Identification and characterization the sources of aerosols over Jharkhand state and surrounding areas, India using AHP model

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ABSTRACT

The Aerosol Optical Depth (AOD) has measured using remote sensing and GIS methods, with MODIS data collected in Jharkhand from 2011 to 2017. The state’s eastern and northern borders have greater aerosol loadings (AOD: >0.5) while the southern and western parts have lower aerosol loadings (AOD: <0.3). Primary, secondary, tertiary, and quaternary aerosol sources have been identified and categorized using the Analytic Hierarchical Process (AHP). Only 1.29% of the study area, which still emits the most aerosols, is covered by primary sources. Industrial zones, mining regions, thermal power plants, cement industries, high road density, and stone crushers are found in many locations throughout the country. Secondary sources of aerosols account for 5.23% of the study and are located near the main sources. The quaternary (54.08%) and tertiary (39.4%) aerosol sources mainly covered the Southern, Western, and North-Western portions of the state, which is enveloped by a heavily vegetated region. AOD, sources of aerosols, wind direction, and velocity were examined here. There were non-separable connections in this area and also AOD distribution is connected to aerosol sources, wind direction, and wind velocity. Finally, it employs the AOD values to identify different aerosol kinds and source heterogeneity to elucidate their influence.

ARTICLE HISTORY

Received 21 January 2021
Accepted 23 June 2021

KEYWORDS

Sources of aerosol; aerosol optical depth; remote sensing; analytic hierarchical process; wind direction; wind velocity

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1. Introduction

Aerosols are a suspension of fine solid or liquid particles in the atmosphere (Tomasi and Lupi 2017). Size of such aerosol particles may vary from a few nanometers to hundreds of microns depending upon nature of their sources (Sayer et al. 2014) such as dust bore of wind, biogenic aerosol, volcanic debris, sea spray, and also anthropogenic activities like nitrates and sulfates from the industrial emissions, waste and biomass burning, fossil fuel combustion and wind-forced into the mineral dust has mobilized in these areas were exploited for the agricultural activities (Banerjee et al. 2015; Singh et al. 2017; Tomasi and Lupi 2017). Although most aerosols reflect sunlight, some also absorb it. An aerosol’s effect on light depends primarily on the composition and colour of the particles. Broadly, bright-colored particles tend to reflect radiation in all directions and back towards space whereas darker aerosols can absorb significant amounts of light (NASA 2017c). The water and carbon exchange of various plants leads to absorb incoming solar radiation and aerosols scattering and also fluctuating the balance of diffuse radiation (Steiner et al. 2013). Most of the particles have been affected by cloud processes and it could change into the cycle of precipitations (Kaufman et al. 2005). Previous studies have been shown the adversarial influence of aerosols on it reflectivity, global climate and also the human health (Correia et al. 2013; Zheng et al. 2015; Fang et al. 2016; Liu et al. 2017). Internationally the proportion of all those components are rising fast due to the effect of vehicular pollution, rapid urbanization, industrialization (Karagulian et al. 2015).

The regional environment and climate are closely related to atmospheric aerosol particles (Chen et al. 2016; Mao 2016; Xu et al. 2017; Chauhan and Singh 2020; Singh et al., 2021). The studies of toxicology and epidemiology have been shown that the overexposure to a very high concentration and increase the air pollution and will occurrence of respiratory and cardiovascular diseases (Jain et al. 2017; Wang et al. 2017). Preceding review of the research work it is observed that the atmospheric elements have varied both in physical and chemical properties (Yuan et al. 2011; Mao et al. 2014; Chen et al. 2019) and originate from various natural and anthropogenic sources (Yuan et al. 2014; Winiger et al. 2015; Roth et al. 2016). The major sources of atmospheric component could be a crucial necessity for the ecosystem health, nutrient replenishment, but the various types of material have negative impacts, with excessive nitrogen loads and acid deposition (Fowler et al. 2009). But the evidence of air pollution and interrelated responses from the extra-terrestrial material have return to atmosphere. The major emission source of the terrestrial biosphere is biogenic volatile organic compounds (VOCs), it responds to the atmosphere to form a secondary organic aerosol (SOA). According to (Guenther et al. 2006), biogenic sources from the global VOC emissions more than two-thirds were estimated, and also biogenic SOA is a major provider to the worldwide aerosol burden (Tsiganidis and Kanakidou 2007). Particularly ozone and anthropogenic pollution may affect the processes of SOA construction from the biogenic VOCs through changing the number of components of the biogenic emissions and comebacks and leads to stress of plants (Carslaw et al. 2010). Thorough the knowledge of aerosol, it is found that various chemical physiognomies and the emission sources play a vital role in the climate and also human health. The factor analysis enrichment is
to determine the emission sources, most of the aerosol particles are estimated (Singh et al. 2004; Chen et al. 2017; 2019; Singh and Chauhan 2020. This is significant for monitoring and reducing the suspended material emissions and pollutants absorption (Fuqiang et al. 2017; Singh et al. 2017; Arif et al. 2021). The AOD values gave information on the aerosol loading, it has been used to describe the spectral dependence of the aerosol particles, and the values will provide the total column absorbing aerosol contained by the ultraviolet bands. (Al-Salihi 2018).

Considerably many research of air pollution over India were motivated in connections with the particles both chemical and morphological ingredients of their particular sources for a selected site. This studies have been concentrated on the cities of India. For Example, the development of the particulate material speciation outlines for major sources in six megacities of India like Delhi, Chennai, Mumbai, Bengaluru, Kanpur, and Pune are reported in this article (Patil et al. 2013).

Massey et al. (2013) has been analyzed the semi-arid region of Indian rural residential environment to relate their metal toxicity concentrations of particulate matter. During the northern central portion of India rainy, winter and summer periods, it has measured the indoor-outdoor environs of rural backgrounds and observed concentration of Particulate Matter (PM1, PM10, PM5.0, and PM2.5) i.e. trace metals (Cd, Fe, Cu, Ni, Cr, Pb, and Mn) of the environment (Massey et al. 2013). Giri et al. (2013), dedicated the composition and sources of carbon-based tracers into the aerosol elements of the industrial site of Central India. It has reported circulations, absorptions, and the sources of organic composites (such as plasticizers, carboxylic acids, alkanes, carbonyl compounds, PAHs, alcohols, and biomarkers) of a PM on ambient of atmosphere of industrial area of the Central India (such as Chhattisgarh and Raipur a coal mega-burning area) (Giri et al. 2013).

In India urban site of Delhi has been found the sources of chemical compositions of PM10 (Sharma et al. 2014). The average concentrations of two particles are Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM) has been analyzed in four-station i.e. Agra city, viz.: (Taj, Itmad-Ud-Daula, Nunhai and Rambagh) has been found in transported pollutants over the Agra area, Weighted Potential Source Contribution Function (WPSCF) for the both of SPM and RSPM (Gogikar and Tyagi 2016).

