Assessing the affect of topography on air pollution using Gaussian Plume Model

Akash Chandra Behera*

Indian Institute of Science Education and Research Kolkata

E-mail: acb19ms126@iiserkol.ac.in

Abstract

The impact of local topographical variations on air pollution, is assessed via a case study of Rourkela, Odisha, with special emphasis on Orographic effect. Data is processed using Gaussian Plume Model for flat terrain. Suggestion are made to remedy Hill chain gap-induced pollution increase.

Introduction

While the impact of local topography on pollution exposure in cities has been extensively studied in developed countries,[1] such studies for Indian cities are rare, given the rapid industrialization the country has underwent in a span of a few decades.[2] This study carries out such an exercise for Steel City Rourkela, one of the major industrial hubs in Eastern India.

Background

Established in 1959 and located in the Gharjat Hill range area, Rourkela Steel Plant (RSP) is one of the oldest of Steel Authority of India Limited(SAIL). With a raw production capacity of 12.6MT, RSP is unique in fact that it is SAIL's only Integrated Steel Plant, that is located in valley surrounded by hills on both sides. The hills towards the North of RSP, form a partially continuous chain of higher elevation area, whereas the hills towards the South form patches of mild elevation (See Fig.1). This unique geological setting of RSP, along with the ample number of air quality monitoring stations spread out across the city, make Rourkela ideal for this study. For the modernization of RSP, an NSPCL Power plant has been made near RSP (See CA3, Fig.2).[3]

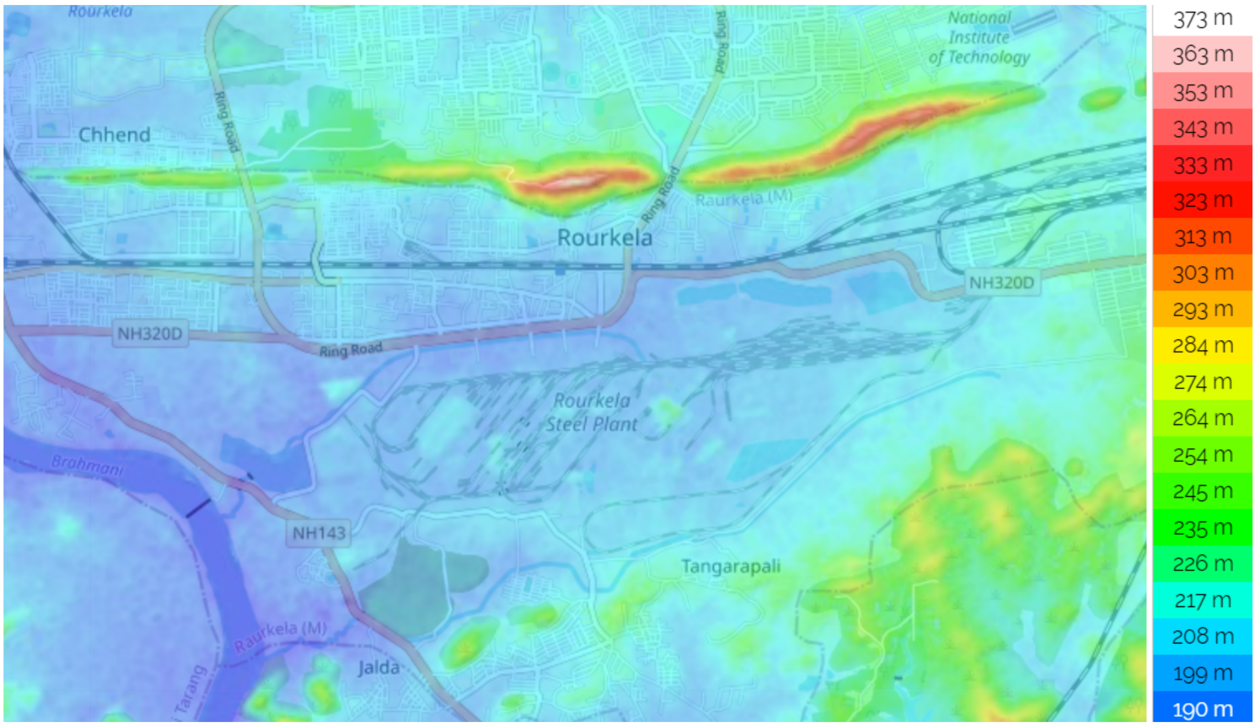


Figure 1: Topographical map of Rourkela (Source : www.en-in.topographic-map.com)

Data

The sources of data used in this study are listed below.

