Improving Air Quality in 132 'Non Attainment' cities of India with Low-Cost Sensors & National Clean Air Policies

11 May 2022

ASIC

Air Sensors International Conference
Pasadena, California

Ronak Sutaria
Respirer Living Sciences
Mumbai, India

Ranking Indian Cities for Air Quality

India: Workers face health risks in world's 'most polluted' city

15 Apr 2022

Bhiwadi in Rajasthan state named world's worst city for air pollution but many workers unaware of risks and shun masks.

63 Indian Cities In 100 Most Polluted Places On Earth: Report

Delhi is the world's most polluted capital for the fourth consecutive year, with pollution rising almost 15 per cent over the previous year, says a report by IQAir

All India | Written by Chetan Bhattacharji, Edited by Debanish Achom | Updated: March 23, 2022 7:09 am IST

Bengaluru: BBMP to float tenders for installation of air pollution monitors

While civic officials did not divulge how many such monitors will be installed across the city, the World Health Organization (WHO) states that there should be one for every five square kilometres.

Written by **Aksheev Thakur** | Bengaluru |
May 6, 2022 12:59:55 pm

Source: IQAir Report 2021

Most Polluted Regional Cities

Rank	City	2021
1	Bhiwadi, India	106.2
2	Ghaziabad, India	102
3	Delhi, India	96.4
4	Jaunpur, India	95.3
5	Faisalabad, Pakistan	94.2
6	Noida, India	91.4
7	Bahawalpur, India	91
8	Peshawar,Pakistan	89.6
9	Bagpat,India	89.1
10	Hisar, India	89
11	Faridabad, India	88.9
12	Greater Noida, India	87.5
13	Rohtak, India	86.9
14	Lahore, Pakistan	86.5
15	Lucknow, India	86

Continuous Air Quality Monitoring Dashboard

atmos real-time air quality

Daily Trends | Air Quality Trends | Pollution Hotspots | Pollution Mix

Select State: All | Select City: All | Select Year: 2021 | Select Season: All

Pollution Hotspots - Seasonal Avg tab is for viewing Top 10 Polluted Locations in a state, city, year and season as per user selection. The data in Central Pollution Control Board (CPCB).
If the user has not selected any filter, cards on the right will show pollutant levels for all the states, cities, years and seasons.

Top 10 Polluted Locations

24 Hour Avg | Monthly

Locality	Avg PM 2.5 (ug/m3)
Chitragupta Nagar, Siwan - BSPCB	215
MIT-Daudpur Kothi, Muzaffarpur - BSPCB	206
Central Jail, Buxar - BSPCB	197
Darshan Nagar, Chhapra - BSPCB	192
Mariam Nagar, Purnia - BSPCB	172
New DM Office, Arrah - BSPCB	168
Mirchaibari, Katihar - BSPCB	164
SDM Office_Khagra, Kishanganj - BSPCB	159
Kareemganj, Gaya - BSPCB	157
Town Hall, Munger - BSPCB	156

Source: NCAP Tracker. Data Courtesy: CPCB Monitor

***NOTE:** In the below table, the green up arrow indicates that the readings taken for selected year(s) for selected city is more than the ideal number of readings and red down arrow conveys vice-versa.

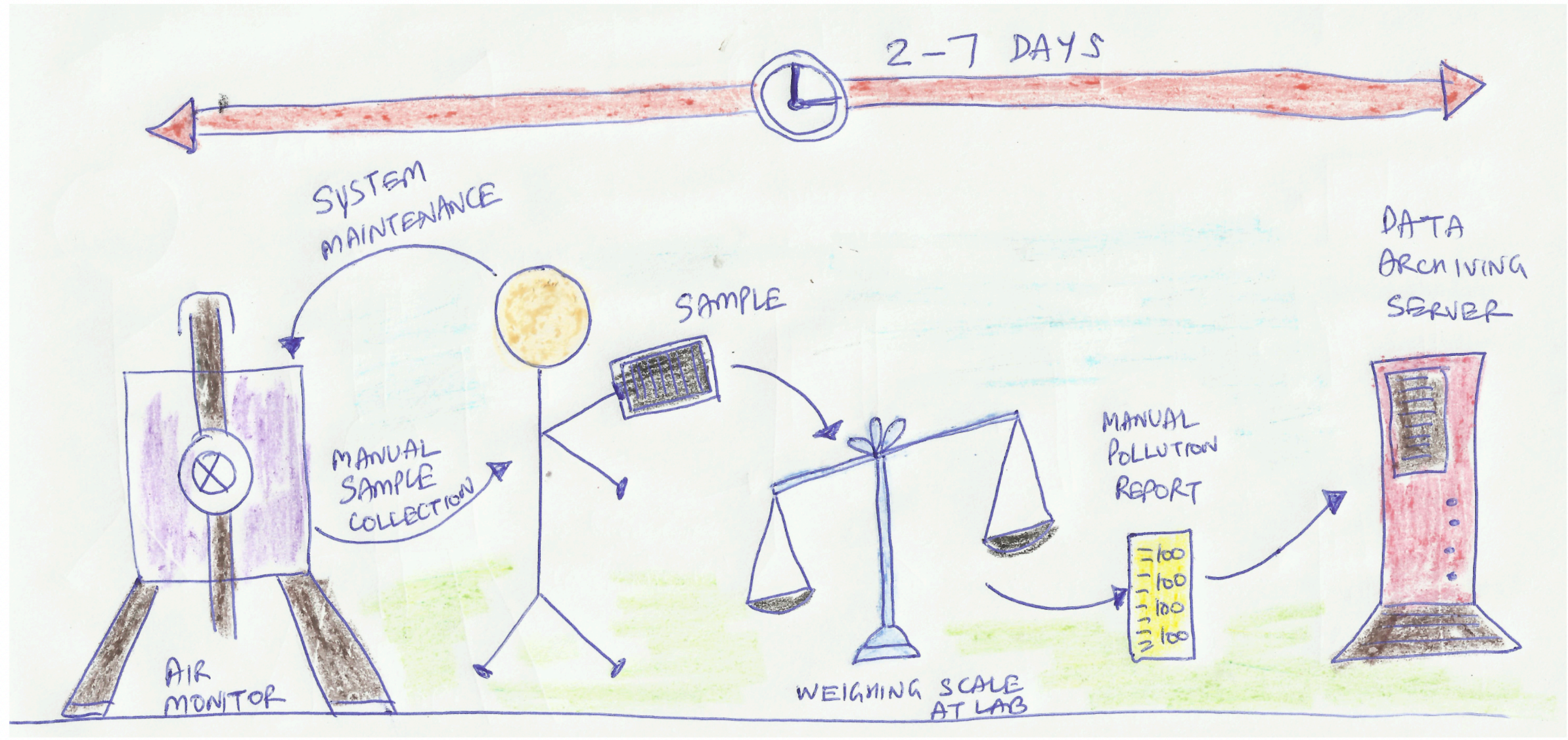
Percentage of No. of Readings taken more/less than Ideal No. of Readings

	State	City	Year	#Monitors	No. of Readings per Year	% Δ	Avg PM 10
1.	Uttar Pradesh	Ghaziabad	2017	2	122	-41.3%	281
2.	Uttarakhand	Dehradun	2017	3	135	-56.7%	248
3.	Uttar Pradesh	Lucknow	2017	8	509	-38.8%	246
4.	Uttar Pradesh	Varanasi	2017	5	362	-30.4%	244
5.	Delhi	Delhi	2017	9	840	-10.3%	240
6.	Jharkhand	Dhanbad	2017	3	78	-75.0%	238
7.	Uttar Pradesh	Kanpur	2017	8	654	-21.4%	225
8.	Punjab	Jalandhar	2017	4	285	-31.5%	223
9.	Uttar Pradesh	Firozabad	2017	3	184	-41.0%	220
10.	Uttar Pradesh	Moradabad	2017	2	172	-17.3%	217

India’s National Clean Air Program (NCAP)

Manual AQ Monitoring

India's flagship national policy "National Clean Air Programme (NCAP)" has identified 132 “Non-Attainment” cities in India based on Particulate Matter (PM10) data collected from the 'manual' monitors in 818 monitors from 352 cities of India.



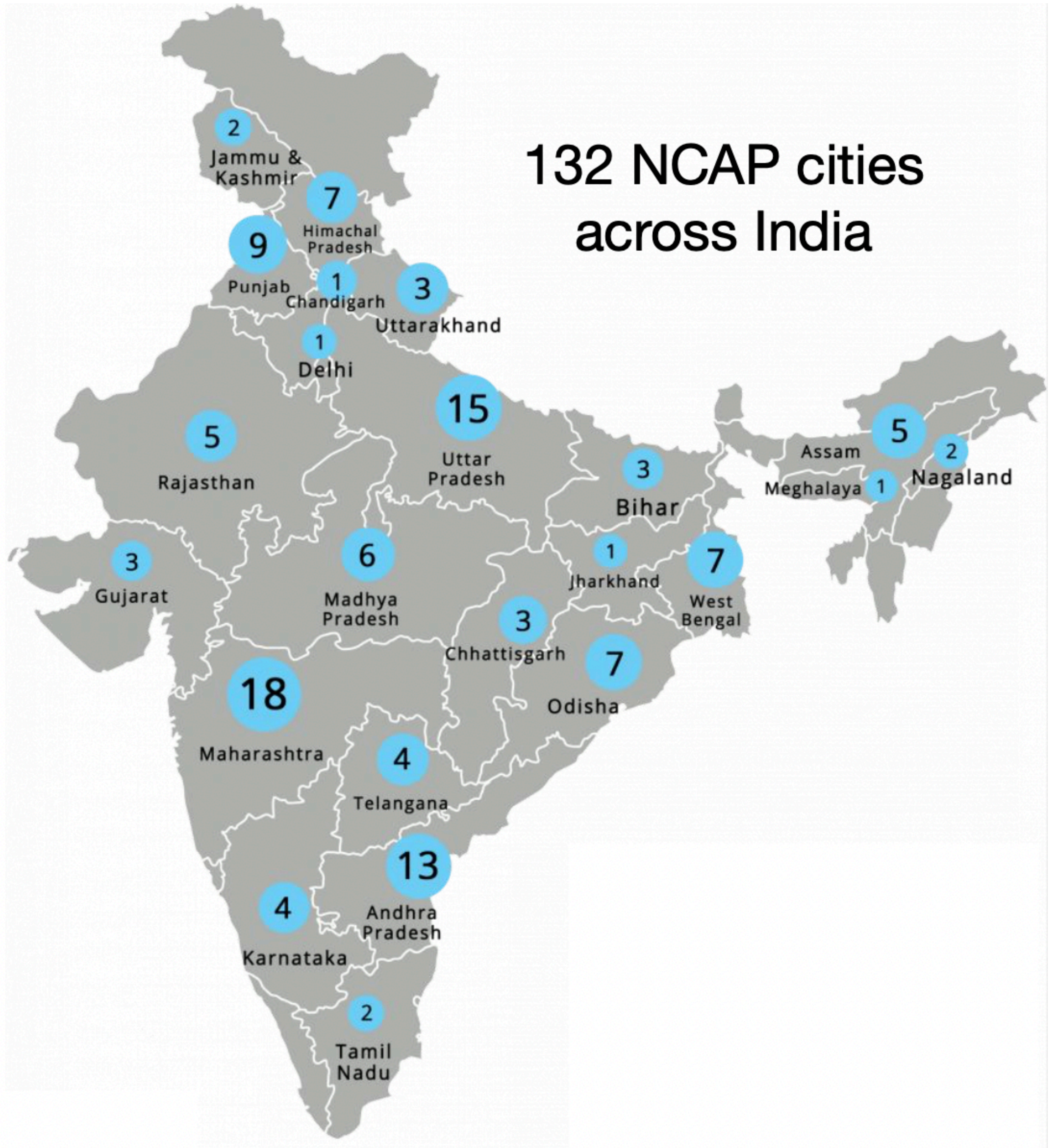
Thanks and Credit for Manual Monitoring Doodle to Urban Emission. Know More Here.

Continuous AQ Monitoring

Besides manual monitors, 349 continuous ambient AQ monitors (CAAQMS) across 180 cities of India provide ‘real-time’ continuous air quality data every 15 mins

NCAP Target

NCAP target is to reduce key air pollutants PM10 and PM2.5 (ultra-fine particulate matter) by 20-30% in 2024 taking the pollution levels in 2017 as the base year to improve upon.



startupindia

सत्यमेव जयते
Department of Industrial Policy and Promotion
Ministry of Commerce and Industry
Government of India

DIPP Certificate: 5311/IMB

NATIONAL STARTUP AWARDS 2020
By #startupindia

National Startup Awards 2020 finalist in Internet of Things category

NASSCOM® Emerge 50 Awards 2021

Respirer Living Sciences is one of India's leading ***IoT and Big Data enabled Climate Sciences and Environment-Tech startup working at the intersection of Air Quality and Climate Change*** *building strategic monitoring technologies & solutions - for Government pollution regulators, Aerosol scientists, Industrial emissions monitoring, Sustainability researchers, Communities and Citizens.*

Respirer has been an industry partner to a 3-year Federal Government supported Indo-US scientific project led by IIT Kanpur & Duke University to develop technology for the Rs. 1350 Crore Particulate Matter (PM) monitoring market in India.

Our journey

2015	2016	2017-2018	2019-2020	2021
LAUNCH	**SCIENTIFIC VALIDATION**	**INNOVATIONS**	**GROWTH**	**LARGE DEPLOYMENTS & NEW PRODUCT LINES**
Developed and launched prototype as part of a Data Journalism Non-Profit initiative - #Breathe.	Research partnerships with **Shakti Foundation, IITK, Duke University**. Azure Research Grant from **Microsoft Research** Data dissemination and awareness building on AQ.	**Gas sensor device development (NO_x, O_3, CO)** as industry partner for **DST-Intel** funded project. Collaboration with **Microsoft Research** to develop **mobile AQ monitoring dashboards.**	Deployments across **26 cities in India** and **global deployments** to the **US, Sweden, South Africa** and **South Asia.** **Collaboration with** Ericsson to develop **Patent Pending Technology** for **low-powered NBIoT** realtime AQ monitoring.	Field evaluation study led by **MPCB & IIT Kanpur.** Data analytics for **NCAP** tracker with **Climate Trends.** MoU with **MOHFW** to evaluate key objectives of **PMUY initiative.** Built **O2 Analyzers,** confirmed project with **MCCAI; Indoor AQ** with **CEPT.**

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Respirer Living Sciences

Innovation for affordable and accurate air quality data

Engineering scope

To build, calibrate and deploy low-cost IoT-enabled air quality monitoring devices, integrated with $PM_{2.5}$, PM_{10}, NO_x and O_3 pollution sensors using wireless sensor network technologies and advanced machine learnings & AI algorithms to provide real-time access to accurate city-level air quality data.

