Poll Res. 40 (3) : 868-876 (2021)

ISSN 0257–8050

IMPACT OF COAL MINING ON AIRBORNE PARTICLES BASED ON REAL-TIME DATA

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(Received 16 January, 2021; Accepted 22 February, 2021)

ABSTRACT

The present investigation focuses on the impact of the activities involved in coal mining operation like excavation, loading, unloading and transportation on particulate matter-2.5 and particulate matter-10 in Talcher coal field area, Odisha. The concentration of particulate matters in air has a strong detrimental effect on human health particularly on respiratory tract if present beyond the standard permissible limit. The online air quality index data are collected in this regard from Central Pollution Control Board (CPCB) of India from December 2018 to 2020. For the analysis, weighted average of sub-indices for 24 hours average of hourly readings of each month is considered. Hence, one year is divided into four seasons, namely winter (December to February), summer (March to May), monsoon (June to September) and post monsoon (October and November). The present investigation reveals that due to PM_{10}, the air pollution level in the surrounding area of Talcher coalfield is found good only in September (AQI: 41) and October (AQI: 47) for the year 2019 and May (AQI: 48), June (AQI: 36) and July (AQI: 33) in 2020. Otherwise, the quality of the air in Talcher coalfield and its neighboring area remained adverse for its inhabitants throughout the stated period of investigation due to the presence of $PM_{2.5}$ and PM_{10} beyond standard limit. Meteorological study reveals the fact that within the study period most of the days of a year the air quality remains unfavorable to sustain human activities and significantly the AQI in winter (December to February) possesses the most hazardous potential to the people living in the surrounding area.

KEY WORDS : Air quality index (AQI), Particulate matter-2.5 ($PM_{2.5}$), Particulate matter-10 (PM_{10}), Real time data.

INTRODUCTION

One of the fastest growing industrial and coal hubs situated on the bank of the river Brahmani in the state of Odisha is Talcher. It is also known as 'Coal City' or 'City of black diamond' and ranked among the highest in terms of gross domestic product (GDP) in Odisha. It accounts for one of the four sub-divisions of Angul district in Odisha, India. The city is surrounded by the coalfields under Mahanadi Coalfields Limited (MCL) and has three Mega Power plants like National Thermal Power Corporation (NTPC), Talcher Thermal Power Station (TTPS), and Jindal power plant. With area coverage of nearly 1800 square kilometers (Singh *et al.,* 2010), Talcher coalfield is producing coal possessing rank of lower grade (Husain, 2014) and consists of about 35 percent, 70 percent and 25 percent fixed carbon, volatile matter and ash content, respectively.

On a daily basis, one hundred thousand tonnes of coal is dispatched to fulfill the demand of various power stations situated in different parts of India (Tranum, 2013). There are five production/administrative areas of Talcher Coalfield namely, Talcher, Jagannath, Kalinga, Lingaraj and Hingula (Mishra *et al.,* 2017).