1. Ambient Air Quality (AAQ) and hourly emission rate reports at various stations:
   https://ospcb-rtdas.com/#/publicPortal/categoryList

2. Daily Wind speed and direction :
   https://www.timeanddate.com/

Complying with the National Standards, RSP and NSPCL power plant have Real-time emission rate monitoring system, furthermore there is a system of Real-time AAQ monitoring stations spread out across Rourkela. This study uses the data of these real-time monitoring systems which publicly available through OSPCB website. As there are no governmental or private weather monitoring stations near Rourkela, the wind speed and direction are obtained through Time and Date AS.

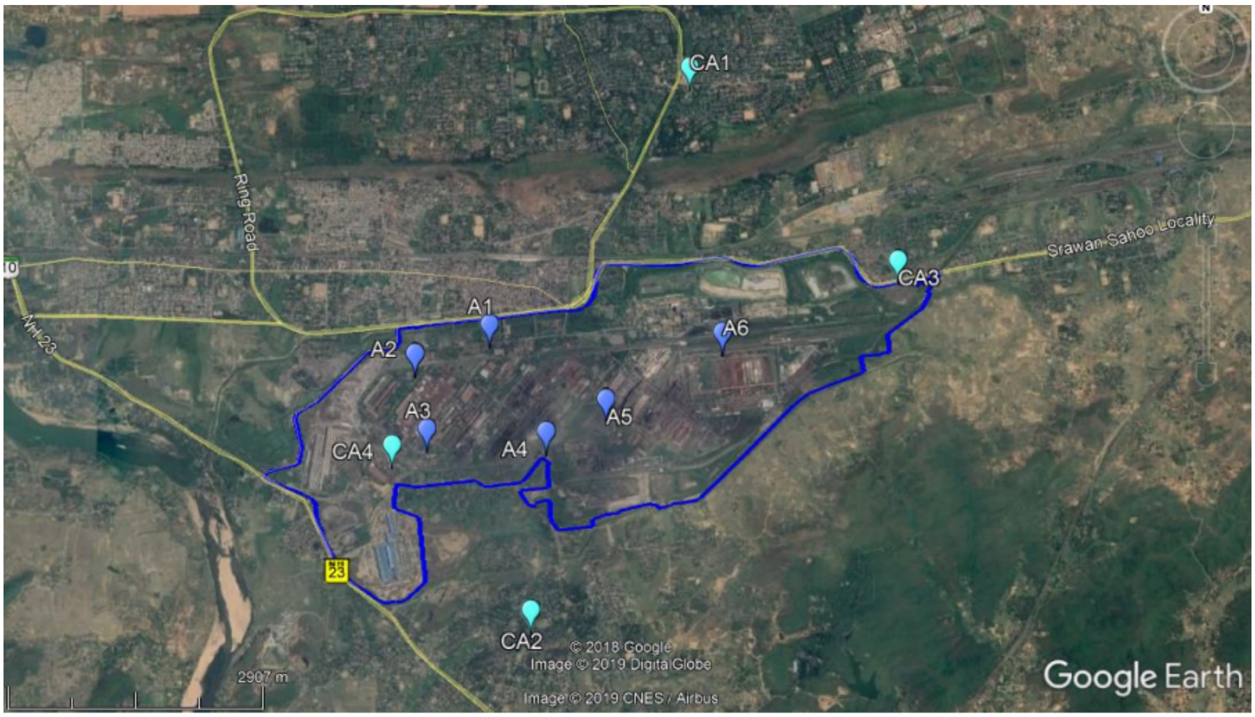


Figure 2: Location of various AAQ monitoring stations[3]

