

transforming **air quality monitoring** through a microscopic lens

March 2020

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Executive Summary

In December 2017, Respirer Living Sciences collaborated with IIT Kanpur to embark on an ambitious project with Shakti Sustainable Energy Foundation (SSEF) to build and deploy a scientifically validated, sensor-based air quality monitoring network tracking real-time Particulate Matter (PM2.5 & PM10) data across 10 cities in India. We did this using Atmos, a sensor-based air quality monitoring device developed by Respirer Living Sciences.

The project, titled Measurement & dissemination of air quality data using low-cost monitors in 10 cities was designed to build upon earlier learnings in air quality monitoring and strengthen the adoption of affordable sensor-based air quality monitoring technology at a nationwide level by policymakers, regulators, community and citizen-focused organizations.

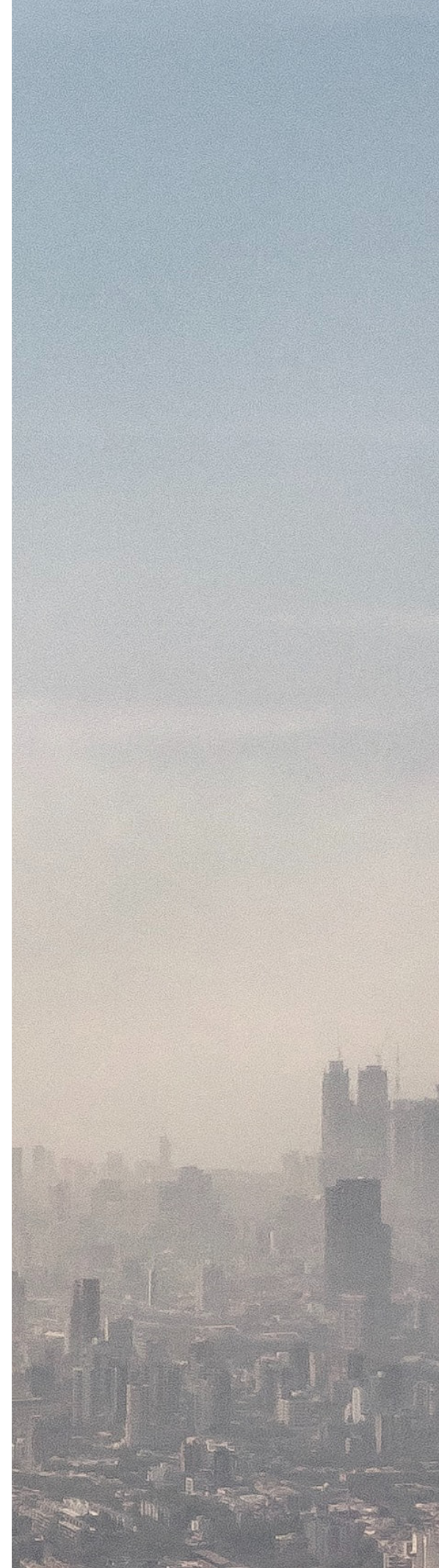
Over a project duration of two years, the collaboration between the partners - Respirer Living Sciences and IIT Kanpur with support from the technical team at SSEF - has contributed to a significant number of high-impact citizen and community-focused developments as well as scientific and policy-level impact in the context of low cost, sensor-based air quality monitoring in India. Combined with the impact of other collaborative projects undertaken by the said partners, the overall impact of the work in this space, using sensor-based technologies, has fundamentally transformed the realm of air quality monitoring in India.

From presenting our work to the Principal Scientific Advisor of India, the highest scientific body in India, to working with local Municipal Corporations and State Pollution Control Boards, the work has received strong recognition in addition to offering a viable and affordable technology to help policymakers and regulators advance their goals in solving this national problem at scale. The work led by the partners in this area that extends beyond this particular project has also been published in and validated by leading scientific peer-reviewed journals.

The following report specifically focuses on a) Performance against project goals: the state of play when we started and where we are today; b) Evolution of the data ecosystem: how the work evolved and key milestones that contributed to furthering the data ecosystem; c) Key achievements & project successes: how the data is being utilized, challenges and lessons learned; and d) Areas of investment going forward: to sustain and grow low cost, sensor-based air quality networks.

The report captures some of the key impact areas and field-level successes while outlining the challenges of running a nationwide air quality monitoring network using advanced IoT sensor-based and machine learning technologies. The rapidly evolving space of IoT data and communications technologies is highly susceptible to underlying changes and upheaval in the telecom sector given the dependence on Machine to Machine (M2M) infrastructure provided by the telecom companies. Big Data, Machine Learning and AI technologies are also rapidly evolving and with that came tremendous learnings on adapting to these changes to ensure the precision, accuracy and calibrations of air quality sensors remained intact. The team continues to work tirelessly to understand and improve the reliability of the air quality sensor data provided by the network.

Last but not least, we have made significant strides in elevating the overall quality and timeliness of communicating real-time air quality monitoring data from the Atmos network through analytics and visualizations. Citizen science and citizen engagement movements based on this is also presented in this report.





ACKNOWLEDGEMENTS

Respirer Living Sciences Pvt. Ltd. would like to thank Shakti Sustainable Energy Foundation for providing funding and strategic assistance in the establishment of the Atmos network in 10 Indian cities. The analyses this report presents is premised on the data from the Atmos monitors.

Shakti Sustainable Energy Foundation (Shakti) works to facilitate India's transition to a sustainable energy future by aiding the design and implementation of policies in the following sectors: clean power, energy efficiency, sustainable urban transport, climate policy and clean energy finance.

Introduction

Mumbai residents spent US\$ 8000 million (INR 601 cr) in 2012 to treat chronic obstructive pulmonary disorder (COPD) and symptoms like breathlessness, allergic rhinitis, wheezing and cough – all of which can be triggered and aggravated by poor air quality, especially high concentration of particulate matter and nitrogen oxides, a study done by the Indian Institute of Technology – Bombay (IITB) and the National Environmental Engineering Research Institute (NEERI). There is little doubt that air pollution is a chronic national health crisis and has been been for some time.

Air pollution has become a major threat not only for those living around industries or marked polluted areas but in smaller cities and rural areas too. While the quality of air or the level of pollutants is being identified, the lack of specialized location-wise air quality monitoring is missing. The level of pollutants being inhaled by us on a real-time basis is also missing.

Whilst 95% of the global population breathes air exceeding WHO exposure targets, vast populations around the world lack access to air quality information. Awareness of air pollution remains low in areas where real-time monitoring is limited but pollution levels may be high.