The Coal India Limited (CIL), which is operating from eight different stations in India, involves in excavating coal by both opencast as well as underground methods. It is true that the negative effect of opencast coal mining is much prevalent (Gautam *et al.*, 2015) than that of underground mines as the former process releases fugitive dust (Chaulya, 2004 and Samara *et al.*, 2018) to the air thereby increases the value of air quality index (AQI). It is obvious that an increase in AQI value indicates poor air quality and higher air pollution level in the surrounding area. In most of the cases, assessment (Chaulya, 2003, van Donkelaar *et al.*, 2015, and Amann *et al.*, 2017) reveals that the ambient air quality in both residential and industrial area are exceeding the standard as mentioned in National Ambient Air Quality Standards (NAAQS) protocol. Moreover, open air burning of coal by native villagers (Smith *et al.*,1983 and Cheng *et al.*, 2017), poor road condition and transportation of coal through various modes (by rail as well as trucks) from mining area to its final destination enhances this problem manifold (Yadav *et al.*, 2019 and Pandey *et al.*, 2014). As a consequence, people belonging from different categories are exposed to high risk of possible health hazard arising out of the air pollution (Crabbe *et al.*, 2000, Wheeler *et al.*, 2000 and Oliveira *et al.*, 2019). Among different components accountable for air quality index (AQI) (Kumar *et al.*, 2011 and Perlmutt *et al.*, 2019) such as particulate matters ($PM_{2.5}$ and PM_{10}), SO_x, NO_x, CO, O_3 and NH_3, the existence of $PM_{2.5}$ and PM_{10} beyond its tolerable limit possesses significant detrimental effect on human heath (Sinha *et al.*, 1997; Das *et al.*, 2015 and Koukoulakis *et al.*, 2019). In comparison of PM_{10}, it is evident that $PM_{2.5}$ is more detrimental as these particles go deeper into the lungs and create harmful effect (Chaulya *et al.*, 2011). Hopefully, this harmful potential of $PM_{2.5}$ (Hao *et al.*, 2018; Yikai *et al.*, 2019; Elliott *et al.*, 2011) has made the World Health Organization (WHO) to put constraints to maintain its standards for all countries (Srimuruganandam *et al.*, 2010). It is a fact that the observed lock-down in India due to COVID-19 has also a direct impact on air pollution level (Shehzad *et al.*, 2020). Many sectors were inoperative or partially operative during that period (started from 25th March-2020). The positive impact in air quality is observed in many sectors (Shehzad *et al.*, 2020). Though the mining operation was not fully inoperative in Indian coalfields (George *et al.*, 2020) due to the support of the corresponding state government, but disruption of other essential factors such as transportation, sufficient manpower, etc. resulted decrease in overall activities (Dash, 2020). Like many other sectors influenced by the lock down effect (Shehzad *et al.*, 2020), no such communication is reported till date regarding this effect in AQI particularly in coalfield area. The present study focuses on the release of $PM_{2.5}$ (fine particulate matters) and PM_{10} (respirable particulate matters) to the ambient air mainly in Talcher coalfield area and its adverse effect to the surrounding people based on the real time online data released by the Central Pollution Control Board (CPCB) of India (CPCB Report, 2020) from December 2018 to December 2020. This short term investigation includes the year 2020 so that the effect of nationwide lock down in India due to COVID-19 on the concentration of $PM_{2.5}$ and PM_{10} in air surrounding the study area can also be analyzed. To investigate the meteorological effect on concentration variation of $PM_{2.5}$ and PM_{10}, the analysis is performed on seasonal basis, namely summer (March to May), monsoon (June to September), post monsoon (October to November) and winter (December to February). The weighted average (sub index) for individual pollutant is calculated from the 24 hours average of hourly readings for each month. The air quality standard is evaluated with the assumption that the sub index calculated is eventually contributing the AQI. It is evident from the present study that AQI value obtained is rarely found good surrounding Talcher coalfield area as per the prescribed standard (CPCB Report, 2020). The aim of the present study is to analyze the seasonal variation of air quality based on the concentration as well as the corresponding AQI for $PM_{2.5}$ and PM_{10}, and its consequences to the people residing in surrounding area. This study has been carried out in Talcher coalfield area, Odisha, India, in 2018 to 2020.

MATERIALS AND METHODS

Site description

The location of the Talcher coalfield is depicted in Fig. 1. There are two parts of the Talcher coalfield (Mishra *et al.*, 2017), namely eastern and western part. The eastern part is covered largely by Barakar formation, on the other hand western part comprises of Kamthi hillocks (Mishra *et al.*, 2017). The elevation in the coalfield, in general, varies within 60 m and