Legends			
Continuous AAQ Stations		Manual AAQ Stations	
CA1	Rourkela Steel Township, Sec.2	A1	EED Buidling rooftop
CA2	Rourkela Steel Township, Sec.22	A2	RDCIS Buidling rooftop
CA3	NSPCL Power Plant	A3	PMPH Buidling rooftop
CA4	Rourkela Steel Plant, ERWPP area	A4	BOD Plant building rooftop
		A5	TOP#2 Admin. Building rooftop
		A6	OBBP Admin. Building rooftop

Method

The data is analysed using MATLAB program written by the author of this study. As, CA1 and CA2 are placed symmetrically on either side of RSP and NSPCL, with one being partially obstructed by a chain of hills, while the other being nearly unobstructed from the RSP and NSPCL area, these will be the focus of our study. To avoid any complications due to environmental chemical reactions on the pollutant concentration, we shall focus expressly on Particle Matter (Both PM_{10} and $PM_{2.5}$ combined) as our subject pollutant. For brevity throughout the rest of this paper we shall use the term Pollutant for Particle Matter, unless mentioned otherwise. To minimize the affect of weather variations in Wind velocity data, 6 days of spring 2021 are selected randomly. Of these 6 days, three are selected such that wind is predominately flowing North-West for a time period of atleast 8 hours, while the other three days are selected such that that wind is predominately flowing South-West for a time period of atleast 8 hours. Data for time of days, when wind flows North West, is used to analyse the impact of Mountainous topography around CA1. Data for time days, when wind flows South West, is used to analyse the impact of Non-mountainous topography around CA2. As the maximum emission stack height of the RSP and NSPCL complexes is 100 metres, the model assumes actual stack height of 100 metres. This model uses stack radius as 3m since stack radius in RSP and NSPCL varies from 2.5 to 4 metres. Gas exit velocity is taken to be 9 m/s.[4] The stability class is obtained using surface wind speed.[5] The hilly terrain is taken to be rough terrain. The longitudinal and latitudinal average of the stacks located at longitudinal and latitudinal extremes, is found to be around LBSS-5S/s, near Sinter plant 2. The model assumes this location as the location of point source. From this location the distance of CA1 and CA2 is found to be 2.4km and 3.6km respectively. All the maps used for this rest of this paper are sourced from Google Maps.

Outline

The outline of the procedure for analysis of (8 hour time period of) each day, is as follows :

- Stability class is determined using wind speed, and other parameters are calculated accordingly.[5]
- Average of Emission data for various stacks, collected every hour in $mg/Nm3$, is obtained.
- It is then converted to $\mu g/s$ using the aforementioned values of stack radius and exit velocity.
- This data is then feed to the code and expected concentration of pollutant is obtained.[5]
- Average of observed (again collected every hour in $\mu g/m^3$) is obtained.
- Noise in the observed concentration, due to other pollution sources is eliminated.[6]
- Calculated and observed concentration is compared and inferences are drawn.

The analysis of 6 days is then used to draw interferences.

