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Evolution of ambient air quality monitoring systems

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Introduction

With increasing population, urbanization, and industrialization, air pollution is emerging as a significant problem. According to WHO (World Health Organization), around 90% of people worldwide breathe polluted air. Further, a study published in The Lancet Journal of Planetary Health states that poor air quality is also the cause of around 1.24 million premature deaths in India. Vehicular pollution, road dust, construction, industrial pollution are some of the major sources responsible for air pollution. Maintaining good air quality is already a major challenge for authorities. As a step towards awareness and maintaining air-quality levels within permissible limits, many countries have developed the Air Quality Index (AQI)

On 17th September 2014, the Government of India announced the Air Quality Index of India.

AQI provides a good understanding of the overall air pollution scenario. But to calculate AQI, it is necessary to measure the concentration of various air-quality parameters such as $PM_{2.5}$, PM_{10}, CO, NO_2, SO_2, O_3, NH_3, etc. Air quality monitoring is also important to understand the spatio-temporal variation of various pollutants. As the saying goes - "you cannot manage, what you cannot measure", air quality monitoring is the first step in understanding the global issue and an inevitable step in developing mitigation strategies.

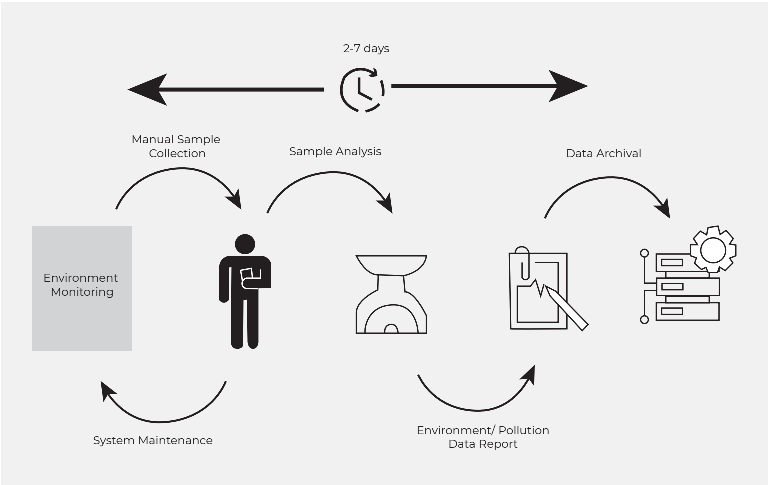
The Evolution

There are many different approaches and methods available to measure the pollutant concentration in the ambient air. They are chosen based on the frequency, purpose, objective, and budget of the monitoring program. The three generations of air quality monitoring systems showcase the technological developments that have taken place over the years

First Generation Ambient Air Quality Monitoring System (AAQMS) – High Volume Air Sampler

High Volume Air Samplers (HVS) are traditional manually operated units that are used to collect air-pollutants like dust particles and gases by maintaining constant air-flow from the instruments, usually for 24 hours. The samples taken from this approach are grab samples, and they are taken at fixed intervals.

For measurement of particulate matter, HVS draws air at a constant flow rate through a pre-weighed filter selected based on the size of particulate to be measured for 24 hours (8-hourly sampling for particulate matter 4 hourly sampling for gaseous pollutants). The filter is then carefully taken to the lab for gravimetric measurement and subsequent calculation of weight difference (pre-sampling and post sampling). While in case of concentration of gaseous pollutants, the sample is collected in an impinger which is pre-filled with the stipulated amount of specific chemical reagent. The solution is then analyzed in the lab with wet-chemical titration (titrimetry). It takesnearly 32-34 hours for a complete analysis of particulates and 4-6 hours for gaseous pollutants. This is then followed by



archiving of the records along with the preparation of reports for the stakeholders.

