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Sustainable Pathways to Energy Utilisation Volume 2: State of the Environment in the Ramagundam and Dorli-Bellampalli coal mines in the State of Telangana

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Sustainable Pathways to Energy Utilisation

State of the Environment in the Ramagundam and Dorli-Bellampalli coal mines in the State of Telangana

Volume 2 of the Energy component of the research conducted in the

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"Interdisciplinary Forays into Human-Environment Interactions: An Integrative Research Initiative in Energy, Ecology and Nonlinear Modelling"

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Cover photo: (Front cover) Thermal Power Plant
(Back cover) DRAGLINE

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Abbreviations

AAQMS	:	Ambient Air Quality Monitoring Stations
AOD	:	Aerosol Optical Depth
AOI	:	Area of Interest
APHA	:	American Public Health Association
BIS	:	Bureau of Indian Standards
BOD	:	Biological Oxygen Demand
BZ	:	Buffer Zone (Area lying within 0 - 10 km from the Mining lease boundary)
CEA	:	Central Electricity Authority, Ministry of Power, Government of India
CEMS	:	Continuous Emission Monitoring Systems
COD	:	Chemical Oxygen Demand
COP	:	Conference of Parties to the UNFCCC
CPCB	:	Central Pollution Control Board
CZ	:	Core Zone - defined by MoEFCC as the area occupied by the Mining Lease
DO	:	Dissolved Oxygen
EC	:	Electrical Conductivity
EEP	:	Energy & Environment Program
FY	:	Financial Year
FY	:	Financial Year (starting in April and ending in March of the next year)
GCF	:	Green Climate Fund
GoI	:	Government of India
GW	:	Ground Water
IDW	:	Inverse Distance Weighted (a technique used for spatial interpolation)
ISRO	:	Indian Space Research Organization
LULC	:	Land-use/land-cover changes
ML	:	Mining Lease granted by the State Government under the MMDR Act, 1957
MMDR Act	:	Mines and Minerals (Development and Regulation) Act, 1957
MoC	:	Ministry of Coal
MODIS	:	Moderate Resolution Imaging Spectroradiometer
MoEFCC	:	Ministry of Environment, Forest and Climate Change, Government of India
MoES	:	Ministry of Earth Sciences, Government of India
MT	:	Million Tons
NAAQS	:	National Ambient Air Quality Standards
NASA	:	National Aeronautics and Space Administration

NDVI	:	Normalized Difference Vegetation Index
NTPC	:	National Thermal Power Corporation – a Public Sector Undertaking controlled by the Government of India
OB	:	Overburden (in this study, the non-coal material removed from coal mines)
OCM	:	Open Cast Mine
OSMRE	:	Office of Surface Mining, Reclamation, and Enforcement
PM	:	Particulate Matter
PM_{10}	:	Particulate Matter with an aerodynamic diameter less than 10 microns
$PM_{2.5}$	:	Particulate Matter with an aerodynamic diameter less than 2.5 microns
SCCL	:	Singareni Collieries Company Ltd. – a Joint Venture between the Government of Telangana and the Government of India
SERB	:	Science and Engineering Research Board
SMCRA	:	Surface Mining Control and Reclamation Act
SW	:	Surface Water
TDS	:	Total Dissolved Solids
TE	:	Total Excavation which is calculated as the sum of overburden and coal (in volumetric terms)
TPP	:	Thermal Power Plant
TSPGENCO	:	Telangana State Power Generation Corporation
UNFCCC	:	United Nations Framework Convention for Climate Change
UZ	:	Undisturbed Zone (10-15 km away from the mining lease boundary)
WPI	:	Wholesale Price Index
WQMS	:	Water Quality Monitoring Stations

Sustainable Pathways to Energy Utilisation

State of the Environment in the Ramagundam and Dorli-Bellampalli coalfields in India

1. Introduction

Coal is the only energy source that India possesses in abundance. Specifically, the Reserve-to-Production (R/P) ratio in India for coal is 140, while it is 15.5 for oil and 49.4 for gas (BP, 2020). The R/P ratio of 132 indicates that India's proved coal reserves at the end of 2019 are adequate for 140 years if India continues to mine coal at the same production rate as it did during the year 2019. While mining operations and coal-fired power generation have positive economic impacts on the local area in terms of infrastructure development and provision of employment and business opportunities for the local population, they also create adverse impacts on the ecology and air environment of the local area. These impacts are particularly significant in the case of opencast coal mines which account for more than 94.4 percent of the coal produced in India (Coal Controller, 2021). The state of Telangana has the sixth highest coal reserves in India with proved reserves of 22.25 BT (Coal Controller, 2021). This research report describes the state of air environment in the Ramagundam and Dorli-Bellampalli coalfields in Telangana. Two large opencast coal mines (Dorli I and Dorli II) in the Dorli-Bellampalli coalfield also entered the closure phase between April 2017 and May 2019. Therefore, this research report also includes the key impacts of mine closure on the air quality and vegetation in the Dorli-Bellampalli coalfield. Since Singareni Collieries Company Ltd. (SCCL) has proposed to convert the final voids in these two opencast coal mines to water reservoirs post-closure, the water environment in this coalfield is also described.

Fine airborne particles ($PM_{2.5}$) can penetrate the bronchioles of human lungs, leading to various ailments including, cardiovascular and respiratory diseases (Dockery *et al*, 1993; Pope *et al*, 1995; Spurny, 1998; WHO, 2013). Nayak and Chowdhury (2018) studied the health impacts of respirable particulate matter emitted from open cast coal mines and have documented the relationship between RSPM level and respiratory illness (RI) during sick days. Fine particulate matter ($PM_{2.5}$) absorbs various chemical compounds, such as metallic elements, ions, organic compounds, and salts, and biological groups and these compounds also have adverse effect on human health (Spurny, 1998; Moreno, 2019).

Conventional coal mining practices include unit operations such as drilling, blasting, loading, haulage, and dumping. All these mining operations generate different classes of airborne dust particles such as Suspended Particulate

Matter (SPM), Respirable Particulate Matter (RSPM), and fine particles with an aerodynamic diameter ≤2.5μm ($PM_{2.5}$) (Banerjee *et al*, 2001; Ghose, 2001). The ambient airborne particles with aerodynamic diameters ≤10μm (PM_{10}) and ≤2.5μm ($PM_{2.5}$) are regulated through the National Ambient Air Quality Standards in India The annual population-weighted mean exposure to ambient particulate matter $PM_{2.5}$ in India was 89.9 μg/m³ (95% uncertainty interval 67–112) in 2017. Further, 76.8% of the population in India was exposed to annual population-weighted mean $PM_{2.5}$ greater than 40 μg/m³ (the limit recommended by the National Ambient Air Quality or NAAQ Standards in India) in 2017 (Lancet Planet Health, 2019). Therefore, there has been an increasing focus on addressing the issues related to ambient particulate pollution in India by various government organizations (CPCB, MoEFCC, and MoES), industries, think tanks and academia in recent times.

However, most of the studies on air pollution related to India focus on urban air emissions. while very few studies have been published on the air pollution in coalfields in India (Pandey *et al.*, 2014; Gurdeep Singh and Amarjeet Singh, 2015; Moreno, 2019; Trivedi *et al.*, 2010).

MoEFCC (2020) launched National Clean Air Programme (NCAP) in January 2019 to tackle the problem of air pollution in a comprehensive manner with targets to achieve 20 to 30 % reduction in particulate matter concentrations by 2024 keeping 2017 as base year. The plan includes 124 non- attainment cities, across 23 States and Union Territories, on the basis of their ambient air quality data. However, there are very few studies of the air pollution in non-urban, industrial areas containing major industries like coalfields and pithead Thermal Power Plants (TPPs). This is one of the key rationale for this research report on the air environment in the Ramagundam and Dorli-Bellampalli coalfields.

In addition to ambient air quality data, this study also includes analysis of geospatial parameters like Aerosol Optical Depth (AOD) and Normalized Difference Vegetation Index (NDVI). Aerosol optical thickness based on satellite measurements are based on the fact that particles change the way the atmosphere reflects and absorbs visible and infrared light. An optical thickness of less than 0.1 (palest yellow) indicates a crystal-clear sky with maximum visibility, whereas a value of 1 (reddish brown) indicates very hazy conditions (NASA, 2021). Elevated aerosol amounts may also be due to anthropogenic air pollution which can be correlated with AOD observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard NASA's Aqua and Terra satellites (NASA, 2021). Time series analysis of NDVI data related to a region can reveal where vegetation is thriving and where it is under stress, as well as changes in vegetation due to human activities such as deforestation caused by coal mining or other anthropogenic activities, or natural disturbances, or changes in plants' phenological stage (Didan, 2015).

One of the major objectives of this study is to study the spatio-temporal variations in geospatial parameters (AOD and NDVI) and correlate them with anthropogenic activities on the ground which contribute to PM pollution or land degradation. This study includes an analysis of both surface and geospatial measurements in two coalfields, thereby facilitating a better understanding of the impact of coal mining (from mine opening to closure) on the local vegetation and air quality. This integration of geospatial and terrestrial observations will aid in monitoring air pollution and land degradation of areas covering several coal mines thereby enabling the regulatory authorities to assess the regional impact of coal mining with the necessary ground-truthing. Finally, this research also shows a way forward to assess the success of revegetation activities incorporated in closure plans submitted by coal mines to the Coal Controller in compliance with the mining plans approved by the Ministry of Coal (MoC, 2020). This is important since 18 opencast coal mines have been closed in the last three years, while nine more opencast coal mines are scheduled for closure in the next three years (MoC, 2021).

The Dorli-Bellampalli coalfield in Telangana has also been included as one of the two study areas for this research since the final closure of two opencast coal mines (Dorli OC-I and Dorli OC-II) within a short duration enables a study of the pre-mining and post-mining environment in an area where there are no other major anthropogenic sources of pollution. The Ramangundam coalfield (including, Ramagundam, Srirampur, and Mandamari areas of SCCL) has been selected as the second study area for this research to assess the combined impact of coal mines and pithead power plants on the regional air environment.

2. Description of Study Area-1 and Study Area-2

The study area has been divided into two parts: Study area-1 and Study area-2 based on the presence (or absence) of TPPs which also create their own impact on the air environment. Study Area-1 in the Dorli-Bellampalli coalfield is bound by Latitudes 19°17'6.29" N to 19°15'19.33" N and Longitudes 79°10'21.36" E and 79°21'42.72" E and covers an area of 163 km^2 in the Kumuram-Bheem-Asifabad district in the State of Telangana (Figure 1). While four OC coal mines are located in this area, there is no other urban area or industrial activity within a radius of 25 km from this area. Therefore, this location formed an ideal setting to study the impact of opencast coal mining on the environment (air, water and vegetation) in a thinly populated area which is devoid of any other source of pollution like industries or vehicular traffic.

Study area-2 is bound by Latitudes N 18°31'6.24" N to 19°4'48.36" N and Longitudes 79°13' 11.28" E to 79°47'48.48" E and covers an area of approximately 3762 km^2 in the Mancherial and Peddapalli districts in the State of Telangana (Figure 1). This area contains five open cast and 19 underground coal mines grouped in three clusters (Ramagundam, Srirampur, and Mandamari areas of SCCL) as well as three coal-fired Thermal Power Plants (TPPs) operated by three Government companies (viz., TSPGENCO, NTPC Ltd., and SCCL) which depend on the adjacent coal mines for their fuel supplies. NTPC Ltd (a Corporation controlled by the Government of India) operates a 2600 MW (3 x 200 MW + 4 x 500 MW) TPP commissioned in three stages between 1983 and 2004. Singareni Collieries Company Limited (SCCL) is a Joint Venture of the Government of Telangana and the GOI which owns all the coal mines in both Study areas as well as a 1200 MW (2 x 600 MW) TPP commissioned in December 2016. As shown in Figure 1, Telangana State Power Generation Corporation Limited (TSPGENCO) also operates a TPP with a capacity of 62.5 MW in this area. The co-location of coal mines and TPPs in Study area-2 makes it an ideal location to assess the combined impact of coal mining and power generation on ambient air quality.

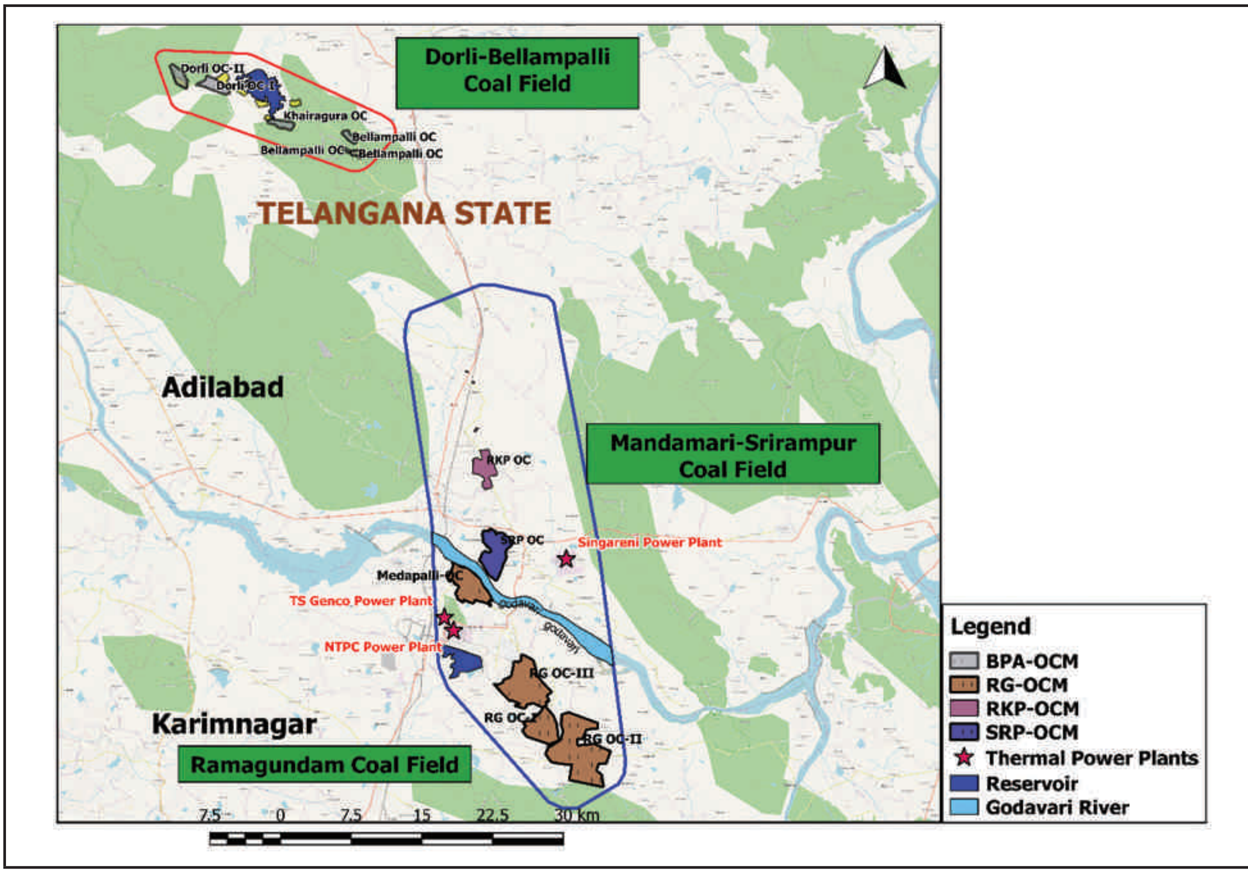

Figure 1: Location of overall study area map with Study area-1 in the Dorli-Bellampalli coalfield and Study area-2 containing the Mandamari, Srirampur, and Ramagundam coal mines

2.1. Geography and Meteorology

The State of Telangana is located in a semi-arid area that receives about 905 mm of rainfall (533 mm – 1199 mm) mainly during the monsoon season which starts in June and lasts until September (Government of Telangana, 2021). The State experiences some of the highest temperatures during summer (maximum temperatures of 46.2°C – 48.9°C) with a dry, mild winter starting in late November and lasting until early February during which the minimum temperature ranges between 2 - 8°C (Government of Telangana, 2021). While the elevation of Study area-1 above mean sea level varies between 218 m and 450 m, the elevation of Study area-2 varies in a narrow band between 144 m and 152.5 m (TSPCB, 2015; 2018a).

The micro-meteorological scenario, state of environment, groundwater, land-use patterns, and demographic data pertaining to Study area-1 and Study area-2 are described in the Environmental Impact Assessment (EIA) reports submitted to the Ministry of Environment, Forest and Climate Change (MoEFCC) and/or the Telangana State Pollution Control Board (TSPCB) by Singareni Collieries Company Limited (SCCL) and NTPC Ltd (e.g., TSPCB, 2015; 2018a).

- Study area-1 falls in the Kumuram-Bheem-Asifabad district of Telangana. While the area is surrounded by hills, it is largely covered with forest land besides some farmland with red grams, jowar and cotton being the main crops. The micro-meteorological station installed in the General Manager's office in the SCCL's Goleti township has recorded wind speeds ranging between 0.5 and 8.8 m/s with the predominant winds blowing from the SSE, SW, and WNW directions. The "normal" level of annual rainfall in this area is approximately 1196 mm though the total rainfall received in 2019-20 was as high as 1467.5 mm (Government of Telangana, 2021).

- Study area-2 falls in the Peddapalli and Mancherial districts of Telangana. While most of the land in this area is barren, this region is industrially well-developed based on the rich coal reserves and availability of water from the Godavari River which flows through the area. Several micro-meteorological stations are maintained by SCCL and NTPC in their offices located in this area, while the Ramagundam meteorological station of the India Meteorological Department (IMD) is located to the south-west of this area. The predominant wind directions are from the NE, S, and SE with wind speeds ranging between 0 and 1 m/s. The "normal" level of annual rainfall in this area is in the range of 1056-1145 mm though the total rainfall received in 2019-20 was as high as 1265-1291 mm (Government of Telangana, 2021).

2.2. Data Sources

The key details of the data sets collected and analyzed during this Study are summarized in Table 1.

(i) Ambient Air Quality Measurements

Long-term measurements of PM_{10}, $PM_{2.5}$ and SO_2 concentration were obtained from three sets of manual ambient air quality monitoring stations established by - State Pollution Control Board, Telangana; NTPC, National Thermal Power Corporation (NTPC), Ramagundam; and Singareni Collieries Company Limited (SCCL).

- The Telangana State Pollution Control Board (TSPCB) is operating two manual ambient air quality (AAQ) monitoring stations in the entire study area. One manual monitoring station is located on the roof of the SCCL Officers' Club in Mandamari while another one is located on top of the Municipal building in Godavarikhani.

- NTPC – Ramagundam reports bi-weekly ambient air quality data from three sampling stations at Pump House, Balancing Reservoirs and Guest House as part of their six-monthly compliance reports to TSPCB and MoEFCC.

- SCCL maintains 59 AAQ monitoring stations in the core zone of coal mines (mining lease area) and 94 monitoring stations in the buffer zone (10 km from the mining lease boundary) of coal mines. The daily ambient air pollutant (PM_{10}, $PM_{2.5}$ and SO_2) observations from June-2012 to September-2020 were aggregated into monthly, seasonal and annual averages (across 8 years) for the present study.

- All AAQ monitoring stations have been installed and monitored by SCCL/NTPC/TSPCB as per CPCB/MoEF guidelines (CPCB, 2011). As per the MoEF (2010) norms, the AAQ monitoring stations should be established in the core zone as well as in the buffer zone for monitoring Particulate Matter (PM_{10} & $PM_{2.5}$), as well as gaseous pollutants SO_2 and NO_2. The locations of these stations are based on the meteorological data, topographical features and environmentally sensitive targets, and finalised in consultation with TSPCB. As per the air monitoring guidelines, a High-Volume Sampler (HVS) is used to measure ambient air PM_{10} concentrations by drawing in air through a size-selective inlet and a Glass-fibre filter (size of 20.3 X 25.4 cm) at a flow rate of 1132 L/min. A CPCB-approved air sampler is used to measure $PM_{2.5}$ concentrations in the ambient air by sucking in air at a constant volumetric flow rate of 16.7 L/min with a specially-designed inertial particle-size separator where the $PM_{2.5}$ particles are collected on a 47 mm polytetrafluoroethylene (PTFE) filter (CPCB, 2011).

(ii) Geospatial Data

The authors also extracted data products from NASA's Earth Observation System collected by MODIS. The MODIS data products used in this study include the Normalized Difference Vegetation Index (NDVI) to study vegetation and Aerosol Optical Depth (AOD) as a proxy for Particulate Matter (PM) pollution.

MODIS-NDVI is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes in plant health. NDVI is calculated as a ratio between the red (R) and near infrared (NIR) values. The NDVI data are calculated based on the relationship between red and near infrared (NIR) spectral bands since chlorophyll is strongly absorbs by the visible (red band) and strongly reflected by the NIR band (Rouse *et al.*, 1974).

$$NDVI = \frac{NIR - R}{NIR + R}$$

MODIS-NDVI values range from -1.0 to 1.0, generally following the scale explained by (Brown, 2015). Generally, MODIS-NDVI values

- between -1 and 0 represent water bodies;
- - 0.1 to 0.1 indicate barren rocks, sand, or snow;
- 0.2 to 0.5 indicate shrubs and grasslands, and
- 0.6 to 1 represent dense vegetation or a tropical rainforest.

Table 1: Datasets used in this study

Datasets used			
Parameter	**Source**	**Spatial Resolution**	**Frequency of Measurement**
NDVI (Normalized Difference Vegetation Index)	MODIS-NDVI 13Q1	250 meters	8 days
AOD (Aerosol Optical Depth)	MODIS-MAIAC (MCD19A2)	1 km	Daily
Study area-1: PM_{10}, $PM_{2.5}$ and SO_2 (µg/m^3)	AAQ data collected by SCCL and submitted to MoEFCC and TSPCB along with Environmental compliance reports.	(24 Hour average AAQ concentration at point locations)	Bi-monthly (in case of Mines)
Study area-2: PM_{10}, $PM_{2.5}$ and SO_2 (µg/m^3)	AAQ data collected by SCCL and NTPC and annexed to Environmental compliance reports submitted to MoEFCC and TSPCB. AAQ data collected by TSPCB at one station each in Ramagundam and Mandamari	(24 Hour average AAQ concentrations at point locations)	Bi-monthly (in case of Mines); Bi-weekly in case of Thermal Power Plants

Vegetation indices act as an important proxy to estimate the loss of biodiversity and habitat (Swain *et al*, 2013). IGIS and open-source GIS software are used for image processing, rectification, band stacking, buffering, digital number to radiance conversion, Image index calculation (NDVI) and image classification (Boken *et al*., 2008). NDVI values were obtained from the MODIS database on a weekly basis for each cell during the period 2004 to 2020 to correlate changes in vegetation due to mine opening and mine closure followed by reclamation and revegetation.

The MODIS instrument on-board the Terra and Aqua satellites operated by NASA constantly obtains daily global measurements at 36 spectral bands ranging from 0.41 to 14 μm and at 3 spatial resolutions (250 m, 500 m, and 1 km). The resolutions are spatially as well as temporally matched for deriving the air quality on local, regional and global scales.

3. Study area-1

3.1. Details of Study area-1

Study area-1 consists of four Opencast Coal Mines (OCMs) operated by SCCL, namely Dorli-I & II, Khairagura Opencast Expansion Project and Bellampalli Open Cast-II Expansion Project. The dates of opening and closing of these four OCMs are given in Table 2. The Tiryani forest is at the north western side of the study area and Goleti hills in the south eastern part. The OCMs along with their external overburden dumps and the respective Ambient Air Quality (AAQ) and Water Quality Monitoring (WQM) stations are depicted in Figure 2. In most cases, the boundaries of a coal mine (and by extension, its economic reserves) get extended continually due to improvements in technology as well as market conditions. Therefore, coal mines are sometimes operated as "relay projects" where the overburden from one coal mine is dumped into the void created by extracting coal from an adjacent coal mine. However, the two Dorli coal mines form an almost unique example of mines where relay projects could not be envisaged due to want of forest clearance for further extension.

3.2. Coal production and overburden removal in the Dorli-Bellampalli coalfield

As per SCCL's production records, the total coal production and Overburden (OB) volumes mined from the four opencast coal mines in Study area-1 are shown in Table 3 and Figure 3. Between Financial Year (FY) 2012-13 and

Table 2: Salient details of OCMs in the Study area (Dorli- Bellampalli coalfield)

S.No.	Study Area	Date of opening	Date of closing
1.	Khairagura (KRG) Open Cast Expansion Project	01/07/2006 01/06/2015	In operation
2.	Bellampalli Open Cast Expansion Project (BPA OC –II)	01/04/2006 01/4/2016*	In operation
3.	Dorli-I	01/12/2007	31/05/2019
4.	Dorli-II	11/07/2011	01/04/2017

*Mining in BPA OC –II was interrupted from 1.04.2012 to 31.03.2016 and resumed in 2017
(Data Sources: SCCL, 2020a; 2020b; 2020c; 2020d)

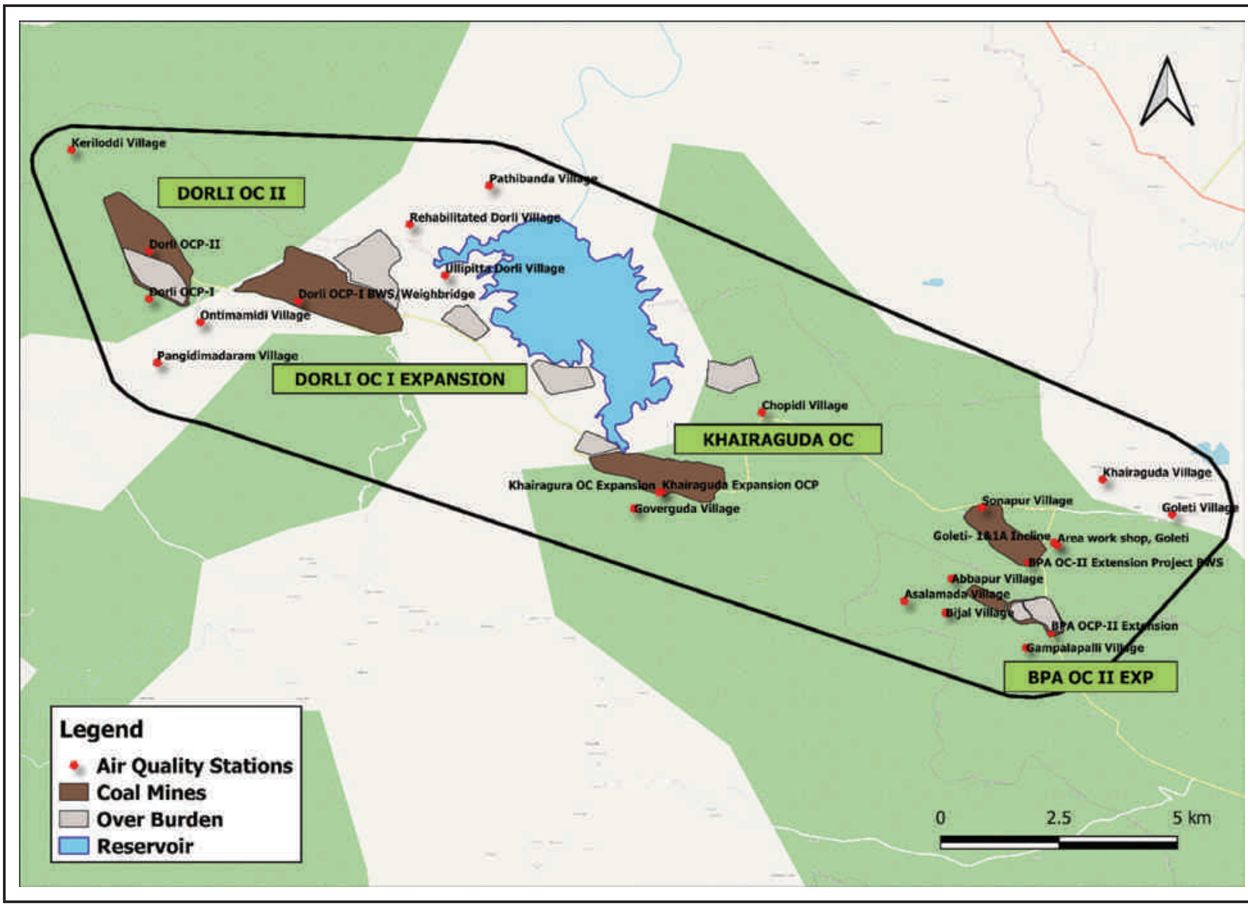

Figure 2: Location of coal mines and their ambient air quality monitoring stations in Study area-1

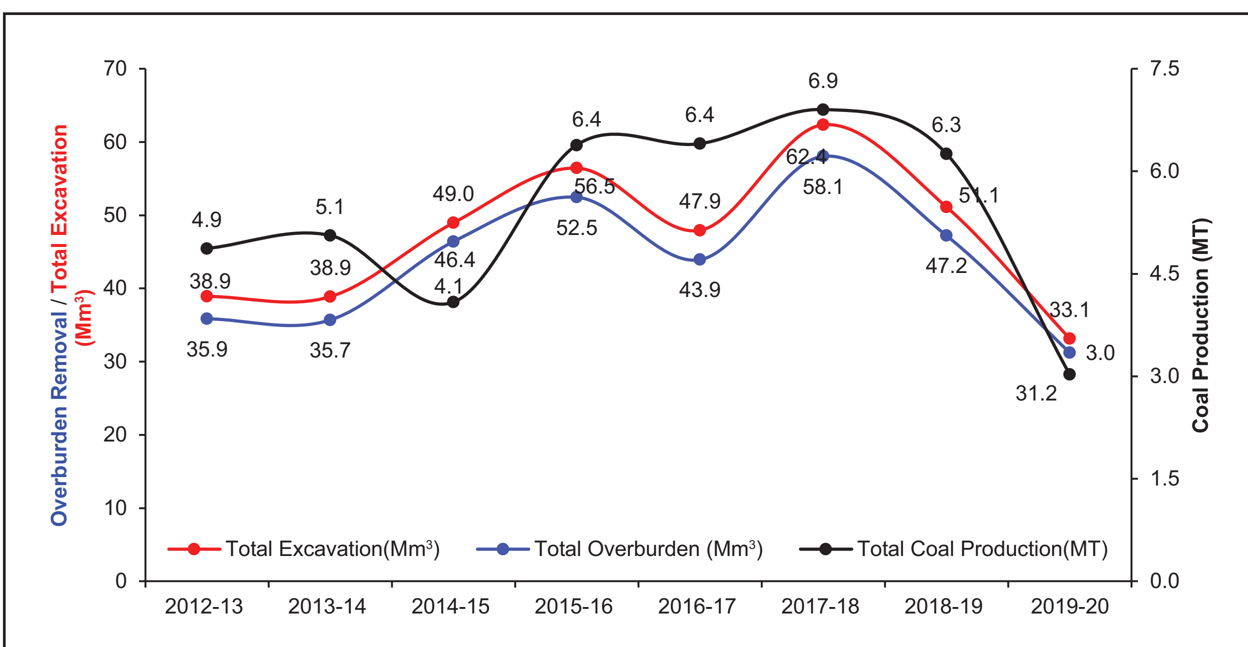

Figure 3: Coal production and overburden removal from Opencast Mines in Study area-1

Table 3: Coal and overburden production from the OCMs in the Dorli- Bellampalli coalfield

Coal Production (MT)					
Year	**Bellampalli OC-II**	**Khairagura Opencast Expansion**	**Dorli - OC I**	**Dorli – OC II**	**Total Production (MT)**
2012-13	-	2.26	1.613	0.997	4.87
2013-14	-	2.97	1.092	0.999	5.06
2014-15	-	2.714	1.146	0.225	4.08
2015-16	-	3.371	2.166	0.847	6.38
2016-17	0.37	3.128	2.626	0.279	6.40
2017-18	0.99	3.414	2.5	-	6.90
2018-19	0.847	2.911	2.498	-	6.25
2019-20	0.406	2.603	0.018	-	3.03
Overburden in Million cubic meters (Mm^3)					
Year	**Bellampalli OC-II**	**Khairagura Opencast Expansion**	**Dorli - OC I**	**Dorli - OC II**	**Total Overburden (Mm^3)**
2012-13	-	10.61	13.55	11.7	35.86
2013-14	-	19.49	6.811	9.4	35.70
2014-15	-	28.46	14.82	3.13	46.41
2015-16	-	24.71	22.7	5.05	52.46
2016-17	6.821	20.088	15.77	1.26	43.93
2017-18	6.648	29.098	22.311	-	58.05
2018-19	7.11	27.48	12.638	-	47.22
2019-20	2.12	29.09	0.04	-	31.24

(Data Sources: SCCL, 2020a; 2020b; 2020c; 2020d)

FY 2018-19, the annual coal production from opencast coal mines in this area increased from 4.9 Million Tons (MT) to 6.3 MT. In addition, the volume of overburden (non-coal material to be excavated to extract the coal in opencast mines) excavated from these opencast coal mines increased from 35.9 million cubic meters (Mm^3) to 47 Mm^3. The total excavation from the opencast mines in the study area increased from 39 Mm^3 during FY 2012-13 to 51 Mm^3 in FY 2018-19. The highest coal production and overburden removal quantities were recorded in FY 2017-18 (6.9 MT and 58.1 Mm^3 respectively) leading to a record high excavation of 62 Mm^3 from the opencast coal mines in this area. However, the lowest coal production and overburden removal quantities were observed in FY 2019-20 due to the complete cessation of Dorli OC-I and Dorli OC-II mine project in study area-2 as shown in Figure 3.

