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Cumulative Air Quality Impacts from Twenty-Two Major Power Plants

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Abstract: Cumulative assessment is a tool for the project developer to try and take into consideration not only their contribution to cumulative impacts but also other projects and external factors that may place their developments at risk. This study assessed the cumulative impacts of air emissions from 22 major power plants in southeast Bangladesh planned to generate 21,550 MW of electricity. It also includes anticipated growth in small to medium size industries, brickfields, highway traffic, inland water transport, transhippers, jetty, and vessel transports used for transporting fuel resources for these power plants. A 50 km by 50 km airshed is considered for air quality modeling. Cumulative analysis indicates that predicted MGLCs (Maximum Ground Level Concentrations) of NO_2 and CO are complying with both Bangladesh NAAQS (National Ambient Air Quality Standards) and WBG (World Bank Group) Guidelines. The daily average MGLC of PM2.5 (62.45 $\mu g/m^3$) from all sources complies with NAAQS, however, exceeds the WBG Guidelines. Annual PM2.5 concentration (15.45 $\mu g/m^3$) exceeds NAAQS and WBG Guidelines. The PM10 concentration complies with the NAAQS for both 24-hour and annual averaging times. Annual average concentration (23.12 $\mu g/m^3$) exceeds WBG Guidelines. Daily average SO_2 concentration (102.49 $\mu g/m^3$) complies with the NAAQS however, it exceeds the WBG guideline values. High concentrations of PM2.5 and SO_2 are due to the contribution of transboundary emissions and secondary pollutants in the atmosphere. This dispersion modeling outcome can be used by the policymakers for the pollution reduction strategy.

Key words: CIA (Cumulative Impact Assessment), dispersion modeling, power generation, Bangladesh.

1. Introduction

Bangladesh has the target to become an upper-middle-income country by 2021 and a high-income country by 2041 [1]. Sustained economic growth with rapidly increasing energy demand is a precondition for reaching these goals. The development of energy and power infrastructure is crucial for the long-term economic growth and development of Bangladesh. Currently, Bangladesh is facing challenges in meeting electricity demand. The electricity demand is expected to exceed the available and planned generation capacity in the country. Through the National Energy Policy of 2005, Bangladesh is to provide reliable and affordable power to all citizens by 2021. The current population coverage of electricity is about 96% [2].

According to the Power System Master Plan (2016) revised in March 2018, the forecasted demand in 2021 is expected to be 19 GW, in 2031 45 GW, and in 2041 82 GW [3]. To support the Power System Master Plan, the Government of Bangladesh has developed, Vision 2041: Long Term Power Development Strategy. The strategy includes different initiatives to generate additional electricity by diversifying fuel mixes, rehabilitating old power plants, and importing electricity from neighbouring countries. It is forecasted that electricity will be generated from Gas/LNG (Liquefied Natural Gas) (41%), coal (about 31%), import from neighbouring countries (14%), nuclear (7%), and liquid fuel (7%) while protecting the local environment and reducing impacts on global climate change [3].

To achieve, Vision 2041, Bangladesh Government is setting up three energy-producing hubs to boost the country's power generation capacity over the next two

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Corresponding author: Md M. Karim, Ph.D., research field: environmental impact assessment. E-mail: info@geec.ca decades. The hubs are located in Cox's Bazar's Moheshkhali and Matarbari in the southeast and Patuakhali's Payra in the southwest. These hubs will house 31 mega power plants with a total generation capacity of 32,670 MW. Port facilities have also been developed in these locations as the power plants will use imported coal and LNG. Of the proposed hubs, Moheshkhali will have eight mega power projects with a generation capacity of about 12,200 MW while Matarbari will house fourteen powerplants with 13,230 MW capacity. The Payra (including Patuakhali) hub will have nine power plants with a generation capacity of 11,120 MW [4]. Both Moheshkhali and Matarbari hubs are located within 25 km and hence these hubs and associated power plants planned and under construction are considered in this study. Foreign countries are investing heavily in Bangladesh's coal power expansion. Entities domiciled in China represent the majority of the proposed coal power capacity—18,000 MW across 15 projects. The United Kingdom and Japan-based companies are involved in three proposed coal projects each, with coal power capacity totaling 4,700 MW and 3,600 MW, respectively [5].

CIA (Cumulative Impact Assessment) is a new concept in developing countries being considered during EIA (Environmental Impact Assessment) studies for complex projects. In the last 30 years, studies have increasingly been in progress to address this issue and have shown that the existing EIA methodologies and assessment tools can be combined effectively to address cumulative impacts [6-8]. CIA is evolving and what is important is that during the process of identifying environmental and social impacts and risks, developers or project sponsors, (a) recognize that their actions, activities, and projects—their developments may contribute to cumulative impacts on VECs (Valued Environmental Components) on which other existing or future developments may also have detrimental effects, and (b) avoid and/or minimize these impacts to the greatest extent possible. Furthermore, their developments may be at risk because of an increase in cumulative effects on ecosystem services they may depend on [9]. The term cumulative effect applies to the concentration of a contaminant in the air that results from the discharges from multiple emitters in a given geographic or local area [10]. Some early-stage dispersion modeling was conducted in Bangladesh to model urban traffic pollution in Dhaka [11]. Other studies were conducted in recent times to model cumulative emissions from power plants for Ghorashal, Bangladesh [12], S.Alam Coal-fired power plant in Bangladesh [13], and Bangladesh-India Maitree Coal Fired Power Generation in Southwest Bangladesh [14]. Cumulative air quality assessments have been done through numerous studies in other parts of the world. For instance, five open pit mine sites and two smelters in Brazil presented an integrated index of environmental impact aiming to quantify the air quality impact around the Congonhas area [15]. A study conducted on coal-fired power generation, transportation, and vessel transport in southern Bangladesh displayed an increase in some criteria pollutants due to the project, such as NO_2, SO_2, and particulate matter. However, these increases were within National ambient air quality standards [16]. They exceeded the WBG (World Bank Group) Guidelines but met Interim Targets set for developing countries [17], if the proposed emissions control technologies are installed and remain effectively operational [14]. In an open pit mine in India some areas surrounding the mine, the cumulative pollutant levels were found significantly high even if the effects of project-related impact were low [18]. There are other studies based on monitoring data from four coal-fired plants in Turkey without using simulation models to compare the Environmental Impact Score for each power plant and their environmental performances as a decision-making tool for environmental investments in those plants [19]. However, these studies were limited to smaller spatial and shorter temporal dimensions and did not cover a large number of emission sources and the development of a 25-year time horizon.