Patent Pending Technology for "Low-Power Dense NBIoT Realtime Ambient Air Quality Monitoring Network"
Co-inventors (Patent Application No: 202011022321, Filed 28 May, 2020):

- Dr SN Tripathi, Expert Committee Member, National Clean Air Programme and Head, Dept. of Civil Engg, IIT Kanpur
- **Ronak Sutaria**, Founder, Respirer Living Sciences Pvt Ltd
- Dr Abhay Karandikar, Director, IIT Kanpur and Member, TRAI

Technical specifications

Air Quality Sensor Integrated

- Digital Laser Scattering Sensor for $PM_{0.3}$ Count, $PM_{2.5}$ and PM_{10} concentrations
- Electro-Chemical Gas Sensors - NO_x and O_3

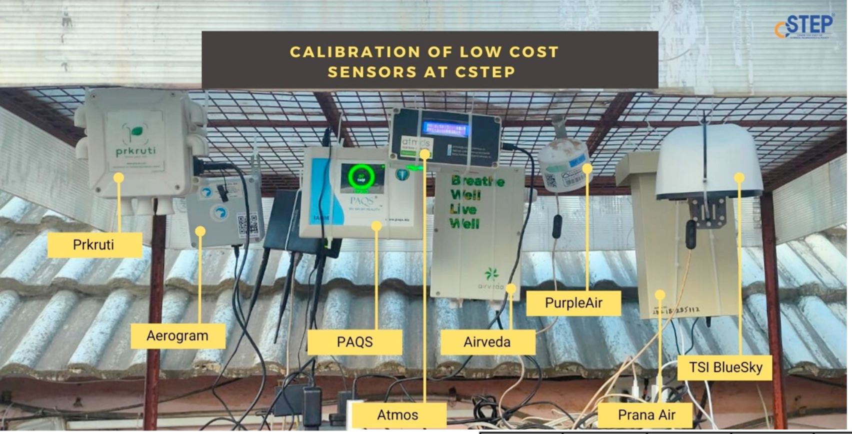
IoT Wireless Sensor Network Communications

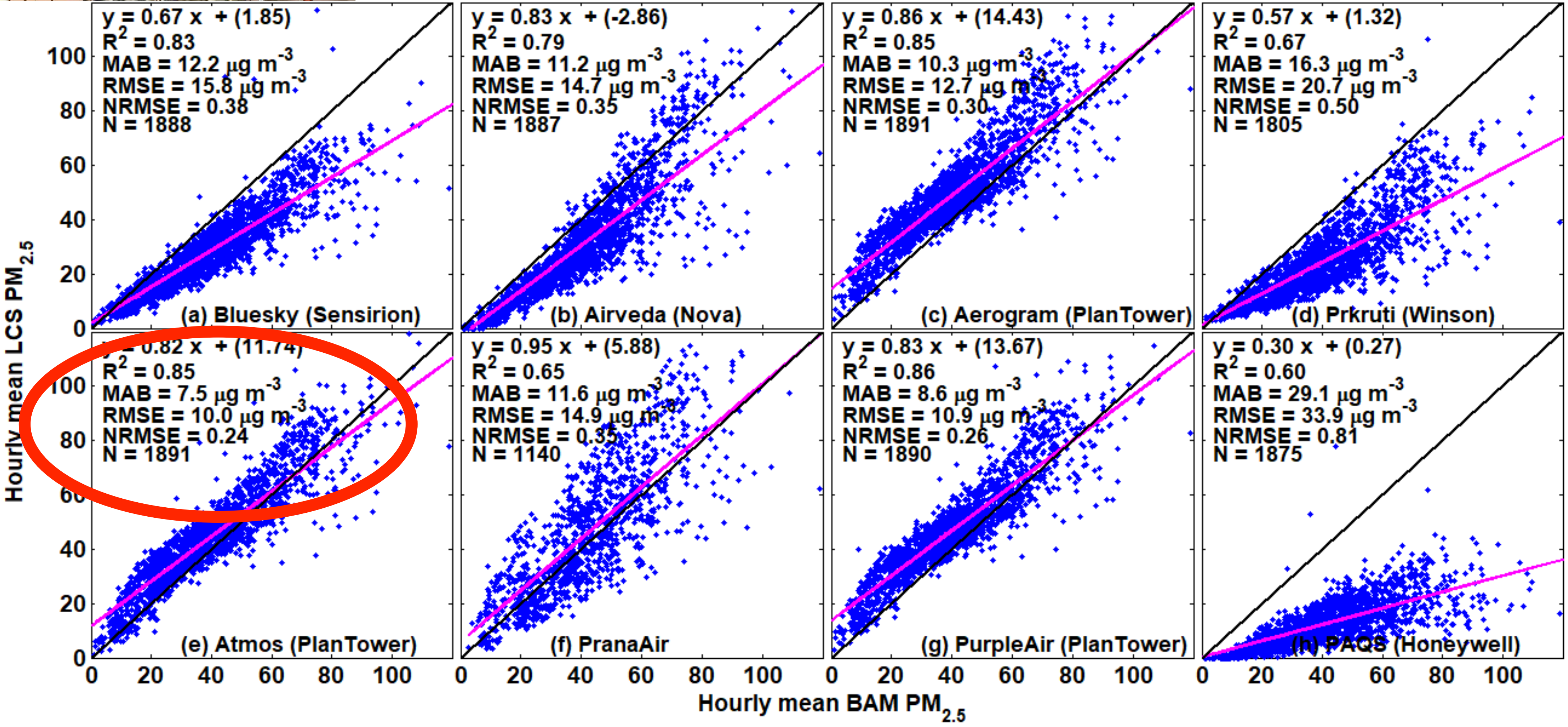
- NBIoT (Narrow Band IoT) - Patent Filed
- 6LoWPAN (IPv6 Low-Power WAN)
- Cellular 2G, 802.11 WiFi

Big Data APIs/Machine Learning Algorithms

- Fast Time-Series/GIS Spatio Temporal Database
- Linear Regression/KNN Machine Learning models implemented

LCS $PM_{2.5}$ Comparison





Evaluation of Air Quality Low-Cost Sensors (LCS) at foremost Air Quality Research Institute in South Africa (NWU)

Atmos (graphs 22 & 23). Atmos Correlation R^2 is 0.94 and 0.96 with intercept of 0.9 and 1

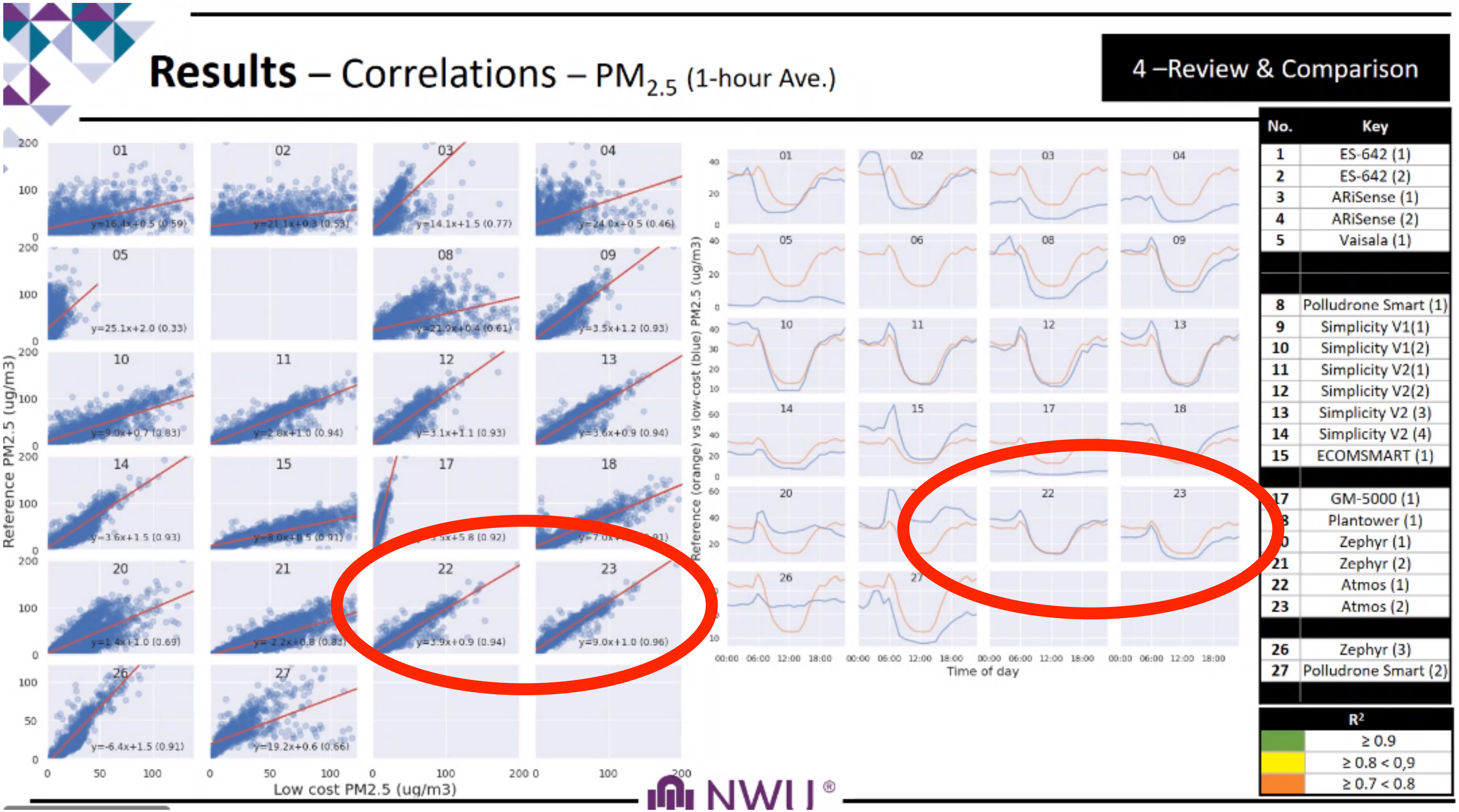
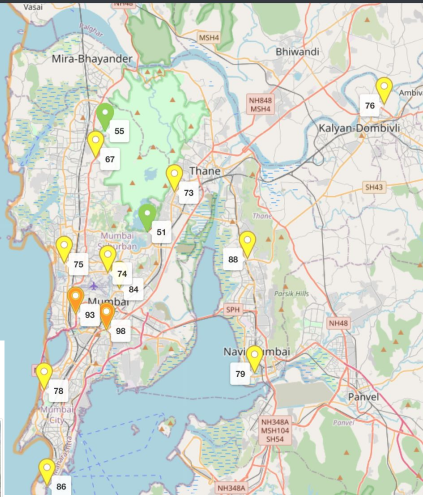


Chart Map Table User Download



Mumbai gets sensor-based monitors as low cost air monitoring feasibility study begins

The sensors will monitor particulate matter (PM10, PM2.5), ozone, oxides of nitrogen (NOx), and sulphur oxides (SOx).

INDIA Updated: Nov 01, 2020, 09:53 IST

Badri Chatterjee
Hindustan Times, Mumbai

Low-cost monitoring sensors measure ambient air quality based on light scattering technology using much smaller equipment as compared to existing air quality measuring technology.(HT PHOTO)

Maharashtra Pollution Control Board
महाराष्ट्र प्रदूषण नियंत्रण मंडळ

Sensor Technology Assessment Project at MPCB

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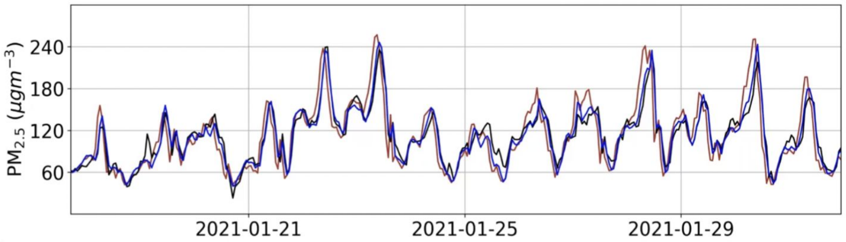
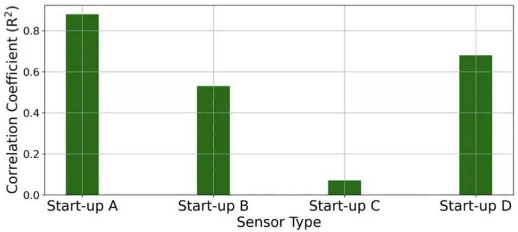
Go Back



Average Calibrated R^2 of the different sensors

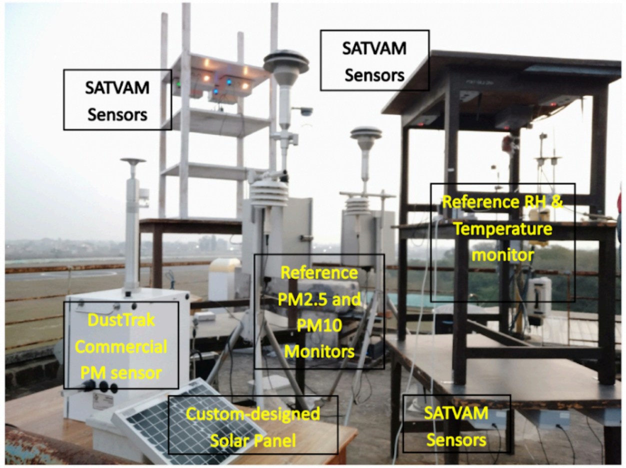


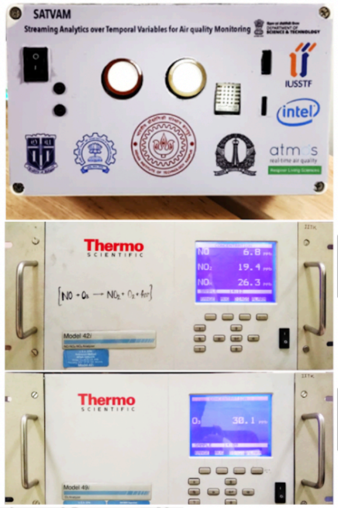
Results from study published by IIT Kanpur & MPCB.
A - Respirer Living Sciences;
B - Airveda;
C - Oizom;
D - PAQS

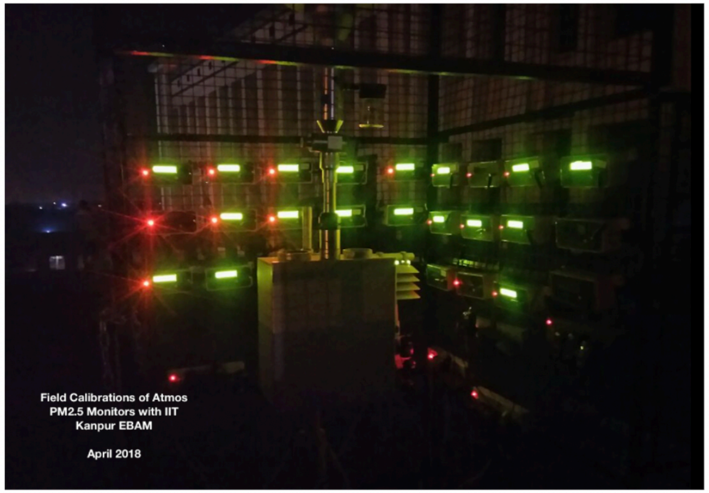
Parameters	Borivali	Kalyan	Kandivali	Kurla	Mahape	Mulund	Nerul	Powai	Vileparle
min	3	1	5	4	5	4	6	5	5
median	62	88	79	81	91	68	91	67	76
max	297	520	238	985	674	208	288	201	263
min	6	11	7	1	8	8	7	5	4
median	67	92	81	84	94	74	81	60	74
max	247	361	273	577	668	243	292	194	270

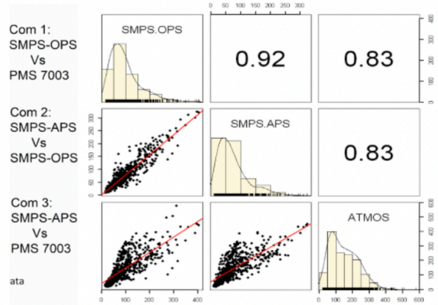
Technical benchmarking with regulatory grade AQ monitors

SATVAM - Streaming Analytics over Temporal Variables for Air quality Monitoring. Industry partner to IITK.

