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Measurements of Air Pollution

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ABSTRACT: Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere.Household combustion devices, motor vehicles, industrial facilities and forest fires are common sources of air pollution. Pollutants of major public health concern include particulate matter, carbon monoxide, ozone, nitrogen dioxide and sulfur dioxide. Outdoor and indoor air pollution cause respiratory and other diseases and are important sources of morbidity and mortality. WHO data show that almost all of the global population (99%) breathe air that exceeds WHO guideline limits and contains high levels of pollutants, with low- and middle-income countries suffering from the highest exposures.Air quality is closely linked to the earth's climate and ecosystems globally. Many of the drivers of air pollution (i.e. combustion of fossil fuels) are also sources of greenhouse gas emissions. Policies to reduce air pollution, therefore, offer a win-win strategy for both climate and health, lowering the burden of disease attributable to air pollution, as well as contributing to the near- and long-term mitigation of climate change. The present paper explains different methods of measuring air pollution.

KEYWORDS: air pollution, population, policies, climate, health, measurement, particulate, devices

I.INTRODUCTION

Air pollution measurement is the process of collecting and measuring the components of air pollution, notably gases and particulates. The earliest devices used to measure pollution include rain gauges (in studies of acid rain), Ringelmann charts for measuring smoke, and simple soot and dust collectors known as deposit gauges.[1] Modern air pollution measurement is largely automated and carried out using many different devices and techniques. These range from simple absorbent test tubes known as diffusion tubes through to highly sophisticated chemical and physical sensors that give almost real-time pollution measurements, which are used to generate air quality indexes. Air pollution is caused by many things. In urban environments, it can contain many components, notably solid and liquid particulates (such as soot from engines and fly ash escaping from incinerators), and numerous different gases (most commonly sulphur dioxide, nitrogen oxides, and carbon monoxide, all related to fuel combustion). These different forms of pollution have different effects on people's health, on the natural world (water, soil, crops, trees, and other vegetation), and on the built environment.[2] Measuring air pollution is the first step in identifying its causes and then reducing or regulating them to keep the quality of the air inside legal limits (mandated by regulators such as the Environmental Protection Agency in the United States) or advisory guidelines suggested by bodies such as the World Health Organization (WHO).[3] According to the WHO, over 6000 cities in 117 countries now routinely monitor the quality of their air. Air pollution is (broadly) measured in two different ways, passively or actively.[5]

Passive devices are relatively simple and low-cost.[6] They work by soaking up or otherwise passively collecting a sample of the ambient air, which then has to be analyzed in a laboratory. One of the most common forms of passive measurement is the diffusion tube, which looks similar to a laboratory test tube and is fastened to something like a lamp post to absorb one or more specific pollutant gases of interest. After a period of time, the tube is taken down and sent to a laboratory for analysis. Deposit gauges, one of the oldest forms of pollution measurement, are another type of passive device.[7] They are large funnels that collect soot or other particulates and drain them into sampling bottles, which, again have to be analyzed in a laboratory

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Active measurement devices are more automated, complex, and sophisticated, though not always more sensitive or reliable.[6] They use fans to suck in the air, filter it, and either analyze it automatically there and then or collect and store it for later analysis in a laboratory. Active sensors use either physical or chemical methods. Physical methods measure an air sample without changing it, for example, by seeing how much of a certain wavelength of light it absorbs. Chemical methods change the sample in some way, through a chemical reaction, and measure that. Most automated air-quality sensors are examples of active measurement.

Air quality sensors range from small handheld devices to large-scale static monitoring stations in urban areas, and remote monitoring devices used on aeroplanes and space satellites.[5]

At one end of the scale, there are small, inexpensive portable (and sometimes wearable), Internet-connected air pollution sensors, such as the Air Quality Egg,

The Air Quality Egg: An example of a low-cost, personal air pollution sensor.