This CIA is based on a feasibility study to provide a technical, financial, and economic review of the construction of a 2,400 MW (four units) USC (Ultra-Supercritical) coal-fired power plant, named Pekua Coal Fired Power Plant in two phases: first phase 2 × 600 MW and second phase 2 × 600 MW. This includes all issues related to project sizing, optimal sitting, technology selection, geotechnical investigation and analysis, ground improvement, coal logistics, economic viability, and environmental, social, and disaster impacts.

The purpose of this study was to assess the air quality in the airshed due to the implementation of 22 mega power plants of 21,550 MW generation capacity. Furthermore, the dispersion modeling exercise is to determine whether cumulative impacts from all sources do not exceed the assimilative capacity of the airshed as defined by ambient air quality objectives. The study was conducted through:

- First, assessing the baseline condition in the air shed, including all current sources.
- Second, assessing the impact on air quality due to the project case (Phase I & II), which includes power plant emissions and emissions from coal transport.
- Third, assessing the cumulative impacts of 22 operational coal and natural gas power plants by 2036. The airshed considered for cumulative impacts covers both Moheshkhali and Matarbari energy-producing hubs.

An assessment of MGLC (Maximum Ground Level Concentrations) was also conducted to complete the air quality analysis. There are many different dispersion models available, but the US EPA regulatory model AERMOD was as its formulation allows, (i) for analysis up to 50 km from the source, (ii) it can accurately model both simple and complex terrain, (iii) can model urban and rural areas, (iv) multiple point, line, area, and volume sources can be modeled, and (v) source releases can be modeled at the surface, near-surface and elevated sources.

2. Methodology for Cumulative Impacts

2.1 Sources for Cumulative Case

The cumulative impact of all major emission sources in the air-shed for 2036 is assessed. Fig. 1 shows all expected major emission sources in the air-shed for 2036. The assessment covers both energy-producing hubs Matarbari and Moheshkhali which include 22 operational coal and natural gas-fired power plants by 2036. In addition, emissions from line sources (highway and marine traffic: mother vessels and lighterage vessels transporting imported coal, Class II Route of Inland Water Transport and Mechanized boats), from area sources (brickfields), from trans-shippers (used for transferring coal from mother vessels to lighterage vessels), and from fugitive emissions (resulting from the process of transferring coal from mother vessels to lighterage vessels) were considered. Full lists of the emission sources are presented in later sections.

Below is a brief description/explanation of some labels in Fig. 1:

- Maritime Route: Vessels (i.e. cargo, container, etc.) called at Chittagong port that passes through the project area.
- Class II Route: Route used by smaller marine (class II vessels) that carry construction materials, fertilizer, etc.
- Moheskhali Route: An expected route for maritime vessels carrying coal for power plants located in the Moheskhali area.
- Matarbari Route: Expected route for maritime vessels carrying coal for power plants located in the Matarbari area.
- FAP (Fair Weather Anchorage Point): FAP, used to trans-ship coal from mother vessel to lighterage vessel for Banskhali PP from June to October.
- PAP (Protected Anchorage Point): PAP, used to trans-ship coal from mother vessel to lighterage vessel for proposed Pekua PP and Banskhali PP from November to May.

- PAP Route: mother vessel route from ocean to protected anchorage point for proposed Pekua PP all year round and for Banskhali PP from June to October.
- FAP Route: mother vessel route from ocean to FAP for Banskhali PP from November to May.

2.2 Emissions Inventory

The following proposed power plants/LNG sources are expected to be operational by 2025:

- Banskhali Power Plant, S. Alam Group 1 & 2 (IPP), 1,320 MW.
- Matarbari USCPP (Ultra-Super Critical Power Plant) (Owner CPGCBL), 1,200 MW.
- Matarbari USCPP, Phase 1 (JV of Symcorp & CPGCBL), 700 MW.
- Moheskhali USCPP (BPDB/ECA), 1,200 MW.
- Reliance Bangladesh LNG Terminal (IPP).
- LNG based 750 MW CCPP (Combined Cycle Power Plant), Phase 1 (BPDP).

