Appendix: Materials and methods

Atmospheric dispersion modeling for the case studies was carried out using version 7 (June 2015) of the CALPUFF modeling system. CALPUFF is an advanced non-steady-state meteorological and air quality modeling system adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts.

Meteorological data for the simulations comes from two sources: 30 hourly surface meteorological observation stations for which data was available through U.S. NCDC under the World Meteorological Organization agreement on sharing meteorological data, and three-dimensional meteorology generated in the TAPM modeling system, developed by Australia's national science agency CSIRO. TAPM uses as its inputs global weather data from the GASP model of the Australian Bureau of Meteorology, combined with higher-resolution terrain data. TAPM outputs were converted into formats accepted by CALPUFF's meteorological preprocessor, CALMET, using the CALTAPM utility, and the meteorological data were then prepared for CALPUFF execution using CALMET. CALMET generates a set of time-varying micrometeorological parameters (hourly 3-dimensional temperature fields, and hourly gridded stability class, surface friction velocity, mixing height, Monin-Obukhov length, convective velocity scale, air density, short-wave solar radiation, surface relative humidity and temperature, precipitation code, and precipitation rate) for input to CALPUFF.

Terrain height and land-use data were also prepared using the TAPM system and global datasets made available by CSIRO. A set of concentric nested grids with a 50x50 grid size and 30km, 10km and 5km horizontal resolutions and 35 vertical levels, centered on the Craiova region, was used for the TAPM simulations.

A full calendar year CALPUFF simulation was carried out for 2015. The latest version of the model, 7.0, was used and U.S. EPA standard default model settings were used throughout. Deposition parameters for mercury, for which there is no default, were based on U.S. EPA (1997).

To estimate emissions, when emission mass flow rates were not given, flue gas volume was calculated from CO2 emissions. This calculation is straightforward, as dry standardized flue gas is essentially comprised of CO2 and ambient air at a specified ratio (6% excess oxygen), with other species such as NOx and SO2 making up less than 1/1000 of the volume. The ratio applied in the calculation is 3563.425 Nm3/tCO2, calculated from EEA (2008, Table D.1).

30% of emitted fly ash was assumed to be PM2.5, and 37.5% PM10, in line with the U.S. EPA AP-42 default value for electrostatic precipitators. Particles larger than 10 microns were modeled with a mean aerodynamic diameter of 15 microns. 95% of NOx was assumed to be emitted as NO, and 5% as NO2. A low share of NO2 reduces predicted air quality and health impacts, as NO must first oxidize into NO2 before it contributes to NO2 levels or can oxidize further into nitrate. Reported annual emissions were converted into average emission rates, which were then applied throughout the year.

Local mercury deposition depends strongly on the speciation of mercury – how much of the mercury is emitted in divalent form (Hg2+), elemental gaseous form and bound to particles. The divalent form is most easily deposited locally. Average distribution of the different species without flue gas desulfurization reported by Lee et al. (2006) were used.

The ISORROPIA II chemistry module of the CALPUFF model requires data on background concentrations of species affecting secondary inorganic aerosol formation. Monthly average ozone concentrations for calendar year 2015 were obtained from Bangladesh MoEF Monthly Air Quality Monitoring Reports[1]. Appropriate measured values could not be obtained for ammonia and H2O2 concentrations, so monthly average values for were imported into the model from baseline simulations using the Geos-Chem global atmospheric model(Koplitz et al 2017).

The CALPUFF results were reprocessed using the POSTUTIL utility to repartition different nitrogen species (NO, NO2, NO3 and HNO3) based on background ammonia concentrations.