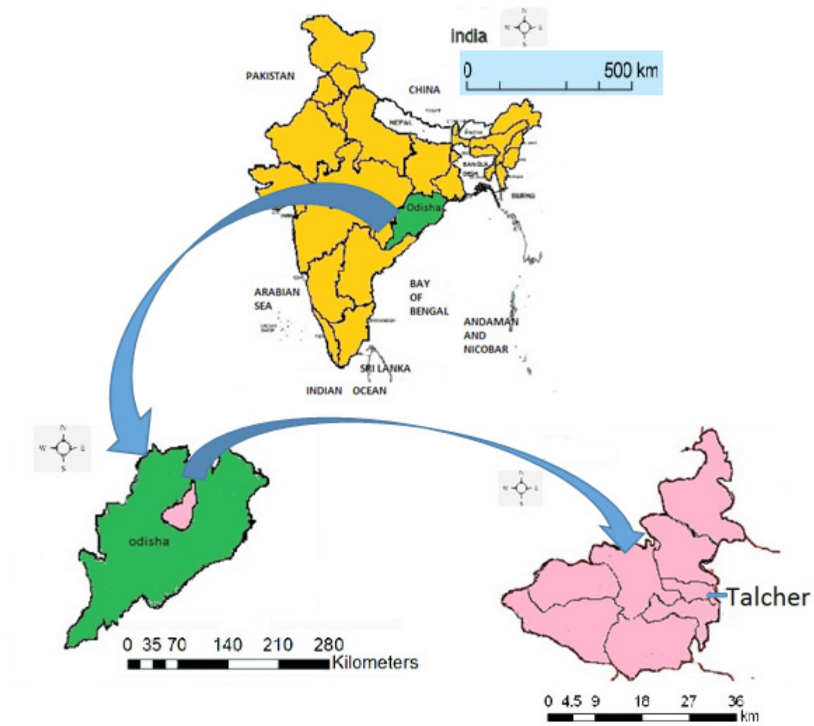

Fig. 1. Geographic location of the study area in Talcher Coalfield in India.

567 m above mean sea level (MSL). The coalfield is drained by the Brahmani River flowing along the eastern fringe of the coalfield.

Major part of the coalfield is basically falling in the district Angul, Odisha. This coalfield is bounded by latitudes of 23°53'N & 21°12'N with longitudes of 84°20'E & 85°23'E (Mishra *et al.*, 2017). With the total area coverage of about 1800 square kilometers, it constitutes south-eastern part of the Lower Gondwana basins within Mahanadi Valley Graben. Angul district constitutes the major part of the present coal mining area whereas few small portions of the coalfield are scattered in the West of Sambalpur district, North of Deogarh district and also to the East of the Brahmani River under Dhenkanal district. The present coal mining activities are confined in the south-eastern part of the coalfield and it is well connected by rail with the capital city Bhubaneswar covering a distance of around 150 kilometers. Apart from that the coalfield area is well connected by rail and road to the rest of India (Mishra *et al.*, 2017).

Measurement of air pollution

Air quality index (AQI)

This is the indicator used to measure the air quality level of the area concerned. It includes the combined effects of considerable pollutants present in the air such as $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, and CO according to the standard specified by concerned coalfield authority or by some central agency like CPCB based on average data of twenty four hours. The air quality level depends upon the range AQI possesses. In fact, the air pollution level from the corresponding AQI values varies country-wise (Gargava, 2014). The following table (Table 1) depicts the air pollution level corresponds to the AQI range as prescribed by CPCB India (CPCB Report, 2020). Based on this range, the air pollution level can be categorized as good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy and hazardous. Accordingly various health implications and cautionary statements for the public are provided.

Table 1. Impact of AQI on Air Pollution Level

AQI	Air pollution level
0-50	Good
51-100	Moderate
101-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very unhealthy
300>	Hazardous

It is important to mention here that $PM_{2.5}$, which is basically fine particulate matters, has some notable health implications and cautionary statements. The AQI range above 101 is not favorable and the intensity of this detrimental effect gradually increases with the increase of the AQI. The AQI value in between 151 to 200 indicates unhealthy to everyone, particularly to more sensitive groups (CPCB Report, 2020). Here, prolonged outdoor exposure may cause respiratory disease, such as asthma and hence it should be avoided. Whenever this AQI range comes in between 201-300, the health implications becomes unhealthy to very unhealthy and potentially more disastrous. The AQI values 300 and above are considered to be hazardous and everyone residing in that area should avoid outdoor exertion to prevent more serious health issues.

The calculation of AQI is a two-step process. Firstly, it requires the formation of sub-indices by incorporating individual pollutants and thereby aggregation of individual sub-indices to get the overall AQI, using Eqs. 1 and 2 (Gargava, 2014).

$$I_i = f_1(X_i) \quad .. (1)$$

Where, i = 1, 2, 3, ... n

$$I = f_2(I_1, I_2, I_3, ...(I_n) \quad .. (2)$$

In the above, Eq. (1) represents the formation of sub-indices. Here, I_i represents componential sub index for individual pollutant, which is a function of its corresponding concentration X_i. This function consists of *n* variables (pollutants), formed on the basis of air quality standard, health effects, etc. It is the reflection of concentration variation of specific pollutants on the environment. The relationship expressed by Eq. 1 between sub-indices with the concentration of pollutant may take various forms such as linear, nonlinear or segmented linear (Gargava, 2014). To obtain an overall index (*I*), which actually represents the AQI; aggregation of sub-indices is carried out as represented by the Eq. 2. This aggregation may indicate a summation, multiplication or a maximum operator.