PurpleAir, and Plume Flow.[8] These constantly sample particulates and gases and produce moderately accurate, almost real-time measurements that can be analyzed by smartphone apps.[9] They can be used for both indoor and outdoor environments and the majority focus on measuring five forms of air pollution: ozone, particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide[6]. Sensors like this were once expensive, but the 2010s saw a trend towards cheaper portable devices that can be worn by individuals to monitor their local air quality levels, which are now sometimes informally referred to as low-cost sensors (LCS).[8][10] A recent review by the European Commission's Joint Research Center identified 112 examples, made by 77 different manufacturers.[11]

Personal sensors can empower individuals and communities to better understand their exposure environments and risks from air pollution.[12] For example, a research group led by William Griswold at UCSD handed out portable air pollution sensors to 16 commuters, and found "urban valleys" where buildings trapped pollution. The group also found that passengers in buses have higher exposures than those in cars[10,11,12]

Unlike low-cost monitors, which are carried from place to place, static monitors continuously sample and measure the air quality in a particular, urban location.[13] Public places such as busy railroad stations sometimes have active air quality monitors permanently fixed alongside platforms to measure levels of nitrogen dioxide and other pollutants.[14] Some static monitors are designed to give immediate feedback on local air quality. In Poland, EkoSłupek air monitors measure a range of pollutant gases and particulates and have small lamps on top that change colour from red to green to signal how healthy the air is nearby[7]

II.DISCUSSION

At the opposite end of the spectrum from low-cost sensors are the large, very expensive, static street-side monitoring stations that constantly sample the various different pollutants commonly found in urban air for local authorities and that make up metropolitan monitoring systems such as the London Air Quality Network[16] and a wider British network called the Automatic Urban and Rural Network (AURN).[17] In the United States, the EPA maintains a repository of air

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quality data through the Air Quality System (AQS), where it stores data from over 10,000 monitors.[18] The European Environment Agency collects its air quality data from 3,500 monitoring stations across the continent.[19]

An air pollution monitoring station in Shaftesbury Avenue, London.

The measurements made by sensors like these, which are much more accurate, are also near real-time and are used to generate air quality indexes (AQIs). Between the two extremes of large-scale static and small-scale wearable sensors are medium-sized, portable monitors (sometimes mounted in large wheelable cases) and even built into "smog-mobile" sampling trucks.[20] Air quality can also be measured remotely, from the air, by lidar,[21] drones,[22] and satellites, through methods such as gas filter correlation.[23] Among the earliest satellite pollution monitoring efforts were GOME (Global Ozone Monitoring Experiment), which measured global (tropospheric) ozone levels from the ESA European Remote Sensing Satellite (ERS-2) in 1995,[24] and NASA's MAPS (Mapping Pollution with Satellites), which measured the distribution of carbon monoxide in Earth's lower atmosphere, also in the 1990s

Each different component of air pollution has to be measured by a different process, piece of equipment, or chemical reaction. Analytical chemistry techniques used for measuring pollution include gas chromatography; various forms of spectrometry, spectroscopy, and spectrophotometry; and flame photometry

Until the late 20th century, the amount of soot produced by something like a smokestack was often measured visually, and relatively crudely, by holding up cards with lines ruled onto them to indicate different shades of grey. These were known as Ringelmann charts, after their inventor, Max Ringelmann,

Ringelmann charts were developed for measuring smoke from chimneys and smokestacks at the end of the 19th century.

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and measured smoke on a six-point scale.[26] In modern pollution monitoring stations, coarse (PM10) and fine (PM2.5) particulates are measured using a device called a tapered element oscillating microbalance (TEOM), based on a glass tube that vibrates more or less as collected particles accumulate on it. Particulates can also be measured using other kinds of particulate matter sampler, including optical photodetectors, which measure the light reflected from samples of light (bigger particles reflect more light) and gravimetric analysis (collected on filters and weighed).[27] Black carbon is usually measured optically with Aethalometer-type instruments.[28]

Nitrogen dioxide (NO_2) can be measured passively with diffusion tubes, though it takes time to collect samples, analyze them, and produce results.[29][30] It can also be measured actively, much more quickly, by a chemiluminescence analyzer, which measures nitrogen oxide levels from the light they give off. In the UK, for example, there are over 200 sites where NO_2 is continuously monitored by chemiluminescence.[31]

Sulphur dioxide (SO_2) is measured by fluorescence spectroscopy. This involves firing ultraviolet light at a sample of the air and measuring the fluorescence produced.[32] Absorption spectrophotometers are also used for measuring SO_2. Flame photometric analyzers are used for measuring other sulphur compounds in the air.