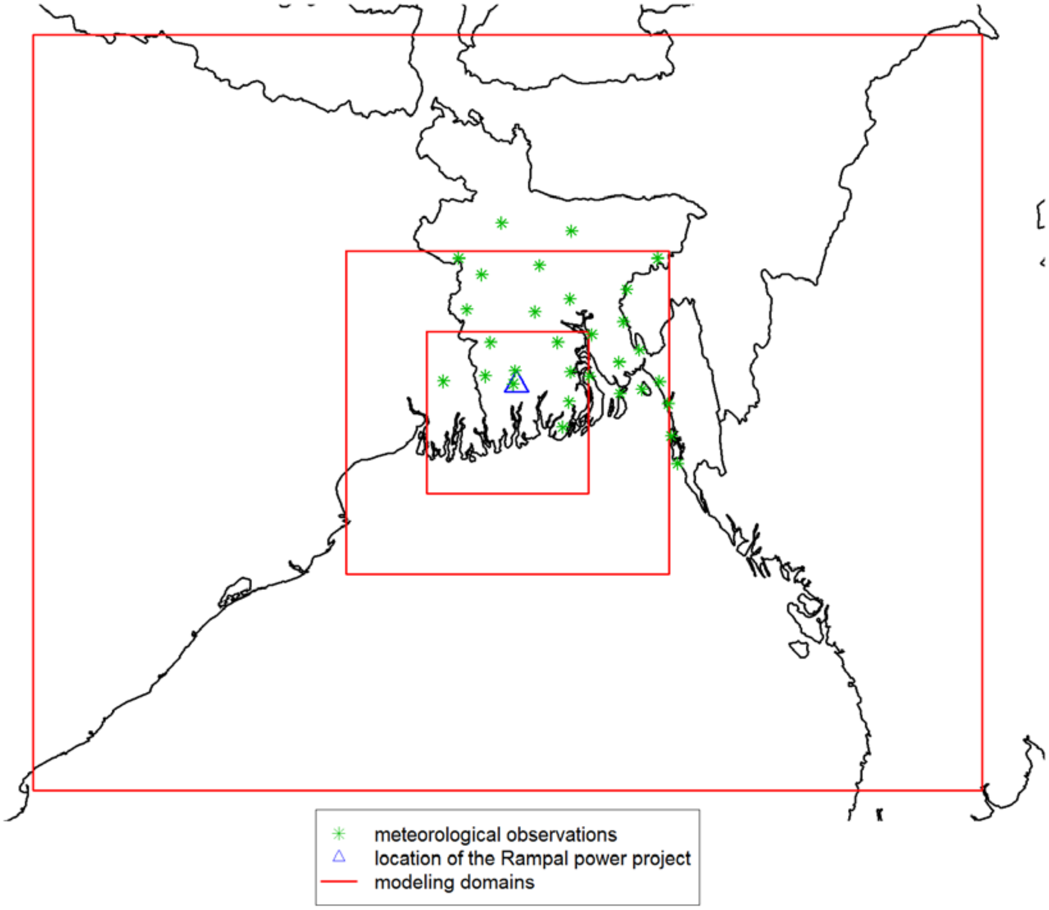

Figure 1. TAPM and Calpuff nested modeling domains, the location of the Rampal power plant and locations of surface meteorological data stations.

Health impacts

The basic foundation for the health impact estimates are numeric scientific studies that show that the risk of chronic diseases such as stroke and lung cancer is increased for people who live in areas with

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[1] http://case.doe.gov.bd/index.php?option=com_content&view=article&id=5&Itemid=9

higher PM2.5 levels. We use relationship derived from dozens of such studies to estimate premature deaths attributable to coal pollution, following the methodology of the Global Burden of Disease (GBD) study.

1. Data on current PM2.5 pollution levels across the study are is used to calculate the overall increase in health risks in each location caused by air pollution, compared with living in clean air[2]. For example, at a PM2.5 level of 50 ug/m3, risk of death from lung cancer is estimated to increase by 30%.
2. Current number of deaths from each cause relevant to air pollution health impacts is calculated in every location by combining high-resolution population data, national age structure data, and national data on death rate from each cause per 100,000 people
3. The current number of deaths and the increase in risk of death give the current amount of "excess" or "premature" deaths.
4. The CALPUFF model is used to estimate the PM2.5 concentrations for which the studied sources are responsible for in each location within the study area. These are compared to the overall pollution level in each location to calculate the share the studied sources out of total PM2.5 levels and total health impacts.

More specifically, the implementation of the GBD methodology followed two steps: first, reproduction of the GBD results for total mortality related to PM2.5 for each grid cell, and second, the calculation of the share of these deaths attributable to the Rampal power plant, based on the atmospheric modeling results.

Health impact assessment was implemented in a 2.5x2.5km grid, with atmospheric modeling results interpolated linearly and population data aggregated to the grid. Total premature deaths in a given grid cell are calculated as

Pdtot = PAF * DR * pop * AF, and

PAF = 1 - 1 / RR(Pbase),

in which RR(Pbase) is the cause-specific risk ratio, based on baseline PM2.5 level Pbase in the grid cell and the non-linear concentration-response functions integrated for the GBD project from dozens of epidemiological studies by Burnett et al (2014). PAF is the population attributable fraction, share of deaths from cause c in the relevant age group that are attributable to PM2.5 exposure, DR is the baseline death rate from cause c in the relevant age group, pop is the total population in the grid cell, and age fraction AF is the fraction of population that belongs to the relevant age group (25 years and above for chronic diseases and under 5 years for Acute Respiratory Infections).

