SENAI, IIT MADRAS

Data Science and IoT for Addressing Environmental Sanctity

Project *Kaatru*

PROBLEM STATEMENT

AWARENESS

We know surprisingly little about our surroundings.

SPATIAL VARIATION

Ambient air quality can vary drastically between locations that are barely a few hundred meters apart.

LIFE EXPECTANCY

3 million people across the globe die due to outdoor air pollution, of which India's burden is 1 million.

QUALITY OF LIFE

Respiratory issues can be acquired and impact the wellbeing of individuals.

EXPENSIVE

Existing air quality monitoring networks are sporadic and prohibitively expensive to expand.

1. I. Kheirbek, K. Ito, R. Neitzel, J. Kim, S. Johnson, Z. Ross, H. Eisl, T. Matte, Spatial variation in environmental noise and air pollution in New York City., J. Urban Health. 91 (2014) 415–431. doi:10.1007/s11524-013-9857-0.
2. World Health Organization. Ambient Air Pollution: A global assessment of exposure and burden of disease. World Health. Organization. 1–131 (2016). Available at: doi:9789241511353

ECONOMIC IMPACT OF AIR POLLUTION

ILLNESS

Air Pollution contributes to 49% of asthma triggers; 30 million Indians suffer from asthma[1].

ANNUAL SPENDING

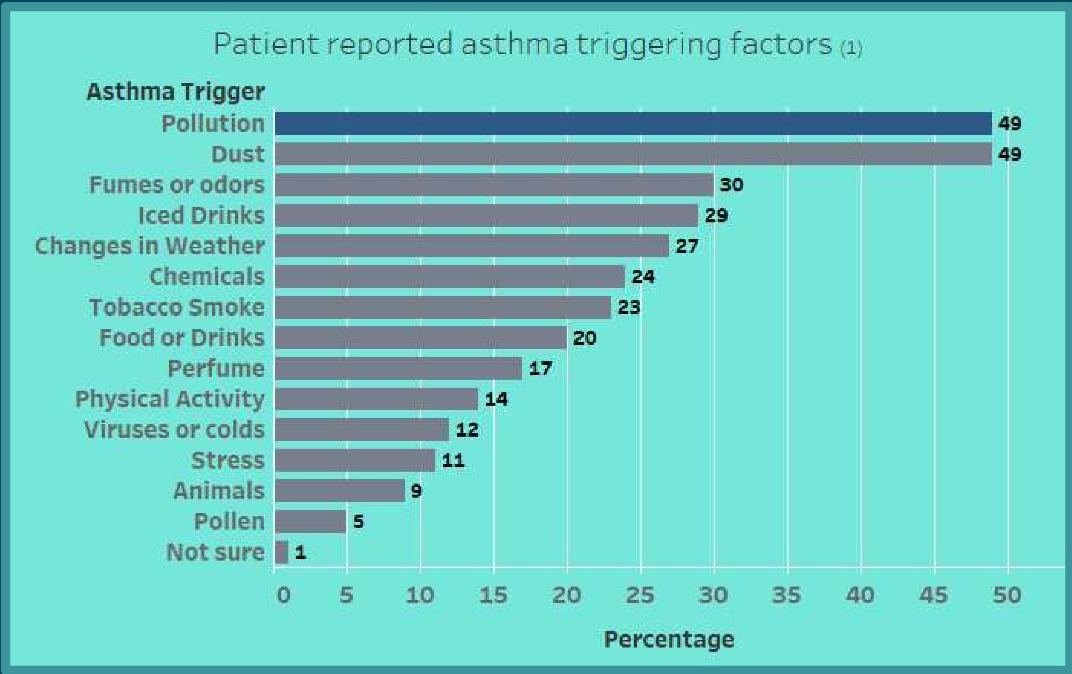
Indians spend INR 139.45 billion every year on asthma treatment(as of 2015)[3]

COST OF TREATMENT

Asthma costs INR 44,095 per year per patient in India[2].

CONSEQUENCES

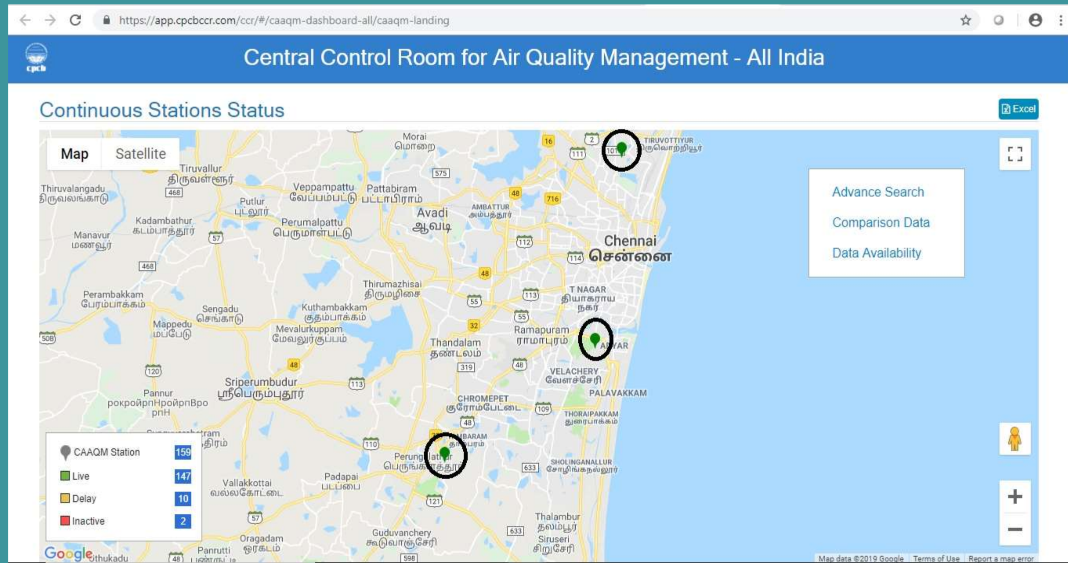
Poor air quality has an impact on child birth and mortality.



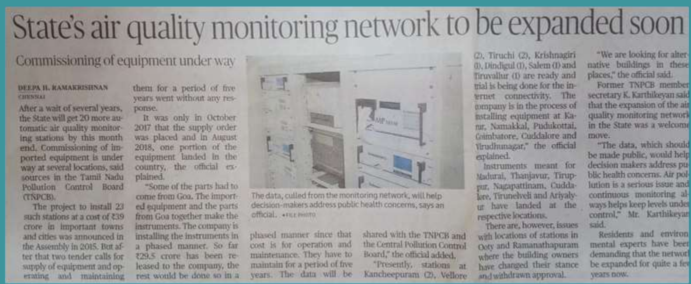
1. Asthma Insights and Management in India: Lessons Learnt from the Asia Pacific - Asthma Insights and Management (AP-AIM) Study; Sundeep S Salvi, Komalkirti K Apte, Raja Dhar, Pradeep Shetty, Rab A Faruqi, Philip J Thompson, Randeep Guleria, J. Accoc. Physicians of India, Sept. 2015
2. Economic burden of asthma among patients visiting a private hospital in South India; Surendran Aneeshkumar, Raj B Singh; Lung India, 2018
3. . Murthy KJ, Sastry JG. Economic burden of asthma. In: Burden of Disease in India. Background Papers. Available from: http://www.who.int/macrohealth/action/NCMH_Burdenofdisease_%2829Sep%202005%29.pdf.

