WHITE PAPER

Mapping of Air Quality Monitoring Systems to cover an area for Hyperlocal Data

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Introduction

Air quality data serves as the basis for all pollution mitigation strategies. A comprehensive air quality monitoring network provides valuable data insights to support effective air pollution management. Traditionally air quality monitoring is carried out using fixed reference-grade analyzers which are inherently very expensive. As a result, they can only be deployed in limited numbers and such sparsely located monitors fail to provide critical pollution concentration at human exposure level. As a result, air pollution exposure continues to affect human health and well-being. With technological advancements, sensor-based air monitoring devices have emerged as the latest generation of air quality monitors. Their economic cost and highly portable design make them a one-stop solution for all air quality monitoring needs. Their feasibility of dense deployment provides unprecedented details of pollutant concentration at the human exposure level. Such a monitoring network facilitates hyperlocal air quality monitoring.

This paper describes what is hyperlocal monitoring and why it is important. The paper also serves as a guide for designing and setting up an air quality monitoring network to cover an area for hyperlocal monitoring.

Hyperlocal Monitoring

Measuring air quality is a complex process because air pollution concentration is highly variable. Its distribution can be highly heterogeneous over a relatively smaller scale. As a result, the air quality of two points can be considerably different even if they are located within the same city block. Conventional air quality monitors such as Continuous Ambient Air Quality Monitors (CAAQMS) cannot account for such high spatial variability in pollutant concentration. They can only provide a general sense of overall air quality and fail in providing human exposure level concentration. Such missing details of pollution exposure creates a data gap in health and well-being studies. Hyperlocal monitoring bridges that gap and provides a detailed picture of air quality at a neighbourhood scale, where people live and work. It provides air quality information at every 30-60 m, depending upon the spatial resolution of the monitoring network. Such a monitoring network called hyperlocal because it provides air pollution information at the human exposure level.

> *"Hyperlocal air pollution monitoring can provide valuable information to target policy and empower citizens with data important to their health. It enables communities to ask the right questions, develop new monitoring studies, and reach for solutions that are available right now to clean the air."*
>
> *-Iyad Kheirbek, Program Director, Air Quality, C40 Cities.*

Importance Of Hyperlocal Monitoring

Sensor-based air quality monitors are cost-effective, portable, and provide high-quality air pollution data. Due to this reason, it is feasible to deploy them at such a high spatial density to cover an area for hyperlocal data. With their use, exposure level pollution can be measured and mapped at places such as educational institute campuses, hospital campuses, housing societies. Even a part of an urban area can be effectively monitored for air pollutants. People spend a significant amount of time at such places and these places are important economic zones too. It is very much important to understand air quality and its dynamics in such places because air pollution affects human health and well-being. Apart from this it also affects cognitive abilities, focus, and attention. This results in reduced work efficiency and productivity, creating a huge economic burden.

Hyperlocal air quality monitoring network provides a complete picture of the air that people are breathing. That understanding serves as the basis to develop unique and customized solutions to reduce pollution exposure. Monitoring hyperlocal air quality serves benefit to everyone and it significantly increases human health, wellbeing, and productivity.

> *"The global economic cost of air pollution in 2018 was $2.9 trillion, out of which $150 billion worth of economic loss was suffered by India.*
> *-Centre for Research on Energy and Clean Air."*

How To Carry Out Hyperlocal Monitoring

Designing a monitoring network involves calculating the number of required monitoring locations. Conventionally guidelines for such calculations are provided by regulatory authorities. However, such guidelines are developed for the fulfilment of regulatory and legal requirements of air quality monitoring. They are not designed to serve as a guide for planning hyperlocal air quality monitoring. The Central Pollution Control Board's (CPCB) guidelines IS5182 (Part 14): 2000, are based on the population of the area. According to it, a city with a population of 0.5 to 1 million should have one station to represent an area of 10 to 20 km2. Even in the regions with a large number of sources, the guidelines mention providing one monitoring station for 5 to 10 km2. Such sparsely located monitoring stations cannot provide detailed air quality information.

Hyperlocal air quality monitoring networks are designed to capture small scale variability in pollutant concentration. Due to its highly subjective nature, it is not possible to derive generalized criteria to set-up hyperlocal monitoring networks. A number of required monitoring stations must be calculated by taking into account unique local factors and the objective of the study. Common purposes/objectives of hyperlocal monitoring are listed below.

