years) AOD observation over India and the Indian Ocean using AATSR, MODIS, and MERRA-2 data exhibits higher and lower AOD concentrations over Indo-Gangetic Plains and the Indian Ocean, respectively (Kuttipputah and Raj 2021). The dust deposition rate varies from the summer season (7.51 to 28.58 g/m3/month) to the winter season (7.40 to 26.37 g/m3/month) and varies from iron mine areas to copper mine areas in Singbhum district, India (Mahato and Singh 2020). Saini et al. (2016) attempted to assess the “Environmental Impact Assessment (EIA)” by applying AHP in Jharia coal field, Jharkhand, and the results identified air as the most affected parameter in the area. Spatio-temporal variation of air pollutants in the Jharia Coalfield disclosed that the air quality is 1.5 times higher in coal mine fire areas compared to non-mine fire areas (Mondal et al. 2020). Mondal and Singh (2021) investigated the level of air pollution and associated health risks in the Dhanbad coal belt region by taking into account the presence of trace elements (i.e., Fe, Mn, Cr, Cd, Ni, Zn, and Pb), and the results show that Cr, Mn, and Fe pose a higher health risk potentiality.

It is evident from the existent literatures that over the years many studies have been conducted to explore different dimensions of air quality in the Jharkhand state (Kundu and Pal 2018, Chaulya et al. 2019, Halder et al. 2024, Mishra et al. 2024) however, few of the previous literatures have calculated air quality index with the help of an MCDM technique. Additionally, very few researches have been done on AOD in the Jharkhand state while focusing on mining activities (Soni et al. 2015, Ranjan et al. 2020, Bandyopadhyay et al. 2021, Mohammad et al. 2022). This study primarily focused on the assessment of CO, O_3, NO_2, SO_2, PM_{10}, and AOD air quality indicators in order to determine the variation and trend of particulate matter in the atmosphere over mining areas in Jharkhand state with the help of the Fuzzy-AHP method. This paper has also pointed out the correlation of Sentinel AOD with ground station observed PM_{10} data and the API of the selected parameter in Jharkhand.

2. MATERIALS AND METHODS

2.1 Study area

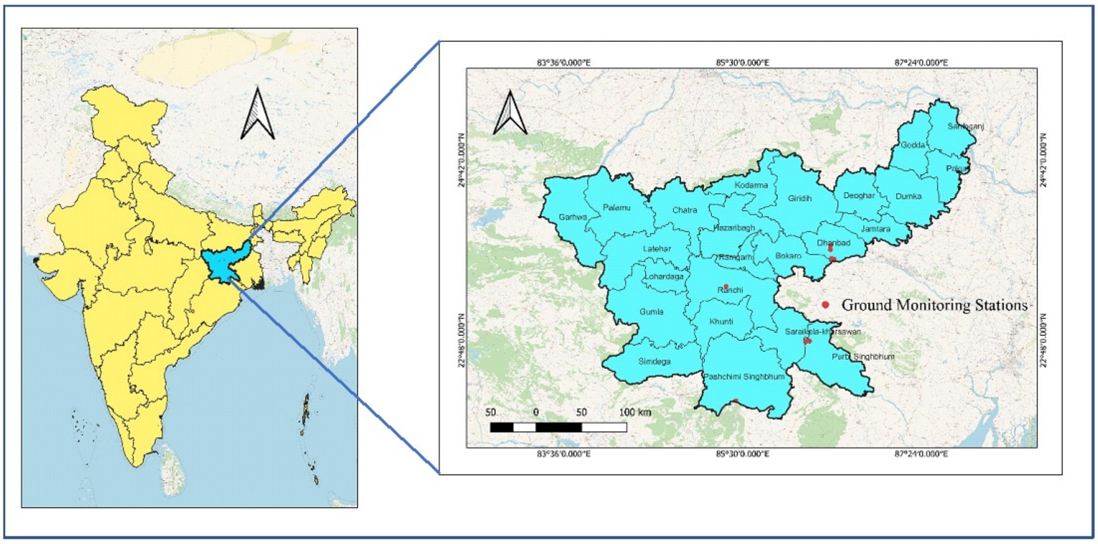
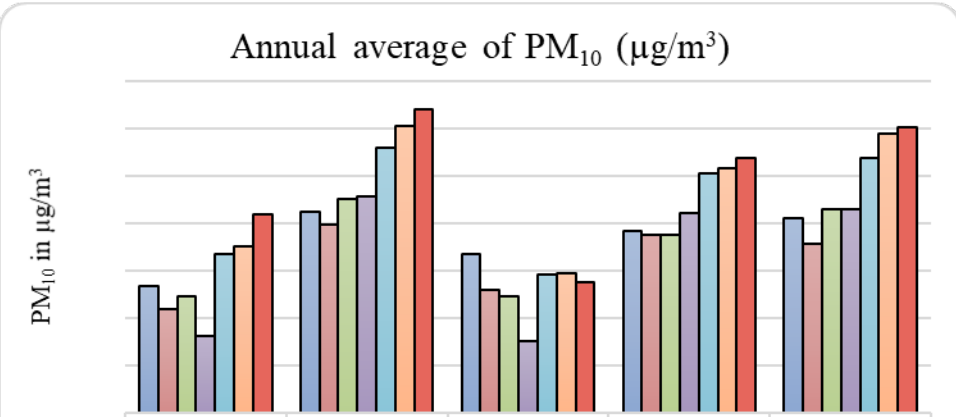


Fig. 1 Study area map

Jharkhand is situated in eastern India and is considered one of the most significant states in India in terms of mineral reserves. Geographically, the GPS coordinates of Jharkhand state fall between 83º 20′ 00″ E to 87º 50′ 00″ E and 25º 20′ 00″ N to 22º 05′ 00″ N (Fig. 1). Jharkhand is a state that is famous for its dense forest, mineral resources (i.e. coal, iron ore, bauxite, copper, and kyanite) and relief. This is why Jharkhand is often referred to as the "Land of Minerals and Forest". Some of the notable rivers that pass through Jharkhand are Damodar, Subarnarekha, Brahmani, Barakar, Sankh, Ajay, Sone and Mayurakhshi. The highest elevation (1376 m) point is located in the southern region (Chota Nagpur Plateau) and on the contrary the lowest elevation point is located along the banks of rivers (e.g. Damodar River). Jharkhand state covers an area of around 79700 km^2 that consists of a population of about 32966238 according to the Census of India 2011 (CoI 2011). Another thing that is significant is its major diversity in tribal communities (32) that include Birhor, Korwa, Lohra, Mahli, Santhal, Oraon, Munda, Sauria Paharia, and Ho tribes with a total population of 8645042. This study has initiated to assess the air pollution in Jharkhand state by applying a multi criteria decision model (MCDM) in order to explore the growing issue of air pollution in the state.