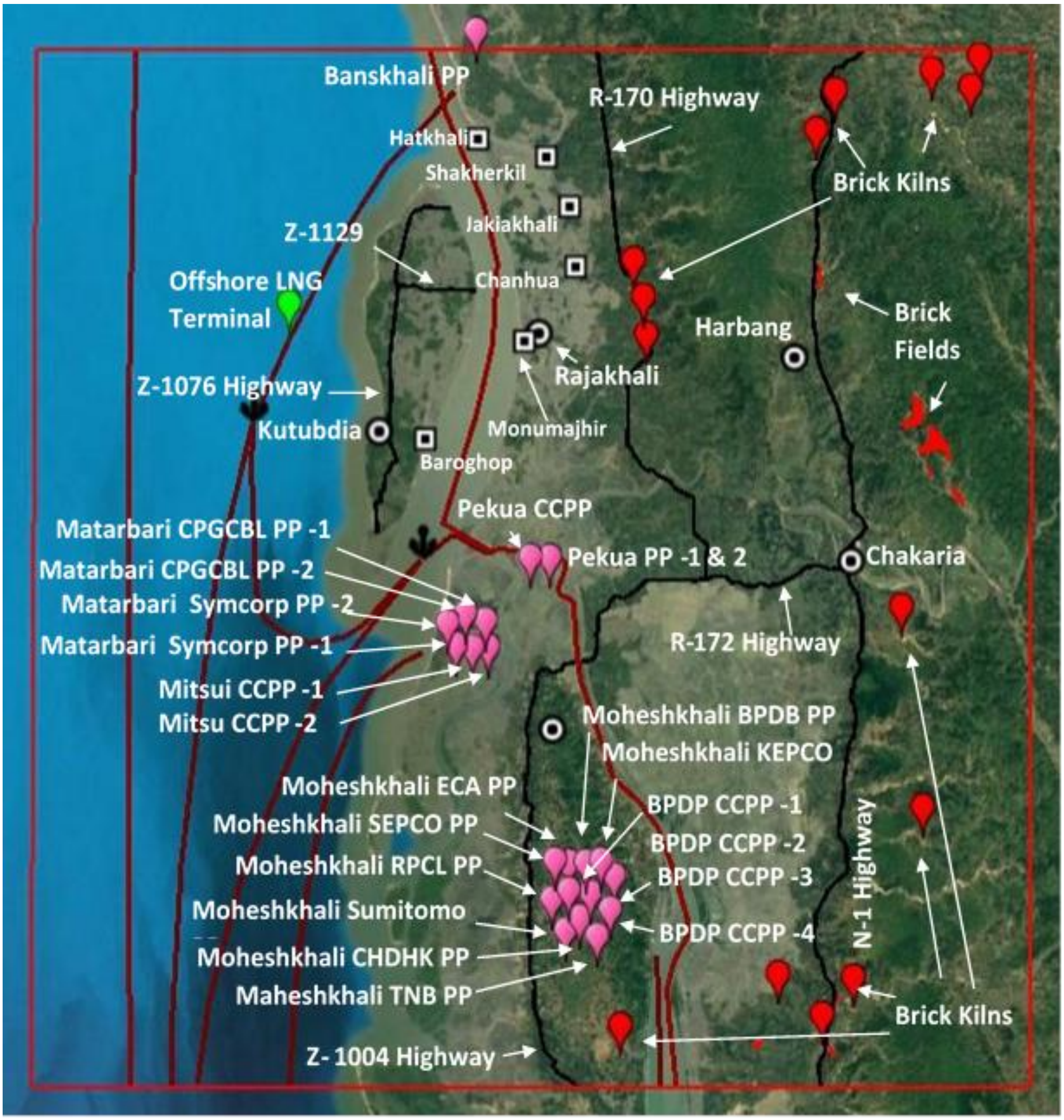


Fig. 1 Sources for cumulative case (2036).

Fig. 2 Sensitive receptor locations.

The following proposed power plants/LNG sources are expected to be operational by 2030:

- Moheshkhali Coal Fired Thermal Power Plant (BPDB-RPCL), 1,320 MW.
- USC Coal-fired power plant (CPGCBL-Sumitomo), 1,200 MW.
- Moheshkhali 1,200 MW USCPP (JV of BPDB & CHDHK, China).
- Moheshkhali 1,200 MW USCPP (JV of BPDB & TNB, Malaysia).
- Matarbari 1,200 MW USCPP, Phase 2.
- Moheshkhali 1,200 MW USCPP (JV of BPDB & SEPCO, China).
- Moheshkhali 1,200 MW USCPP (JV of BPDB & KEPCO, South Korea).
- Mitsui LNG based CCPP, Phase 1 (CPGCBL), 550 MW.
- LNG based 750 MW CCPP, Phase 2 (BPDP).
- LNG based 750 MW CCPP, Phase 3 (BPDB).

Power Plants which are expected to become operational between 2030 and 2036 are:

- Matarbari 700 MW USCPP, Phase 2 (JV of Symcorp & CPGCBL).
- Moheshkhali 1,000 MW USCPP (BPDB).
- Pekua 450 MW Dual Fuel CCPP (EGCB).
- Mitsui 550 MW LNG-based CCPP, Phase 2 (CPGCBL).
- LNG based 750 MW CCPP, Phase 4 (BPDB)

Table 1 Sensitive receptor sites.