The main objectives of this research paper are to identify the potential sources of aerosols over Jharkhand state and surrounding areas. This study observed the sources of aerosols and their characteristics using different remote sensed and ground verified data. Finally, finding the interrelationship among aerosol optical depth, sources of aerosols, wind direction and wind velocity over the study area for investigating their contribution to the spatial pattern of aerosol optical depth (AOD) and its characters. The research work results will expectantly endorse our existing sympathetic origins and differences of local pollutants, and provide the policy-makers primary and secondary data to express a rational policy for pollution control.
2. Study area

Jharkhand is situated at the heart of Chotanagpur Plateau towards North-West of Kolkata about 160 km radial distance and about 770 km in South-East of Delhi. It is confined within 22°00’-24°37’North (latitude) and 83°15’-87°01’ (longitude) East (Figure 1). The physio-geographical area 79,714 sq. km, which is 2.4% of the countries in a total of the geographic area (Bhatt 2002). It consists of the area that is mostly tribal people in origin. It lies predominantly of the Chotanagpur plateau, in the part of Deccan Biogeographic area. The landscape pattern of the State is rippled and occupied of hillocks and flat terrain. A 50 km buffer zone from the boundary of Jharkhand towards the east (West Bengal) and towards the south (Odisha) is considered for this study. We also focussed on four typical areas of Jharkhand (Ranchi, Hazaribagh, Dhanbad and Jamshedpur) for characterization of sources of aerosol in the perspective of wind direction, wind velocity and the spatial distribution of AOD. These are the highly developed (industrial) areas and are probably the major contributors to air pollution over the entire state.

3. Materials and methods

3.1. Data used

The present study for retrieving the AOD, we have used the Moderate Resolution Imaging Spectroradiometer (MODIS) Product. The MODIS Terra satellite has been launched on 18 December 1999 onboard the Terra platform as portion of the NASA’s Earth Observing System (EOS) mission. The MODIS by its 2330-km observation strip provides constant regular worldwide coverage (Chu et al. 2002; Dobber et al. 2006). The MODIS sensor has been used to measure brightness in the visible to
Figure 2. Most important parameters for the identification of sources of aerosols: (a) spatial distribution of average NDVI; (b) forest fire (constant occurrence from 2011-2017); (c) cement industries; (d) thermal power plants; (e) mines; (f) highly polluting industries; (g) road density; and (h) population density over Jharkhand state and surrounding areas (Census of India 2011).
infrared area with a spectral range of 0.4 to 14.4 m for land, atmospheric, and ocean applications (Esaias et al. 1998). The Terra MODIS Collection 6 Level 2 aerosol data (MOD04_L2), it has spatial resolution is 3 km are covered and it obtained from the NASA’s Atmosphere Archive and Distribution System (NASA 2017a) for the period 2011-2017. The different remote sensing and ground data were used for the identification of the potential sources of aerosols over the study area, such as cement industries, thermal power plants (TPPs), highly polluted industries (HPIs), mines (Jharkhand State Pollution Control Board, 2017), forest fire (NASA 2017b) road density (Openstreetmap 2017), Normalized Difference Vegetation Index (NDVI) (Rouse et al. 1973), and also population density (Census of India 2011). Wind data from Automatic Weather Station (AWS), Jharkhand Space Applications Center (Jharkhand Space Application Center’s (JSAC) and Automatic and Weather Station (AWS) Data 2017) has been used during the satellite overpass (± 1 hour) of MODIS-Terra for analyzing wind rose diagram to get a picture of wind direction and speed variation as well as the spatial pattern of wind behaviour over the study area during the period of the study (as the wind data available from January 2017 onward, we have used its data throughout the year, 2017). Appendix 1 has a detailed description of all of the datasets utilized in this study.

3.2. Methodology

The aerosol products of the MODIS sensor have to monitor the surrounding aerosol stacking and other properties of aerosol over the cloud-free, ocean, and land surfaces. Using different spectral and spatial observations provided by MODIS, multiple algorithms are applied to retrieve aerosol properties over diverse surfaces of the study area. The primary data product from all of these is the AOD at a particular wavelength is 550 nm (Remer et al. 2006). In this study, AOD is derived from the MODIS Terra datasets (MOD04_L2) using the AOD_550_Dark_Target_Deep_Blue_Combined algorithm.
(Sayer et al. 2014). The combined DT-DB AOD was found to have higher precision for coarse-dominated airborne conditions, when the uniqueness between DT furthermore, DB is most noteworthy (Mhawish et al. 2017). The 550 nm spectral information extracted from MODIS Terra aerosol dataset (MOD04_L2), then rectify, masking and changed the layout using the ENVI software. From these extracted AODs an average value during the period 2011-2017 has been generated for retrieving the spatial patterns of AOD over the study area using ERDAS IMAGINE 2014 software. The Spatial distribution of Cement Industries, Thermal Power Plants (TPPs), Mines, Highly Polluted industries, Forest Fire, Road density, Normalized Difference Vegetation Index (NDVI) and population density has used in the AHP (Analytic Hierarchy Process) Model (Saaty 1990) for identification of the sources of aerosols. Step by step followed methods may be found in the Appendix 2. Wind direction and wind velocity have been used for correlating the sources of aerosols and the spatial distribution of aerosols (Appendix 1). Figure 4 depicted the flowchart of this entire study.

4. Results and discussion

4.1. Sources of aerosol over Jharkhand and surrounding areas

Aerosols are highly variable in time and space, and the identification sources of the aerosols are very deceptive. There are various natural and anthropogenic activities are responsible for the emission of aerosols. The AHP model is used to identify the sources of aerosols over Jharkhand state and surrounding areas using geolocation information of the cement industries, thermal power plants, mining, other highly polluting industries, forest fire, road density, NDVI and population density in space-time scale. It has been categorized the sources of aerosols into four categories, those are mainly primary sources, secondary sources, tertiary sources and also the quaternary sources of aerosols. These all categories represent the quantitative responsibility for the emission of aerosols over the study area. The primary sources of aerosols over Jharkhand and surrounding area occurred in the different places over the study area. In the north-eastern part Godda, Sahibganj, Pakur, Dumka, and Murshidabad district covered the primary sources which are generated by National Thermal Power Corporation (NTPC), highly polluting industries, Coal mines, stone crusher, and brick factory beside the Ganga River, etc. Another aspect of this area is covered by low vegetation (average NDVI < 0.4) across the whole area, high population density (>770 per square km). The secondary sources of aerosols situated over the maximum part of this area, namely Pakur, Farakka, and surrounding areas. In the middle-eastern portion of the study area is covered with massive primary and secondary sources of aerosols like Bokaro, Dhanbad, Jamtara, Giridih, Bardhaman etc. where the primary industrial zones overlap. Like a collection of cement industries, coexist with thermal power plants, steel plants, coal mining, brick kilns beside the Damodar, Barakar River, etc. The maximum emission of aerosol occurred in this region. Dhanbad and its surrounding areas contain a lot of coal mines and high population density (>770 per square km), thermal power plants, high road density and nearest to the cement industries of Asansol-Durgapur region.
The middle section of the study area has covered by primary, secondary and tertiary sources of aerosols. This area covered by Ranchi, Ramgarh, Hazaribagh, Bokaro and the southern portion of Kodarma, Chatra, the western part of Dhanbad district. In this region lot of cement industries, thermal power plants, high road density (>17 km per square km), and other highly polluting industries are located, which are generally responsible for aerosol generation over this area (Figure 5).
The south-eastern part also covered by the primary sources of aerosol over Jharkhand and the surrounding areas. This area covered by mines and thermal power plants, high road density, cement industry, and other highly polluting industries. The maximum emission of aerosol in this area occurred from the Jamshedpur region. The southern and western part of the study area are revealed quaternary sources of aerosol. All of these area is characterized by dense vegetation cover, low road density as well as low population density and lack of highly polluting industrial activity. Though some part of Angul, Baleswar, Debagarh, Jharsuguda, Kendujhar, Mayurbhanj, Sambalpur, Sundargarh of Odisha and West Singhbhum district of Jharkhand depicted the primary sources of aerosols. In this area, a lot of Iron mines situated, from which huge amount of aerosols emitted though this area is covered by dense vegetation (NDVI >0.5), low population (<270 per square km) and low road density (<3 km per square km).

