Determining a suitable location for the construction of a coal powered power plant maintaining safe SO_2 concentrations at nearby vulnerable locations

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ES2202 Term Paper: Methods

Determining a suitable location for the construction of a coal powered power plant maintaining safe SO_2 concentrations at nearby vulnerable locations
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Introduction

Construction of power plants require proper planning and precautions to ensure that the air quality in nearby cities do not suffer significantly. Here, the gaussian plume model is used to estimate the expected concentration of SO_2 at a hospital for varying separation between the power plant and the hospital. A location suitable for the construction of the power plant is then selected, which satisfies the recommended annual SO_2 exposure limit by National Ambient Air Quality Standards.

Methods

The government hospital situated in Malur, Karnataka (Population as of 2011: 40,050)[^india census 2011] is chosen as the location at which the SO_2 concentration is calculated.

The wind speed across the region at an altitude of 200m from the ground spanning the hospital and the location of the power plant is approximated to $7.97 ms^{-1}$ with an azimuth of 270^o.[1] The surface windspeed is $3.82 ms^{-1}$.

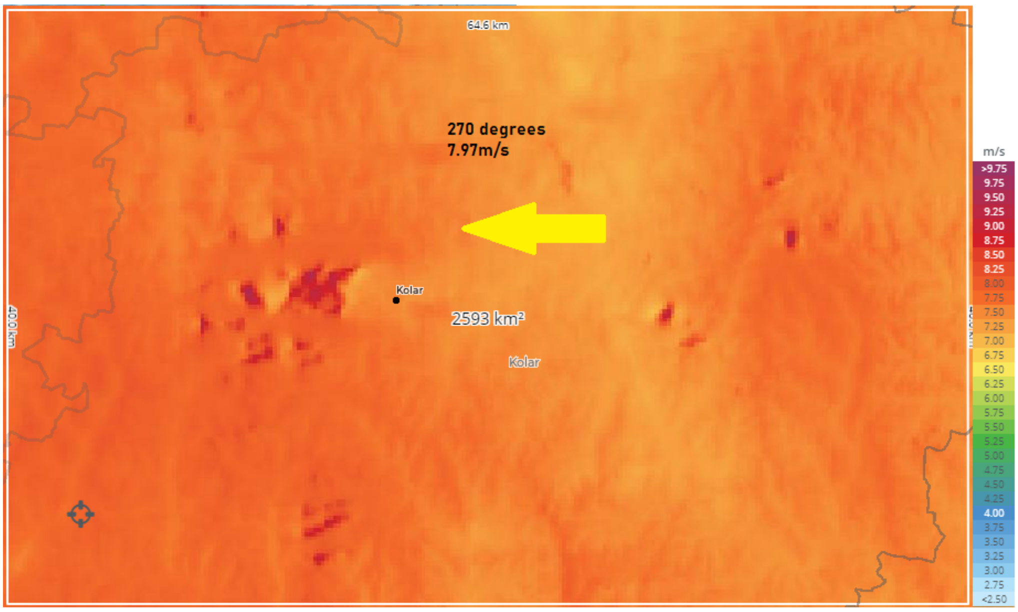

Fig (1): Average wind speed over the concerned area.
The arrow shows the direction of averaged windspeed.

This location is chosen since a large area of sparsely populated land is available in the eastern and northeastern directions, where building the power plant would be much less disruptive. Moreover, the windspeed is nearly constant over the region. The topography also does not vary significantly over this region.

Power plant

The powerplant is modeled after the *JSW energy Ratnagiri plant*, located in Post Jaigad, Maharashtra.