Sensitive receptor No.	Description	Distance from the proposed power plant (km)	Coordinates (UTM)	
			Easting (m)	Northing (m)
SR 1	Khan Bahadur Khamar Bari: Population Cluster	2.2	387,800.00	2,407,493.00
SR 2	Mohori Guna: Population Cluster	8.5	383,175.00	2,398,645.00
SR 3	Uttar Nalbila: Govt. Primary School	3.4	389,162.00	2,401,756.00
SR 4	Badarkhali South: Population Cluster	3.8	392,094.00	2,403,745.00
SR 5	Badarkhali East: Population Cluster	3.0	391,707.00	2,405,362.00
SR 6	Badarkhali West: Population Cluster	2.7	391,271.00	2,404,519.00
SR 7	Badarkhali North: Population Cluster	2.6	391,122.00	2,405,951.00
SR 8	Matarbari: Population Cluster, High School	3.1	386,051.00	2,403,478.00
SR 9	Pekua: Population Cluster	6.7	391,066.00	2,411,535.00
SR 10	Magnama: Population Cluster	5.0	388,140.00	2,412,570.00
SR 11	Tabelarchor: Government Primary School	8.1	380,977.00	2,408,078.00
SR 12	Kutubdia Island: Population Cluster	7.8	381,724.00	2,409,167.00
SR 13	Purbo Ali Akbar Dail: Govt Primary School	7.6	381,878.00	2,408,994.00
SR 14	Kutub Nogor: Government Primary School	4.0	392,025.00	2,403,103.00
SR 15	Junglekata: Govt. Primary School	8.9	396,630.00	2,409,134.00

In the case of a single stack with multiple flues, it is standard regulatory practice to treat multiple flues as a single flue. A pseudo stack diameter is used in the calculations, such that the total volume flow rate of the stack gases is correctly represented.

2.3 Sensitive Receptors Sites

A uniform Cartesian grid was used to model the receptors in AERMOD. Important sensitive receptors (i.e., population clusters, schools, etc.) close to the proposed project were also included in the grid area. Fig. 2 presents identified sensitive receptors close to and around the proposed power plant that may be impacted negatively by air emissions from all sources.

Table 1 presents a brief description of coordinates (UTM), and distance from the proposed power plant to the sensitive receptors.

3. Dispersion Modeling and Data

The AERMOD dispersion model was developed by the AERMIC (American Meteorological Society (AMS)/ United States EPA (Environmental Protection Agency) Regulatory Model Improvement Committee. The USEPA maintains and updates the AERMOD dispersion modeling system, as well as provides modeling regulations and guidelines. In conducting the dispersion modeling in this study, USEPA guidelines and procedures on modeling were followed where applicable.

3.1 Modeling Input Data

Emissions for the proposed Pekua coal-fired power plant were calculated based on design specifications and mass flow balance calculations. Emissions data of other coal-fired power plants in the air shed were estimated based on the Pekua power plant emissions, their expected power capacity, estimated coal usage, and efficiency. It was assumed that other proposed coal-fired power plants in the air shed would have similar emissions control technology to the Pekua Power plant.

Emissions data for other anthropogenic sources such as brick fields, road vehicle traffic, and marine vessels were estimated based on available fuel consumption data and emission factors from USEPA AP-42 [20]. Other input information such as ship stack heights, diameter, etc. was established based on industry specifications, past project databases for the region [12, 13], and best practice values. Where applicable, the most conservative values were used to assess the worst-case scenario, this is a standard practice in dispersion modeling.

Pre-processed hourly meteorological data for the years 2015-2017 were obtained from Cox's Bazar and Chattogram Airports' metrological stations in WRF format and processed for use with AERMOD. A DEM (Digital Elevation Model) of the area was prepared based on ground elevations for input into the Software as well.

3.2 AERMOD Modeling System

USEPA regulatory model AERMOD was used to predict and simulate the effects of criteria pollutants from major emission sources in the project area and analyze the effect on ambient air quality in the air-shed. AERMOD works by incorporating air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain. The AERMOD dispersion modeling suite incorporates three modules, combined with a post-processor for analysis of results:

A steady-state plume dispersion model, which models the concentration distribution to be Gaussian in both vertical and horizontal stable boundary layers. In the convective boundary layer, the horizontal distribution is also modeled to be Gaussian, however, the vertical distribution is modeled with a bi-Gaussian probability density function

AERMET is a meteorological data preprocessor that uses surface meteorological data and upper air data to calculate atmospheric parameters (mixing heights, friction velocity, Monin-Obukov length surface heat flux, etc.) required by the dispersion model.

AERMAP, a terrain preprocessor that provides a physical relationship between terrain features and the behavior of air pollution plumes. It generates location and height data for each receptor location.

For analysis of results, a post-processor called 3D Analyst is used. This statistical processing program is used to summarize and tabulate the pollutant concentrations calculated by AERMOD and produce contour diagrams.

3.3 Project Modeling Area

The first step in setting up the AERMOD dispersion model is defining the modeling area and receptor grid. A pre-run assessment showed that emissions' impacts beyond 10 km from the power plant stack are negligible, this is discussed further in the MGLC section of the report. However, an area, 50 km by 50 km centered close to the stack of the studied power plant (388,621.00 m E, 2,406,307.00 m N) was established as the modeling area. This 50 km by 50 km area was chosen to ensure a complete assessment of the air shed by including emissions impacts of other sources (i.e. roads, brick kilns, and other proposed power plants) considered when assessing the cumulative air quality. Fig. 1 (red colored outline) shows the boundary of the modeling area, existing sources (point and area), the proposed Pekua power plant, and several proposed power plants that are expected to be operational by the time the Pekua power plant comes into operation in 2025 and additional sources and forecasted data for 2036.

A DEM of the area was prepared based on ground elevations for input into the AERMOD Software. The defined 50 km by 50 km modeling area lies between two DEM zones: N21E091 and N21E092. A uniform Cartesian grid was established to model the receptors. The model area was divided into a grid with an interval of 1,000 m, where receptors are located on the corner of each grid for plotting air quality data for the modeled project area. Fifteen (15) sensitive receptors close to the proposed project area were also included in the grid and are discussed in the next section.