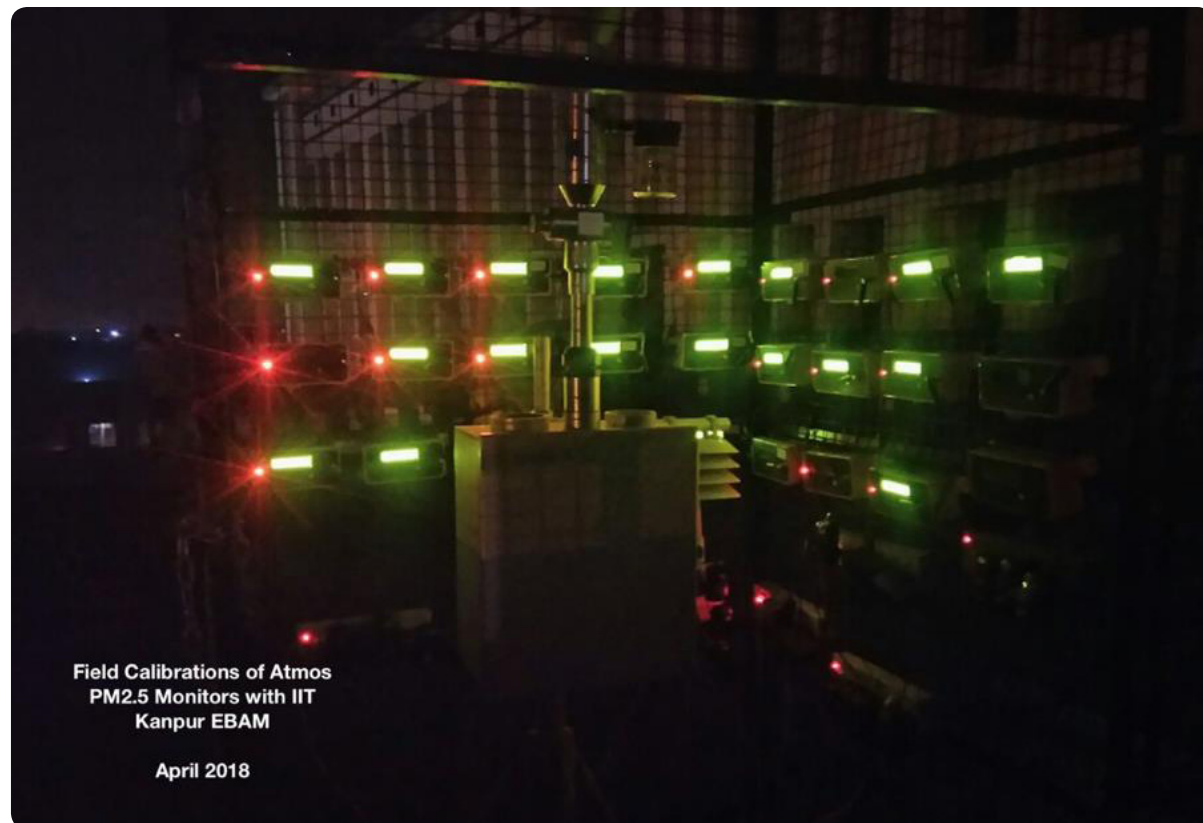
Six years ago, the air quality monitoring landscape in India was dependent on US and European companies to support and provide expensive equipment, and each city could afford a maximum of two to five monitoring stations. In Mumbai, for example, over the past eight years, the city has been relying on data from only two stations – Sion and Bandra. States like Chhattisgarh continue to have zero citizen-facing real-time air quality monitoring stations.

Now, Mumbai is set to get 90 sensor-based air quality monitoring stations in the city making it the single largest and dense network in India. 80 real-time continuous air monitoring stationary stations will give location-wise updates while 10 mobile sensors (setup on Brihanmumbai Electric Supply and Transport buses) will provide representative air quality sampling in the rest of the city. The solution is in the form of low-cost Atmos air quality sensors making a dynamic change in the air quality space with citizens having access to the air they breathe. If low-cost real-time air quality stations are adapted under the Centre's National Clean Air Programme (NCAP) covering 122 cities, the entire country will have access to robust data and it will make it easier for policymakers, researchers, scientists, strategists, etc. to all come together and inventories decisive mitigation measures affecting a hyperlocal space.

Respirer Living Sciences has been at the forefront of building technology through the development of low-cost air quality monitoring network devices. Displaying the huge evolution in the space, conversations with various stakeholders have opened up doors and increased awareness, substantially around the untapped potential and the need to invest in this technology. The credibility of the partnership with Delhi-based Shakti Sustainable Energy Foundation and Indian Institute of Technology-Kanpur (IIT-K) has further opened up a paradigm shift and commenced the evolution of the data ecosystem, which is easily understood and shared with citizens as well as commercial and private stakeholders on government and non-government levels.



PROJECT GOALS



Field-Evaluations and Validation of Atmos Low-Cost Air Quality Monitoring Network

One of the primary goals of the project was to understand the use of scientifically validated and affordable sensor-based real-time air quality monitoring network for policy and government use in monitoring and mitigation of air pollution in India. In this context,

