Designing an Air Sensor Monitoring Network

Starting a monitoring network but not sure where to begin? Use this guide!

What is an air monitoring network?

An air monitoring network is a collection of air sensor sites distributed throughout a region. BBecause air pollution is emitted by many sources and it moves with the wind and weather, a network lets you detect air pollution across a city, town, or region. When designed and operated well, an air monitoring network can be used for a wide range of applications. The goals of a monitoring network are to create general air quality awareness, identify areas of exposure, and identify sources.

This worksheet will help you design an air quality monitoring network:

General Air Quality Awareness

Understand general air quality in the monitoring area & inform the public

Exposure Identification

Identify areas where people experience high exposure to pollution

Source Identification

Locate emission sources

Introduction

The goal of an air sensor network is to understand air quality differences in time and space. These differences allow you to see when and where air pollution is higher and lower.

Emission sources and weather cause air quality to vary over time and location. For example, the area around a major source of pollution may have higher pollution concentrations, but on a windy day, that pollution may get blown into other areas.

Variations can also be caused by the seasons; typically in the spring or fall, agricultural land is often burned, which produces smoke and $PM_{2.5}$. Likewise, sunlight converts emissions to ozone during summer's direct sunlight.

Measuring Pollutants

Particulate matter ($PM_{2.5}$, PM_{10}), Ozone (O_3), and nitrogen dioxide (NO_2) are the major pollutants of concern when creating an air sensor network. These pollutants have serious health effects, and their concentrations are accurately measured by air sensors.

Air sensors can measure other pollutants such as carbon monoxide (CO) and carbon dioxide (CO_2), but typically these pollutants are not major health risks outdoors. Also, there are many other air pollutants in the air. Certain pollutants are very difficult to measure with air sensors, such as sulfur dioxide (SO_2), volatile organic compounds (VOCs), and hydrogen sulfide (H_2S).
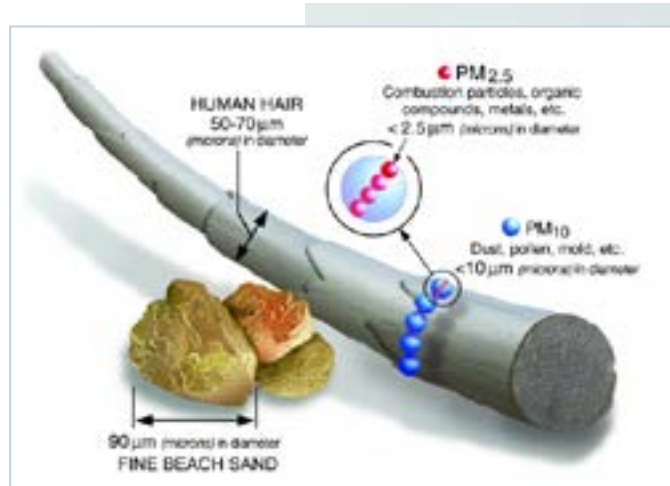
Pollutants and their Sources

Pollutant	Sources
Particulate matter ($PM_{2.5}$) – Microscopic particles of soot, and other matter, including tiny liquid droplets	Diesel engines, power plants, industrial processes, wood stoves, fireplaces, and wildfires
Particulate matter (PM_{10}) – larger particles of soot and dust	Industrial processes, windblown dust, road dust, construction activities
Ozone (O_3) – a gaseous pollutant that forms in the atmosphere from Nitrogen Oxide and VOCs	Vehicle exhaust and other fumes, industrial processes, sources of VOCs
Nitrogen dioxide (NO_2) – a gaseous compound made up of nitrogen and oxygen that forms in the atmosphere	Vehicles, power plants burning fossil fuels, coal-burning stoves

Sensor Placement

A well-designed and representative network lets you measure air quality for many applications. This section guides you through where to place sensors using a geographic map. On this map, you will identify areas of interest using some general criteria and guidelines. You'll then evaluate the network and compare it to other air monitoring networks.

Step 1: Locate a Map 🗺️

Get a map of the area you're planning to monitor. You could use an online mapping tool like Google Maps or a GIS mapping software (ArcGIS online). You will need to be able to place markers on whatever mapping tool you choose. Alternatively, you could use a hardcopy map to identify areas of interest such as residential and industrial zones on the map and put pins or dots on the map to mark the air sensor sites.

Step 2: Placing Sensors on the Map: Guidelines

Use the following guidelines to site sensors on your map. Each siting guideline should help you place sensors that fit into the goals of the network: understanding general local air quality, identifying places of high exposure to pollution, and identifying emission sources.