4. Results and Discussions

4.1 Predicted Concentrations

Tables 2 and 3 present the output of cumulative impacts on the air quality for all existing, project, and future sources up to 2036. For NO_2, MGLCs were modeled for 1-hour and annual averaging periods to compare with national standards [16] and WBG Guidelines. For short-term compliance modeling (i.e., a 1-hour averaging period), percentiles are used to account for unusual/extreme metrological conditions and avoid overestimation of predicted concentrations.

USEPA Tier-1 approach assumes 100% conversion of NO_x emissions into NO_2, this approach tends to drastically overestimate results. In the Tier-2 (Ambient Ratio Method, ARM) approach, the predicted ground level concentrations are multiplied by an ambient NO_2/NO_x ratio to get more realistic and accurate results. The ARM uses an ambient equilibrium NO_2/NO_x ratio which is empirically derived based on regional monitoring data [21]. Theoretically, equilibrium occurs when the rate of NO_2 formation (from oxidation of NO) equals the rate of dissociation of NO_2 by sunlight [22, 23].

When site-specific data are unavailable, the EPA exposure assessment guidelines recommend using a default ambient equilibrium NO_2/NO_x ratio of 0.75, based on a study by Chu and Meyer [22]. According to data from the Narayanganj CAMS (Continuous Air Monitoring Station) monitoring station of the Department of Environment (DOE) [12] an ambient equilibrium NO_2/NO_x ratio of 0.65 was calculated. However, this ratio is dependent on many regional factors such as sunlight, climate, etc. and Narayanganj is about 200 km from the project site. Therefore, as per the practice of modeling for worst-case scenarios, the 0.75 value is used in this study.

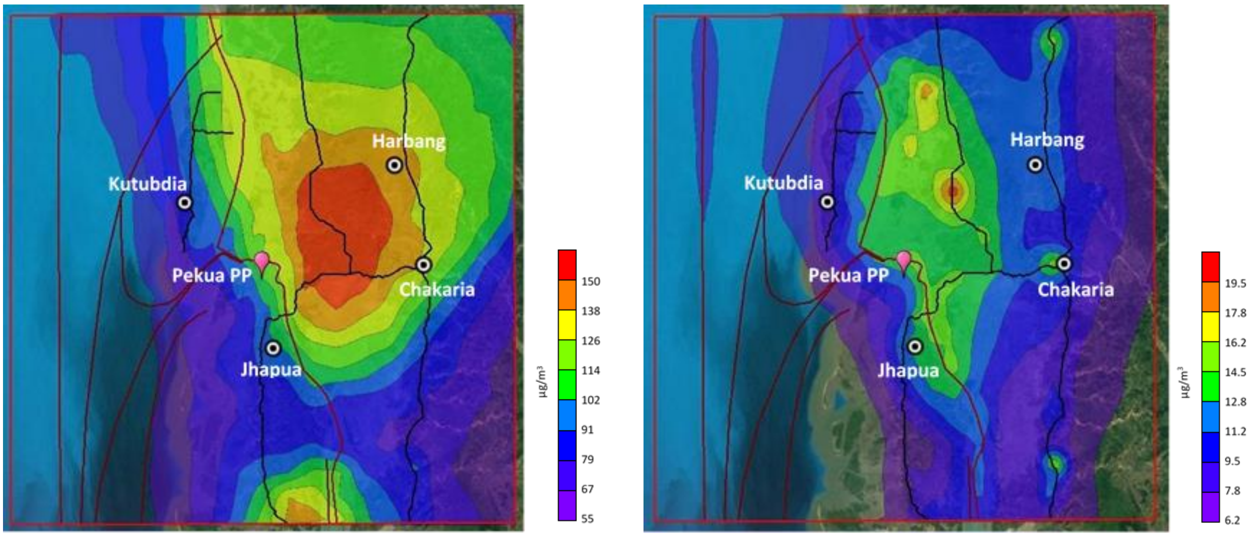
A Tier-3 approach was used to model the NO_2 concentrations in this study [24]. In a Tier-3 approach, along with using an ambient equilibrium ratio, background ozone levels are also considered, to get the most realistic results for the fate of NO_2 in the atmosphere. Once NO_x enters the atmosphere, several potential chemical reactions can occur, depending on the relative amounts of NO and NO_2, the total NO_x, the ambient meteorological conditions, and other atmospheric trace gasses available for reaction. In most cases, the fastest and most important reactions of NO_x involve O_3 [25, 26] as per the following equation:

$$NO + O_3 \rightarrow NO_2 + O_2$$

Fig. 3 presents contour diagrams of predicted 1-hour and annual maximum ground level NO_2 concentrations for the cumulative case. Table 2 shows the predicted MGLCs of 1-hour and annual averaging values for the cumulative case. The cumulative value is well within the National Standards and WBG Guideline values by the implementation of all projects in both energy-producing hubs (including all power plants and additional marine vessels required for coal transportation). Table 3 gives the predicted maximum ground-level concentrations at sensitive and key receptor sites. The results are well within the National Standards and WBG guidelines.

Predicted maximum ground level CO concentration at 1-hour and 8-hour averaging values are given in Table 2, the highest predicted concentrations attained for averaging periods (1-hour or 8-hour) based on 3 years meteorological data comply with the Bangladesh Standards. There are no WBG Guidelines for CO. As seen from the table, the CO concentration is very low, a fraction of the standards, therefore is of no concern. Table 3 presents the predicted concentrations at sensitive receptors.