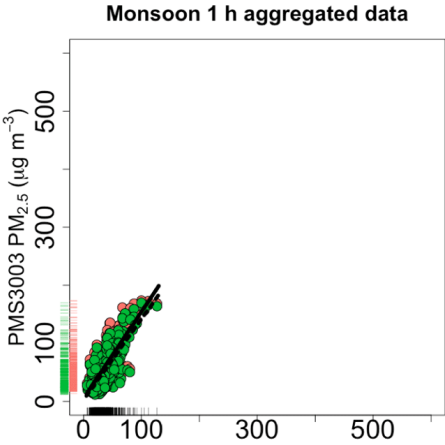
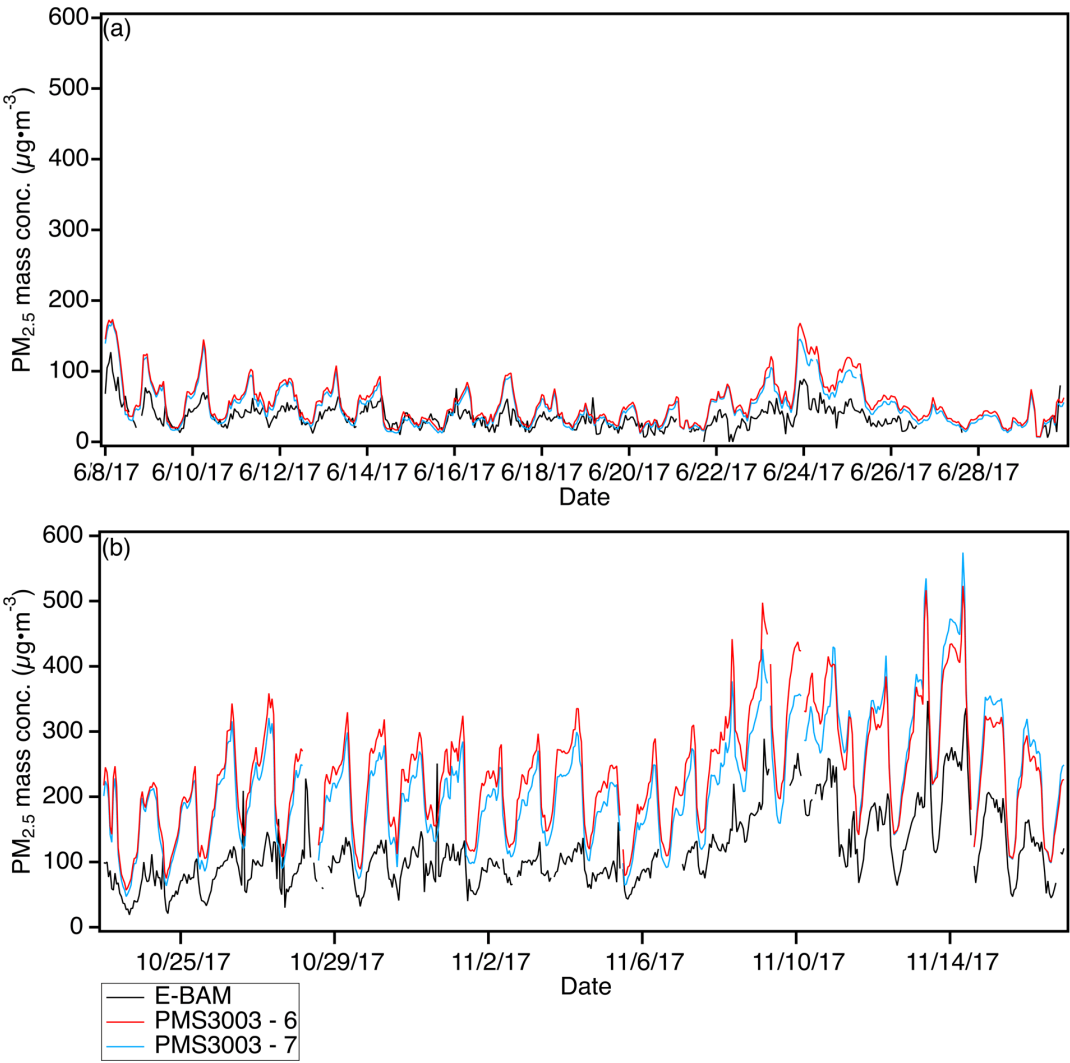
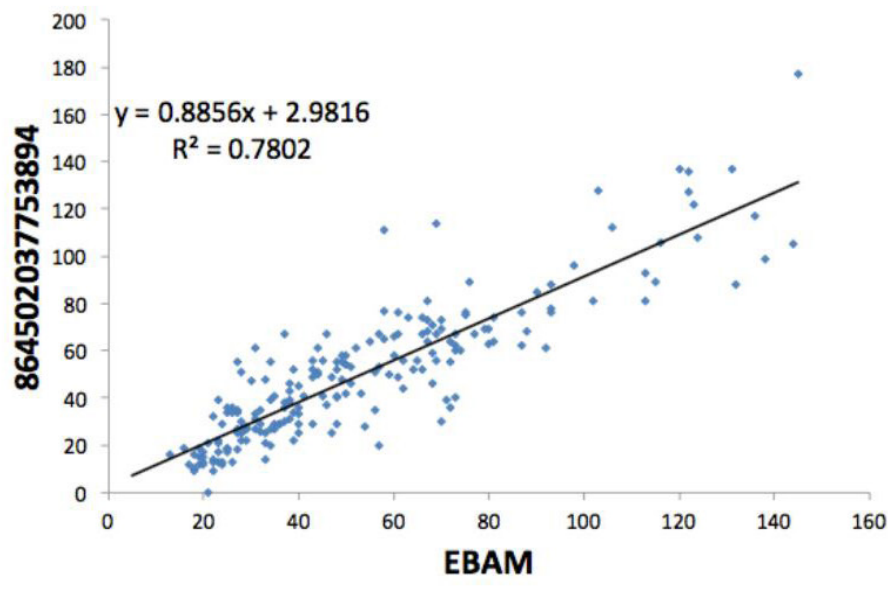
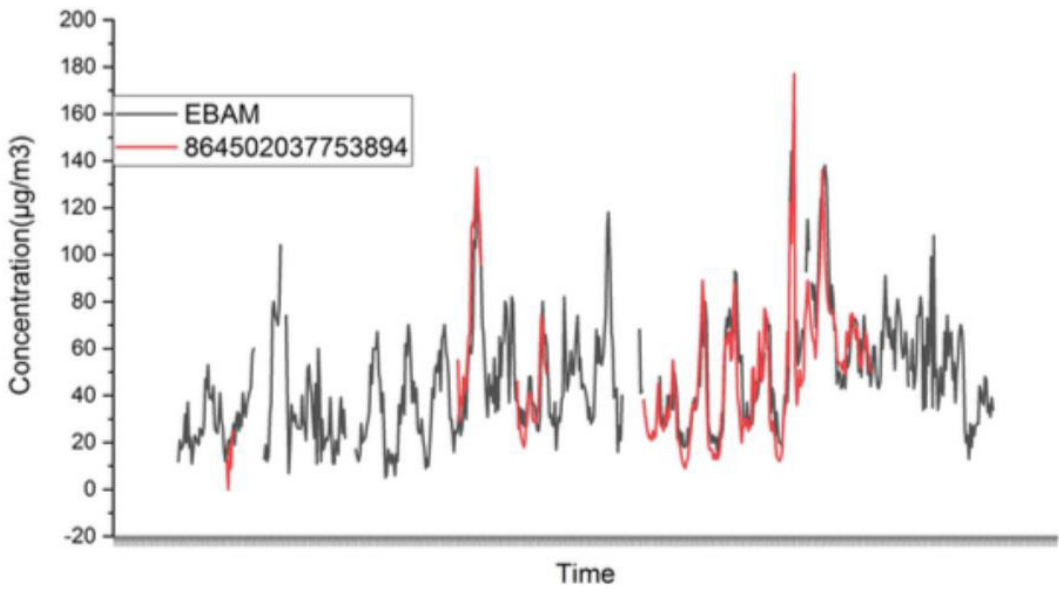
50 Atmos monitors were developed using Particulate Matter (PM) sensors and in April 2018,

the monitors were co-located with reference grade Environmental Beta Attenuation Mass Monitor (EBAM) at Manav Rachna International University (MRIU) in Delhi NCR. Below is the setup site during the field-calibration done for the Atmos monitors.