Sub index for air quality

It indicates the concentration of individual pollutant present in air. In fact, the overall AQI depends on this sub index of individual pollutant as represented by Eq. 2.

As stated, the AQI is the reflection of the concentration (μg/m^3) of the pollutant whose contribution in sub index is maximum. For example, if the different concentrations of PM_{10}, $PM_{2.5}$, SO_x, NO_x, O_3 and NH_3 in μg/m^3 on a twenty four hours average with hourly basis are 121.0, 34.0, 0.0, 8.0, 57.0 and 34.0, then the corresponding sub index values are 114, 57, 0, 10, 57, and 9, respectively. Obviously, AQI will possess the value of 114, which comes from the maximum sub index contributing pollutant that is PM_{10}. Definitely, proper precaution needs to be taken if concentration of the contributing pollutant exceeds its tolerable limit. Hence, measurement of concentration of individual pollutant is essential to know the AQI. In this context, Fig. 2 depicts the variation of concentration (μg/m^3) of $PM_{2.5}$ and PM_{10} with their corresponding sub-indices. One can observe that due to the difference in break points and correlation to each fraction for the same concentration of $PM_{2.5}$ and PM_{10}, the corresponding sub index value of $PM_{2.5}$ is higher which eventually contributes the AQI value.

RESULTS AND DISCUSSION

In this investigation, the pollution level in the Talcher coalfield area is analyzed. In this regard, twenty four hours average real time data released online by the CPCB from December 2018 to 2020 are considered. As stated, each pollutant sub index may be responsible for the AQI, if its individual concentration contributes the maximum sub index. It is observed (CPCB Report, 2020) that the frequency of variation in concentration of $PM_{2.5}$ and PM_{10} is high compared to other pollutants and its excessive presence in air may develop serious health complicacies to the people living in surrounding areas. In most of the cases, either of these two ($PM_{2.5}$

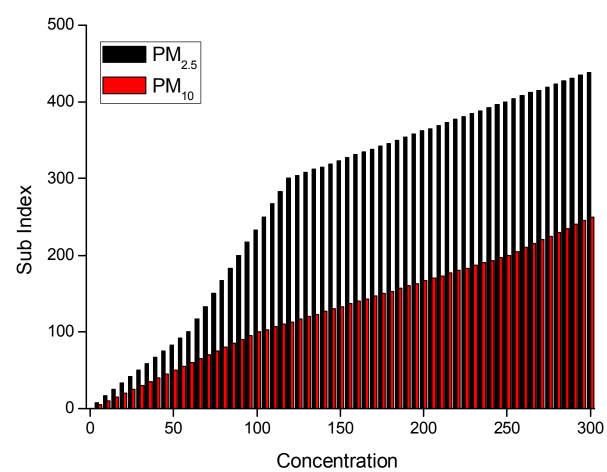

Fig. 2. Variation of Concentration (μg/m^3) with Sub Index for $PM_{2.5}$ and PM_{10}.

or PM_{10}) possess the dominating effect on AQI. Hence, the present analysis is restricted to these two pollutants namely, $PM_{2.5}$ and PM_{10}. In fact, the concentration of $PM_{2.5}$ and PM_{10} are measured primarily in $\mu g/m^3$and thereafter these values are converted from $\mu g/m^3$ to AQI levels as per the standard specified by the Environmental Protection Agency (EPA) (Gargava, 2014). For the sake of analysis the real time data collected are categorized on seasonal basis, that is summer (March to May), monsoon (June to September), post monsoon (October to November) and winter (December to February). Additionally, the effect of lockdown from 25th March-2020 for COVID-19 on AQI of Talcher coalfield area is also incorporated in the current study.

Contribution of $PM_{2.5}$ on AQI

For simplification of analysis, it is assumed that the sub index value contributed by $PM_{2.5}$ is maximum as compared to other pollutants responsible for AQI. Hence, the AQI value is equal to the sub index value provided by $PM_{2.5}$. As per the data depicted in Fig. 3, weighted average is taken for each month starting from Dec-2018 to Dec-2020. These weighted averages are calculated from the real time data available online. The corresponding concentration profile of $PM_{2.5}$ in $\mu g/m^3$represented in Fig. 4.