	R. O. Dhanbad	MADA, Jharia	PDIL, Sindri	Bastacola	CGMO, Kusunda
2012	133.78	211.92	166.36	191.55	204.92
2013	109.17	198.18	129.7	187.29	177.53
2014	122.69	224.55	121.79	187.88	214.43
2015	80.2	228.46	74.85	210.94	214.34
2016	166.6	279.63	144.85	252.41	268.89
2017	175.68	302.68	147.4	257.34	294.18
2018	208.66	319.89	136.83	268.6	300.7

Fig. 2 Annual average of PM_{10} concentration (µg/m³) in Dhanbad district (GoJ 2018)

Fig. 2 presents the annual average of PM_{10} concentration (µg/m³) in Dhanbad district from year 2012 to 2018. Most of the monitoring station around Dhanbad district shows a positive trend in PM_{10}(µg/m³) concentration in the atmosphere between 2012 and 2018 except for PDIL, Sindri station as it presents minimum variation in the concentration of PM_{10} particles.

2.2 Data source

In this study, the extraction of CO, O_3, NO_2, SO_2, PM_{10}, and AOD (aerosol optical depth) data was carried out using satellite data (i.e. Sentinel-5P) and Daily average PM_{10} data was acquired from ground station data available from CPCB of Indian Government (Table 1). This study was conducted by following the methodological framework illustrated in Fig. 3.

Table 1: Data used in this study

Data	Acquisition time	Source	Agency
Political boundary map	August, 2023	https://onlinemaps.survey-ofindia.gov.in/Home.aspx	Survey of India
Sentinel-5P	August, 2023	https://code.earthengine.google.com/?scriptPath=Examples:Datasets/COPERNICUS/COPERNICUS_S5P_NRTI_L3_AER_AI	European Union/ESA/Copernicus (Downloaded from Earth Engine)
Daily Avg. PM_{10}	August, 2023	https://cpcb.nic.in/index.php	Central Pollution Control Board (CPCB), Government of India