Fig. 4 presents contour diagrams of predicted 24-hour and annual maximum ground-level PM2.5 concentrations for the cumulative case. For PM2.5 the predicted maximum ground level 24-hour and annual concentrations are given in Table 2. The background concentration for PM2.5 was found 14 $\mu g/m^3$ (for a 24-hour averaging period) and as discussed in the previous section, it is suspected that there is a sizable contribution to this from transboundary sources. The background PM2.5



NO_2—1 hour NO_2—Annual

Fig. 3 Cumulative impacts of NO_2 concentration.

and PM10 values for the 24-hour averaging period are quite high for a remote location in the Moheshkhali, 56% and 27% of the WBG guideline values of 25 and 50 μg/m^3, respectively. It is estimated that a significant portion of the PM2.5 concentration in Bangladesh is transboundary (secondary pollutants formed from NO_x and SO_x after chemical transformation in the ambient air); predominately from West Bengal and North India [27, 28]. Studies show that on average 35% of the PM2.5 concentration is transboundary and can be as high as 67% depending on the season and direction of the wind [21].

Table 2 shows that the cumulative $PM_{2.5}$ concentrations are well within the Bangladesh National standards of 65 μg/m^3; but the 24-hour average value is above the WBG guidelines of 25 μg/m^3; Target-3 and Target-2 values of 37.5 μg/m^3 and 50 μg/m^3; respectively. The predicted concentrations, however, meet WBG interim Target-1 of 75 μg/m^3 for a 24-hour averaging time. Interim targets are provided for developing countries in recognition of the need for a staged approach to achieving the recommended guidelines. The predicted annual concentration exceeds NAAQS (15 μg/m^3), WBG guideline (10 μg/m^3), and Target-3 (15 μg/m^3) values for annual averaging time, however, complying with the Target-2 value of 25 μg/m^3. Table 3 presents the predicted ground-level concentration at the sensitive receptors. All concentrations are complying with Bangladesh Standards, however, exceed WBG Guidelines (25 μg/m^3) for 24-hour averaging time. The annual average concentration complies with the WBG Guideline (10 μg/m^3) except at the Badarkhali East receptor.

Fig. 5 presents contour diagrams of predicted 24-hour and annual maximum ground-level PM10 concentrations for the cumulative case. For PM10 the maximum ground level 24-hour and annual concentrations are given in Table 2. The background concentration for PM10 was found 13.33 μg/m^3 for a 24-hour averaging period. The table shows that the PM10 concentrations are well within the Bangladesh National Standards for both 24-hour and annual averaging times. However, the 24-hour averaging concentration is above the WBG guidelines (50 μg/m^3) and Interim Target-3 (100 μg/m^3). The predicted concentration does meet WBG Interim Target-1 for 24-hour averaging time (150 μg/m^3). On the other hand, annual concentrations are within Bangladesh National Standards (50 μg/m^3) and WBG Interim Target-3, however, exceeds WBG Guidelines of 20 μg/m^3. Table 3 shows the concentration at sensitive receptor locations. The predicted daily

Table 2 Predicted maximum concentrations of cumulative case.

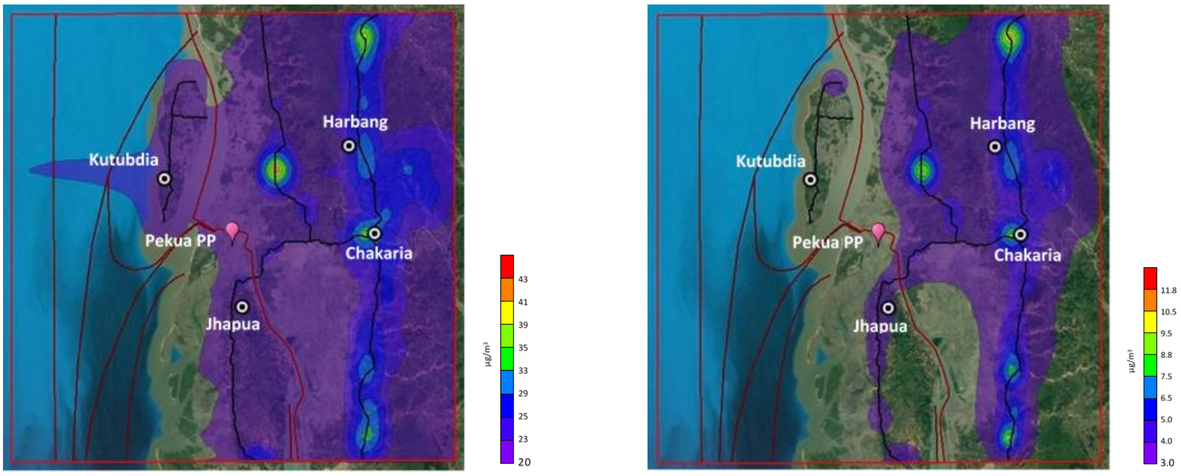
Pollutant	Averaging time	Concentration (μg/m^3)			Coordinates of max point (UTM)	
		ECR 1997 (as amended, 2005)	WBG Guidelines	Max value	East (m)	North (m)
NO_2	1-hour	N/A	200	168.95	393,621	2,381,307
	Annual	100	40	22.06	393,621	2,413,807
CO	1-hour	40,000	N/A	4,185.67	393,621	2,413,807
	8-hour	10,000	N/A	1,818.89	393,621	2,413,807
PM2.5	24-hour	65	75 (IT-1)	62.45	403,616.2	2,386,482
	Annual	15	15 (IT-3)	15.45	403,616.2	2,386,482
PM10	24-hour	150	150 (IT-1)	104.07	403,616.2	2,386,482
	Annual	50	30 (IT-3)	23.12	403,616.2	2,386,482
SO_2	24-hour	365	125 (IT-1)	102.49	396,121	2,396,307
	Annual	80	-	14.78	396,121	2,396,307

Table 3 Cumulative concentration at sensitive receptor sites.