EXISTING INFRASTRUCTURE

Conventional air quality monitoring station



Current distribution of CPCB owned monitoring stations across Chennai



State's air quality monitoring network to be expanded soon

Commissioning of equipment under way

DEEPA H. RAMAKRISHNAN
CHENNAI

After a wait of several years, the State will get 20 more automatic air quality monitoring stations by this month end. Commissioning of imported equipment is under way at several locations, said sources in the Tamil Nadu Pollution Control Board (TNPCB).

The project to install 23 such stations at a cost of ₹39 crore in important towns and cities was announced in the Assembly in 2015. But after that two tender calls for supply of equipment and operating and maintaining them for a period of five years went without any response.

It was only in October 2017 that the supply order was placed and in August 2018, one portion of the equipment landed in the country, the official explained.

"Some of the parts had to come from Goa. The imported equipment and the parts from Goa together make the instruments. The company is installing the instruments in a phased manner. So far ₹29.5 crore has been released to the company, the rest would be done so in a phased manner since that cost is for operation and maintenance. They have to maintain for a period of five years. The data will be shared with the TNPCB and the Central Pollution Control Board," the official added.

The data, culled from the monitoring network, will help decision-makers address public health concerns, says an official. • FILE PHOTO

"Presently, stations at Kancheepuram (2), Vellore (2), Tiruchi (2), Krishnagiri (1), Dindigul (1), Salem (1) and Tiruvallur (1) are ready and trial is being done for the internet connectivity. The company is in the process of installing equipment at Karur, Namakkal, Pudukottai, Coimbatore, Cuddalore and Virudhunagar," the official explained.

Instruments meant for Madurai, Thanjavur, Tiruppur, Nagapattinam, Cuddalore, Tirunelveli and Ariyalur have landed at the respective locations.

There are, however, issues with locations of stations in Ooty and Ramanathapuram where the building owners have changed their stance and withdrawn approval.

"We are looking for alternative buildings in these places," the official said.

Former TNPCB member secretary K. Karthikeyan said that the expansion of the air quality monitoring network in the State was a welcome move.

"The data, which should be made public, would help decision makers address public health concerns. Air pollution is a serious issue and continuous monitoring always helps keep levels under control," Mr. Karthikeyan said.

Residents and environmental experts have been demanding that the network be expanded for quite a few years now.

Tamil Nadu's air quality monitoring network expansion plan:
(The Hindu, June 19, 2019)

INR **39** crores to install **23** monitoring stations across **13** towns.

1. https://economictimes.indiatimes.com/news/politics-and-nation/noida-gets-its-first-automatic-air-ambient-monitoring-system/articleshow/58685064.cms?from=mdr
2. https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing

OBJECTIVES

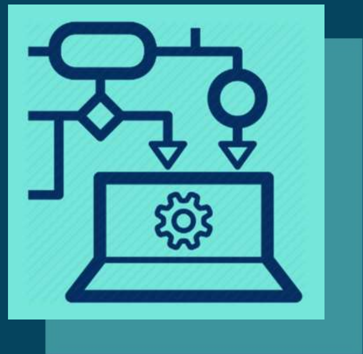
- **Provide hyper-local environmental insights by combining information from multiple sources.**
- **Leverage Big Data Analytics, Data Science, Artificial Intelligence and IoT to develop:**
  - AI driven self calibrating high accuracy distributed sensing network
  - Intelligence for spatio-temporal hotspot identification
  - Country-wide pollution map
  - Personal exposure assessment (based on mode of transport)
  - Strategies for mitigation and abatement
- **Develop customized solutions for social and commercial impact.**
- **Develop high accuracy low cost sensing principles.**

COMPONENTS OF PROPOSED SOLUTION

Satellite Remote Sensing

Dispersion Models

IoT | Sensor Network



Big Data and Data Science

IoT | DISTRIBUTED MOBILE SENSOR NETWORK

A mobile, low cost sensor network is built by deploying IoT(Internet of Things) devices on vehicles. These devices, containing an array of sensors, act as agents for measuring multiple environmental parameters with high spatio-temporal resolution.

Merits

- Ground level information with high spatio-temporal resolution
- Real data from physical sensors