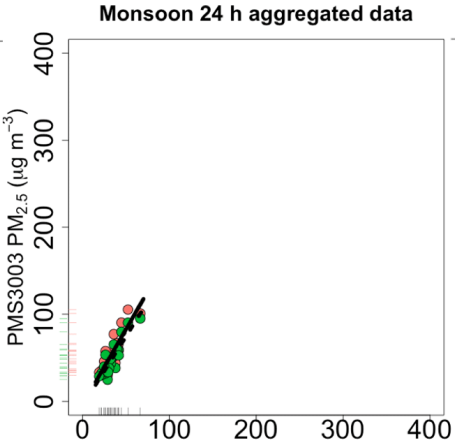
The results of this calibration were presented in the report submitted to Shakti Foundation in May 2018. Correlation metrics and time-series graphs were plotted by the IIT Kanpur team to provide a baseline understanding of the performance of the monitors before the project started.

Subsequent to the above evaluations, the team has undertaken a number of additional studies to validate the accuracy and precision of Atmos based air quality monitors in the field.

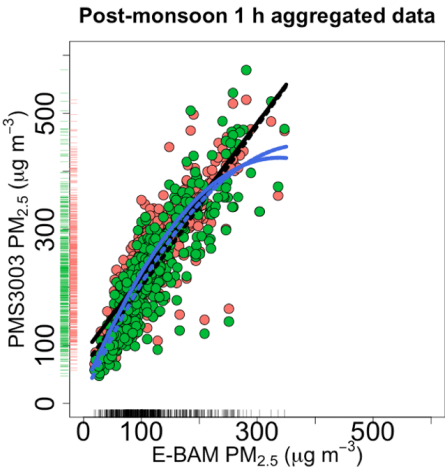
Results from pre-monsoon and post-monsoon evaluations of the low-cost sensor based Atmos air quality monitors in scientific peer-reviewed journals:



Intercept	slope	R2
6.6	1.5	0.61
3.8	1.4	0.61

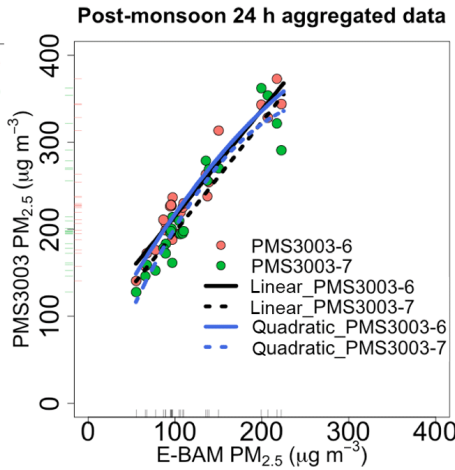


Intercept	slope	R2
-3.8	1.7	0.77
-4.9	1.6	0.79



Intercept	slope	R2
86	1.3	0.73
62	1.4	0.75

a0	a1	a2	R2
23	2.4	-0.004	0.76
10	2.3	-0.003	0.77



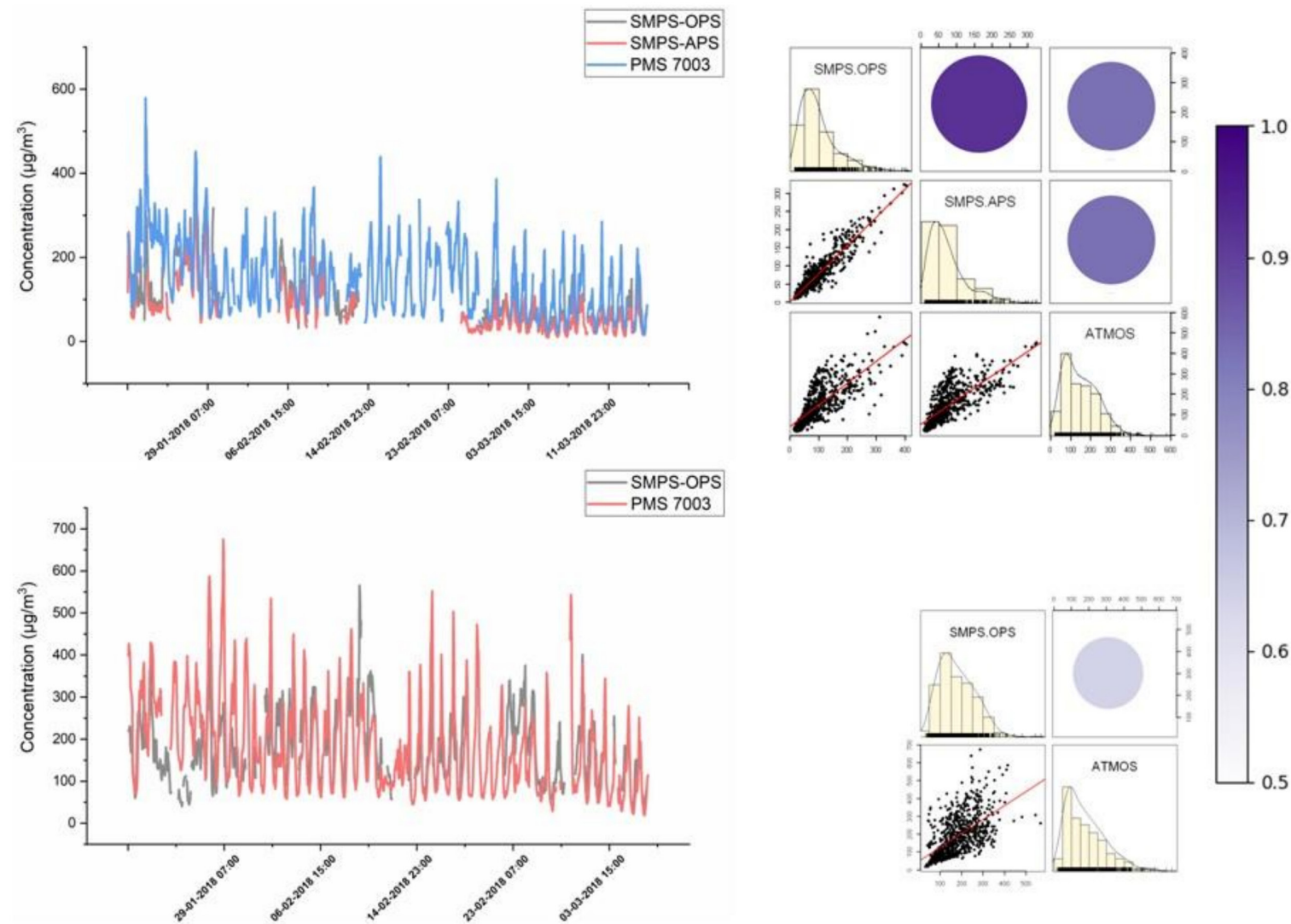
Intercept	slope	R2
93	1.2	0.92
71	1.3	0.89

a0	a1	a2	R2
52	1.9	-0.002	0.93
-14	2.6	-0.005	0.91

The above results demonstrated that substantial improvement in the accuracy of the sensor-based air quality monitors can be achieved by doing field-calibrations of the PM2.5 sensors.