3.3. Air Environment

3.3.1. Ambient air PM concentrations in and around Dorli OC-I and Dorli OC-II

The PM_{10} concentrations in the core zones of Dorli OC-I and Dorli OC-II and in the corresponding buffer zones during the study period (2012-13 to 2019-20) are shown in

Figures 4(a) and 4(b) and Figures 5(a) and 5(b), respectively. The buffer zone of a project includes an area with a radius of 10 km around the mining lease in the case of a mining project. As shown in Figures 4(b) and 5(b), the annual average PM_{10} concentrations in the buffer zone generally exceed the applicable NAAQ standard (60 $\mu g/m^3$) during the mine operation period and comply with the standard only after mine closure. The marked decline in the PM_{10} concentrations during FY 2019-20 is due to the closure of both Dorli OC-1 and Dorli OC-II in May 2019 and April 2017, respectively.

The $PM_{2.5}$ concentrations in the core zones of Dorli OC-I and Dorli OC-II and in the corresponding buffer zones during the study period (2012-13 to 2019-20) are shown in Figures 6(a) and 6(b) and Figures 7(a) and 7(b), respectively. The annual average $PM_{2.5}$ concentrations in the buffer zone generally exceed the applicable NAAQ standard (40 $\mu g/m^3$) during the mine operation period and comply with the standard only after mine closure in May 2019.

The seasonal variations of PM_{10} between 2012 and 2020 are shown in Figures 4(c) and 5(c), while the corresponding $PM_{2.5}$ concentrations are shown in Figures 6(c) and 7(c). Generally, the PM concentrations in the buffer zones of OCMs in the coalfields of India attain a peak during the summer followed by winter. This indicates that Environmental Impact Assessment (EIA) studies should generally be carried out during summer season in coal mines in India to assess the air pollution scenario under adverse climatological conditions. MoEFCC can consider changing their mandate for EIA studies accordingly.

3.3.2. Ambient air concentrations of airborne pollutants in Study area-1 (Dorli-Bellampalli Coalfield)

Since ambient air monitoring stations in the buffer zone of coal mines in India are generally set up in the neighbouring villages based on the wind direction in the proximity of the mine, the ambient air concentrations in the buffer zones of the four opencast coal mines in the Dorli-Bellampalli coalfield have been analysed in this section. The ambient air concentrations of PM_{10}, $PM_{2.5}$, and SO_2 in the buffer zones of the entire Dorli-Bellampalli Coalfield are shown in Figures 8, 9, and 10.

As shown in Figures 8 and 9, the airborne PM concentrations in the buffer zones of OCMs in the Dorli-Bellampalli coalfield exceed the applicable NAAQ standards (60 $\mu g/m^3$ for PM_{10} and 40 $\mu g/m^3$ for $PM_{2.5}$) during the operation period of the Dorli I and Dorli II OCMs. The drop in PM concentrations from FY 2018-19 onwards (Figures 8 and 9) is due to the closure of Dorli II OCM (in March 2017) and Dorli I OCM (in March 2019). This indicates the need for increasing the frequency of measurement (and reporting) of airborne PM concentrations in coal mines from the current fortnightly frequency to a bi-weekly frequency (as in the case of Thermal Power Plants). Therefore, MoEFCC may consider changing the frequency of air pollutant measurements in coal mines since the current Standards were issued by the Government of India on September 5, 2000, more than 20 years ago (CPCB, 2000).

Further, the prevalence of higher-than-standard airborne dust concentrations in the buffer zones of the OCMs in Study area 1 indicates the need for better dust control arrangements in OCMs

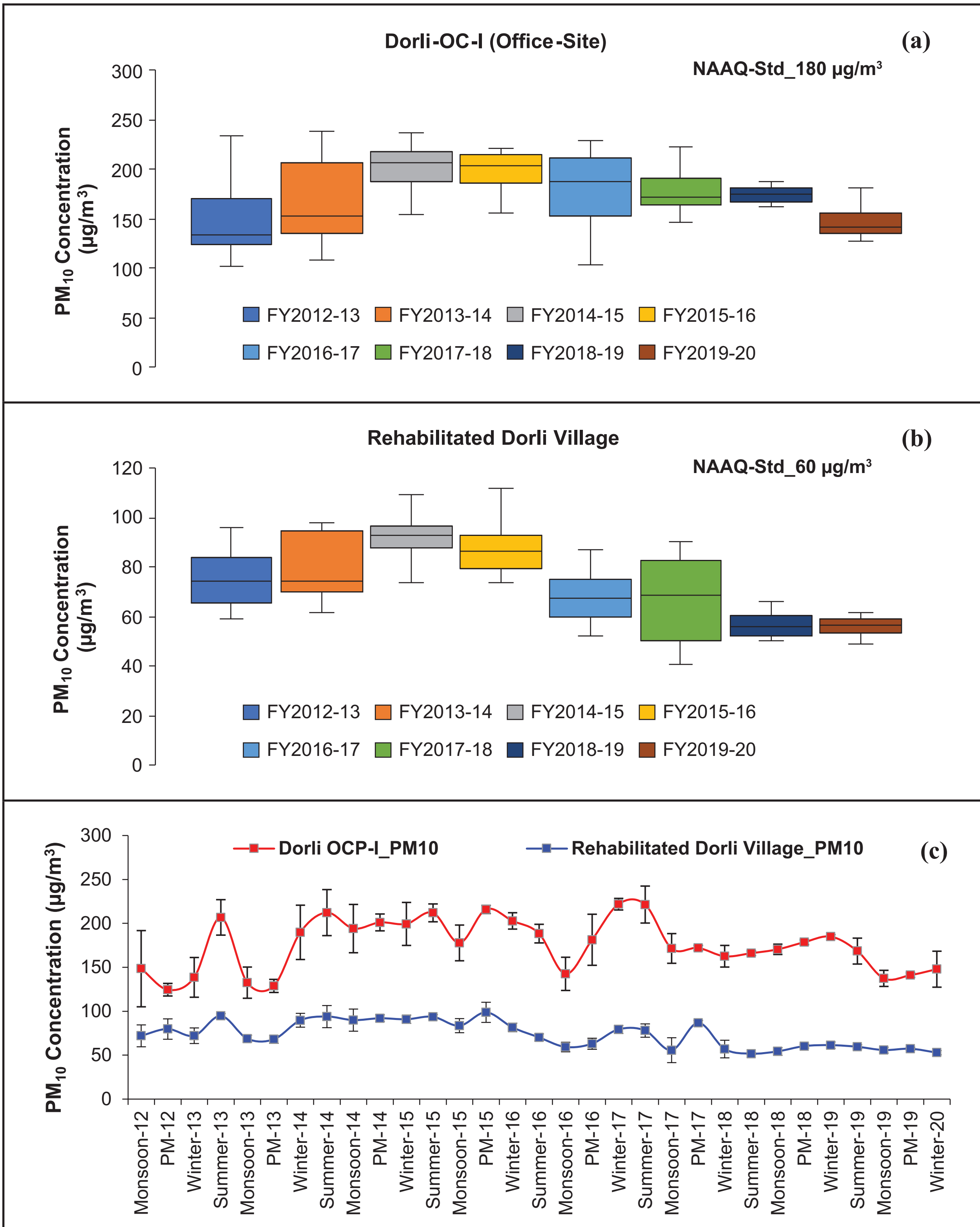

Figure 4: Annual average PM_{10} concentrations (a) in the core zone of Dorli OC-I; (b) in the buffer zone of Dorli OC-I (rehabilitated Dorli village); (c) Seasonal average PM_{10} concentrations in the core and buffer zones of Dorli OC-1

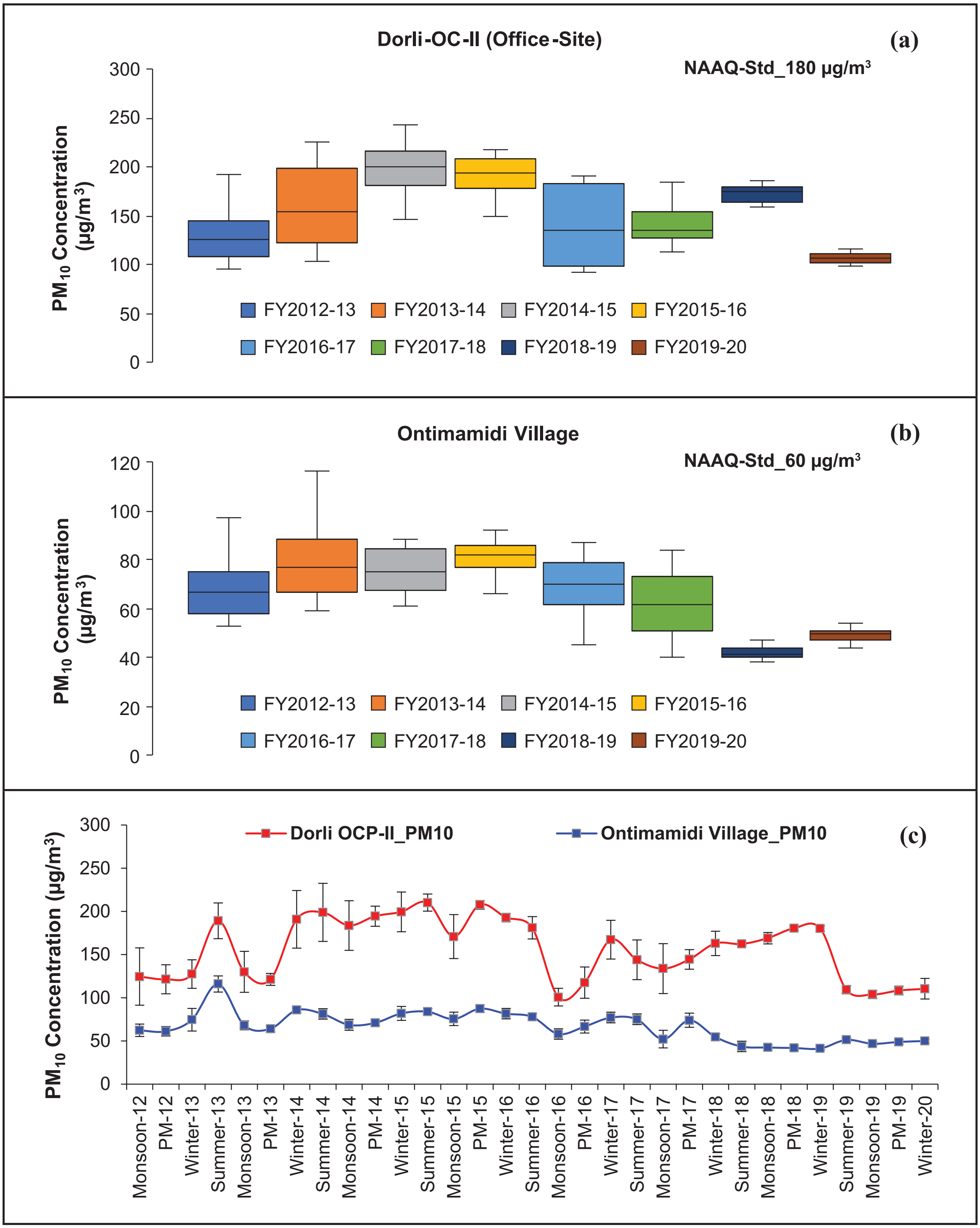

Figure 5: Annual average PM_{10} concentrations (a) in the core zone of Dorli OC-II; (b) in the buffer zone of Dorli OC-II (Ontimamidi village); (c) Seasonal average PM_{10} concentrations in the core and buffer zones of Dorli OC-II

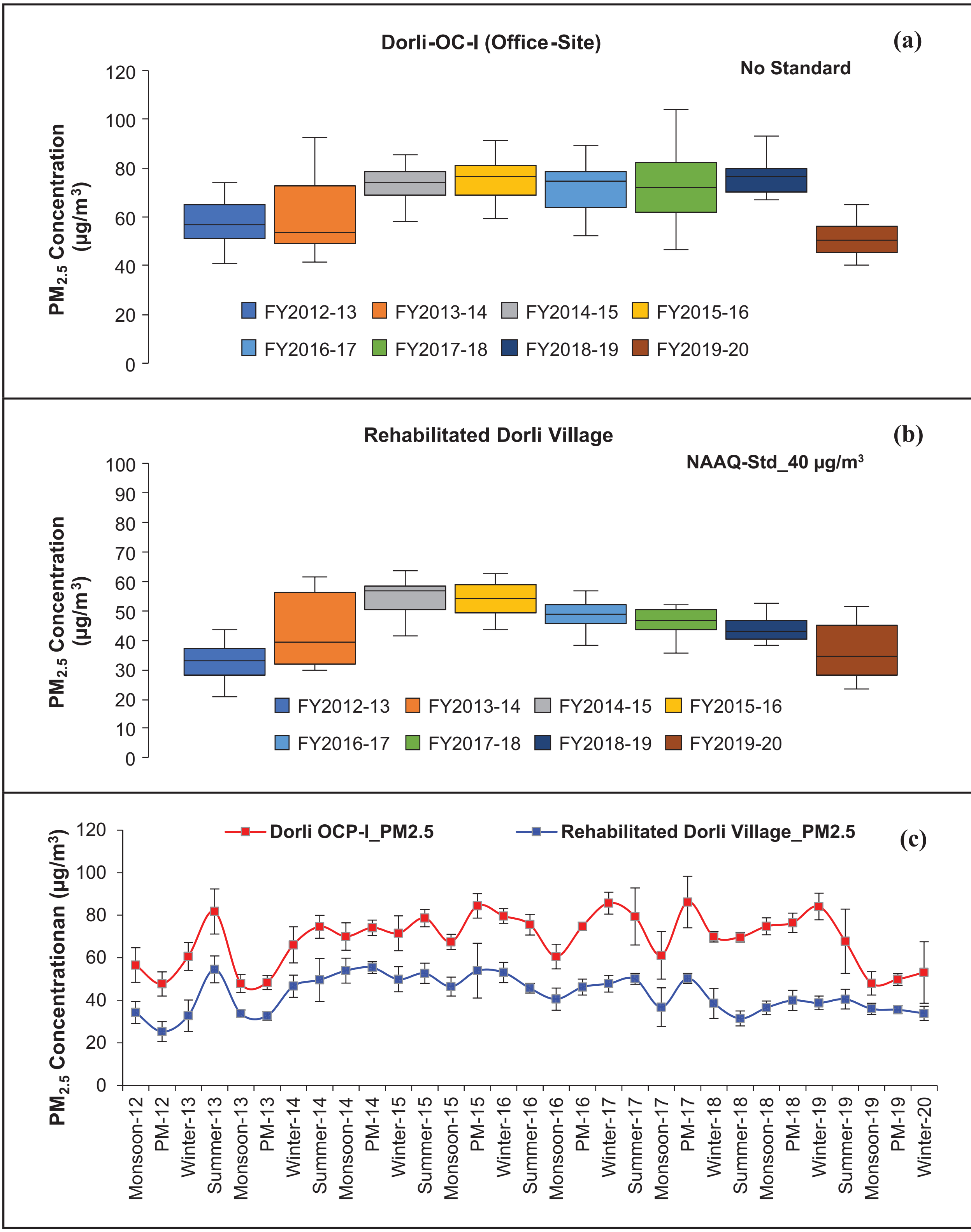

Figure 6: Annual average $PM_{2.5}$ concentrations (a) in the core zone of Dorli OC-I; (b) in the buffer zone of Dorli OC-I (Rehabilitated Dorli Village); (c) Seasonal average $PM_{2.5}$ concentrations in the core and buffer zones of Dorli OC-1.

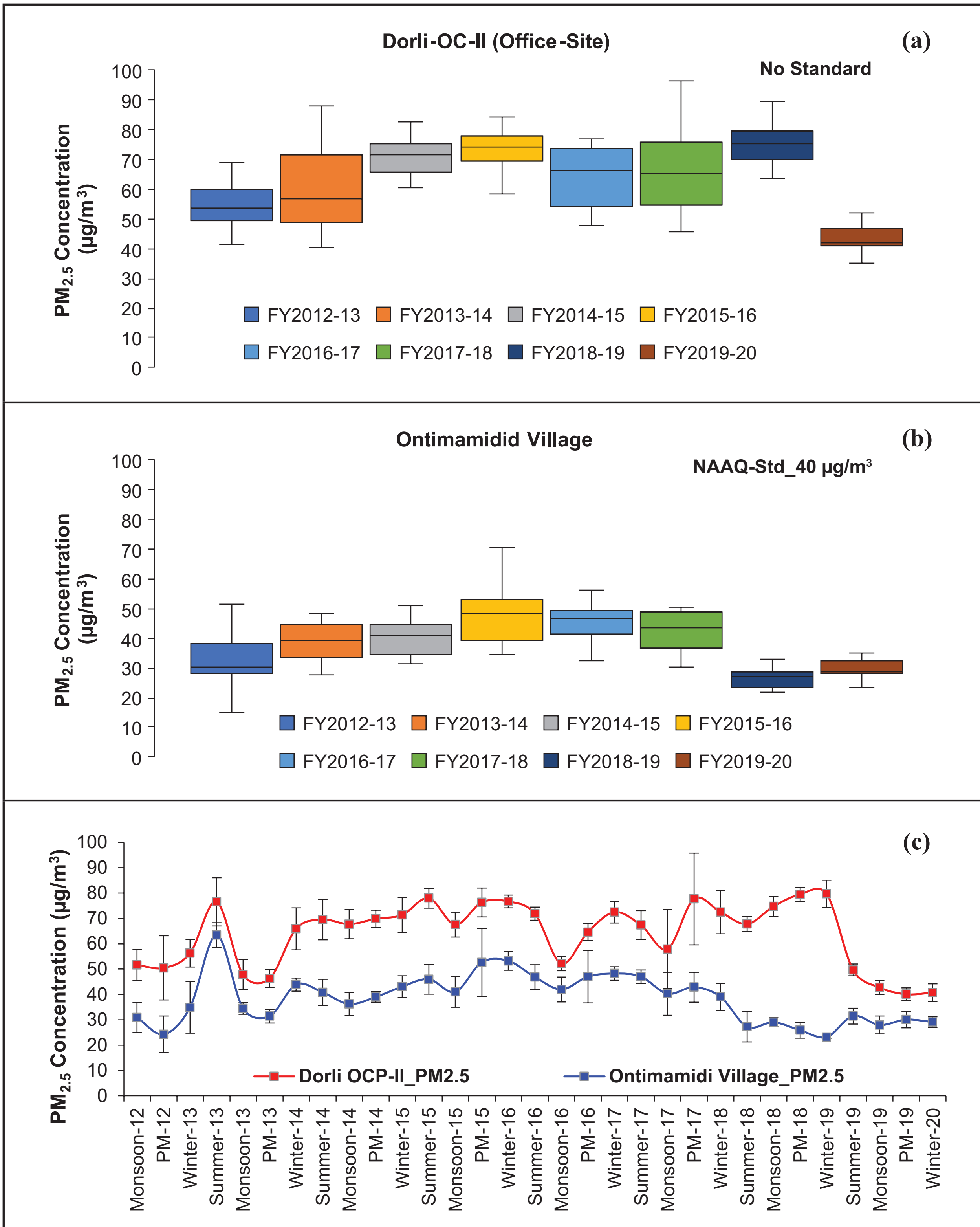

Figure 7: Annual average $PM_{2.5}$ concentrations (a) in the core zone of Dorli OC-II; (b) in the buffer zone of Dorli OC-II (Ontimamidi Village); (c) Seasonal average $PM_{2.5}$ concentrations in the core and buffer zones of Dorli OC-II

including, dust suppression arrangements on haul roads, reduction of traffic density on haul roads, wet drilling, etc., during mining operations (DNRME, 2019; OMSHR, 2014; Stanton *et al,* 2006). Besides, the villages in the buffer zone must be shielded from the dust generated in the OCMs with a suitable green belt. However, as shown in Figure 10, the annual SO_2 concentrations in the Dorli-Bellampalli coalfield are far below the standard of 50 µg/m^3.

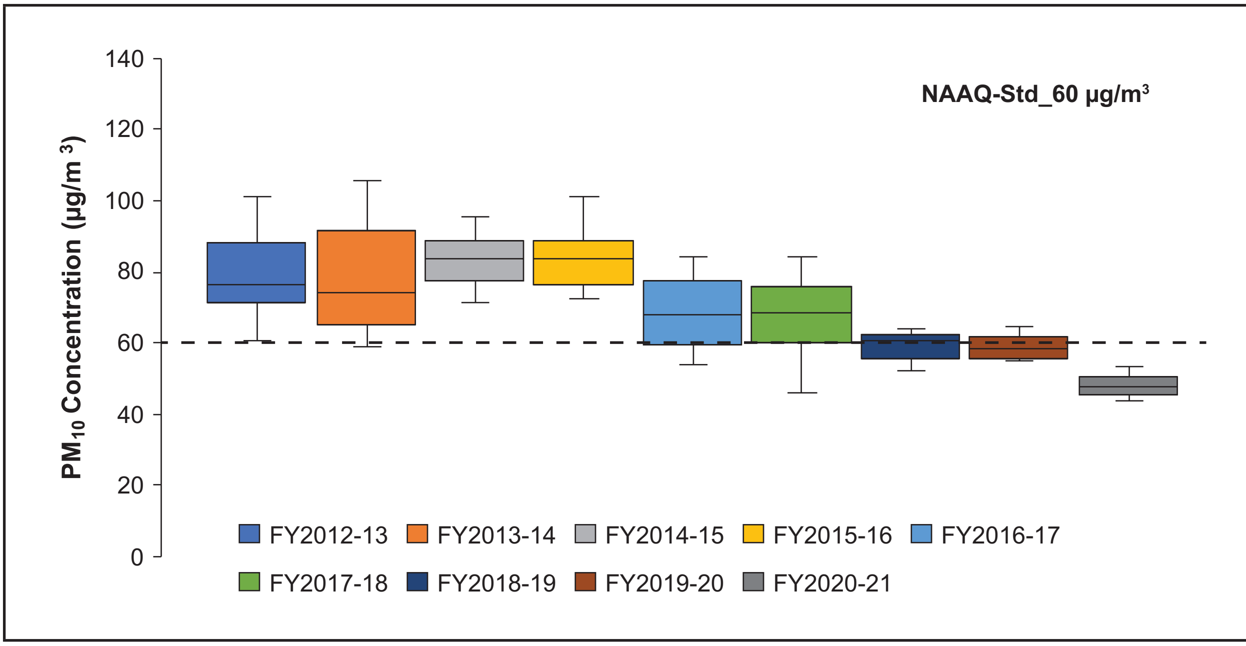

Figure 8: PM_{10} concentrations in the buffer zone of OCMs in Study area-1

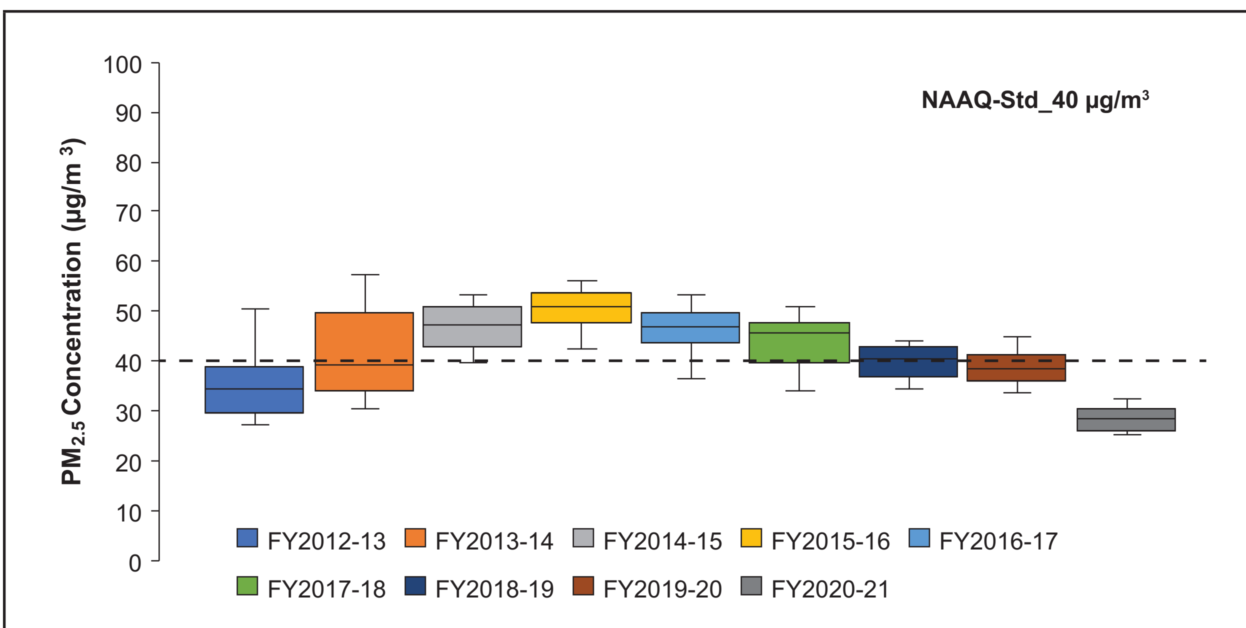

Figure 9: $PM_{2.5}$ concentrations in the buffer zone of OCMs in Study area-1

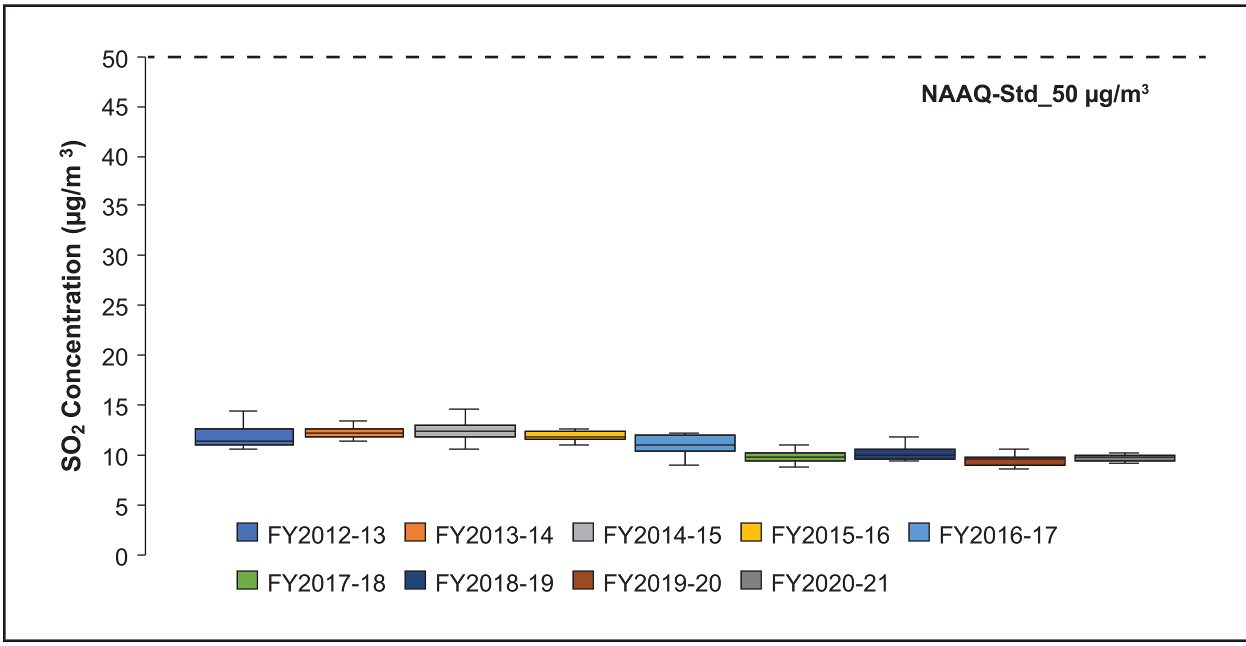

Figure 10: SO_2 concentrations in the buffer zone of OCMs in Study area-1

3.3.3. Spatial analysis of the ambient air concentrations in the Dorli-Bellampalli coalfield

The Inverse Distance Weighted (IDW) method is a spatial interpolation technique that has been used in conjugation with GIS software to create visually comparable choropleth maps. Maps prepared using the IDW technique are used for visualizing air pollution data to understand the spatial distribution of pollutant concentrations (Gomez-Losada *et al*, 2019; Jumaah *et al*, 2019; QGIS Documentation, 2021).

Spatial distributions of the airborne pollutant concentrations (annual average) during the years FY 2016-17 and 2019-20 in Study area-1 are analyzed using the IDW technique as shown in Figure 11 and Figure 12. During the year FY 2016-17, all four OCMs in Study area-1 were in operation, while in the year FY 2019-20, both Dorli I and Dorli II OCMs were closed. The impact of mining operations on the air environment in the area is very evident from this analysis.