Demerits

- Fidelity of low cost sensors is not established

SCHEMATIC OF SOLUTION

LOW-COST IoT SENSOR ARRAY

DEPLOYMENT ON VEHICLES

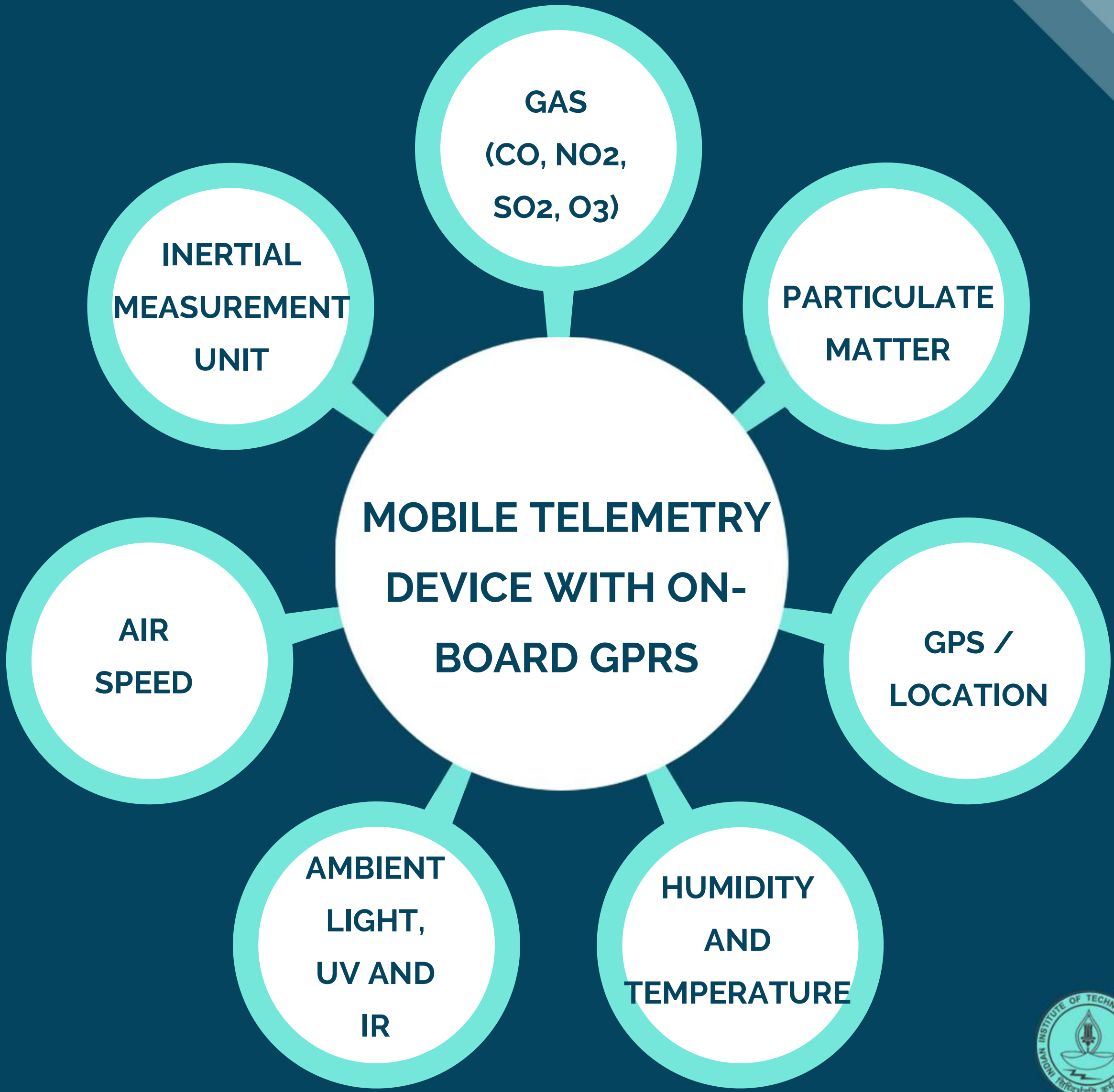
DATA AGGREGATION

MODELLING AND ANALYSIS

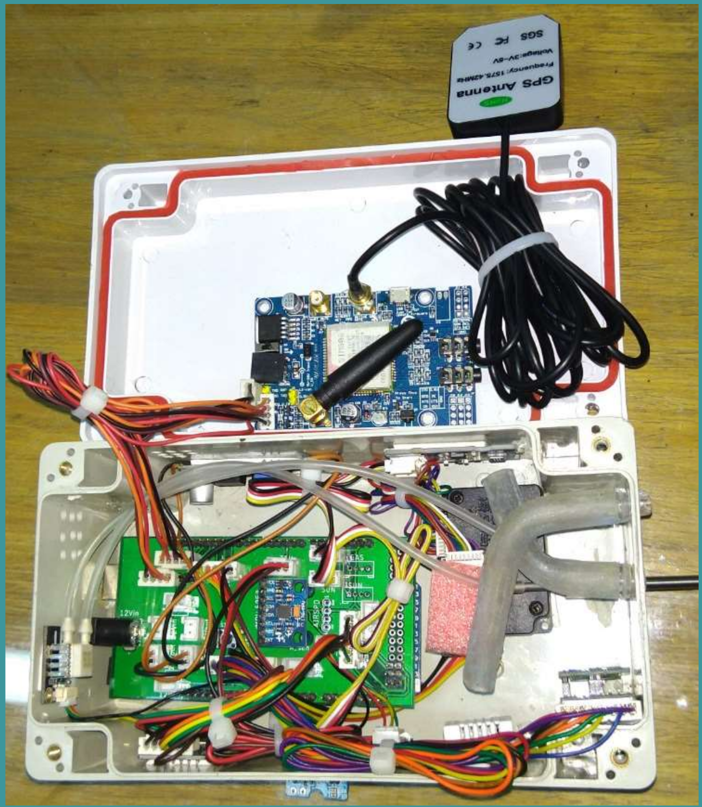
SPATIO-TEMPORAL AIR QUALITY MAP

SENSING DEVICE
HARDWARE SPECIFICATIONS

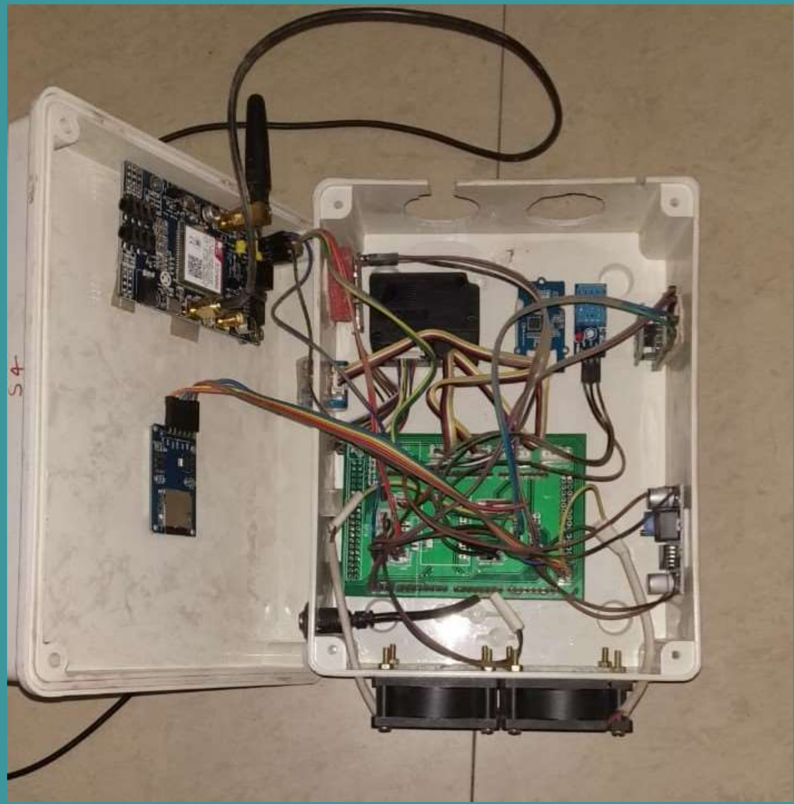
- The hardware setup is a standalone, location aware telemetry device with bidirectional communication with a central server.
- 25 environmental parameters measured along with location and time
- Modular design of the hardware allows for integration of additional sensors based on demand



SENSING DEVICES



Mobile device with active air sampling



Static device with passive air sampling

DEVICE DEPLOYMENT

Test vehicle in Chennai carrying mobile sensing device on top

Mobile device fixed on top of E-Rickshaws in Gurugram

Mobile device on Motorbike in Gurgaon

SATELLITE REMOTE SENSING

Data from satellites and satellite imagery products are used to estimate environmental parameters and determine land use patterns.