4.2. Evaluation of AOD over Jharkhand state

Figure 6 displays the geographical distribution of AOD over Jharkhand state during the period 2011-2017. The highest AOD (0.659) observed over the Sahibganj and the surrounding area, which is located in the most densely populated and nearest to the Eastern Coal Limited (ECL), Rajmahal Coal Mines (RCM) and many others mines, nearest to the forest fire-prone area. It is observed that high concentration of AOD due to presence of stone crushers, brick kilns beside the Ganga River, and nearest to National Thermal Power Corporation (NTPC), Kahalgaon Power Station which is situated in Bihar near the boundary of Jharkhand (Sahibganj district). The high level of AOD was
associated with the suspended particle of aerosols and the attributable to huge extents of the airborne dust from the various anthropogenic sources of aerosols. The Lowest AOD (0.218) observed over the middle-western section of the study which occurred in the Gumla District. In this area vegetation cover is high (NDVI values >0.5), less population density (< 277 per square km) and there is no presence of any mining activity, thermal power plants, and any other highly polluting industries. And also this area is covered by low road density (<3.5 km per square km), polluting industries.

The high loading of AOD (>0.5) is covered by the northern and eastern boundary of the state. The northern boundary covered by the northern part of Palamu, Chatra, Koderma and Godda district whereas the eastern boundary of the state covered by Sahibganj, east Pakur, southern part of Jamtara, Dhanbad and Bokaro district, east Saraikela-Kharsawan and whole Purbi-Singhbhum district where highly polluting industries, stone crushers, mines, thermal power plants etc. are positioned.

The medium concentration of AOD (0.3 to 0.5) occurred mainly most part of the state like in the middle-northern parts of the state like Giridih, Deogarh, Dumka, Daltonganj, Ranchi, Ramgarh, Laterhar, Garhwa and southern part of Palamu, Chatra, Koderma district. The middle-south part like Khunti, Simdega and norther parts of Paschim Singhbhum district also covered by the medium concentration of aerosols. The lowest concentration of aerosol (AOD < 0.30) were observed mainly in the south-west part of the study area, only Gumla and Lohardaga district where these
areas are surrounded by dense forest (NDVI > 0.5) and absence of highly polluting industries like mining, thermal power plant, cement industries etc.

4.3. Characterization of sources of aerosols

Figure 5 identifies the potential sources of aerosols over the Jharkhand state and its surrounding areas and categorized them into primary, secondary, tertiary and quaternary sources of aerosols. To understand the spatial variation and interrelationship among AOD, sources of aerosols, wind direction and wind velocity for the four selected areas of interest across the entire study area were compared and analysed using overlay analysis technique (Figure 7). Here the study focussed over Ranchi, Hazaribagh, Dhanbad and Jamshedpur areas. It is evident that though the primary and secondary sources of aerosols covered only 1.29% and 5.23% of the total study area respectively, these areas are much more responsible for the emission of high amount of particulate pollutants (Figures 5, 6, 7a-d, 8a-f). In the case of Ranchi and surrounding areas (Figure 7a), the spatial distribution of aerosol loading i.e. AOD is gradually increasing from the south-west (AOD: 0.28) to north-east (AOD: 0.52).
Where the primary and secondary sources of aerosols were observed in the middle and northern parts. In order to understand the interrelationship, we plotted the average wind direction and wind velocity (wind rose) over the Ranchi district (Station Id.- ISRO0968_15F3C8_BDO-D.C. Office-Angara) in the year 2017. It is observed that the annual average wind direction towards north-north-east (resultant vector: 39 degrees; 19%) (Table A5) in which 66.3% wind having a velocity of less than 5 km/hour and 33.7% wind having a velocity of 5-10 km/hour. It is revealed that the spatial pattern of AOD over Ranchi and surrounding areas is driven by the location of major sources of aerosols, wind direction and wind velocity. Because of these, the spatial pattern of AOD was elevated towards north-east. In case of Hazaribagh, the spatial patterns of AOD, wind direction and wind velocity are pretty much same to Ranchi. Although the aerosols loading and wind velocity both are slightly much more than Ranchi (Figure 7a-b, 8c) due to presence of highly polluting industries, forest fire, mines and thermal power plants in the southern part of the district etc. Here the aerosol concentration was increasing from the south-west (AOD: 0.36) to north-east (AOD: 0.58) as the average wind direction towards north-north-east (resultant vector: 19 degrees; 91%) (Table A5) in which 19%, 54%, 21%, 6% wind having a velocity of <5 km/hour, 5-10 km/hour, 10-20 km/hour and >20 km/hour respectively. The highest wind speed was observed in this area (Station Id.- ISRO0948_15F3B4_Vinobha Bhave University-Hazaribag) in comparison to others stations over the entire Jharkhand (Figure 3b; Table A5). Because of this the high amount of aerosols were transported as well as elevated towards north-east (Figures 7b, 8c).

But in the case of Dhanbad and Jamshedpur areas (Figures 7c-d, 8a & b, 8d, 8e & f), the spatial pattern is different. It was observed in Dhanbad and surrounding areas (Station Id.- ISRO0930_15F3A2_DESE-ISM Dhanbad), the wind is blowing in the reverse direction of Ranchi and Hazaribagh, towards the west (resultant vector: 250 degrees; 26%) (Table A5) in which 96% wind having a velocity of less than 5 km/hour and 4% wind having a velocity of 5-10 km/hour. That’s why a little bit less aerosols were

Figure 8. Sources of Aerosols over Jharkhand state: (a) Kotshila Steel Ltd; (b) Dhanbad Road; (c) Brick Kiln in Hazaribagh; (d) & (e) Steel Industries of Jamshedpur; (f) Dhansour Coal Mines (a, c, d, e and f are the primary sources of aerosols and b is the secondary sources of aerosols.
transported over this area. Although there is an indication that the concentration of aerosols decreasing from the south-east (AOD: 0.6) to north-west (AOD: 0.46). It is observed that the primary, secondary and tertiary sources covered most of the part, where primary and secondary sources occurred like a belt from east to west in the southern part of Dhanbad. Whereas in case of Jamshedpur the spatial distribution of aerosol loading observed high (AOD: 0.56) in eastern part which surrounded by primary and secondary sources of aerosols and low (AOD: 0.36) in the south-western part of Jamshedpur which covered by dense vegetation. It is found that, in two ground stations are installed for monitoring wind characteristic. In which one station in the Jamshedpur (Station Id.- ISRO0985_15F3D9_BDO-D.C_Office-Kharsawan). Here the annual average wind direction is towards south-south-west (resultant vector: 205 degrees; 26%) (Table A5) in which 75% wind having a velocity of less than 5 km/hour and 25% wind having a velocity of 5-10 km/hour. It is depicted that aerosols were being transported towards south-south-west from Jamshedpur areas. Though the percentage of transportation is not too much due to lower wind speed. It is also observed a reverse pattern (stretched towards south-east in comparison to south-eastern part of Jamshedpur) of aerosol concentration and wind direction in the north-west part of Jamshedpur area (Station Id.- ISRO0982_15F3D6_BDO-Arki). From where 24% winds were directed towards south-east for which the AOD swelled up towards south-east in this part. Therefore, it is depicted that the spatial distribution patterns of aerosols are directly driven by the sources of aerosols, wind direction and velocity.