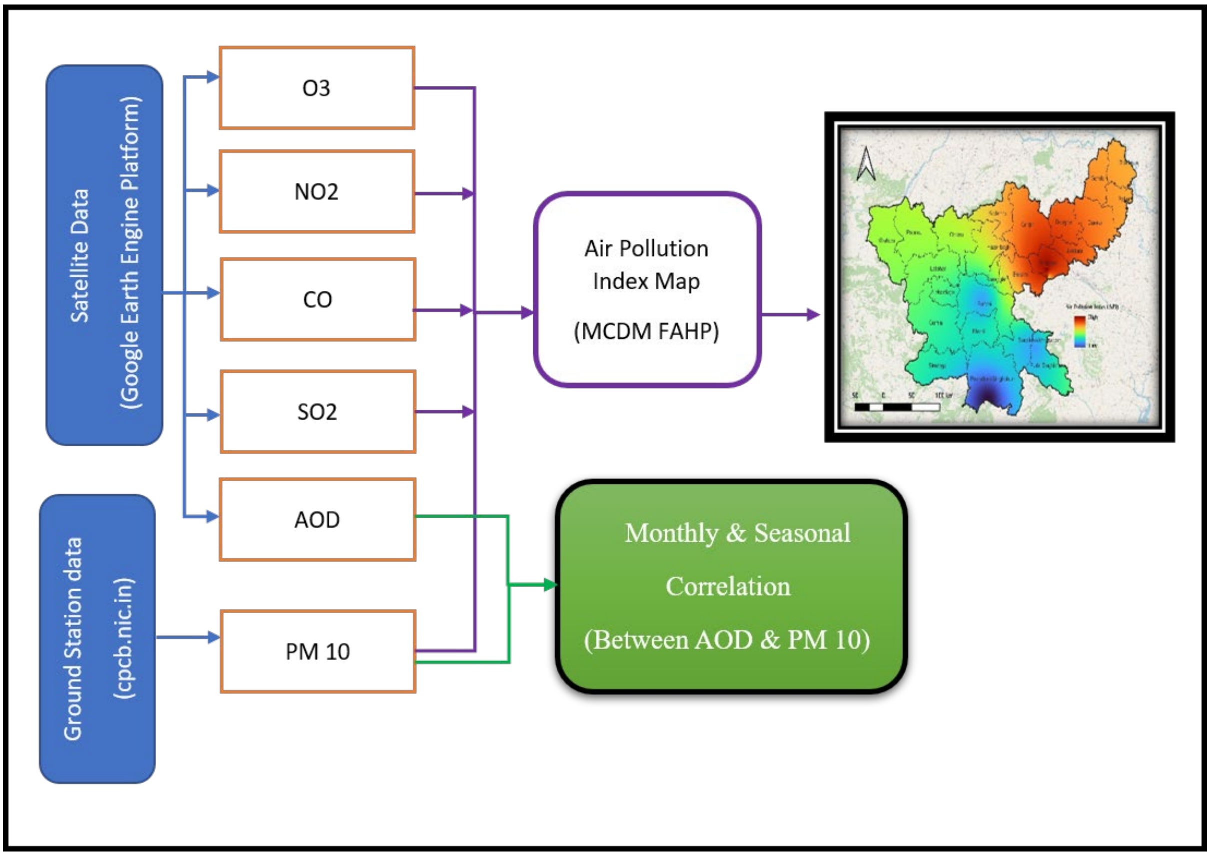


Fig. 3 Methodological framework followed in this study

2.3 Selected parameters of air pollution

This Air pollution is determined based on the concentration of different suspended pollutants in the atmosphere that can adversely affect human health, depending on the population's vulnerability (e.g., time of exposure and pollution level). WHO considered the concentration of PM 2.5 as the most significant determinant of air pollution (WPR 2023). Dust particle concentrations are relatively high in Jharkhand mining areas, particularly in coal fields (e.g., Jharia, Dhanbad), iron ore, and bauxite quarry areas, due to activities such as crushing, drilling, blasting, and open-cast mining. In this study, the researcher has selected five key elements to assess the air pollution in the Jharkhand state: carbon monoxide (CO), ozone at ground level (O3), nitrogen dioxide (NO2), sulfur dioxide (SO2), and smaller than 10 µm suspended particulate matter (PM10). The Central Pollution Control Board (CPCB) of the Government of India emphasizes calculating air quality (AQ) by incorporating at least three pollutant elements, one of which must be particulate matter (either PM2.5 or PM10). However, this study focuses on assessing air pollution (AP) using an alternative method that incorporates FAHP while taking all five pollutants (i.e., CO, O3, NO2, SO2, and PM10) into account as criteria. Data concerning all five parameters of AP was obtained from satellite data and monitoring stations combined. In the AP assessment, all the different parameters have different pollution potentials, and the actual damage (e.g., health risks) caused by the parameters are perfectly known through this process as well.

Concentration of CO gas added from fuel burning activities, specially wood, propane, charcoal etc. burning and its high concentration leads to replacement of red blood cells in the body to CO which can cause serious damage tissue of even death. O3 is a pale blue gas which smells like pungent and its intaking in higher concentration leads to abnormalities in lung function, asthma attack which sometimes cause death and respiratory dysfunction such as throat irritation, pain sometimes burning in the chest. Similar health issues are also seen due to intaking high concentration of NO2 and researches claimed more than 200 µg/m3 can cause significant health issues (Pandey et al., 2021). SO2 emits specially from industries causes irritation in skin, nose, throat and lungs. Particulate matters (PM) carries large number of toxic substances and by inhaling it directly accumulates in the lungs. Being the region belongs to coal mining and open cast coal mining is practiced in the region which highly contributes PM and thus in the study it gives much significance (Temesi et al., 2003).

2.4 Fuzzy AHP

This Generally, the analytical hierarchy process (AHP) is a multi-criteria decision analysis (MCDA) technique that considers different criteria organized in a hierarchical manner. The hierarchical organization of the criteria in this technique is determined by the relative importance of the criteria themselves, and the relative importance is given on the basis of an AHP scale. This AHP scale was first proposed by Saaty, and the scale value is determined through experience and knowledge of the respective field (Saaty 1977). Because real-world problems and scenarios are so complex, AHP techniques fall short due to their simplified scale and less critical approaches (Darko et al. 2019). Thus, the Fuzzy AHP comes into the scenario to overcome those drawbacks and tries to solve real-life problems with complex and critical introspection. In FAHP, instead of only using AHP crisp values, fuzzy crisp values are assigned to each of the criteria in order to organize them hierarchically. The FAHP is used with the help of a linguistic statement that compares two criteria and is expressed on a Fuzzy Comparison Ratio Scale. In this scale, each of the membership functions is composed of three possible fuzzy values in a triangular fuzzy number (TFN) namely, smallest (l), most appropriate (m) and largest (u) (Table 2). These values are as follows:

Table 2: Linguistic Variables of FAHP (Chang 1996, Sun 2010, Tripathi et al. 2021)

Linguistics	TFN	Reciprocal TFN
Absolute/Perfect	(9, 9, 9)	(1/9, 1/9, 1/9)
Very Good	(7, 8, 9)	(1/9, 1/8, 1/7)
Good	(4, 5, 6)	(1/6, 1/5, 1/4)
Appropriate	(3, 4, 5)	(1/5, 1/4, 1/3)
Equal	(1, 1, 1)	(1, 1, 1)

The implementation of F-AHP in this study has passed through various steps and these steps are mentioned in the following paragraphs.

Step 1: Construction of pairwise comparison matrix (PCM) (Buckley 1985)

In this section, first, all the criteria in the study are allocated linguistic terms in the PCM based on the question of which is the more influential or important of each two criteria and according to their linguistic terms TFN and reciprocal TFN are assigned in the PCM, as following matrix C̃ ()and Table 3 present the application of this matrix C̃.

$$\tilde{C} = [1\ \tilde{a}_{12} \cdots \cdots \tilde{a}_{1n}\ \tilde{a}_{21}\ 1 \cdots \cdots \tilde{a}_{2n} \vdots \cdots 1 \cdots \vdots \vdots \cdots \cdots \ddots \vdots\ \tilde{a}_{n1}\ \tilde{a}_{n2} \cdots \cdots 1\ ] =$$
$$\left[1\ \tilde{a}_{12} \cdots \cdots \tilde{a}_{1n}\ \frac{1}{\tilde{a}_{12}}\ 1 \cdots \cdots \tilde{a}_{2n} \vdots \cdots 1 \cdots \vdots \vdots \cdots \cdots \ddots \vdots\ \frac{1}{\tilde{a}_{1n}}\ \frac{1}{\tilde{a}_{2n}} \cdots \cdots 1\right] \qquad \ldots(1)$$

Step 2: Calculating the geometric mean of PCM using a geometric mean technique for each criterion (i.e., 5) involved in the study (Hsieh et al. 2004)

There are multiple studies available to obtain FAHP weights from PCM. It includes the geometric mean (GM) method (Buckley 1985), a programming based linear method (Wang and Chin 2008), a nonlinear method based on programming (Mikhailov 2003), a least square method using logarithms (Wang et al. 2006), extended method (Chang 1996), and synthetic extend method (Murat et al. 2015). However, in this study, the researcher has opted for the GM method to calculate the crisp weights for all the criteria (Table 4).

$$\tilde{r_i} = \left[\tilde{a}_{i1} \otimes \dots \dots \otimes \tilde{a}_{ij} \otimes \dots \dots \otimes \tilde{a}_{in}\right]^{\frac{1}{n}} \qquad \dots(2)$$

This Where, $\tilde{a}_{ij} = i$ dimension fuzzy comparison value of j criteria, $\tilde{r_i}$ = geometric mean of PCM of criteria i to each.