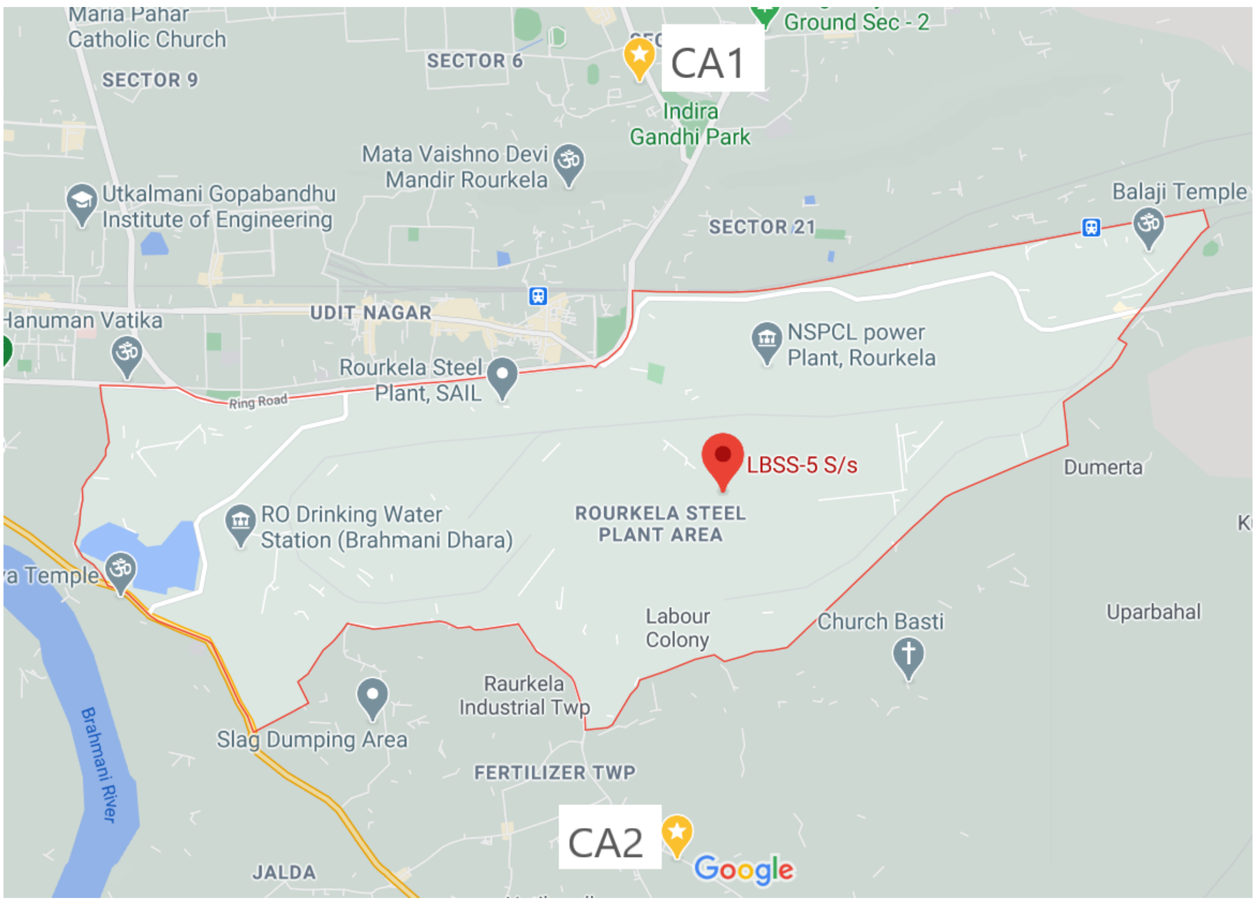


Figure 3: Location of Source point with respect to CA1 and CA2

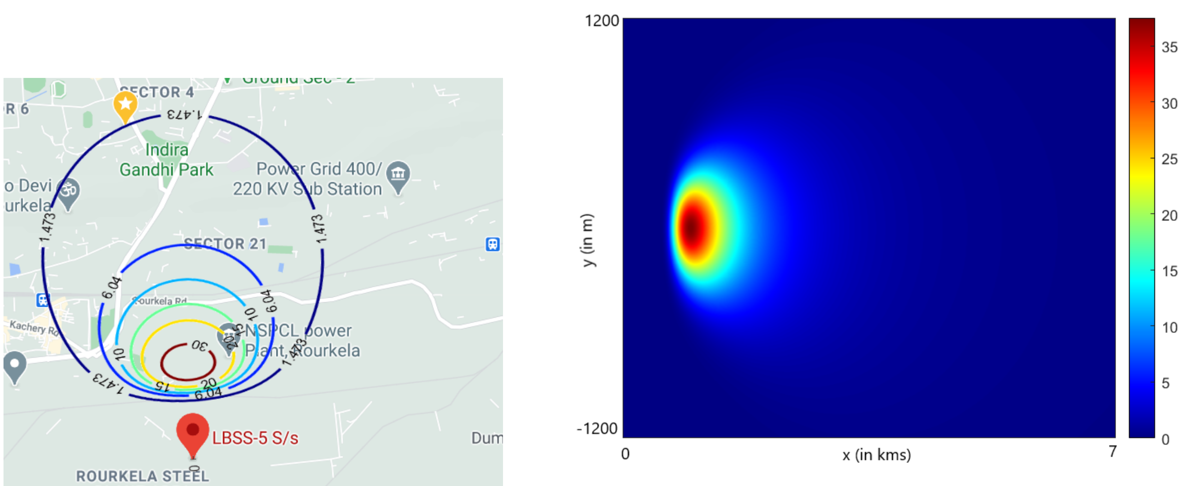
Results

Mountainous Topography

Results CA1 (in $\mu g/m^3$)			
Date	Recorded Concentration	Observed concentration adjusted	Calculated concentration
09/02/2021	24.6	6.15	1.473
10/02/2021	47.8	11.95	3.263
08/04/2021	47.6	11.9	2.157