Similar evaluations were done in **Delhi NCR for PM10** data from the **Atmos monitors**.

The results have been published in a scientific journal, as given below:



The above work was done in parallel to the duration of the Shakti Foundation project and involved support and funding from DST-Intel (administered by IUSSTF) and TSI, Inc. The work done in the above projects had complimentary goals and objectives as the project undertaken with Shakti Foundation.

The above studies, results of which were evaluated and presented in the duration of the Shakti Foundation project have helped reach the overall goal of the project of understanding the field-evaluations of the precision and accuracy of the low-cost sensors when deployed in high- and low-concentration regions of India.

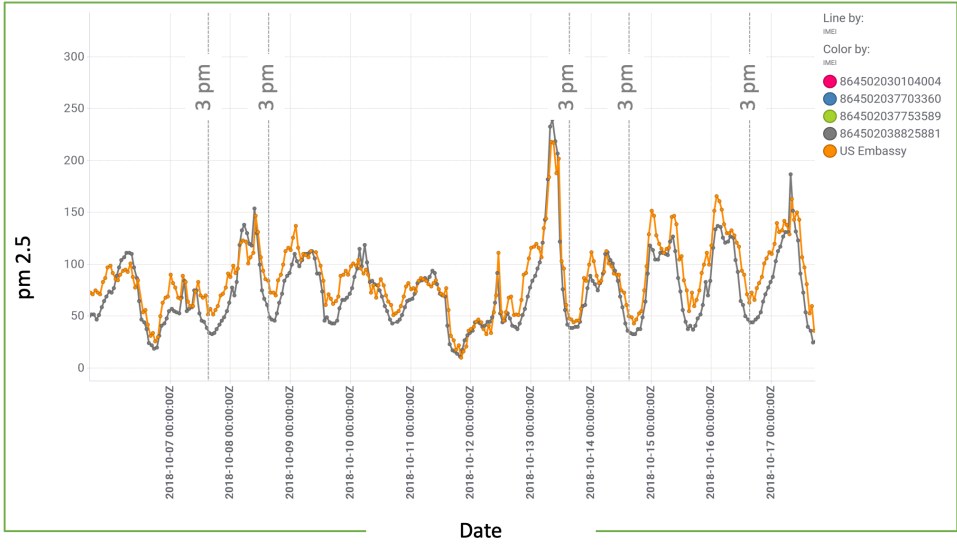
The overall implementation of calibration algorithms on the real-time server side data requires understanding of several other factors such as meteorology of the air-shed, age of the sensors, etc. to be put in place. The performance of these calibration algorithms in different environmental and meteorological conditions is still work-in-progress and hence, more work is left to be done before these calibration algorithms can be used at scale for nationwide deployments.

Additional field-evaluations done by independent research groups using the Atmos monitors demonstrated the relevance and applicability of this technology for using in city-scale air quality monitoring requirements:

Sahu, Ravi; Dixit, Kuldeep K.; Mishra, Suneeti; Kumar, Purushottam; Shukla, Ashutosh K.; Sutaria, Ronak; Tiwari, Shashi; Tripathi, Sachchida N. 2020. "Validation of Low-Cost Sensors in Measuring Real-Time PM10 Concentrations at Two Sites in Delhi National Capital Region." Sensors 20, no. 5: 1347.

While the scientific studies demonstrated the relevance of field-validations and calibrations to improve the air quality sensor data, the last two graphs showed the applicability of this Atmos sensor data in the context of the more expensive BAM monitors and that the sensors were able to closely track the data from reference monitors.