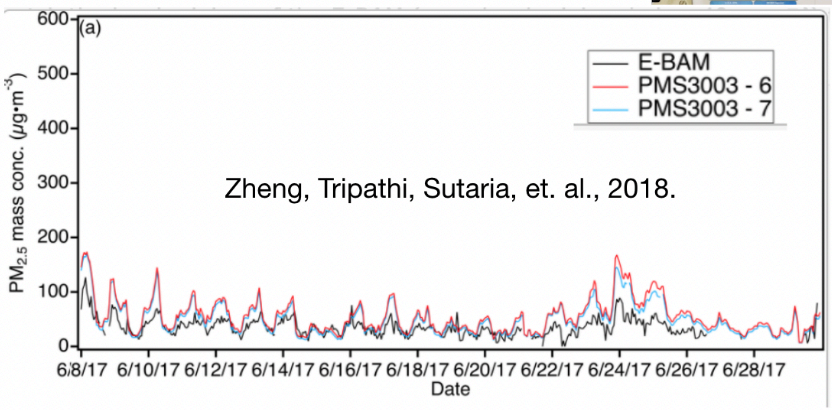




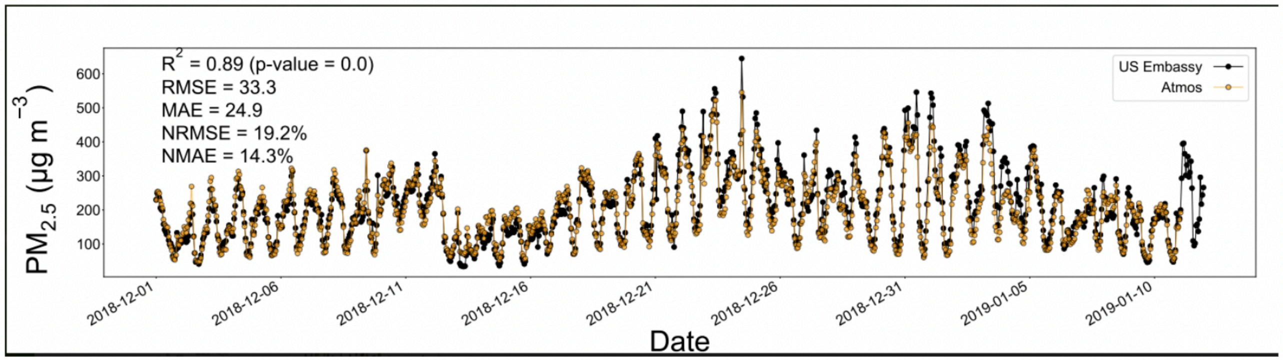




Sahu, Tripathi, Sutaria, et. al., 2020.



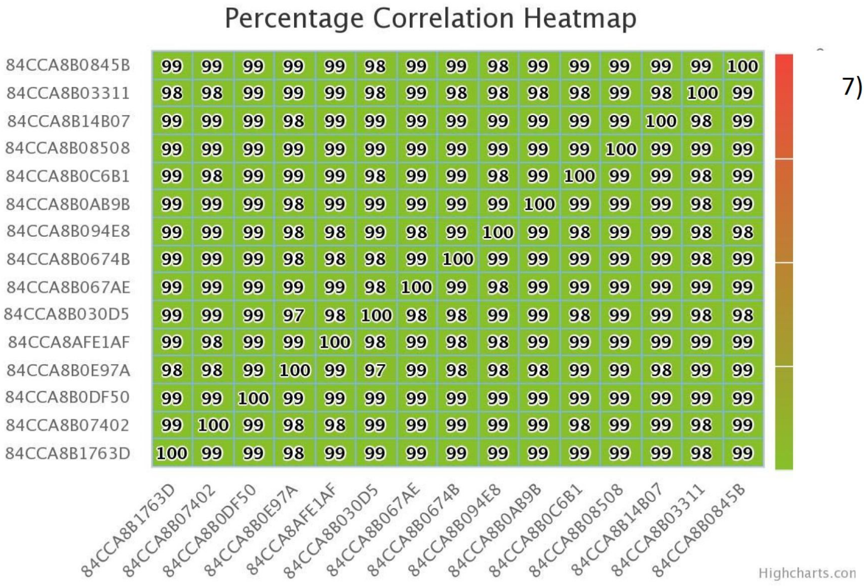
Zheng, Tripathi, Sutaria, et. al., 2018.



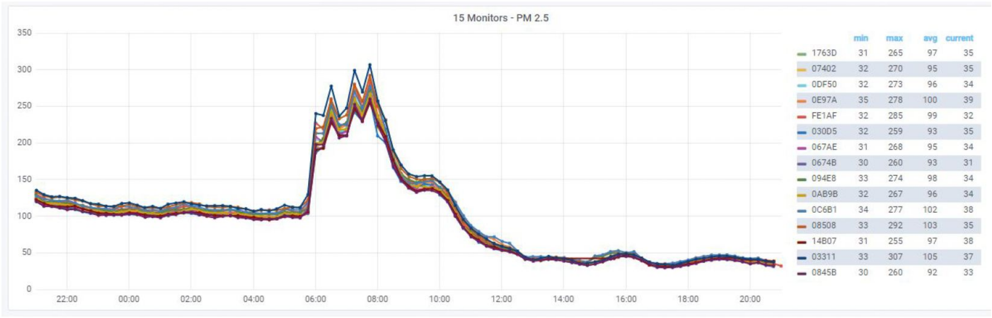
Blind-evaluation done by Duke University with US Embassy, New Delhi BAM & Atmos

Inter-Device Correlation Performance

Extremely reliable for relative hotspot tracking / monitoring, urban planning, health communications



7) Timeline graph with 15 minutes average of PM 2.5 values:



Link to graph: Link to Graph

IoT integration across data sensing, access, analytics and democratisation

DATA SENSING
Sensor-based NOx, O3 and PM monitors

IoT technologies implemented - 6LoWPAN, GPRS, NBIoT, WiFi, Bluetooth

DATA ACCESS
Streaming data APIs

Real-time data access via standardized streaming APIs for air quality data

New APIs have been developed which provide real-time data access to the streaming spatio-temporal data from the SATVAM devices

API Request/Response format is as follows:

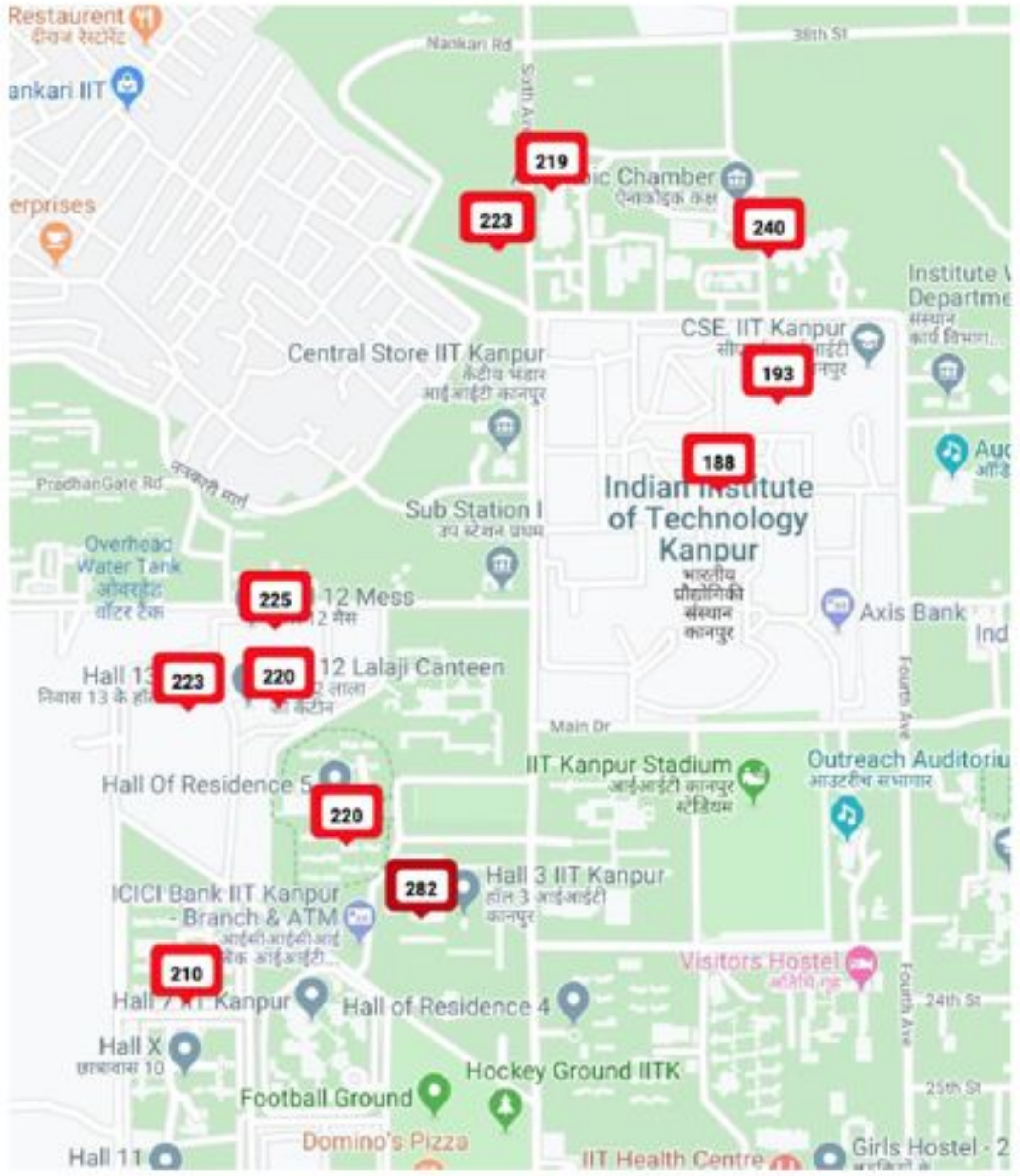
```
Input:
/mobilepm/imei/<value>/start/<yyyymmddhhmm>/end/<yyyymmddhhmm>/type/<xml or
json or csv>/ts/<mm or hh or dd>/avg/<0,1-24>/ApiKey/<ApiAuth>

Output: Raw data for following variables:
timestamp,
imei, pm1cnc=10&pm1cnt=20&pm2.5cnc=30&pm2.5cnt=40&pm10cnc=50&pm10cnt=60&pm0.3
cnt-70&pm0.5cnt-80&pm5cnt-90&no2op1-100&no2op2-200&o3op1-300&o3op2-400&temp-2
5&humd-50&pres-500&lat-19.12312&lon-77.2323

ts (time-slice): mm-minutes; hh-hours; dd-days // time-slice for avg
avg:
if value is 0 = then it is raw data
if value is 1,2,3,.. - avg period for time-unit given in above time-slice
```

Figure: Streaming air quality temporal data access via JSON APIs

Other data formats supported by the API are XML, KML and CSV. New GIS enabled features are being added to the Streaming data APIs which will allow more advanced geo-spatial queries to be run on the data – for e.g. to return all air quality data from devices within a 5 kms radius of a location.

APIs implemented with big data technologies - Apache Cassandra, KairosDB, Java APIs

DATA ANALYTICS
Fixed site AQ visualisation dashboards



Map-based visualisations

DATA DEMOCRATISATION
IoT Integrations with Media Platforms

AQ IoT integrations on citizen-friendly platforms

Hybrid Air Quality Data Applications

Tamil Nadu Pollution Control Board
தமிழ்நாடு மாசு கட்டுப்பாடு வாரியம்

EETINGS ⌄ INFORMATION ⌄ GALLERY AWARDS CONTACT US REAL TIME MONITORING ⌄ TNPCB & YOU ONLINE LOGINS ⌄

17 Category of Highly Polluting Industries

The Ministry of Environment and Forests, Government of India have classified the following 17 category of Industries as highly polluting industries which are to be closely monitored.

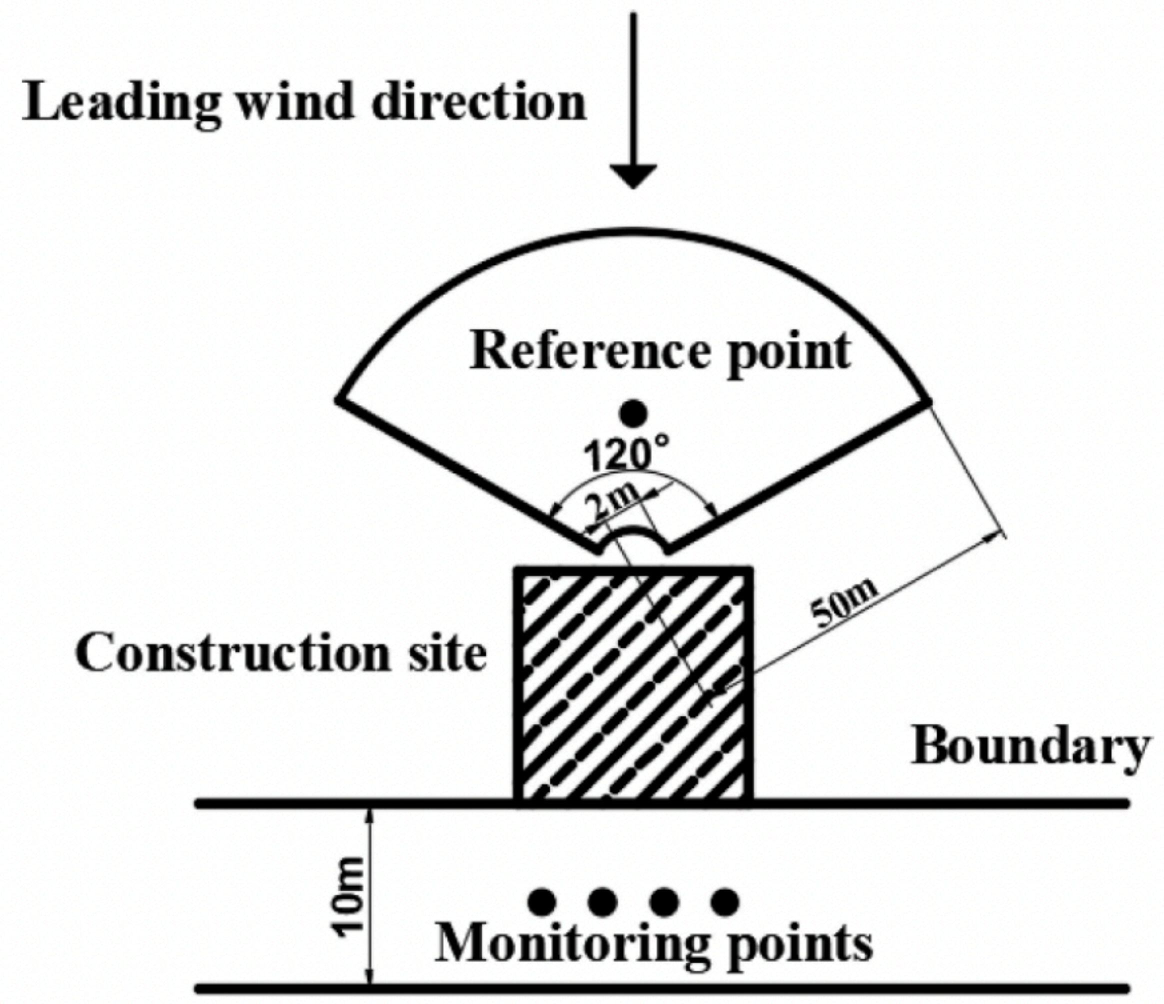
S.No	Category	View Details	S.No	Category	View Details
1	Sugar	Click Here	10	Caustic Soda	Click Here
2	Cement	Click Here	11	Pharmaceuticals	Click Here
3	Distillery	Click Here	12	Dye and Dye Stuff	Click Here
4	Petrochemical	Click Here	13	Refinery	Click Here
5	Pulp & Paper	Clich Here	14	Copper Smelter	Clich Here
6	Fertilizer	Click Here	15	Iron & Steel	Click Here
7	Tannery	Click Here	16	Zinc Smelter	Nil
8	Pesticides	Click Here	17	Aluminium	Nil
9	Thermal Power Station	Click Here			