Step 3: Calculating respective crisp weights of each criterion (Table 5) involved in this study (Ayhan 2013)

$$\tilde{w}_i = \tilde{r}_i \otimes [\tilde{r}_1 \oplus \dots \oplus \tilde{r}_i \oplus \dots \dots \dots \tilde{r}_n]^{-1} \qquad \dots(3)$$

Where, $\tilde{w}_i$ = fuzzy weight of ith criteria each.

Step 4: De-fuzzified and normalization of crisp weights

After the calculation of respective crisp weights of all the criterion it is de-fuzzified (Table 6) by a technique called "Centre of area method" and the normalized using equation 5(Chou and Chang 2008).

$$M_i = \frac{l_{w_i} + m_{w_i} + u_{w_i}}{3} \qquad \dots(4)$$

Where, M_i = de-fuzzified number and l_{w_i}, m_{w_i}, u_{w_i} refers to the TFN numbers and their respective weights in fuzzy scale.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i} \qquad \dots(5)$$

Where, N_i = normalized number derived from de-fuzzified number.

In the very last step of the process, the de-fuzzified weights of all the selected criteria are used to calculate the air pollution index (API) value. It is computed by multiplying each criterion with their respective weights and finally through summation of all the values.

$$API = (CO * WCO) + (O3 * WO3) + (NO2 * WNO2) + (SO2 * WSO2) + (PM10 * WPM10) \qquad \dots(6)$$

There have been numerous studies that have used the FAHP method to solve problems from various knowledge domains and have attempted to assist in risk prediction (Pan 2008, Shaverdi et al. 2014, Mosadeghi et al. 2015, Chou et al. 2019, Liu et al. 2020, Bakir and Atalik 2021, Tripathi et al. 2021, Majumder and Fatma 2024).

3. RESULTS AND DISCUSSIONS

3.1 Assessment using FAHP model

The fuzzy AHP model is a very compact method for finding a solution to a complex problem using multi-criteria, and it is also applicable for API assessment. In this study, the researcher has applied fuzzy AHP to create an air pollution index by integrating five air pollution elements as criteria to identify air pollution levels across the state of Jharkhand. Fuzzy AHP takes expert opinion, advice and knowledge into consideration to select the criteria of a complex problem and determine the linguistic terms and their respective TFN values of the criteria based on experience and expertise.

Table 3 Pair-wise comparisons of air pollution parameters

Parameter	O3	NO2	CO	PM 10	SO2
O3	(1,1,1)	(3,4,5)	(4,5,6)	(7,8,9)	(9,9,9)
NO2	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)	(4,5,6)	(7,8,9)
CO	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)	(4,5,6)
PM 10	(1/9,1/8,1/7)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(3,4,5)
SO2	(1/9,1/9,1/9)	(1/9,1/8,1/7)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)

3.1.1 Calculation of pairwise comparison matrix (PCM)

The selection of linguistics and their respective TFN values are assigned to the criteria based by comparing each two criteria at a time and determining the importance of one criteria over another and their respective reciprocal values. This procedure aided the researcher in identifying the most important parameter (i.e. O_3) as well as the least essential parameter (i.e. SO_2) in the calculation of API (Table 3). The PCM was implanted by following equation 1.

3.1.2 Geometric mean calculation of fuzzy PCM

After calculating the pairwise comparison matrix (PCM) following equation 1 mentioned in the methodology section the researcher has calculated the geometric mean using equation 2 and it is presented in Table 4. The geometric mean is calculated for each criterion from PCM and arrayed in a hierarchical manner according to their fuzzy number. Additionally, the total values and their respective reciprocal values are mentioned.

Table 4 Geometric mean of fuzzy PCM

Parameter	Fuzzy Geometric Mean values		
O3	3.76447	4.28225	4.75468
NO2	3.36	2.09128	2.459509
CO	0.83255	1	1.201124
PM 10	0.40659	0.47818	0.568772
SO2	0.21032	0.00014	0.265641
$\Sigma\,\widetilde{r_i}$	8.57393	7.85185	9.249727
$(\Sigma\,\widetilde{r_i})^{-1}$	0.11663	0.12736	0.108111

Table 5 Relative fuzzy weights of parameters

Parameter	Fuzzy weights ($\tilde{W}_i$)		
O3	0.43906	0.54538	0.51403
NO2	0.39189	0.26634	0.2659

CO	0.0971	0.12736	0.12986
PM 10	0.04742	0.0609	0.06149
SO2	0.02453	1.8E-05	0.02872

Table 6 Average weights of parameters

Parameter	Weights (M_i)
O3	0.499
NO2	0.308
CO	0.118
PM 10	0.057
SO2	0.018

Table 5 shows the relative fuzzy weights (Wi) of air pollution parameters obtained using equation 3, and the average fuzzy weights (M_i) calculated by adding the triangular fuzzy weights (TFW) and dividing them by three using equation 4 (Table 6). Equation 5 is used to compute the normalised non-fuzzy weights (N_i) of each parameter.

3.2 Assessment of Air Pollution Index (API)

Jharkhand has a literacy rate of 66.41%, is ranked 34th in the HDI report of 2019, is ranked 26th in per capita income, is ranked 2nd in the Poverty report of 2021, is ranked 19th in GDP, and is ranked 27th in India's sustainable development index. These facts describe the multifaceted challenges that the state is currently experiencing, and the overexploitation of natural resources adds to the misery of this current scenario. Jharkhand is a state with a large reserve of natural resources; however, over-exploitation of these natural resources (e.g., coal, iron ore, bauxite, kyanite, and copper) has caused plenty of challenges in various dimensions, the most concerning of which include water pollution and air pollution.