Carbon monoxide (CO) and carbon dioxide (CO_2) are measured by non-dispersive infrared (NDIR) light absorption based on the Beer-Lambert law.[34] CO can also be measured using electrochemical gel sensors and metal-oxide semiconductor (MOS) detectors

Carbon dioxide and nitrogen dioxide sensors at Birmingham New Street train station.

Ozone (O_3) is measured by seeing how much light a sample of ambient air absorbs.[36] Higher concentrations of ozone absorb more light according to the Beer-Lambert law. These are measured using gas chromatography and flame ionization (GC-FID) Hydrocarbons can be measured by gas chromatography and flame ionization detectors.[38][39] They are sometimes expressed as separate measurements of methane (CH_4), NMHC (non-methane hydrocarbons), and THC (total hydrocarbon) emissions (where THC is the sum of CH_4 and NMHC emissions). Ammonia (NH_3) can be measured by various methods including chemiluminescence.

III.RESULTS

Air pollution can also be assessed more qualitatively by observing the effect of polluted air on growing plants such as lichens and mosses (an example of biomonitoring).[41][42][43] Some scientific projects have used specially grown plants such as strawberries. The amount of pollutant present in air is usually expressed as a concentration, measured in either parts-per notation (usually parts per billion, ppb, or parts per million, ppm, also known as the volume mixing ratio), or micrograms per cubic meter (µg/m³). It's relatively simple to convert one of these units into the other, taking account the different molecular weights of different gases and their temperatures and pressures.[45][51]

These units express the concentration of air pollution in terms of the mass or volume of the pollutant, and they are commonly used for measurements of both gaseous pollutants, such as nitrogen dioxide, and coarse (PM10) and fine (PM2.5) particulates. An alternative measurement for particulates, particle number, expresses the concentration in terms of the number of particles per volume of air instead, which can be a more meaningful way of assessing the health harms of highly toxic ultrafine particles (PM0.1, less than 0.1 µm in diameter).[46][47]

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Urban air quality index (AQI) values are computed by combining or comparing the concentrations of a "basket" of common air pollutants (typically ozone, carbon monoxide, sulphur dioxide, nitrogen oxides, and both fine and coarse particulates) to produce a single number on an easy-to-understand (and often colour-coded) scale.[48]

Air pollution was first systematically measured, in Britain, in the 19th century. In 1852, Scottish chemist Robert Angus Smith discovered (and named) acid rain after collecting rain samples that turned out to contain significant quantities of sulphur from coal burning. According to a chronology of air pollution by David Fowler and colleagues, Smith was "the first scientist to attempt multisite, multipollutant investigations of the chemical climatology of the polluted atmosphere".[49][50]

In the early 20th century, Irish physician and environmental engineer John Switzer Owens and the Committee for the Investigation of Atmospheric Pollution, of which he was secretary, greatly advanced the measurement and monitoring of air pollution using a network of deposit gauges. Owens also developed a number of new methods of measuring pollution.[50]

In December 1952, the Great Smog of London led to the deaths of 12,000 people.[51] This event, and similar ones such as the 1948 Donora smog tragedy in the United States,[52] became one of the great turning points in environmental history because they brought about a radical rethink in pollution control. In the UK, the Great Smog of London lead directly to the Clean Air Act, which may have had consequences even more far reaching than it originally intended.[53] Catastrophic events like this lead to pollution being measured and controlled much more rigorously.[49]

An air quality index (AQI) is used by government agencies[1] to communicate to the public how polluted the air currently is or how polluted it is forecast to become.[2][3] AQI information is obtained by averaging readings from an air quality sensor, which can increase due to vehicle traffic, forest fires, or anything that can increase air pollution. Pollutants tested include particulates, ozone, nitrogen dioxide, carbon monoxide, sulphur dioxide, among others.