Maharashtra is the most industrialized state of India with over 1,00,000 industries:

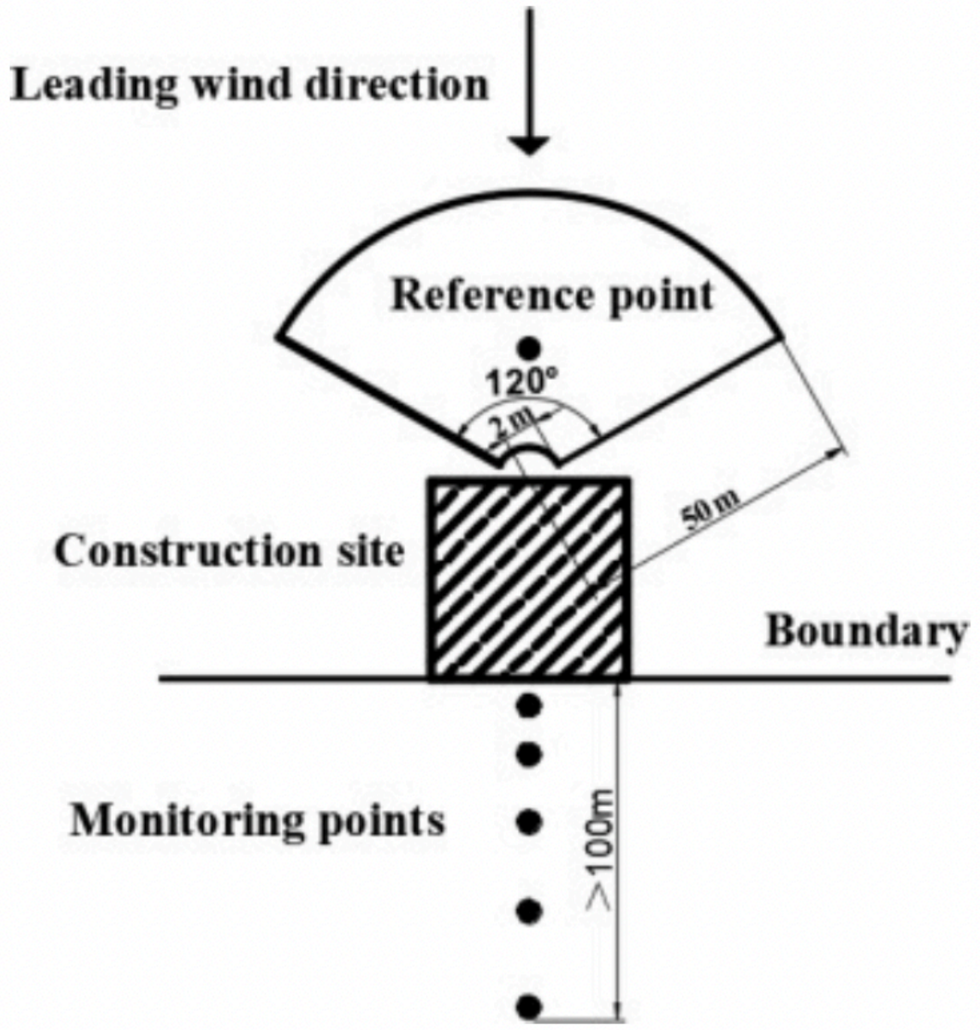
- **23,500** high pollution potential
- **25,500** medium pollution potential
- **51,000** low pollution potential

Official MPCB data

AQ Monitoring Locations Fenceline



AQ Monitoring Locations Downwind



(a) Air quality monitoring is not necessarily limited to regulatory purpose but have its use for planning, neighborhood monitoring, hot spot identification etc, and therefore relying on CAQMS only leads to high cost monitoring.

(b) AQMS is regular requirements, and enabling provision shall be made to promote Atmabharat program and also to provide opportunity to the scientific studies being undertaken by leading Indian institutes in this domain

(c) A hybrid system for AQM is viable solution and shall be worked out.

(d) Optimization of present CAAQMS units and rationalization of its requirement

(e) Protocol to be developed for use of LCS and corresponding hybrid AQMS

Scaling Up Via Construction Zone Monitoring Services

Air pollution classified as carcinogenic to humans (Group 1)

International Agency for Research on Cancer

World Health Organization

PRESS RELEASE
N° 221

17 October 2013

IARC: Outdoor air pollution a leading environmental cause of cancer deaths

Lyon/Geneva, 17 October 2013 – The specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), announced today that it has classified outdoor air pollution as *carcinogenic to humans* (Group 1).[1]

In India, over 1.2 to 1.6 million deaths are attributed to air pollution. Indoor air pollution (from solid cooking fuels in chulahs) accounted close to 1 million deaths.

20 million people have reduced quality of life due to air pollution.

Residents gasp for air as Metro work turns Sabarmati, Motera into dust bowls

By Megha Bhatt, Ahmedabad Mirror | Updated: May 3, 2019, 06:00 IST

A- A+

(PIC: ANCELA JAMINDAR)

Sabarmati and Motera areas of the city have registered a significant rise in number of people suffering from respiratory ailments due to construction of Metro rail project. The excavation work along a three-kilometre stretch, from Sabarmati toll naka to Motera gam, has damaged the road while the extracted sand has not been removed and dumped by the roadside.

Mumbai grows, pollution soars: Construction dust ups risk of stroke, shows data

Level of dangerous particles in the air you breathe has risen drastically in 3 years; PM 10 levels in city 2.5 times the annual safe limit, shows environment ministry study

MUMBAI Updated: Jul 30, 2018 14:15 IST

Badri Chatterjee
Hindustan Times

People walk through dust created by roadwork in Mumbai. (Pratik Chorge/HT Photo)

Delhi's deadly dust: how construction sites are choking the city

▲ Around 70% of the buildings that will exist in India's cities by 2030 are yet to be built. Photograph: Money Sharma/AFP/Getty Images

THIS STORY IS FROM JANUARY 9, 2019

Construction dust, open waste dumping top polluting activities

Ritam Halder | TNN | Updated: Jan 9, 2019, 5:14 IST

A- A+

NEW DELHI: In December, garbage burning, violations of dust norms during construction and demolition activities and open dumping of waste topped the polluting activities in the city, revealed the ground visits of Central Pollution Control Board teams across Delhi and complaints received on its Sameer app.

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Scaling Up Via Geofencing Services

- Geofencing Industrial Clusters, Townships, State Boundaries, Townships
- Requires a combination of ground-based low-energy low-cost sensors and remote sensing (ISRO / NASA / Other Satellites)
- A series of ground-based sensors (particulate, gases, and toxics – Methane, Hydrogen Sulfide) are placed upwind, downwind, and cross-wind based on meteorology and air dispersion modeling
- Hyperlocal monitoring leads to better decision-making on process upsets during normal operations and flaring which lead to air quality exceedances
- Improved monitoring for worker safety, health, and compliance with environmental permit and ambient air quality standards

GeoFencing Industrial Clusters

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real-time air quality
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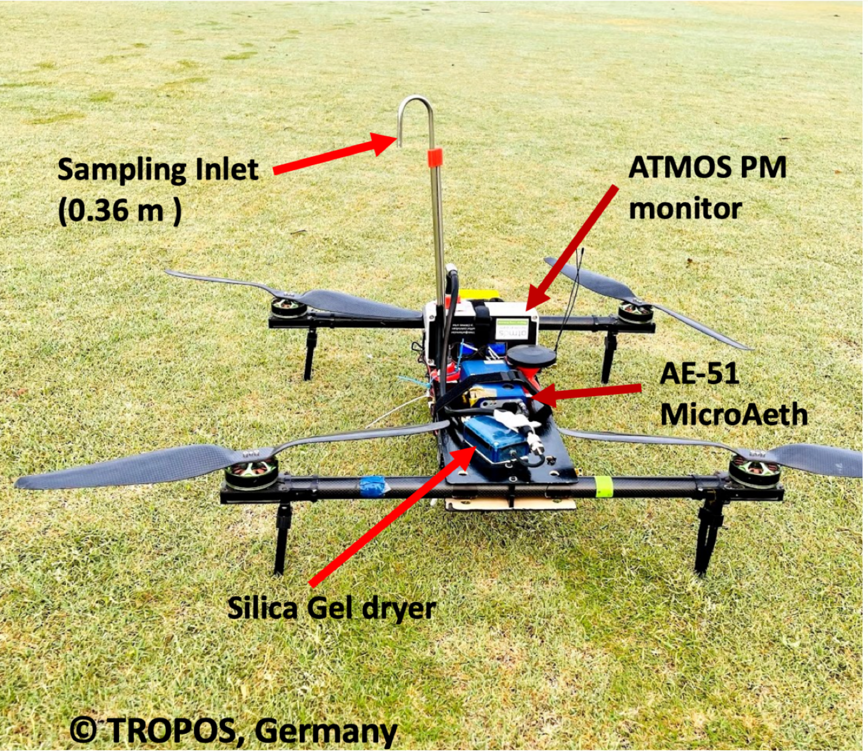
Global & India – Market Size of Air Quality Sensor Technology

PM Monitoring Solutions	End-to-end Monitoring Solutions	Cost of Govt AQ Monitoring in India
Expected to reach **USD 2.5 Billion**[1] **(INR 18,223 Crores) by 2025**.	Expected **USD 6.5 Billion** by 2025.	Each Govt AQ monitoring site costs the Govt. Rs. 1.5 Crore (US$200,000) per site. As of Oct 2021, 312 sites running having costed > Rs. 450 Crores
India and China expected to dominate growth in Asia.	Continuous monitoring largest revenue share (includes industrial emissions).	Each city in India requires ~ 30 to 100 AQ sites. Budget per city is ~ 50 Crores. Need across India is for 4000 AQ monitoring sites - at Rs. 6,000 Crores
Indian market size is said to be **INR 1,350 Crores**.	India estimated at over **INR 4,000 Crores**.	Cost of AQ sensor technology is ~ Rs. 50,000 per pollutant and 2.5 Lakhs for key pollutants. Entire city can be monitored in Rs. 2.5 Crore.

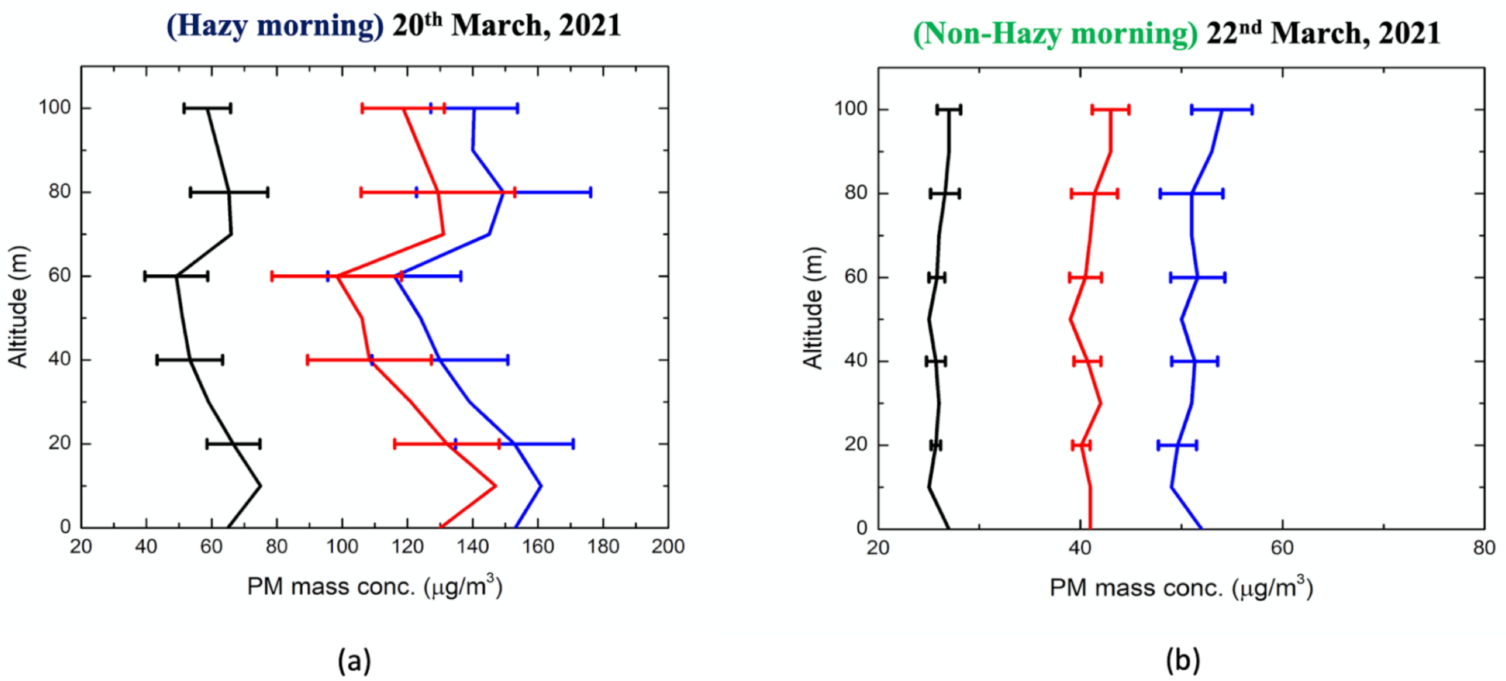
1 Global PM sensor market: https://www.industryarc.com/Report/19233/particulate-matter-sensor-market.html
2 Global gas sensor market: https://www.fnfresearch.com/gas-sensor-market

Applications of UAV/Drones for AQ Plume Tracking



- **ATMOS PM Monitor for measurement of PM_1, $PM_{2.5}$ and PM_{10}**
- **AE-51 for eBC measurement**
- **Temperature and humidity sensors (HYT 939)**

Vertical profiles of PM mass concentration (Hazy and Non Hazy Morning)