The API is estimated in this study using five air pollution determinants (CO, O_3, NO_2, SO_2, and PM_{10}). The distribution and fluctuation of these five air pollutants in the Jharkhand district are depicted in Fig. 4. In the O_3 map, Sahibganj district has a very high concentration (0.123223 mol./m2) of ground-level ozone (GLO), whereas the western parts of Latehar and Gumia districts have low concentrations (0.120968 and 0.120939 mol./m^2) of GLO in comparison to the rest of the state. Aside from these locations, other districts with a high concentration of GLO include Dhanbad, Giridih, and Deoghar. Select areas of Dhanbad, Bokaro, Kodarma, and Purbi Singhbum have higher NO_2 concentrations (0.000159, 0.000169, 0.000139, and 0.000178 mol/m^2) than other districts since these areas have a high concentration of urban habitation and transportation mediums. The remainder of the districts, on the other hand, have an average concentration of NO_2. Dhanbad, Giridih, Bokaro, Jamtara, and Deoghar districts have quite high PM10 concentrations (242.52, 221.89, 229.23, 225.30, and 228.10 μg/m^3) due to the position of mineral quarries, coalfields, or their near proximity to mining operations. Ranchi, Paschimi Singhbhum, and Kunti have relatively low PM10 values in the atmosphere (114.90, 90.81, and 127.07 μg/m^3). Some areas of Bokaro, Dhanbad, Purbi Singhbhum, and Saraikela-Kharsawan districts possess elevated concentrations of CO (0.049906, 0.051123, 0.050991, and 0.047872 mol./m^2), while others, such as Gumia, Latehar, and Lohardaga districts, have low concentrations (0.036493, 0.036152, and 0.035781 mol./m^2). In the case of the SO2 concentration map, Purbi Singhbhum, Saraikela-Kharsawan, Dhanbad, and Bokaro show comparatively significant concentrations (0.000440, 0.000371, 0.000299, and 0.000299 mol/m^2) of SO2 in the atmosphere due to massive vehicular emissions in the area, and other districts show an average to low concentration of SO2 in the atmosphere.

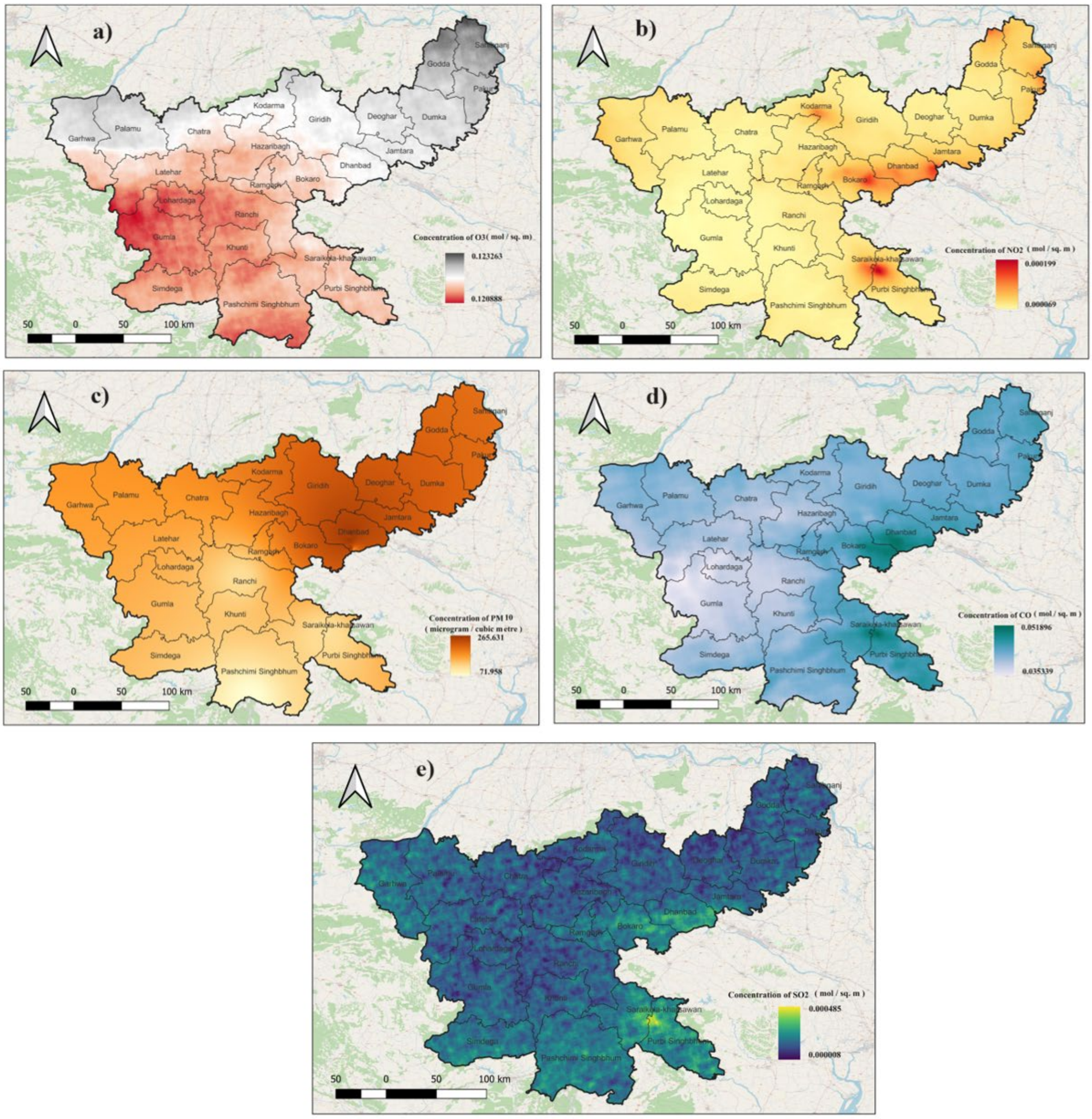


Fig. 4 Concentration of air pollutants across the districts of Jharkhand, (a) O_3, (b)NO_2, (c)CO, (d) PM_{10} and (e) SO_2