Analysis based on winter (December to February)

As per the Fig. 3, the AQI values owing to $PM_{2.5}$ for the three consecutive months that is December (2018), January and February in 2019 during winter are 160, 185 and 151, respectively. As depicted in Table 1, the corresponding air pollution levels are unhealthy for AQI values 160,185 and 151. An observation at the AQI values of the next year for the same consecutive months provides 172 for December (2019), 221 and 163 for January and February in 2020, respectively. In this regard, the pollution levels are unhealthy for AQI 172 and 163 and very unhealthy for AQI 221. As per the observation, in the winter season the air pollution level remains unhealthy in most of the time owing to $PM_{2.5}$ as indicated by the corresponding AQI in the surrounding area of Talcher Coalfield.

Analysis based on summer (March to May)

The month March to May is considered to be summer in the area of investigation. During the stipulated months, the AQI data (as per Fig. 3) for $PM_{2.5}$ are 117, 103 and 93 in 2019, and 99, 103 and 86 in 2020, respectively. Hence, the air pollution level remains moderate (for AQI values 86, 93 and 99) to unhealthy (for AQI values 103 and 117) for sensitive groups.

Analysis based on monsoon (June to September)

The real time data for the four consecutive months as depicted in Fig. 3 provides AQI values 81 for June, 69 for July and August-2019 and 64 for September-2019. Hence, the air pollution level remains moderate throughout. Similar observation for another year provides AQI values 75, 70 and 71, for the months June and September, July and August-2020, respectively, keeping the air pollution level unchanged.

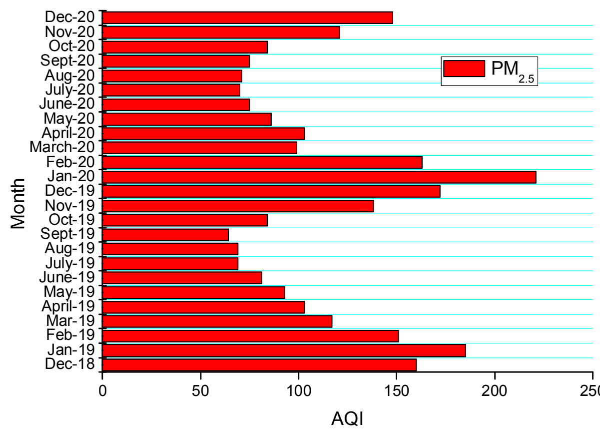

Fig. 3. The impact of $PM_{2.5}$ on AQI (Dec-2018 to 20).

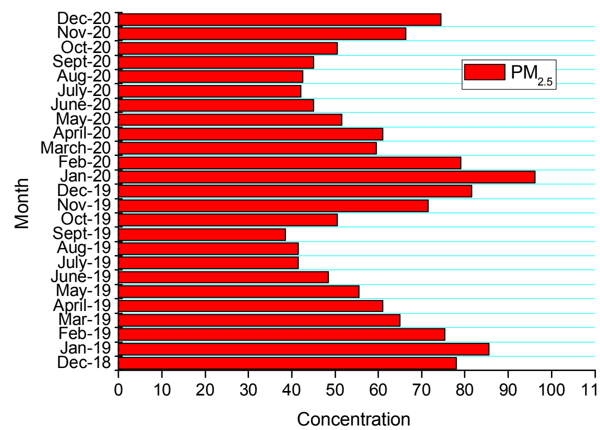

Fig. 4. The concentration profile ($\mu g/m^3$) of $PM_{2.5}$ (Dec-2018 to 20).

Analysis based on post monsoon (October and November)

For these two months, the air pollution level remains moderate for the month of October-2019 and 2020 with the corresponding AQI value 84. This AQI value changes to 138 and 121 for the month of

November-2019 and November-2020, respectively, indicating the air pollution level unhealthy for sensitive groups. One can observe moderate air pollution level (as depicted in Table 1) with AQI values are at its lowest range for the month of June to September that is in monsoon. This air pollution level goes from unhealthy to very unhealthy indicating its highest range AQI values for the month of December to February that is in winter. The intermediate air pollution levels indicating moderate to unhealthy for sensitive groups along with the corresponding AQI values are observed in summer (March to May) as well as in post monsoon periods for both the years 2019 and 2020.

Clearly, there is a significant contribution of the $PM_{2.5}$ to air pollution level as well as to AQI surrounding the area of Talcher coalfield throughout the year and rarely occupies the AQI range indicating good air pollution level as depicted in Table 1. It is important to mention that since the observation period is also including the nationwide lockdown period for COVID-19, but no significant improvement is noticed in the AQI values with respect to $PM_{2.5}$.