Merits

- Extensive coverage

Demerits

- Need ground measurements for calibration
- Low spatio-temporal resolution

FUNDAMENTALS OF SATELLITE REMOTE SENSING

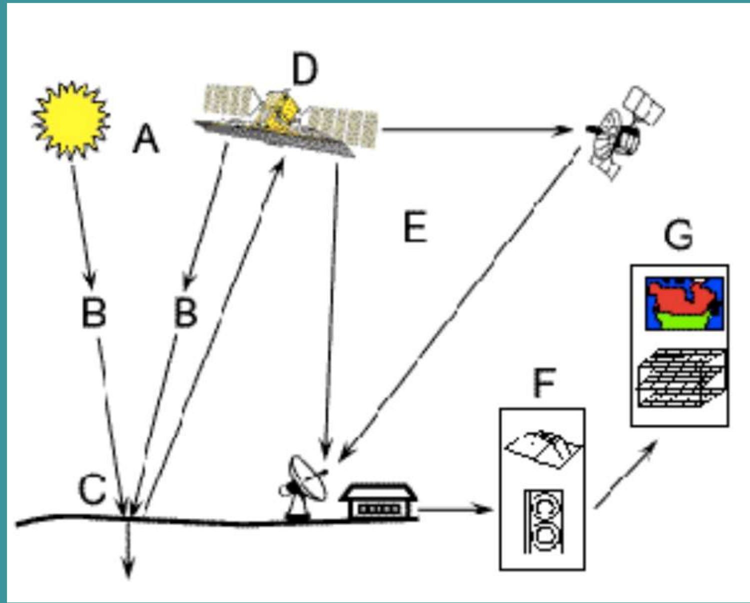
- **OBJECTIVE: To estimate spatial concentrations in vertical directions of atmosphere over a time period.**

- **In the figure:**

A – Energy source / Illumination
B – Radiation and Atmosphere
C – Target interaction
D – Sensor recording
E – Transmission, Reception and Processing
F – Interpretation and Analysis
G – Application

- Our work comprises of F and G parts.

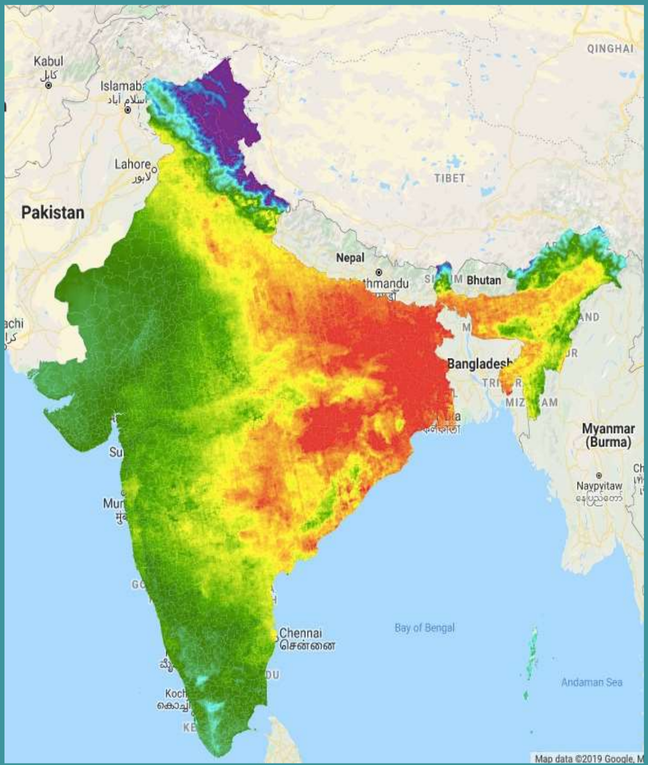
[1]



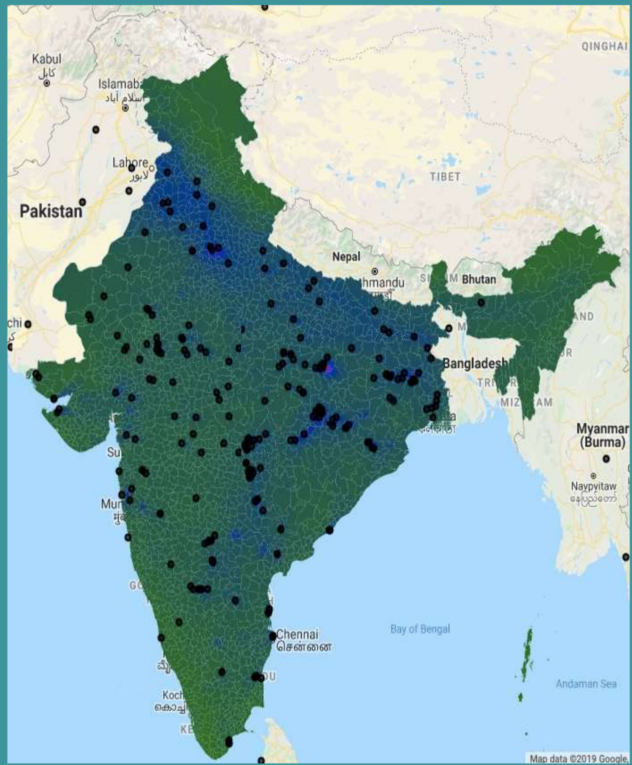
A flow chart of satellite remote sensing process

1. Fundamentals of Remote Sensing – A Canada Centre for Remote Sensing Tutorial

GOOGLE EARTH ENGINE (GEE)



Carbon Mono Oxide (CO) Concentration, India, June 2019
Red – highest concentrations, Blue - lowest

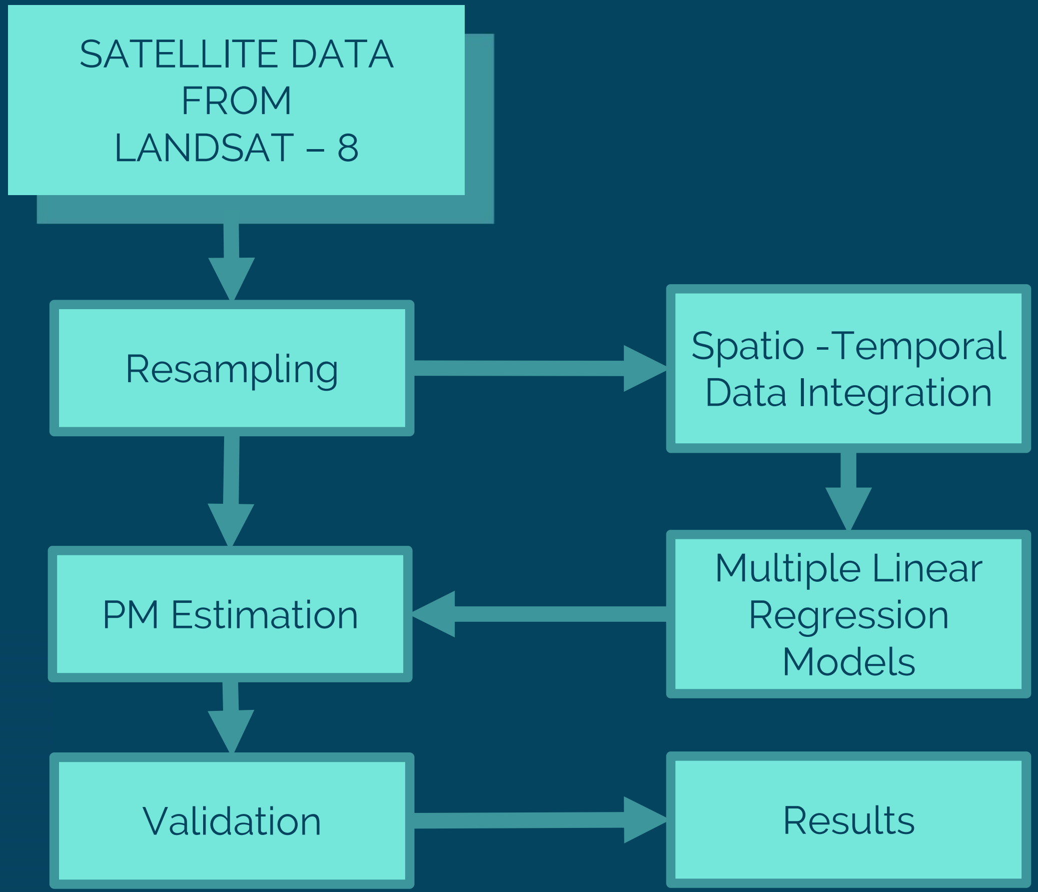


Nitrogen Di Oxide Concentration, India, June 2019
Black dots – Thermal Power Plants

- **GEE** – An open source platform with catalog of satellite imagery and geospatial datasets as a platform for Earth science data and analysis.