Fig. 5 shows the air pollution index (API) map by applying FAHP technique and following the procedure referred in Fig. 3. According to the analyzed index map of air pollution, places such as Dhanbad, Jharia, Giridih, Deoghar and eastern side of Bokaro district are situated on the highest and higher side of API value (14.40, 14.90, 12.51m and 13.07) and these places has very poor quality as well and the report published by CPCB also states that in December and January month, these places had very poor (315) and poor (201) air quality, respectively (Cpcb 2020). On another side, Ranchi, Jamshedpur, Saraikela, Barajamda has low API value (7.54, 6.27, 7.17, and 4.19) and fall under low health risk and the report published by CPCB also confirms the finding by providing data for the December (102, 130, 136, and 136; moderate) and January (106, 135, 125, and 82; moderate to satisfactory), respectively (Cpcb 2020). From the overall point of view all the 5 selected pollutants' concentration is highest in the north eastern part of the state and southern part of the state shows lowest concentration of the selected pollutants. Jharia coal field, Bokaro Coal mine, Koderma mica mine are located in the north eastern zone Jharkhand and their associated polluting factors contributes such high concentration in Jharkhand. Noamundi Iron ore mine, Ghatsila Copper Mine, Chaibasa Bauxite mine, Uranium mine of Jamshedpur and Jadugora are located in the south eastern part of the state though we observe from our mapping that contribution air pollution is comparatively less than the northern mines. Although SO2, CO and NO2 pollutants have high concentration in the allocating southern part of the mining regions though the PM10 concentration is less in the southern part thus it can be concluded that the respective mines take appropriate measures to reduce the concentration of PM10.

Aerosols concentration had been studied and result depicts high aerosols was observed in north and eastern part of Jharkhand while low aerosols were observed along the south-western part of the state which is similar to this study (Bandyopadhyay et al., 2021). In another research it is observed that "Air Quality Health Index" is much critical in the south-western part of the study (Panda et al., 2019).

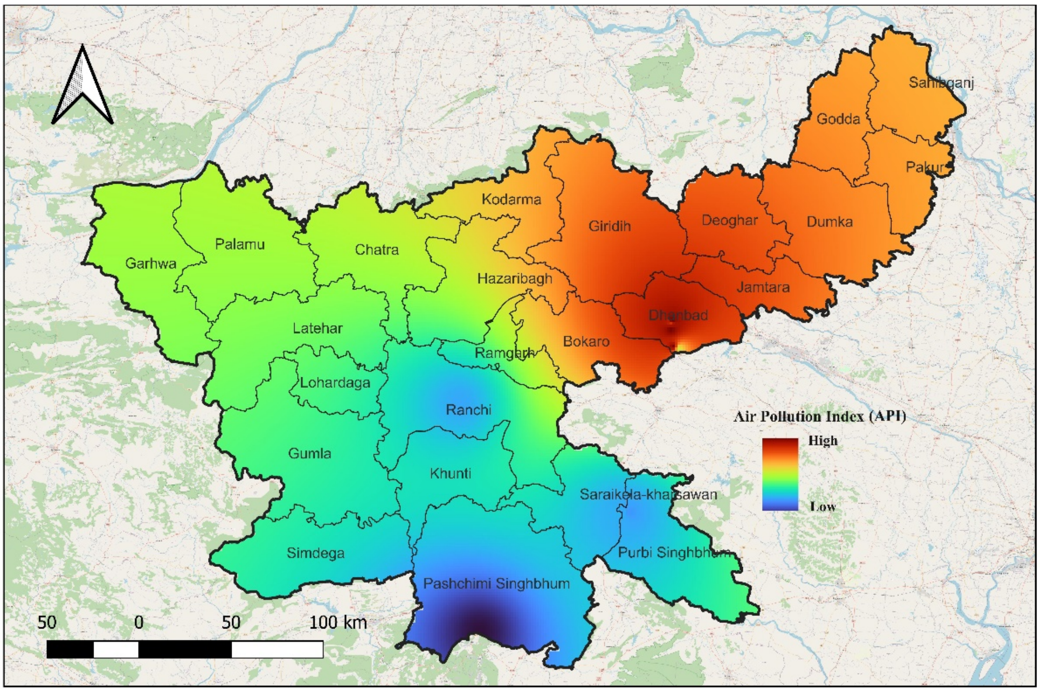


Fig. 5 Air pollution index (API) map of Jharkhand state

3.3 Relationship between TROPOMI AOD and PM_{10} concentration

Fig. 6 presents the relationship between a selected parameter of API (i.e. PM_{10}) and TROPOMI AOD for different months in a year. According to the relationship, it is evident that the PM_{10} holds a significant association with TROPOMI AOD during average monthly data from January to June with R^2 values of 0.0625, 0.1243, and 0.2858, respectively. Here, R^2 is the "coefficient of determination" and its value always falls between 0 and 1. R^2 is applied to measure the extent of the dependent variable that can be explained by the independent variable in a relationship.

Fig. 7 shows the relationship between PM_{10} and TROPOMI AOD from July month to December month and among these six months, October and November (R^2 = 0.176 and 0.0299) signifies a good relationship between PM_{10} and TROPOMI AOD. In the months of January and February, the concentration of PM_{10} particles in the atmosphere stays very high to the extent that it reaches a maximum value of 450 μg/m^3 approximately. With increasing PM_{10} the AOD in the atmosphere of Jharkhand state increases as well. In March the association between PM_{10} and TROPOMI AOD is very low and more or less it stays neutral. April and May do provide a very good positive relationship (R^2 = 0.1243 and 0.2858) however, the availability of PM_{10} data from the ground station is near to none hence, the small number of samples cannot explain the actual scenario of the relationship. In the month of June, July, and August the association between PM_{10} and TROPOMI AOD is weak negative (i.e. R^2 = 0.0782, 0.0066, and 0.05961) which signifies the anomaly between the satellite AOD data and ground station data. September and December show no significant association (R^2 = 0.0021 and 0.0007) between PM_{10} and TROPOMI AOD to the point where it can be considered as no association. Additionally, October and November month shows a small positive trend in the relationship between the two variables.

Fig. 8 shows the seasonal concentration of AOD and PM_{10} and presents their relationship as well. For the winter season, the trend line shows a weak negative relationship (R2 = 0.0194) between the two variables in the Jharkhand district. However, during the summer season, the concentration of both TROPOMI AOD and PM_{10} in the atmosphere slightly increases (R^2 = 0.0305) and in the monsoon season, it stays neutral explaining no significant association and variance between the two variables.