Sl.	Receptor	NO_2 concentration (μg/m^3)									
		NO_2		CO		$PM_{2.5}$		PM_{10}		SO_2	
		1-hour	Annual	1-hour	8-hour	24-hour	Annual	24-hour	Annual	24-hour	Annual
1	Khan Bahadur Khamar Bari	129.25	15.74	2,006.86	870.39	36.25	7.17	62.24	12.32	62.69	8.75
2	Mohori Guna	83.21	7.20	2,211.76	640.66	35.49	6.72	60.90	11.36	43.03	4.10
3	Kutubdia Island	107.67	12.97	2,532.25	894.60	37.13	7.69	63.05	12.65	60.52	7.78
4	Badarkhali South	148.88	16.77	2,464.98	954.89	40.83	8.79	69.11	14.10	64.99	10.92
5	Badarkhali East	141.95	14.66	2,381.65	906.87	36.50	7.45	63.20	12.36	64.47	10.28
6	Badarkhali West	136.38	15.39	2,403.85	898.07	36.56	7.46	62.73	12.36	64.29	9.94
7	Badarkhali North	138.23	14.82	2,279.63	857.62	36.98	7.32	63.63	12.18	63.99	10.05
8	Matarbari	101.19	10.31	2,929.69	614.67	35.49	6.90	61.20	11.61	50.79	5.86
9	Pekua	149.02	15.03	2,112.50	1,199.53	37.45	7.42	65.71	12.32	77.36	11.57
10	Magnama	137.66	14.89	1,884.41	824.96	37.06	7.22	66.70	12.05	66.28	10.83
11	Khan Bahadur Khamar Bari	81.06	9.80	2,019.12	614.51	38.66	7.46	65.69	12.34	50.19	5.30
12	Mohori Guna	110.31	10.70	2,300.43	652.72	36.19	6.91	62.80	11.61	51.98	5.62
13	Kutubdia Island	110.60	10.92	2,300.31	661.25	36.15	6.88	62.72	11.58	51.41	5.65
14	Badarkhali South	149.59	16.48	2,514.63	928.33	39.59	8.42	66.96	13.62	65.84	10.71
15	Badarkhali East	167.22	16.84	2,417.07	959.58	42.90	10.20	73.32	16.01	83.61	12.65

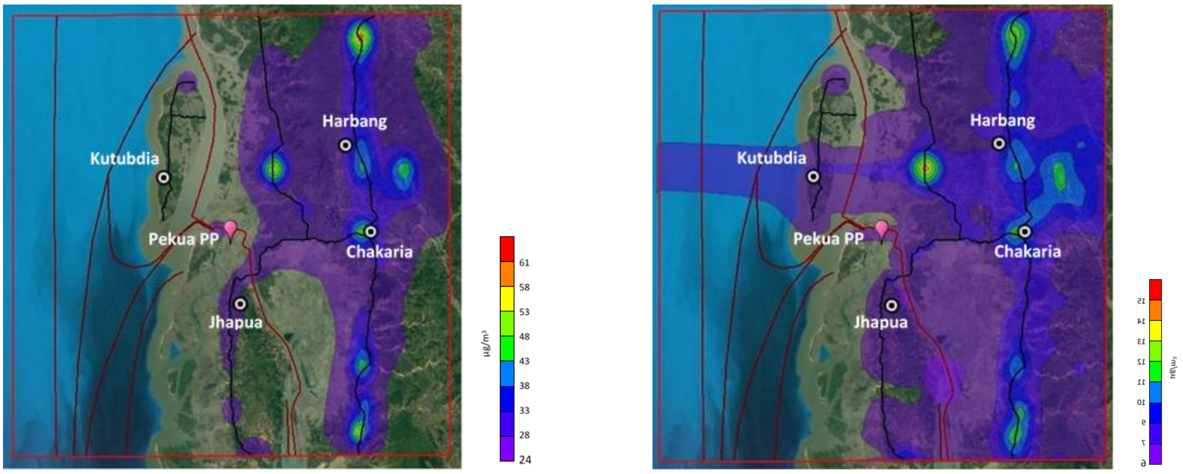
average concentrations at all sensitive locations are within Bangladesh National Standards (150 μg/m^3) and exceed WBG Guidelines (50 μg/m^3). And predicted annual average concentrations are within both Bangladesh Standards and WBG Guidelines.

Fig. 6 presents contour diagrams of predicted 24-hour and annual maximum ground-level SO_2 concentrations. For SO_2, the maximum ground level 24-hour and annual concentrations are presented in Table 2. The table shows that the predicted SO_2 concentrations for the cumulative case are well within the Bangladesh National standards (365 μg/m^3), however are above the WBG guideline values (20 μg/m^3). The background concentration for SO_2 was found 22.25 μg/m^3 for 24-hour averaging in a remote area (which exceeds the WBG Guideline value) and as discussed in the previous section, it is suspected that there is a sizable contribution to this from transboundary sources. The predicted concentrations do meet WBG Target-1 for a 24-hour averaging time (125 μg/m^3). Table 3 shows the predicted concentration at sensitive and key receptor locations. The results meet the Bangladesh National Standards. There are no WBG guidelines for annual average SO_2 concentration.