- **Data source:**
Sentinel-5P satellite

PROPOSED APPROACH FOR ESTIMATION OF Particulate Matter (PM)



Activities

- Creating pollution maps for various cities.
- Estimating average values for time period.
- Comparing results with that of sensor data and dispersion models.

DISPERSION MODELLING

CFD/Transport principles would be used to model the dispersion of pollutions in macro environments. Multiscale agent based models will be developed as part of this work to estimate air pollutant concentration at different spatial and temporal scales.

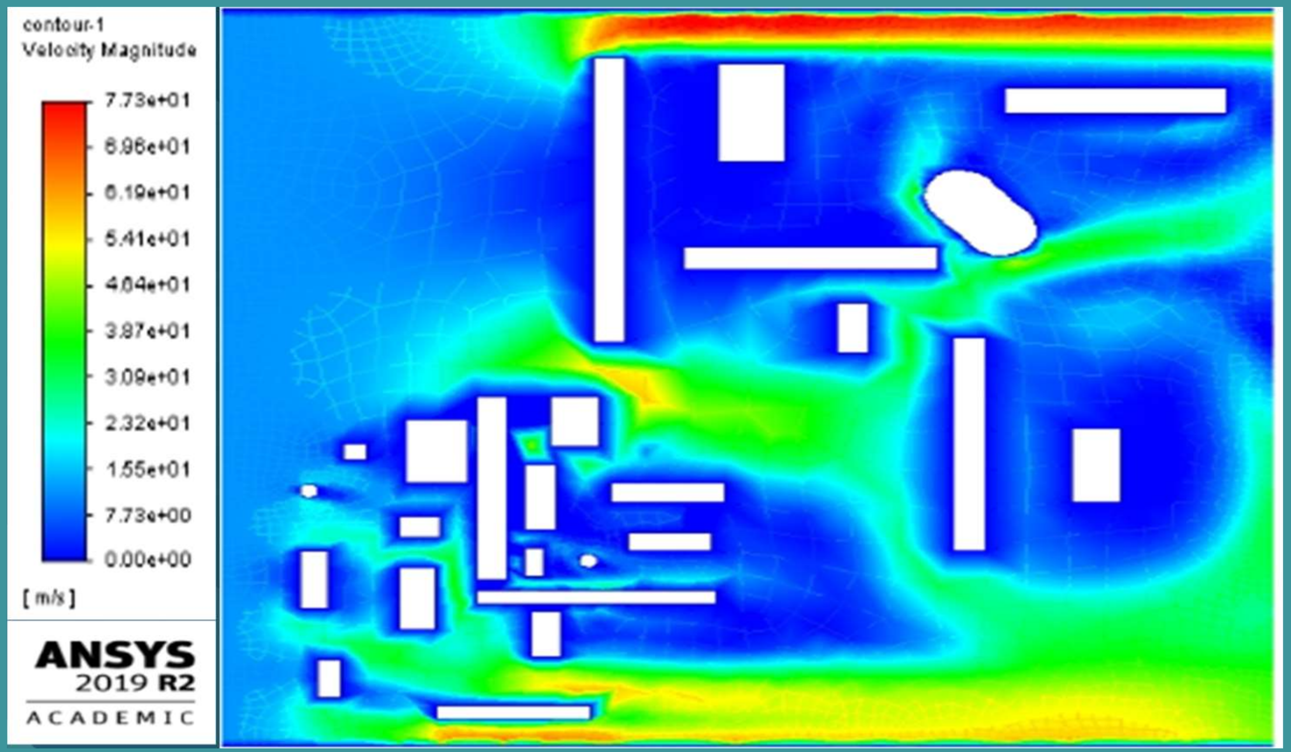
Merits

- Established method for air quality assessment.
- Models are scaleable in both space and time.

Demerits

- Accuracy of the model is dependent on modelling approach and data source.
- Needs to be validated against ground measurements.

DISPERSION MODELS



2-D analysis of velocity in a model city

- An urban environment presents many obstacles to dispersion of pollutants.
- Buildings, trees, walls, etc. can throttle or stagnate the flow of air.
- To understand transport behavior of pollutants, Air Dispersion Models are used

CONVENTIONAL AIR DISPERSION MODELS

SENAI, IIT MADRAS | 2019

GAUSSIAN DISPERSION MODEL

MERITS

- Continuous emission model.
- Can capture overall, large-scale dispersion trend.

DEMERITS

- Steady-state model.
- Suitable only for flat and open terrain.
- Dispersion parameters are assumed to be function only of velocities.

LAGRANGIAN PUFF MODEL

MERITS

- Simulates continuous puffs of pollutants.
- Unsteady state analysis possible.

DEMERITS

- Puff diffusion is Gaussian.
- Suitable only for long distance transport of pollutants.

CFD BASED MODEL

MERITS

- Fully resolves transport equation.
- Complex geometries and obstacles can be taken into account.

DEMERITS

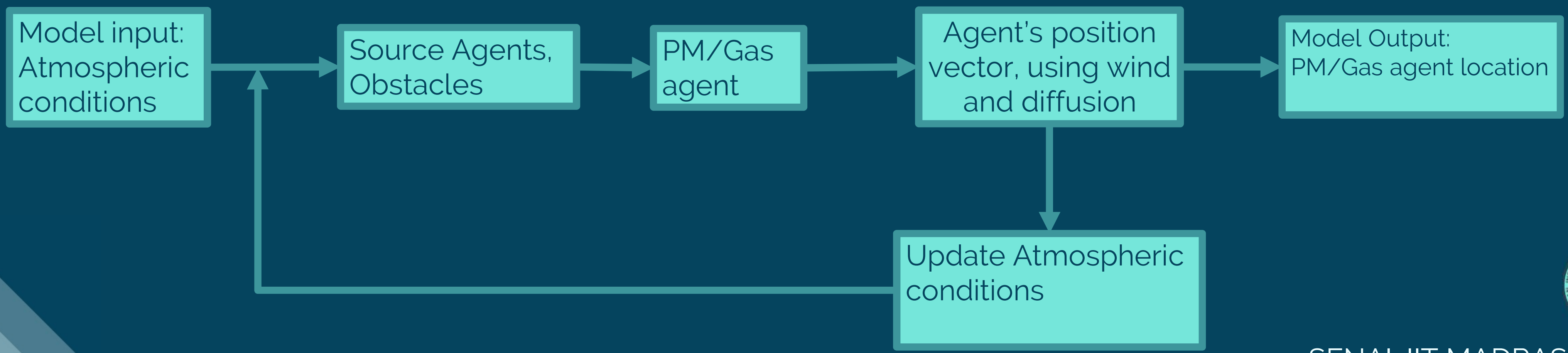
- Introduces first and second order errors.
- Computationally expensive for complex geometries.