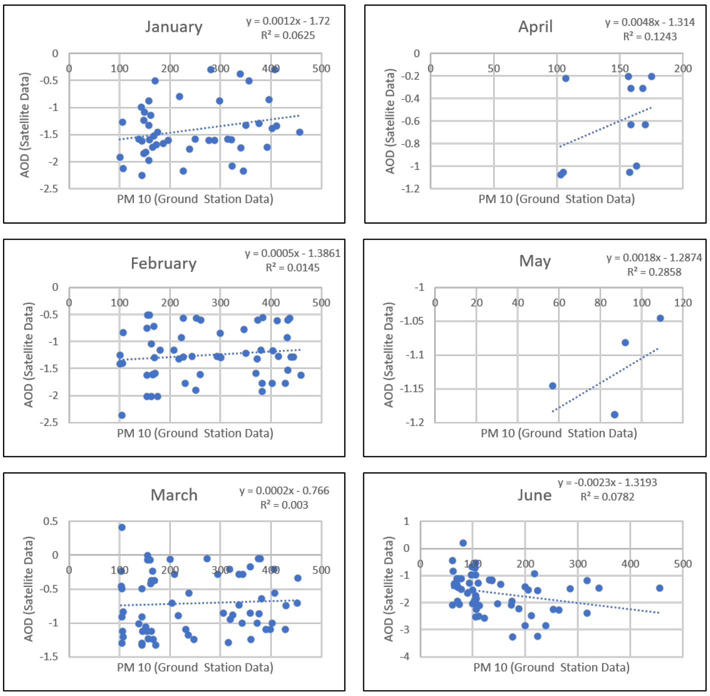


Fig. 6 Correlation between AOD and PM_{10} from January to June month

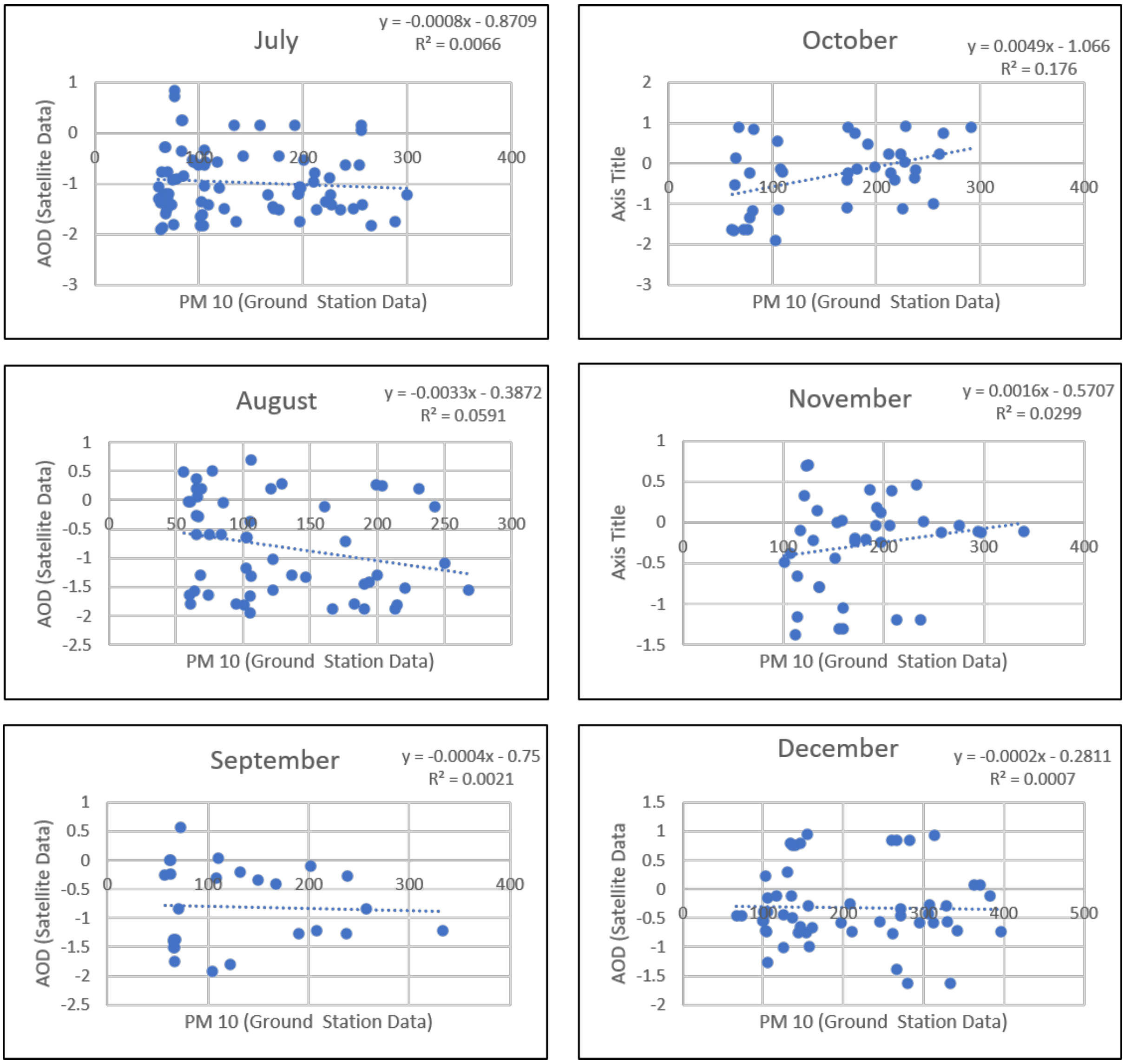


Fig. 7 Correlation between AOD and PM_{10} from July to December month

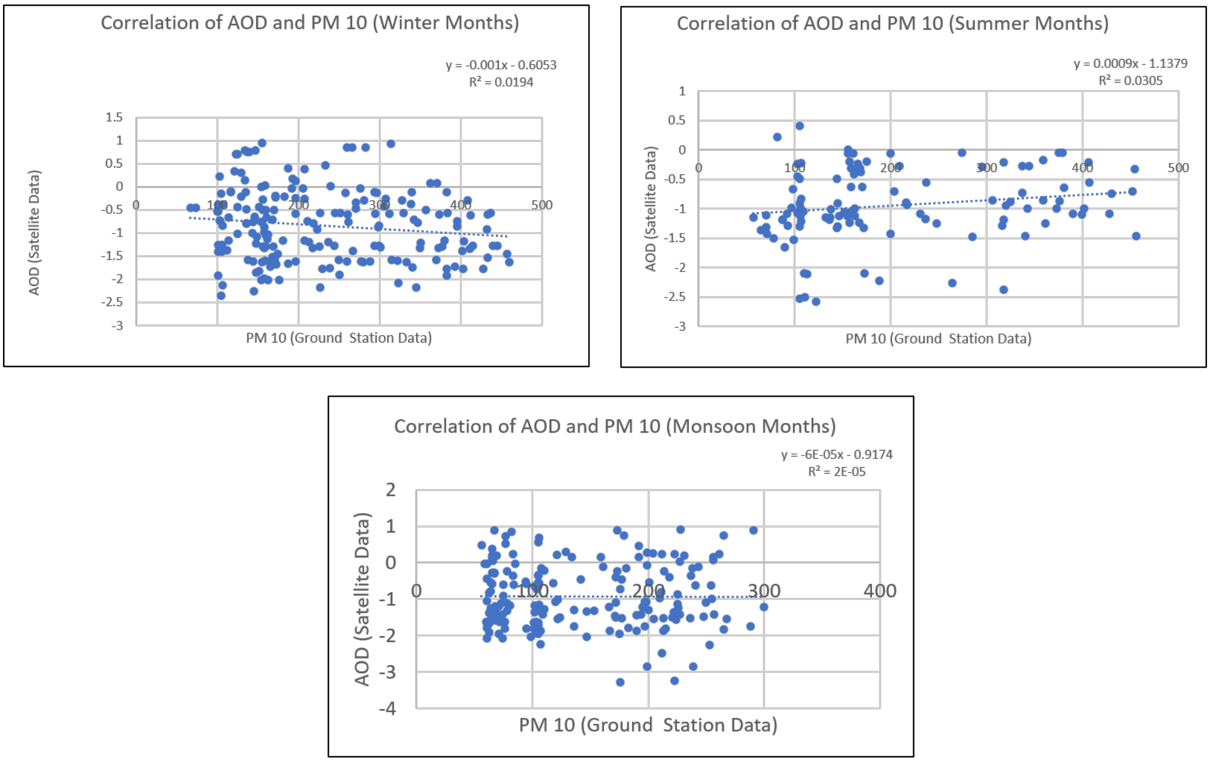


Fig. 8 Seasonal correlation between AOD and PM_{10}

There are some significant factors temperature, relative humidity, the blowing direction of winds as well as wind speed influencing the correlation of AOD and PM_{10} which might responsible for weak correlations (Stirnberg et al., 2018; Kong et al., 2016). Low wind speeds show strong agreement between AOD and PM_{10} and vice versa. The researchers have not incorporated the temperature, relative humidity in this study which are the limitation of this study apart from that satellite data accuracy is another limitation of the study. $PM_{2.5}$ data must also be incorporated and correlated with AOD but due to absence of availability of $PM_{2.5}$ data the researcher fails to incorporate it.

Being the region is mines, industries dominancy the region is likely to prone air pollution and there is need to check the pollution by incorporating appropriate planning strategies. Apart from the pollution measures adopted by management companies, local authorities, pollution control board of the state government and central government of India should incorporate appropriate measure to mitigate of reduce the vulnerability of the health risk of the local residents in sensitive areas. There are some suggestive measures that could be incorporated like SPM concentration could be reduced by imposing restriction of the overloading trucks, regular cleaning of roads, regular spraying water using effective advance sprinkling methods, regular maintaining and repairing of roads, applying of binding agent on the unpaved roads.

Greenbelts must be constructed around the mining areas, the industries and other sensitive polluting sources. "Greenbelt" is a model of mass of pollutant-tolerant tree plantation incorporates to mitigate the air pollution by absorbing, intercepting and filtering pollutants which was developed by Kapoor and Gupta (1984) incorporating distance from the pollution sources, height and width of the green belts. *Butea monosperma, Ficus infectoria, Anthocephalus cadamba* are some suggested plant species that can planted in greenbelts to reduce SPM pollution (Chaulya et al., 2003).

4. CONCLUSIONS