5. Conclusions

The geographical patterns of AOD over Jharkhand state using Terra MODIS Collection 6 Level 2 aerosol data (MOD04_L2) with a 3 km spatial resolution, retrieval algorithm: AOD_550_Dark_Target_Deep_Blue_Combined. Analytic Hierarchical Process (AHP) was applied to delineate the potential source of aerosol and categorized them into four classes, viz., (i) primary, (ii) secondary, (iii) tertiary and (iv) quaternary. In order to understand the characteristics of sources of aerosols and their contribution to the emission of aerosols and transportation from one place to another, the study focussed on the average spatial distribution of AOD from 2011 to 2017 and wind behaviour. A total of 14760 collocated AWS observations were obtained in the study period, 2017 (as the data is available 2017 onward) and are evaluated wind characteristics from 18 ground station over the entire Jharkhand state against overpass time (± 1 hour) of MODIS Terra satellite. The major findings are:

1. The high aerosols loadings (AOD: >0.5) were observed in the northern and eastern boundary of Jharkhand state whereas the low aerosols loading (AOD: <0.3) were observed in the south-western part of the state.
2. The primary sources of aerosols located (1.29% of the study area) in the north-eastern, mid-eastern, and south-eastern and southern parts of the study area, which is mostly covered by industrial zones and thermal power plants, mining areas, cement industries, stone crushers, etc. whereas the secondary sources of aerosols mostly found (5.23% of the study area) around primary sources which
covered by low vegetation density, high population density, brick kilns and along with high road density etc.

3. The tertiary (39.4% of the study area), and quaternary (54.08% of the study area) sources of aerosols mostly covered the Southern, Western and North-Western part of the state, which is enshrouded by densely vegetated area and less population density.

4. Spatial patterns of both sources of aerosols and aerosol loading (AOD) are analogous. The primary and secondary sources of aerosols are overlapped by the high concentration of AOD.

5. Finally, the overlay analysis was employed to determine and characterization of Sources of aerosols over the Jharkhand state and to investigate the spatial heterogeneity in their influence depending on their origins.

6. In order to understand the interrelationship among AOD, sources of aerosols, wind direction and velocity across the entire study area were compared and analyzed. Non-separable correlations were observed among these variables in this region.

Acknowledgements

The Authors extend their thanks to the Deanship of Scientific Research at King Khalid University for funding this work through the large research groups under grant number RGP. 2/173/42.

Disclosure statement

The authors declare that they have no conflict of interests.

Ethical approval and consent to participate

Not applicable

Consent for publication

All the co-authors agreed to publish the manuscript.

Authors contributions

Jatisankar Bandyopadhyay: Supervision, Resources, Investigation, Writing - review & editing

Lal Mohammad: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing, and, Software; Ismail Mondal: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing; Kunal Kanti Maiti and Nadhir Al-Ansari, Khaled Mohamed Khedher: Visualization, Investigation, Writing - review & editing; Quoc Bao Pham: Supervision, Visualization, Writing - review & editing.

Availability of data and materials

All the data and materials related to the manuscript are published with the paper, and available from the author [Quoc Bao Pham, email: phambaoquoc@tdmu.edu.vn], upon request.
Funding

This research work was supported by the Deanship of Scientific Research at King Khalid University under Grant number RGP 2/173/42.

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Appendix 1

A1. Data used for identification of sources of aerosols

The identification of potential sources of an aerosol is very tricky. Because the presence of aerosol does not only depend on the sources, it also depends on the wind direction and wind velocity. We have considered the 50 km buffer zones from the boundary of this study area towards East (West Bengal) and South (Odisha). In this present study, we have considered eight criteria or the parameters for the detection of the potential sources of aerosols. Those are Normalized Difference Vegetation Index (NDVI), Forest Fire, Cement Industries, Thermal Power Plants (TPPs), Mines, Highly Polluted industries, Road Density, and Population density respectively.

A1.1. Remote sensing data

A1.1.1. Normalized difference vegetation index (NDVI)

The NDVI index has calculated using Erdas Imagine 2014 software to analyze and demonstrates the vegetation distribution pattern of Jharkhand state and surrounding areas. We have used OCM version 2 Normalized Difference Vegetation Index (NDVI) with 1 km spatial resolution for the period 2011-2017. The Normalized Difference Vegetation Index (NDVI) was computed with NIR (OCM2-B8) and Red (OCM2-B6) bands Top of Atmosphere reflectance data:

\[
NDVI = \frac{\rho_{\text{NIR}} - \rho_{\text{R}}} {\rho_{\text{NIR}} + \rho_{\text{R}}}
\]

Where \(\rho\) is the OCM satellite band atmospherically corrected ground reflectance band. OCM2_NDVI products are at 4-byte float value. In the NDVI product, all pixels with values less than or equal to zero were brought to zero to enhance the variation in vegetation more predominantly (NRSC, 2014; Kumar et al. 2014). A total of 136 OCM version 2 NDVI collected and generated an average spatial distribution over the study area. In this study, we have considered NDVI as an important criterion for the identification of the potential sources of aerosols. Maximum area is covered by vegetation or Grassland. We have categorized the vegetation cover into five classes, which are i) Dense Forest (> 0.5), ii) Moderate Forest (0.4 – 0.5), iii) Open Forest (0.3 – 0.4), iv) Grass Land (0.2 – 0.3) and v) Non Forest (< 0.2) (Brown 1997; Mondal and Bandyopadhyay 2014) covered by 17.72%, 34.61%, 17.37%, 17.87% and 12.43% respectively (Figure 2a, Table A1). The Non-Forest area is more responsible for generating the aerosols than the others (He et al. 2016). The maximum non-forest area situated in the middle and middle-north part of the study area. In the middle-east part near the Dhanbad, Asansol, Durgapur and northern part of Purulia are also has the Non-Forest areas, which are the more responsible area for aerosol production. Dense forest occurred in the north-western part like Daltonganj, Netarhat etc. around the Koel river and surrounding areas. Also the south-eastern part like Topra, Barbil, Rourkela i.e. eastern part of South Koel and Brahmani River covered by dense forest.

A1.1.2. Forest fire

The forest fire plays an important role in air pollution as a major contributor to atmospheric gaseous and particulate pollutants (Lazaridis et al. 2008). A large destructive fire that includes particulate matter (PM), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), aldehydes, and semi volatile and volatile organic compounds (VOCs) (Schwela et al. 1999; Sapkota et al. 2005). Forest fire is an unregulated fire happening in the environment. Occasionally, forest fire takings on a higher form and it takes with a long time that firefighting squads to get regulator of the condition. This can affect an enormous SPM, its apprehension to the prescribed burner because they decrease visibility (Lazaridis et al. 2008). We are using the VIIRS and MODIS data to detect and identify the forest fire zone. In this study, we obtained forest fire regarding data of Fire Information for Resource Management System (FIRMS) (Fire Information for Resource Management System (FIRMS), NASA, 2017). We used only those observations (forest fire) occurred during the period 2011-2017 which intersect
the vegetation cover and also overlaps (within 1 km buffer zone) with previous forest fire reports by the Forest Survey of India (Forest fire, Forest Survey of India (FSI), Ministry of Environment, 2017). In this case, north-western part of the study area near Daltonganj, Balumath, Netarhat and Hazaribagh regions took place forest fire massively which are covered by dense forest. The north-east part of the study area also contains few forest fires near Sahibganj, Dumka and western side of Pakur district. In the southern part of the study area, Saranda forest region and also near to the Rourkela, Barbil, Noamundi, Chakradharpur and Topra observed a large number of a forest fire. The south-eastern part, near Baripada, Jhargram occurred some forest fire (Figure 2b). These all sites of forest fire are the major contributor of particulate pollutants.