PROPOSED AIR DISPERSION MODEL

Agent Based Modeling (ABM):

- Models pollutants, surroundings and environment to be distinct agents.
- Agents follow set of predefined rules.
- Set of predefined rules define interactions between different agents .
- Captures Lagrangian perspective as description of agents and the Eulerian perspective as the description of environment.
- Low computational costs

Use of ABM in air Dispersion:



BIG DATA AND DATA SCIENCE

- Big data and data science are the two cornerstones of this project.

- Raw environmental data collected from multiple sources are collated, processed and analyzed to obtain meaningful information.

- The enormous quantities, variety and velocity of data collected necessitates the need to incorporate a Big Data framework to manage and process data effectively.

- A variety of data science tools and techniques along with custom Machine Learning algorithms developed in-house are used to generate insights and solutions.

- Custom packages for curation and analysis of spatio-temporal data will be developed under the scope of this project.

OVERVIEW OF DATA COLLECTED[1]

15 Devices

25 Parameters

20 Seconds per sample

5.7 Hrs/day

240* Days

>2,000,000* Samples

>50,000,000* Data points

1. Real data collected in the central server by the distributed sensors network deployed in Gurugram and Chennai, India, from February 2019 through November 2019.

* The sensor network continues to collect data

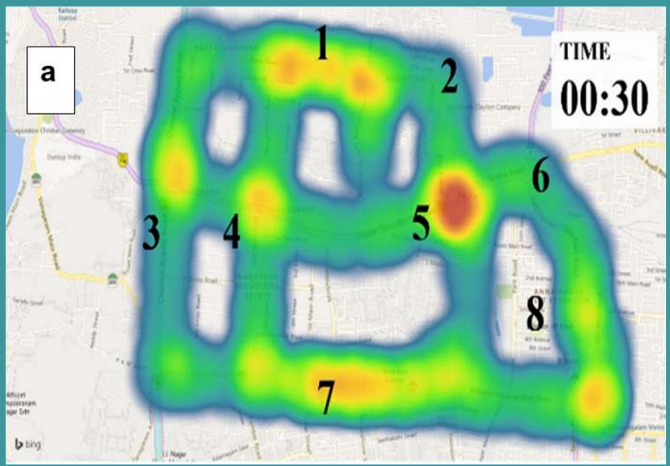
CASE STUDY 1 – AMBATTUR, CHENNAI

- A pilot study was run in Ambattur – Moggapair – Korratur – Padi, areas in Chennai with one mobile device fitted on a van.
- The route was chosen such that the vehicle would travel 25 kilometres in each trip covering an effective area of roughly 13 sq. km (~5 x 2.5 km).
- Data collected over 30 days of study was condensed into a 24 hour frame for analysis.

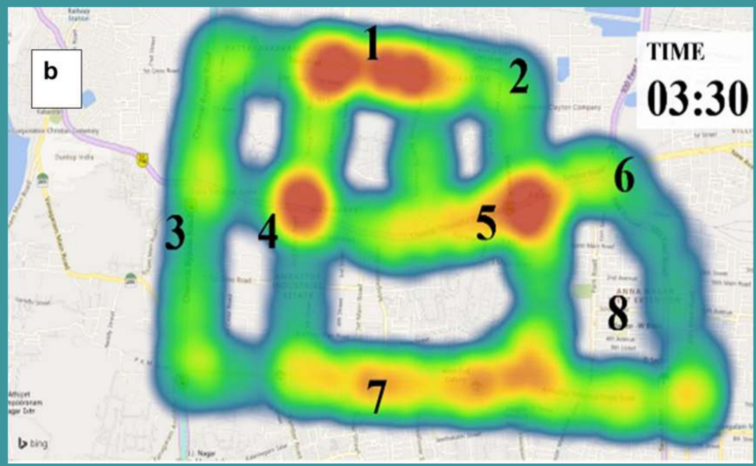
Route covered by the vehicle during pilot study along with key locations.

PARTNER FOR THE STUDY: Centre For Urbanization Buildings And Environment (CUBE), IIT M Research Park, Chennai.

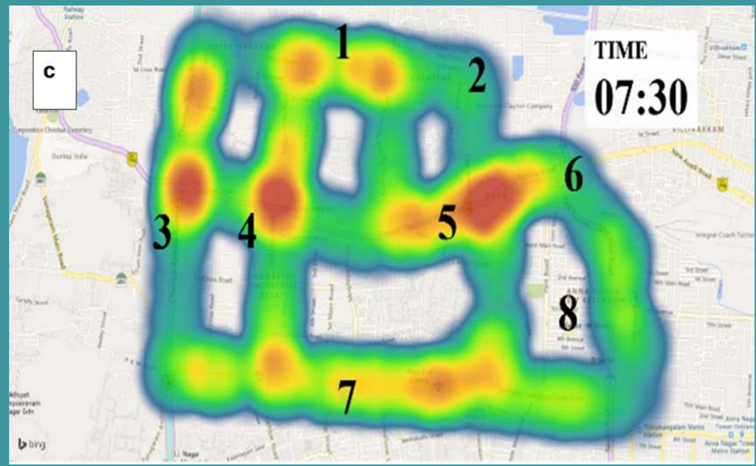
CASE STUDY 1 – AMBATTUR, CHENNAI



At 0030 hours there is very little vehicular pollution. There is however some traces of residual PM 2.5 at location 5. Location 5 is a narrow traffic junction with tall buildings around. This prevents particulate matter from dispersing and thus causing them to accumulate in the region.

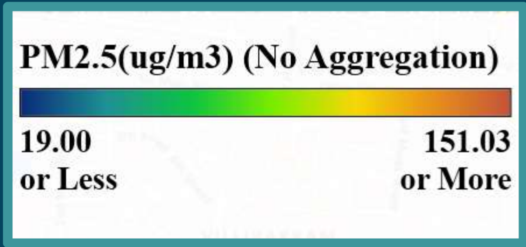


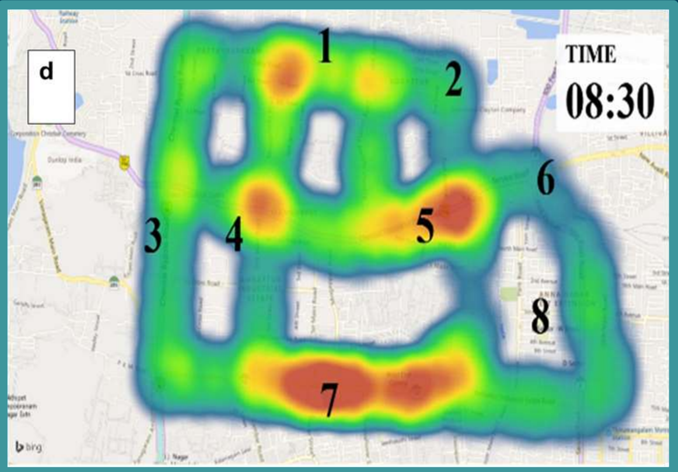
At 0330 hours, there is significant spike in PM2.5 concentration at location 1; entrance to the state owned milk factory. This is attributed to the outflow of trucks that leave the factory to deliver the morning batch of milk.