- Identifying sources of pollution and marking hotspots.
- Assessing source impact on population
- Human exposure studies / epidemiological studies
- Creating awareness and urgency for poor air quality in a locality or city

- Monitoring air quality to take mitigative actions and plan policies like; Public health interventions, transportation planning, and traffic management, zoning or permitting building codes, targeted investment, and incentives for emission reduction projects.
- Planning of Low Emissions Zones (LEZ)
- Fill data gaps in the existing network of regulatory air quality monitors.
- Efficacy assessment of policy intervention

Development Of Hyperlocal Air Quality Monitoring Network

Identifying the purpose of monitoring gives an overview of the monitoring locations and also provides a fair idea of the required number of monitoring locations. However, to plan and deploy a network of air quality monitors, additional information on a given area is required. Understanding of pollutant concentration variability and distribution is required to calculate the required number of monitoring locations. A preliminary survey is carried out to gather and analyze the following information. Based on the following details and objectives of the study number of monitors and their locations are selected.

Demographic Data

A preliminary survey is conducted to understand and identify potential sites for monitoring. Primary data such as population distribution, density, land use, industries, sensitive receptors (schools, parks, hospitals) are studied. Monitors are placed in areas with high population density or sensitive receptors at the breathing level. Opinions from the nearby communities and experts are also considered for selecting the locations of the monitoring instruments.

Emission And Meteorological Data

Emissions due to industries, vehicular activities, construction and mining, airports, etc. deteriorate the ambient air quality. Emission data from studies like emission inventory are required to identify the hotspots and selecting the locations of the monitoring instruments. The air pollutants from such hotspots are transported to different places based on meteorological parameters such as wind speed, wind direction, temperature, mixing layer, etc, and topographical features. Based on existing emission and meteorological data dispersion analysis is carried out using dispersion models to generate isopleths and contours. Isopleths help in understanding the spatial variability of the ambient air pollutant concentration. This further helps in selecting the location and determining the number of ambient air monitors.

Existing Monitoring Stations

Air quality data from previously installed continuous ambient air quality monitoring stations

(CAAQMS) or manual air quality stations is analyzed to identify the spatial pattern of ambient air concentrations. Statistical analysis is carried out to understand the trend of air quality. A hybrid network is developed by deploying new low-cost sensor-based monitors in the area lacking monitoring stations.

Calculation And Selection Of Required Monitoring Stations

Based on the above-mentioned information, the number and location of monitoring devices can be calculated. Various models such as Multi-Criteria Decision Making (MCDM) Models can be used to aid location selection process. These models also take various siting criteria into consideration and rank sites in order of suitability for various applications. As a result, a customized hyperlocal air quality monitoring network can be designed. Based on the factors explained above, various case-studies have derived a provisional reference number of required monitoring locations for hyperlocal monitoring.

Environmental Defense Fund's (EDF) case-study in Oakland, Houston, and London (Breathe London Program) suggests the requirement of 6-7 monitoring devices to represent 1 km^2 area in case of very high variability and pollution distribution. It is sometimes difficult to achieve this number due to budget constraints. In a general case for urban monitoring, OIZOM recommends 12-15 monitoring devices to represent an area of 25 km^2. Such a network can be aided with dispersion modelling capabilities and 100 x 100 m resolution pollution maps can be generated at economical cost. However, budget constraints can be also overcome by efficiently placing monitors based on the objective. For example, in the case of university, hospitals or housing society; hotspots of human activities can be identified and monitors can be placed in order to record human pollution exposure.

Based on various empirical studies and factors explained above, a generalized station requirement is identified. The table summarizes station requirements for various monitoring objectives. The reference table only serves as a piece of general guiding information. The actual number of monitoring locations must be calculated for a given region based on the factors mentioned above.

Onsite Factors

The height of the device is determined based on the purpose of the monitoring such that a representative data is recorded.