The stack diameter is calculated to be $5m$, given the area of the opening of $19.64m^2$.[2]

The stack height is given to be $220m$.[2]

The exit velocity is measured to be $22.4ms^{-1}$.[2]

The percentage sulphur content in the coal used as fuel is given to be 0.6% from which we can calculate the emission rate. [3]

The exit temperature is measured to be 144^oC or $417K$[2]

The ambient temperature is around 25.3^oC or $298.4K$.[4]

The JSW power plant, with two active stacks, has an output of $1200MW$. Thus the proposed powerplant has a capacity of $600MW$ with a single stack. [5]

Gaussian plume model

The gaussian plume model allows us to determine the concentration of a pollutant in the downwind direction at any specified distance from the plant. It is governed by the following equation

$$C(x,y) = \frac{Q}{\pi u_H \sigma_y \sigma_z} \exp\left(\frac{-H^2}{2\sigma_z^2}\right) \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \tag{1}$$

- u_H is the average windspeed at the effective height of the stack. We approximate this to be the average wind speed at 200m. This approximation is used instead of that suggested by Peterson (1978), of calculating the windspeed at an altitude from the that at the ground level, since this method gets less accurate as we go higher and higher.
- y is the horizontal distance from the plume centerline.
- Q is the emission rate of SO_2 to be determined from the percentage of sulphur in coal, and the amount of coal burnt.

Stability class

The chosen location belongs in the stability class $B - C$ as the windspeed at the surface lies between 3 and 5, and the powerplant is usally operational during daylight.[6] The region has an year round average cloud cover close to 50%.[4] The stability class of $B - C$ represents moderate to slightly unstable conditions.

σ_y is given by the equation,

$$\sigma_y = a \cdot x^{0.894} \tag{2}$$

σ_z is given by,

$$\sigma_z = c \cdot x^d + f \tag{3}$$

Where x is the distance downwind, measured in km. Assuming stability class $B - C$, the values of a, b, c and d are tabulated below, by averaging their values for the stability conditions B and C separately.

Parameters	$x \leq 1km$	$x \geq 1km$
a	130	130
c	83.8	84.6
d	1.03	1.0045
f	1.65	1.0

Effective stack height

It is the sum of the actual stack height and the **plume rise** which is a result of the momentum due to exit velocity and the boyancy.

$$H_{\text{effective}} = H_{\text{actual}} + \Delta h$$

The buoyancy flux parameter F is given by,

$$\begin{aligned} F &= gr^2\nu\left(1 - \frac{T_a}{T_s}\right) \\ &= 9.8 \cdot 2.5^2 \cdot 22.4 \cdot \left(1 - \frac{298.4}{417}\right) \\ &= 390.21 m^4 s^{-3} \end{aligned}$$

For the stability conditions dealt with here, and given that $F \geq 55 m^4 s^{-3}$ [7] the plume rise is given by,

$$\begin{aligned}\Delta h &= \frac{1.6}{u_H} \cdot F^{\frac{1}{3}} \cdot \left(120 \cdot F^{0.4}\right)^{2/3} \\ &= \frac{1.6}{7.97} \cdot (390.21)^{\frac{1}{3}} \cdot \left(120 \cdot 390.21^{0.4}\right)^{\frac{2}{3}} \\ &= 175.2m\end{aligned}$$

Hence,

$$\begin{aligned}H &= 220m + 175.2m \\ &= 395.2m\end{aligned} \tag{3}$$

Air quality standards

The National Ambient Air Quality Standards recommends a maximum of 140 ppb averaged over a 24 hour period, and a maximum of 30 ppb averaged annually. [8]

Another standard is that recommended by the World Health Organisation which sets the limit at an annual average of 19 ppb.[9]

Conclusions

The methods for calculating all the parameters required to apply the gaussian plume model has been established. The concentration of SO_2 over a large area due to different positions of the power plant can now be calculated.

Once we have the different concentrations at differing positions of the power plant, we can select some suitable location such that the sulfur dioxide concentration at the hospital is safe.

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1. https://globalwindatlas.info/ ↩
2. JSW half yearly compliance report 2020. Page 16., 17. ↩ ↩ ↩ ↩
3. JSW half yearly compliance report 2020. Page 4. ↩
4. www.worldweatheronline.com/malur-weather-averages/karnataka ↩ ↩
5. Global power plant database ↩
6. Turner, 1970. ↩
7. Briggs (1972) ↩
8. Primary National Ambient Air Quality Standard (NAAQS) for Sulfur Dioxide ↩
9. Sulfur dioxide - WHO/Europe ↩