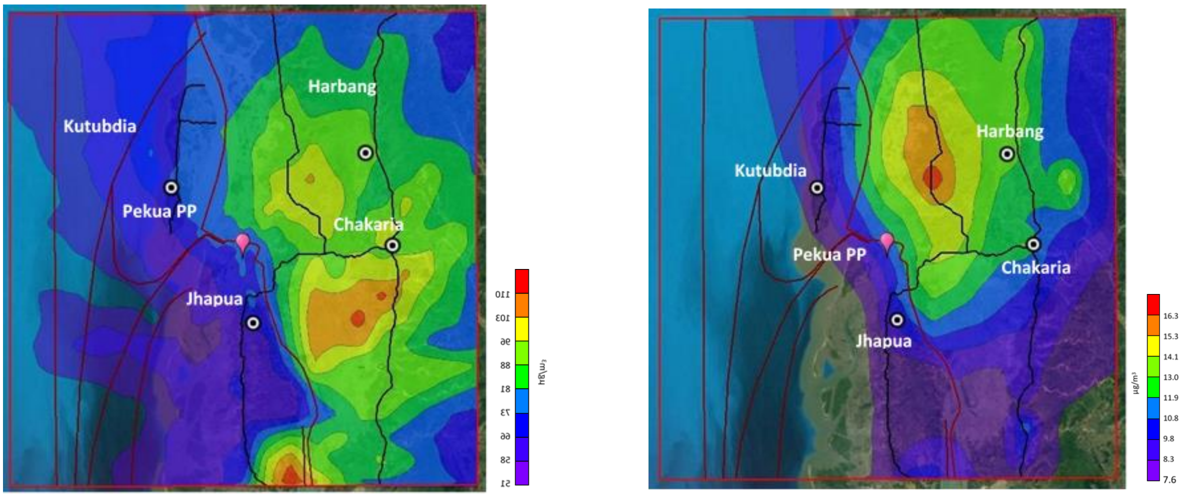
PM2.5—24-hour PM2.5—Annual

Fig. 4 Cumulative impacts of PM2.5 concentration.



PM10—24-hour PM10—Annual

Fig. 5 Cumulative impacts of PM_{10} concentration.



SO_2—24-hour SO_2—Annual

Fig. 6 Cumulative impacts of SO_2 concentration.

4.2 MGLC versus Distance

The distance emissions disperse from the stack depends on various factors, including the height of the stack, wind speed, direction, mixing heights, temperature of the flue gas and air, flue gas exit velocity, and surrounding air. This section presents the distance vs. MGLC graphs for NO_2, SO_2, CO, PM2.5, and PM10. NO_2, SO_2, CO, PM2.5, and PM10 reach MGLCs at 7,560 m, 7,711 m, 5,180 m, 9,043 m and 7,087 m from the stack, respectively. The MGLC is reached more than 5 km from the stack, this is expected since the stack is very high at 275 m. The higher the altitude, the higher the wind speed is, since there is no friction. Close to the ground, wind speed is lower due to friction and other factors. All criteria pollutants hit a maximum concentration at a certain distance away, and then gradually decrease as the distance increases.

MGLC and distance are a decisive factor for selecting emission monitoring stations for power plants. An accurate prediction of MGLC location can benefit project proponents to intelligently locate continuous emission monitoring stations. An incorrect location can significantly affect the investment, provide incorrect concentration and cannot present representative data. This is crucial for policymaking in emission control and airshed improvement.

5. Conclusions

A cumulative air quality assessment was made to assess the capacity of the airshed for all planned and foreseeable future development in two major energy-producing hubs of southeastern Bangladesh. The study result is extremely useful for the policymakers to make an informed decision on the future development in the area. The outcome can be applied to policy decisions in other parts of the country and the region. The results of this cumulative assessment can be a useful tool to assess future air quality and make policy decisions for the current development. Once information is available about the state of air quality after the implementation of the first round of projects in 2025 and the pressures on it, the regional criteria have been determined. It is then possible to quantify the emission reductions required from different sources (both operating and planned for the years 2030 and 2036) to achieve the criteria or guideline value. Reduction targets are the percentage amount by which emissions into the airshed can be reduced from each source, using various control measures, including state-of-the-art control technologies in the major emission sources. Reduction strategies involve a range of options that can be implemented to manage air quality, including regional air quality plans, education strategies, national regulations, and incentive schemes. Strategies for improving air quality can include sound policies based on the following information:

- development of a permanent ambient air monitoring program, representing the areas in concern
- identify key sources using emission inventory studies and how they change over space and time in both short and long term
- analysis and projection of trends in emissions, influencing factors, and air pollution levels
- atmospheric dispersion modeling studies and exposure assessments to determine the spatial extent and frequency of areas where pollution levels exceed the guideline value, and their impacts
- analysis of the options for improving air quality and their cost-effectiveness
- community views on the desirable level of air quality and options required to improve it
- analysis of potential other causes, such as transboundary pollution.

Once reduction strategies and actions are implemented, their effectiveness needs to be assessed over time by ongoing air quality monitoring and dispersion analysis of the emission sources. Assumptions used to predict the effectiveness of different measures can be monitored. For example, if an emission inventory model incorporating environmental control technologies was used to predict the reductions associated with a particular policy, the assumptions used in the model should be periodically checked and re-evaluated. Likewise, air quality monitoring can be used to check predicted improvements in air quality, taking into account the influence on meteorology. Given the factors affecting air quality, it may take several years before a clear trend can be determined. If the evaluation shows that the predictions were inaccurate and the rate of anticipated improvements is not being achieved, plans and policies should be reviewed and revised. The same applies if improvements are faster than anticipated and particular rules or policies are perhaps not needed as urgently as understood.

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