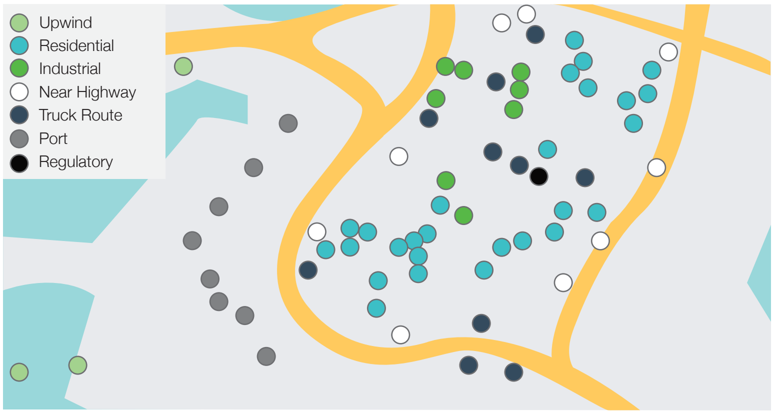
Purpose	Height
Human Exposure	Human Breathing Zone at the height of 2 - 4 meters.
Background Monitoring	Away from the influence of ground-level sources at the height of 10 - 14 meters.

After the locations are selected, sites are manually surveyed to determine the place of deployment of the instrument. Various factors like obstruction, overshadowing, presence of strong electromotive force (EMF) disrupt the sensor functioning and generate erroneous results. The following site-specific criteria ensure accurate data:

Location Of Monitor	Purpose	Minimum Requirement Of Stations Required
Industry / Construction sites / Airports / Ports / Mining sites	Source monitoring	1 station/device each near the source.
	Dispersion Study	1 station/device upwind to the plant boundary 1 station/device downwind to the plant boundary 1 station/device each at the nearby receptor/s.
	Health Exposure	1 station/device for every 0.5 - 1 km2
Hospitals / Universities / Schools / Parks	Source monitoring	1 station/device near vehicular activity
	Health Exposure	1 station/device each at the location with maximum human exposure risk.
	Background Monitoring	1 station/device upwind to the location.
Residential Areas	Health Exposure	1 station/device for every 0.5 - 2 km2
Tunnels / Underground Parkings	Health Exposure	Total 2 stations/devices at the entry and exit of the tunnel or parking. 1 station/device in the parking or tunnel centre for every 0.5 km2.

Table 1.1: Minimum number of monitoring stations based on the purpose of monitoring.

- A clear Angle of 270 degrees.
- A clear spacing of 2-5 meters from buildings.
- North facing orientation.
- Clearance of 1-meter radius.
- 10 meters away from the dripline of trees.
- Away from mobile network towers, transformers, generators, high voltage electrical lines.
- The detailed good practices for selecting locations for robust monitoring can be found in Oizom's Whitepaper - Location of Sensor-Based Monitoring Systems.



However, the number of monitoring devices greatly depends on the overall budget allocated for the project.

Budget Consideration

The number of monitoring devices depends on the purpose of monitoring, targeted pollutants, and the budget. The cost of low-cost sensors ranges from USD 100$ to 10,000$. The budget allocated to the project includes the initial capital cost of the sensors, maintenance and calibration cost, analysis cost, etc. Sometimes it may not seem economically feasible to deploy the designed number of monitoring instruments (For eg 6.7 monitors/ km2). The number of stations per km2 is reduced, to 1 per 0.5km2 or 1 per 2-4 km2. For example, the BEACO2N project in Northern California developed a distributed network of approximately 50 multi-pollutant sensors 'nodes', at approximately 2 km spacing in locations surrounding the San Francisco Bay Area.

If a limited number of devices are available, an active device can be relocated after calibrating it with the reference station at the new location. However, it is suggested not to relocate the monitoring device to a new location.

System And Calibration

Once an air quality monitoring network is established, it is very much important to ensure that the air quality data recorded by them is accurate. Periodic calibration of sensor-based systems is required to accurately measure air pollutant concentration in all environmental conditions. Data quality checks and assessment (QA / QC) ensures that the highest quality data is recorded. There are many methods and approaches to carry-out calibration and data QA / QC; which are explained below.

Laboratory Calibration

Manufactured sensors are passed through various laboratory tests to check for their precision and accuracy. It is a pre-deployment calibration approach. The sensor is exposed to a reference gas of known concentration to calibrate it from errors and data bias. Such tests are repeated several times to ensure the highest level of data quality. Only those sensors with benchmark performance in precision and accuracy are declared passed from the test to be deployed in the field.