A1.2. Ground data

A1.2.1. Cement industry

The emission of particulate pollutants from cement industries take a major role in ambient air quality. In this study, we have considered the cement industry as a primary criterion for sources of aerosols. The key environmental matters are related to the cement manufacture, our consumption of raw materials and energy has been using along with emissions to the air (Stajanča and Ėstoková 2012). The polychlorinated dibenzo-p-dioxins and carbon oxides, total organic carbon, dibenzofurans, hydrogen fluoride, hydrogen chloride, and also metals are emitted as well as that (Oguntoke et al. 2020). We obtained the spatial distribution of all the cement industries over the study area from the Jharkhand State Pollution Control Board (Jharkhand State Pollution Control Board 2017) and Google Earth. Then we have plotted all the cement industries on the map for further analysis. We have detected 26 cement industries over Jharkhand state and surrounding areas. Within these, 7 cement industries have already detected by JSPCB in Jharkhand state and another 19 cement industry we have detected from Google Earth. And we have also considered two other thermal power plants of Bihar, which exist nearer to

| Category       | NDVI | Area (Square Km) | Area in Percentage |
|----------------|------|------------------|--------------------|
| Dense Forest   | > 0.5| 22034.17         | 17.72%             |
| Moderate Forest| 0.4 - 0.5| 43020.68       | 34.61%             |
| Open Forest    | 0.3 - 0.4| 21596.28       | 17.37%             |
| Grass Land     | 0.2 - 0.3| 22212.64       | 17.87%             |
| Non Forest     | < 0.2| 15452.98        | 12.43%             |
| Total          |      | 124316.75       | 100.00%            |

A1.2.2. Thermal power plants

The major source of electricity of the maximum developing country around 60% is thermal power plants. The main sources of the air pollution are thermal power plants (TPPs) and its effects on environment segments. The deterioration of air quality is responsible for the effect on the environment, due to a large number of SOx, NOx & SPM are generated (Prasad et al. 2012; Chopra et al. 2017; Singh et al. 2018). The Jharkhand State Pollution Control Board (Jharkhand State Pollution Control Board 2017) already detected 18 thermal power plants over Jharkhand which are responsible for high air pollution. It is found and detected that rest of the 9 thermal power plants from the Google Earth and field verification during this study. And we have also considered two other thermal power plants of Bihar, which exist nearer to
the state boundary of Jharkhand. One is BRBCL (4X250MW) thermal power plant which existed near the north-west part of the state boundary (Palamu) beside the Son River and another is NTPC Kahalgaon power station, which existed near the north-east boundary (Sahibganj). Maximum power plant density observed in the south-east of Jamshedpur area. This area has 5 thermal power plants within a certain distance which exist very intensively beside the Subarnarekha River, which are Usha Martin Ltd. (TPP), Tata Power Ltd. (Jojobera Power Plant), Adhunik Power and Natural Resources, AIA, Divine Vidhyut Limited and Industrial Energy Ltd. Middle part of the study area, which is covered by Dhanbad, Bokaro, Ramgarh, Ranchi, Hazaribagh district, these areas contain 13 power plants beside the Damodar River. And also another power plants located beside the Damodar River in the Bardhaman district, near Dhanbad. Towards north-east of the study area, there are two power plants that are located in the Murshidabad district; one is TPC Limited, Farakka Super Thermal Power Plant and another is Sagardighi Thermal Power Project. These two power plants are very responsible for the air pollution of Jharkhand as wind blow towards Jharkhand from this area. In the middle-north part located a power plant in Kodarma District, which is Koderma thermal power station (Figure 2d).

A1.2.3. Mining

The mining is to remove metals and minerals from the earth’s surface. Mining operations i.e. blasting, collection, drilling, hauling, and transport is the focal sources of air pollution. Coal has left on the ground surface it could apprehend to fire, and also mine fires are very challenging to control. Mine has burned for eras or even centuries to create the main source of air pollution. In the opencast mining, a huge overburden should have to be detached to spread of the mineral deposits. It should be requiring to diggers, transporters, loaders, conveyor belts, etc. that would outcome in an enormous discharge of subtle particulate to the overburden ingredients. Correspondingly, standard operations will also require excavation, transportation, loading, unloading, size reduction, stockpiling, etc. (Ghose1989).

In India, Jharkhand state has the richest areas deposit the minerals and forests. In this state has a large store of coal mines, bauxite, iron ore, mica, and limestone’s and significant assets of kyanite, asbestos, copper, chromite, clay, manganese, dolomite, uranium, etc. We have detected all the mines over Jharkhand and surrounding areas of 50 km buffer zone towards the east (West Bengal) and south (Odisha). Total of 41 mines was observed using Google Earth and field visit during this study. Geographically these mines are distributed in a form of different patches. In the southern part near Rourkela, Noamundi, Barbil an intensive collection of mines was observed. Jamshedpur region also covered by lots of mines. The northern middle part towards east-west from Durgapur to Netarhat massive mines were observed. The northeastern part (Sahibganj and Pakur district) also contain an intensive mine (Figure 2e).

A1.2.4. Highly polluting industries

The air pollution is an effect on interior particulates of the earth surface, harmful gasses, organic molecules into the atmosphere, disease and harmful to other living and non-organisms. The air pollutants mainly come from different highly polluting industries. In different industrial sectors in high emissions after are considered through widespread pollutants contingent on the several industrial zones and also above type of technology has been used. In an effort to reduce the morbidity and mortality that can result from exposure to these pollutants (Jharkhand State Pollution Control Board 2017).

The Jharkhand State Pollution Control Board (Jharkhand State Pollution Control Board 2017) already detected 56 of the highly polluting industries over the Jharkhand. They have announced that 17 categories of highly polluting industries in Jharkhand is responsible for environmental degradation. Some of these are very responsible for air pollution. Such as caustic soda; Grasim Industries Ltd. (chemical division) and Captive Power Plant, copper smelter; Hindustan Copper Ltd, distilleries; Ankur Bio-Chem Pvt. Ltd, Dyes & Dye intermediated; Tata Pigments Ltd, which are situated in the Palamu, East Singhbhum, Dhanbad, and Jamshedpur.
district respectively. And already 52 Integrated Iron & Steel Industry has been found to account for particulate pollutants over the Jharkhand and surrounding areas. And we have detected the rest of the industries using the Google Earth and field visit during the study period.