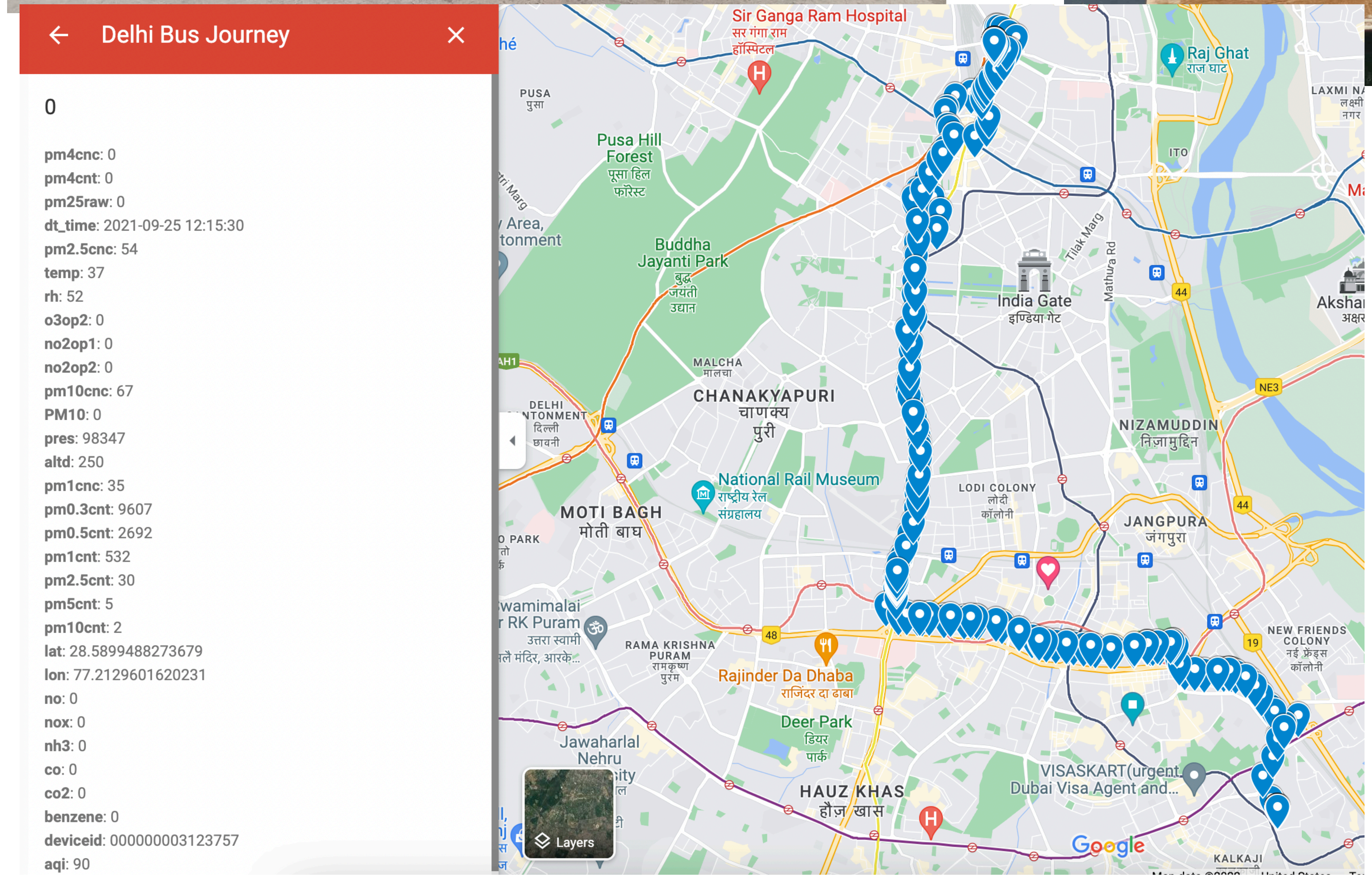
Vertical variation in PM mass concentration. The measured PM mass conc. in μg/m^3 with standard deviations at 20, 40, 60, 80 and 100 m respectively. The black, blue and red lines denotes PM_1, $PM_{2.5}$ and PM_{10} mass concentration measured in μg/m^3. Figure (a) The measured profiles are on 20th March, 2021 (Hazy morning) (b) The measured profiles are on 22nd March, 2021 (Non-Hazy morning)

Ajit Ahlawat et al., 2021 , In preparation

2020 recorded the highest number of Crop Residue Burning (CRB) fires (~70,000) when compared to last three years farm fires (VIIRS data from FIRMS). UAV Swarms can provide highly granular 3-dimensional spatial & temporal $PM_{2.5}$ levels at varying atmospheric layers which will help forecasting and warning systems for the city of Delhi.

Mobile AQ Monitoring on Public Transit Buses

- Department of Science & Technology supported project with IIIT Delhi to install High-Precision GPS-enabled Mobile AQ monitors on Delhi Transport Corp buses
- AQ monitors enabled with Solar Panel integration for completely autonomous power supply
- Interpolation of AQ data across the city to find cleanest routes for city commuters using non-air conditioned public transit services



SATVAM

Streaming Analytics over Temporal Variables for Air quality Monitoring

Air Quality Sensors

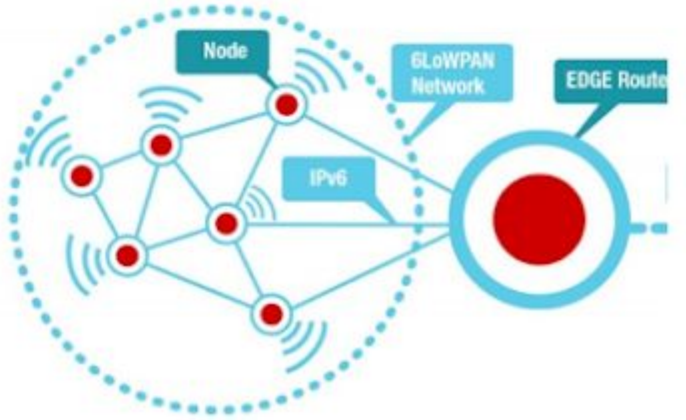
2G 2ND GENERATION wireless network | **3G** 3RD GENERATION wireless network | **4G** 4TH GENERATION wireless network

Cellular M2M / IoT Wireless

NB-IoT

Wi Fi

802.11ac

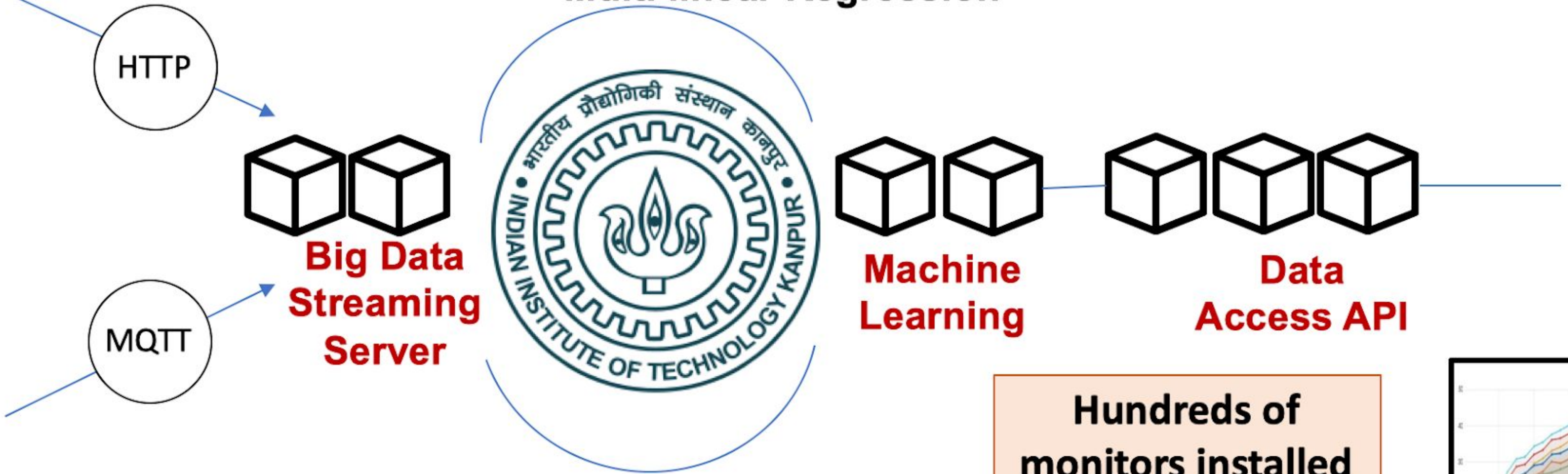


6LoWPAN
IPv6 over Low Power Network

Particulate Matter ($PM_{2.5}$, PM_{10}) Calibration

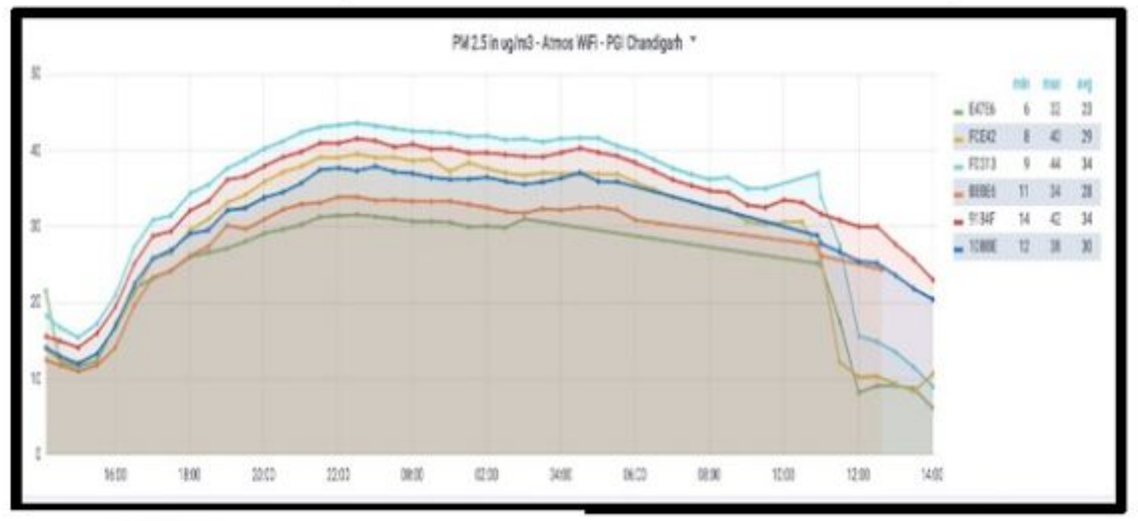
Linear Regression

Multi linear Regression



Ozone, NO2 Calibration
KNN (D),
Linear Mixture Model

Hundreds of monitors installed across 20+ cities



Department of Science and Technology
Ministry of Science and Technology
Government of India

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INDIAN INSTITUTE OF SCIENCE
भारतीय विज्ञान संस्थान

atmos
real-time air quality
Respirer Living Sciences

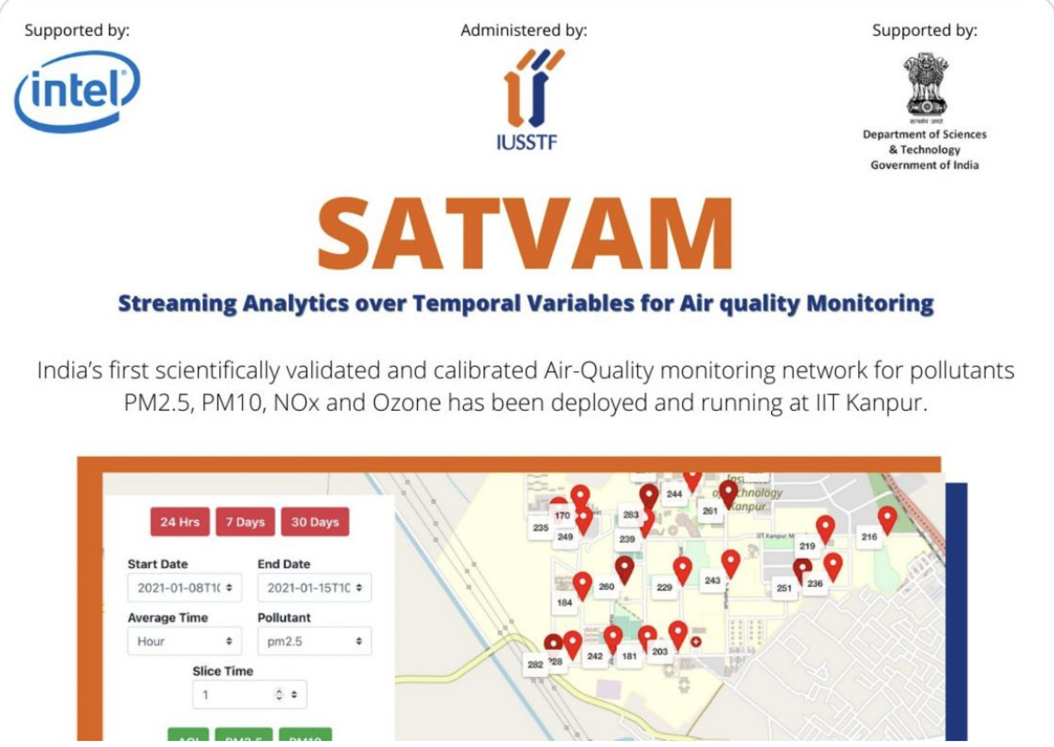
Who is talking about us? - Awards & Recognition

atmos real-time air quality
Respirer Living Sciences

Collaborative project with IITK, IITB, IISc and Duke with Respirer as Industry Partner

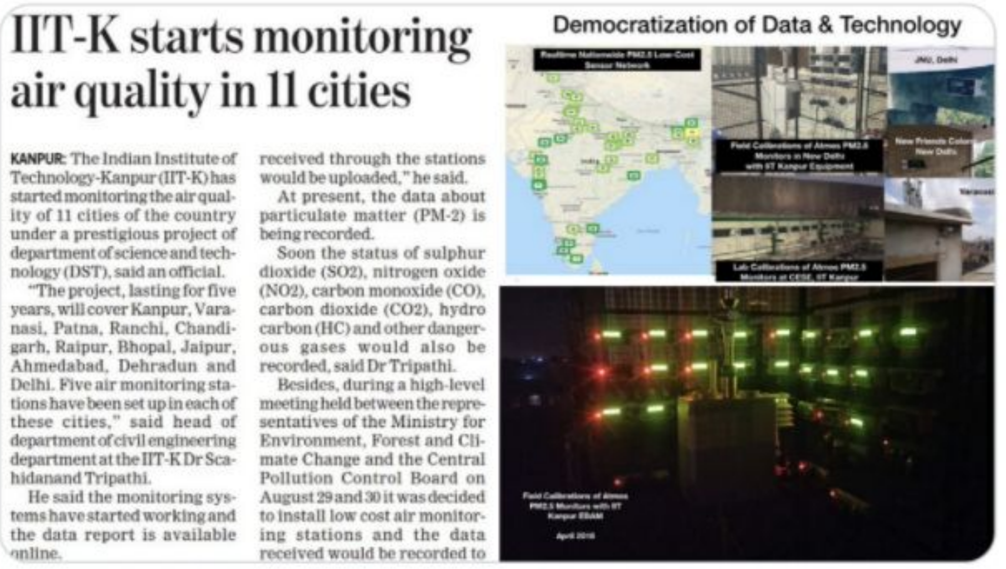
IUSSTF
@INDOUSSTF

India's first scientifically validated and calibrated air quality monitoring network is now live at @IITKanpur. 'SATVAM' can monitor pollutants like PM2.5, PM10 and Ozone. Supported by @IndiaDST, @IntelIndia and @INDOUSSTF; with @iitbombay, Duke University and @urbansciencesIN.