Table 4: LULC Change detection in Dorli-I OC and Dorli-II OC coal mines in Study area-1

Year	Plantation (Ha)		Water Bodies (Ha)	
	Dorli-I	Dorli-II	Dorli-I	Dorli-II
2015	19.33	27.86	3.33	6.36
2020	53.27	103.67	17.59	18.72
Change	33.94	75.81	14.26	12.36
Change (%)	**176%**	**272%**	**428%**	**194%**

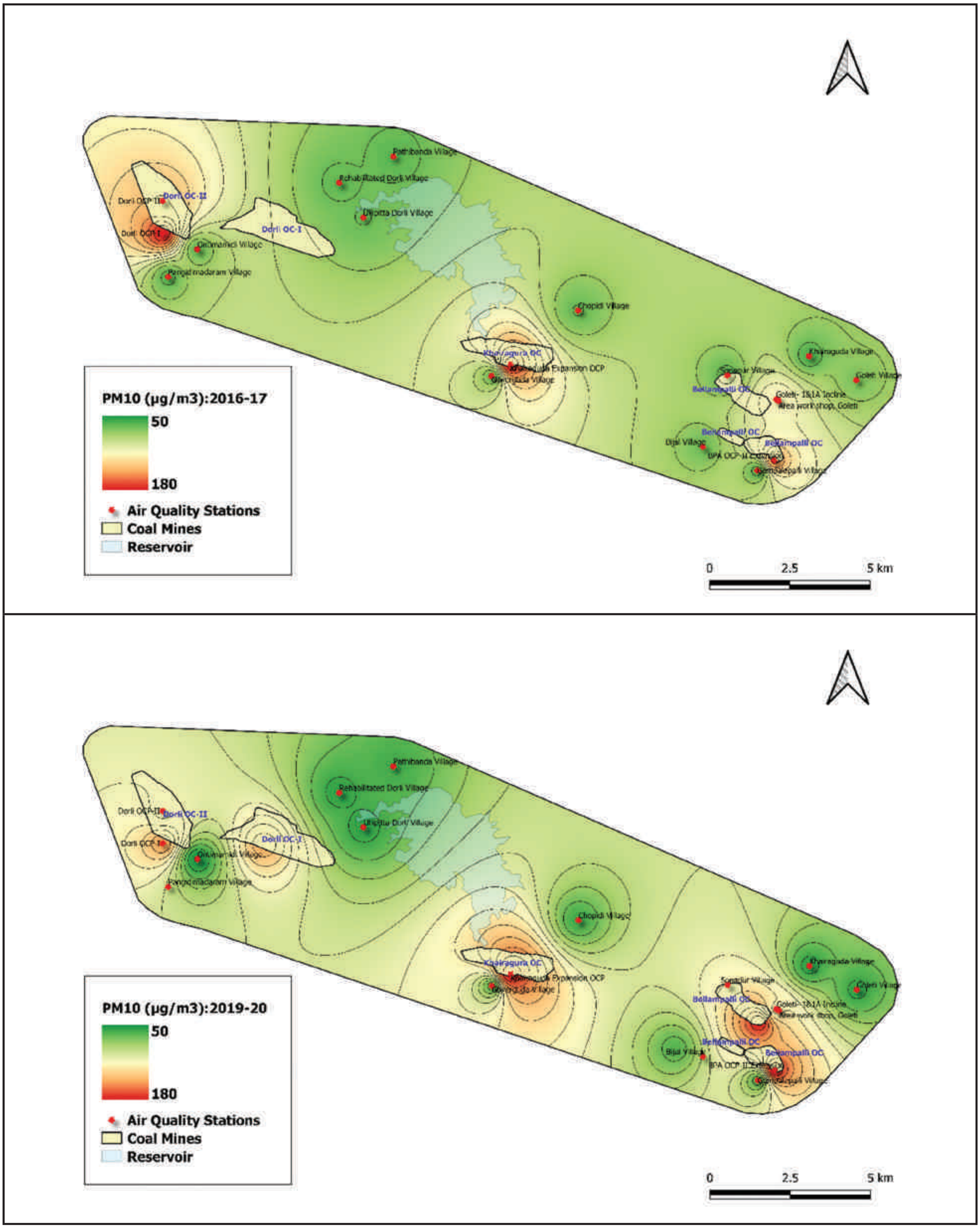

Figure 11: Spatial variability in PM_{10} concentrations during (a) FY 2016-17 and (b) FY 2019-20 before and after closure of Dorli I OC and Dorli II OC coal mines

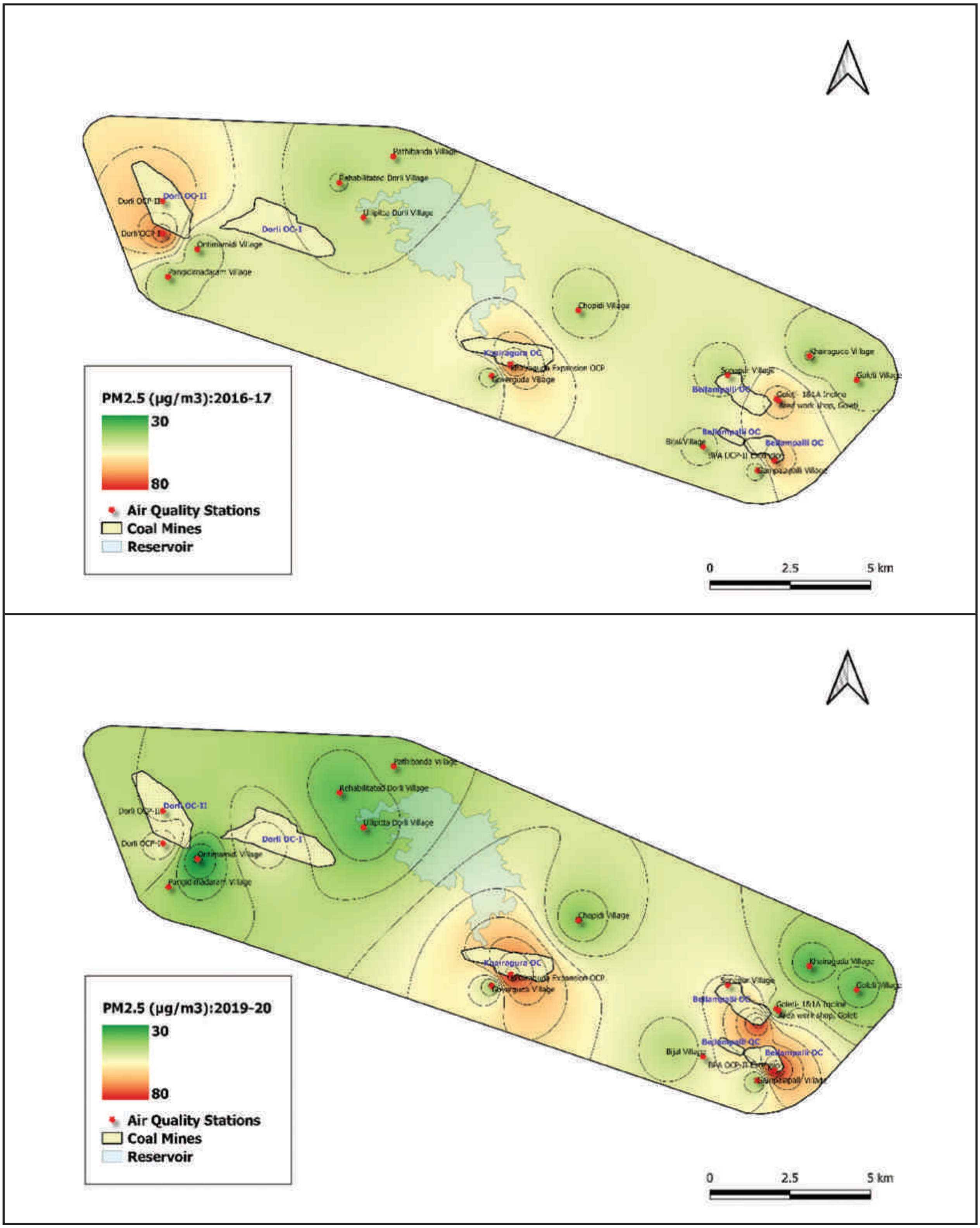

Figure 12: Spatial variability in $PM_{2.5}$ concentrations during (a) FY 2016-17 and (b) FY 2019-20 before and after closure of Dorli I OC and Dorli II OC coal mines

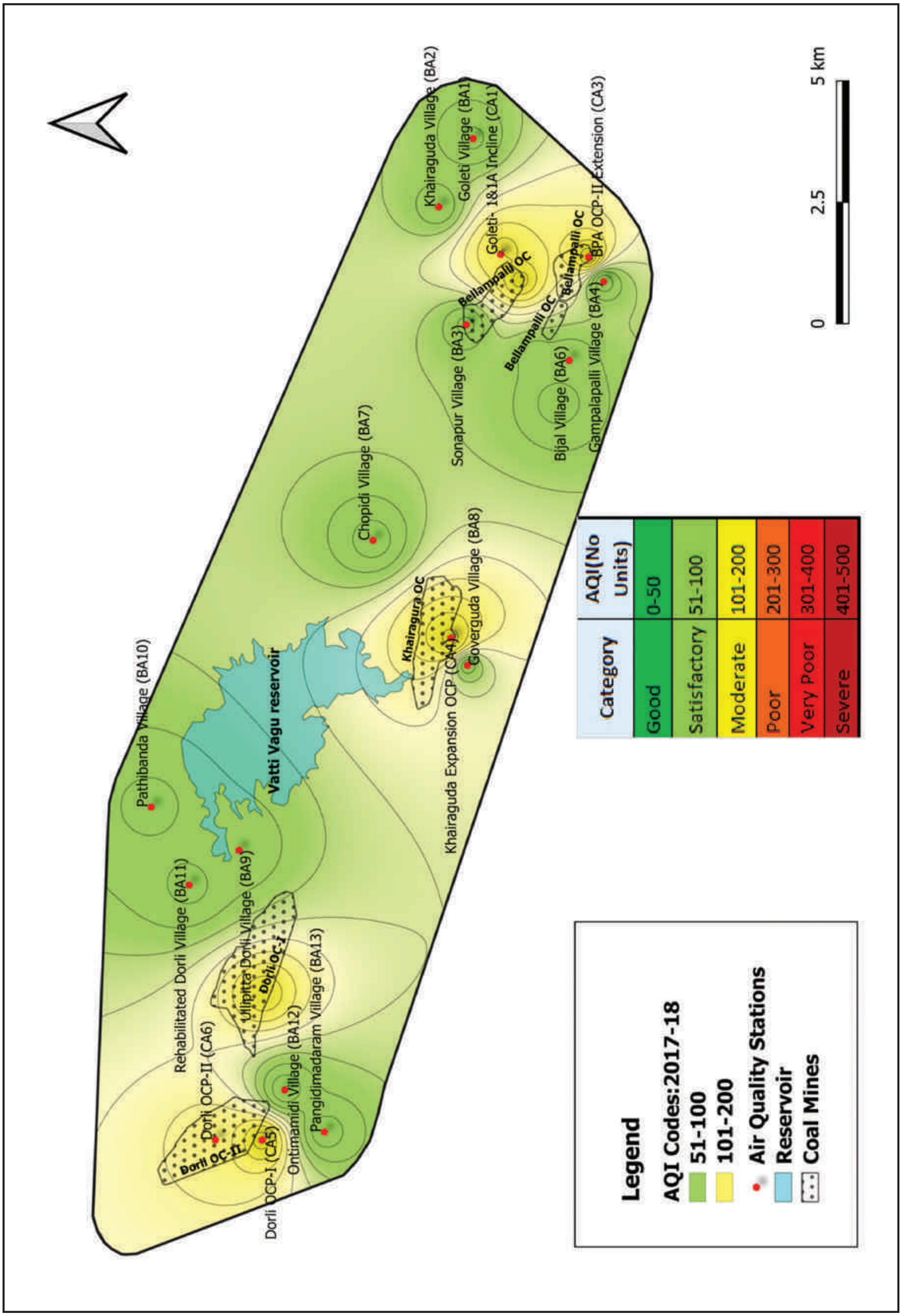

Figure 13: Spatial distribution of Air Quality Index (AQI) at the peak of mining activities in the Study area during FY 2017-18

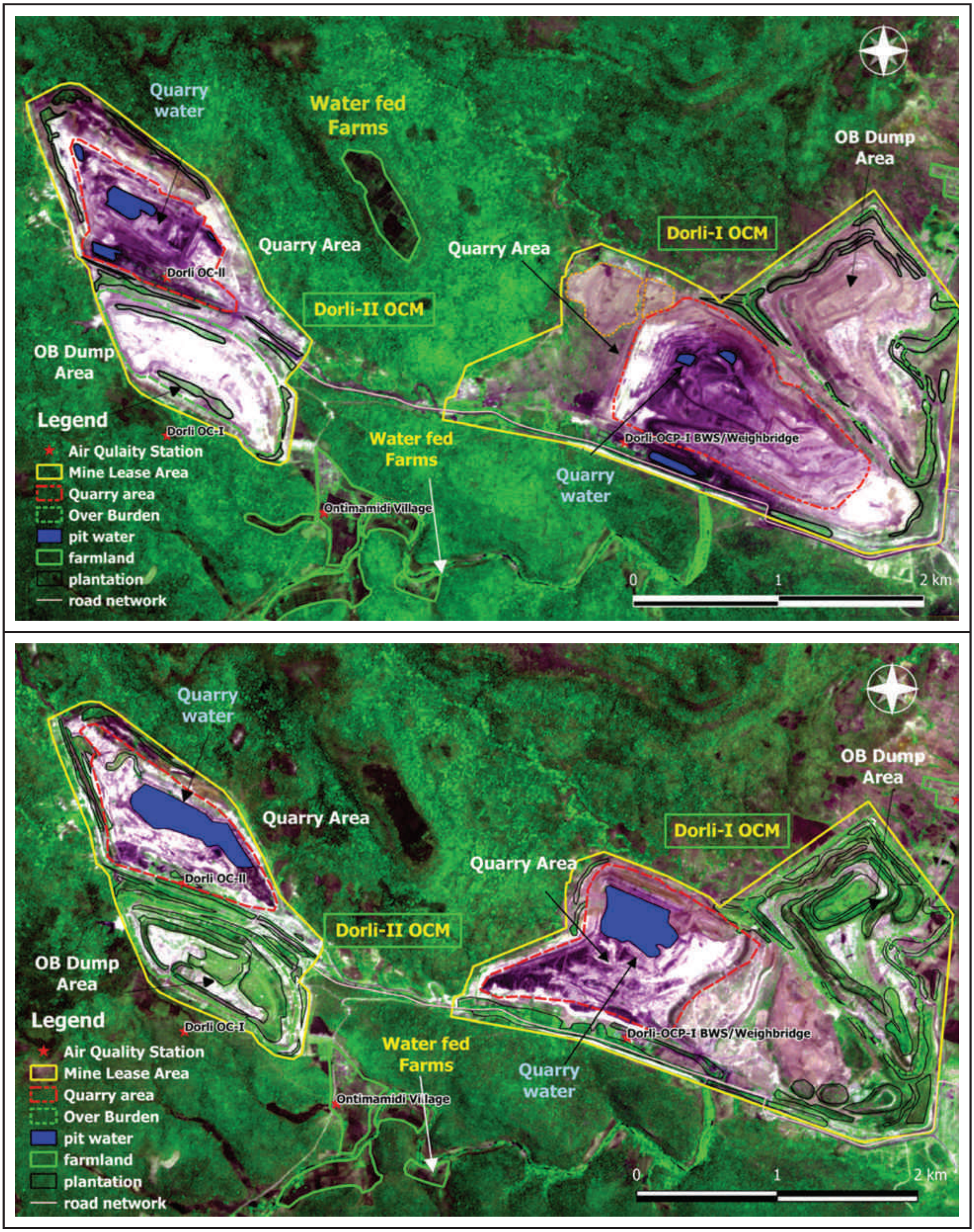

Figure 14: Satellite images of Dorli I OC and Dorli II OC: (a) during active mining in May 2015; (b) in January 2020 during the closure process of Dorli I OC and Dorli II OC coal mines

3.3.4. Air Quality Index (AQI) in Study area-1

Air Quality Index (AQI) is one of the primary tools for the assessment of ambient air quality (Gufran Beig *et al.*, 2010; Kyrkilis *et al.*, 2007; Mirabelli *et al.*, 2020; Sharma *et al.*, 2019). In this study, AQI calculations are carried out using the IND-AQI procedure based on the measurement of four criteria pollutants (PM_{10}, $PM_{2.5}$, SO_2 and NO_2) in the study area during the year 2017-18 (CPCB, 2014). The annual average AQI at each of the 24 AAQM stations set up by SCCL's four coal mines in the Study area is calculated based on the 24-hour average concentrations of four criteria pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NO_2) measured at fortnightly intervals throughout FY 2017-18 (24 sets of measurements at each AAQM station). The year 2017-18 is selected since the mining activities in the Study area (reflected in the cumulative total excavation quantity from the OCMs) reached a maximum during this year (Figure 13).

GIS techniques are applied to examine the spatial pattern of air pollution in this area during the year FY 2017-18 (Dadhich *et al.*, 2018). Specifically, the Inverse Distance Weighted (IDW) tool in-built with GIS software (QGIS version 3.x) is used to analyze the spatial variability of AQI in the study area due to the impact of airborne pollution caused by mining activities (Documentation QGIS3, 2021). As shown in Figure 13, the overall AQI in the core zone (mining lease area) is in the moderately-polluted category (AQI: 101-200) while it is in the satisfactory category (AQI: 51-100) in the buffer zone. At each AAQ monitoring location, the $PM_{2.5}$ concentrations have the highest sub-indices in the AQI determination. Therefore, $PM_{2.5}$ is the critical pollutant to be controlled in this area.

The Indian Space Research Organization (ISRO) operates the "Resourcesat – 1" satellite to provide imageries of the earth's surface with advanced on-board sensors like the Linear Imaging and Self Scanning Sensor (LISS-III) and the High-Resolution Multispectral Sensor (LISS-IV) which can provide a ground resolution of 5.8 m (NRSC, 2021). The post-interpretation LISS 4 images of Dorli I and II procured from the National Remote Sensing Centre (NRSC) of ISRO are shown in Figures 14(a) and 14(b) to understand the major changes in the core zone of these OCMs between April 2017 and May 2019. The overall LULC change (%) in Dorli OC-I and Dorli-OC-II in year 2015 and 2020 is given in Table 4. As shown in Figure 14(b), SCCL has achieved some success in reclaiming and revegetating the overburden dumps.

3.3.5. Spatial analysis of the Normalized Difference Vegetation Index (NDVI) levels in the Dorli-Bellampalli coalfield

NDVI maps of Study area-1 used to study the seasonal and anthropogenic changes due to coal mining activities in this area are shown in Figure 15. Specifically, the impact of different seasons on the vegetation cover in Study area-1 is evident from the satellite images taken during the Kharif Season (Oct, Nov, Dec, Jan) and the Rabi Season (Mar, April, May, June) in FY 2005-06, FY 2012-13, and FY 2020-21, which represent the pre-mining, during-mining, and post-mining scenarios in this area, respectively.

The NDVI data averaged during each of these years - FY 2005-06 (before Dorli OC I commences), during operations of both Dorli OCMs (FY 2012-13), and post-closure of the two Dorli OCMs (FY 2019-20) is shown in Figures 16 (a), (b), and (c). The pre-mining (FY

2005-06), during-mining (FY 2012-13) and post-mining (FY 2019-20) annual average NDVI values for these three scenarios are extracted from Figures 16 (a), (b), and (c).

According to SCCL's submissions to MoEFCC, 7,38,415 seedlings have been planted on the Dorli OC-I overburden dump (328.62 Ha area) between 2008 and 2019, while 85,729 saplings have been planted on Dorli OC-II overburden dump (139.32 Ha area) between 2013 and 2019 (SCCL, 2020a). Proper selection of plant species which can grow easily in the local soil and environment conditions is very important (Kiranmay Sharma, 2005).

While the survival rate of these seedlings planted by SCCL is not known, the sharp increase in NDVI values (for each season) in Dorli OC-I and Dorli OC-II post-closure as shown in Table 5 is due to SCCL's success in systematic revegetation of the overburden dumps in these two OCMs. The United States Department of Agriculture has published their recommendations on revegetation of mined-out land (FRA, 2016). MoEFCC must commission such studies across coal mines in India to increase green cover and reduce the risk of climate change by enhancing the carbon sink potential in our coal mines post-closure.

However, as shown in Table 5, there is no change in NDVI values in the buffer zones (within a radius of 10 km from the ML boundary) or in the undisturbed zone (10 – 15 km from the ML boundary) of Study area-1. This shows that the radial extent of the impact of air pollution from coal mines on the vegetation in Study area 1 is limited to the core zone. Such studies must be conducted by MoEFCC across other coalfields in India before this finding can be generalized.

The impact of mining operations and mine closure on the vegetation in Study area-1 is more clearly illustrated in Figure 17 where multiple values of NDVI extracted from Dorli I OCM, Dorli II OCM, the buffer zone around these OCMs, and the undisturbed area around these OCMs, are averaged to derive an annual average for each area from FY 2004-05 (before commencement of mining operations in the Dorli OCMs) to FY 2019-20 (post-closure of Dorli OCMs). The sharp decrease in the NDVI from FY 2008-09 (opening of Dorli OC-I) and FY 2012-13 (opening of Dorli OC-II) and the increase in FY 2019-20 (closure of Dorli OC-I after Dorli OC-II) indicates the potential for NDVI to be used as one of the indicators of a sustainable ecosystem post-closure. Further, the lack of any noticeable change in the NDVI values in the buffer and undisturbed zones indicates the localized impact of coal mining operations on the vegetation in Study area-1.

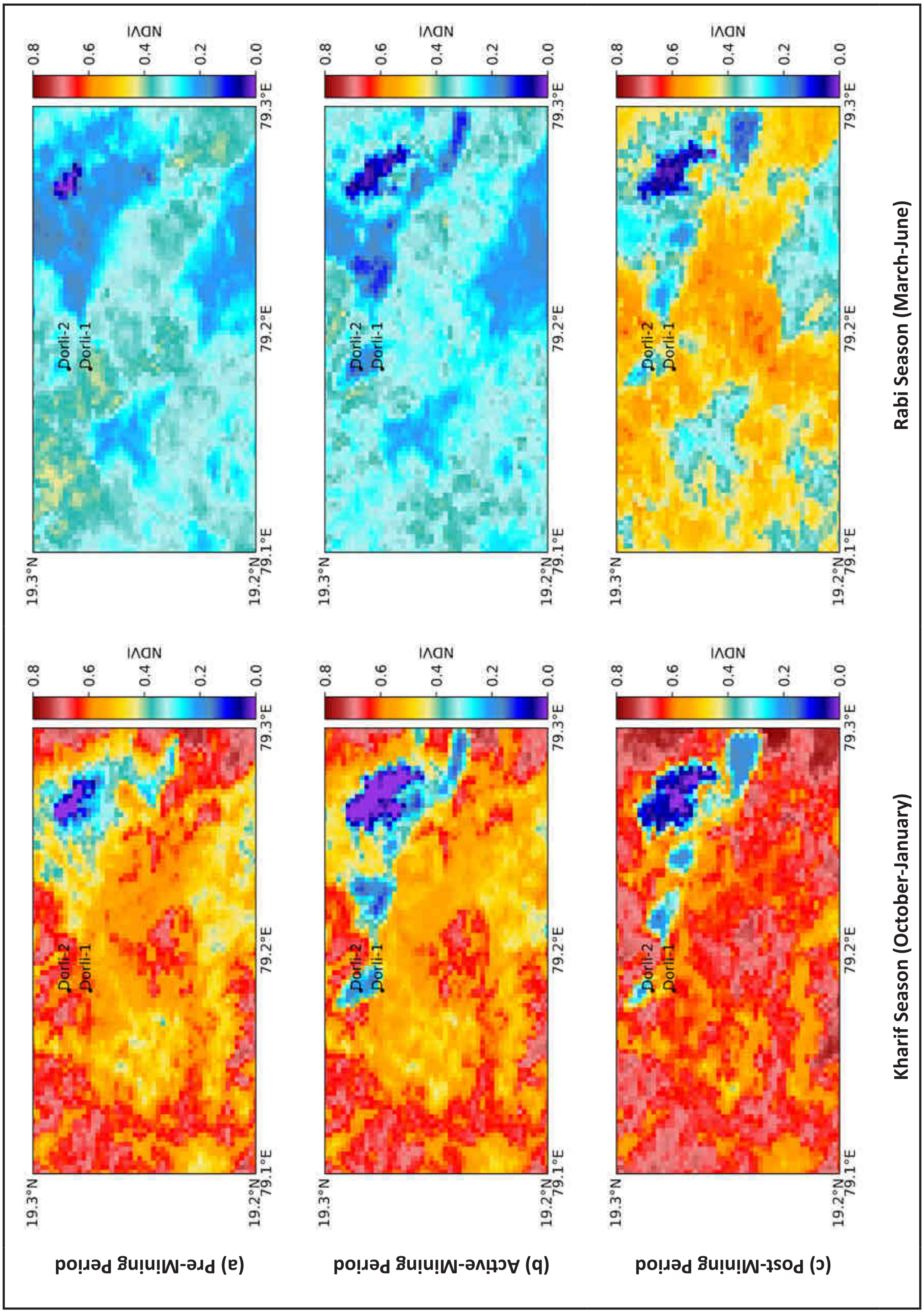

Figure 15: NDVI values in Study area-1 (a) before Dorli OC-I opening (2005-06); (b) during operations of Dorli OCMs (2012-13) and (c) post-closure of Dorli OCMs (2020-21) during the Kharif Season (Oct, Nov, Dec, Jan) and the Rabi Season (Mar, April, May, Jun)

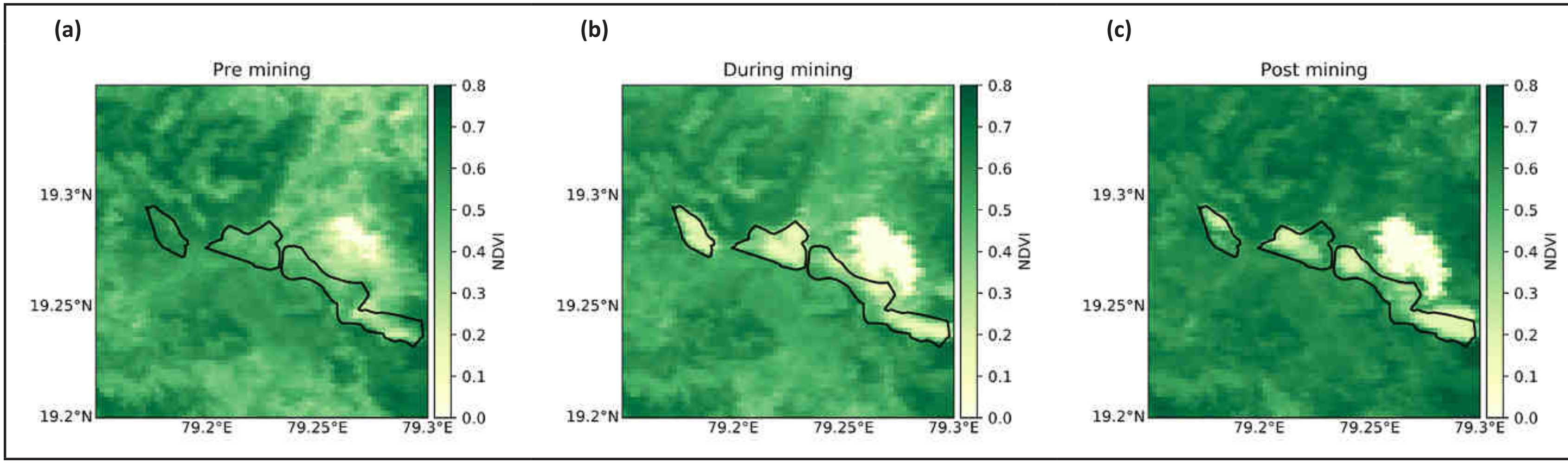

Figure 16: Impact of mining activities in Dorli I OC and Dorli II OC on MODIS-NDVI values in the Study area: (a) pre-mining (FY 2005-06), (b) during mining (FY 2012-13), and (c) during the closure process of both Dorli I OC and Dorli II OC (FY 2019-20)

Table 5: Average MODIS-NDVI values: pre-mining, during mining, and post-mining in the core, buffer and undisturbed zones of Study area-1

Season	Pre-Mining MODIS-NDVI values				MODIS-NDVI values (during mining)				MODIS-NDVI values (post-mining)			
	Dorli OC-I	Dorli OC-II	Buffer Zone	Undisturbed Zone	Dorli OC-I	Dorli OC-II	Buffer Zone	Undisturbed Zone	Dorli OC-I	Dorli OC-II	Buffer Zone	Undisturbed Zone
Winter (D, J, F)	0.33	0.43	0.43	0.43	0.17	0.21	0.43	0.44	0.46	0.37	0.47	0.47
Summer (M, A, M)	0.24	0.36	0.37	0.33	0.16	0.17	0.38	0.35	0.31	0.27	0.37	0.34
Monsoon (J, J, A, S)	0.41	0.61	0.51	0.50	0.22	0.24	0.51	0.50	0.50	0.44	0.53	0.53
Post-Monsoon (O, N)	0.49	0.69	0.65	0.65	0.21	0.23	0.64	0.66	0.61	0.51	0.68	0.71

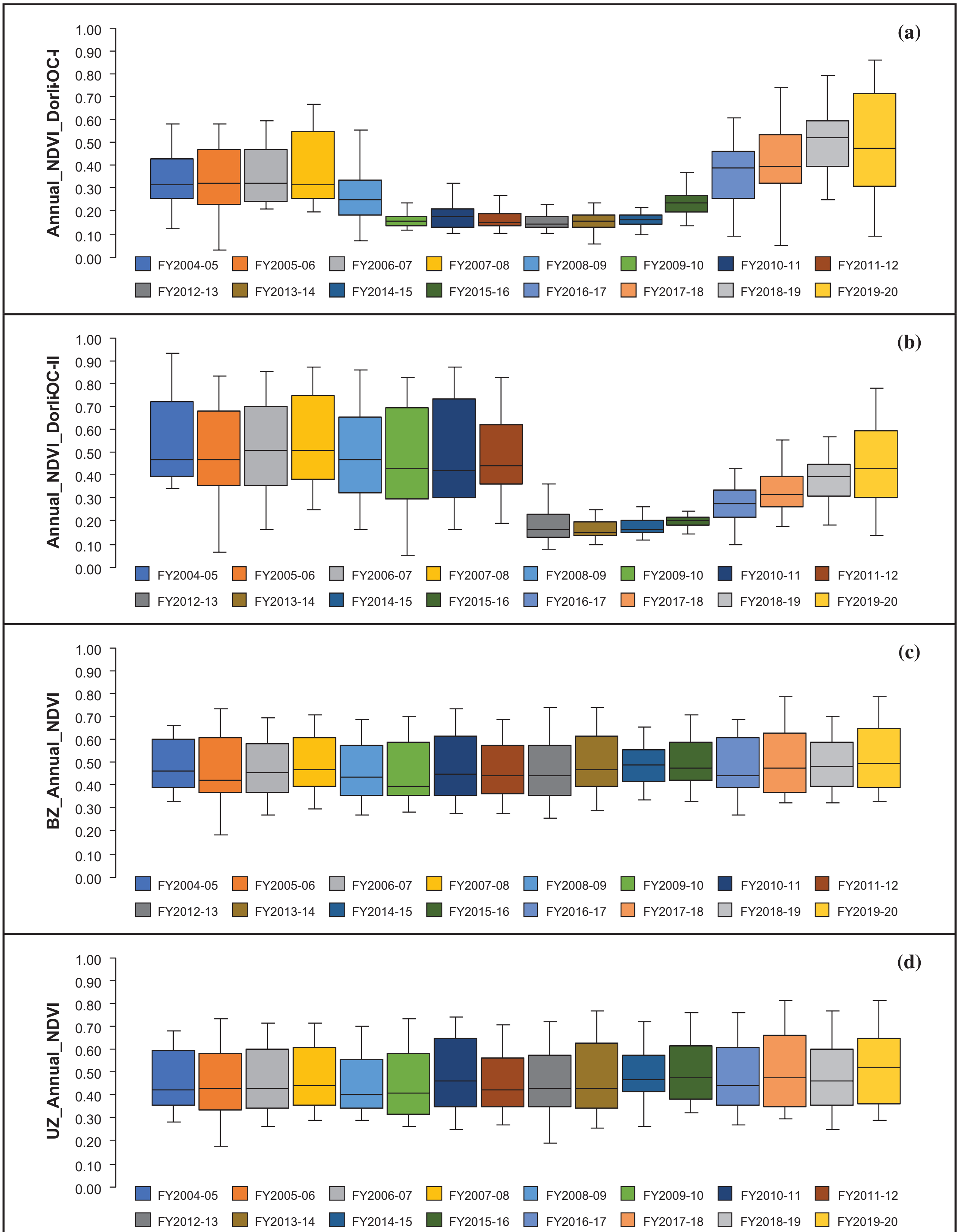

Figure 17: MODIS-NDVI values in the core zone of (a) Dorli-OC-I; (b) Dorli-OC-II; (c) buffer zones (< 10 km of the ML) and (d) undisturbed zone (10-15 km of the ML)

3.3.6. Correlation between PM_{10} concentrations and NDVI

The correlation between NDVI and PM_{10} in the core zone and buffer zone of opencast coal mines is also examined in this study. The monthly average PM_{10} concentrations and corresponding NDVI values in the core zones of Dorli OC-I and Dorli OC-II are plotted in Figure 18. Similarly, the monthly average PM_{10} concentrations and corresponding NDVI values in the buffer zones of Dorli OC-I and Dorli OC-II are plotted in Figure 19.

As explained in Sections 3.3.5, and 3.3.6 of this report, the seasonal impact on PM concentrations as well as NDVI is quite pronounced in coal mines in India. However, the NDVI values are also affected by mining activities which generate

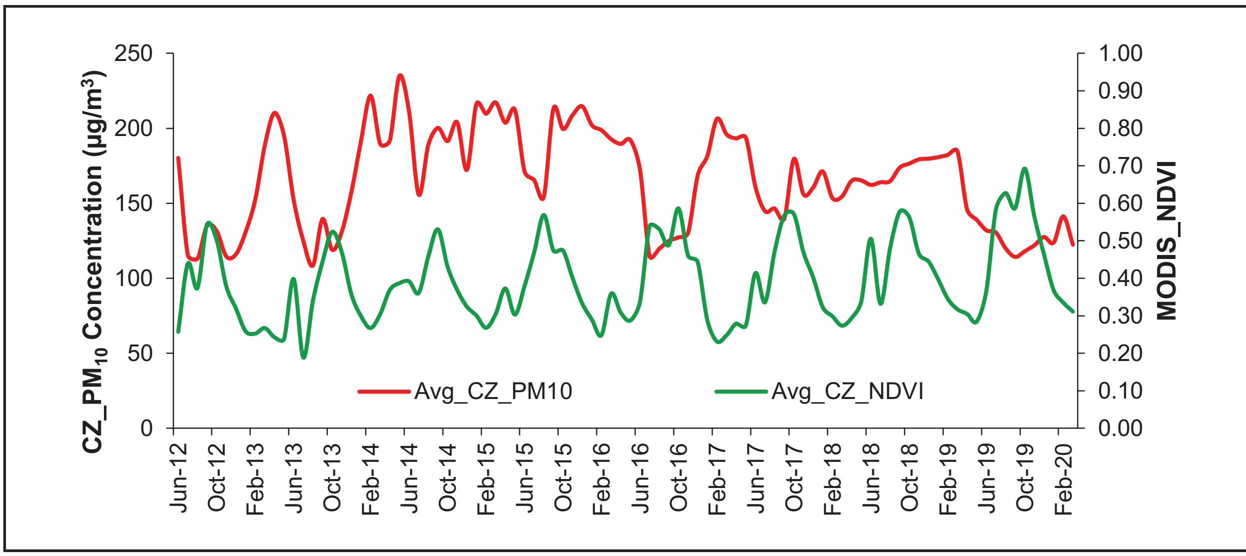

Figure 18: Monthly-average PM_{10} concentrations and MODIS-NDVI values in the core zones of Dorli-I OC and Dorli-II OC between June 2012 and March 2020

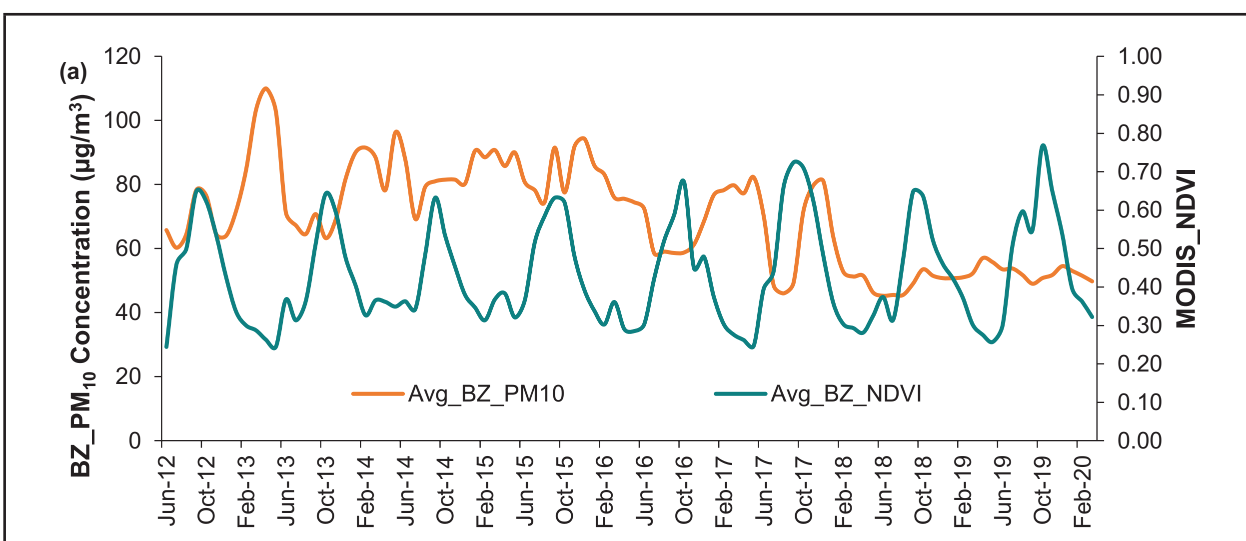

Figure 19: Monthly-average PM_{10} concentrations and MODIS-NDVI values in the buffer zones of Dorli-I OC and Dorli-II OC between June 2012 and March 2020

PM pollution. NDVI is found to be negatively correlated with PM_{10} concentrations in the core zones of Dorli OC-I (r = -0.428) and Dorli OC-II (r = -0.443). These correlations are significant at the 99 percent ($p < 0.01$) level. However, while the PM_{10} concentrations in the buffer zones of Dorli OC-I and Dorli OC-II decreased gradually from December 2017 after the closure of both Dorli OC-I and Dorli OC-II in May 2019, the NDVI values remain unchanged (barring the normal seasonal variations) throughout the period 2012-13 to 2019-20 (Figure 19). This indicates that mining activities in Study area-1 did not affect the vegetation outside the core zone.