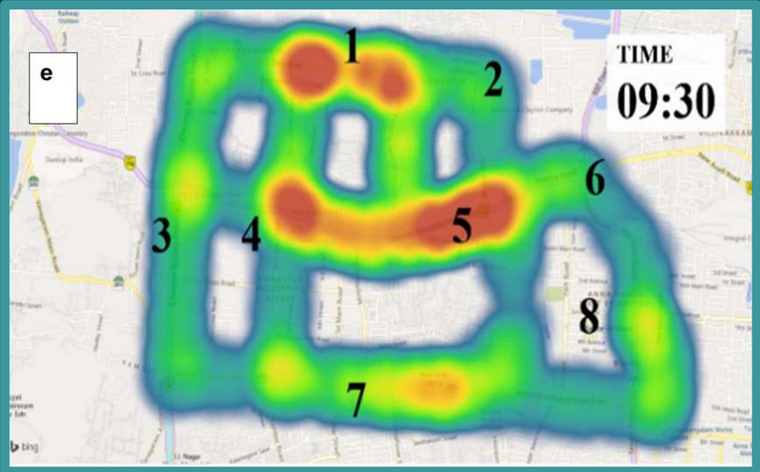
At 0730 hours, PM2.5 concentration at location 1 has reduced, coinciding with the end of milk dispatch time window and in turn a decline in the number of trucks leaving the factory. However, the aftereffects of the trucks' movement can be seen on adjacent roads.

CASE STUDY 1 – AMBATTUR, CHENNAI

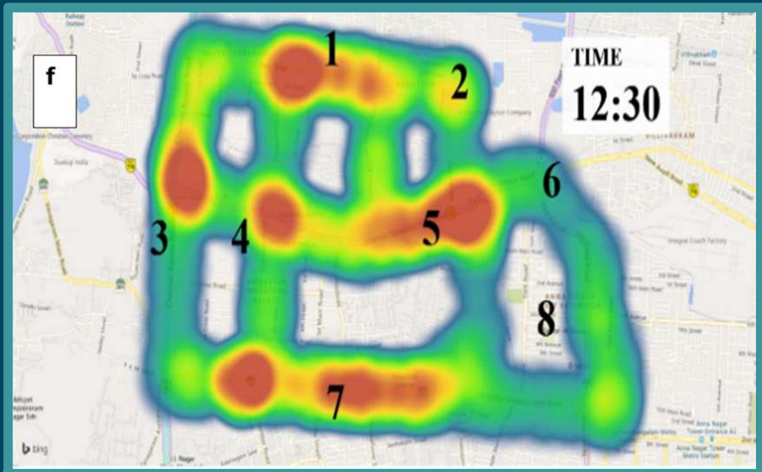




At 0830 hours, one can notice the sudden spike in PM2.5 concentration at location 7, i.e. the school area. It coincides with the school start time when students are dropped at the school in the morning. There are about 15 schools comprising both junior and senior sections within a 500 meter radius around the school area.

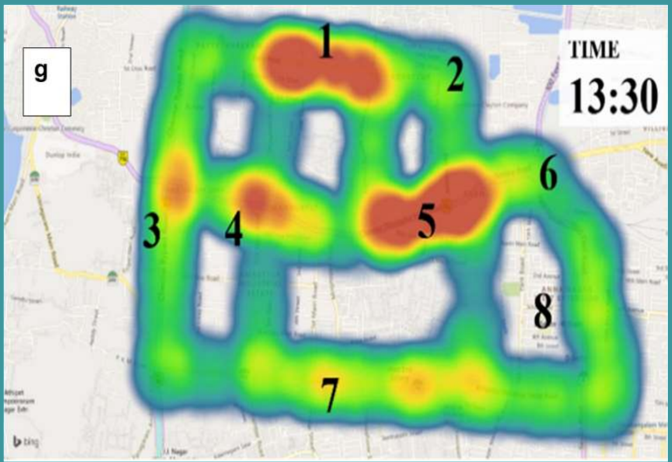


At 0930 hours, there is a drastic shift in the PM2.5 concentration away from the school zone and towards the road leading to the Ambattur Industrial Estate (locations 4 and 5). This shift is attributed to the reduction in traffic at the school zone while there's an increased traffic of employees working in the Ambattur industrial estate and adjacent areas. It should be noted that the PM concentration in school area changes within an hour.

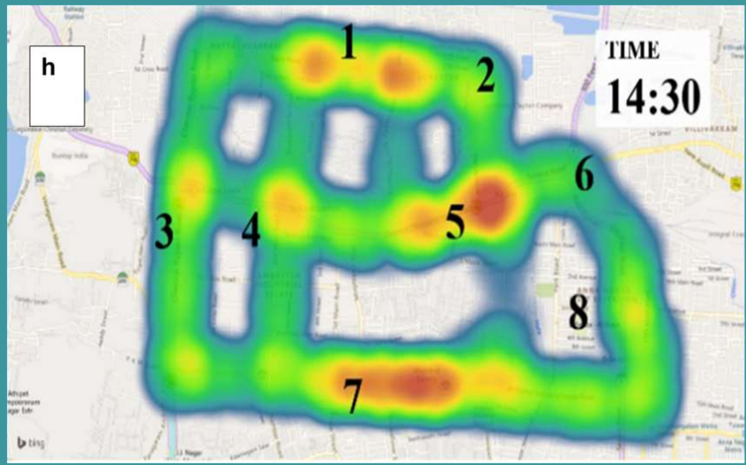


At 1230 hours, another significant change is observed when there is a higher PM2.5 concentration at multiple locations. The spike at location 7 is attributed to the dismissal time for the junior sections of the school. By this time, regular traffic has picked up in locations 3, 4, and 5.

CASE STUDY 1 – AMBATTUR, CHENNAI



At 1330 hours, PM concentration near the school area (location 7) drops significantly within a short duration again. However, there is slight redistribution in the PM2.5 concentration in locations 3, 4, and 5.



At 1430 hours, the PM concentration spike once again at the school zone. This coincides with the dismissal time for the senior sections in school. It is worth noting that the PM2.5 concentration around location is really dynamic. This could be attributed to the relatively wider road at location 7, lack of tall buildings, and lesser traffic in general other than during school times. Another key point to be noted is that there is drop in the traffic in all the other segments which is captured by the lower PM concentration in those areas.