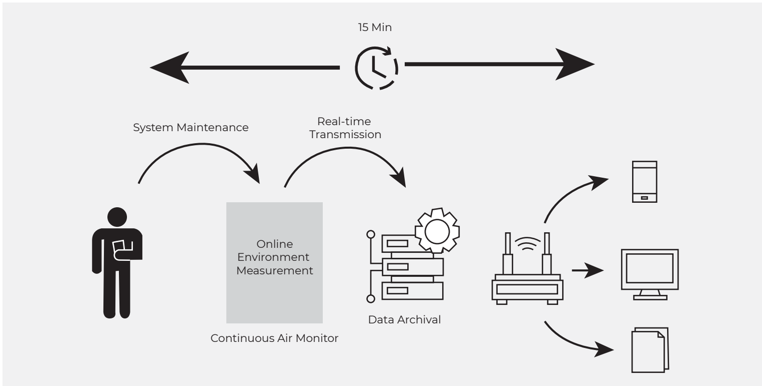
The operation of High volume air samplers demands extensive manpower. Additionally, ensuring the data quality requires analytical quality control, highly skilled staff, periodic maintenance of instruments, a fully functioning & properly maintained laboratory. Hence, the possibility and probability of human and instrumental errors increases. Such operational limitations led the Indian guidelines to set a frequency of bi-weekly measurement with a minimum of 104 measurements per year. According to the National Clean Air Program (NCAP) report 2019, there are 703 monitoring stations in 307 cities in India.

The Schedule of Sampling and Analysis Charges for Environmental Samples, MOEF&CC, states the cost of sampling and analyzing all the parameters of AQI using HVS for 8 hours is $175 and for 24 hours is $260. If Lead is measured through Energy Dispersive X-ray Fluorescence (EDXRF) then it is $235 and $330 respectively.

Second Generation Continuous Ambient Air Quality Monitor System (CAAQMS)

With all the manual and laboratory work in the first-generation monitors, the total time from sampling to getting the results typically takes a few days. Consequently, even with continuous sampling through HVS, the opportunity of taking corrective action is delayed. CAAQMS are specially designed to solve this problem. According to the NCAP 2019 report, there are currently 134 CAAQMS stations in 71 cities and 17 States.

CAAQMS consist of various sophisticated automatic analyzers that measure the concentration of targeted pollutants. They work on the principles such as Ultraviolet Fluorescence, Non-dispersive infrared spectroscopy, Gas Chromatography based continuous analyzers, etc. All such analyzers are placed in a fixed station, which is usually a kiosk lab (usual dimensions according to CPCB: 4.2m x 3.5m x 2.5m). The monitoring station automatically takes an air sample at the interval of a few minutes and measures the concentration of different pollutants in the respective analyzer. The results can be automatically published and they are usually reflected on a web server, designated website, etc. CAAQMs require very less manual intervention and the frequency of maintenance work is also very less.



Although the manpower demand is low, individual analysers and larger space requirements make the capital investment higher for these systems which majorly comprises the monitoring station costing around $100,000. In addition to this, the cost of the space along with operational costs like manpower, electricity and calibration gases make it an expensive solution. Although they provide quick results that are near real-time in nature and also provide a good picture of the temporal variation of pollutant concentration, these stations being stationary, expensive and having a higher footprint, make their deployment limited. Due to these limitations, CAAQMS are economically not viable for applications where larger areas (city/town) to be monitored with high spatio-temporal resolution.

Third Generation AAQM – Sensor Based Monitors / Low-Cost Sensors

Air quality is a very dynamic property and it shows great spatio-temporal variations. The first and second-generation air quality monitors are unable to create a representative picture of a region due to limitations in multiple installations. Sensor-based air quality monitors are the latest advancement in the line of ambient air quality monitoring devices. They can measure a wide range of particulate and gaseous air pollutants based on the proven working principles such as light scattering, electrochemical sensors, photoionization detection (PID), nondispersive infrared (NDIR), etc.

	1st Generation : AAQMS Ambient Air Quality Monitoring System	2nd Generation : CAAQMS Continuous Ambient Air Quality Monitoring Station	3rd Generation : CAAQMS Sensor-based Continuous Ambient Air Quality Monitoring System
Technology	Gravimetric & Titration Analysis using HVS (High Volume Samplers)	Analyzer Instrumentation	Sensor Based
Data Monitoring Method	Manual Analysis in Laboratory	Automated Continuous Monitoring	Automated Continuous Monitoring
Data Frequency	1 data point from 8Hr sample	Continuous (every minute)	Continuous (every minute)
Man-power Required	16 Man Hours per monitoring	Not Required	Not Required
Electricity Required	600-800 Kw.Hr. / year	4-5 Mw.Hr. / year	25 Kw.Hr. / year (No power required if Solar Powered)
Cost * for PM2.5, PM10, SOx, NOx, CO, O3 Monitoring	CAPEX : $7000 - $10,000 OPEX : $500,000 / year	CAPEX : $80,000 - $120,000 OPEX : $15,000 / year	CAPEX : $5000 - $ 8000 OPEX : $1000 / year