4. Study Area-2

4.1. Details of Study area-2 (Mandamari-Srirampur-Ramagundam Coalfield)

Study area 2 covers an area of approximately 3762 km^2 in the Mancherial and Peddapalli districts in Telangana and is bound by Latitudes 18°31'6.24" N to 19°4'48.36" N and Longitudes 79° 13'11.28" E to 79°47'48.48" E. (Seetharam and H. Ramakrishna, 2016; Garai and Narayana, 2018). Study area-2 contains five OCMs and 19 underground coal mines as well as three coal-fired Thermal Power Plants (TPPs) operated by three Government companies (viz., TSGENCO, NTPC Ltd., and SCCL) which depend on the adjacent coal mines for their fuel supplies. NTPC Ltd is a Government Company (in which the Government of India (GOI) owns more than 56 percent of the shares) operates a 2600 MW (3 x 200 MW + 4 x 500 MW) TPP commissioned in three stages between 1983 and 2004. Singareni Collieries Company Limited (SCCL) is a Joint Venture of the Government of Telangana and the GOI which owns all the coal mines in the Study area and has also commissioned a 1200 MW (2 x 600 MW) thermal power plant in December 2016 to meet the shortfall of power in Telangana. Telangana State Power Generation Corporation Limited (TSPGENCO) also operates a TPP with a capacity of 62.5 MW in this area. The locations of these coal mine clusters and major TPPs and their respective Ambient Air Quality Monitoring (AAQM) sites are depicted in Figure 20. The co-location of coal mines and TPPs in this area makes it an ideal location to assess the combined impact of coal mining and power generation on ambient air quality.

4.2. Coal production and overburden removal in Study area-2

The increasing trend in coal production and overburden removal from clusters of OCMs has led to the release of large amount of dust (coal and topsoil removal) pollutants which pose a negative impact on air quality around mines and nearby village areas. Over exploitation of natural resources can degrade the environment. Garai and Narayana (2018) studied the effect of coal mining on the land use/land cover and the regional environment in the Godavari coal field area between 1990 and 2014. As the mining area increased from 0.04% in 1990 to 0.23% of the total coalfield area in 2014, forest cover decreased from 36.38% in 1990 to 31.67% in 2014, while built-up area and barren land increased from 0.34% to 0.89% and 1% to 1.69%, respectively. The annual coal production and overburden removal from the OCMs in Study area-2 between FY 2013-14 and FY 2019-20 are shown in Figure 21 and Table 6. As per SCCL's production records, OCMs produce 81 percent of the coal mined from all coal mines (opencast and underground) in Study area-2. As shown in Figure 21, between FY 2013-14 and

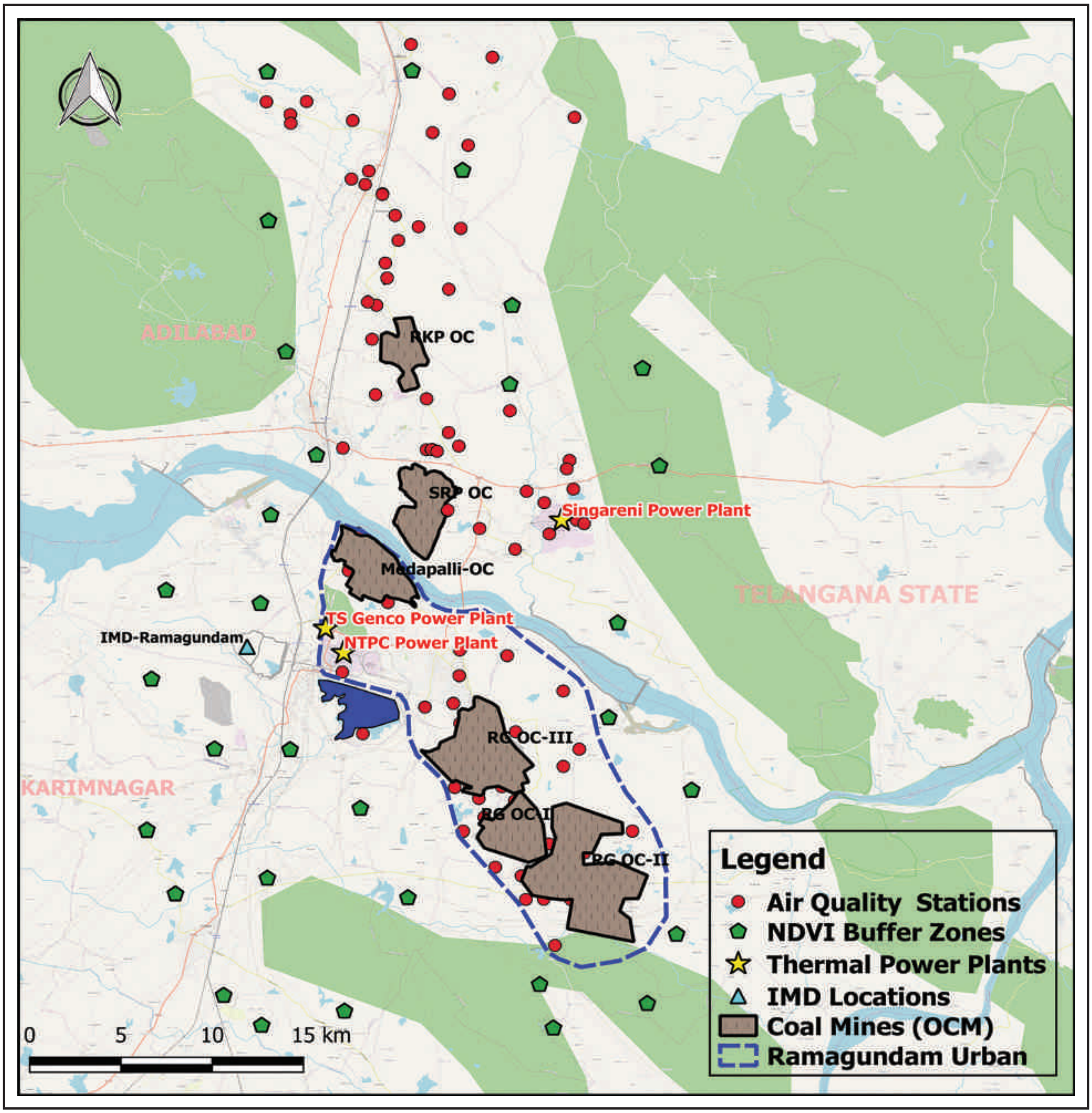

Figure 20: Location of coal mines and TPPs with their respective AAQ monitoring stations in the Mancherial and Peddapalli districts of Telangana State.

FY 2018-19, the annual coal production from OCMs in this area increased from 14.5 million tons (MT) to 23.5 MT before declining to 22 MT in FY 2019-20. However, the volume of overburden (non-coal material to be excavated to extract the coal in opencast mines) excavated from these OCMs increased from 67 million cubic meters (Mm^3) to 208 Mm^3 between FY 2013-14 and FY 2017-18 before declining to 160 Mm^3 in FY 2019-20. Therefore, the total excavation from the opencast mines in Study area-2 increased from 76 Mm^3 during FY 2013-14 to 174 Mm^3 in FY 2019-20. However, the highest coal production and overburden removal quantities were recorded in FY 2017-18 (23.5 Mt and 208 Mm^3 respectively) leading to a record high excavation of 223 Mm^3 from the OCMs in this area during this year. As shown in Figure 21, the coal production from the OCMs in Study area-2 declined in FY 2019-20, presumably due to lower power demand from TPPs in this area.

4.3. Air Environment

4.3.1. Ambient air concentrations of airborne pollutants in Study area-2

The annual and seasonal PM_{10} concentrations in the buffer zone of this area between June 2012 and September 2020 are shown in Figures 22 (a)

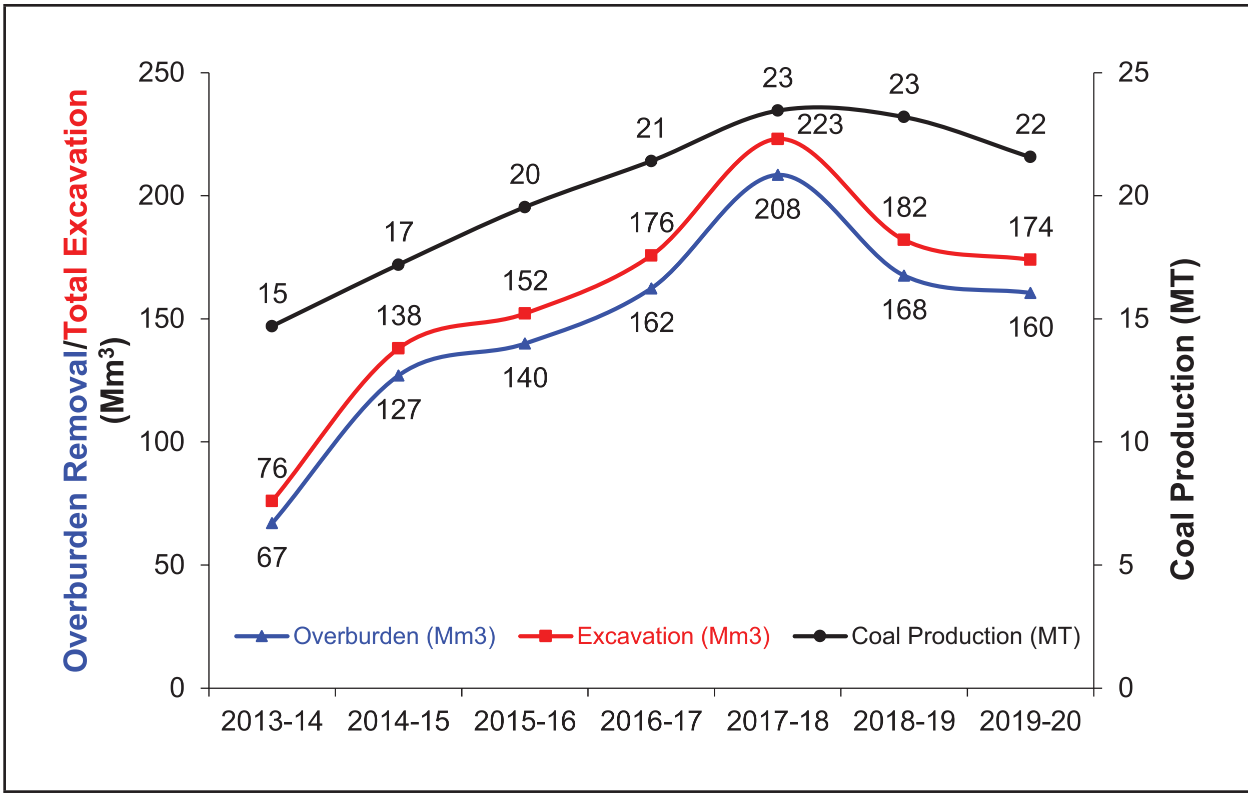

Figure 21: Coal production and overburden removal from OCMs in Study area-2

Table 6: Coal production and overburden removal from OCMs in Study area-2

Year	Ramagundam OCMs		Srirampur OCMs		Ramakrishnapur OCM (Mandamari area)	
	Coal Production (MT)	Overburden Removal (Mm3)	Coal Production (MT)	Overburden Removal (Mm3)	Coal Production (MT)	Overburden Removal (Mm3)
2015-16	16.01	106.28	2.70	19.26	0.84	14.40
2016-17	17.66	113.41	2.03	22.99	1.71	25.98
2017-18	18.60	128.31	2.58	35.15	2.29	44.98
2018-19	17.66	92.53	2.98	31.13	2.56	43.90
2019-20	14.88	96.08	2.97	24.55	3.72	39.87

and (b). The annual average PM_{10} concentration in the buffer zone increases marginally from 74 µg/m^3 in FY 2012-13 to 77 µg/m^3 in FY 2017-18 before decreasing to 62 µg/m^3 in FY 2020-21 (April - September 2020). The annual and seasonal $PM_{2.5}$ concentrations in the buffer zone of this area between June 2012 and September 2020 are shown in Figures 23 (a) and (b).

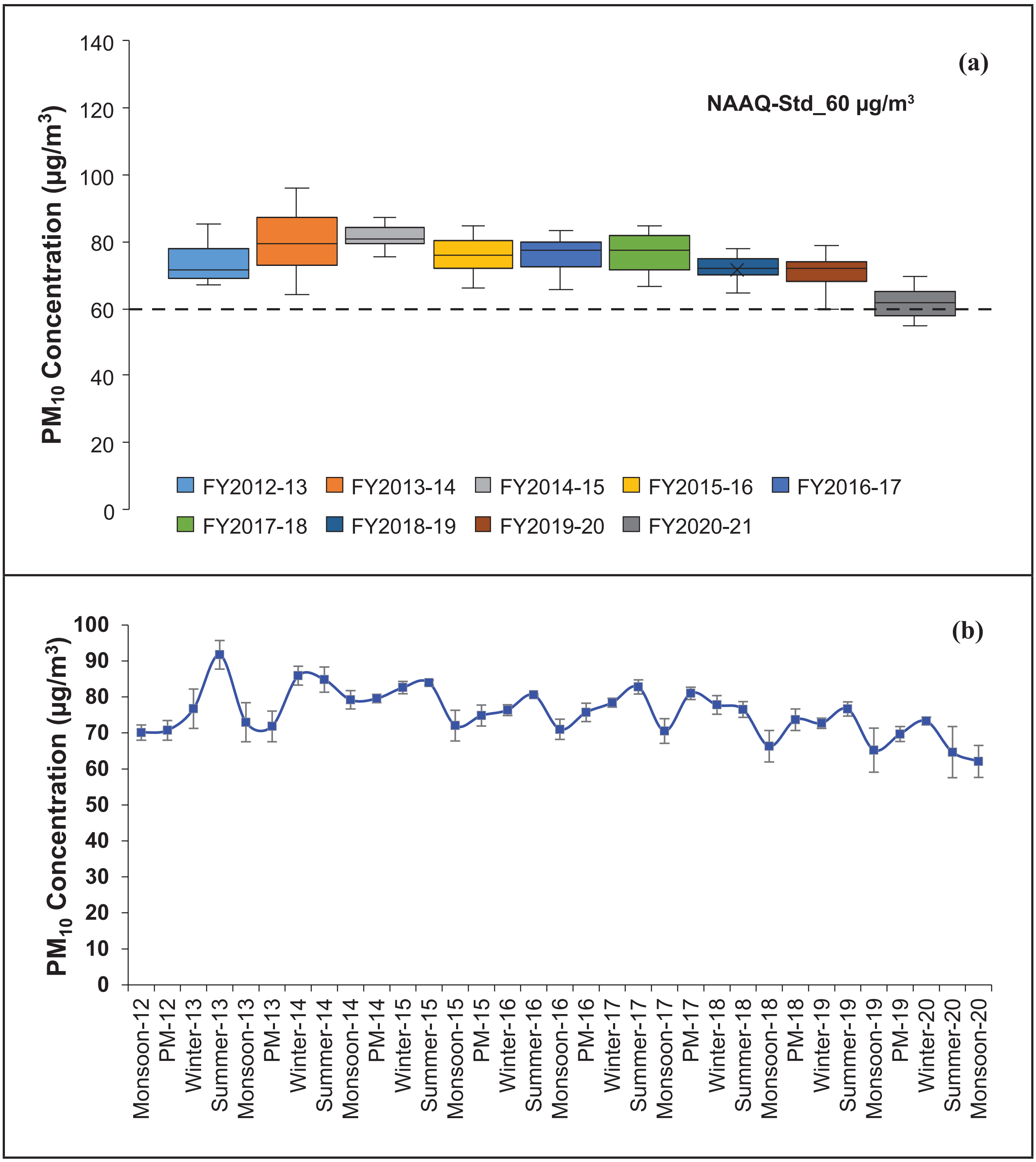

Figure 22: PM_{10} concentrations in the buffer zone of coal mines in Study area-2 (a) Annual average and (b) seasonal average

As in Study area-1, the ambient air PM concentrations are highest in the summer season and lowest in the monsoon season. However, the PM concentration data pertaining to FY 2020-21 is not representative of the entire year since the data was available only till September 2020 (H1 of FY 2020-21) at the time of writing this report. As shown in Figures 22 (a) and 23 (a), the

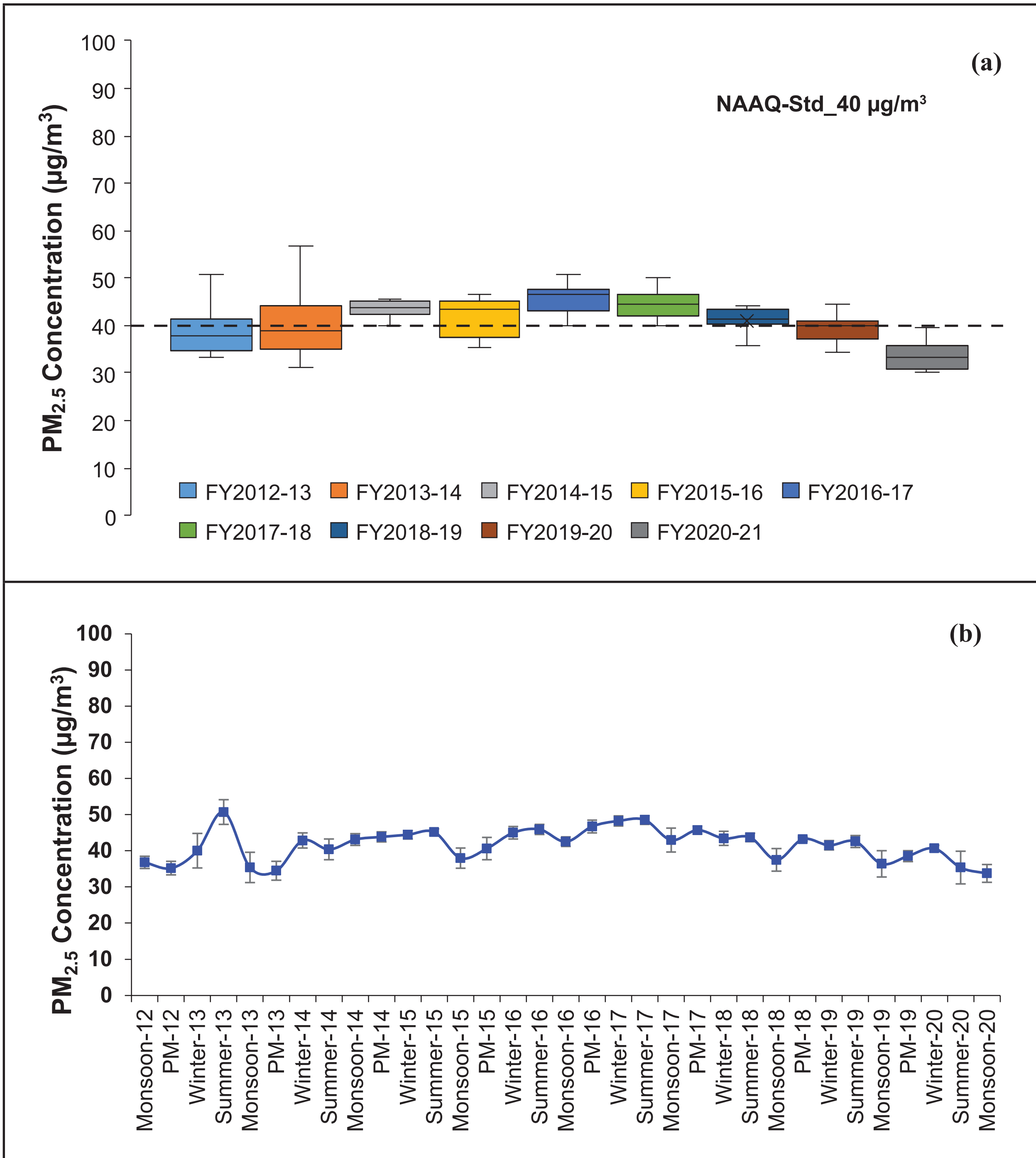

Figure 23: $PM_{2.5}$ concentrations in the buffer zone of coal mines in Study area-2 (a) Annual average and (b) seasonal average

annual average PM_{10} and $PM_{2.5}$ concentrations in the buffer zone were consistently higher than the NAAQ (2009) threshold limits of 60 µg/m[3] and 40 µg/m[3], particularly between FY 2014-15 and FY 2017-18 when the production levels increased year-after-year. However, the ambient SO_2 levels that vary between 10-14 µg/m[3] in the buffer zone of Study area-2 comply with the NAAQ standard of 50 µg/m3 (Figure 24 (a)).

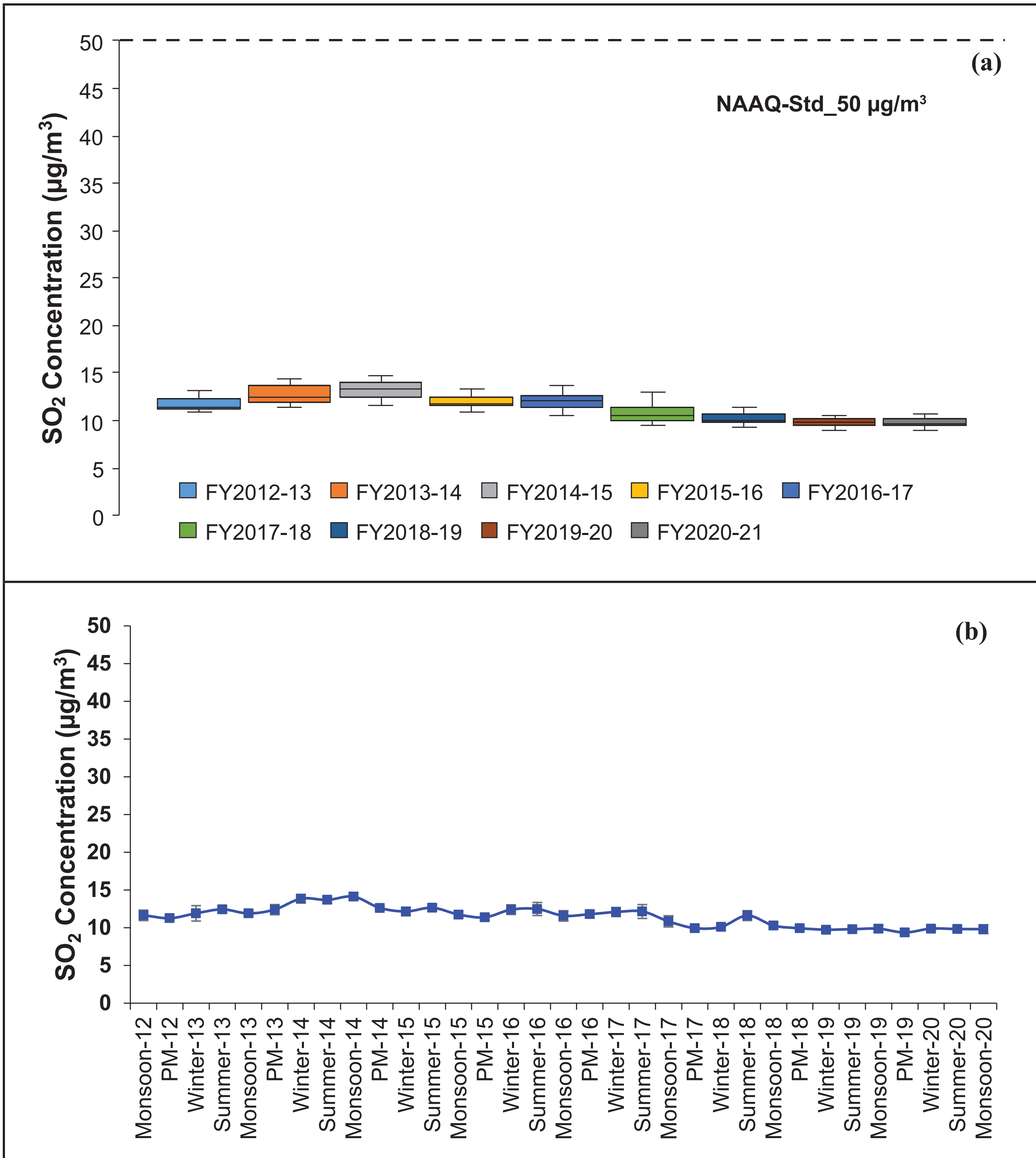

Figure 24: SO_2 concentrations in the buffer zone of coal mines in Study area-2 (a) Annual average and (b) seasonal average

4.4. Correlation between Total Excavation and ambient particulate matter concentrations

The ambient air PM_{10} and $PM_{2.5}$ concentrations in the Ramagundam urban region reached their peak during the years 2017 and 2018. Therefore, the correlation between mining activities (total excavation of coal and overburden) and ambient air PM concentrations in the buffer zone of the OCMs in the Ramagundam division are also explored in this study. The relationships between the PM_{10} concentrations (56.6 μg/m^3 - 91.8 μg/m^3) and $PM_{2.5}$ concentrations (28.9 μg/m^3 - 50.6 μg/m^3) in the buffer zone with the monthly total excavation quantities (4.9 Mm^3 - 14.3 Mm^3) of the OCMs in the Ramagundam division are examined in this research. The analysis of the data collected during this research indicates that there is a highly significant correlation (p-value: <0.001) between the average ambient air PM concentrations in the BZ (buffer zone) of the OCMs in the Ramagundam division and the total excavation volumes from the OCMs in this division. The linear relationships between the ambient air PM concentrations and the monthly total excavation quantities from the OCMs in this division are shown in Figures 25 (a) and 25 (b). However, such linear relationships may be limited to the range of values for excavation quantities and PM concentrations found in this Study.

PM_{10} particles also include fine ($PM_{2.5}$) and ultrafine particles (PM_1). The ratio of $PM_{2.5}/PM_{10}$ can be used for ex post facto analysis for predicting $PM_{2.5}$ mass concentration without direct measurement of $PM_{2.5}$ (Limin Jiao *et al*, 2017). The $PM_{2.5}/PM_{10}$ ratio in the core zone of all OCMs studied vary between 0.24 and 0.58 (mean: 0.37), while the value of this ratio in the buffer zone of the OCMs ranged between 0.40 and 0.84 (mean: 0.56). On an average, $PM_{2.5}$ pollutants contribute 37 percent of PM_{10} concentrations in the core areas of the OCMs studied, while they account for 56 percent of the PM_{10} levels in the buffer zones of these OCMs. The higher $PM_{2.5}/PM_{10}$ ratio in the buffer zone may be due to the greater proportion of fine particles in the atmosphere away from the core zone of the OCMs since coarser particles settle down closer to the point of generation than the finer $PM_{2.5}$ particles which may remain entrained for longer periods. This also confirms the findings of Trivedi *et al*, (2010) who have carried out ambient air quality measurements around five OCMs in the Wardha Valley coalfield which is approximately 140 km north of Study area-2.

4.5. Air Pollutants in the buffer zone of Thermal Power Plants (TPPs) in Study Area-2

The electricity generated in each of the three TPPs in this area is shown in Table 7. As shown in Table 7, the total quantum of electricity generated in Study area-2 has reduced by 7.5 percent (from 28,918 GWh to 26,751 GWh) between FY 2017-18 and FY 2019-20. The electricity generated by TSPGENCO Ramagundam – B, NTPC-RG, and SCCL-TPP during the year FY 2020-21 decreased by 28 percent, 2 percent, and 20 percent, respectively compared to their generation levels during FY 2019-20 (NPP, 2021). The focus of this study is on the NTPC and SCCL TPPs only since the +50-year-old TSGENCO Ramagundam-B TPP equipped with obsolete technology may be retired shortly since the power generated from this TPP can be compensated by the electricity generated by modern TPPs owned by TSGENCO in the State of Telangana. Both units of SCCL TPP are connected to one 275-m tall stack, while different units of the NTPC-RG TPP have stack heights of 225/275 m in compliance with the applicable MoEF norms between 1983 and 2016.

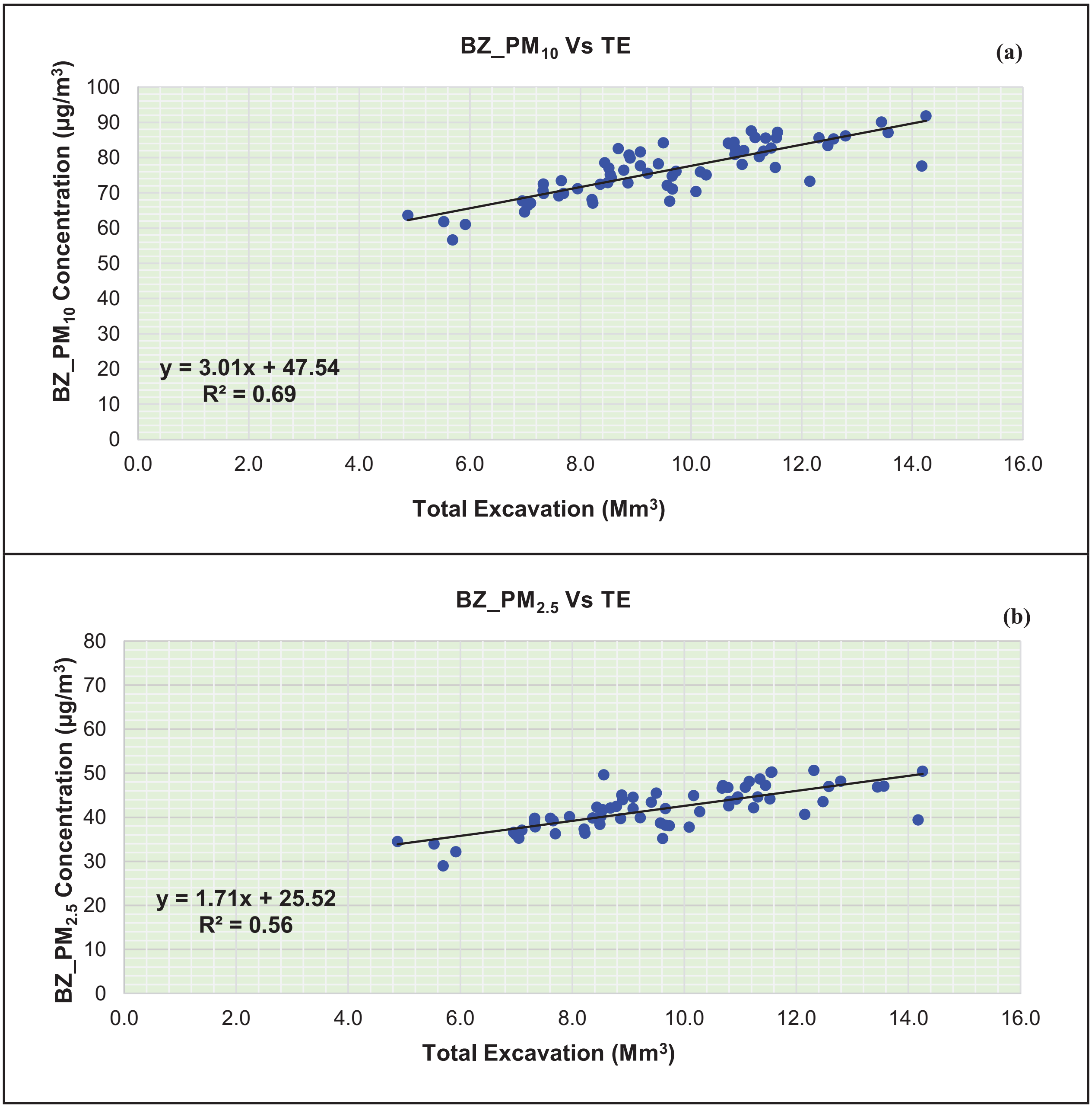

Figure 25: Relationships between the total excavation quantities from the OCMs in Ramagundam division and a) PM_{10} and b) $PM_{2.5}$ concentrations in the buffer zones of the coal mines

The stack emissions and ambient air PM concentrations in the buffer zones of SCCL-TPP and NTPC-RG are extracted from the compliance reports and environmental statements submitted by SCCL and NTPC to MoEFCC and TSPCB, respectively (NTPC, 2016a - 2016c; 2017a - 2017c; 2017d; 2018a - 2018c; 2019a - 2019d; 2020; SCCL, 2018a -2018z; 2019a - 2019c). Besides, the authors also collected key information from NTPC and TSPCB under the Right to Information Act, 2005. The stack emission data provided by NTPC-RG under the RTI Act, 2005 is summarized in Table 8. Analysis of this data indicates that the average concentration of SPM in the stack emissions from the most modern unit in this TPP can be reduced to 61.6 mg/m^3 compared to levels exceeding 108 mg/Nm^3 in the same TPP. This may be due to varying efficiencies of the ESPs installed over a period of 21 years in NTPC-RG. On the other hand, the average SPM concentration in the stack emissions of SCCL-TPP varied between 45.2 and 68.9 mg/Nm^3 (average 55.8 mg/Nm^3) (SCCL, 2018z; 2019c). The variation in the SPM concentrations in the stack emissions from these two TPPs (and within different units in NTPC-RG) may be due to variations in ESP efficiencies. Besides, the differences in the stack heights and flue-gas exit velocities may also create different dispersion patterns (Jayant Singh *et al.*, 2020).