Abhay Karandikar @karandi65 · Sep 7, 2018

The team at Centre for Environmental Science & Engineering @IITKanpur in collaboration with social enterprise @urbansciencesIN & support from @ShaktiFdn has calibrated & deployed the Atmos - Realtime Low-Cost #AirQuality Monitoring network in 10 cities of #India .@IndiaDST



IIT-K starts monitoring air quality in 11 cities

KANPUR: The Indian Institute of Technology-Kanpur (IIT-K) has started monitoring the air quality of 11 cities of the country under a prestigious project of department of science and technology (DST), said an official.

"The project, lasting for five years, will cover Kanpur, Varanasi, Patna, Ranchi, Chandigarh, Raipur, Bhopal, Jaipur, Ahmedabad, Dehradun and Delhi. Five air monitoring stations have been set up in each of these cities," said head of department of civil engineering department at the IIT-K Dr Scahidanand Tripathi.

He said the monitoring systems have started working and the data report is available online.

received through the stations would be uploaded," he said.

At present, the data about particulate matter (PM-2) is being recorded.

Soon the status of sulphur dioxide (SO2), nitrogen oxide (NO2), carbon monoxide (CO), carbon dioxide (CO2), hydro carbon (HC) and other dangerous gases would also be recorded, said Dr Tripathi.

Besides, during a high-level meeting held between the representatives of the Ministry for Environment, Forest and Climate Change and the Central Pollution Control Board on August 29 and 30 it was decided to install low cost air monitoring stations and the data received would be recorded to

Director, IIT Kanpur on collaborative project with Shakti Foundation

NDTV
@ndtv

Call to ban firecrackers across country, Supreme Court decision today ndtv.com/india-news/cal...

#firecrackers #AirPollution #Pollution

Clear #AirPollution temporal trend seen in multiple locations of #Delhi. As part of #GRAP need to enable better mandatory timings when children are forced to be outdoors. Schools should start late. @rsutaria in conversation with @divyawadhwa on @ndtv. @CBhattacharji @NavrozDubash

NDTV Prime-time coverage of Atmos Data

Ericsson India @EricssonIndia · Dec 18, 2019

Partnering with @IITKanpur & @airtelindia, we showcased our initiative to improve **air quality** in #Delhi at #IMC2019. Know how we are using the power of Nb-IoT, to provide real time **air quality** data and drive awareness. #EricssonAtIMC @exploreIMC #DelhiPollution

Ericsson India talking about Respirer/Atmos

Microsoft
15,337,591 followers
8mo •

India tops the list of the most polluted cities in the world but there's not enough awareness outside big cities. Here's how Respirer Living Sciences' Ronak Sutaria is using #PowerBI to provide air quality data across 122 cities as part of MSR India's SCAI program. http://msft.it/6042VBrDn

Democratizing air pollution data so India can clear its cities of choking smog - Microsoft Stories India

news.microsoft.com • 8 min read

Microsoft (Global) with 15M followers talking about Respirer/Atmos and its founder

HT Hindustan Times

Mumbai gets sensor-based monitors as low cost air monitoring feasibility study begins

The sensors will monitor particulate matter (PM10, PM2.5), ozone, oxides of nitrogen (NOx), and sulphur oxides (SOx).

Hindustan Times, Mumbai | By Badri Chatterjee
PUBLISHED ON NOV 01, 2020 09:53 AM IST

Low-cost monitoring sensors measure ambient air quality based on light scattering technology using much smaller equipment as compared to existing air quality measuring technology.(HT PHOTO)

Coverage in HT on project with MPCB, Mumbai

National Startup Awards 2020 finalist in the Internet of Things/Industry 4.0 category
https://www.startupindia.gov.in/nsa/

Our industry reach

We are a core member of the CII-ITC Centre of Excellence for Sustainable Development's initiative titled "India CEO Forum for Clean Air".

The forum brings together leaders across high-emissions industries to collaborate on solving the problem.

Airshed Management

Clean Air Better Life propagates the scientific evidence for implementation of actionable and cost-effective solutions in participatory manner with local communities and stakeholders to improve air quality.

CII partnered with NITI Aayog in 2017 to create four multi-stakeholder Task Forces to design source-specific action plans for severely polluted Delhi NCR based on the latest scientific evidence and consultation with stakeholders across common airshed.

In 2020, we started working in one of India's fast developing logistic and business hub, Indore Metropolitan Region, to demonstrate airshed management and planning approach in partnership with the Madhya Pradesh Pollution Control Board, Smart City Indore, California Air Resources Board and Indian Institute of Technology (Delhi), Lung Care Foundation and Respirer Living Sciences. The objective is to develop a robust framework for data-driven approach on air quality management across rapidly developing Indore Metropolitan Region.

O_2 Analyzer & Resource Analytics

atmos
real-time air quality
Respirer Living Sciences

OXYMOS PORTABLE HAND-HELD ANALYZER

- O_2 concentration / purity sensing
- Flow rate and air temperature tracking
- Geo-tagged and, time-stamped 02 data
- Data transmitted in real time to cloud server, stored on SD card, displayed on LCD screen on device
- Device with in-built battery to run for 8 hours on a single charge
- Can be used in-line for continuous monitoring, to enable usage tracking

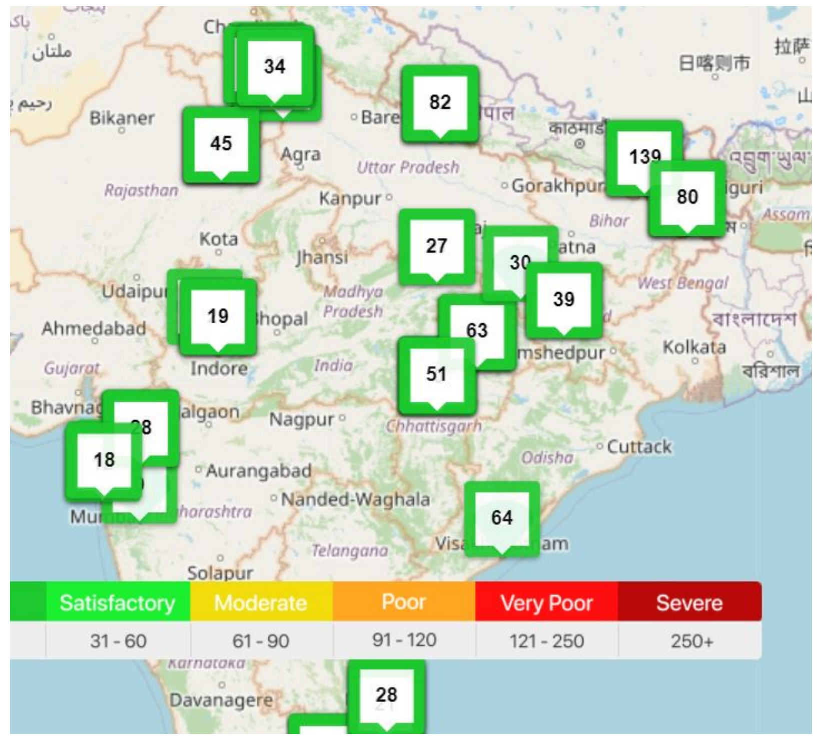
- OC audits (to track down shoddy . malfunctioning OCs)
- O_2 resource map
- Usage analysis

Equipment worth ₹100 crore deployed under 'Mission Vayu'

Our Bureau | Pune | Updated on May 07, 2021

Costs shared by Temasek, Temasek Foundation, ACT Grants, the Swasth Alliance and over 1,000 donors and members of PPCR

Pune Platform for Covid-19 Response (PPCR), anchored at Mahratta Chamber of Commerce Industries and Agriculture (MCCIA), supported by ACT Grants and the Swasth Alliance has successfully implemented two phases of Mission Vayu by donating 7,800 oxygen concentrators, 875 BiPaP ventilators, and 50,000 pulse oximeters across India.



O2 RESOURCE MAP & USAGE TRACKING

Respirer Living Sciences

mccia

MEMORANDUM OF UNDERSTANDING

This Memorandum of Understanding (**"MOU"**) is executed as of date: 12th July 2021 (**"Effective Date"**) between

Party 1 :

MAHRATTA CHAMBER OF COMMERCE, INDUSTRIES AND AGRICULTURE, a company registered under the erstwhile Section 25 of the Companies Act, 1956 (Section 8 of the Companies Act, 2013), having its registered office at 5TH Floor, International Convention Center, Trade Tower, S.B. Road, Pune – 411016 ("**MCCIA**") and

Party 2 :

Respirer Living Sciences Pvt. Ltd., an entity incorporated under the laws of India, having its registered office at 302, 3rd Floor, Rayaba, Near Terraza Society, New DP Road, Aundh, Pune 411 007 ("**Respirer**").

IoT based N95 mask testing resource in collaboration with TIFR, Mumbai and selected for DST CAWACH