Delhi atmos 5881 co-located with US embassy device – 10 days in October



PM Patna – Hourly Median – Nov 1 2018 – Dec 31 2018



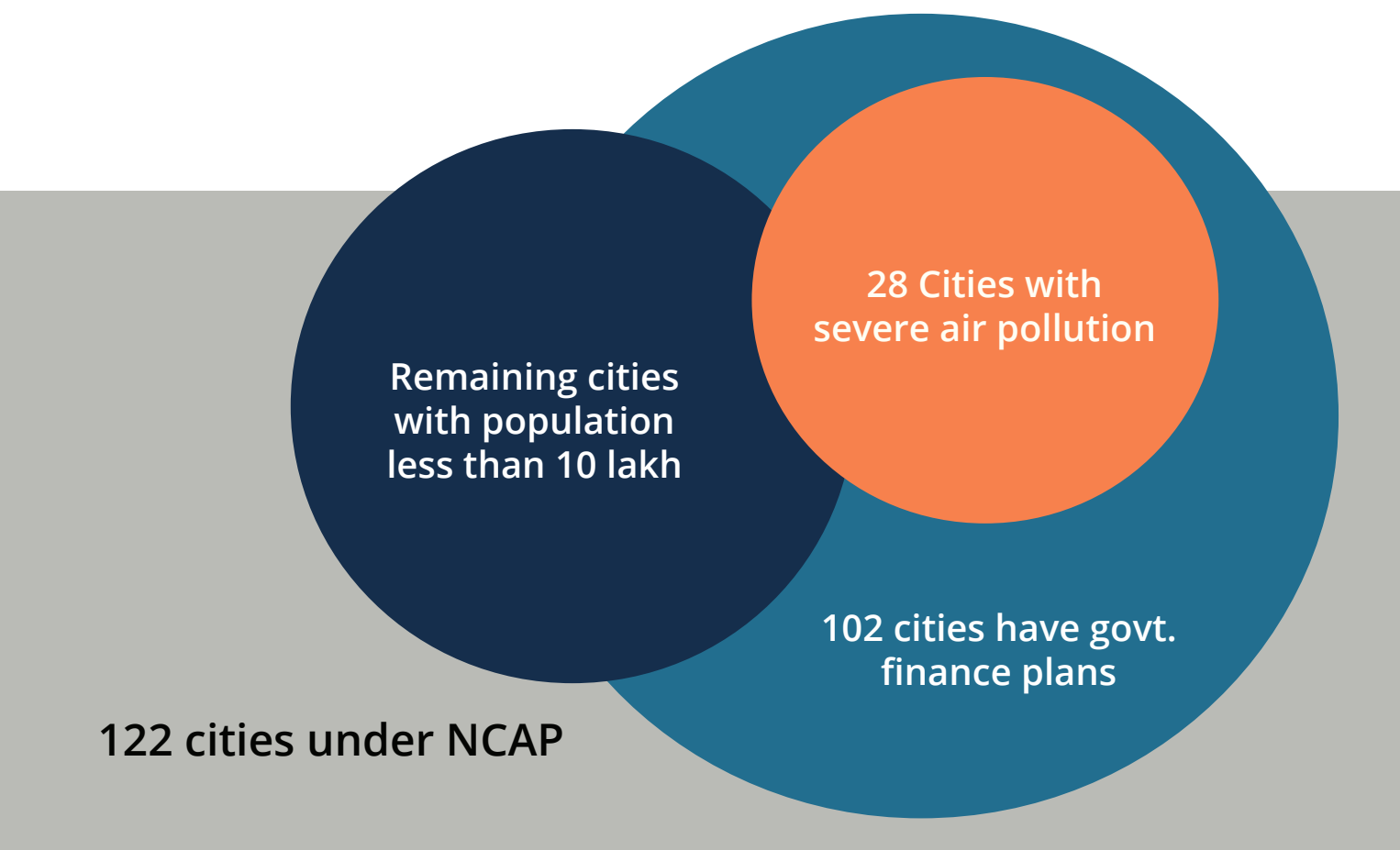


THE AIR QUALITY DATA ECO-SYSTEM

Today's Picture

The National Clean Air Program (NCAP) is going to be India's earnest effort towards monitoring and mitigating air pollution issues. Air pollution Monitoring and Real-Time monitors are and will play a major role in this. With good monitoring they will know pain points and if any implemented measures are effective. The NCAP team has made its target to reduce air pollution in all non-attainment cities by 30% till 2024. Currently the city-level air quality monitoring done by the Center and State Pollution Control Boards in India is with the help of Manual Monitors or CAAQMS (Continuous Ambient Air Quality Monitoring Stations).

Manual Monitors use Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week. The CAAQMS are state of the art equipment, but cost Rs. 1.2 crore (USD \$200K) or more. They also have a high maintenance cost. Because of their high cost, a large part of NCAP budget gets utilised in implementing handful of CAAQMS for the city. Due to their size and setup, these monitoring stations are static in nature and cannot be taken around.



For,

28
cities

with -



new

65



78 cr

+ existing 54 CAAQMs
+171 Manual Monitors

Total Spending by NCAP
on new monitors

with Atmos,

4,200

150 monitors per city

In terms of technology, the key focus areas of Respirer Living Sciences for the Atmos technology has been as follows:



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:

```
/model/eqm/1model/1value/1start1/cyyyyymmddhmm/1end1/cyyyyymmddhmm/1type/1cm1 or 1son or 1sv/1fx/1cm or 1h or 1d/1wsp/0,1,24/1api/req/1ip1to1to
```

Output: Raw data for following variables:

```
1time/1time;
1model, 1pm1cent=16qpm1cent=20qpm2, 1scnt=16qpm2, 1scnt=40qpm1(1scnt=60qpm0, 1scnt=70qpm0, 1scnt=89qpm0scnt=90scnt2opt=110qpm2opt=209qpm1opt=105qpm2opt=403scnt=254scnt=56qpm0scnt=5091at=19,11231216time=77,1123
```

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



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 km radius of a location

[illegible]

A screenshot of a tweet from Archil Srivastava (@ArchileSriva) posted on November 12, 2017, at 9:40 AM. The tweet text reads: "Air quality levels as recorded over the past 1 hour. #breathe pic.twitter.com/HkZha6Kalt". Below the tweet is a screenshot of the "IndiaSpendAir" app interface. The app shows PM2.5 at 849 µg/m³ and PM10 at 230 µg/m³, both labeled as "Severe". A circular gauge indicates the AQI Sub-index is 861.0, with a red needle pointing to the "Severe" section. The gauge has five segments: "Very Poor", "Poor", "Moderate", "Satisfactory", and "Good". To the right of the gauge, the text "Possible Health Impacts" states: "Affects healthy people and seriously impacts those with existing diseases". Below this, the "Data Center" information is listed: "Shakti Office, Manirika Phase III, New Delhi, Delhi NCR". At the bottom right, it says "LAST UPDATED NOV 12, 09:41".

AQ IoT integrations on citizen-friendly platforms

In Chandigarh, the Chandigarh Pollution Control Committee (CPCC) is carrying out a field evaluation study using network monitors' data to assess the performance of low-cost air quality sensors in comparison to the regulatory grade monitors.

An Al Jazeera documentary has recently featured the Atmos device in their "People and Power" series on air pollution.

Industry giants that have come forward to invest into hardware and physical network research and demonstration include Microsoft Research India and Ericsson India. They have collaborated with Respirer to build and test sensor networks. Respirer has been selected as part of the MSR India Center for Societal Impact through Cloud and Artificial Intelligence (SCAI) to work on Urban Air Pollution issues using advanced sensor and AI technologies.

<https://www.microsoft.com/en-us/research/theme/scai/>

IIT-Kanpur has become the foremost academic research group in India in using low-cost air quality sensor technology: Machine learning research group from IIT Kanpur is using network's data to develop an air quality prediction model. IIT-Kanpur, along with Respirer have conducted multiple analytics using the sensors.

In Jaipur, Doctors for Clean Air (DFCA) champions host Atmos monitors to provide health advisories to asthma patients and advocate for clean air.