The spatial distributions of the industries are concentrated primarily in two different zones. One is Jamshedpur region where all the industries are located intensively beside the Subarnarekha River and another is the middle-north portion of the study area which is covered by Bokaro, Dhanbad, Ramgarh, Hazaribagh, Chatra districts. All the industries are developed besides the Damodar, Barakar and Mayurakshi River. In the middle-east part of the study area (Asansol and Durgapur Region) also a major colony which is much more responsible for the particulate pollutants over the study area. Whereas the highly polluting industries are observed in the northern part of Ranchi and Hazaribagh district are also a primary contributor of aerosol over the study area (Figure 2f).

A1.2.5. Road density
In this 21st-century rapid urbanization growths, the large number of motor vehicles are inflicting a severe effect on environment system and human life. Air mass mainly effects on transport sector due to high intensive pollution (Shrivastava et al. 2013). The major impact of environmental issues is too significant in the transport network system, the high energy and burns most of the world's petroleum. Now the whole world fetching global warming through the emission of carbon dioxide (EIT, 2017; Zheng et al. 2020). The road is another important parameter for the detection of sources of aerosols. Transportation is the main source of air pollution in city centres and population centres. In the case of rural area haul, roads are more responsible for the generation of suspended particulate matter. In this study, we have collected the road map of the Jharkhand and surrounding areas from the OpenStreetMap (OSM). The OSM is a portable satellite navigation device that has been used for the availability of map information. After rasterization (using 1000 meters’ search radius) and reclassification, we have categorized according to the road density. We found the maximum road density is 22.94 km/Sq in the major towns like Ranchi, Dhanbad, Jamshedpur, Hazaribagh of Jharkhand, Asansol, Durgapur of West Bengal and Rourkela of Odisha (Figure 2g). All of these are coincide with the various industries and high population density fields.

A1.2.6. Population density
Population density is the fundamental amplifier of air pollution. The population growth rate is an important factor in worsening air quality. Now a day the world’s air pollution continuously increasing due to different anthropogenic activities. In this study, we have used population density as a considerable criterion for the detection of the potential sources of aerosols. We obtained population density data of 2011 (Census of India 2011) and categorized the entire study area on the basis of population density. The high dense populated categories are greater than the 770 population per square km. This category covered by Dhanbad, Bardhaman and Murshidabad district which are situated towards the North-East Part of the Study area. The low dense populated category is less than 168 population per square km. This category covered by the South-West part of the study area like Simdega district of Jharkhand and Sambalpur of Odisha. The overall distribution of population density can be subdivided into three categories High, Medium and Low. The highly populated districts are Dhanbad, Bokaro, Bardhaman, Murshidabad, Ramgarh, Bokaro, East Singhbhum districts, which have greater than 543 Population per square km. The medium populated district is Ranchi, Koderma, Giridih, Godda, Palamu, Sarikela-Kharsawan, Pakur, Sahibganj district of Jharkhand and Purulia, Bankura district of West Bengal, which have 277 to 543 population per square km (Figure 2h). And the less populated districts are situated towards south-west of the study area. This area covered by Latehar, Lohardaga, Gumla, Simdega, Khunti, Chatra West Singhbhum districts of Jharkhand and Sundargarh, Sambalpur, Kendujhar, Mayurbhanj District of Odisha (Table A2).
Characterization of sources of aerosols over Jharkhand state and surrounding areas is very tricky. In order to understand the characteristics of sources of aerosols and their contribution to the emission of aerosols and transportation from one place to another, we focussed on the average spatial distribution of AOD from 2011 to 2017 and Wind behaviour (wind direction and wind speed). A total of 14760 collocated AWS observations were obtained in the study period, 2017 (as the data is available 2017 onward) and are evaluated wind characteristics from 18 ground station over the entire Jharkhand state against overpass time (± 1 hour) of MODIS Terra satellite.

### A2. Wind direction

Aerosol Concentration does not depend only on the sources of aerosols but also depends on wind direction and wind velocity. In another ward wind direction and velocity is a major criterion for the detection of sources of aerosol. Because wind direction plays a vital role in transportation of aerosols from one place to another place. We obtained wind direction data of
Jharkhand state from Jharkhand Space Application Center (JSAC), Automatic & Weather Station (AWS) data (Jharkhand Space Application Center’s (JSAC) and Automatic and Weather Station (AWS) Data 2017; Wind Direction 2017). We have used only those data which coincide with overpass time (± 1 hour) of MODIS-Terra that is approximately 9:30 a.m. to 11:30 a.m. We have considered 12 wind directions; those are i) North, ii) North-North-East, iii) East-North-East, iv) East, v) East-South-East, vi) South-South-East, vii) South, viii) South-South-West, ix) West-South-West, x) West, xi) West-North-West, and xii) North-North-West.

The primary wind blows over the entire study area is from the south-east to north-west. In this study, we observed the utmost wind direction towards the north (345° – 15°) which is 19.44% and the minimum wind blowing towards east-south-east (105° – 135°) that is only 4.40% of the total (14760) observations of 18 stations over the entire state. The resultant vector of average wind direction of the entire state is towards north-north-west (323 degree), which is 24% of total wind blowing (Figure 3a; Table A3).

### Table A3. Average wind direction over Jharkhand state in 2017.

| Wind Direction       | Wind Direction (in Degree) | Frequency | Percentage |
|----------------------|----------------------------|-----------|------------|
| North                | 345 – 15                   | 2870      | 19.44%     |
| North-North-East     | 15 – 45                    | 1250      | 8.47%      |
| East-North-East      | 45 – 75                    | 840       | 5.69%      |
| East                 | 75 – 105                   | 710       | 4.81%      |
| East-South-East      | 105 – 135                  | 650       | 4.40%      |
| South-East-East      | 135 – 165                  | 1140      | 7.72%      |
| South                | 165 – 195                  | 690       | 4.67%      |
| South-South-West     | 195 – 225                  | 820       | 5.56%      |
| West-South-West      | 225 – 255                  | 1280      | 8.67%      |
| West                 | 255 – 285                  | 1710      | 11.59%     |
| West-North-West      | 285 – 315                  | 1760      | 11.92%     |
| North-North-West     | 315 – 345                  | 1040      | 7.05%      |
| Total                |                            | 14760     | 100.00%    |

Jharkhand state from Jharkhand Space Application Center (JSAC), Automatic & Weather Station (AWS) data (Jharkhand Space Application Center’s (JSAC) and Automatic and Weather Station (AWS) Data 2017; Wind Direction 2017). We have used only those data which coincide with overpass time (± 1 hour) of MODIS-Terra that is approximately 9:30 a.m. to 11:30 a.m. We have considered 12 wind directions; those are i) North, ii) North-North-East, iii) East-North-East, iv) East, v) East-South-East, vi) South-South-East, vii) South, viii) South-South-West, ix) West-South-West, x) West, xi) West-North-West, and xii) North-North-West.

The primary wind blows over the entire study area is from the south-east to north-west. In this study, we observed the utmost wind direction towards the north (345° – 15°) which is 19.44% and the minimum wind blowing towards east-south-east (105° – 135°) that is only 4.40% of the total (14760) observations of 18 stations over the entire state. The resultant vector of average wind direction of the entire state is towards north-north-west (323 degree), which is 24% of total wind blowing (Figure 3a; Table A3).