Since SCCL-TPP is a modern plant commissioned only in December 2016 compared to NTPC-RG (commissioned by NTPC in three stages between 1983 and September 2004), ESPs with 99.98% efficiency have been installed in SCCL-TPP right from the beginning (SCCL, 2018). NTPC-RG has also placed orders to upgrade the ESPs installed in their older (3 x 200 MW) units to comply with the applicable SPM standard of 100 mg/Nm^3 notified by MoEFCC (2015).

As shown in Figure 26(a), the PM_{10} concentrations in the buffer zone of SCCL-TPP decreased sharply from 78.4 µg/m^3 to about 40 µg/m^3 between FY 2016-17 to FY 2019-20. This may be due to the stabilization of the ESPs and other Pollution Control Technologies (PCTs) in SCCL-TPP. In the case of NTPC-RG, electricity generation recorded a slight decline from 19,598 GWh in FY 2016-17 to 18,548 GWh in FY 2018-19 and 17,126 GWh in FY 2019-20 (CEA, 2015; 2016; 2018; 2019; NPP, 2020). However, as shown in Figure 26(b), the average PM_{10} concentrations in the buffer zone of NTPC-RG increased from 50.4 µg/m^3 in FY 2016-17 to more than 60 µg/m^3 (NAAQ standard) for three consecutive years (FY 2017-18, FY 2018-19, FY 2019-20). NTPC-RG is also upgrading the ESPs installed in the TPP to control PM pollution in compliance with the MoEFCC (2015) norms by delinking the required ESP

Table 7: Electricity generated by the three TPPs in Study area – 2

Thermal Power Plant (TPP)	Installed Generation Capacity (MW)	Electricity Generated (GWh)		
		FY 2017-18	FY 2018-19	FY 2019-20
TSGENCO - Ramagundam - B	62.5	475	423	398
NTPC – Ramagundam (RG)	2600 (3 x 200 + 4 x 500) MW	18,868	18,548	17,126
SCCL	1200 (2 x 600 MW)	9,575	8698	9,227
Total		**28,918**	**27,669**	**26,751**

(Data sources: (CEA, 2017; 2018; 2019. NPP, 2020)

Table 8: Stack emissions from NTPC-Ramagundam TPP in Study area -2

	FY 2015-16	FY 2016-17	FY 2017-18	FY 2018-19
SPM (mg/m^3)	95.4	93.9	94.2	87
SO_2 (mg/m^3)	1321.8	1448.1	1686	1625
NO_x (mg/m^3)	459.8	416.3	374	394

(Data Source: Replies received from NTPC under the RTI Act)

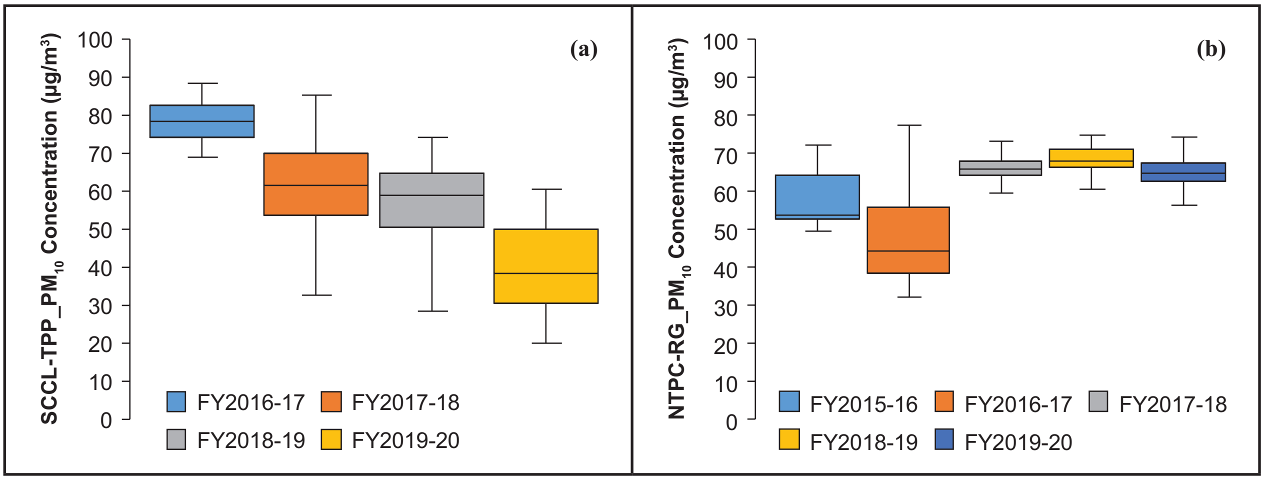

Figure 26: PM_{10} concentrations in the buffer zone of Thermal Power Plants in Study area-2

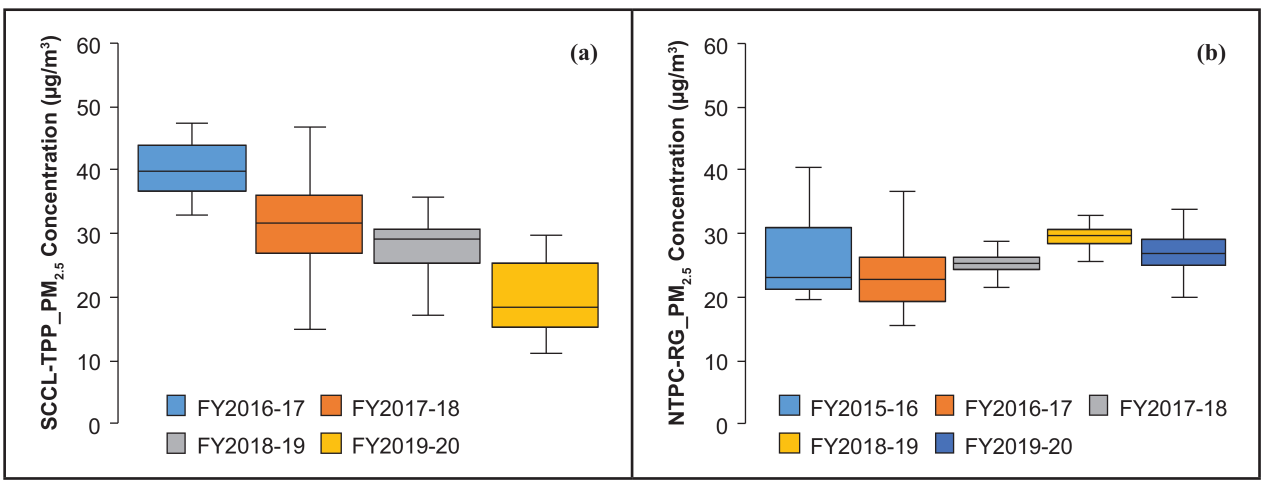

Figure 27: $PM_{2.5}$ concentrations in the buffer zone of Thermal Power Plants in Study area-2

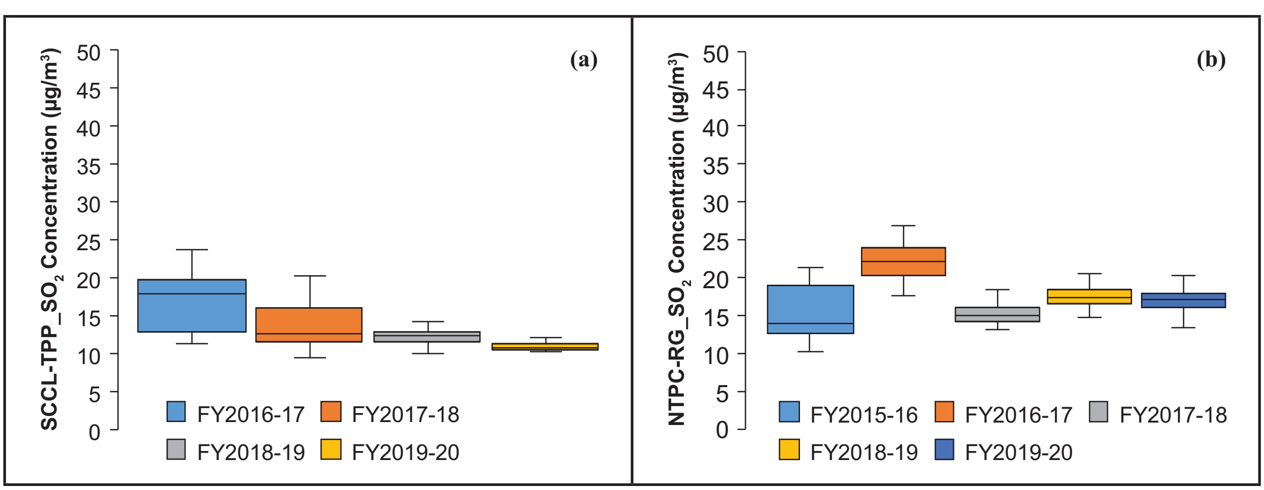

Figure 28: SO_2 concentrations in the buffer zone of Thermal Power Plants in Study area-2

upgradation projects from the FGD installation deadlines fixed by CPCB (2018).

The annual average $PM_{2.5}$ concentrations in the buffer zones of SCCL-TPP and NTPC-RG are shown in Figures 27(a) and 27(b). The $PM_{2.5}$ levels in the buffer zone of NTPC-RG during FY 2018-19 were higher than those recorded in FY 2016-17 and FY 2017-18. As shown in Figure 27(a), the average $PM_{2.5}$ concentrations in the buffer zone of the TPPs declined from 40 $\mu g/m^3$ to 18 $\mu g/m^3$ around SCCL-TPP, they remained in the 23 - 28 $\mu g/m^3$ range in the case of NTPC-RG. These pollution levels are lower than the NAAQ annual standard of 40 $\mu g/m^3$ for ambient air $PM_{2.5}$ concentrations though they are significantly higher than the US EPA annual standard of 12 $\mu g/m^3$ (CPCB, 2009; EPA, 2013). As shown in Figures 28(a) and 28(b), the average SO_2 concentrations in the buffer zone of the TPPs varied between 11 and 22 $\mu g/m^3$. These levels are far lower than the NAAQ annual standard of 50 $\mu g/m^3$ for ambient air SO_2 concentrations, which indicates that FGDs may be redundant in these TPPs due to a combination of favorable conditions including, low sulfur content of the coal used, the stack heights, and the local meteorological parameters which ensure dispersion under all conditions.

4.6. CPCB Ambient Air Quality Monitoring Network

The ambient air concentrations of PM_{10} and Sulphur di oxide (SO_2) recorded at Ambient Air Quality Monitoring (AAQM) stations maintained by the Central Pollution Control Board (CPCB) in five major power hubs of India are shown in Figures 29(a) and 29(b). As shown in Figure 29(a), the average PM_{10} concentrations exceed the annual NAAQ standard (60 $\mu g/m^3$) in all these five power hubs. On the other hand, the ambient SO_2 concentrations in all these power hubs are far below the annual NAAQ standard (50 $\mu g/m^3$) as shown in Figure 29(b). The Ramagundam coalfield is a representative case study to study the cumulative environmental impact of OCMs and TPPs co-located in a power hub.

4.6.1. TSPCB ambient air quality data analysis

Pallavi *et al*, (2018) summarized the regulatory monitoring landscape of PM_{10} concentration data from the national regulatory monitoring network for 12 years (2004–2015) and proved that less than 1% of all PM_{10} measurements (11 out of 4789) were found to meet the annual average WHO guideline (20 $\mu g/m^3$), while only 19% of the locations were in compliance with the NAAQ standards for PM_{10} (60 $\mu g/m^3$). Therefore, it is important to study the PM concentrations in Study area-2 where two AAQ monitoring stations are operated by the Telangana State Pollution Control Board (TSPCB). These two AAQ monitoring stations are located on SCCL's Mandamari club in Mancherial and on the Godavarikhani Municipal Complex building in Ramagundam. TSPCB provided the daily-average data for the last four years (2017-2020) against our request under the Right to Information Act, 2005. The annual-average (based on at least 100 measurements in each year) PM_{10} concentrations recorded in TSPCB's Mancherial AAQ monitoring station between 2017 to 2020 are shown in Figure 30, while the corresponding data for the Ramagundam station are shown in Figure 31. In both cases, the annual average PM_{10} concentrations show an increasing trend between 2017 and 2020 and exceed the annual NAAQ standard of 60 $\mu g/m^3$ in all four years. Therefore, both Mancherial and Ramagundam fall into the category of "Non-attainment cities" as per the MoEFCC (2020) criteria.

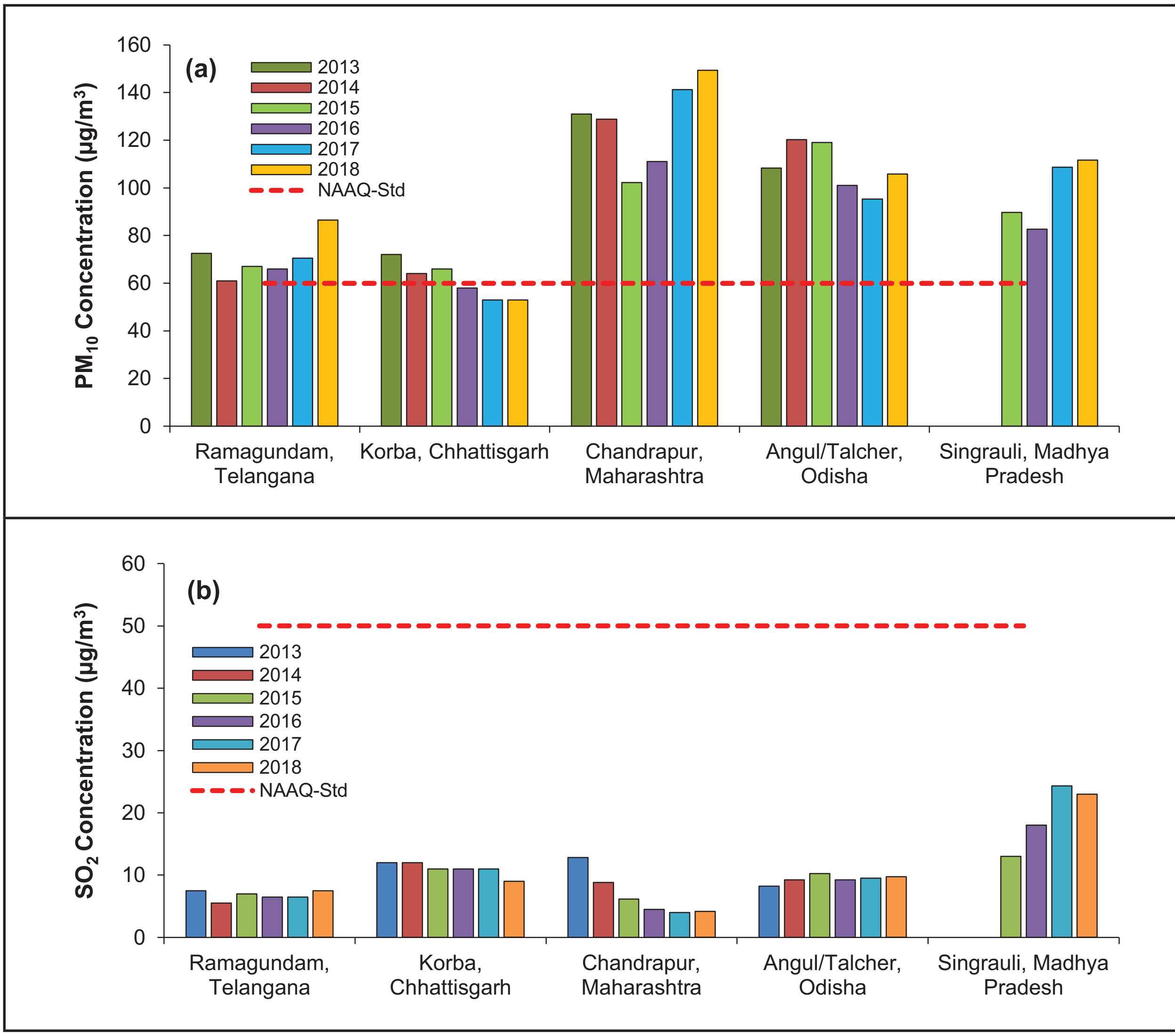

Figure 29: Annual average (a) PM_{10} and (b) SO_2 concentrations in five power centers of India

4.6.2. Comparison of TSPCB PM_{10} data with self-reported data

An empirical cumulative distribution function (CDF) Plot has been used to fit a distribution to the monthly-average PM_{10} concentration data recorded by the TSPCB and SCCL AAQ monitoring stations (located within 1-2 km of each other) between 2017 and 2020 at Mandamari and Ramagundam. These distributions are depicted in Figures 32 and Figure 33. While the mean monthly-average PM_{10} concentration recorded by TSPCB at their Mandamari station is 70 µg/m^3, the corresponding value recorded by SCCL at Mandamari is only 61.7 µg/m^3. The standard t-test is used to assess whether PM_{10} concentration data independently recorded by TSPCB and SCCL at Mandamari belong to the same population or not. The test results indicate that these data sets (from SCCL and TSPCB) come from different populations since the p-value of the test is less than the critical significance level of 0.05. Similarly, the mean monthly-average PM_{10} concentration recorded by TSPCB at their Ramagundam station is

92.2 μg/m³, while the corresponding value recorded by SCCL at Ramagundam is only 80.7 μg/m³. In this case also, the t-test results indicate that these data sets come from different populations since the p-value of the test is less than the critical significance level of 0.05. These conclusions are also supported by a perusal of the cumulative distribution functions depicted in Figures 32 and 33.

4.7. Air Quality Index (AQI) in Study Area-2

Air Quality Index (AQI) is one of the primary tools for the assessment of ambient air quality (Beig *et al.*, 2010; Kyrkilis *et al.*, 2007; Mirabelli *et al.*, 2020; Sharma *et al.*, 2019). In this study, AQI calculations are carried out using the IND-AQI procedure based on the measurement of four criteria pollutants (PM_{10}, $PM_{2.5}$, SO_2 and

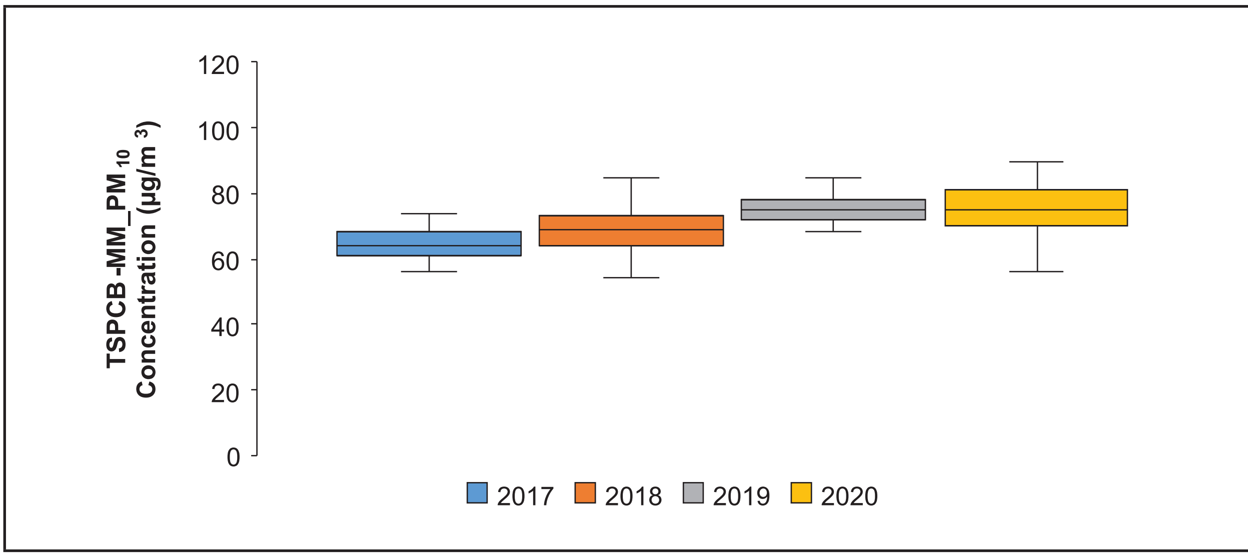

Figure 30: Annual average PM_{10} concentration measured by TSPCB in Mandamari, Mancherial (Source: Replies received from TSPCB under the RTI Act, 2005)

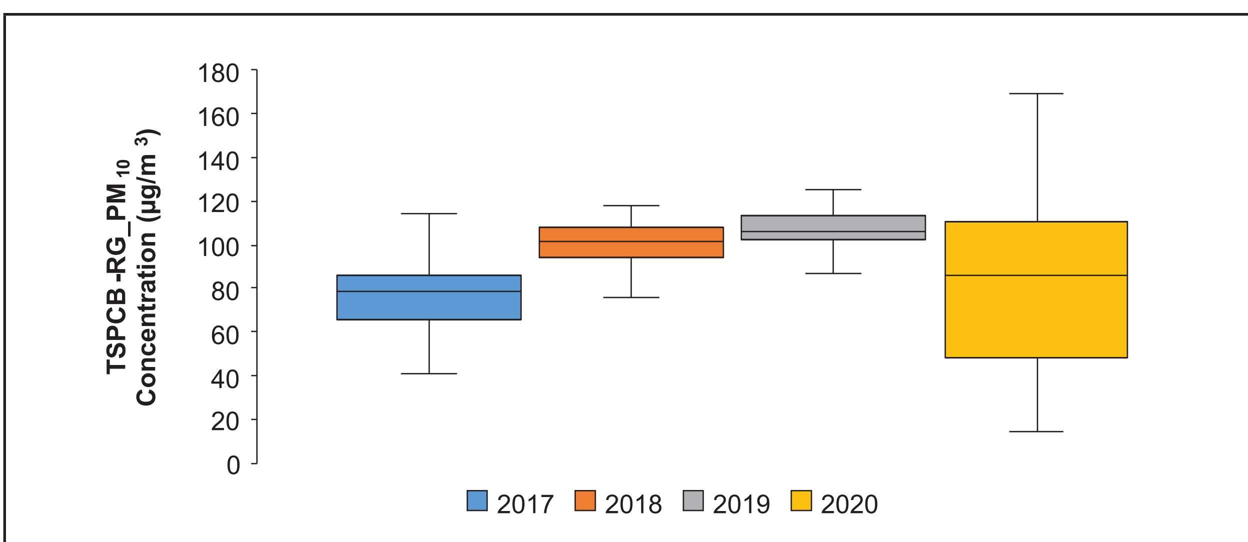

Figure 31: Annual average PM_{10} concentrations measured by TSPCB in Godavarikhani, Ramagundam (Source: Replies received from TSPCB under the RTI Act, 2005)

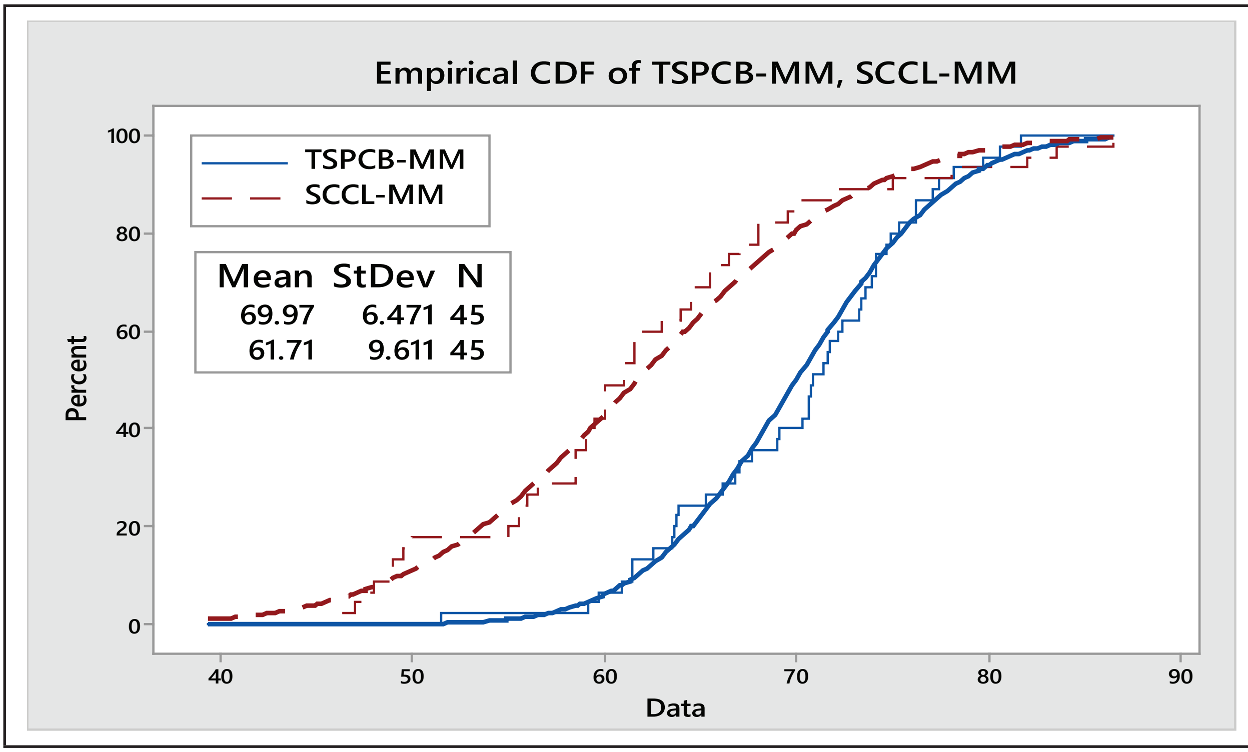

Figure 32: Monthly-average PM_{10} concentrations ($\mu g/m^3$) measured by TSPCB and SCCL at Mandamari, Mancherial

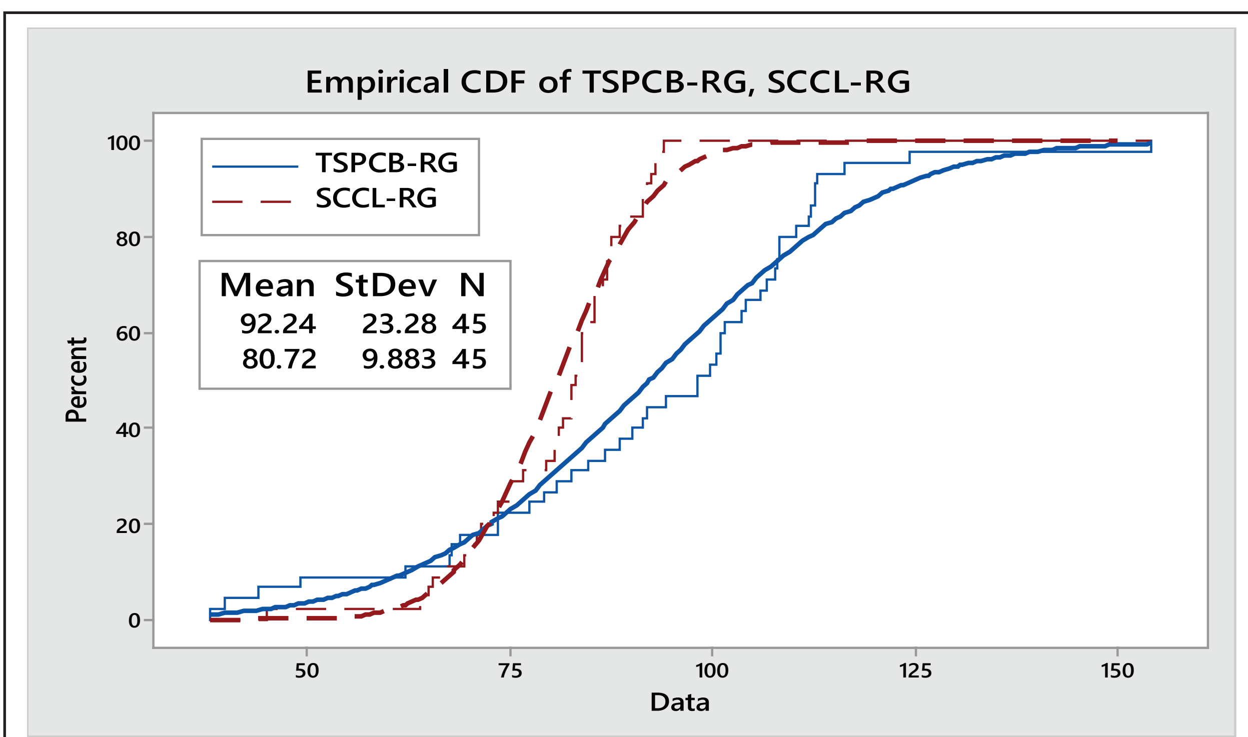

Figure 33: Monthly-average PM_{10} concentrations ($\mu g/m^3$) measured by TSPCB and SCCL at Godavarikhani, Ramagundam

NO_2) in Study area-2 during the year 2017-18 (CPCB, 2014). The annual average AQI at each of the 130 AAQM stations set up by SCCL's coal mines is calculated based on the 24-hour average concentrations of the major pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NOx) measured at fortnightly intervals throughout FY 2017-18 (24 sets of measurements at each AAQM station). The annual average AQI at each of the three AAQM stations set up by the NTPC-RG is calculated based on the 24-hour average concentrations of the aforesaid pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NOx) measured at bi-weekly intervals (104 sets of measurements at each AAQM station in FY 2017-18). The annual average AQI at each of the nine AAQM stations set up by the SCCL TPP is calculated based on 32 - 46 sets of measurements of the 24-hour average concentrations of the major pollutants (PM_{10}, $PM_{2.5}$, SO_2, and NOx) during FY 2017-18 (SCCL, 2018z).

GIS techniques are applied to examine the spatial pattern of air pollution in this area during the year FY 2017-18 (Dadhich *et al*, 2018). Specifically, the Inverse Distance Weighted (IDW) Kriging tool in-built with GIS software (QGIS version 3.x) is used to analyze the spatial variability of AQI in the Ramagundam region due to the combined impact of airborne pollution caused by mining activities and power generation (Documentation QGIS3, 2021). The year 2017-18 is selected since the total excavation quantities from the OCMs (Figure 21) and power generation from TPPs (Table 7) in Study area-2 were at high record-high levels during this year. The spatial variability of AQI

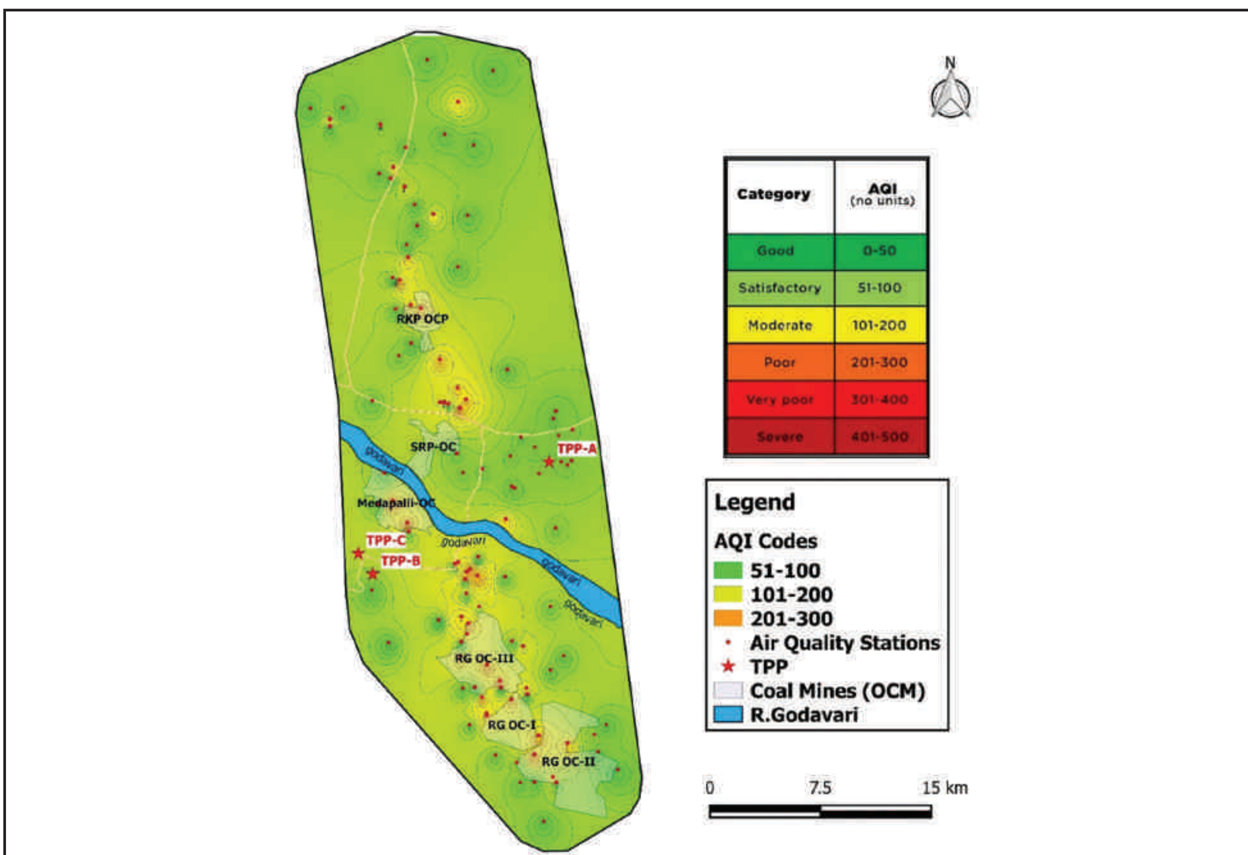

Figure 34: Spatial distribution of Air Quality Index (AQI) at the peak of mining activities in the Study area-2 during FY 2017-18

values in Study area-2 is shown in Figure 34. The overall AQI in the core zone (mining lease area) is under the moderately-polluted category (AQI: 101-200) while it is in the satisfactory category (AQI: 51-100) in the buffer zone. In all cases, $PM_{2.5}$ concentrations have the highest AQI sub-indices in the AQI determination and therefore form the critical pollutant to be controlled in this area (Jay S. Patel, 2017).