Public health risks increase as the AQI rises, especially affecting children, the elderly, and individuals with respiratory or cardiovascular issues. During these times, governmental bodies generally encourage people to reduce physical activity outdoors, or even avoid going out altogether. The use of face masks such as cloth masks may also be recommended.

Different countries have their own air quality indices, corresponding to different national air quality standards. Some of these are Canada's Air Quality Health Index, Malaysia's Air Pollution Index, and Singapore's Pollutant Standards Index.[52]

Computation of the AQI requires an air pollutant concentration over a specified averaging period, obtained from an air monitor or model. Taken together, concentration and time represent the dose of the air pollutant. Health effects corresponding to a given dose are established by epidemiological research.[4] Air pollutants vary in potency, and the function used to convert from air pollutant concentration to AQI varies by pollutant. Its air quality index values are typically grouped into ranges. Each range is assigned a descriptor, a color code, and a standardized public health advisory.

The AQI can increase due to an increase of air emissions. For example, during rush hour traffic or when there is an upwind forest fire or from a lack of dilution of air pollutants. Stagnant air, often caused by an anticyclone, temperature inversion, or low wind speeds lets air pollution remain in a local area, leading to high concentrations of pollutants, chemical reactions between air contaminants and hazy conditions.[5]

On a day when the AQI is predicted to be elevated due to fine particle pollution, an agency or public health organization might:

- advise sensitive groups, such as the elderly, children, and those with respiratory or cardiovascular problems, to avoid outdoor exertion.[6]
- declare an "action day" to encourage voluntary measures to reduce air emissions, such as using public transportation.[7]
- recommend the use of masks to keep fine particles from entering the lungs[8]

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During a period of very poor air quality, such as an air pollution episode, when the AQI indicates that acute exposure may cause significant harm to the public health, agencies may invoke emergency plans that allow them to order major emitters (such as coal burning industries) to curtail emissions until the hazardous conditions abate.[9]

Most air contaminants do not have an associated AQI. Many countries monitor ground-level ozone, particulates, sulfur dioxide, carbon monoxide and nitrogen dioxide, and calculate air quality indices for these pollutants.[10]

The definition of the AQI in a particular nation reflects the discourse surrounding the development of national air quality standards in that nation.[11] A website allowing government agencies anywhere in the world to submit their real-time air monitoring data for display using a common definition of the air quality index has recently become available.[12]

The National Air Quality Index (AQI) was launched in New Delhi on September 17, 2013, under the Swachh Bharat Abhiyan.[24][25][26][27]

The Central Pollution Control Board along with State Pollution Control Boards has been operating National Air Monitoring Program (NAMP) covering 240 cities of the country having more than 342 monitoring stations.[28] An Expert Group comprising medical professionals, air quality experts, academia, advocacy groups, and SPCBs was constituted and a technical study was awarded to IIT Kanpur. IIT Kanpur and the Expert Group recommended an AQI scheme in 2013.[29] While the earlier measuring index was limited to three indicators, the new index measures eight parameters.[30] The continuous monitoring systems that provide data on near real-time basis are installed in New Delhi, Mumbai, Pune, Kolkata and Ahmedabad.[31]

There are six AQI categories, namely Good, Satisfactory, Moderate, Poor, Severe, and Hazardous. The proposed AQI will consider eight pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) for which short-term (up to 24-hourly averaging period) National Ambient Air Quality Standards are prescribed.[32] Based on the measured ambient concentrations, corresponding standards and likely health impact, a sub-index is calculated for each of these pollutants. The worst sub-index reflects overall AQI. Likely health impacts for different AQI categories and pollutants have also been suggested, with primary inputs from the medical experts in the group. The AQI values and corresponding ambient concentrations (health breakpoints) as well as associated likely health impacts for the identified eight pollutants are as follows:

AQI Category, Pollutants and Health Breakpoints

AQI Category (Range)	PM_{10} (24hr)	$PM_{2.5}$ (24hr)	NO_2 (24hr)	O_3 (8hr)	CO (8hr)	SO_2 (24hr)	NH_3 (24hr)	Pb (24hr)	Colour
Good (0–50)	0–50	0–30	0–40	0–50	0–1.0	0–40	0–200	0–0.5	Deep Green
Satisfactory (51–100)	51–100	31–60	41–80	51–100	1.1–2.0	41–80	201–400	0.5–1.0	Light Green
Moderate (101–200)	101–250	61–90	81–180	101–168	2.1–10	81–380	401–800	1.1–2.0	Yellow
Poor (201–300)	251–350	91–120	181–280	169–208	10–17	381–800	801–1200	2.1–3.0	Orange
Severe (301–400)	351–430	121–250	281–400	209–748	17–34	801–1600	1200–1800	3.1–3.5	Red
Hazardous (401-500)	430+	250+	400+	748+	34+	1600+	1800+	3.5+	Maroon

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AQI	Associated Health Impacts
Good (0–50)	Minimal impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people.
Moderate (101–200)	May cause breathing discomfort to people with lung disease such as asthma, and discomfort to people with heart disease, children and older adults.
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure, and discomfort to people with heart disease.
Severe (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases.
Hazardous (401-500)	May cause respiratory impact even on healthy people, and serious health impacts on people with lung/heart disease. The health impacts may be experienced even during light physical activity.

IV.CONCLUSIONS

Environmental monitoring describes the processes and activities that need to take place to characterize and monitor the quality of the environment. Environmental monitoring is used in the preparation of environmental impact assessments, as well as in many circumstances in which human activities carry a risk of harmful effects on the natural environment. All monitoring strategies and programs have reasons and justifications which are often designed to establish the current status of an environment or to establish trends in environmental parameters. In all cases, the results of monitoring will be reviewed, analyzed statistically, and published. The design of a monitoring program must therefore have regard to the final use of the data before monitoring starts. Air pollutants are atmospheric substances—both naturally occurring and anthropogenic—which may potentially have a negative impact on the environment and organism health. With the evolution of new chemicals and industrial processes has come the introduction or elevation of pollutants in the atmosphere, as well as environmental research and regulations, increasing the demand for air quality monitoring.[1]

Air quality monitoring is challenging to enact as it requires the effective integration of multiple environmental data sources, which often originate from different environmental networks and institutions.[2] These challenges require specialized observation equipment and tools to establish air pollutant concentrations, including sensor networks, geographic information system (GIS) models, and the Sensor Observation Service (SOS), a web service for querying real-time sensor data.[2] Air dispersion models that combine topographic, emissions, and meteorological data to predict air pollutant concentrations are often helpful in interpreting air monitoring data. Additionally, consideration

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of anemometer data in the area between sources and the monitor often provides insights on the source of the air contaminants recorded by an air pollution monitor.

Air quality monitors are operated by citizens,[3][4][5] regulatory agencies,[6][7] and researchers[8] to investigate air quality and the effects of air pollution. Interpretation of ambient air monitoring data often involves a consideration of the spatial and temporal representativeness[9] of the data gathered, and the health effects associated with exposure to the monitored levels.[10] If the interpretation reveals concentrations of multiple chemical compounds, a unique "chemical fingerprint" of a particular air pollution source may emerge from analysis of the data.[11] Passive or "diffusive" air sampling depends on meteorological conditions such as wind to diffuse air pollutants to a sorbent medium. Passive samplers, such as diffusion tubes, have the advantage of typically being small, quiet, and easy to deploy, and they are particularly useful in air quality studies that determine key areas for future continuous monitoring.[12]

Air pollution can also be assessed by biomonitoring with organisms that bioaccumulate air pollutants, such as lichens, mosses, fungi, and other biomass.[13][14] One of the benefits of this type of sampling is how quantitative information can be obtained via measurements of accumulated compounds, representative of the environment from which they came. However, careful considerations must be made in choosing the particular organism, how it's dispersed, and relevance to the pollutant.[14]

Other sampling methods include the use of a denuder,[15][16] needle trap devices, [53] and microextraction techniques.[17]

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