### A2.2. Wind velocity

Wind velocity is another important parameter which directly influences the spatial distribution of AOD. The increase of aerosol concentration is well recognized due to the enhanced wind velocity that means wind speed and aerosol optical depth are proportionally related to each other. Because higher wind speed means more energy and it can carry more aerosols. This is a positive indicator for higher aerosol optical depth (AOD). Although it also depends on surface conditions (dryness) as well as geological compositions, land covers etc. In this study, we have tried to correlate AOD with wind velocity and wind velocity. We obtained wind velocity data of Jharkhand state from Jharkhand Space Application Center’s (JSAC), Automatic & Weather Station (AWS) Data (Jharkhand Space Application Center’s (JSAC) and Automatic and Weather Station (AWS) Data 2017) and used only those data which coincides with MODIS Terra’s overpass time (± 1 hour) that is approximately 9:30 a.m. to 11:30 a.m. (Figure 3b). All the data of wind velocity of 18 stations of the various districts of Jharkhand categorized into five categories (Table A4) (Wind Speed 2017).

### A2.3. Wind rose

We have plotted station wise all the data over the entire state according to their real-time location. In the north-eastern part most of the wind blowing towards the north but there is another pattern observed in the south-east part of this region like Dumka, Deogarh, Jamtara, Dhanbad district show up the major wind direction towards the west to west-west-north. Though the Hazaribagh region and its surrounding areas carry the evidence of reverse direction i.e. towards north-east to north-north-east and here the maximum average wind velocity
(> 20 km/hour) observed which is 5.4% throughout the year in 2017. In the middle part of the state (Ranchi and its surrounding areas) revealed the pattern of wind direction towards north-north-east to north-east whereas the Jamshedpur areas depicted fully reverse wind direction i.e. towards south to south-west. And in the north-western part of the state like Gumla, Lohardaga, Latehar, Palamu and Garhwa district depicted another picture of wind direction and wind velocity, where the major wind direction towards the west and west-west-north. Moderate wind velocity (5 – 20 km/hour) observed in the Garhwa and Palamu district towards the west (Wind Rose, 2017). The overall average resultant vector of 18 stations of Jharkhand is 323 degrees 24% of all the observations. That means the primary wind direction is towards north-north-west, which is 24% of total wind blowing (Figure 3b).

Appendix 2

Methodology for identification of sources of aerosol

The Analytic Hierarchy Process (AHP) (Belton 1986; Saaty 1986; Zahedi 1986; Harker and Vargas 1987; Dyer 1990; Vargas 1990) is a theory of measurement. At the point when applied for decision making helps to portray the overall choice activity by disintegrating an intricate issue into a staggered hierarchic structure of objectives, criteria, sub-criteria and alternatives. AHP provides a fundamental scale of relative magnitudes expressed in dominance unit judgments in the form of paired comparisons (Saaty 1986; Harker and Vargas 1987). The Multi-

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**Table A4. Annual average wind velocity of Jharkhand.**

| Beaufort   | Name                              | Wind Velocity (km/hour) | Observations | Percentage of Observations |
|------------|-----------------------------------|-------------------------|--------------|----------------------------|
| 0          | Calm                              | < 1                     | 2890         | 19.58%                     |
| 1          | Light air                         | 1 – 5                   | 8050         | 54.54%                     |
| 2          | Light breeze                      | 5 – 10                  | 3490         | 23.64%                     |
| 3          | Gentle breeze                     | 10 – 20                 | 280          | 1.90%                      |
| 4          | Moderate breeze                   | > 20                    | 50           | 0.34%                      |
| **Total**  |                                   |                         | **14760**    | **100.00%**                |

**Table A5. Resultant vectors of wind rose of the different station over Jharkhand state.**

| Sl. No. | Name of Station                           | Latitude | Longitude | Resultant Vector | Direction | Percentage (%) |
|---------|------------------------------------------|----------|-----------|-----------------|-----------|----------------|
| 1       | ISRO0984_15F3DB(BDO-D.C Office-Rajmahal) | 25.04    | 87.84     |                 | 6.00      | 35.00          |
| 2       | ISRO0957_15F3BD(BDO-D.C.Office-Hariharganj) | 24.56    | 84.28     |                 | 19        | 91             |
| 3       | ISRO0929_15F3A1(BDO-D.C.Office Devipur)   | 24.40    | 86.59     |                 | 266       | 48             |
| 4       | ISRO0931_15F3A3(BDO-Dhumka-D.C.Office-    | 24.28    | 87.26     |                 | 283       | 15             |
| 5       | ISRO0961_15F3C1(BDO-D.C.Office-Pandu-)    | 24.33    | 83.97     |                 | 47        | 31             |
| 6       | ISRO0935_15F3A7(BDO-Dandai)              | 24.12    | 83.62     |                 | 290       | 51             |
| 7       | ISRO0945_15F3B1(BDO-Jamua-D.C.Office-)   | 24.18    | 86.00     |                 | 0         | 100            |
| 8       | ISRO0948_15F3B4(VinobaBhave University-Hazaribag) | 24.02    | 85.38     |                 | 37        | 61             |
| 9       | ISRO0949_15F3B5(BDO-Narayanpur-D.C.Office-) | 24.05    | 86.61     |                 | 310       | 15             |
| 10      | ISRO0962_15F3C2(BDO-D.C.Office-Panki-)   | 24.03    | 84.47     |                 | 282       | 43             |
| 11      | ISRO0930_15F3A2(DESE-ISM Dhanbad-)       | 23.81    | 86.44     |                 | 250       | 26             |
| 12      | ISRO0974_15F3CE (BDO-Burma)              | 23.57    | 85.13     |                 | 289       | 67             |
| 13      | ISRO0968_15F3C8(BDO-D.C.Office-Angara)   | 23.40    | 85.51     |                 | 39        | 19             |
| 14      | ISRO0947_15F3B3(BDO-Ghaghra-D.C.Office-) | 23.27    | 84.56     |                 | 233       | 40             |
| 15      | ISRO0976_15F3D0(BDO-Lapung)              | 23.22    | 85.05     |                 | 297       | 58             |
| 16      | ISRO0982_15F3D6(BDO-Arki)               | 22.96    | 85.44     |                 | 245       | 26             |
| 17      | ISRO0985_15F3D9(BDO-D.C Office-Kharsawan) | 22.77    | 85.95     |                 | 205       | 26             |
| 18      | ISRO0966_15F3C6(BDO-D.C.Office-Chakulia-) | 22.48    | 86.72     |                 | 69        | 26             |
Criteria decision-making technique of AHP first introduced by Prof. Thomas L. Saaty in 1986. This method is mainly used for pairwise comparisons of data and also to derive the ratio scales (Saaty, 1986). AHP allows some little inconsistency in judgement since human isn’t generally reliable. The ratio scales are derived from the principal Eigen-vectors and the consistency index is derived from the principal Eigen-value (Saaty 1990). In this study we considered the AHP to identify the potential sources of aerosols over the entire study area. To make a decision in an organized way to generate priorities we need to decompose the decision into the following steps.

**Step-1: Defining the problem**

In this study, we have tried to identify the potential sources of aerosols over Jharkhand state and surrounding areas. And there are various factors which are responsible for the emission of aerosol. All of these factors are distributed in a dispersive way over the study area.