5. Geospatial Data Analysis

Geospatial data analysis offers a unique opportunity to assess ambient air quality around mines and TPPs, particularly in the power hubs of India which experience elevated concentration of air pollution but lack adequate spatial-temporal coverage by air pollution monitoring networks.

5.1. Normalized Difference Vegetation Index (NDVI)

The MODIS-NDVI levels in Study area-2 between 2004 and 2020 are shown in Figure 35. Unlike in Study area-1, there is no clear trend in NDVI levels in Study area-2 since there have been no major mine closures in this area till date. Medapalli OCM (one of the largest OCMs in this area) will be entering the mine closure process due to the exhaustion of coal reserves after which the air environment in Study area-2 is likely to undergo a significant change.

5.2. Spatial variability in Aerosol Optical Depth (AOD_{550}) in Study area-2

In this section, airborne dust particle distribution patterns are analysed using AOD_{550} from MODIS. MODIS-AOD at 550 nm (AOD_{550}) is retrieved at 16 locations in the buffer zones of the coal mines and TPPs in Study area-2. While the variability of AOD at these locations is shown in Figure 36(a), the annual total excavation (TE) from the OCMs in this area (sum of coal production and over burden volumes) is shown in Figure 36(b). As shown in Figure 36(a), there is an increasing trend in AOD from the year

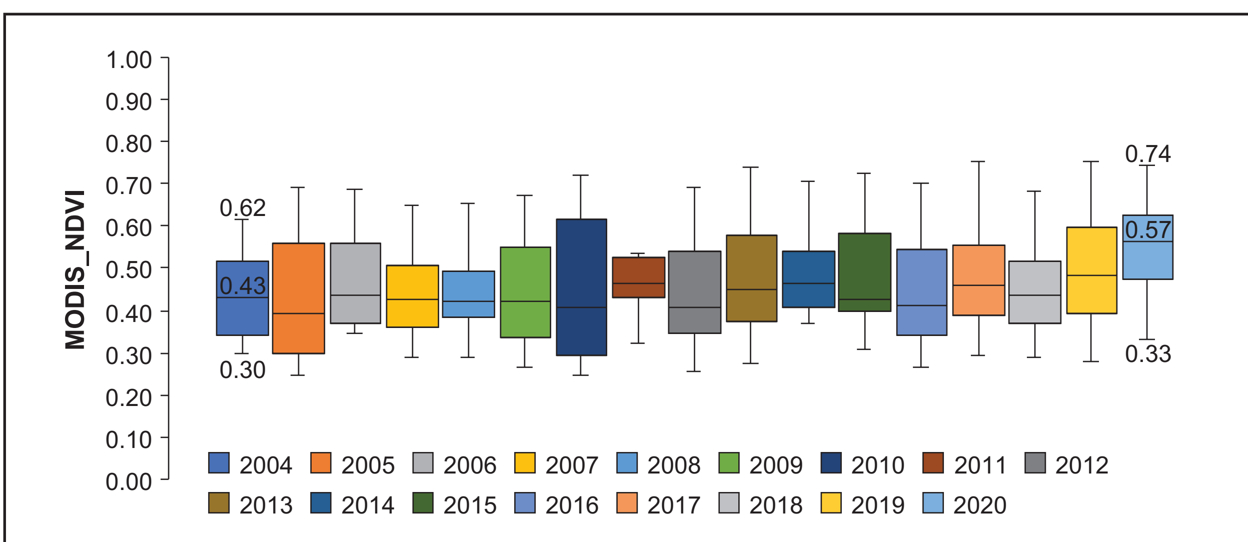

Figure 35: MODIS-NDVI levels in the buffer zones in Study area-2 between 2004 and 2020

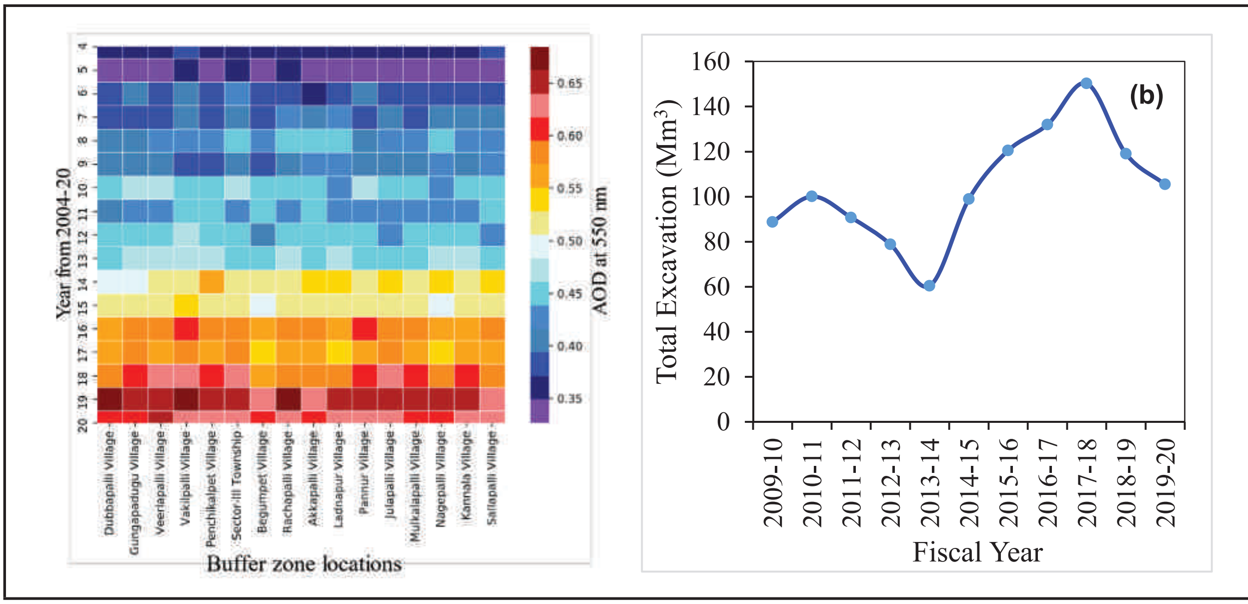

Figure 36: (a) AOD_{550} in the buffer zones of the coal mines and TPPs in Study area-2 between 2004 and 2020; (b) Total excavation from OCMs in Study area-2

2013-14, which can be partly explained by the increase in excavation up to FY 2017-18 (Figure 36(b)). The annual average AOD_{550} values at 30 monitoring locations in the buffer zone of coal mines and TPPs in Study area-2 are shown in Figure 37. As shown in Figure 37**,** the mean AOD_{550} levels in the buffer zone of the coal mines and TPPs increase from 0.39 to 0.58 between 2004 and 2020**.**

The spatial distribution of AOD_{550} in Study area-2 during 2012-13 and 2019-20 is shown in Figure 38. As shown in Figure 38, the airborne dust concentrations show a distinct increase in 2019-20 compared to 2012-13 which may be due to the increase in total excavation (from 78 Mm^3 in 2012-13 to 105 Mm^3 in 2019-20) between these years as depicted in Figure 36(b).

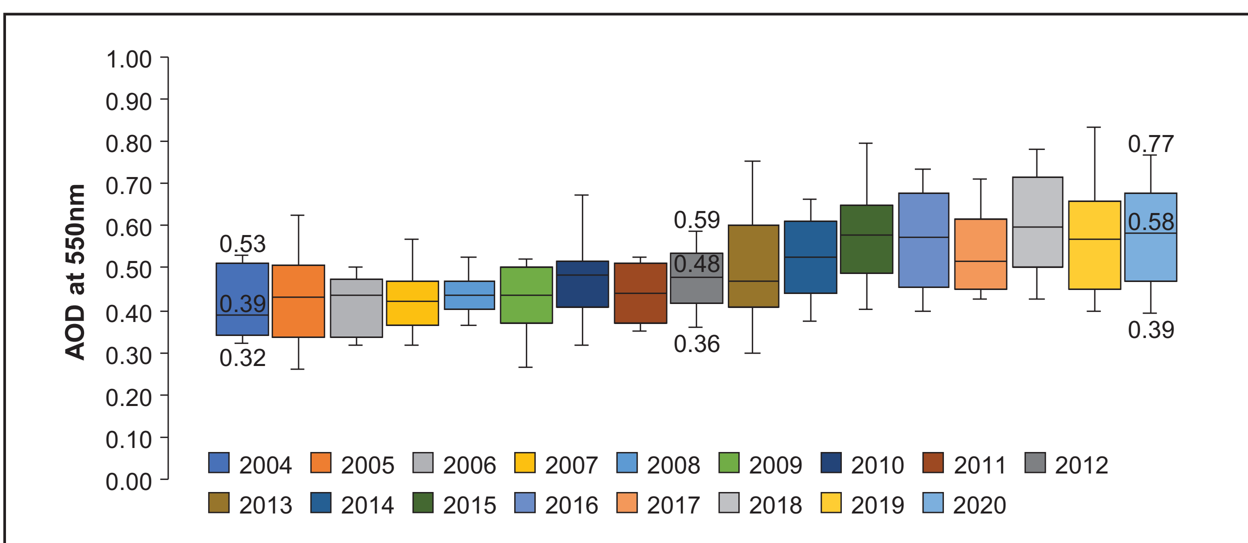

Figure 37: Annual average AOD_{550} values in Study area-2 from 2004 to 2020

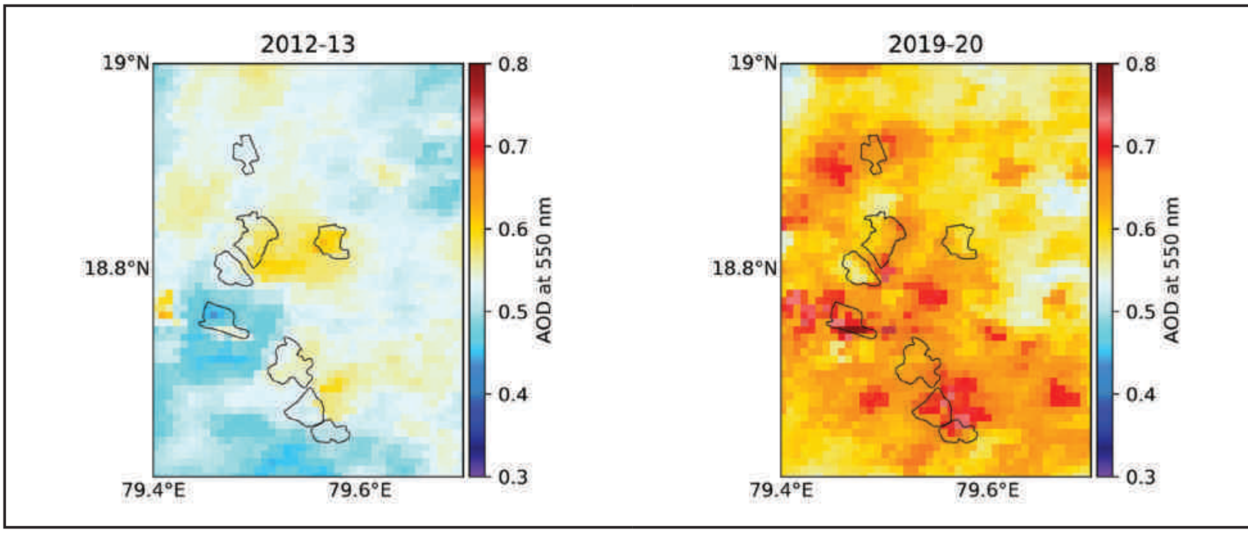

Figure 38: Spatial distribution of AOD_{550} in Study area-2 during 2012-13 and 2019-20

6. Water Environment

SCCL has assessed water quality in Study area-1 (Dorli-Bellampalli coalfield) for two categories of water samples: 1) Ground water quality (IS 10500) and 2) Surface water quality (IS 2296). Study area-1 is selected for this analysis since there are no anthropogenic sources of pollution other than coal mines in this area. Therefore, this study is useful to analyse the impact of opencast coal mining on surface and ground water quality around the coal mines.

SCCL collected surface and ground water samples at specific locations upstream and downstream of the OCMs in the Study area-1 as shown in Figure 39. Samples were collected in every season corresponding to the four quarters of a year: June-August: (Monsoon); September-November (Post-monsoon); December-February (Winter) and March-May (Summer). SCCL has carried out these analyses as per the standard methods for examination of water samples described by American Public Health Association (APHA, 1992) and included the results in their compliance reports to TSPCB and MoEFCC (e.g., SCCL, 2020a - 2020d).

6.1. Seasonal quality of surface water and groundwater

urface and ground water exhibit their chemical signatures which are produced as result of several factors such as rainfall, rock-water interaction and several anthropogenic inputs. The locations in Study area-1 from where surface water samples were drawn by SCCL for analysis are shown in Figures 40- 45. The temperature of the groundwater samples at different locations around the Dorli-Bellampalli OCMs ranges between 22-25.3°C with an average of 23.5°C. The pH values in the surface water and ground water samples collected around Dorli-I OC and Dorli-II OC varies from 7.5 to 8.5 (average = 8.0) and 7.2 to 8.1 (average = 7.5), respectively. The pH values of all water samples collected in this area are within the permissible limit of 8.5 throughout the year (BIS, 2004). The electrical conductivity (EC), a good indicator of the salinity ranged between 123 to 640 mmhos/cm (average = 283.2 mmhos/cm) in the surface water and between 202 to 1710 mmhos/cm (average = 1060 mmhos/cm) in groundwater. The maximum Electrical Conductivity (EC)

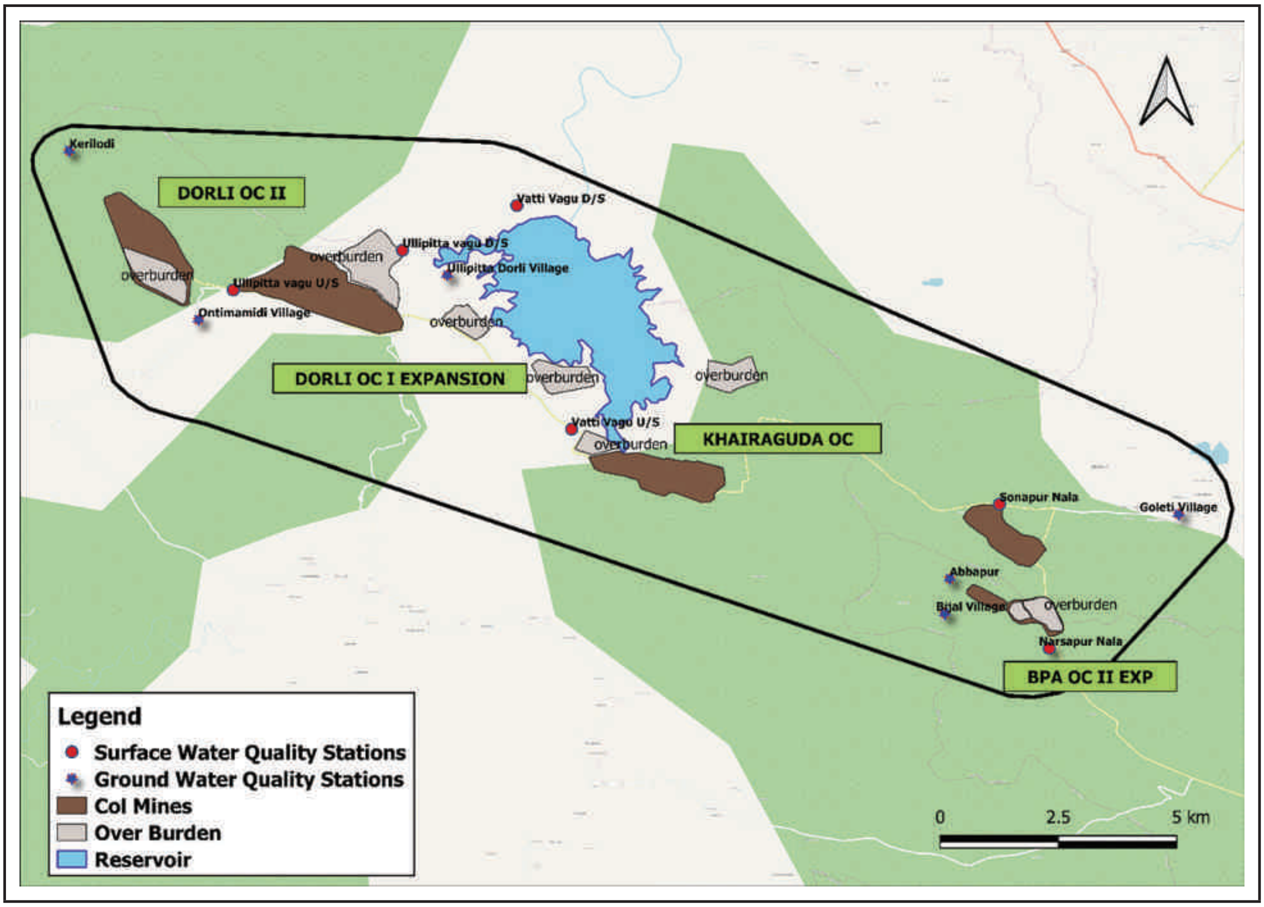

Figure 39: Location of coal mines with their respective water quality monitoring stations in Study area-1 (Dorli-Bellampalli coalfield)

values in the groundwater (GW1) are recorded during post-monsoon, but within the safe limits. In the surface water, the Dissolved Oxygen (DO) values ranged between 4.2 to 6.4 mg/L (average = 4.8 mg/L), showing optimal aeration. Slightly higher DO values were observed in the samples collected from SW1 in the study area during post-monsoon. These values exceeded the permissible range of 4 - 8 mg/L (BIS, 2004), possibly due to the mixing of large amounts of atmospheric oxygen in the surface water. The pH and EC values are found to be well within the CPCB / BIS limits (Figures 40 - 43; BIS, 2004). In the case of site SW4 (in the vicinity of Dorli II OC), the pH values were higher compared to other sites in the summer season, while SW3 showed higher EC values in the Post-monsoon season. Overall, the values for DO exceed the CPCB standard values during all four seasons as shown in Figures 44 and 45.

The monitoring locations from where ground water samples are drawn are shown in Figures 46 - 51. The seasonal pH and EC values exceed the pre-mining values over all the seasons and years; however, the values are within the prescribed the CPCB limits (BIS, 2004). Similar trends are observed with respect to total alkalinity (mg/L) concentrations. Overall trends show that apart from specific occurrences, all the major water quality parameters in Study area-1 are within the permissible limits.

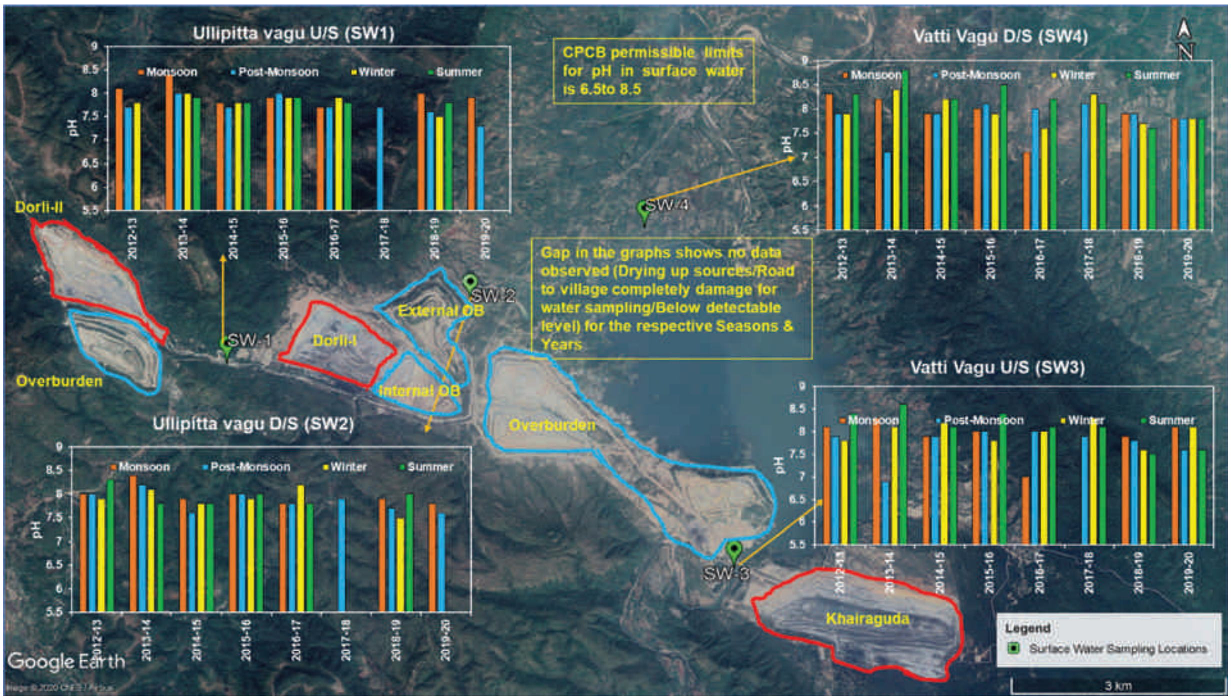

Figure 40: Seasonal variations in the pH of surface water around Dorli OC-I, OC-II and Khairagura coal mines

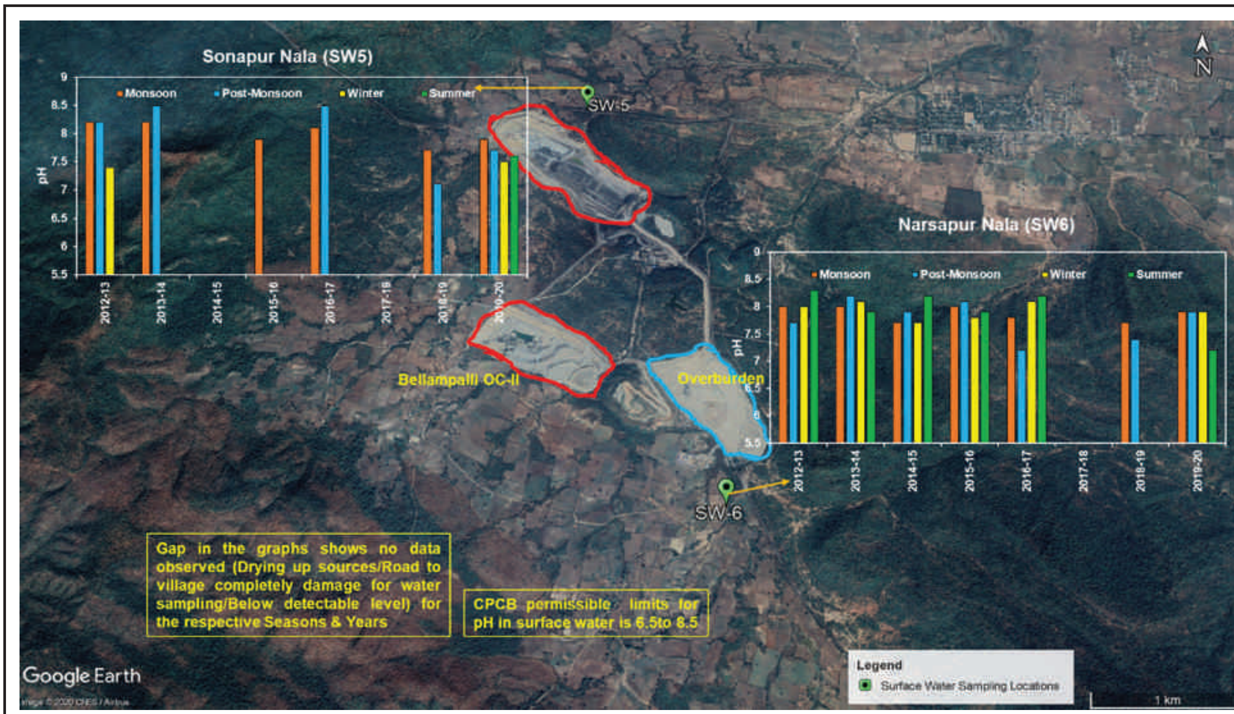

Figure 41: Seasonal variations in the pH of surface water around Bellampalli OC-II

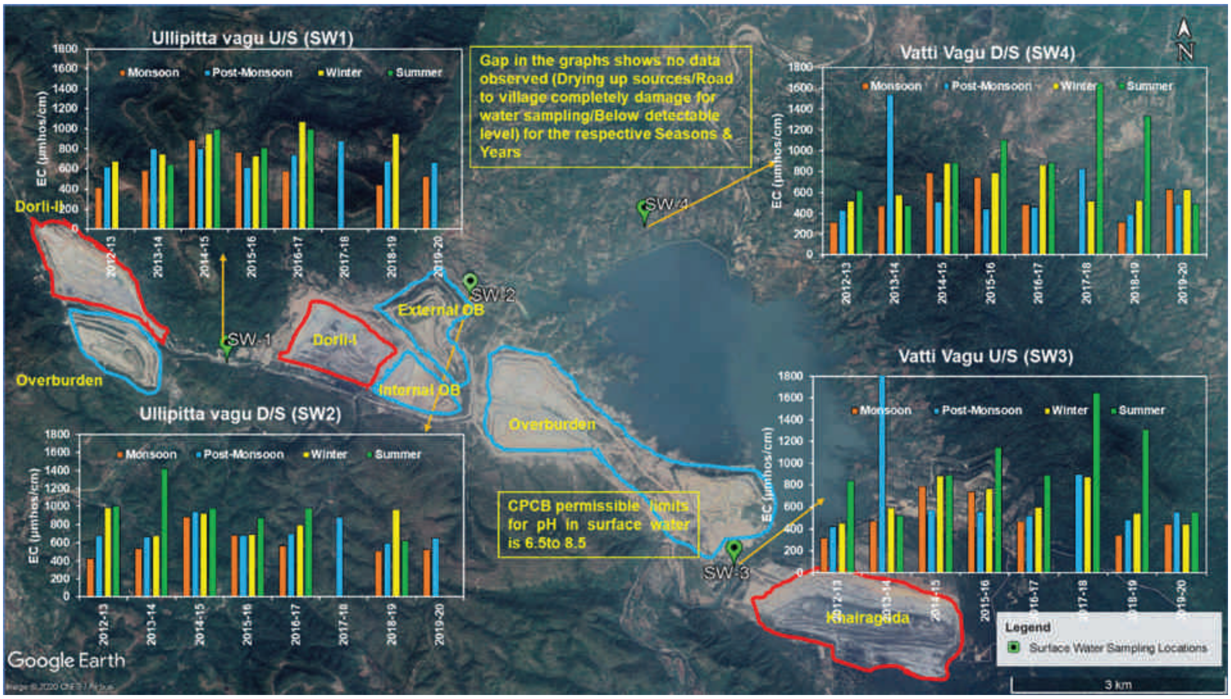

Figure 42: Seasonal variations in the Electrical Conductivity (µmhos/cm) of surface water around Dorli OC-I, OC-II and Khairagura coal mines

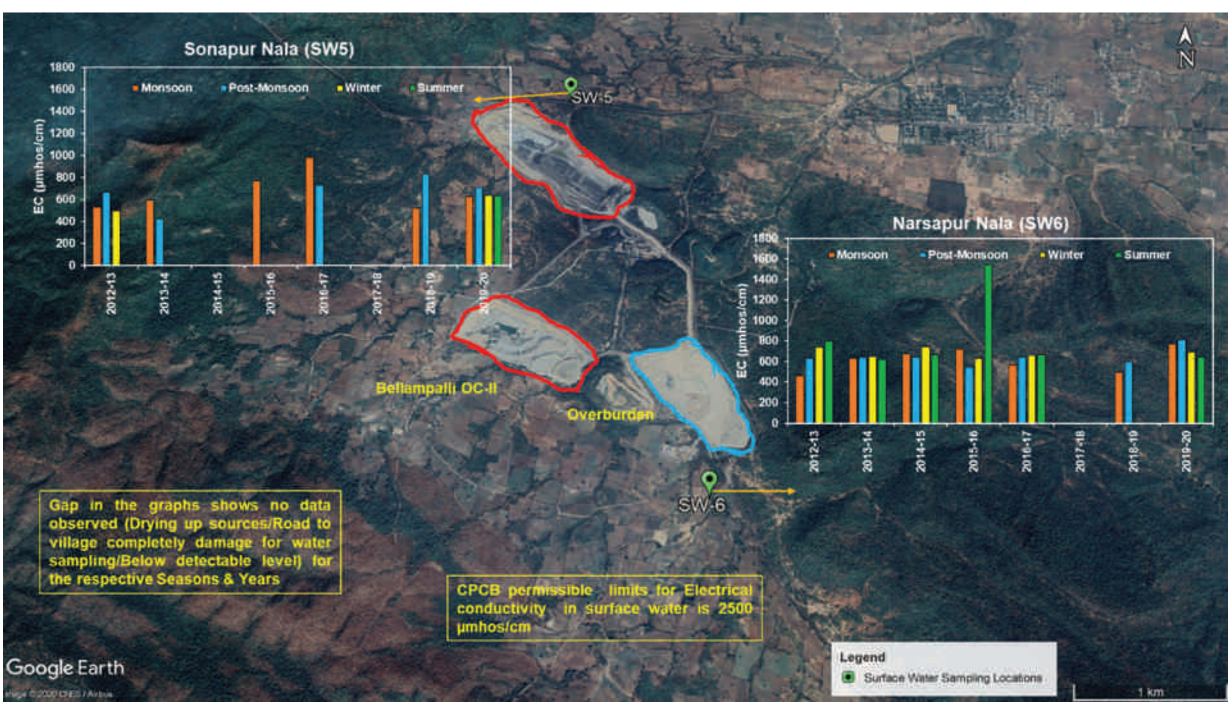

Figure 43: Seasonal variations in the Electrical Conductivity (µmhos/cm) of surface water around Bellampalli OC-II

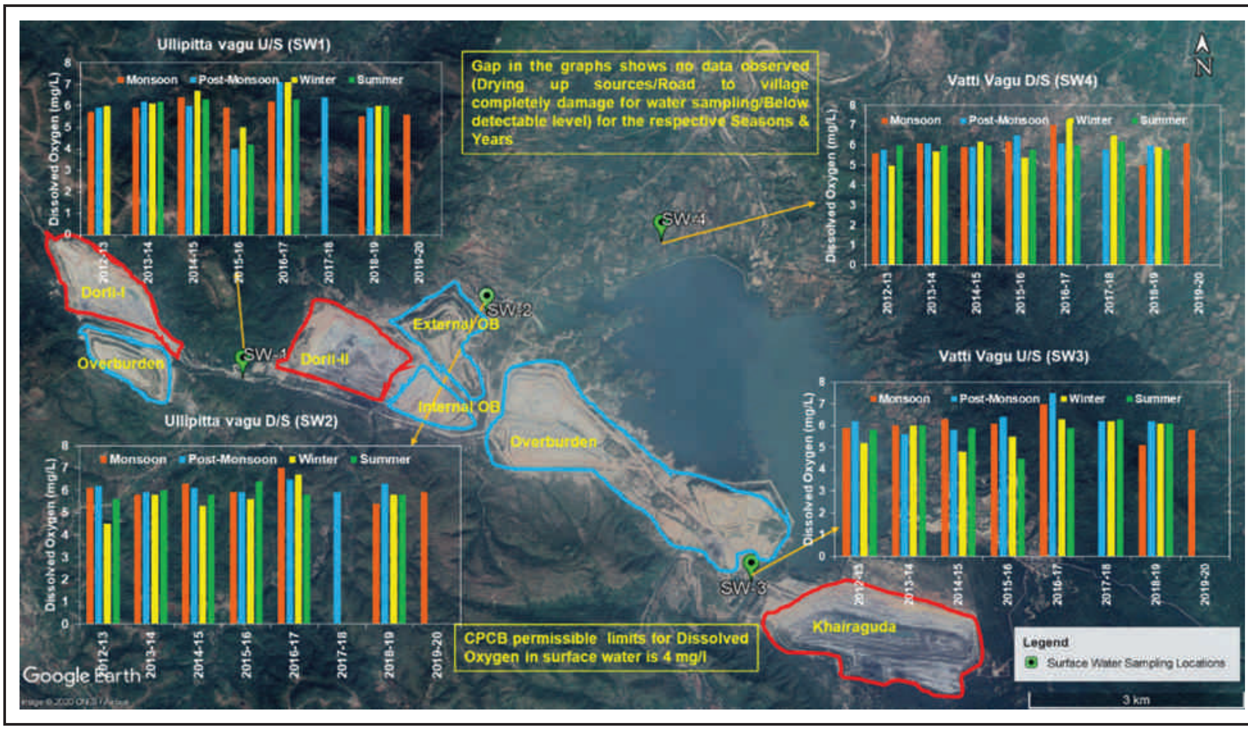

Figure 44: Seasonal variations in the Dissolved Oxygen (mg/L) content of surface water around Dorli OC-I, OC-II and Khairagura coal mines