Here the adjusted values are calculates using empirically obtained results.[6] Comparing the calculated pollutant concentration and actual recorded concentration, we note that CA1 consistently recorded higher than calculated concentration.

Note, in the following overlay contour plots, the star indicates the AAQ monitoring station in consideration whereas the red marker is the point source. Heat maps have the source at the origin.

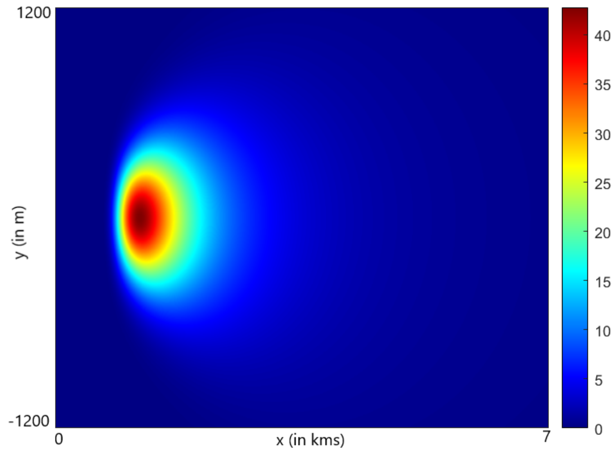


(a) GPM contours overlaid on map

(b) Heat map of GPM

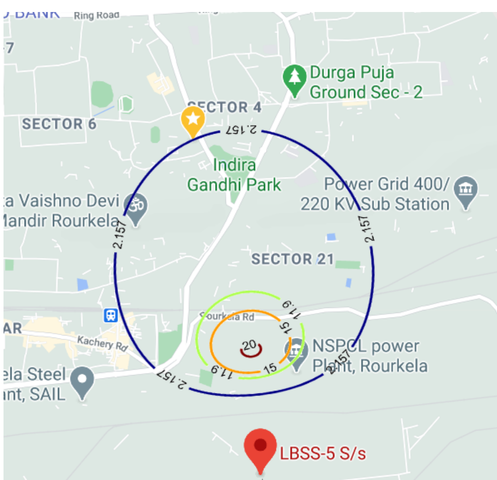
Figure 4: 09 February 2021

(a) GPM contours overlaid on map

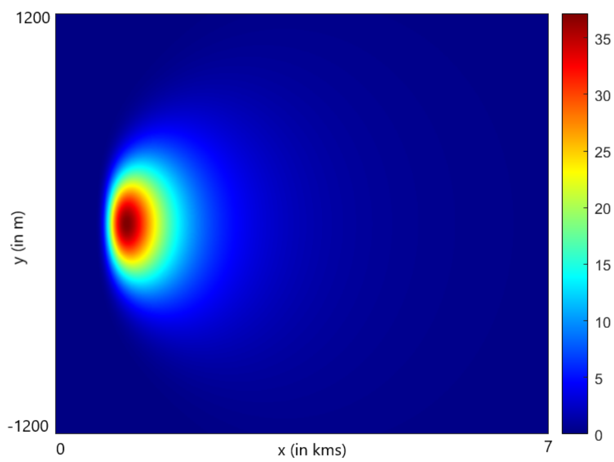


(b) Heat map of GPM

Figure 5: 25 March 2021



(a) GPM contours overlaid on map



(b) Heat map of GPM

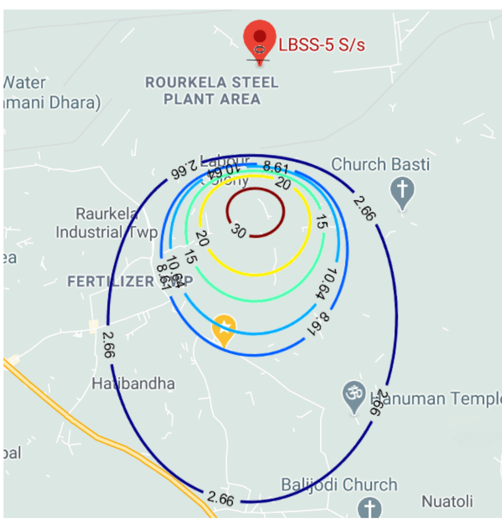
Figure 6: 25 March 2021

Non-mountainous topography

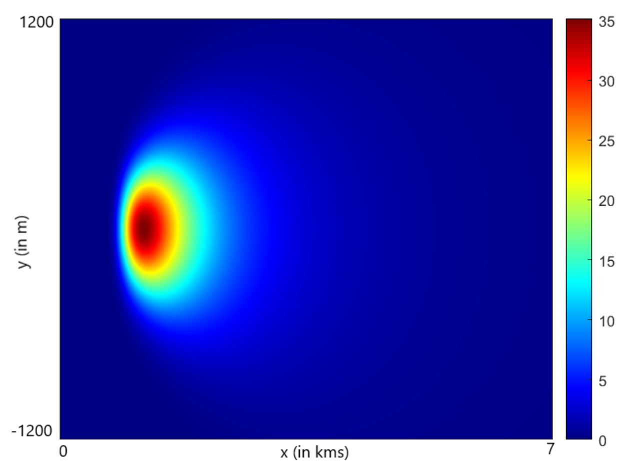
Results CA2 (in $\mu g/m^3$)			
Date	Recorded Concentration	Observed concentration adjusted	Calculated concentration
04/02/2021	10.64	2.66	8.61
11/02/2021	10.53	2.64	25.377
25/03/2021	10.72	2.68	5.62

Again, the adjusted values are calculated using empirically obtained results.[6] Comparing the calculated pollutant concentration and actual recorded concentration, we note that CA2 consistently recorded lower than calculated concentration.

Note, in the following overlay contour plots, the star indicates the AAQ monitoring station in consideration whereas the red marker is the point source. Heat maps have the source at the origin.