atmos
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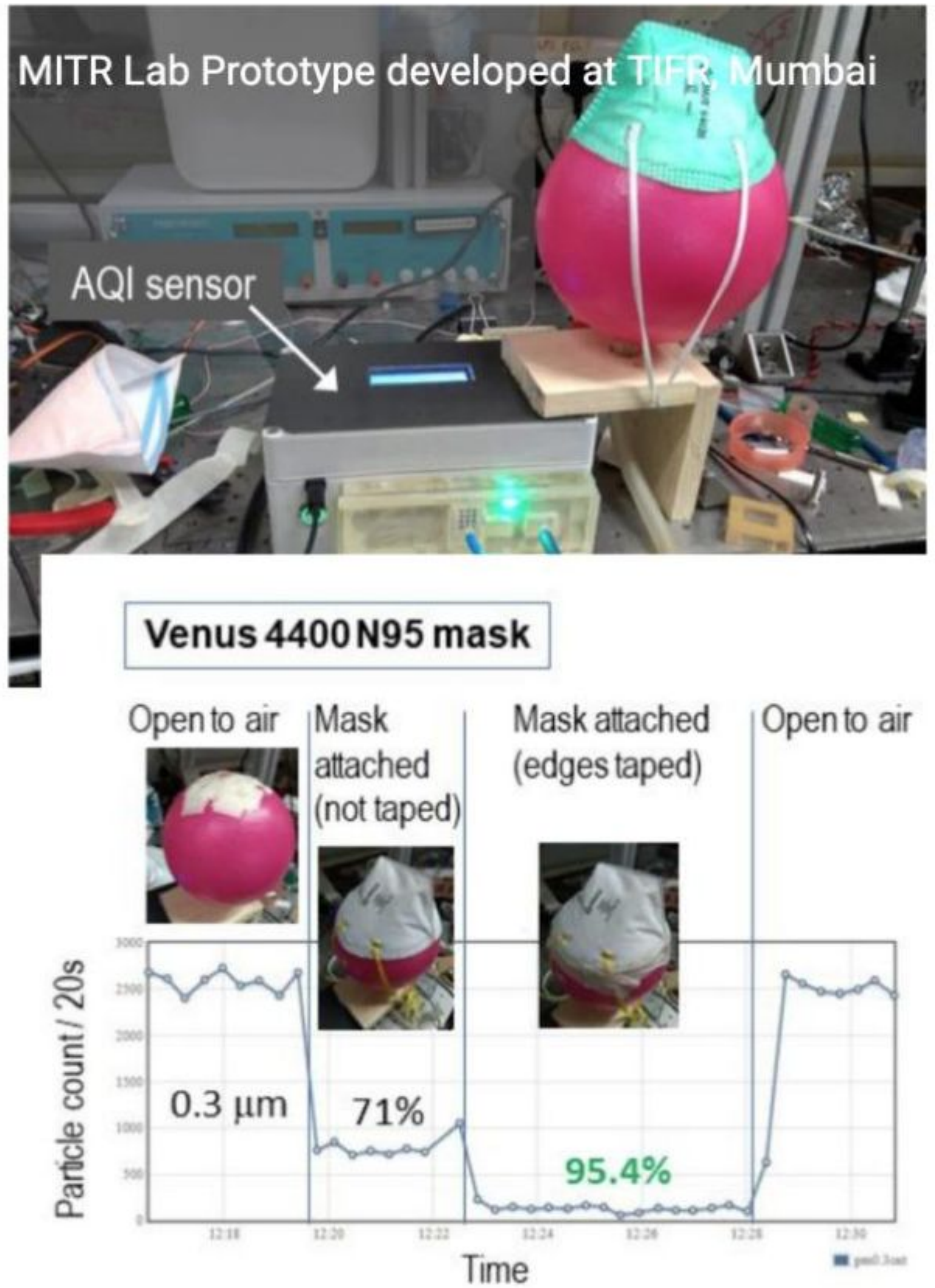
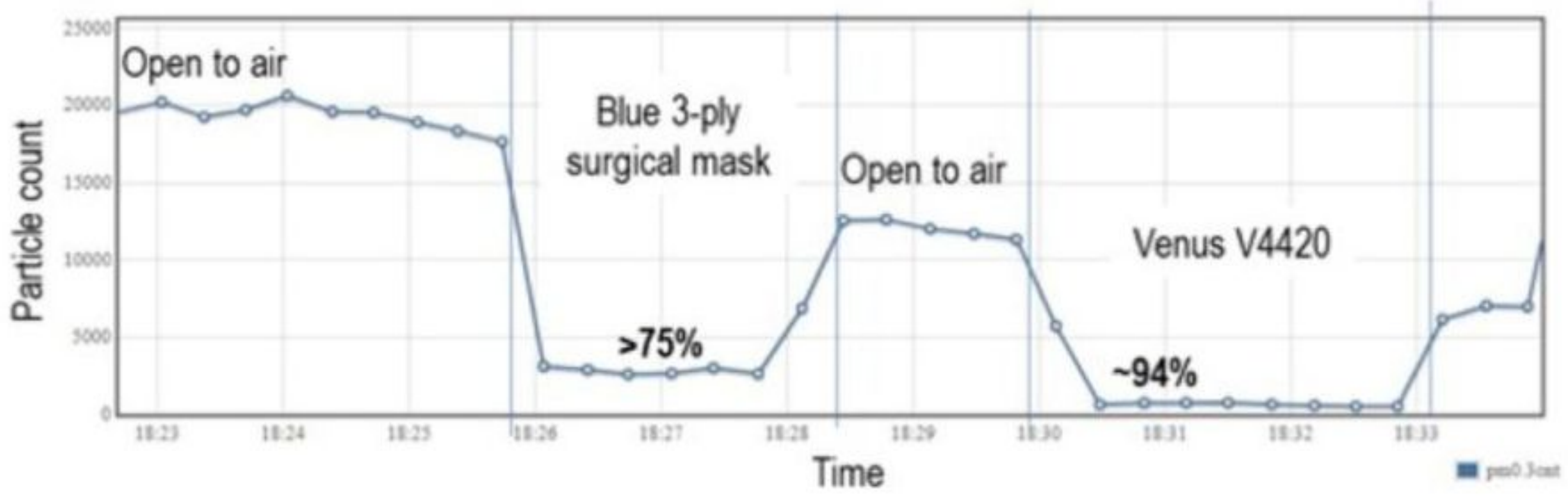
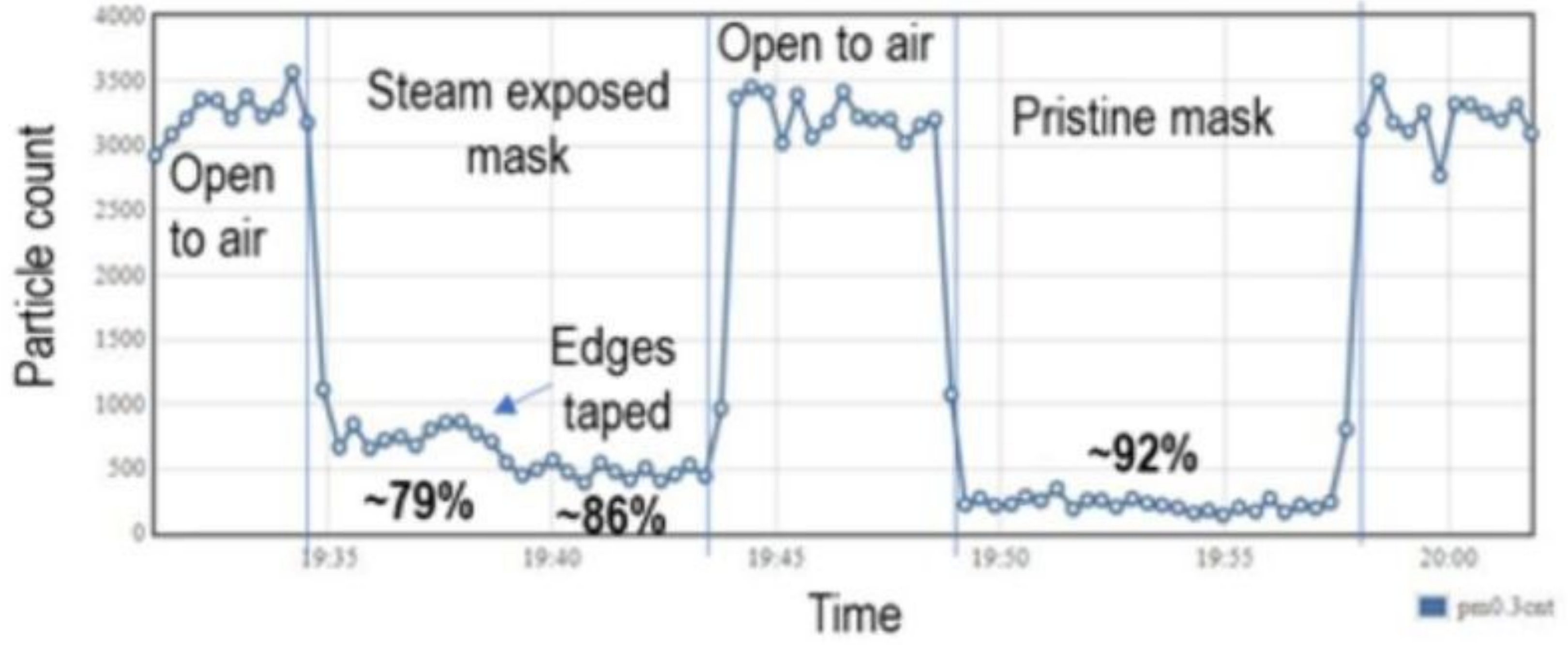
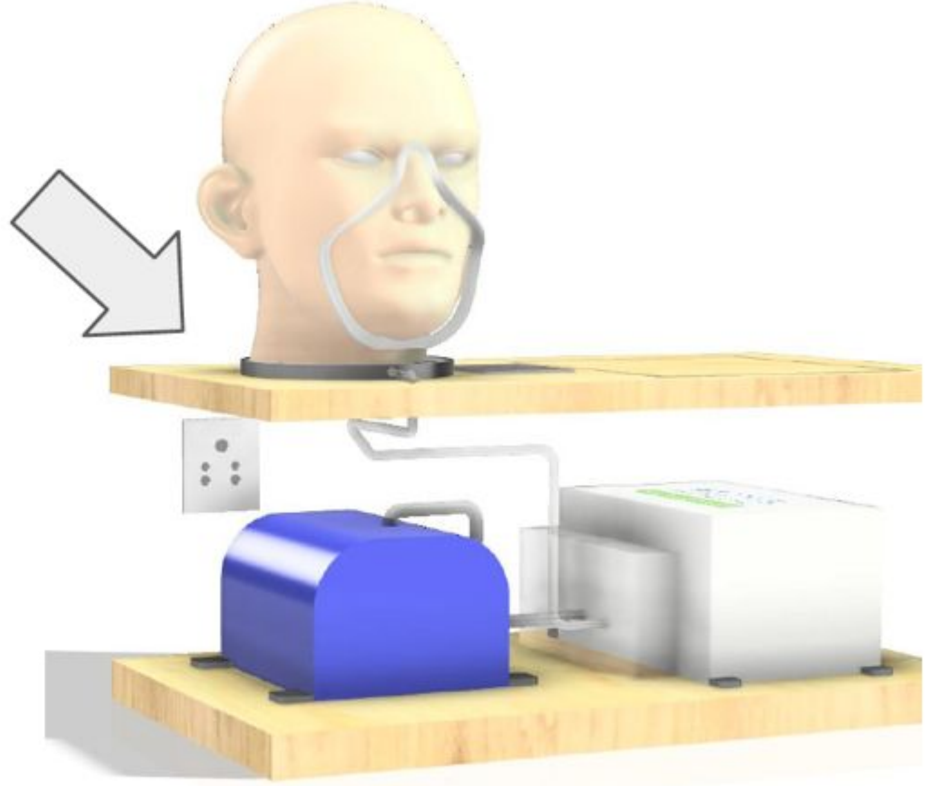






Respirer Living Sciences

TSI - Mask Tester with Accessory



Commercial-grade design of MITR with Phantom head for fit-testing

Respirer Living Sciences

सत्यमेव जयते
Department of Science & Technology
Govt. of India

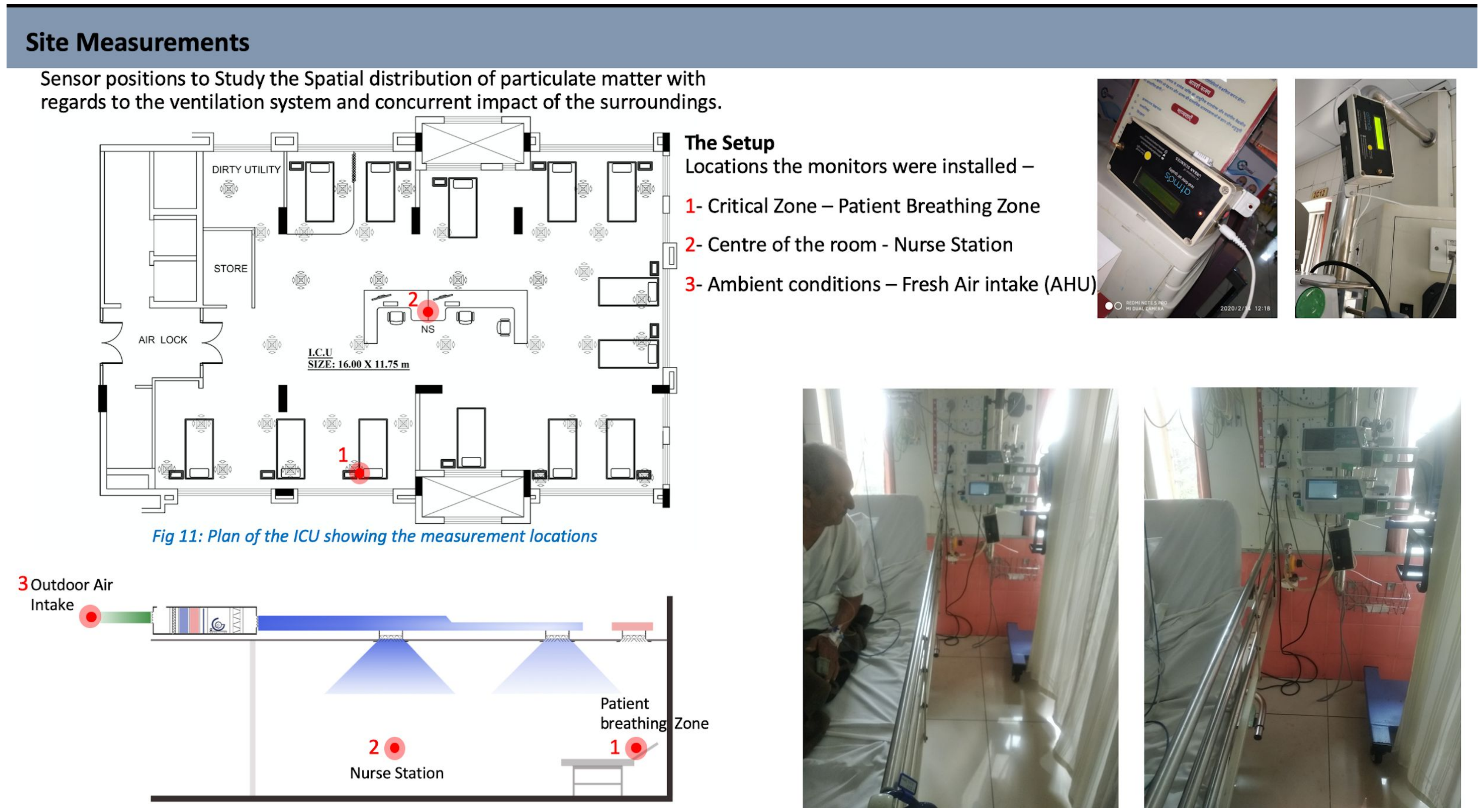
IIT Bombay
SINE
Business Incubator

Centre for Augmenting WAR with COVID-19 Health Crisis
(CAWACH)

Indoor air quality monitoring for buildings and offices

MAPIE Atmos

Indoor Thermal Comfort and Air Quality Measurement Kit



Collaborative work done with Building Energy Performance researchers at Centre for Advanced Research in Building Science and Energy (CARBSE) CEPT, Ahmedabad and Respirer Living Sciences, Mumbai

atmos
real-time air quality
Respirer Living Sciences

Mission: democratization of data and technology

(What are we solving?)

Participatory urbanism and data democratization using IoT and Big Data - for improving quality of living

Societal Challenge

- **21 of the 30 most polluted global cities are in India**
- 7935 cities and towns in India need real-time air quality monitoring, across 4,000 to 8,000 locations. At present, available at 310 locations nationwide.
- Regulatory grade $PM_{2.5}$ monitoring costs up to Rs. 15 Lakhs ($20K) per location. **Total cost per air quality monitoring site Rs. 1.5 Crore ($200K) for all notified pollutants.**

Founder with his 4 week old baby (born Sept 2021) looking for a clean air city to live in.

World Health Organization (WHO): Air pollution and child health, 2018

1.67 million deaths in India attributed to ambient air pollution and over 20 million living with disability adjusted life years.
Source: Lancet - Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019

Contribution

Establishing **Make-In-India IoT-monitoring products & solutions** as among the leading solutions in the domain of low-cost, sensor-based air quality monitoring network solutions, to bridge the affordability and scalability gap.

Atmos. Meas. Tech., 11, 4823–4846, 2018
https://doi.org/10.5194/amt-11-4823-2018

Atmospheric Measurement Techniques
Open Access

Field evaluation of low-cost particulate matter sensors in high- and low-concentration environments

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Received: 7 April 2018 – Discussion started: 23 April 2018
Revised: 26 July 2018 – Accepted: 10 August 2018 – Published: 22 August 2018

Abstract. Low-cost particulate matter (PM) sensors are promising tools for supplementing existing air quality monitoring networks. However, the performance of the new generation of low-cost PM sensors under field conditions is not well understood. In this study, we characterized the performance capabilities of a new low-cost PM sensor model (Plantower model PMS3003) for measuring $PM_{2.5}$ at 1 min, 1 h, 6 h, 12 h, and 24 h integration times. We tested the PMS3003 sensors in both low-concentration suburban regions (Durham and Research Triangle Park (RTP), NC, US) with 1 h $PM_{2.5}$ (mean ± SD) of 9 ± 9 and 10 ± 3 $\mu g\, m^{-3}$, respectively, and a high-concentration urban location (Kanpur, India) with 1 h $PM_{2.5}$ of 36 ± 17 and 116 ± 57 $\mu g\, m^{-3}$ during monsoon and post-monsoon seasons, respectively. In Durham and Kanpur, the sensors were compared to a research-grade instrument (environmental β attenuation monitor, E-BAM) to determine how these sensors perform across a range of $PM_{2.5}$ concentrations and meteorological factors (e.g., temperature and relative humidity, RH). In RTP, the sensors were compared to three Federal Equivalent Methods (FEMs) including two Teledyne model T640s and a Thermo Scientific model 5030 SHARP to demonstrate the importance of the type of reference monitor selected for sensor calibration. The decrease in 1 h mean errors of the calibrated sensors using univariate linear models from Durham (201 %) to Kanpur monsoon (46 %) and post-monsoon (35 %) seasons showed that PMS3003 performance generally improved as ambient $PM_{2.5}$ increased. The precision of reference instruments (T640: ±0.5 $\mu g\, m^{-3}$ for 1 h; SHARP: ±2 $\mu g\, m^{-3}$ for 24 h better than the E-BAM) is critical in evaluating sensor perfor mance, and β-attenuation-based monitors may not be idea for testing PM sensors at low concentrations, as underscore by (1) the less dramatic error reduction over averaging time in RTP against optically based T640 (from 27 % for 1 h t 9 % for 24 h) than in Durham (from 201 % to 15 %); (2) th lower errors in RTP than the Kanpur post-monsoon seaso (from 35 % to 11 %); and (3) the higher T640–PMS3003 cor relations ($R^2 \geq 0.63$) than SHARP–PMS3003 ($R^2 \geq 0.25$) A major RH influence was found in RTP (1 h RH = 64 ± 22 %) due to the relatively high precision of the T640 mea surements that can explain up to ∼30 % of the variance i 1 min to 6 h PMS3003 $PM_{2.5}$ measurements. When prope RH corrections are made by empirical nonlinear equation after using a more precise reference method to calibrate th sensors, our work suggests that the PMS3003 sensors ca measure $PM_{2.5}$ concentrations within ∼10 % of ambient val ues. We observed that PMS3003 sensors appeared to ex hibit a nonlinear response when ambient $PM_{2.5}$ exceede ∼125 $\mu g\, m^{-3}$ and found that the quadratic fit is more appro priate than the univariate linear model to capture this nonlin earity and can further reduce errors by up to 11 %. Our result have substantial implications for how variability in ambien $PM_{2.5}$ concentrations, reference monitor types, and meteoro logical factors can affect PMS3003 performance characteri zation.

Published by Copernicus Publications on behalf of the European Geosciences Union.