Similarly to CAAQMs, sensor-based monitors are capable of recording pollutant concentrations at every minute and provide real-time pollutant concentrations. The results can be easily published via a website, web server, an app or integrated to any existing platforms. Also, using advanced algorithms, the temperature-humidity compensation in sensor-based systems can be carried out at the data processing level. However, compact and lightweight form-factor enables retrofitting in an existing infrastructure like a lamp-post, wall, fence etc. Due to very low capital cost compared to instruments of the previous two generations, limited manpower associated with its operation, and subsequent negligible operational cost, they are also referred to as low-cost monitoring sensors. Low-cost sensors consume less power and have capabilities to work on battery backup & solar power.

Remote calibrations and OTA (over the air) updates are possible with the low-cost sensor-based monitoring system. Periodic spot calibration is recommended at least twice in a year which can be carried out by either using a reference station (CAAQMS) or recently calibrated (against reference station) sensor-based system. Similar to CAAQMS (Reference stations), on-site calibration is also possible using reference gases. However, this is possible only if the sensor-based monitoring system works on an active sampling method. In active sampling, a sophisticated inlet and exhaust mechanism assists the span calibration of gases by proper fitment to reference gas cylinders.

The Future Of Air Quality Monitoring

Experts mention air quality research as a field that requires high spatial and temporal resolutions of air pollution monitoring and it is important to create a representative picture of the air quality for any region to mitigate the air pollution issue. Air quality monitors suitable for regulatory quality data collection must meet the very exacting standards of performances like that of regulatory grade instruments, and currently, no low-cost sensor meets this strict data quality and performance requirement. But, direct collocation of sensor-based systems with regulatory grade instruments is one approach United States Environmental Protection Agency

(USEPA) researchers, and other researchers have employed to establish the calibrated response from the low-cost sensors. Various studies on accuracy and precision on low-cost sensors are being conducted evaluating their performance as compared to reference stations, accuracy and precision so that they can be an alternative to the FRM Federal Reference Method (FRM) grade instruments. Nevertheless, advantages like low cost, feasibility in wider deployment, portability, real-time display & data dissemination, ease of operation, less maintenance and operational cost enables us to use them in the following cases:

USEPA, in its Roadmap for Next Generation Air Monitoring, has identified sensor-based systems as the next generation of air monitoring devices, and advances in the air pollution sensors are also part of EPA's new E-Enterprise for Environment initiative. European Union has also identified the importance of low-cost sensor-based monitors and employed them for air quality monitoring research, which was carried out by MACPoll, 2 a research program under the European Metrology Research Program, and AIRMONTEC, a research program financed by the European Commission. In India, the BIS (Bureau of Indian Standards) is working with NPL (National Physics Laboratory) and CPCB to develop technical specifications for Particulate matter $PM_{2.5}$ and PM_{10}. Policy interest is also increasingly growing in potential deployment of low-cost monitors, especially in the areas which are not covered by the traditional regulatory networks, and also as supplementary monitoring networks, where air sensors are deployed along with the regulatory monitors to complement the data and to fill the spatial gaps. With recent advances in AI and Machine learning, it is possible that in the near future usage of reference stations may be limited to a hybrid network in combination or for calibration of low-cost sensors on a semi-annual basis.

Oizom's Offerings

Oizom has a wide range of sensor-based air quality monitoring systems for all kinds of applications which provides real-time air quality monitoring data along with meteorological parameters. Deep machine learning algorithms of Oizom ensure high data quality which gives more than 90% accurate data when calibrated against the standard reference system.

Oizom not only provides air quality monitoring but also offers comprehensive and scalable analytics. The data sent by Oizom's sensors over the cloud is made actionable by performing advanced analytics. The data can be published on various mediums like Web App, Mobile App, Display units, and can be further used in dispersion modelling, emission inventory, and health exposure studies.

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