Residential Areas

Place air sensors in different neighborhoods where people live.
- ✓ Locate sensors in areas that represent different socioeconomic levels - place sensors in upper-, middle-, and lower-income areas
- ✓ Especially consider neighborhoods closer to major emission sources (industry, traffic, etc.)
- ✓ Consider schools, as they are typically located in residential areas and are a great place to monitor air quality near sensitive individuals

Industrial Areas

Place air sensors near industrial processes that generate pollutants so that you can quantify pollution emitted from these areas.
- ✓ Locate sensors in or near industrial areas of concern
- ✓ Consider locating sites upwind and downwind of industrial areas to evaluate the differences in pollution that the industry may generate

Industrial Emissions = B – A

Wind direction →

Up-wind Sensor   Down-wind Sensor

A   Industrial Emission Source   B
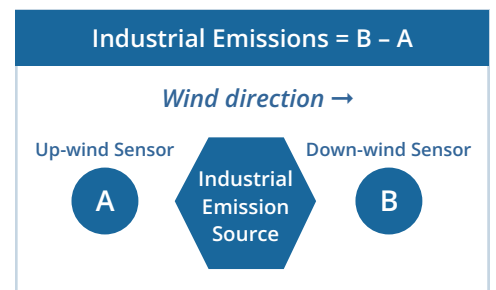
The figure above shows how having a sensor upwind and downwind of an emission source can capture the source's pollution.

Commercial Areas

Put sensors in areas where people shop, work, eat, and conduct other types of business.
- ✓ Locate near the central business district, as well as other major commercial areas

Traffic Locations

Locate sensors near areas of high traffic/vehicle use.
- ✓ Locate sensors in areas with low-, moderate-, and high-volume traffic
- ✓ Consider several different types of intersections
- ✓ Place sensors on corners near crosswalks, or locations where personal exposure is highest

Recreation Spaces *(parks, golf courses, sports centers, etc.)*

Locate sensors to determine what residents breathe when they exercise and relax.
- ✓ Locate sensors in high-use recreational areas
- ✓ Especially consider area use by sensitive individuals e.g., children and elderly adults

Perimeter/Outskirts

Locate sensors outside your area of interest to quantify the air pollution flowing out but also in from nearby locations.
- ✓ Locate sensors around the border of the monitoring area
- ✓ Place sensors down and upwind of the monitoring area
- ✓ Consider prevailing wind directions and/or geographically specific winds (e.g., valleys or sea breeze) and place sites that can measure pollutants during different weather conditions

Reference Monitors/Collocation

To have accurate sensor data, you will need sensors placed near reference monitors to compare against.
- ✓ Locate sensors at several reference sites operated by government and regulatory organizations
- ✓ Consider reference monitors in different areas of interest (e.g., traffic and residential locations) because sensor accuracy could change with different operating environments
- ✓ Locate sensors at these reference sites for the entire duration of your study
- ✓ Consider placing two air sensors at each reference site to evaluate the sensor's precision

Comparison Sites

For each sensor you placed above, make sure there is a sensor in an area outside of the area or away from the pollutant source to compare with. For example, if you place a sensor near a major emission source, you'll want to make sure there is another sensor in your network that is away from this source so that you can compare the measurements. Without a comparison, you will not be able to tell if the pollution the sensor measures at the major emission site is normal for your area or not.

Plan for Spares

Include spares to replace broken sensors or utilize if more sensors are needed for emergency events.

Step 3: Check Your Network

Now that you have mapped out your sensor network, it's time to conduct a couple of checks.

Coverage

Review your map and distribution of air sensors.
- ✓ Do sensors cover most of your city/region?
- ✓ Does your sensor network cover the most important parts of your city/region?
- ✓ Are there any areas not measured – is there a reason for not measuring in this location?
- ✓ Are sensors placed evenly throughout the region?
- ✓ Are there some locations where there are too many sensors?
- ✓ Can you combine some sensor locations?
- ✓ Think through what the purpose of each sensor is and make sure they address at least one purpose: locating emission sources, identifying areas of high exposure to pollution, and establishing an understanding of general air quality in the monitoring area.

Number of Sensors

Count the number of sensors. Gather other information (population, area of your region, and the number of reference sites). Then compare your network with other recent air sensor networks. Some metrics and guidelines include:
- Sensors should be about 25-35 times the number of reference sites
- Five (5) sensors for every 100,000 residents
- Two to three (2-3) sensors for every 10 km^2

Created by

TD ENVIRONMENTAL SERVICES
Air quality sensing, analytics, and insights

Contact Us: Tim@TDEnviro.com // 707-310-5541

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