In this study, the amount of air pollution in the Indian state of Jharkhand, a region known for its natural resource mining, was examined using a relatively new methodology for air pollution assessment. The goal of this study is to address the issue of elevated levels of particulate matter (PM10) and PM2.5 in the air, which are caused by dust deposition from nearby mining operations. Data on the five main air pollution parameters (CO, O3, NO2, SO2, and PM10) were gathered, and API was computed using the combination of the five parameters in order to create a more thorough analysis of air pollution. The API presents a usually reliable evaluation of Jharkhand's air pollution and incorporates all the significant factors that contribute to it in the study area. Researchers can identify areas with high air pollution levels and associated threats to human health in the area with the aid of the air pollution evaluation. The API (i.e., using FAHP) showed a larger percentage of weight in O3 and NO2 pollutants in the mining pockets dispersed around the state, despite PM10 being the most problematic pollutant in the state of Jharkhand. Because mining activity is concentrated in the northeastern region of the state, the results of the API show that the region has a high concentration of API and a low concentration in the southern region. The association between TROPOMI AOD and PM10 concentration on a monthly and seasonal basis is also shown in the data. The concentration of PM10 particles in the atmosphere and the TROPOMI AOD presents a mild to moderately positive association and in contrast, a negative correlation was observed for June, August, December, and the winter season). This study used a novel approach to evaluate air pollution in Jharkhand by taking into account the assessment of AOD in relation to other air pollutants. The findings of this study can be utilized in various fields to promote sustainable mining practices, for example, strict enforcement of environmental regulations (in cases of emission, dust control, and waste management), holding mining companies accountable for their share of environmental degradation and health impacts, incentives for mining companies that incorporate eco-friendly technologies, and investment in healthcare facilities to address issues related to air pollution except for these major implications some other broader implications also include sustainable extraction of mineral resources, usage of green energy, etc. Lastly, it can be concluded that this study only incorporated one of the most used MCDM methods (i.e., FAHP) which can be improved in the future by adding a machine learning technique as an extra edge to AQI calculation. Moreover, this study could have been more accurate if real-time in-situ sensor data can be utilized in the future to calculate and predict air quality in mining areas of India.

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