Contribution of PM_{10} on AQI

In this section, the effect of another important pollutant PM_{10} in the AQI is discussed. As stated, for the present analysis the entire year is divided into four seasons. It is important to mention here that the contribution of sub index for PM_{10} is assuming maximum, so that it becomes the AQI contributor. As per the Fig. 5, highest range AQI due to PM_{10} can be observed in winter that is in the month of December to February in the two consecutive years (2018-2019). On the other hand, the lowest range AQI is observed in monsoon (June to September). An intermediate AQI values are observed in

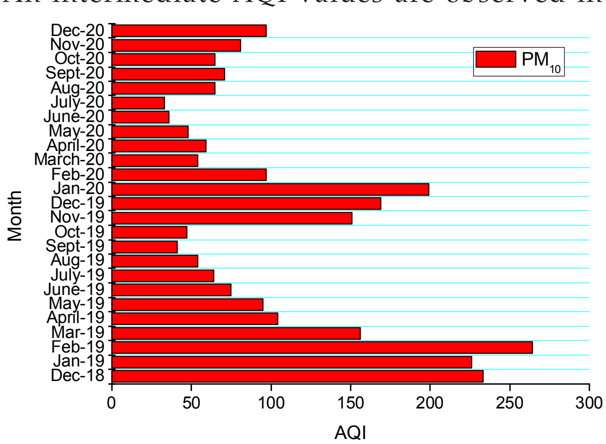

Fig. 5. The impact of PM_{10} on AQI (Dec-2018 to 20)

summer (March to May) as well as in post monsoon periods (October and November). In this context, the concentration profile of PM_{10} in $\mu g/m^3$ is depicted in Fig. 6.

Analysis based on winter (December to February)

As per the data provided in Fig. 5, the AQI values for PM_{10} are 233, 226, 264 and 169, 199, 97 for December (2018), January (2019), February (2019) and December (2019), January (2020), February (2020), respectively. The corresponding air pollution levels are very unhealthy (AQI: 233, 226 and 264), unhealthy (AQI: 169 and 199) and moderate (AQI: 97).

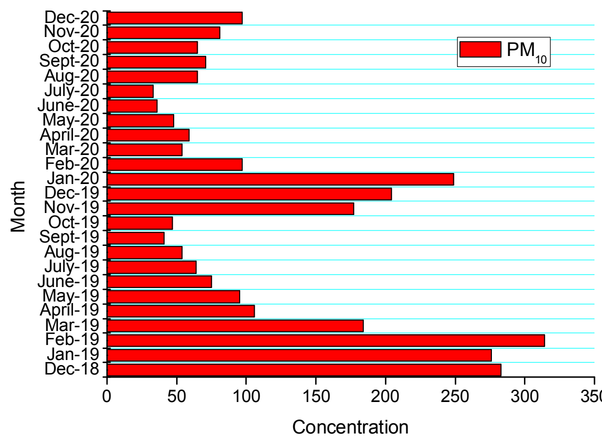

Fig. 6. The concentration profile (ìg/m^3) of PM_{10} (Dec-2018 to 20)

Analysis based on summer (March to May)

In summer, the AQI values are 156, 104, 95 and 54, 59, 48 for March (2019), April (2019), May (2019) and March (2020), April (2020), May (2020), respectively. Air pollution levels are good (AQI: 48), moderate (AQI: 54, 59, 95) and unhealthy for sensitive groups (AQI: 104).

Analysis based on monsoon (June to September)

The AQI values (depicted in Fig. 5) in this case are 75, 64, 54, 41 and 36, 33, 65, 71, respectively, for the months June (2019), July (2019), August (2019), September (2019) and June (2020), July (2020), August (2020), September (2020), respectively. Hence, a combination of moderate (AQI: 75, 71, 65, and 64) and good (AQI: 41, 36 and 33) air pollution levels are observed.

Analysis based on post monsoon (October and November)

In this case, a combination of good (AQI: 47) and unhealthy (AQI: 151) air pollution level is observed for the month of October and November-2019. Observation for another year 2020 provides moderate air pollution level with AQI values 65 and 81 for the month of October and November-2020, respectively.