Atmos. Meas. Tech., 12, 5161–5181, 2019
https://doi.org/10.5194/amt-12-5161-2019

Atmospheric Measurement Techniques
Open Access

Gaussian process regression model for dynamically calibrating and surveilling a wireless low-cost particulate matter sensor network in Delhi

Tongshu Zheng[1], Michael H. Bergin[1], Ronak Sutaria[2], Sachchida N. Tripathi[3], Robert Caldow[4], and David E. Carlson[1,5]

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Received: 11 February 2019 – Discussion started: 1 March 2019
Revised: 19 July 2019 – Accepted: 30 August 2019 – Published: 26 September 2019

Abstract. Wireless low-cost particulate matter sensor networks (WLPMSNs) are transforming air quality monitoring by providing particulate matter (PM) information at finer spatial and temporal resolutions. However, large-scale WLPMSN calibration and maintenance remain a challenge. The manual labor involved in initial calibration by collocation and routine recalibration is intensive. The transferability of the calibration models determined from initial collocation to new deployment sites is questionable, as calibration factors typically vary with the urban heterogeneity of operating conditions and aerosol optical properties. Furthermore, the stability of low-cost sensors can drift or degrade over time. This study presents a simultaneous Gaussian process regression (GPR) and simple linear regression pipeline to calibrate and monitor dense WLPMSNs on the fly by leveraging all available reference monitors across an area without resorting to pre-deployment collocation calibration. We evaluated our method for Delhi, where the $PM_{2.5}$ measurements of all 22 regulatory reference and 10 low-cost nodes were available for 59 d from 1 January to 31 March 2018 ($PM_{2.5}$ averaged 138 ± 31 $\mu g\, m^{-3}$ among 22 reference stations), using a leave-one-out cross-validation (CV) over the 22 reference nodes. We showed that our approach can achieve an overall 30 % prediction error (RMSE: 33 $\mu g\, m^{-3}$) at a 24 h scale, and it is robust as it is underscored by the small variability in the GPR model parameters and in the model-produced calibration factors for the low-cost nodes among the 22-fold CV. Of the 22 reference stations, high-quality predictions were observed for those stations whose $PM_{2.5}$ means were close to the Delhi-wide mean (i.e., 138 ± 31 $\mu g\, m^{-3}$), and relatively poor predictions were observed for those nodes whose means differed substantially from the Delhi-wide mean (particularly on the lower end). We also observed washed-out local variability in $PM_{2.5}$ across the 10 low-cost sites after calibration using our approach, which stands in marked contrast to the true wide variability across the reference sites. These observations revealed that our proposed technique (and more generally the geostatistical technique) requires high spatial homogeneity in the pollutant concentrations to be fully effective. We further demonstrated that our algorithm performance is insensitive to training window size as the mean prediction error rate and the standard error of the mean (SEM) for the 22 reference stations remained consistent at ∼30 % and ∼3 %–4 %, respectively, when an increment of 2 d of data was included in the model training. The markedly low requirement of our algorithm for training data enables the models to always be nearly the most updated in the field, thus realizing the algorithm's full potential for dynamically surveilling large-scale WLPMSNs by detecting malfunctioning low-cost nodes and tracking the drift with little latency. Our algorithm presented similarly stable 26 %–34 % mean prediction errors and ∼3 %–7 % SEMs over the sampling period when pre-trained on the current week's data and predicting 1 week ahead, and therefore it is suitable for online

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sensors

MDPI

Article

Validation of Low-Cost Sensors in Measuring Real-Time PM_{10} Concentrations at Two Sites in Delhi National Capital Region

Ravi Sahu [1], Kuldeep Kumar Dixit [1], Suneeti Mishra [1], Purushottam Kumar [1], Ashutosh Kumar Shukla [1], Ronak Sutaria [2], Shashi Tiwari [3] and Sachchida Nand Tripathi [1,*]

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check for updates

Abstract: In the present study, we assessed for the first time the performance of our custom-designed low-cost Particulate Matter (PM) monitoring devices (Atmos) in measuring PM_{10} concentrations. We examined the ambient PM_{10} levels during an intense measurement campaign at two sites in the Delhi National Capital Region (NCR), India. In this study, we validated the un-calibrated Atmos for measuring ambient PM_{10} concentrations at highly polluted monitoring sites. PM_{10} concentration from Atmos, containing laser scattering-based Plantower PM sensor, was comparable with that measured from research-grade scanning mobility particle sizers (SMPS) in combination with optical particle sizers (OPS) and aerodynamic particle sizers (APS). The un-calibrated sensors often provided accurate PM_{10} measurements, particularly in capturing real-time hourly concentrations variations. Quantile–Quantile plots (QQ-plots) for data collected during the selected deployment period showed positively skewed PM_{10} datasets. Strong Spearman's rank-order correlations (r_s = 0.64–0.83) between the studied instruments indicated the utility of low-cost Plantower PM sensors in measuring PM_{10} in the real-world context. Additionally, the heat map for weekly datasets demonstrated high R^2 values, establishing the efficacy of PM sensor in PM_{10} measurement in highly polluted environmental conditions.

Keywords: urban air pollution; PM_{10}; real-time monitoring; low-cost sensors; data merging tool; data validation

Atmos. Meas. Tech., 14, 37–52, 2021
https://doi.org/10.5194/amt-14-37-2021

Atmospheric Measurement Techniques
Open Access
EGU

Robust statistical calibration and characterization of portable low-cost air quality monitoring sensors to quantify real-time O_3 and NO_2 concentrations in diverse environments

Ravi Sahu[1], Ayush Nagal[2], Kuldeep Kumar Dixit[1], Harshavardhan Unnibhavi[3], Srikanth Mantravadi[4], Srijith Nair[4], Yogesh Simmhan[3], Brijesh Mishra[5], Rajesh Zele[5], Ronak Sutaria[6], Vidyanand Motiram Motghare[7], Purushottam Kar[2], and Sachchida Nand Tripathi[1]

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[5]Department of Electrical Engineering, Indian Institute of Technology, Mumbai, India
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Correspondence: Sachchida Nand Tripathi (snt@iitk.ac.in)

Received: 3 April 2020 – Discussion started: 12 June 2020
Revised: 4 October 2020 – Accepted: 1 November 2020 – Published: 4 January 2021

Abstract. Low-cost sensors offer an attractive solution to the challenge of establishing affordable and dense spatio-temporal air quality monitoring networks with greater mobility and lower maintenance costs. These low-cost sensors offer reasonably consistent measurements but require in-field calibration to improve agreement with regulatory instruments. In this paper, we report the results of a deployment and calibration study on a network of six air quality monitoring devices built using the Alphasense O_3 (OX-B431) and NO_2 (NO2-B43F) electrochemical gas sensors. The sensors were deployed in two phases over a period of 3 months at sites situated within two megacities with diverse geographical, meteorological and air quality parameters. A unique feature of our deployment is a *swap-out* experiment wherein three of these sensors were relocated to different sites in the two phases. This gives us a unique opportunity to study the effect of seasonal, as well as geographical, variations on calibration performance. We report an extensive study of more than a dozen parametric and non-parametric calibration algorithms. We propose a novel local non-parametric calibration algorithm based on metric learning that offers, across deployment sites and phases, an R^2 coefficient of up to 0.923 with respect to reference values for O_3 calibration and up to 0.819 for NO_2 calibration. This represents a 4–20 percentage point increase in terms of R^2 values offered by classical non-parametric methods. We also offer a critical analysis of the effect of various data preparation and model design choices on calibration performance. The key recommendations emerging out of this study include (1) incorporating ambient relative humidity and temperature into calibration models; (2) assessing the relative importance of various features with respect to the calibration task at hand, by using an appropriate feature-weighing or metric-learning technique; (3) using local calibration techniques such as k nearest neighbors (KNN); (4) performing temporal smoothing over raw time series data but being careful not to do so too aggressively; and (5) making all efforts to ensure that data with enough diversity are demonstrated in the calibration algorithm while training to ensure good generalization. These results offer insights into the strengths and limitations of these sensors and offer an encouraging opportunity to use them to supplement and densify compliance regulatory monitoring networks.

Published by Copernicus Publications on behalf of the European Geosciences Union.

Aerosol and Air Quality Research

ORIGINAL RESEARCH
https://doi.org/10.4209/aaqr.210170

Indoor and Ambient Air Pollution in Chennai, India during COVID-19 Lockdown: An Affordable Sensors Study

Naveen Puttaswamy[1*], V. Sreekanth[2], Ajay Pillarisetti[3], Adithi R. Upadhya[4], Sudhakar Saidam[1], Balachandar Veerappan[1], Krishnendu Mukhopadhyay[1], Sankar Sambandam[1], Ronak Sutaria[5], Kalpana Balakrishnan[1]

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[4] ILK Labs, Bengaluru, India
[5] Respirer Living Sciences Private Limited, Pune, India

ABSTRACT

The Tamil Nadu Air Pollution and Health Effects study (TAPHE-2) aims to evaluate the relationship between air pollution and birth outcome in a rural-urban cohort of 300 pregnant women. Due to COVID-19 related lockdowns, some TAPHE-2 activities were delayed; however, continuous indoor and outdoor air quality data were collected in and around Chennai, India. We report here the impact of graded COVID-19 lockdown on indoor particulate matter ($PM_{2.5}$ and PM_{10}) levels based on calibrated data from affordable real-time PM sensors called *atmos*™ and ambient PM levels from publicly available regulatory monitors. The study period was between 11 March and 30 June 2020 (i.e., 100 days of continuous monitoring), which coincided with four phases of a nationwide graded lockdown. Field calibration coefficients for the atmos PM were derived by collocating them with reference-grade PM monitors. The normalized root mean square error (NRMSE) of the atmos hourly $PM_{2.5}$ (PM_{10}) improved from 41% to 15% (33% to 18%) after applying the field calibration coefficients. Lockdowns resulted in significant reductions in indoor and ambient PM levels, with the highest reduction observed during lockdown phase 2 (L2) and phase 3 (L3). Reductions as high as 70%, 91%, and 62% were observed in ambient $PM_{2.5}$, indoor $PM_{2.5}$, and indoor PM_{10} relative to pre-lockdown levels (PL), respectively. The indoor $PM_{2.5}$/PM_{10} ratio decreased during the lockdown, suggesting a decline in the fine mode dominance in PM_{10}. The indoor-to-outdoor (I/O) ratios in $PM_{2.5}$ marginally increased during L1, L2, and L3 phases compared to that of PL levels, suggesting an uneven reduction in indoor and ambient $PM_{2.5}$ levels during the lockdown.

Keywords: Optical scattering, $PM_{2.5}$, PM_{10}, Beta Attenuation Monitor, Indoor to outdoor ratio

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1 INTRODUCTION

Air pollution continues to be a significant environmental and public health issue in Indian megacities. The disease burden attributable to air pollution is predominantly driven by $PM_{2.5}$ (mass concentration of particulate matter with an aerodynamic diameter of 2.5 µm and less). An estimated 0.67 million (95% uncertainty interval: 0.55–0.79) and 0.48 million (95% uncertainty interval: 0.39–0.58) premature deaths in India (in 2017) were attributed to ambient and household particulate matter pollution, respectively (Balakrishnan *et al.*, 2019). The annual average population-weighted $PM_{2.5}$ exposures in India have been increasing steadily from 62 µg m^{-3} in

CurrentSense: A novel approach for fault and drift detection in environmental IoT sensors

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ABSTRACT

Sensor data quality plays a fundamental role in increasing the adoption of IoT devices for environmental data collection. Due to the nature of the deployment, i.e., in-the-wild and in harsh environments, coupled with limitations of low-cost components, sensors are prone to failures. A significant fraction of faults result from drift and catastrophic faults in sensors' sensing components leading to serious data inaccuracies. However, it is challenging to detect faults by analyzing just the sensor data as a faulty sensor data can mimic non-faulty data and an anomalous sensor reading need not represent a faulty data. Existing data-centric approaches rely on additional contextual information or sensor redundancy to detect such faults. This paper presents a systematic approach to detect faults and drifts, by devising a novel sensor fingerprint called CurrentSense. CurrentSense captures the electrical characteristics of the hardware components in a sensor, with working, drifted, and faulty sensors having distinct fingerprints. This fingerprint is used to determine the sensors' health, and compensate for drift or diagnose catastrophic faults without any contextual information. The CurrentSense approach is non-intrusive, and can be applied to a wide variety of environmental sensors. We show the working of the proposed approach with the help of air pollution sensors. We perform an extensive evaluation in both controlled setup and real-world deployments with 51 sensors across multiple cities for 8 months period. Our approach outperforms existing anomaly detectors and can detect and isolate faults with an F_1 score of 98% and compensate for sensor drift errors by 86%.

CCS CONCEPTS

• **Computer systems organization → Embedded and cyber-physical systems**; • **Hardware → Fault tolerance**.

KEYWORDS

Fault detection and isolation; Drift detection

1 INTRODUCTION

The proliferation of the Internet of Things (IoT) devices has led to the deployment of billions of sensors in various domains to sense and monitor the environment [25]. Applications of IoT in environmental monitoring range from air pollution monitoring, water quality monitoring, extreme weather sensing, endangered species protection, to commercial farming and many more. Since these applications rely on the fidelity of the sensed data for making decisions, it is *fundamental to determine the quality of the sensor data*, by detecting whether the sensor is working, faulty, or drifted.

A vast majority of IoT devices deployed today utilize compact digital sensors owing to their reliability and ease of installation. While these digital sensors have paved the way for large-scale IoT deployments, it is quite challenging to determine the accuracy, and the fidelity of the data, just by analyzing the digital data stream. Especially, given the nature of the IoT deployments in environmental monitoring, i.e., in-the-wild and in harsh conditions, IoT sensors are prone to failures [32]. A majority of these faults are due to drift and catastrophic faults in sensors' sensing components [35]. Typically, when a sensor fails, either due to malfunctioning of a few components (leading to catastrophic faults) or wear and tear (leading to drift), they do not just stop sending data, but continue to transmit faulty or dirty data [16, 19]. Given the uncontrolled environment in which these sensors are deployed, it is impossible to assess the accuracy of the data without additional contextual information or sensor redundancy [32].

In this paper, we present a novel approach called CurrentSense to detect catastrophic faults and drift in digital sensors, going beyond traditional data-centric approaches. CurrentSense is based on the following simple idea: Every electrical or electro-mechanical sensor draws current from the IoT device for its operation. By sampling the current drawn by the sensor we can derive a unique electrical characteristic fingerprint that differs between working, faulty, and drifted sensors. Our key observation based on theoretical and extensive experimental evidence is that when any sensor component accumulates damage that causes a fault or drift, the damage also changes other physical properties of the sensor, which affects its current consumption. Thus, by monitoring the current consumption of the sensor without any additional details of the sensor, we can now accurately derive the status of the sensor.

Current signature analysis has played a key role in fault diagnosis over the past decade mostly in household appliances (such as HVAC) or industry equipment's (such as induction motors) [23]. The focus has been limited towards detecting abnormalities in power consumption patterns of an appliance. This limitation is due to the dynamic change in consumption patterns either due to the complexity of the appliance being monitored (e.g., multiple states in a washing machine cycle) or usage variations due to the presence of users (turning on/off appliances at any point). Our work is inspired and build upon the recent works in energy monitoring area [26, 34, 36]. Our key novelty is the application of current monitoring for accurate fault detection and isolation in low-cost

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