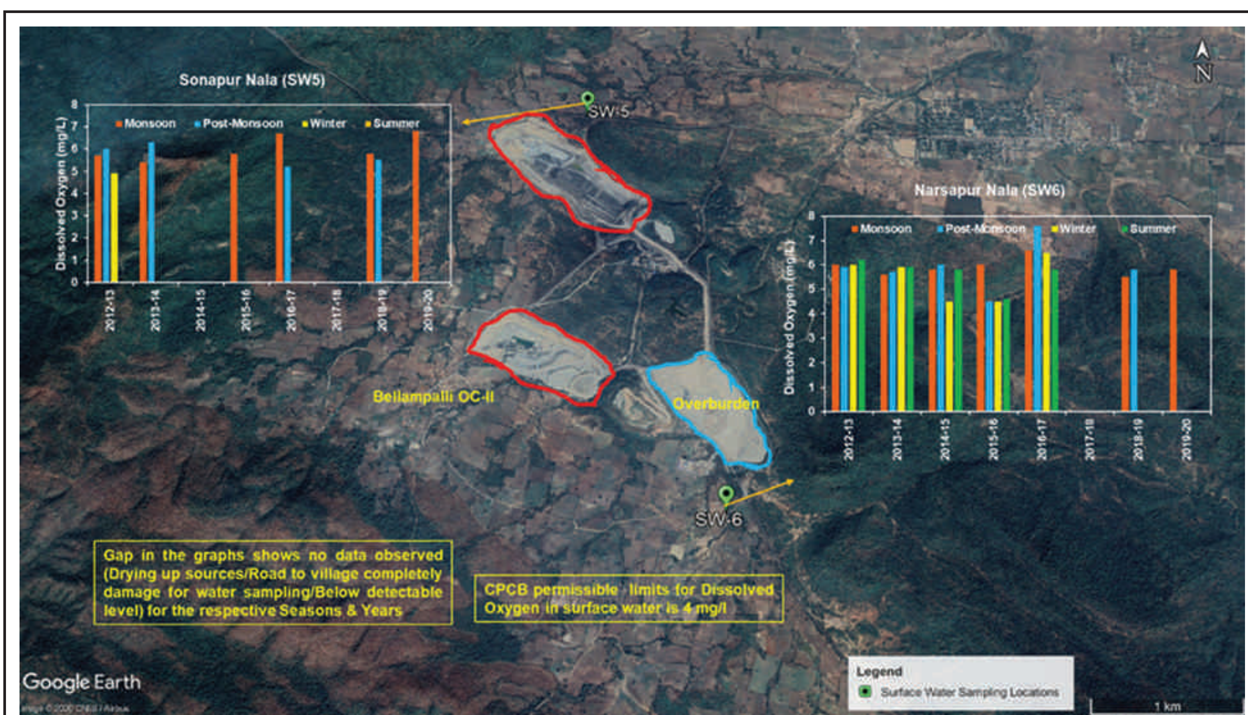

Figure 45: Seasonal variations in the Dissolved Oxygen (mg/L) content of surface water around Bellampalli OC-II

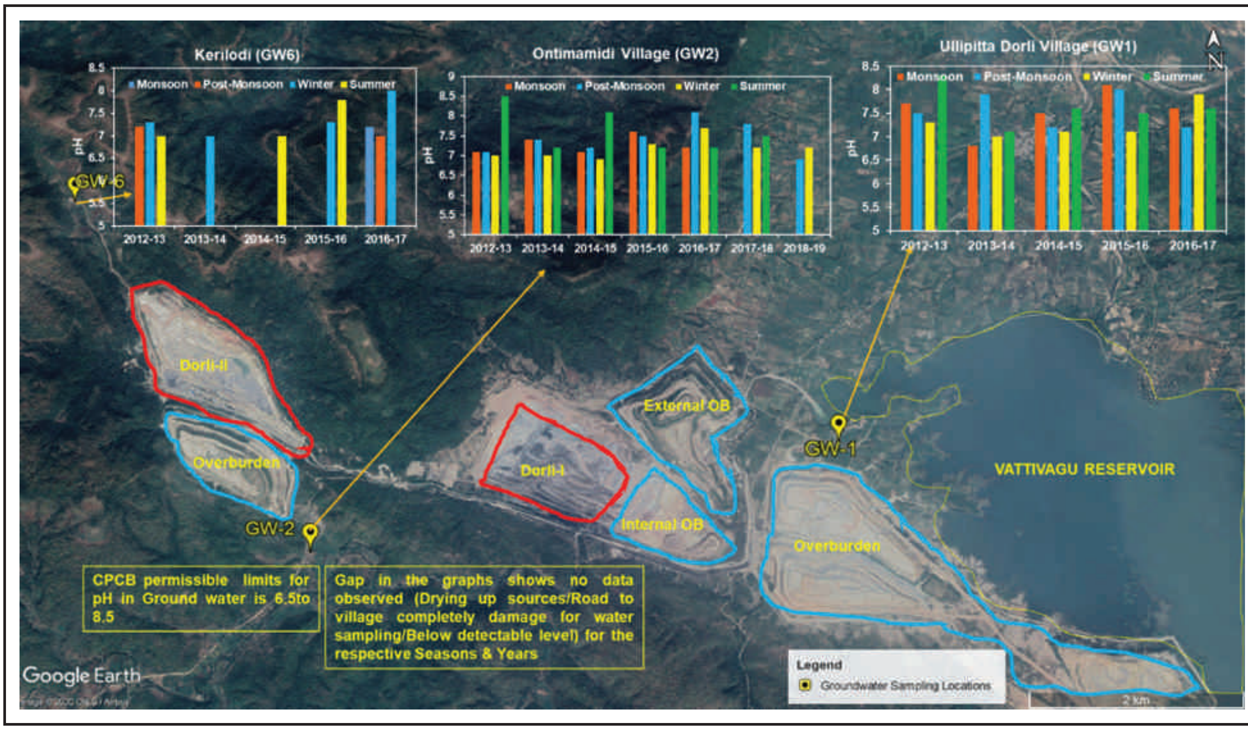

Figure 46: Seasonal variations in the pH of ground water around Dorli OC-I, OC-II and Khairagura coal mines

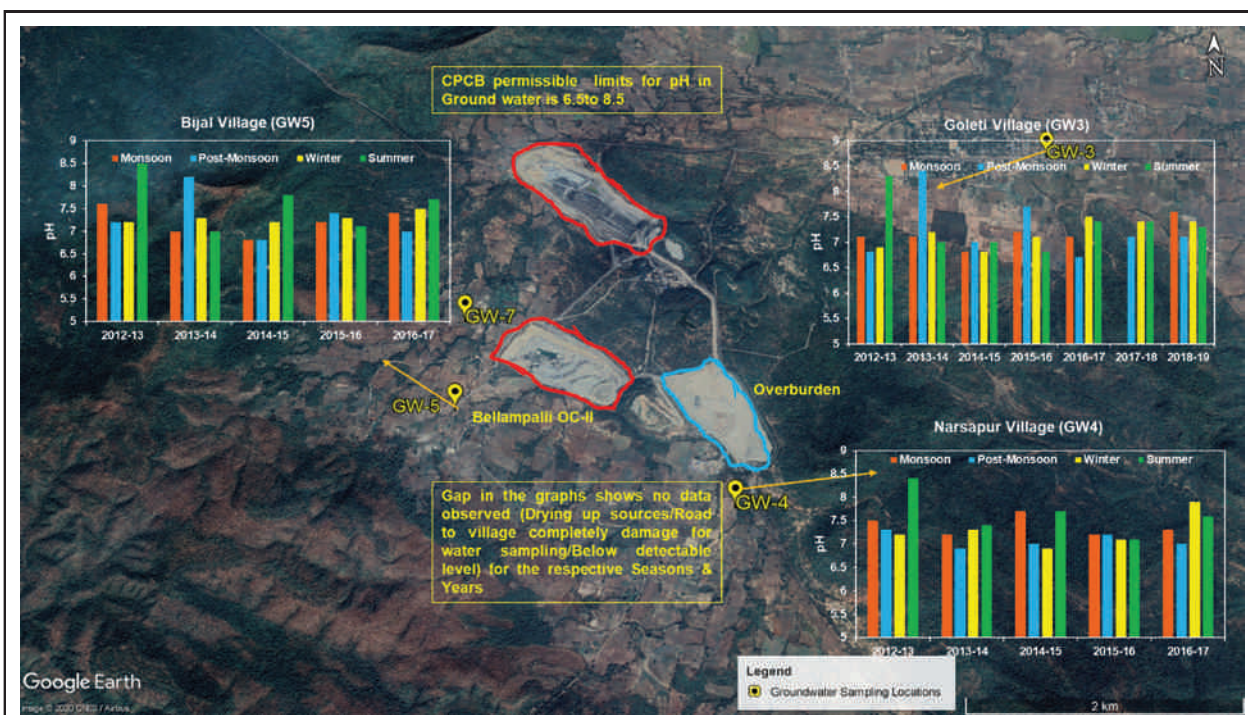

Figure 47: Seasonal variations in the pH of ground water around Bellampalli OC-II

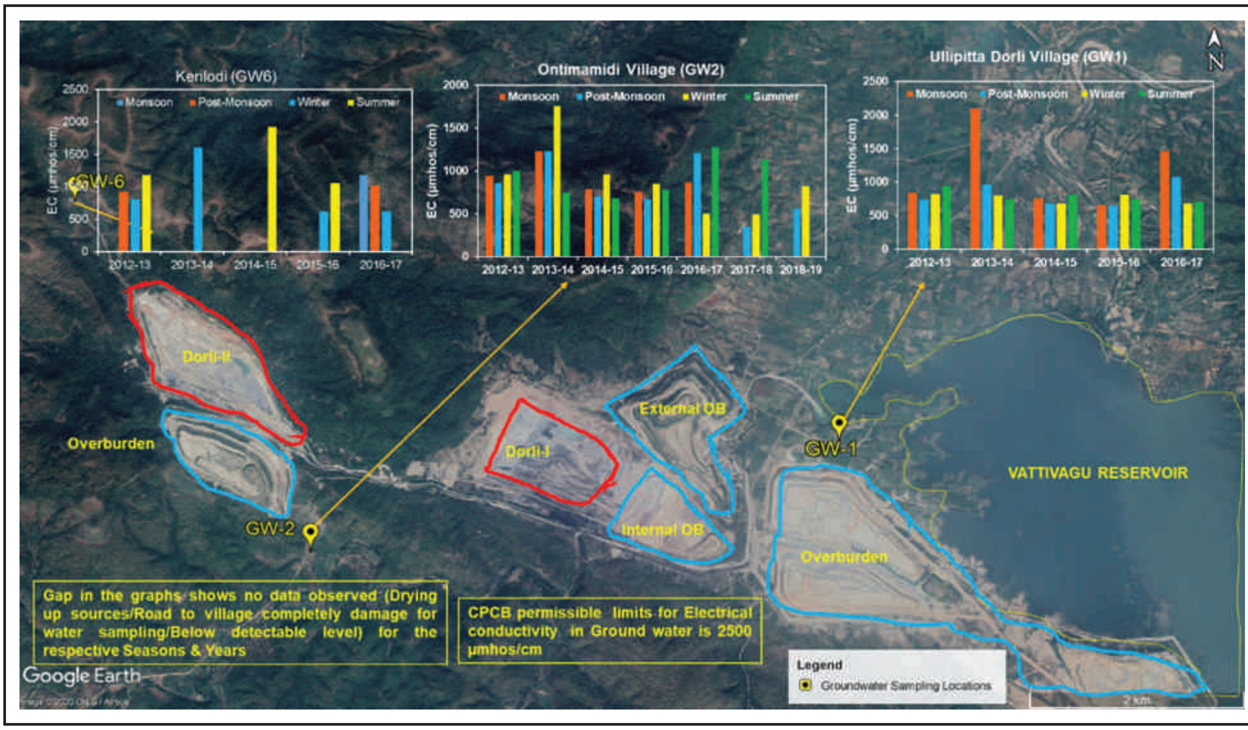

Figure 48: Seasonal variations in the Electrical Conductivity (µmhos/cm) of ground water around Dorli OC-I, OC-II and Khairagura coal mines

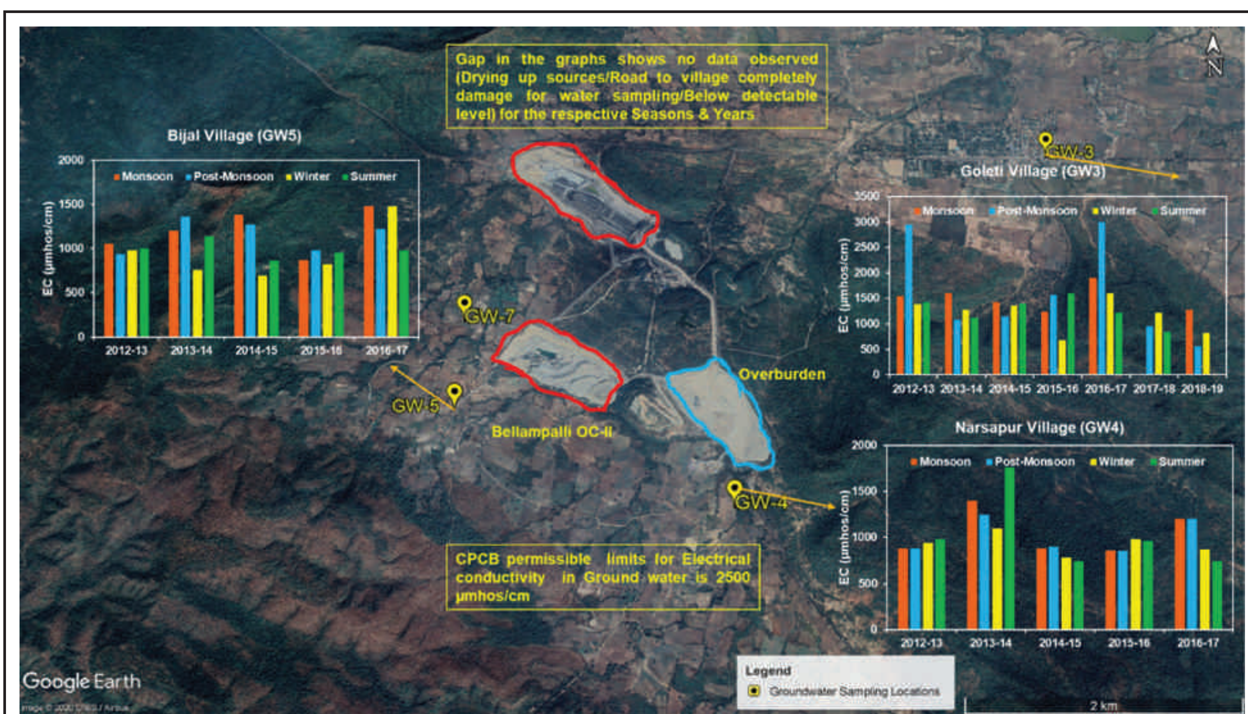

Figure 49: Seasonal variations in the Electrical Conductivity (µmhos/cm) of ground water around Bellampalli OC-II

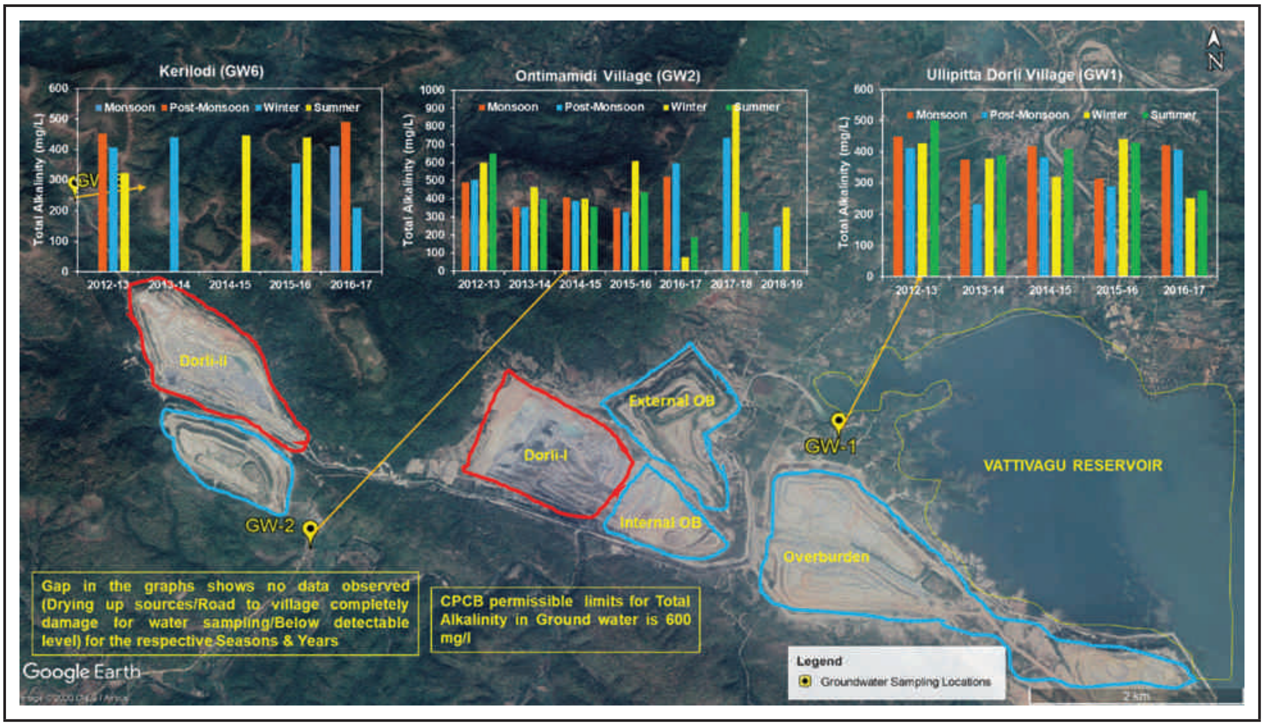

Figure 50: Seasonal variations in the Total Alkalinity (mg/L) of ground water around Dorli OC-I, OC-II and Khairagura coal mines

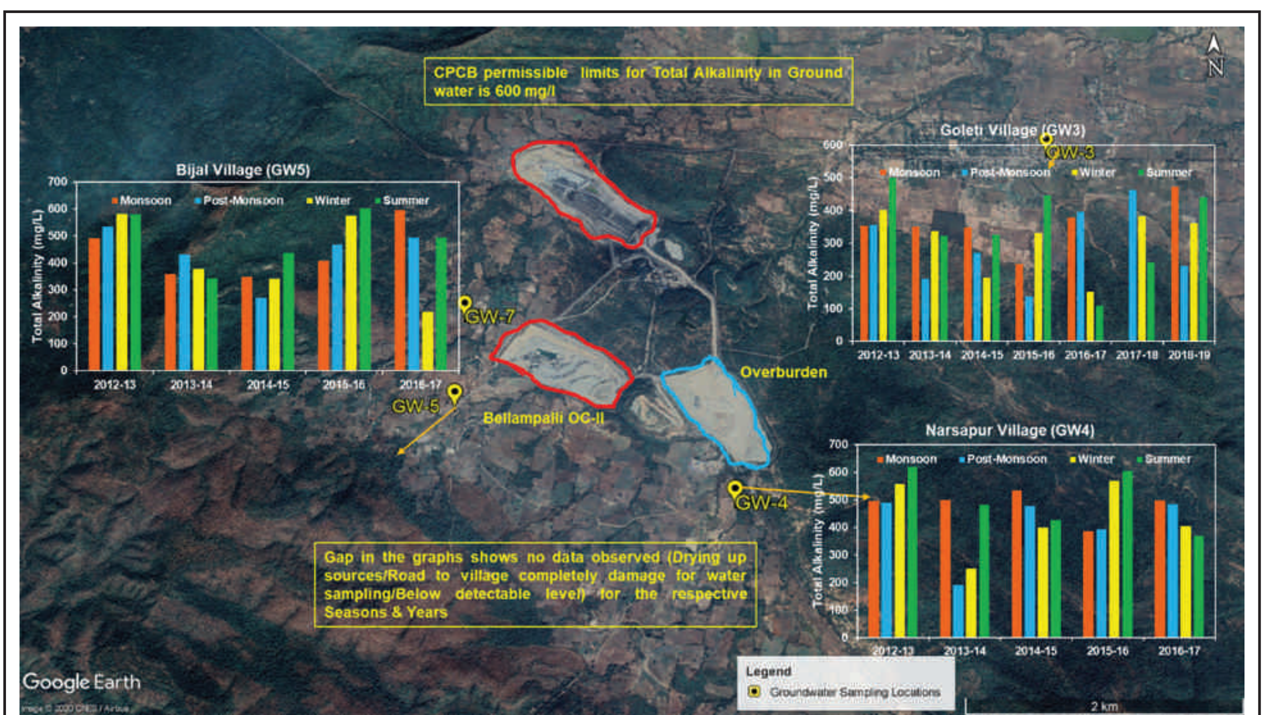

Figure 51: Seasonal variations in Total Alkalinity (mg/L) of ground water in Bellampalli OC-II

On an annual basis, the average pH of the groundwater samples collected from all sites in Study area-1 are consistent and closer to the neutral pH of 7.0 reflecting the absence of contamination (Chanchal Chauhan *et al.*, 2020). The total alkalinity (mg/L) which determines the dissolution characteristics for the groundwater is relatively high over the years (albeit within the permissible limit of 600 mg/L) reflecting a high probability for the presence of ions in dissolved state in the groundwater due to weathering or seepage. Except in the case of GW3 and GW6 samples, the average EC values of the ground water in all other locations is generally around 1000 μmohs/cm. While the average EC values in the case of GW3 and GW6 reach a peak of 1700 μmohs/cm in certain years (2012-13 and 2016-17 in the case of GW3, 2014-15 in case of GW6), all EC values of the ground water in the study area are within the norm of 2500 μmohs/cm. While there are annual variations in the ground water quality even at the same location, the reason for these variations can be established through a more detailed study based on more frequent sample collection and analysis.

As shown in Table 3, Dorli I OCM recorded an all-time record of 22 Mm^3 in Overburden (OB) removal during FY 2017-18. While this could have potentially increased the concentration of solids in surface water and therefore the EC values of SW2 in FY 2017-18, there has been only a slightly increase in EC values in that year compared to earlier years. This is indicative of the good management practices followed by SCCL in order to maintain a good water quality. Analysis of the EC values of surface water and groundwater before and after resumption of mining activities in Bellampalli OC II indicates that there has been no significant change in the EC values from FY 2016-17 onwards (when mining activities resumed in this coal mine) compared to the values recorded earlier. In all cases, the EC values of the surface water and ground water as reported by SCCL are within permissible levels. This again indicates good managerial practice.

The water quality data presented in this study has also been used to classify the surface water as per the best-use classes specified by CPCB. This analysis indicates that the surface water around the OCMs in the Dorli-Bellampalli coalfield is suitable for Class C use (drinking water) after suitable tertiary treatment. However, this water is also fit for Class D use (propagation of wildlife and fisheries) and Class E use (irrigation) without further treatment. Therefore, there is a need to assess the utility of pit lakes for the local communities. Based on the initiative of the Ministry of Coal (MoC) for providing sustainable coal mining solutions by creating a sustainable development cell on December 15, 2019, it would be useful to explore the impact of mining on the water environment in two ways:

1. By assessing the long-term datasets for significant spatial and temporal variations in the datasets for detecting any crucial changes to the water environment.

2. By providing innovative solutions for the use of constructed ecosystems such as pit lakes to manage the surface water resources of the region efficiently.

7. Summary and Conclusions

- In general, the annual average ambient air PM_{10} and $PM_{2.5}$ concentrations in the coalfields of India exceed the NAAQ standards of 60 μg/m^3 and 40 μg/m^3, respectively. Specifically, the overall AQI was found to fall under the moderately polluted category (101-200) in the core zone and in the satisfactory class (51-100) in the buffer zone of coal mines and TPPs in Study area-2. $PM_{2.5}$ was found to be the main driver of air quality in this area.

- $PM_{2.5}$ is the main driver of AQI in the core zone as well as the buffer zone of the coal mines. Since $PM_{2.5}$ emissions are particularly harmful to human health, coal mines in India must take immediate steps to control PM emissions at all stages of mining, crushing, and transportation more effectively, and also maintain a suitable "green belt" along the boundary of their respective CZs to shield public exposure to airborne respirable dust.

- Since the PM concentrations in the buffer zone of the coal mines in the study area exceed the NAAQ standard, MoEFCC must increase the frequency of mandatory recording of air pollution measurements in coal mines from the current fortnightly interval to a bi-weekly frequency that is already applicable to AAQ monitoring stations operated by SPCB and thermal power plants as per CPCB (2011) guidelines.

- The relationships between PM concentrations and total excavation in the OCMs in the Ramagundam area are statistically significant. Therefore, high-production opencast coal mines must utilize proven dust control technologies like more effective dust suppression on haul roads and coal stockpiles, wet drilling and dust extractors in coal handling plants (DNRME, 2019; OMSHR, 2014; Stanton *et al.*, 2006). Further, the use of public roads to transport coal must be avoided by using closed pipe conveyors and/or rail transportation systems.

- Since PM emissions from 220 TPPs in India exceed the MoEFCC (2015) emission norms, the retrofit of high-performance Electrostatic Precipitators (ESPs) with a guaranteed efficiency of 99.97 percent which can ensure compliance with the PM must be expedited in all TPPs by delinking the ESP modernization from FGD installation (CEA, 2020a).

- In general, the ambient SO_2 concentrations around TPPs using Indian coal are compliant with the NAAQ standard of 50 μg/m^3. This is due to the location of TPPs in the tropical regions of India where the local climatological conditions, low-Sulphur content of Indian coal, and the stack heights of TPPs act synergistically to disperse ambient SO_2 concentrations below the NAAQ standards (CEA, 2020b; CPCB, 1984; Thomas *et al.*, 1963; World Bank, 1998).

- CPCB (1984) has fixed the minimum height of TPP stacks (220 m - 275 m) to ensure dispersion of SO_2 emissions from the stack in such a manner that the ambient air concentrations of SO_2 remain much below the NAAQ standard under the climatological conditions prevalent around TPPs in India (Jayant Singh *et al.*, 2020; Thomas *et al.*, 1963). Analysis of the data presented in this report also indicates that, due to the climatological conditions in India, SO_2 levels are not a major concern from TPPs using low-Sulphur (< 0.7%) Indian coal which comply with the stack height and flue gas velocity limits mandated by MoEFCC for TPPs (CPCB, 1984; Jayant Singh *et al.*, 2010).

- It is estimated that capital investments of the order of Rs.80,000 crores (approximately, USD 11 billion) are required to retrofit FGDs in existing TPPs to comply with the stack emission limits for SO_2. In the prevailing scenario of financial stress in India's power sector, retrofits of imported FGDs to control SO_2 emissions must be mandated for TPPs using low-Sulphur Indian coal only if they are located in critically polluted/sensitive/urban sites and are not scheduled for retirement before 2025 (A V Krishnan and R Srikanth, 2020). This prioritization of FGDs for TPPs located in critically polluted areas and near Mega cities as well as the need to avoid expensive, imported FGDs in 448 TPPs across the country has also been recognized by MoEFCC on March 31, 2021 by notifying the Environment (Protection) Amendment Rules, 2021 (MoEFCC, 2021).

- MoEFCC must mandate all coal mines and TPPs to upload on their website in real-time, the data collected from their own Continuous Emission Monitoring Systems (CEMS). In addition, MoEFCC must ensure that these CEMS are properly sealed in the presence of an authorized CPCB/SPCB official after periodic calibration is carried out in the approved calibration facility as prescribed in the CPCB guidelines. This mandate towards enhanced transparency and quality assurance will improve the effectiveness of regulation and enhance public trust.

- India's National Green Tribunal (NGT) has already directed CPCB to expand the list of non-attainment cities by including other cities and towns which do not meet the prescribed NAAQ Standards so that the National Clean Air Program is not limited to only 124 cities. Therefore, MoEFCC must enhance funding for CPCB and the SPCBs to increase the number of CPCB/SPCB-maintained air quality monitoring stations (NGT, 2021).

- While MoEFCC mandates the submission of an Environmental Impact Assessment (EIA) along with an Environmental Management Plan (EMP) for any new TPP or coal mine or expansion of such projects, there is no provision for a regional EIA to determine the cumulative impact of all these projects in a coalfield where several coal mines and TPPs may be operating on the basis of separate EIAs and EMPs. CPCB/SPCBs must conduct cumulative impact assessments in coalfields along with interdisciplinary research to correlate these assessments with systematic investigations into public health. This research can then be utilised to review the NAAQ Standards (CPCB, 2009).

- A study of the impact of opencast coal mining on the air and water environment around four OCMs in Study area-1 (Dorli-Bellampalli coalfield) indicates that these OCMs have averted any adverse impact on the quality of water in the surrounding communities by diverting the surface streams away from the mines before the commencement of mining and by maintaining well-designed garland drains and/or settling ponds around the mines and overburden dumps. While the dissolved oxygen values indicate higher levels of aeration in the surface water than in the groundwater samples, the pH, electrical conductivity, and total dissolved solids values in the water samples drawn from this area are within the prescribed BIS/CPCB limits though they exceed the pre-mining values. Therefore, the water collected in these pit lakes may be useful for domestic purpose (after suitable treatment) or for irrigation after suitable steps are taken to prevent anthropogenic pollution and the formation of an anoxic layer in the pit lake.

- However, there is a need to address several vital gaps in our knowledge of coal mine pit lakes. To enable this, MoC must conduct interdisciplinary studies (combining science, technology and social science) to assess the current and upcoming pit lakes in terms of their utility to the surrounding communities with an integrated approach.

- Geospatial data including, AOD and NDVI can be very useful tools for surveillance and change detection in the air quality and vegetation in coalfields (Soni et al., 2015). This requires ground-truthing at strategic locations in each coalfield with the help of continuous Ambient Air Quality Monitoring Stations (AAQMS). Therefore, MoEFCC must encourage research on the use of geospatial data for air pollution control by enhancing CPCB funding to install continuous AAQMs in all coalfields of India. This will be of great benefit in enhancing the reach of the National Clean Air Program (NCAP) in an efficient and cost-effective manner.

- Specifically, monitoring of NDVI values in and around coal mines can be used to ensure that the vegetation in the buffer zone of the coal mines is not affected by mining operations. NDVI is also useful to monitor the success of progressive and final reclamation and revegetation programs that is critical for the progress towards a self-sustaining ecosystem post-closure of opencast coal mines. Therefore, MoEFCC must work more closely with ISRO to enhance the application of geospatial technologies to monitor the sustainability aspects of the mining sector in India.

- Productive forests create value for society by providing watershed protection, wildlife habitat, and other environmental services. MoEFCC must commission studies across coal mines in India to enhance the carbon sink potential in our coal mines post-closure while using the mined-out land for the benefit of local communities.

- One of the Nationally Determined Contributions (NDCs) committed by India in the Paris Agreement is to reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from the 2005 level. TPPs based on advanced ultra-supercritical technology can reduce specific coal consumption as well as emission of pollutants and CO_2 (MoP, 2017). While TPPs with Integrated Gasification Combined Cycle (IGCC) technology have demonstrated net plant efficiency as high as 45% and have the best environmental performance, the development of IGCC is slow throughout the world due to its high capital cost (Lifeng Zhao *et al.*, 2008). A coal-rich but energy-poor country like India with no access to low-cost natural gas and a low nuclear energy share must ensure sustainable coal utilisation by deploying indigenous High-efficiency, Low-emissions (HELE) technologies like IGCC also (Minchener, 2020).

- During the 16th Conference of Parties (COP16) held in Cancun, Mexico in 2010, the Parties agreed to set up the Green Climate Fund (GCF) to act as the working entity to facilitate climate finance. Specifically, the developed country Parties committed to a goal of mobilizing jointly US$100 billion per year by 2020 to address the needs of developing countries and facilitate meaningful mitigation actions and transparency on implementation.

- Technology transfer at affordable costs is crucial for developing countries like India to enhance their contribution to reduction of CO_2 emissions to control global temperature rise to 1.5 degrees above the pre-industrial levels. While the developed countries committed to provide one (1) trillion dollars to the GCF cumulatively during the last ten years, not even 2 percent of this amount has materialized (PIB, 2019). Therefore, UNFCCC must convince the developed countries to meet their commitments as per the Paris Agreement and also release funds from the GCF for low-carbon energy pathways like IGCC power plants (using high-ash coal) and nuclear power plants in addition to grid-scale battery storage and grid integration of variable renewable energy sources (e.g., wind and solar). This will enable India to meet the NDCs committed in the Paris Agreement while protecting India's energy security with 24x7 power supply to all Indians as per SDG 7.