It is observed that the trend of air pollution level owing to PM_{10} is similar for a particular season for the two consecutive years. But the AQI value is observed well in monsoon particularly for the year 2020. The prolonged lockdown due to COVID-19, for which activities (specifically loading, unloading and transportation) related to coal mine operation, might have been hampered (Gargava, 2014., and Mishra *et al.*,2017) and as a consequence air pollution level was reduced. It is true that getting AQI data prior to the setup of coal mine in Talcher coalfield (starting year 1837) is not available in literature, so there is no scope to evaluate the AQI standard prior to its start-up.

CONCLUSION

In the present study, a short term analysis of real time data is performed for the two major AQI contributors, namely $PM_{2.5}$ and PM_{10}. The real time data considered in this connection for the Talcher coalfield area are released by CPCB India for December-2018 to 2020. A seasonal analysis provides the information that in winter (December to February)the air quality deteriorates most, possessing an alarming (from unhealthy to very unhealthy) air pollution level with respect to sub index contribution of both the pollutants $PM_{2.5}$ and PM_{10}. As a consequence, people from all age groups living in the surrounding area are exposed to high health risk. Analysis of the AQI in summer (March to May) reveals that the corresponding air pollution level varies in between moderate (AQI: 86, 93 and 99) to unhealthy (AQI: 103 and 117) for sensitive groups owing to $PM_{2.5}$. On the other hand, it indicates a combination of good (AQI: 48), moderate (AQI: 54, 59 and 95), unhealthy for sensitive groups(AQI: 104) and unhealthy (AQI: 156) air pollution level for PM_{10}. An observation in the monsoon (June to September) provides moderate (AQI: 64, 69, 70, 71, 75, and 81) air pollution level for $PM_{2.5}$. For PM_{10}, there is a mixed indication of moderate (AQI: 54, 64, 65, 71, and 75) to good (AQI: 33 and 36) air pollution level for both the year 2019 and 2020. The post monsoon period (October and November) for the two consecutive years provides a combination of moderate (AQI: 84) and unhealthy for sensitive groups (AQI: 121 and 138) for $PM_{2.5}$. In case of PM_{10}, there is a combination of good (AQI: 47) and unhealthy (AQI: 151) for the year 2019 and moderate (AQI: 65 and 89) for the year 2020. The prime reason behind this seasonal variation of air pollution level is meteorological parameters such as humidity, temperature, wind speed and direction. In winter, because of low humidity and wind speed the concentration of these pollutants becomes severe in the surrounding area. Apart from that several other activities like uncovered transportation of coal, scattered coal consumption, dust re-suspension from road dust and dust storms which eventually increase the concentration of PM_{10} from $PM_{2.5}$ and thereby enhance this problem manifold. As per the study based on $PM_{2.5}$ and PM_{10} for the two successive years (Dec-18 to Dec-20), it is evident that except few months (September, October in 2019 and May to July in 2020) for PM_{10}, most of the time of a year, the quality of the air surrounding Talcher coalfield area remains adverse for its inhabitants exposing them to serious health complications. The effect of prolonged lockdown owing to COVID-19 might have hampered the coal mining and associated activities like loading, unloading and transportation. The law enforced in this regard was very stringent in India at the time of its commencement, and as a consequence the AQI level showed quite improvement particularly, in March 2020, by indicating a reduced air pollution level with respect to the pollutant PM_{10}.

Author Contributions

All authors had fully accessed all data and information presented in the current investigation. Md. Aurangzeb and S. Banerjee both formulated the study goals and aims, statistical processing, figure updating. Additionally, S. Banerjee conducted the literature review and prepared the manuscript.

ACKNOWLEDGEMENT

The authors are thankful to the Central Pollution Control Board (CPCB) of India for the access of its online data.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

Abbreviations

AQI	Air quality index
CIL	Coal india limited
CO	Carbon monoxide
COVID-19	Coronavirus disease 2019
CPCB	Central pollution control board
Dec	December
E	East
EPA	Environmental protection agency
Fig.	Figure
GDP	Gross domestic product
m	meter
MCL	Mahanadi coalfields limited
MSL	Mean sea level
N	North
NAAQS	National ambient air quality standards
NH_3	Ammonia molecule
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NTPC	National thermal power corporation
O_3	Ozone molecule
PM_{10}	Particulate matter less than 10 microns in diameter
$PM_{2.5}$	Particulate matter less than 2.5 microns in diameter
S	South
SO_x	Oxides of sulphur
TTPS	Talcher thermal power station
W	West
WHO	World health organization
$X^o Y'$	*X* degrees *Y* minutes
$\mu g/m^3$	Microgram per cubic meter

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