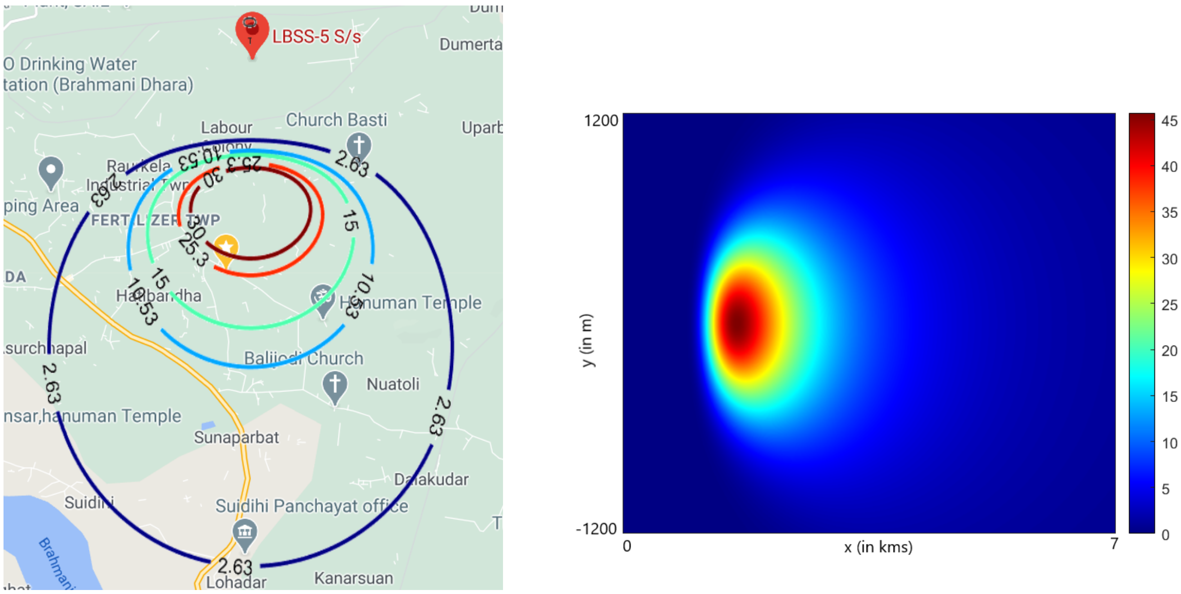


(a) GPM contours overlaid on map



(b) Heat map of GPM

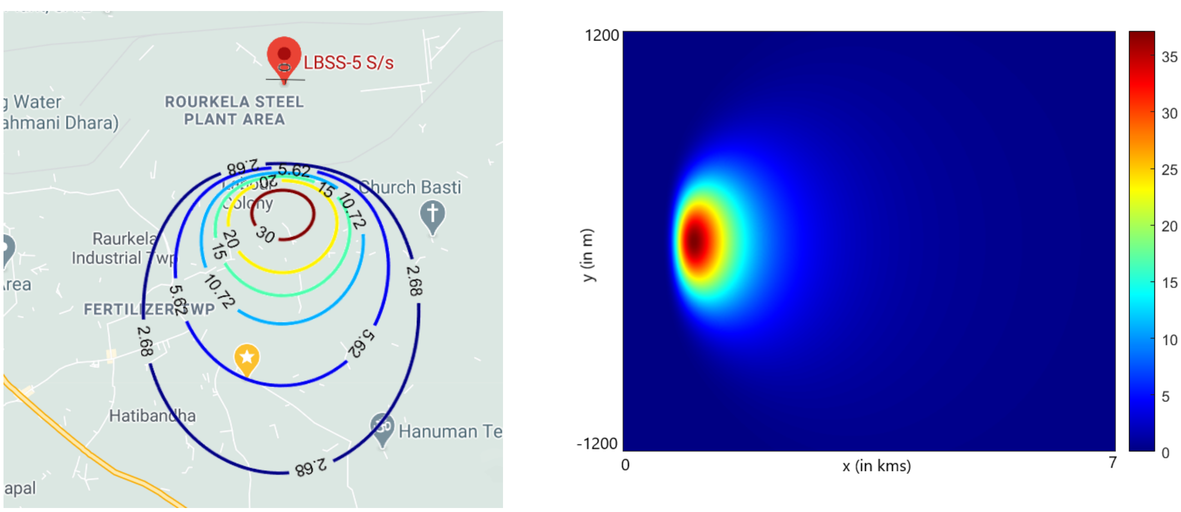
Figure 7: 4th Feb 2021



(a) GPM contours overlaid on map

(b) Heat map of GPM

Figure 8: 11 February 2021



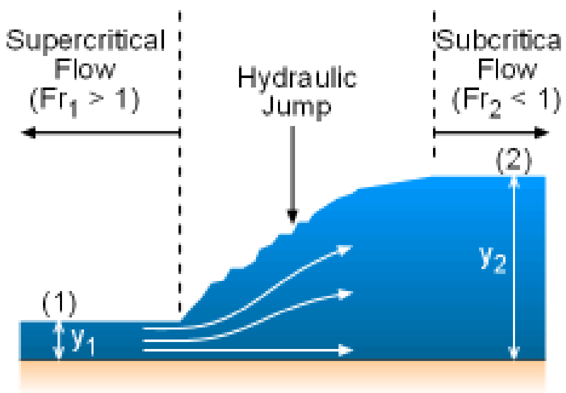
(a) GPM contours overlaid on map

(b) Heat map of GPM

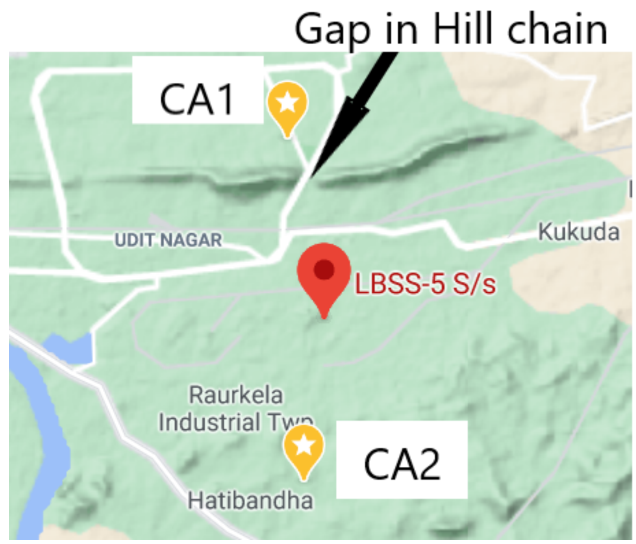
Figure 9: 25 March 2021

Discussion

We hypothesize that the higher than calculated value of pollutants at CA1 is due to formation of a hydraulic jump at the mouth of the gap in the Northern hill chain, when the winds blow North-West.



(a) Illustration of a hydraulic jump (Source : Oklahoma university)



(b) Location of the Gap in Hill chain

Figure 10: Visual aid on the Phenomenon of Hydraulic jump near CA1

Considering the width of the hills is short, we may assume Bernoulli's equation holds, thus as the air passes through this gap and undergoes the hydraulic jump, the velocity of the gas decreases and (following Bernoulli's equation) the Pressure and density of the air increases, consequently the density of pollutants also increases. If we take into account the climatic conditions on the Leeward and Windward side of the hills, we find that the hotter temperature on the leeward side will add further heat to the air, intensifying the hydraulic jump. And as the hydraulic jump increases the pressure the it will further