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References

1. APHA (American Public Health Association) Standard methods for analysis of water and wastewater. 18th Ed. American Public Health Association, Inc., Washington D C. 1992. retrieved from <https://law.resource.org/pub/us/cfr/ibr/002/apha.method.9221.1992.pdf> (Last accessed on March 2, 2020).
2. A. V Krishnan and R Srikanth, (2020). Transition Plan for thermal power plants in India. NIAS Policy Brief. National Institute of Advanced Studies, IISc Campus, Bengaluru. 560012. 4 pp.
3. APHA (American Public Health Association) Standard methods for analysis of water and wastewater. 18th Ed. American Public Health Association, Inc., Washington D C. 1992. retrieved from <https://law.resource.org/pub/us/cfr/ibr/002/apha.method.9221.1992.pdf> (Last accessed on March 2, 2020).
4. Banerjee, G. K., Srivastava, K. K., and Chakraborty, M. K. (2001). SPM is the Major Pollution in Open Cast Mining - a case study. Journal of Scientific and Industrial Research 60(5):416-420. retrieved from <http://nopr.niscair.res.in/bitstream/123456789/26491/1/JSIR%2060%285%29%20416-420.pdf> (Last accessed on April 14, 2021).
5. Beig, Gufran, Ghude, S. D., and Deshpande, A. (2010). Scientific evaluation of air quality standards and defining Air Quality Index for India. Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Pune, India. Research report No-127. retrieved from <https://www.tropmet.res.in/~lip/Publication/RR-pdf/RR-127.pdf> (Last accessed on April 14, 2021).
6. BIS IS 15442, (2004). (Reaffirmed Year: 2015). Parameters for environmental impact assessment of water resources projects. retrieved from <https://standardsbis.bsbedge.com/BIS_SearchStandard.aspx?Standard_Number=IS%2015442&id=713> (Last accessed on March 2, 2020).
7. Boken *et al.* (2008). Monitoring peanut contamination in Mali using AVHRR satellite data and a crop simulation model. International Journal of Remote Sensing, 29(1), pp. 117-129.
8. BP (British Petroleum) (2020). Statistical Review of World Energy 69th Edition, 2020; retrieved from <https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf> (Last accessed on March 9, 2021).
9. Brown, J. F. (2015). NDVI, the Foundation for Remote Sensing Phenology. USGS remote sensing phenology: Vegetation Indices. retrieved from <https://www.usgs.gov/core-science-systems/eros/phenology/science/ndvi-foundation-remote-sensing-phenology> (Last accessed on April 19, 2021).
10. CEA (2016). Energy wise - Performance Status All India - Region wise. retrieved from <http://www.cea.nic.in/reports/monthly/generation/2016/March/actual/opm_16.pdf> (Last accessed on August 26, 2020).
11. CEA (2017). Energy wise - Performance Status All India region-wise. retrieved from <http://www.cea.nic.in/reports/monthly/generation/2017/March/actual/opm_16.pdf> (Last accessed on August 26, 2020).
12. CEA (2018). Energy wise - Performance Status All India region-wise. retrieved from <http://www.cea.nic.in/reports/monthly/generation/2018/March/actual/opm_16.pdf> (Last accessed on August 26, 2020).
13. CEA (2019). Energy wise - Performance Status All India – region-wise during FY 2018-19 versus 2017-18. retrieved from <http://www.cea.nic.in/reports/monthly/generation/2019/March/actual/opm_16.pdf> (Last accessed on August 26, 2020).
14. CEA (2020a). Quarterly Review Report (January

– March 2020): Renovation & Modernisation of Thermal Power Station. retrieved from <http://www.cea.nic.in/reports/quarterly/trm_quarterly_review/2020/trm_qrr-03.pdf> (Last accessed on September 14, 2020).

15. CEA (2020b). Plant location specific emission standards. retrieved from <https://cea.nic.in/wp-content/uploads/notification/2020/12/Review_of_Plant_Emission_Standards_29.pdf> (Last accessed on April 1, 2021).

16. CEA (Central Electricity Authority) (2015). Energy-wise - Performance status, All India – Region-wise. retrieved from <http://www.cea.nic.in/reports/monthly/generation/2015/March/actual/opm_16.pdf> (Last accessed on August 26, 2020).

17. Chanchal Chauhan *et al.* (2020). Sustainability of Coal Mining: Case study of Dorli-Bellampalli coal mines. (NIAS Research Report No. NIAS/NSE/EEP/U/RR/06/2020). National Institute of Advanced Studies. Bengaluru. India 560012.

18. Coal Controller (2021). Coal Director of India: 2019-20. retrieved from <http://www.coalcontroller.gov.in/writereaddata/files/download/coaldirectory/CoalDirectory2019-20.pdf> (Last accessed on April 28, 2021).

19. CPCB (2000). Air Quality Standards for Coal Mines, Serial No.90, Rule 2(1) of the Environment (Protection) Amendment Rules, 2000. Notification G.S.R. 742(E). retrieved from <https://cpcb.nic.in/displaypdf.php?id=SW5kdXN0cnktU3BlY2lmaWMtU3RhbmRhcmRzL0VmZmx1ZW50LzQ5NC0xLnBkZg==> (Last accessed on March 2, 2020).

20. CPCB (2009). National Ambient Air Quality Standards. retrieved from <https://cpcb.nic.in/uploads/National_Ambient_Air_Quality_Standards.pdf> (Last accessed on September 27, 2019).

21. CPCB (2009). National Ambient Air Quality Standards. retrieved from <https://cpcb.nic.in/uploads/National_Ambient_Air_Quality_Standards.pdf> (Last accessed on September 27, 2019).

22. CPCB (2011). Guidelines for sampling and measurement of notified ambient air quality parameters. retrieved from <https://cpcb.nic.in/openpdffile.php?id=UmVwb3J0RmlsZXMvMjdfMTQ1ODExMDQyN19OZXdJdGVtXzE5N19OQUFRTVNfVm9sdW1lLUkucGRm> (Last accessed on March 30, 2021).

23. CPCB (2014). National Air Quality Index. retrieved from <http://www.indiaenvironmentportal.org.in/files/file/Air%20Quality%20Index.pdf> (Last accessed on May 27, 2019).

24. CPCB (2018). Timelines for implementation of new emission norms for Thermal Power Plants (notified on 07.12.2015) as per the directions issued on 11.12.2017 and 06.04.2018 u/s 5 of EP Act, 1986. retrieved from <https://cpcb.nic.in/uploads/direction/Direction_tpp_Combined_12.06.2018.pdf> (Last accessed on November 4, 2019).

25. CPCB (Central Pollution Control Board) (1984). Emissions Regulations Part-1. retrieved from <http://cpcbenvis.nic.in/scanned%20reports/COINDS-17%20EMISSION%20REGULATIONS%20PART_1.pdf> (Last accessed on July 10, 2020).

26. Dadhich, A. P., Goyal, R., and Dadhich, P. N. (2018). Assessment of spatio-temporal variations in the air quality of Jaipur city, Rajasthan, India. The Egyptian Journal of Remote Sensing and Space Science. Vol. 21. Issue 2. pp. 173–181; retrieving from <https://www.sciencedirect.com/science/article/pii/S1110982317301357> (Last accessed on April 19, 2021).

27. Didan, K. (2015). MYD13Q1 V006. retrieved from <https://doi.org/10.5067/MODIS/MYD13Q1.006> (Last accessed on April 19, 2021).

28. DNRME (Department of Natural Resources, Mines and Energy) (2019). Dust control in surface mines. retrieved from <https://www.resources.qld.gov.au/__data/assets/pdf_file/0005/1462685/recognised-standard-20-dust-control-surface-mines.pdf> (Last accessed on April 3, 2021).

29. Dockery, D. W., Pope, C. A., Xu, Xiping, *et al.* (1993). An association between air pollution and mortality in Six U.S. Cities. The New England Journal of Medicine. Volume 329. Number 24. pp. 1753-1759. retrieved from <https://www.nejm.org/doi/full/10.1056/NEJM199312093292401> (Last accessed on April 14, 2021).

30. EPA (Environmental Protection Agency) (2013). Revised Air Quality Standards for particle pollution and updates to the Air Quality Index. retrieved from <https://www.epa.gov/sites/production/files/2016-04/documents/2012_aqi_factsheet.pdf> (Last accessed on October 1, 2019).

31. FRA (2016). The Forestry reclamation approach: Guide to successful reforestation of mined lands. retrieved from <https://www.fs.fed.us/nrs/pubs/gtr/gtr_nrs169.pdf> (Last accessed on April 2, 2021).

32. Garai, D. and Narayana, A. C. (2018). Land use/land cover changes in the mining area of Godavari coal fields of southern India. The Egyptian Journal of Remote Sensing and Space Sciences; 21 (2018) 375–381. retrieved from <https://doi.org/10.1016/j.ejrs.2018.01.002> (Last accessed on March 30, 2021).

33. Ghose (2002). Air Pollution due to opencast coal mining and the characteristics of air-borne dust- An Indian Scenario. International Journal of Environmental Studies, 2002, Vol. 59(2), pp. 211–228; ISSN: 0020-7233 Print; ISSN:1029-0400. retrieved from <https://doi.org/10.1080/00207230210927> (Last accessed on March 30, 2021).

34. Gomez-Losada, Francisca, M. S., Gilbert, K., *et al.* (2019). A data science approach for spatiotemporal modelling of low and resident air pollution in Madrid (Spain): Implications for epidemiological studies. Computers, Environment and Urban Systems. 75, 1–11. retrieved from <https://doi.org/10.1016/j.compenvurbsys.2018.12.005> (Last accessed on March 4, 2020).

35. Government of Telangana (2021). Statistical Abstract. retrieved from <https://tsdps.telangana.gov.in/Statistical_Abstract_2020.pdf> (Last accessed on March 30, 2021).

36. GCF (Green Climate Fund) (2021). About GCF. retrieved from <https://www.greenclimate.fund/about/timeline> (Last accessed on April 28, 2021).

37. Gurdeep Singh and Amarjeet Singh (2015). Ambient air quality assessment with particular reference to particulates in Western part of Jharia Coalfield, India. Current World Environment Vol. 10(2), 523-528. retrieved from <https://www.cwejournal.org/vol10no2/ambient-air-quality-assessment-with-particular-reference-to-particulates-in-western-part-of-jharia-coalfield-india/> (Last accessed on March 30, 2021).

38. Jay S. Patel (2017). Ambient Air Quality Assessment using Air Quality Index of Delhi. International Conference on Research and Innovations in Science, Engineering &Technology. Selected papers in Civil Engineering. Kalpa Publications in Civil Engineering Volume 1. Pages 124-131.

39. Jayant Singh., Srikanth, R., Ramasesha, S. K., (2020). Dispersion of particulate matter and Sulphur Oxides from a thermal power plant: A case study. retrieved from <https://www.preprints.org/manuscript/202007.0231/v1> (Last accessed on September 12, 2020).

40. Jumaah, H. J., Ameen, M. H., Kalantar, B. *et al.* (2019). Air quality index prediction using IDW geostatistical technique and OLS-based

GIS technique in Kuala Lumpur, Malaysia. Geomatics, Natural Hazards and Risk, 10(1), 2185–2199. retrieved from <https://doi.org/10.1080/19475705.2019.1683084> (Last accessed on March 4, 2020).

41. Kiranmay Sharma (2005). Impact of Coal Mining on Vegetation: A case study in Jaintia Hills District of Meghalaya, India. Master of Science Theses in Geoinformation Science and Earth Observation with Specialization in Natural Hazard Studies submitted to the International Institute of Geo-information Science and Earth Observation (ITC).

42. Kyrkilis, George, Arhontoula Chaloulakou, and Pavlos A Kassomenos (2007). Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: Relation to potential health effects. Environment International. Vol. 33. No. 5. pp. 670-676. retrieved from <https://doi.org/10.1016/j.envint.2007.01.010> (Last accessed on April 14, 2021).

43. Lancet Planet Health (2019). The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017; The Lancet Planet Health Volume 3, Issue 1, Pages e26-e39. retrieved from <https://www.thelancet.com/action/showPdf?pii=S2542-5196%2818%2930261-4> (Last accessed on June 12, 2020).

44. Lifeng Zhao, Yunhan Xiao, Kelly Sims Gallagher, *et al.* (2008). Technical, environmental, and economic assessment of deploying advanced coal power technologies in the Chinese context. Energy Policy. 36 (7). pp. 2709-2718.

45. Limin Jiao *et al.* (2017). Spatial and Temporal Variability of the PM2.5/PM10 Ratio in Wuhan, Central China. Aerosol Air Qual. Res. 17: 741-751. retrieved from <https://doi.org/10.4209/aaqr.2016.09.0406> (Last accessed on May 24, 2019).

46. Minchener, A (2020). The importance of high-efficiency low-emissions technologies for sustainable coal utilisation. retrieved from <https://www.unece.org/fileadmin/DAM/energy/se/pdfs/CES/ge15_2019/HELE_report.pdf> (Last accessed on September 14, 2020).

47. Mirabelli, M. C., Stefanie Ebelt, and Scott A Damon (2020). Air Quality Index and air quality awareness among adults in the United States. retrieved from <https://doi.org/10.1016/j.envres.2020.109185> (Last accessed on April 14, 2021).

48. MoC (Ministry of Coal) (2020). Guidelines for preparation, formulation, submission, processing, scrutiny, approval, and revision of the mining plan. retrieved from_<https://coal.nic.in/sites/upload_files/coal/files/curentnotices/Comprehensive_Guideline_Mining_Plan_29_05_2020.pdf> (Last accessed on August 5, 2020).

49. MoC (2021). Import of coal. Unstarred question no. 2757 answered by the Hon Minister for Coal in the Lok Sabha on 10.03.2021. retrieved from <http://164.100.24.220/loksabhaquestions/annex/175/AU2757.pdf> (Last accessed on March 12, 2021).

50. MoEF (Ministry of Environment & Forests) (2010). Environmental Impact Assessment Guidance Manual for mining of minerals. retrieved from <http://environmentclearance.nic.in/writereaddata/Form1A/HomeLinks/miningofminerals_10may.pdf> (Last accessed on February17, 2019).

51. MoEFCC (2020). Most polluted cities. Unstarred question no. 973 answered by the Hon Minister for Environment, Forest and Climate Change in the Lok Sabha on 18.09.2020. retrieved from <http://164.100.24.220/loksabhaquestions/annex/174/AU973.pdf> (Last accessed on March 12, 2021).

52. MoEFCC (2021). Environment Protection (Amendment Rules), 2021. G.S.R. 243(E). MoEFCC Gazette Notification issued on March 31, 2021. 3 pp.

53. MoEFCC (Ministry of Environment, Forest and Climate Change) (2015). Standards for emission or discharge of environmental pollutants from thermal power plants. retrieved from <https://cpcb.nic.in/displaypdf.php?id=SW5kdXN0cnktU3BlY2lmaWMtU3RhbmRhcmRzL0VmZmx1ZW50L1RQUC5wZGY=> (Last accessed on March 2, 2020).

54. MoP (Ministry of Power) (2017). Construction of ultra-supercritical thermal power plant. Question No.1613 answered by the Minister of Power in the Lok Sabha on 28.12.2017. retrieved from <http://164.100.24.220/loksabhaquestions/annex/13/AU1613.pdf> (Last accessed on September 14, 2020).

55. Moreno (2019). Trace element fractionation between PM_{10} and $PM_{2.5}$ in coal mine dust: Implications for occupational respiratory health. International Journal of Coal Geology 203 (2019) 52–59. retrieved from <https://doi.org/10.1016/j.coal.2019.01.006> (Last accessed on March 20, 2020).

56. NASA (National Aeronautics and Space Administration) (2021). MODIS. retrieved from <https://modis.gsfc.nasa.gov/about/media/modis_brochure.pdf> (Last accessed on April 14, 2021).

57. Nayak and Chowdhury (2018). Health Damages from Air Pollution: Evidence from Opencast Coal Mining Region of Odisha, India. Ecology, Economy and Society– The INSEE Journal 1 (1): 43–65.

58. NGT (National Green Tribunal) (2021). Final Order on Original Application No. 681/2018. retrieved from <https://greentribunal. gov.in/gen_pdf_test.php?filepath=L25ndF9kb2N1bWVudHMvbmd0L2Nhc2Vkb2MvanVkZ2VtZW50cy9ERUxISS8yMDIxLTA0LTA4LzE2MTgzODgzNjkxNjI3OTgyMzU2MDc2YTU5MTdjNWQ1LnBkZg==> (Last accessed on May 12, 2021).

59. NPP (2021). Energy wise - Performance Status All India – region-wise. retrieved from <https://npp.gov.in/public-reports/cea/monthly/generation/18%20col%20act/2021/MAR//18%20col%20act-16_2021-MAR.pdf> (Last accessed on June 9, 2021).

60. NPP (National Power Portal) (2020). Energy wise - Performance Status All India – region-wise during FY 2019-20 versus 2018-19. retrieved from <https://npp.gov.in/monthlyGenerationReportsAct> (Last accessed on April 1, 2021).

61. NRSC (National Remote Sensing Centre) (2021). Resourcesat-1. retrieved from <https://www.nrsc.gov.in/sites/default/files/pdf/brresourcesat1.pdf> (Last accessed on April 14, 2021).

62. NTPC (National Thermal Power Corporation Limited) (2016a). Annual Environmental Statement for the year FY 2015-16. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Environmental-Statement-year-2015%20-%2016.pdf> (Last accessed on October 11, 2019).

63. NTPC (2016b). Half Yearly Compliance Report from October-2015 to March-2016. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Ramagundam-HYC-October-2015-to-March-2016.pdf> (Last Accessed on October 11, 2019).

64. NTPC (2016c). Half Yearly Compliance Report from April-2016 to September-2016. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/HYCREPORTRAMAGUNDAMSTPPSTIII.pdf> (Last accessed on October 11, 2019).

65. NTPC (2017a). Annual Environmental Statement for the year FY 2016-17. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Environmental-Statement-year-2016-17.pdf> (Last accessed on October 11, 2019).

66. NTPC (2017b). Half Yearly Compliance Report from October-2016 to March-2017. retrieved from <https://www.ntpc.co.in/sites/default/

files/downloads/Ramagundam-HYC-Oct-16-to-March-17.pdf> (Last accessed on October 11, 2019).

67. NTPC (2017c). Half Yearly Compliance Report from October-2016 to March-2017. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Ramagundam-HYC-October-2016-to-March-2017_compressed.pdf> (Last accessed on October 11, 2019).

68. NTPC (2017d). Half Yearly Compliance Report from April-2017 to September-2017. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/SixMonthlyReportRamagundamApril17toSep2017.pdf> (Last accessed on October 11, 2019).

69. NTPC (2018a). Annual Environmental Statement for the year FY 2017-18. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Environmental-Statement-year-2017-18.pdf> (Last accessed on October 11, 2019).

70. NTPC (2018b). Half Yearly Compliance Report from October-2017 to March-2018. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Ramagundam-HYC-October-2017-to-March-2018-compressed.pdf> (Last accessed on October 11, 2019).

71. NTPC (2018c). Half Yearly Compliance Report from April-2018 to September-2018. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Ramagundam-HYC-April-2018%20-to-September%20-2018-compressed.pdf> (Last accessed on October 11, 2019).

72. NTPC (2019a). Annual Environmental Statement for the year FY 2018-19. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/NTPC-Ramagundam-Environment-Statement-2018-19.pdf> (Last accessed on December 10, 2020).

73. NTPC (2019b). Half Yearly Compliance Report from October-2018 to March-2019. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/Ramagundam-HYC-Oct-18-to-March-2019.pdf> (Last accessed on December 10, 2020).

74. NTPC (2019c). Half Yearly Compliance Report from October-2018 to March-2019. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/NTPC-Ramagundam-HYC-EC-Oct-18-to-March-2019.pdf> (Last accessed on December 10, 2020).

75. NTPC (2019d). Half Yearly Compliance Report from April-2019 to September-2019. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/NTPC-Ramagundam-HYC-EC-Apr-19-to-Sept-19.pdf> (Last accessed on May 2, 2020).

76. NTPC (2020). Half Yearly Compliance Report from October-2019 to March-2020. retrieved from <https://www.ntpc.co.in/sites/default/files/downloads/NTPC-Ramagundam-HYC-EC-Oct-19-to-Mar-20.pdf> (Last accessed on May 2, 2020).

77. OMSHR (Office of Mine Safety and Health Research) (2014). Best practices for controlling respirable dust in coal mines. retrieved from <https://arlweb.msha.gov/endblacklung/docs/6%20Surface%20Mine%20Dust%20Control%20-%20Beckley%202014.pdf> (Last accessed on July 19, 2020).

78. Pallavi *et al.* (2018). Monitoring Particulate Matter in India: Recent Trends and Future Outlook. Air Quality, Atmosphere & Health retrieved from <https://doi.org/10.1007/s11869-018-0629-6> (Last accessed on March 30, 2021).

79. Pandey, B., Agrawala, M., and Singh, S. (2014). Assessment of air pollution around coal mining area: Emphasizing on spatial distributions, seasonal variations, and heavy metals, using cluster and principal component analysis. Atmospheric Pollution Research. retrieved from <https://www.sciencedirect.com/science/article/pii/S1309104215303445> (Last accessed on April 14, 2021).

80. PIB (Press Information Bureau) (2019). Statement of Union Environment Minister, Government of India, at UNFCCC COP25. retrieved from <https://pib.gov.in/Pressreleaseshare.aspx?PRID=1595787> (Last accessed on April 27, 2021).

81. Pope, C. A. 3rd, Bates, D. V. and Raizenne, M. E. (1995). Health Effects of Particulate Air Pollution: Time for Reassessment. Environmental Health Perspectives. 103(5): 472–480. retrieved from <https://doi.org/10.1289/ehp.95103472> (Last accessed on April 14, 2021).

82. QGIS Documentation (2021). A gentle introduction to GIS: Spatial Analysis (Interpolation). retrieved from <https://docs.qgis.org/3.16/en/docs/gentle_gis_introduction/spatial_analysis_interpolation.html> (Last accessed on April 10, 2021).

83. Rouse, J. W. Jr., Haas, R. H., Schell, J. A., *et al*. (1974). Monitoring vegetation systems in the Great Plains with ERTS. NASA Special Publication, *351*, 309.

84. SCCL (2018a). Annual environmental statement of Ramagundam Opencast-III (EP) PH-II Coal Mine Project for the Year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/200175.pdf> (Last accessed on October 1, 2019).

85. SCCL (2018b). Annual environmental statement of GDK 9 (Extension) Vakilpalli, SCCL for the Year 2017-18; retrieved from <https://scclmines.com/env/docs/ECS/200115.pdf> (Last accessed on October 1, 2019).

86. SCCL (2018c). Annual environmental statement of Ramagundam Opencast - I Coal Mine Project Expansion - Phase-II of SCCL for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/200155.pdf> (Last accessed on October 1, 2019).

87. SCCL (2018d). Annual environmental statement of GDK 10 incline of Adriyala project for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/200035.pdf> (Last accessed on October 1, 2019).

88. SCCL (2018e). Annual environmental statement of Ramagundam Opencast - II coal mine extension Project of SCCL for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/200165.pdf> (Last accessed on October 1, 2019).

89. SCCL (2018f). Annual environmental statement of Adriyala shaft underground coal mining expansion project for the year 2017-18 retrieved from <https://scclmines.com/env/docs/ECS/200025.pdf> (Last accessed on October 1, 2019).

90. SCCL (2018g). Annual environmental statement of Kasipet pit project of Mandamari Area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320015.pdf> (Last accessed on October 1, 2019).

91. SCCL (2018h). Annual environmental statement of Kalyani Khani-1 Incline project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320035.pdf> (Last accessed on October 1, 2019).

92. SCCL (2018i). Annual environmental statement of Kalyani Khani-1A Pit Project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320055.pdf> (Last accessed on October 1, 2019).

93. SCCL (2018j). Annual environmental statement of Ramakrishnapur opencast project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320045.pdf> (Last accessed on October 1, 2019).

94. SCCL (2018k). Annual environmental statement of Shanthi Khani pit project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320065.pdf>

(Last accessed on October 1, 2019).

95. SCCL (2018l). Annual environmental statement of Kalyani Khani-5 Pit project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320075.pdf> (Last accessed on October 1, 2019).

96. SCCL (2018m). Annual environmental statement of Kalyani Khani opencast project of Mandamari area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/320085.pdf> (Last accessed on October 1, 2019).

97. SCCL (2018n). Annual environmental statement of Ravindra Khani No. 5 Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340025.pdf> (Last accessed on October 1, 2019).

98. SCCL (2018o). Annual environmental statement of Ravindra Khani No. 6 Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340035.pdf> (Last accessed on October 1, 2019).

99. SCCL (2018p.) Annual environmental statement of Ravindra Khani No. 7 Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340045.pdf> (Last accessed on October 1, 2019).

100. SCCL (2018q). Annual environmental statement of Ravindra Khani New-Tech. Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340055.pdf> (last accessed on 1 October 2019).

101. SCCL (2018r). Annual environmental statement of Srirampur No. 3&3A Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340065.pdf> (Last accessed on October 1, 2019).

102. SCCL (2018s). Annual environmental statement of Srirampur No. 1 Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340095.pdf> (Last accessed on October 1, 2019).

103. SCCL (2018t). Annual environmental statement of Srirampur Opencast Project – I for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340075.pdf> (Last accessed on October 1, 2019).

104. SCCL (2018u). Annual environmental statement of Srirampur Opencast Project – II for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340085.pdf> (Last accessed on October 1, 2019).

105. SCCL (2018v). Annual environmental statement of sand mining project in Godavari river bed near Chennur Village for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340115.pdf> (Last accessed on October 1, 2019).

106. SCCL (2018w). Annual environmental statement of Ravindra Khani No. 8 Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340145.pdf> (Last accessed on October 1, 2019).

107. SCCL (2018x). Annual environmental statement of Indaram Khani No. 1A Incline for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340155.pdf> (Last accessed on October 1, 2019).

108. SCCL (2018y). Annual environmental statement of Area Stores and Area Workshop, Srirampur Area for the year 2017-18. retrieved from <https://scclmines.com/env/docs/ECS/340165.pdf> (Last accessed on October 1, 2019).

109. SCCL (2018z). Environmental Statement of the 2x600 MW Coal Based Thermal Power Plant of SCCL for the year 2017-18 submitted to TSPCB vide Letter No. STPP/ENV/637/2018/1630.

110. SCCL (2019a). Annual environmental statement of Medapalli opencast expansion project for the year 2018-19. retrieved from <https://scclmines.com/env/docs/ECS/200135.pdf> (Last accessed on 1 October 2019).

111. SCCL (2019b). Annual environmental statement of GDK 11A Incline RG - I Area of SCCL

for the year 2018-19. retrieved from <https://scclmines.com/env/docs/ECS/200075.pdf> (Last accessed on October 1, 2019).

112. SCCL (2019c). Environmental statement of the 2X600 MW coal-based thermal power plant for the year 2018-19. retrieved from <https://scclmines.com/env/docs/ECS/340125.pdf> (Last accessed on October 1, 2019).

113. SCCL (2020a). Dorli-I opencast coal mine project. Post project environmental monitoring data and other reports for the period October-2019 to March-2020. retrieved from <https://scclmines.com/env/docs/ECS/310041.pdf> (Last accessed on April 3, 2021).

114. SCCL (2020b). Dorli-II opencast coal mine project. Post-project environmental monitoring data and other reports for the period October-2019 to March-2020. retrieved from <https://scclmines.com/env/docs/ECS/310051.pdf> (Last accessed on April 3, 2021).

115. SCCL (2020c). Bellampalli opencast coal mine extension project-II. Half yearly monitoring report on compliance of environmental clearance conditions for the period April-2020 to September-2020. retrieved from <https://scclmines.com/env/docs/ECS/310031.pdf> (Last accessed on April 3, 2021).

116. SCCL (2020d). Khairagura opencast expansion coal mining project. Half yearly monitoring report on compliance of environmental clearance conditions for the period April-2020 to September-2020. retrieved from <https://scclmines.com/env/docs/ECS/310021.pdf> (Last accessed on April 3, 2021).

117. Seetharam and H. Ramakrishna (2017). Permian paleo-wildfire on Gondwana land: Charcoal remains from the Yellandu coalfield, Godavari graben, Telangana State, India. 35(1): retrieved from <https://www.researchgate.net/publication/314081527_Permian_Palaeo-Wildfire_on_Gondwana_Land_Charcoal_Remains_from_the_Yellandu_Coalfield_Godavari_Graben_Telangana_State_India > (Last accessed on September 27, 2019).

118. Sharma, R., Kumar, R., Sharma, D.K. *et al.* (2019). Inferring air pollution from air quality index by different geographical areas: case study in India. Air Qual Atmos Health. Vol. 12. pp. 1347–1357. retrieved from <https://doi.org/10.1007/s11869-019-00749-x> (Last accessed on April 20, 2021).

119. Soni, K., Parmar, K. S., Kapoor, S. (2015). Time series model prediction and trend variability of aerosol optical depth over coal mines in India. Environ Sci Pollution Res Vol. 22. Pp. 3652–3671. retrieved from <https://link.springer.com/article/10.1007/s11356-014-3561-9> (Last accessed on April 14, 2021).

120. Spurny, K. R. (1998). On the physics, chemistry and toxicology of ultrafine anthropogenic, atmospheric aerosols (UAAA): new advances. Toxicology Letters. Vol. 96-97. pp. 253-261. retrieved from <https://doi.org/10.1016/S0378-4274(98)00080-0> (Last accessed on April 14, 2021).

121. Stanton, D. W, Belle, B. K., Dekker, Kobus, *et al.* (2006). South African mining industry best practice on the prevention of silicosis. retrieved from <https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_118101.pdf> (Last accessed on April 14, 2021).

122. Swain, A. K., and Barik, K. K. (2013). Spatial greening pattern estimation of Himachal Pradesh, India using IRS-P6 AWiFS seasonal data. *RED*, *56*, 737. retrieved from <https://www.ijsr.net/search_index_results_paperid.php?id=SUB157667> (Last accessed on August 29, 2020).

123. Trivedi, R., Mondal, A., Chakraborty, M. K., *et al.* (2010). A statistical analysis of ambient air quality around opencast coal projects in Wardha Valley Coal Fields, Western Coalfields Limited, India. IJEP 30(12): pp. 969-977. retrieved

from <http://environmentportal.in/files/open%20cast%20coal%20projects%20in%20Wardha%20Valley.pdf> (Last accessed on April 14, 2021).

124. TSPCB (2018a). Draft EIA of proposed 800 MW coal-based thermal power plant in Mancherial district, Telangana. retrieved from <https://tspcb.cgg.gov.in/publichearings/Singareni%20Collieries%20Company%20Ltd.,%20Mancherial%20Dist.%20-%20Draft%20EIA%20Report.pdf> (Last accessed on September 26, 2019).

125. TSPCB (2018b). Draft environmental impact assessment / Environmental management plan for the proposed Srirampur opencast - II expansion project. retrieved from <https://tspcb.cgg.gov.in/publichearings/SCCL,%20Srirampur%20Open%20Cast%20Mine-II,%20Singapur%20(V),%20Naspur%20(M),%20Mancherial-Draft%20EIA%20Report%20ENG.pdf> (Last accessed on September 29, 2019).

126. TSPCB, 2015. Draft environmental impact assessment report for Telangana super thermal power project stage-I (2x800 MW) at Ramagundam, Karimnagar District, Telangana State. retrieved from <https://tspcb.cgg.gov.in/publichearings/NTPC%20(Telangana%20STPP%20Stage%20I),%20Karimnagar%20Dist.%20-%20EIA%20Report.pdf> (Last accessed on September 26, 2019).

127. WHO (World Health Organization) (2013) Review of evidence on health aspects of air pollution: REVIHAAP Project: Technical report. retrieved from <https://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report> (Last accessed on June 15, 2020).

Document Control Sheet

1	**Document No and Year**	:	NIAS/NSE/EEP/U/RR/07/2021
2	**Title**	:	Sustainable Pathways to Energy Utilisation – Volume 2: State of the Environment in the Ramagundam and Dorli-Bellampalli coal mines in the State of Telangana
3	**Type of Document**	:	Research Report
4	**No. of Pages and Figures**	:	66 + ix pages, 8 tables and 51 figures
5	**No. of References**	:	127
6	**Authors**	:	Chanchal Chauhan, Aariz Ahmed, Harsh Kamath, Harini Santhanam, and R Srikanth
7	**Originating School**	:	Natural Sciences and Engineering
8	**Programme**	:	Energy and Environment
9	**Collaboration**	:	NA
10	**Sponsoring Agency**	:	IRPHA Project SB/IR/NIAS/2016 of the Science and Engineering Research Board

11 **Abstract:**

India's per capita electricity consumption is less than one-third of the World's average though 72 percent of the electricity generated in India is powered by coal of which India is the World's second-largest producer. Coal mining and thermal power generation are critical for India to achieve Sustainable Development Goals (SDGs), but their long-term sustainability must be ensured.

In this report, the trends in air quality, vegetation, and water quality before, during, and after closure of opencast coal mines are compared by analyzing the data collected from two study areas in the State of Telangana to study the impact of coal mining on the air, water, and land environment. In addition to ambient air quality data, AOD_{550} values and NDVI values have been extracted from MODIS to study the long-term trends in PM concentrations and vegetation cover, respectively.

The ambient PM concentrations around the opencast coal mines and TPPs studied exceed the NAAQ standards. However, the ambient SO_2 concentrations around the TPPs studied are well below the standard of 50 $\mu g/m^3$. This is due to the location of TPPs in a tropical region where the climatological conditions, low-Sulphur content of Indian coal, and the stack heights of TPPs act synergistically to disperse SO_2 concentrations below the NAAQ standards.

MoEFCC must encourage research on the use of geospatial data for monitoring air pollution and mine closure by enhancing CPCB funding to operate continuous air quality monitors in all coalfields of India and extend the National Clean Air Program.

To assess the utility of pit lakes for the local communities, MoC must conduct inter-disciplinary studies to assess the current and upcoming pit lakes in terms of their utility to the surrounding communities with an integrated approach.

UNFCCC must convince the developed countries to meet their commitments as per the Paris Agreement and also release funds from the GCF for low-carbon energy pathways like IGCC power plants (using high-ash coal) and nuclear power plants in addition to grid-scale battery storage and grid integration of variable renewable energy sources (e.g., wind and solar). This will enable India to meet the NDCs committed in the Paris Agreement while protecting India's energy security with 24x7 power supply to all Indians as per SDG 7.

12 **Keywords:**

AOD; Air pollution; NDVI; Coal mines; Mine closure; Thermal Power Plants; Pit Lakes.

13 **Security Classification** : Unrestricted

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