Collocation with Reference Monitors

Various factors of ambient air such as high temperature, relative humidity, high dust pollution may affect the sensor's ability to measure air quality accurately. Laboratory calibration cannot account for such factors inside the controlled environment of laboratory conditions. Colloca-

-tion is a pre-deployment calibration approach to calibrate air quality monitors by placing them along with reference monitors in real-world situations. Data from sensor-based systems are compared with reference stations to carry-out calibration. To know more about collocation study, steps involved in it and various statistical methods read OIZOM's whitepaper - Collocation study of sensor-based CAAQMS with Reference systems.

On-field Calibration

Similar to the laboratory calibration approach, reference gas of known concentration is exposed to sensors after deployment in the field. Sensors such as OIZOM's PolludroneTM works on the principle of active sampling, which maintains a controlled micro-environment within the system body. Such a design allows the on-field calibration through reference gas. With this approach, the effect of the ambient environment on the sensor's performance can be quantified. However, this is a costly and time-consuming method.

Setting up a Hybrid Monitoring Network

A hybrid network of air quality monitoring devices can be set-up by deploying multiple sensor-based air quality monitors with reference stations in the same locality. As reference stations are also placed within a similar ambient environment, air quality data from reference stations can be compared with air quality data from sensor-based monitors. It is a very cost-effective approach that ensures high data quality. However, the establishment of a hybrid air quality monitoring network depends upon the availability of reference stations in the same locality.

Spot Calibration by Data Comparison

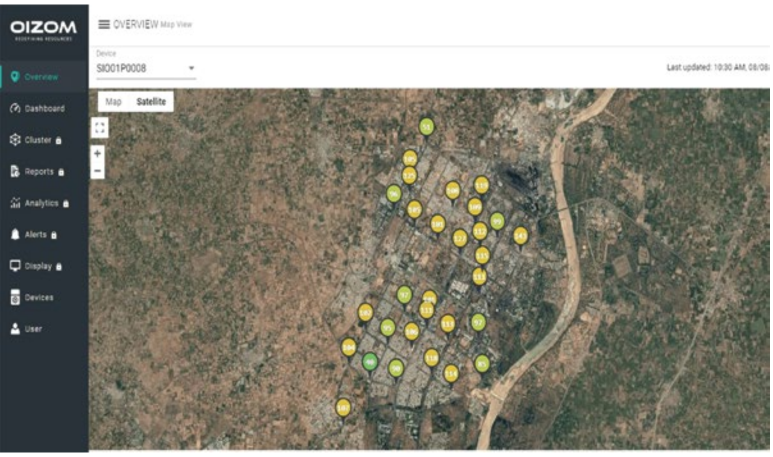
An air quality monitoring network consisting of multiple air quality monitors facilitates inter-comparison of air quality data. When any of the monitoring devices record outliers or data drift, it can be compared with data recorded by other devices of the network. If it is found that the outlier is due to the sensor's error, required data corrections are carried out. Algorithms can be trained to perform such tasks automatically or with minimum human intervention. Spot calibration can also be carried out by comparing data with recently calibrated monitors.

The selection of the calibration approach depends upon the objective of the study, the ambient condition of monitoring location, budget availability, and required data accuracy. The details can be found in Oizom's Whitepaper - Different Stages for Calibration of Air Quality Monitoring System.

Oizom's Offering

Case study of Gandhinagar city:

Gandhinagar, the capital city of Gujarat, has undertaken a number of projects as a part of its Smart City Mission. Real-time air pollution monitoring was an integral part of their Smart City Mission. Gandhinagar Municipal Corporation with the help of Oizom deployed PolludroneTM for conducting hyperlocal monitoring to constrain the negative impact of pollution on the city using advanced technology. An ambient air monitoring nexus was created throughout the city by strategically installing the equipment. The data generated helped in assessing the ill-effects of polluted ambient air on citizen's health. This helped in taking data-driven actions to mitigate pollution at highly risk-prone areas like Akshardham Temple, Adalaj ni Vaav and other heritage sites along with the State Government Buildings.



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