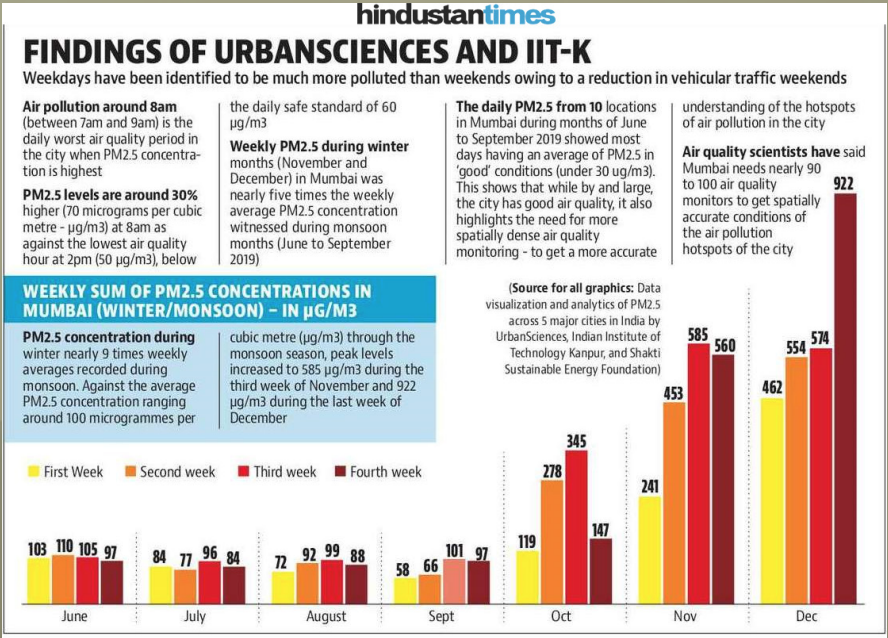
In Raipur, the State Health Resource Centre (SHRC), and the Public Health Department of Chhattisgarh are extensively using the network monitors' data for public health awareness and outreach in the city.

Research labs and regulatory bodies that have procured Atmos sensors to generate data and test sensor reliability include State Pollution Control Boards of Meghalaya, State Pollution Control Boards of Haryana, Indian Institute of Tropical Management, India Institute of Sciences, IIT-Gandhinagar, IIIT-Delhi, IIT-Delhi.

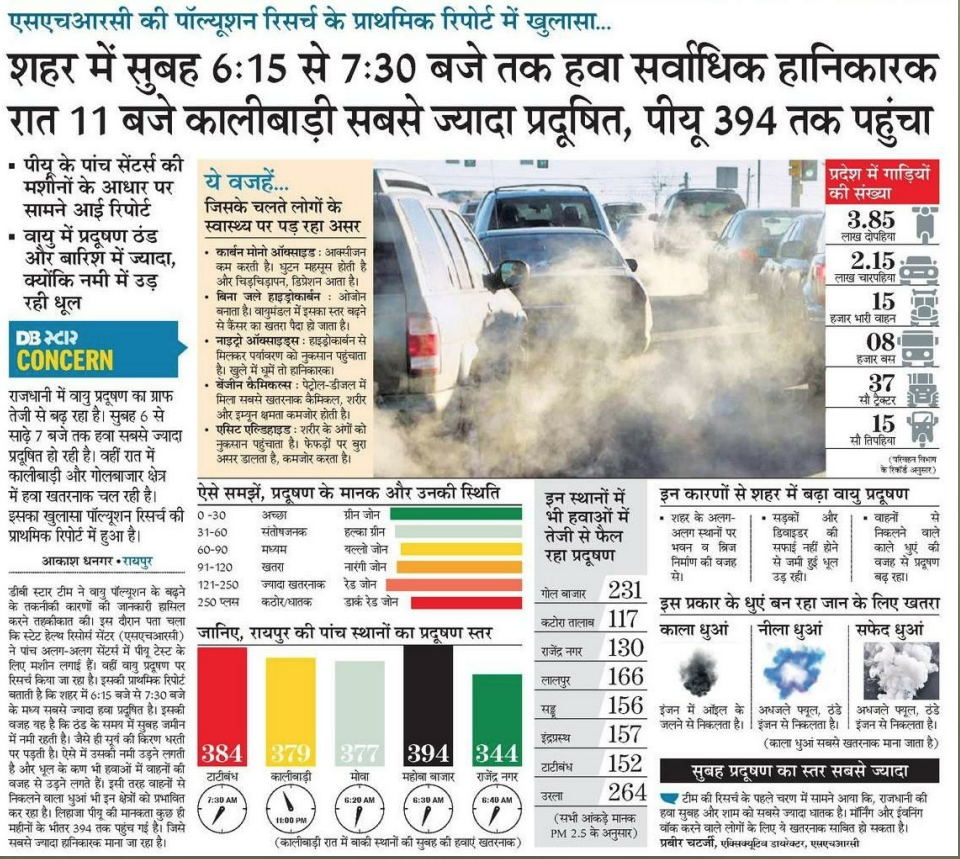
http://www.engager-energy.net/wp-content/uploads/2019/09/DAY-2_Patrik-Oskarsson-1.pdf

Impact of the Project

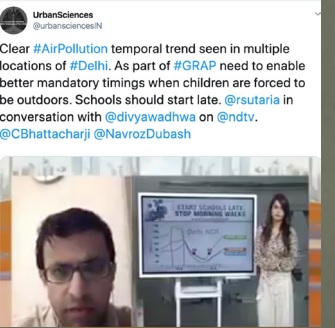
Based on the scientific validation of the Atmos air quality monitors, the deployment of 50 Atmos monitors were done in 10 cities of India. A number of city-level analytics reports were submitted as part of the data collected from the 10 cities. Many of these reports have been regularly featured in mainstream news media to further the data-driven understanding and conversations of air quality for the specific cities.



Findings from the Shakti report were published as a half-page story in the Hindustan Times on 9 Jan 2020.



Coverage in local media of Raipur air quality (based on the Atmos air quality monitors deployed in Raipur as part of the Shakti project).



Atmos monitors from the Shakti project were used for reporting on NDTV during the Ravana effigy burning and firecrackers episodes.

http://adriindia.org/adri/real_time_air_quality_status

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REAL-TIME AIR QUALITY STATUS

Patna ADRI PM2.5 µg/m³ - Shakti Fdn 10 City Project | Atmos Data

CEECC at ADRI, in collaboration with its consortium partners CSTEP & Urban Emission, has been preparing the Clean Air Action Plan for Patna, Gaya and Muzaffarpur under the patronage of Bihar State Pollution Control Board. This project is fiscally funded by Bloomberg Philanthropies through Sustainable Energy Foundation and Growald Family Fund. Under this project, CEECC at ADRI along with Urban Sciences has installed air quality sensors at various sites across Patna and Ranchi to monitor the air quality status.

Data from the Atmos Patna monitors were integrated into the ADRI portal and presented to the Bihar state PCB.

Following reports have been submitted by the team, as part of the city-level analytics:

<https://shaktifoundation.in/initiative/low-cost-air-quality-monitors-in-50-indian-cities-to-provide-real-time-and-credible-air-quality-data>

Data Visualization and Analytics of PM 2.5 Air Pollution in 5 Indian Cities (June 2019 to November 2019)

Data Visualization and Analytics of PM 2.5 Air Pollution in 5 Indian Cities (October 2018 To May 2019)

Visualizing the Impact of Episodic Air Pollution During October 2018 to February 2019

Visualising the Impact of Air Pollution During October and November 2018

What can you do?