increase temperature setting up a positive feedback loop, which will consequently lead to high pollution concentration around CA1. Such Mountain gap-induced hydraulic jumps has been found at many other places yet only recently have these been brought into the purview of scientific study.[7]

Regarding CA2, we note that there is little to obstruction to wind flow in the region around CA2, thus the flow is relatively less turbulent, allowing for a higher local wind velocity and lower pressure and density. An contributing factor in reduction of pollutants can be the higher forest coverage around CA2, it has been shown that forests can reduce urban air pollution especially SPM (Suspended Particle Matter).[8]

To remedy the Gap-induced hydraulic jump and subsequent increase in pollutant concentration, we suggest that energy dissipaters be constructed on the leeward side of the hill chain and in the vicinity of the Hill chain gap, as such energy dissipaters have been found to be quite effective in case of Dams. Such energy dissipaters can take any form, be it a apartment complex, office building or just tress be planted on the leeward.

Thus, this paper highlights the potential impact local topography can have on air pollutant distribution across an area. Given the scarcity of such studies in the Literature, especially for the case of India, more studies in this field are needed to understand and properly remedy topography induced increase in air pollution.

References

(1) Bellander, T.; Berglind, N.; Gustavsson, P.; Jonson, T.; Nyberg, F.; Pershagen, G.; Järup, L. Using geographic information systems to assess individual historical exposure to air pollution from traffic and house heating in Stockholm. *Environmental health perspectives* **2001**, *109*, 633–639.

(2) Naik, S. Studies on pollution status of Bondamunda area of Rourkela industrial complex. Ph.D. thesis, 2005.

(3) MECON,; MoEFCC, Addenum to EIA/EMP Report. *EIA/EMP Report* **2019**, 172.

(4) Bouwes Sr., N. W.; Hassur, S. M. Estimates of Stack Heights and Exit Gas Velocities For TRI Facilities in OPPT's Risk-Screening Environmental Indicators Model. *EPA Reports* **1999**, 11–13.

(5) Masters, G.; Ela, W. Introduction to Environmental Engineering and Science, 3rd Ed. **2014**, 438–486.

(6) Kavuri, N. TSP aerosol source apportionment in the urban region of the Indian steel city, Rourkela. *Particuology* **2015**, *20*, 124.

(7) Gohm, A.; Mayr, G. J.; Fix, A.; Giez, A. On the onset of bora and the formation of rotors and jumps near a mountain gap. *Quarterly Journal of the Royal Meteorological Society: A journal of the atmospheric sciences, applied meteorology and physical oceanography* **2008**, *134*, 21–46.

(8) Yang, J.; McBride, J.; Zhou, J.; Sun, Z. The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening* **2005**, *3*, 65–78.