It is worth noting that the residential areas, 2 and 8 are generally cleaner throughout the day than the rest of the area. This could be attributed to the tree cover and lack of traffic.

There is very little to no PM2.5 accumulation in locations 3 and 6. This could probably be attributed to the availability of ample open area for the PM2.5 particles to disperse unlike locations 4 and particularly 6 which is one of the most congested parts in the study area.

Location 3 is the Chennai Bypass road which is a 6-lane expressway with very few buildings around and mostly open land on one side of the expressway. Location 6 is a flyover and the height of this location coupled with lack of tall buildings or trees, makes more room available for dispersion of PM2.5 particles.

COUNTRY-WIDE POLLUTION MAP

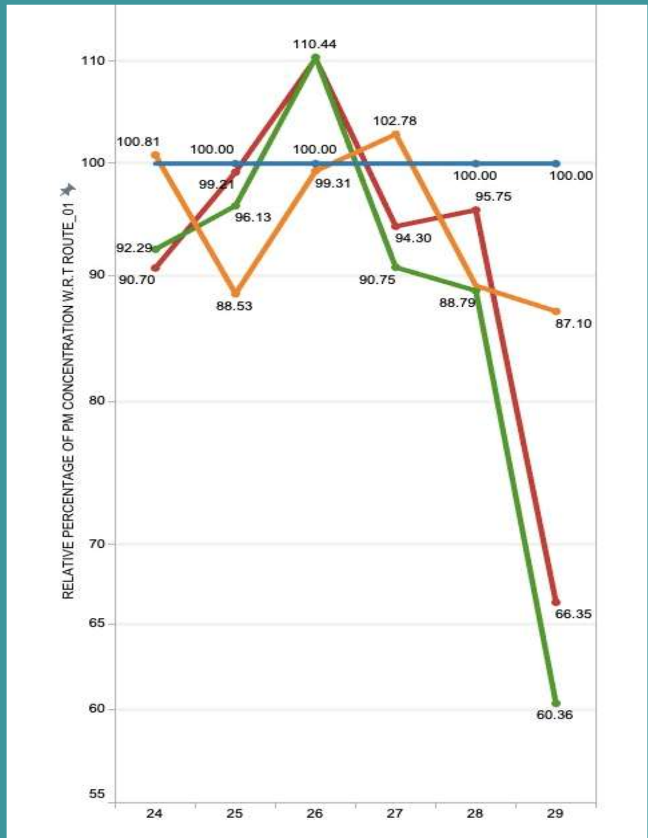
- Machine learning algorithms are used to project air quality information across the entire country
- Low cost sensor network is deployed in reference cities.
- A list of features containing land use information and other city specific information is collected.
- Data from sensor network is mapped to the cities' features.
- This information is used in a machine learning framework to estimate air quality in cities across the country.

PERSONAL EXPOSURE ASSESSMENT

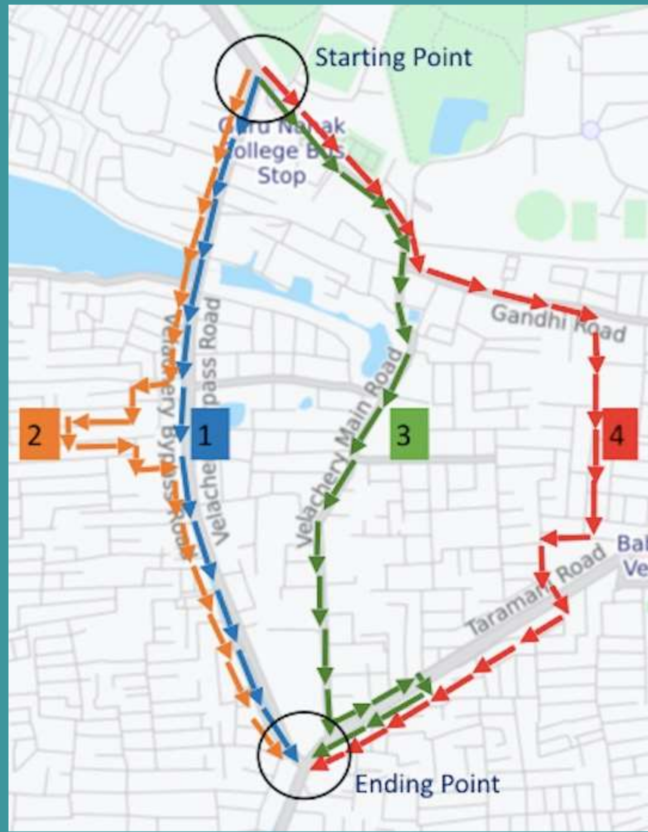
- Given hyperlocal air quality information is available, the next step is estimate exposure to individuals.
- Formulations for personal exposure would developed based on the following information:
  - Time activity of individuals
  - Exposure as a factor of mode of transport
  - Air quality along the route of travel as a function of space and time
  - Indoor air quality
- Ability to provide dynamic predictions of cleanest routes in real time.

SAFEST ROUTE

- There exists variation between multiple routes between the same two locations.
- Based on data collected during Diwali of 2019, we compare PM2.5 concentrations across the routes to identify the safest route
- Velachery Routes during Diwali 2019 (R):
  - 1 - Bypass road
  - 2 - A small detour through residential
  - 3 - Main road
  - 4 - Commercial + Residential route
- 27 Oct 2019- Diwali, more pollution estimated in residential areas.
- R2 is fairly better than R1.
- Pre-Diwali (26 Oct) estimate is significantly higher due to commercial activity and bursting crackers.



Relative percentage of PM2.5 concentrations across the 4 routes in Velachery over 6 days in October 2019



4 routes in Velachery area chose for study

STRATEGIES FOR MITIGATION AND ABATEMENT

- Develop actionable insights from the data
- Identification and classification of sources of pollution
- Suggest strategies for mitigation and abatement
- Study the effect of city planning initiatives on air quality.

SUMMARY

- The project proposes to provide hyper-local environmental information.
- Low cost mobile distributed sensor network is used to obtain high resolution ground level information.
- Satellite remote sensing data is used to augment sensor network.
- Theoretical models are used to obtain high resolution data over larger areas.
- Big data, machine learning and artificial intelligence is used to combine data from all sources to obtain high resolution, accurate and reliable air quality information.
- Preliminary results from multiple pilot projects validate the efficacy of the technology.
- Customized solutions for impact are developed

FUNDING SUPPORT

thsti
Translational Health Science and Technology Institute

Carbon Zero Challenge

RBC DSAI
ROBERT BOSCH CENTRE FOR DATA SCIENCE AND ARTIFICIAL INTELLIGENCE IIT MADRAS

CONTACT

Prof. Raghunathan Rengaswamy
MSB 150, Mechanical Sciences block
Department of Chemical Engineering
IIT Madras, India.
E-mail: raghur@iitm.ac.in

SENAI Lab:
MSB 147, Mechanical Sciences block
Department of Chemical Engineering
IIT Madras, India.

Website:
https://che.iitm.ac.in/~senai/