Real-time Air Quality monitors are used to monitor the ambient quality of the air that we breathe. Now there are a lot of advantages of monitoring the quality of air that you are breathing in real time.



Policy makers can implement evidence-based policy-design for regulatory compliance and for knowing ambient conditions across the city on long term basis.



Industries use air quality monitors to figure out the pollution levels caused by them and implement mitigation methods to control air pollution at the source.



Doctors are using Ambient Air Quality Monitors to observe air quality inside hospitals, especially ICU wards where air quality is critical. Also programs like DFCA (DoctorsForCleanAir) collaborate with doctors to spread awareness and steps against air pollution and health tips.



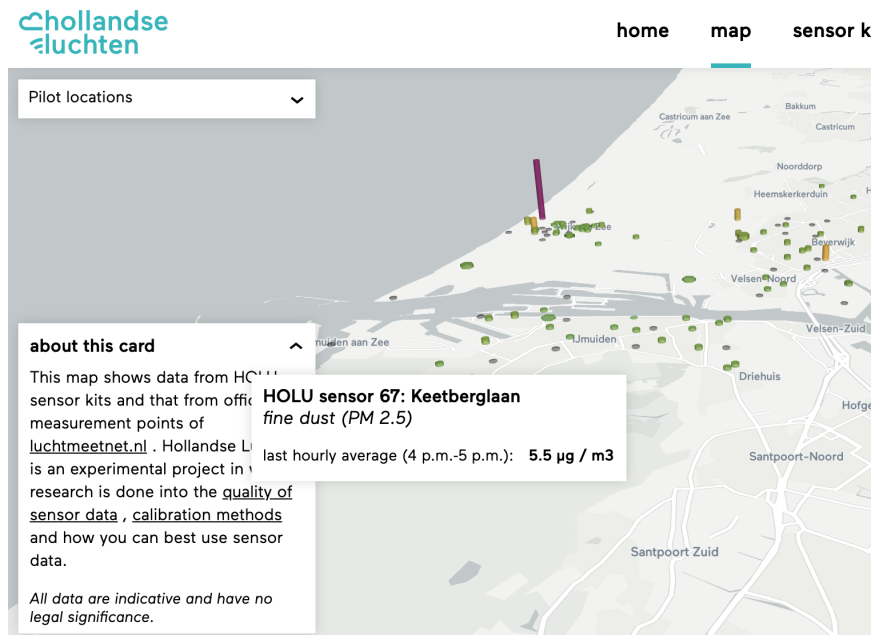
Indoor air quality monitoring in a residential complex or inside homes is very common. People use special filters in their air conditioners or special air purifiers to improve air quality. Also the outdoor air pollution levels measured by citizens helps create a database network spreading air quality awareness.



Air pollution affects children the most leaving long term effects. Education Institutions, Day Cares, Playgrounds and other organizations that work with children monitor ambient air pollution and try and maintain good air quality.



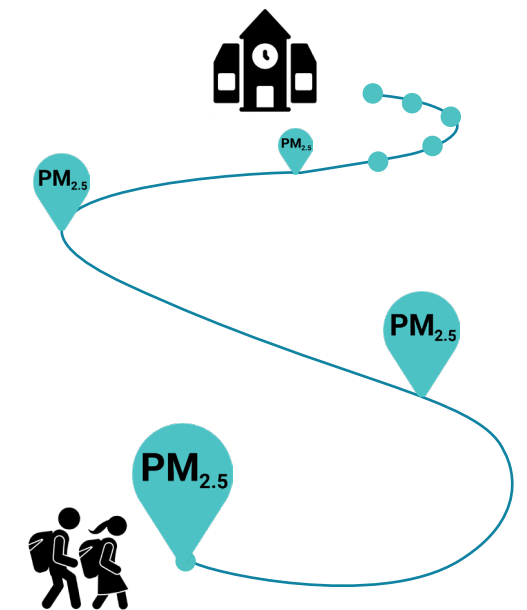
Big companies, commercial buildings and co-working spaces are using HVACs (Heating, Ventilation and Air Conditioning) and air quality monitors to improve their systems to have good air quality inside their buildings.



Public health researchers are using low-cost air quality sensors to better understand the effects of industrial air pollution in high-emission zones like notified industries (cement/concrete factories, steel plants, thermal power plants, etc). Setting up fence-line monitoring around high polluting industries can result in substantial health benefits for citizens living in the vicinity of that industry.

An example of this is the city-level fence line monitoring done by citizens to monitor a steel plant in Amsterdam.

Building a specialized air quality community engagement analytics platform, where specific communities of users can access air quality and air pollution analytics for more informed decision making at an individual or community level. An example of this would be a children/school focused air quality analytics platform for a given city. Such a platform would allow schools which are using realtime Atmos air quality monitors to get deeper insights into their air quality data, especially from an exposure perspective to children at different times of day. Citizen science studies like “Changing a child’s route to school can halve exposure to air pollution” has found that just changing the route taken by a child from main roads to smaller by-lanes to reach their school can halve their exposure to air pollution. Studies like these use low-cost air quality sensors combined with simple to understand air quality analytics platforms which can inform citizen while they are taking daily decisions which can impact their health.





LOOKING FORWARD

Sustaining Low-Cost Real-Time Air Quality Monitoring Networks

The Shakti Sustainable Energy Foundation (SSEF) supported project “Measurement & dissemination of air quality data using low cost monitors in 10 cities” enabled core science and technology related advances in the field of low cost air quality monitoring. The dissemination of the data collected in the duration of this project facilitated several important dialogues and awareness related to air pollution in the 10 cities where these monitors were installed.

Respirer Living Sciences, in collaboration with foremost technology companies like Microsoft Research, Ericsson India and academic research institutes like IIT Kanpur, IIT Bombay and IISc Bangalore is working on building a very robust, scalable and advanced low cost realtime air quality monitoring device and networking technology.

A lot more focus and investments are required in the use of realtime air quality data for impacting evidence based air quality policy design and citizen engagement in India. For building sustainable low-cost air quality monitoring networks in India, continued investments are needed in developing the low-cost air quality monitoring analytics platform.

In summary, building a sustainable low-cost air quality monitoring network requires more focused ground-level air quality monitoring around known high-emissions sources, especially industries and construction sites. Combining this with advanced air quality analytics and visualization system would make the necessary impact in building awareness as well as building lasting mitigation solutions for urban air pollution.

You can make a difference-

For feedback, suggestions, PM2.5 datasets and API access to the data, email – research@urbansciences.in

For more technical details and to view the realtime dashboard, visit – <http://atmos.urbansciences.in/dashboard/SSEF>