For stroke and ischaemic heart disease, the GBD concentration-response functions are age-specific. Appropriate functions for the entire Bangladesh adult population are derived as averages of the age-specific functions weighted by the population share of each age group in Bangladesh.

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[2] The GBD methodology assumes a “no-harm” concentration of 6.8µg/m3.

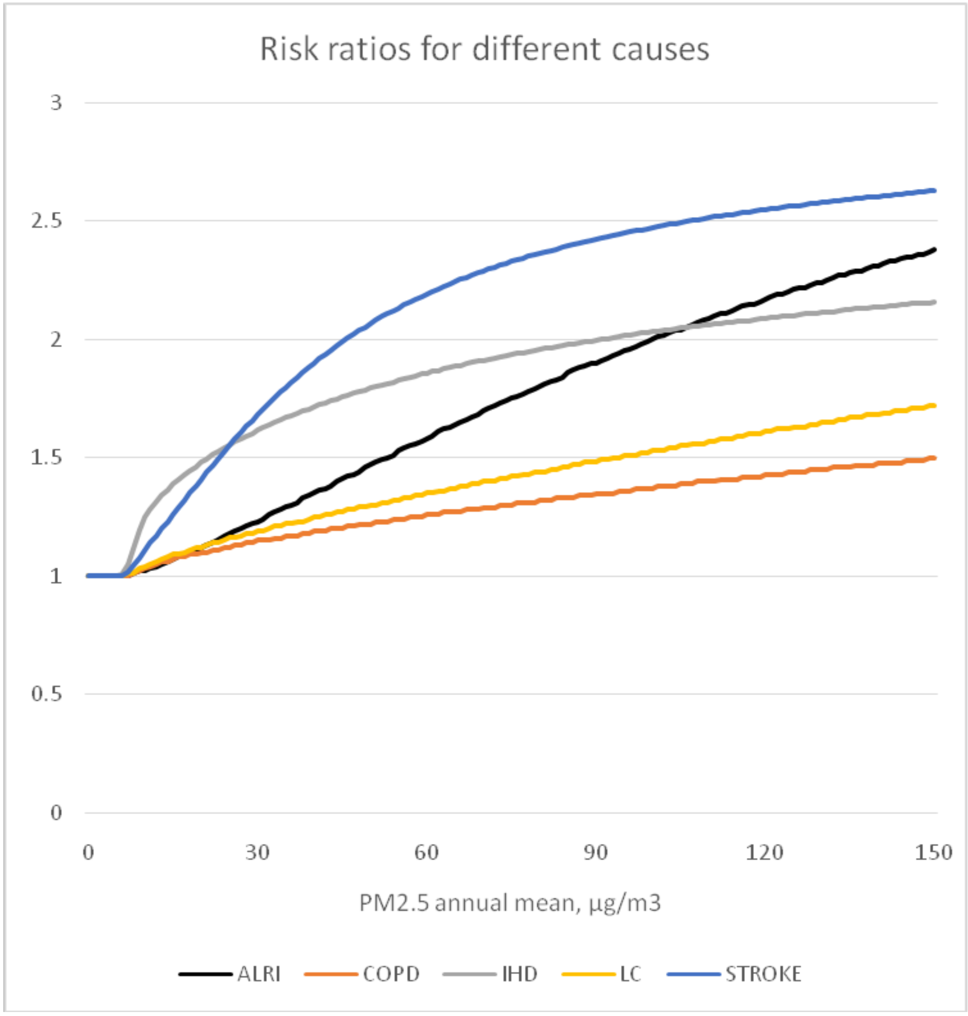

Figure 2. Concentration-response functions developed for the Global Burden of Disease study and applied to assessing the health impacts of the Rampal coal power project.

National average mortality for each country was obtained from WHO (2014) Global Health Estimates database.

To get baseline PM2.5 concentrations we used global gridded PM2.5 data for 2015 derived by combining available ground-level measurements with satellite-based aerosol retrievals and atmospheric model outputs (van Donkelaar et al 2016) for 2015. High-resolution gridded population data for 2015 was obtained from NASA SEDAC (CIESIN,FAO and CIAT 2016).

In the second step, premature deaths attributable to the emissions from the power plant specifically were calculated as

PDcpp = PDtot * Pcpp / Pbase,

where Pcpp is the modeled PM2.5 concentration at the given grid cell that is attributable to emissions from the power plant.

Table 1. Additional risk ratios used for health impact assessment.

Risk ratio for 10μg/m^3 increase in exposure (Pollutant)	Central	95% CI, low	95% CI, high	Reference
Low birth weight (PM2.5)	1.100	1.030	1.180	Dadwand et al 2013
Deaths, all causes (NO2)	1.0060	1.0033	1.0087	Mills et al 2016