**Step-2: Defining a set of criteria**

For this study, we have considered eight different important criteria that are very responsible for the emission of aerosol or air pollution (Table A10). These are given below-

1. Cement Industry
2. Thermal Power Plants
3. Mines
4. Others Highly Polluting Industries
5. Forest Fire
6. Road Density
7. Normalized Difference Vegetation Index and
8. Population Density

**Step-3: Criterion standardization**

Criteria Standardization is the process of implementing the priority of each alternative within criteria based on their contribution to this problem. There are different methods for criteria standardization, like maximum score method, score range method etc. In this study, we have considered the score range method for criteria standardization (cost criteria).

\[
X'_{ij} = \frac{(X_{ij} - X_{\text{min}})}{(X_{\text{max}} - X_{\text{min}})}
\]

where \(X'_{ij}\) = Standardized Score of \(i\)th substitute and \(j\)th Criteria.
\(X_{ij}\) = Raw value of \(i\)th substitute and \(j\)th Criteria.
\(X_{\text{max}}\) = Maximum value of \(i\)th alternative and \(j\)th Criteria.
\(X_{\text{min}}\) = Minimum value of \(i\)th substitute and \(j\)th Criteria.

We have prepared the criteria map of cement industry, thermal power plants, mining, other industries and forest fire map by multiple ring buffer and rasterized them for further analysis. And also we have prepared a road density map, population density and NDVI map for this study. Then reclassified all the criteria map and standardized all the criteria. We have considered the standardized value 1 for under 1.5Km radius from the cement industry, thermal power plants, mining, other industries, and forest fire. And it is proportionally decreasing with the increasing of distance from these hotspot (highly polluting) areas. The details of other criteria of the standardized score given below (Tables A6–8).
Step-4: Criterion weighting by pair-wise comparison method

The Pairwise comparison method of compare entity in pairs to arbitrator has to favour in several quantitative possessions specifies and how many times are more significant or leading one of the components is over to alternative component with the respect of criterion or property due to that they are likened. Specified tables are given below and to display the scale (Tables A9–12).

- Estimation of Consistency Index:

\[ CI = \frac{\lambda - n}{n - 1} \]

Where \( \lambda = \) Lambdan = Number of Criteria

\[ CI = \frac{8.829 - 8}{8 - 1} \]
\[ CI = 0.12 \]

- Random Index for a number of criteria: (S. 5)
Estimation of Consistency Ratio \( CR = \frac{C}{RI} \)

\[
CR = \frac{0.12}{1.41} = 0.08
\]

Step-5: Simple Additive Weighting:

The Simple Additive Weighting (SAW) a technique known as the multi-criteria decision analysis (MCDA) or process for assessing a numeral of substitutes in a relation to a numeral number of decision criteria analysis. We assume that \( w_j \) represents the comparative weight of rank of the criterion \( a_j \) and \( a_{ij} \) is the recital value of substitute \( A_i \) after the assessed the criterion \( a_j \). Formerly, the whole (i.e. criteria are measured concurrently) importance of substitute \( A_i \) signified as \( A_i^{WSM-score} \) is distinct as follows:

\[
A_i^{WSM-score} = \sum_{j=1}^{n} w_ja_{ij}, fori = 1, 2, 3, ..., m.
\]

According to Huang et al. 2013 to deliberate the Multi-Attribute Utility Theory (MAUT) where it produces discrete decision maker’s partiality for the solitary characteristics to signs of progress as an efficacy purpose through scientific preparation. For the decision-maker is a common aggregation method i.e. SAW and MAUT. These two methods preferential levels do not consider the decision group maker to an assessment of alternatives. This method appears to instinctive in realizing the compromise and promise for group decision aggregation (Huang et al., 2013).
| CRITERIA               | Cement Industry | Power plant | Mines | Industries | Forest Fire | Road Density | NDVI | Population Density | Criterion Weight | (Rounded) |
|-----------------------|-----------------|-------------|-------|------------|-------------|--------------|------|------------------|-----------------|-----------|
| Cement Industry       | 0.26            | 0.38        | 0.30  | 0.25       | 0.19        | 0.15         | 0.11 | 0.16             | 0.22            | 22        |
| Power plant           | 0.13            | 0.19        | 0.30  | 0.25       | 0.19        | 0.15         | 0.11 | 0.19             | 0.19            | 18        |
| Mines                 | 0.13            | 0.09        | 0.15  | 0.25       | 0.19        | 0.19         | 0.18 | 0.16             | 0.17            | 17        |
| Industries            | 0.13            | 0.09        | 0.08  | 0.13       | 0.28        | 0.19         | 0.18 | 0.19             | 0.16            | 16        |
| Forest Fire           | 0.13            | 0.09        | 0.08  | 0.04       | 0.09        | 0.24         | 0.22 | 0.13             | 0.13            | 13        |
| Road Density          | 0.09            | 0.06        | 0.04  | 0.03       | 0.02        | 0.05         | 0.15 | 0.09             | 0.07            | 7         |
| NDVI                  | 0.09            | 0.06        | 0.03  | 0.03       | 0.02        | 0.01         | 0.04 | 0.06             | 0.04            | 4         |
| Population Density    | 0.05            | 0.03        | 0.03  | 0.02       | 0.02        | 0.02         | 0.02 | 0.03             | 0.03            | 3         |
| Total                 | 1               | 1           | 1     | 1          | 1           | 1            | 1    | 1                | 1               | 100       |
Table A12. Estimation of Consistency Vector.

| CRITERIA       | Cement Industry | Power plant | Mines | Industries | Forest Fire | Road Density | NDVI | Population Density | Consistency Vector |
|----------------|-----------------|-------------|-------|------------|-------------|--------------|------|--------------------|--------------------|
| Cement Industry| 0.22            | 0.37        | 0.34  | 0.32       | 0.26        | 0.20         | 0.12 | 0.14               | 8.82               |
| Power plant    | 0.11            | 0.19        | 0.34  | 0.32       | 0.26        | 0.20         | 0.12 | 0.17               | 9.05               |
| Mines          | 0.11            | 0.09        | 0.17  | 0.32       | 0.26        | 0.26         | 0.21 | 0.14               | 9.24               |
| Industries     | 0.11            | 0.09        | 0.08  | 0.16       | 0.38        | 0.26         | 0.21 | 0.17               | 9.24               |
| Forest Fire    | 0.11            | 0.09        | 0.08  | 0.05       | 0.13        | 0.33         | 0.25 | 0.11               | 9.07               |
| Road Density   | 0.07            | 0.06        | 0.04  | 0.04       | 0.03        | 0.07         | 0.17 | 0.08               | 8.52               |
| NDVI           | 0.07            | 0.06        | 0.03  | 0.03       | 0.02        | 0.02         | 0.04 | 0.06               | 8.16               |
| Population Density | 0.04        | 0.03        | 0.03  | 0.03       | 0.02        | 0.02         | 0.02 | 0.03               | 8.54               |
et al. 2013). We performed this technique (SAW) using ArcGIS10.4 for the identification of potential sources of aerosol over Jharkhand state and surrounding areas. For this model, we have used cement industry, thermal power plants, mining, other highly polluting industries, forest fire, road density, NDVI and population density using the criterion weight of 22, 18, 17, 16, 13, 7, 4, and 3 respectively. And got a weighted sum output map, which represents the quantitative responsibility for sources of aerosols over the entire study area.

| No of Observation | RI    | No of Observation | RI    |
|-------------------|-------|-------------------|-------|
| 1                 | 0     | 6                 | 1.24  |
| 2                 | 0     | 7                 | 1.32  |
| 3                 | 0.58  | 8                 | 1.41  |
| 4                 | 0.9   | 9                 | 1.45  |
| 5                 | 0.12  | 10                | 1.49  |